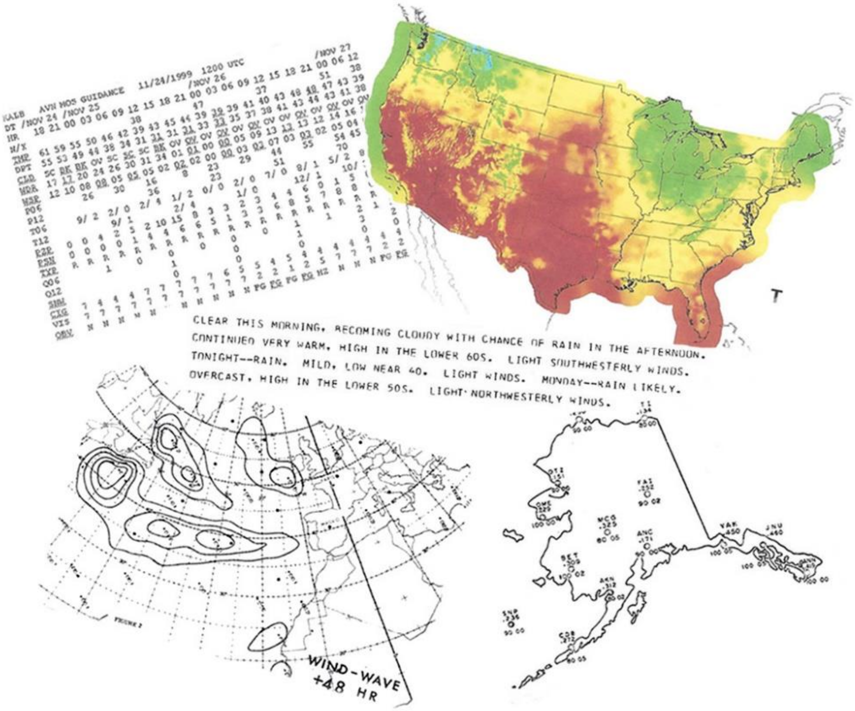
50 YEARS OF MODEL INTERPRETATION AT THE METEOROLOGICAL DEVELOPMENT LABORATORY

By

Bob Glahn



CLEAR THIS MORNING, BECOMING CLOUDY WITH CHANCE OF RAIN IN THE AFTERNOON. CONTINUED VERY WARM. HIGH IN THE LOWER 60S. LIGHT SOUTHWESTERLY WINDS. TONIGHT--RAIN. MILD. LOW NEAR 40. LIGHT WINDS. MONDAY--RAIN LIKELY. OVERCAST. HIGH IN THE LOWER 50S. LIGHT NORTHWESTERLY WINDS.

2022

CONTENTS

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Introduction

The Techniques Development Laboratory (TDL) was formed in 1964 from portions of the Weather Bureau's Office of Meteorological Research just as Numerical Weather Prediction was gaining a foothold. One of the projects ongoing was the building of a mesoscale model with the intent to develop statistics from it to forecast weather characteristics. The need for a model with a grid-length smaller than the 381 km then in use at the National Meteorological Center (NMC) was apparent. While the model actually developed was not "mesoscale" in todays terminology, it did have a grid length one quarter of NMC's model. Building statistics on this model started one of the primary activities of TDL that has lasted for over 50 years. The Weather Bureau's (WB) name was changed to National Weather Service (NWS) in 1970. TDL's name was changed almost imperceptibly to the Meteorological Development Laboratory in 2000. This document concentrates on the operational model interpretative products produced by TDL and MDL and distributed for use through NMC. The techniques used to produce them are explained only briefly, but many references are provided. Statistical work influencing TDL's entry into model interpretation is also summarized in the first two chapters.

For a time, the activity had no more specific name than "statistical weather forecasting." For a decade or so in the 1980's and 90's, a preferred term used internationally was "model interpretation." More recently, "postprocessing" has been predominantly used. I have chosen to use model interpretation because it sounds a bit less ambiguous than postprocessing and closer to the intent of the activity. MOS (model output statistics) and PP (perfect prog) are names MDL's products are known for and fit within interpretation.

Any history such as this has to stop at some point in time. This one ends in 2014 at the 50th-year mark of the activity and TDL/MDL's 50th anniversary, even though model interpretation is still a lively endeavor in MDL.

The primary source of information for this document was the Technical Procedures Bulletins (TPB) issued by the WB and NWS. These spanned a period of 36 years and describe many of the forecast product changes made at NMC and its successor the National Centers for Environmental Prediction (NCEP). After the TPB's demise in 2003, a similar series was written by MDL for MDL products until 2013. Another important source was the papers written by developers. I have referenced many of these papers to try to give some small measure of recognition of the many hours and good science that went into the products provided for field forecasters, national centers, and meteorological partners.

Bob Glahn

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CHAPTER I

EARLY STATISTICAL WEATHER FORECASTING– THE PRE-COMPUTER CLASSICAL PERIOD

Statistical weather forecasting is one of the two “objective” forecasting methods, numerical weather prediction (NWP) being the other. In 1951, Allen and Vernon (1951) in the *Compendium of Meteorology* defined an objective forecast as

> “. . . a forecast which does not depend for its accuracy upon the forecasting experience or the subjective judgment of the meteorologist using it. Strictly speaking, an objective system is one which can produce one and only one forecast from a specific set of data.”

However, they go on to state,

> “From the practical standpoint it appears reasonable to include as objective, . . , those forecasts which require meteorological training. . .It would be throwing away information of demonstrated value . . . if . . . an objective forecasting system were not permitted to make use of isobaric patterns on analyzed maps because of the objection that they are arrived at subjectively. The test of whether a system is objective is whether different meteorologists using the system independently arrive at the same forecast from a given set of maps and data.”

Even earlier, Irving Gringorten (1949) had described an objective forecast as one that

> “. . . is made without recourse to the personal judgment of the forecaster.” And, he went on to state, “. . . two forecasters using the same system will necessarily make the same forecast independently of each other.”

Of course, statistical and numerical systems are built on the subjective judgment of their inventors, but once built, the input is specified and dictates the result.

It is impossible to know the first such objective system. Likely rudimentary methods existed before the recorded history of mankind, and when we consider some of the historic artifacts that have survived, they may have been more than rudimentary. It takes very little to develop an objective statistical system, which is, in reality, just conditional climatology—the value of the event to be predicted conditioned on some other variable or variables that can be known. Even climatological relative frequencies conditioned on time of day and day of year provide a zeroth order system. To go beyond that, the conditions are based on some other meteorological variable or variables. Objective systems are usually not meant to produce the “final” forecast, but rather the results are to be used by a meteorologist to modify by considering factors not taken into account by the objective method. According to Gringorten (1949),

> “. . . meteorology is much too complex to allow one to believe that objectivity in forecasting will, eventually, completely replace subjectivity. But an objective forecast manual[1] can be an invaluable aid in making the forecasts.”

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[1] Gringorten used the term “forecast manual” as “a collection of rules that are used in forecasting.”

Certainly, there were statistical systems before numerical, the latter dating back only to the mid 1900's. As early as 1905, Besson (1905) studied the rainfall at Paris as a function of pairs of meteorological observations. Although he used the term rain, he considered it ". . . as every type of precipitation, liquid or frozen." He stated, ". . . .if one has at one's disposal a sufficient number of observations, the problem can be resolved by statistics, which will furnish, for each case, not only the most probable forecast, but also the degree of probability of the event forecast." He composed diagrams, based on 21 winters of data, with the relative frequency of precipitation as a function of one variable (e.g., pressure) and two variables (e.g., pressure and wind direction). He found only marginal success by using two variables rather than just one, and stated it might not be beneficial to compute relative frequencies of rain as a function of three variables. He also noted to do so would require about 10 times the amount of data to achieve the same precision. This is puzzling, because later others using essentially the same procedure gained benefit in using more than one or two variables. However, perhaps Besson required more "improvement" than other authors, and it is not clear to what extent other authors actually tested for improvement as each predictor was added.

While there are other articles in the literature describing how to forecast a particular meteorological variable based on existing conditions, essentially statistical objective forecasting aids (e.g., Hollenbeck 1920), it seems the impetus for more widespread and systematic use of truly objective systems, at least in the U.S. Weather Bureau (WB), stemmed from Glenn Brier's work in 1946 (Brier 1946). As part of a WB project to forecast rainfall in a portion of Tennessee called the Tennessee Valley, he authored *Research Paper* No. **26**[2] in which he presented an ingenious set of diagrams which when used led to a rainfall forecast (see Fig. I-1). He tested the method on data from a year following those on which the method was based and found a correlation of 0.69 with the observed amounts. This he found to be statistically significant. Brier started with a series of diagrams each relating rainfall to two meteorological variables, then the results from these diagrams were successively paired, which eventually led to a final diagram. He essentially extended Besson's (1905) method to multiple variables.

Glenn Brier as he received an Outstanding Achievement Award at the International Meeting on Statistical Climatology held in Toronto, Canada, in June 1993 (Murphy and Zweirs, 1993). (Photo from *Bull. Amer. Meteor. Soc.*, **74,** 1993, p 1723.)

Both Woodrow (Woody) Dickey (1949) and Jack Thompson (1950) used Brier's approach, Dickey to estimate the probability of a large fall in temperature at Washington D.C., and Thompson to forecast rainfall in the Los Angeles area. Woody compared results obtained with his technique with official forecasts, and calculated skill scores of 0.63 and 0.67, respectively. Thompson took his verification a bit further. Not only did he compare with the official WB forecasts, but the forecasters knew of the test being run, and even had available the forecast made by the objective method as well as, in some cases, more recent data. The objective method actually gave better forecasts, as judged from the Heidke skill score[3], but Jack

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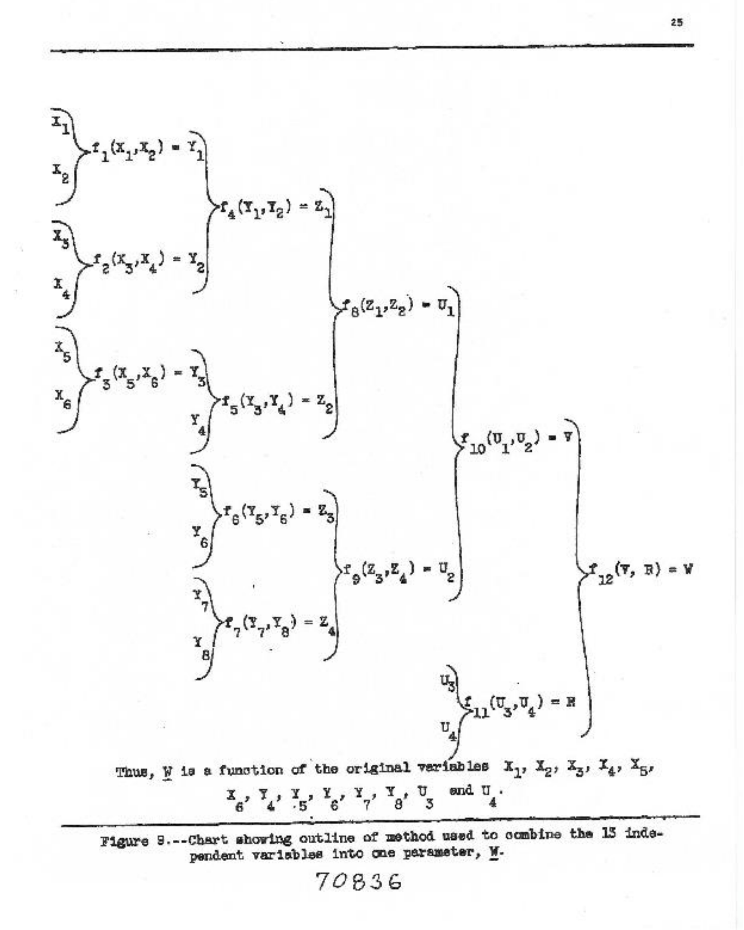
[2] The Weather Bureau published a series called *Research Papers* from 1943 to 1957.

[3] Although Jack didn't identify it as the one put forth by Heidke [see Joliffe and Stephenson (2012, pp. 32, 65)].

found the difference to not be statistically significant. He concluded, ". . . the technique produced results which were at least as accurate as, and were not improved upon, by conventional methods." He bent over backward to not say the objective system performed better than the official forecasts. Note that both of these two studies were in terms of predicting the *probability* of the event, and Jack was even then advocating the use of probabilities in decision making and using the cost/loss ratio he brought more directly into the meteorological literature in 1952 (Thompson 1952).



Thus, W is a function of the original variables X_1, X_2, X_3, X_4, X_5, X_6, Y_4, Y_5, Y_6, Y_7, Y_8, U_3 and U_4.

Figure 8.--Chart showing outline of method used to combine the 13 independent variables into one parameter, W.

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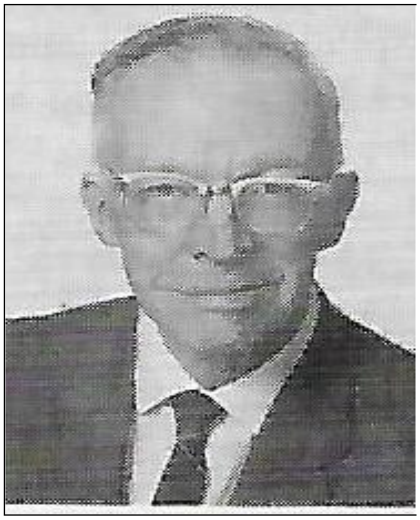
Fig. I-1. Chart showing outline of method used to combine 13 independent variables into one parameter. (From Brier 1946.)

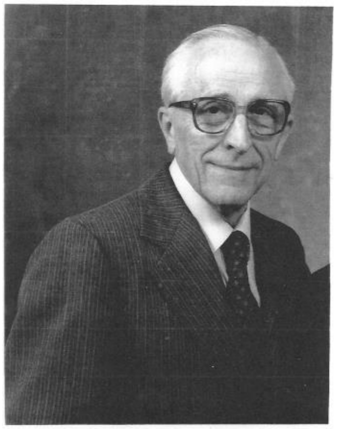


Jack Thompson had a big influence on the evolution of statistical studies. He was an observer and forecaster in the WB in California, and became a "District Forecaster," one of the higher level positions in the WB at the time, in the Los Angeles office. By 1958, he was in Washington D.C. working for Harry Wexler, Chief of the Office of Meteorological Research. Jack was given a special award by the American Meteorological Society (AMS) in 1988 "for major contributions as an operational weather forecaster, teacher, and meteorological consultant over almost fifty years." **(**Photo from *Bull. Amer. Meteor. Soc.***, 69,** 1988, p 657.)

These early papers set the stage for development of more formal objective procedures than had been employed in the past. It was logical that most of this work was being done by WB employees, because it was they who were making the forecasts and wanted to make improvements. Objective forecasting aids were almost always for individual sites. A forecaster, having an idea, would collect some data, do an analysis, produce some graphs, and make the results available for use on-station. There was little central production or distribution of these studies, but a few found their way into publications or internal WB documents (e.g., Dickey 1960).

The Weather Bureau did, though, have a Research Forecaster Program in which there was a designated position at about a dozen offices. The research forecaster's job was, in part, to do statistical studies for sites in his immediate area. This program was coordinated by Roger Allen who headed the Short Range Forecast Development Section (SRFDS), part of the Weather Bureau's Office of Meteorological Research headed by Harry Wexler. Woody Dickey was in Washington, D. C. when he did his study (Dickey 1960**)**, and likely was working for Roger. Allen's and Brier's offices were just a few doors apart in the "Old Annex" in the WB compound at 24th and M Streets in D. C. **[4]**. Thompson had done his study while he was in the Los Angeles WB office, but by the time of publication, he was in SRFDS also working for Allen. The research forecasters would periodically congregate at a central location, such as the WB headquarters at 24th and M Streets in Washington, D.C., and discuss their work and make plans for the future. It was into SRFDS**[5]** that I was hired in the fall of 1958 and participated in such a conference on May 11, 1960 (Glahn 1960).


The Old Annex at the Weather Bureau compound at 24th and M Streets, Washington, D.C., 24th street entrance. The headquarters building is in the background. (Photo by Bob Glahn 1965.)


Roger Allen was Chief of the Short Range Forecast Development Section of the Weather Bureau's Office of Meteorological Research. This was the group most involved with statistical weather forecasting when I joined them in 1958. Roger coordinated the statistical activities for the Bureau for many years. (Photo furnished by Rogers's family.)


Attendees at the Research Forecasters Conference in May 1960. Believed to be: Front: Roger Allen, Larry Hughes, ?, Hal Root, ?; Center: ?, ?, ?, Woody Dickey, Chet Glenn. Back: ?, ?, Bob Glahn, Jim Huntoon, ?.

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[4] The building that came to be called the Old Annex was built in 1889 when the Signal Corps, which at the time was responsible for meteorological activities of the United States, moved to the 24th and M location. The headquarters was housed in an imposing building built by David Ferguson and was used as such until a new building was built in 1941 (see Glahn 2012 for more information).

[5] The Short Range Forecast Development Section was established in 1946. This is recorded in Chief of the Weather Bureau Reichelderfer's annual report for 1946, p. 220 (see Glahn 2012, pp. 37, 38).

One objective of Allen's group when I joined was to assist with studies of weather conditions at airports where the official WB observations were taken. These were "published" in a *Terminal Forecasting Reference Manual*.[6] Working on such studies when I arrived were John (Jack) Ellis and Joseph (Joe) Sassman, with some meteorological technician (met tech) support in tabulating data, etc. It is likely Allen's group was coordinating the overall WB effort. These studies are dated throughout the 1950's, with a few in 1960, at which point the work essentially stopped, although there are a couple dated 1968. The demise of production coincided with the growing availability of digital computers. These studies tended to be brief and to include only climatological information in addition to physical site descriptions. However, there was an occasional one with essentially a primitive objective forecasting technique. For instance, the one for the Anchorage International Airport in Alaska had a diagram on which type of precipitation was plotted as a function of 1000-850 mb thickness and surface wet bulb temperature.

The SRFDS (1959) put together a "Selected Bibliography on Local Forecast Development" that was printed as a *Weather Bureau Manuscript*, an unnumbered series in use at the time. It was updated by Jack Ellis (1965), by that time a member of the Techniques Development Laboratory (TDL)[7], with essentially the same title, and again was printed as a *WB Manuscript*.


Always the meteorologist, Roger had a "cotton shelter" as part of his personal weather observing system in his back yard in Mclean, Virginia. (Photo furnished by Roger's family.)

There were two "centers of activity" for statistical studies in the WB in the 1940's, 50's, and 60's. One was headquartered in the Office of Meteorological Research (OMR), of which the SFRDS was a part, and the other in the Extended Forecast Division (EFD) located at Suitland Maryland. Each group was trying to assist the forecaster. The studies mentioned above tended to be for local sites, and an individual forecaster was responsible for short-range forecasts over a limited area. The EFD was responsible for nationwide forecasts of mean values of temperature a few days in advance. This drove these researchers to think more in terms of circulation patterns and their forecastability than those who were supporting "next day" forecasting.

William (Bill) H. Klein, a leader in statistical development in the EFD, studied, as had Brier (1946), wintertime precipitation in the Tennessee Valley (Klein 1948). He related 5-day average precipitation to concurrent, hand prepared "perfect-prognostic," 5-day mean, 700-mb maps. He states:

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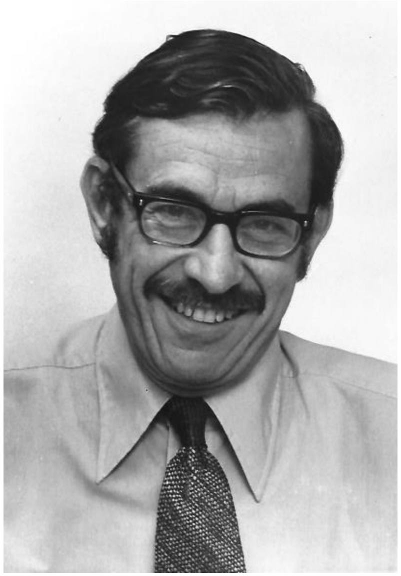
[6] A copy of the *Terminal Forecasting Reference Manual* (bound, 3 inches thick!) is in the National Oceanographic and Atmospheric Administration (NOAA) Central Library in Silver Spring, Md., catalogue number M09 U587t. Allen's abbreviated copy is on file in the Meteorological Development Laboratory in Silver Spring, Maryland.

[7] Allen's group was one of several that moved into TDL when it was formed in 1964.

> “. . . it is the writer’s belief that, in the long run, both our understanding of the weather and our ability to forecast it will be improved most by separate considerations of two fundamental forecast problems, the prognosis of the circulation and its interpretation in terms of weather.”



William H. Klein was likely the first to apply the output of NWP in an operational statistical forecasting process. He championed the “perfect prog” technique and was later an avid supporter of MOS. (Photo from MDL archives.)

He contrasts his study with others, some of which, for example Brier (1946), have been mentioned above. He found that when he verified on independent data and used the observed 700-mb maps, the results gave the correct anomaly class about two-thirds of the time and were definitely superior to the forecasts made by an official forecaster of the Extended Forecast Section. However, when the inputs were prognostic maps prepared by forecasters, the forecasts were correct only about one-fourth of the time and were inferior to “subjective forecasts made by an official forecaster at the Extended Forecast Section.” He concludes that the objective method is potentially of great forecast value, but will have to wait until the quality of the prognostic maps is considerably improved.

Glenn Brier, Jack Thompson, Roger Allen, and Bill Klein had a great influence on the way statistical forecasting developed in the Weather Bureau.

This line of thinking dominated Klein’s thoughts and his championing this method for two decades—a method which came to be called the **perfect prog (PP)**. While PP has largely faded out for day-to-day forecasting, Bill’s idea of separating the problem into forecasting the circulation and then the interpretation of weather still remains. NWP has concentrated on the circulation, and the tougher problem of “weather” forecasting has come more slowly and has been largely in the purview of statistical methods until quite recently. Bill said “circulation,” because at that time geopotential heights and winds dominated the upper atmospheric forecasts. It was likely beyond anyone’s ken to think about useful forecasts of temperature and moisture above the surface. But Bill, if asked, would have undoubtedly extended division of the problem to “upper atmosphere” and “surface.”

Klein had related weather to upper air variables and applied the results to subjectively prepared forecasts of those variables. In a similar manner, following some work by the U.S. Navy, Sassman and Allen (1958) related precipitation occurrence at three stations (St. Louis, Missouri;[8] Washington D. C.; and Albany, New York) to upper air variables, and applied the results to vertical velocity forecasts produced from the thermotropic model being run at the Joint Numerical Weather Prediction Unit (Thompson and Gates 1956; Shuman 1989). They separated the cases, comprised of 5 months in each of two seasons, into three categories, and found the relative frequency of precipitation for Albany varied among the classes from 6% to 71% on the

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[8] Interesting choice of stations. Allen had been stationed in St. Louis for a short time before coming to Washington.

dependent data and from 14% to 63% on test data. They state, "These results cannot be used operationally until prognostic vertical motion charts are again issued routinely." Evidently the vertical motion charts had been discontinued, and perhaps the thermotropic model had been replaced, as it only ran for a short time. Sassman and Allen must have shared Klein's view that the key to predicting "surface weather" was in predicting the upper atmosphere, and relating the surface weather to those upper atmospheric predictions. Although Roger's SRFDS and the EFD where Klein worked were both in the WB, they were across the city and there is no evidence that they collaborated at any time in their development of forecasting techniques.[9]

Other organizations outside the WB were also interested in objective forecasting aids, especially the U.S. Air Force. For instance, Professor George Wadsworth (1948) of MIT produced under Air Force contract a 202-page report, "*Short Range and Extended Forecasting by Statistical Methods*." This publication was started in 1942, before the significant work of Brier, Dickey, and Thompson, and although Wadsworth does not include a list of references, there is no indication he was aware of Brier's 1946 work when he published in 1948; the report does not seem to furnish much useful information for an operational forecaster.

The Air Force Cambridge Research Laboratory (AFCRL) had an active program in studying and deriving methods of forecasting. In particular Irving Gringorten (1949) and Iver Lund (1955) were leaders in this pre-computer era. Irving's 1949 paper, "A Study in Objective Forecasting," was especially significant because he defined the terms "**predictor**" and "**predictand.**" These terms soon became widespread in relation to statistical forecasting. He chose to study a pertinent problem for the Air Force—the16.5-h prediction of combinations of ceiling height and visibility of importance to aircraft operations at Randolph Field, Texas. His process was different from previous ones in that he put his data onto "IBM punched cards." There was by this time a program to put meteorological data onto cards at the Air Force Data Control Unit at New Orleans, Louisiana, and some of the data for the study could be obtained in that format. He used data from 3 wintertime months for 8 years. Sets of tables and rules were formed to yield an objective system. Although the data were on punched cards, a computer was not used in the analysis. Rather, he worked from listings of the data and prepared a "forecast manual." He tested this system on a future year, not only over the months for which the method was derived, but also on other neighboring months, and found improvement over the subjective forecasts.[10] He concluded in his abstract, "But the most important feature of the objective system is that it enables one to state the probability of occurrence of each event." Note that his and Brier's works were not too far apart in time; Brier's was better suited for forecasters emulating his method leading to better forecasts, but Irving's was pointing toward the computer processing of data. Gringorten (1955) later gives a good discussion of statistical forecasting techniques, and shows he was aware of the work of WB authors at that time.

Gringorten (1950), while still recognizing that forecasts cannot be perfect and had best be probabilistic, also recognized the need to evolve the probabilistic forecast to meet an operational requirement. He suggested a "critical frequency" be defined by the person requiring a yes/no forecast, then that could be applied to the probabilistic forecast. He went on to discuss this

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[9] SRFDS was at 24th and M Streets in downtown D.C.; EFD was in Suitland, Maryland.

[10] Irving did not state what subjective forecasts these were, but they were probably made by Air Force forecasters at Randolph Field.

critical frequency in terms of costs and losses. This paper, discussing a critical frequency in terms of costs and losses is sandwiched between Thompson's (1950, 1952) two well-known papers on the subject. The concept was likely arrived at independently, as neither author referenced the other, and the time span of these three papers was only 2 years. TDL, not having pertinent costs and losses available, has used this concept of a critical frequency over the years to maximize some score thought to measure accuracy or usefulness.

The U.S. Navy (1963) was also interested in statistical methods, and provided a discussion of the subject, with an excellent list of references, primarily regarding the pre-computer era.

It was realized early that linear regression was a way to combine various predictors to estimate a predictand, and the method was used even before computers. It was also recognized that the predictors could be binary, and Suits (1957) described the process in 1957. In these early days, he felt it necessary to explain, and in the *Journal of the American Statistical Association*, no less, that if one were to divide a continuous variable into N classes, yielding N binary predictors, which he called "dummy" variables, that only N-1 could be put into the regression; putting all of them in would make the cross-product matrix necessary for solution singular.

Even earlier, Lund (1955) used binary variables not only as predictors, but the predictand was binary (an event) and the estimation of it was treated as the probability of the event. This interpretation of the result soon became widespread. Lund stated this analysis, with a very few predictors, could be readily done on a desk calculator using Crout's (Crout 1941) method of solution.**[11]**

One of the earliest studies that made use of regression was done in SFRDS by Conrad Mook and Saul Price (Mook and Price 1947) who derived regression equations for forecasting the minimum temperature at Washington D.C. This early work followed WB sponsored contract work at New York University done by J. E. Miller and A. E. Burgtorf. Physical reasoning was used in the work to select temperature predictors upstream of Washington. The equations were developed on 9 months of data. Results on new data were mixed, and it was noted much more research was needed.

Analogues were viewed by some as a viable way of approaching weather forecasting. The theory is that if two "weather maps" are similar, the weather that follows will be similar. The U.S. Air Force, Navy, and the WB put much work into generating the *Historical Weather Maps, Northern Hemisphere*, series covering the 40 years from 1899 to 1939 (McMurray 1956). These maps were printed and provided to field offices.**[12]** The generation and use of the series was spurred by World War II. According to Cartwright and Sprinkle (1966):

> "Then the dates for all similar weather situations (weather types) were placed in a special file for each major war theater. Thus, when the current map was analyzed at one of the major

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[11] One of my projects in my year at MIT in 1957-1958 was cranking a Marchant calculator in solving a regression equation by the same method.

[12] An item in *Weather Bureau Topics* and Personnel (1947) instructs the Officials in Charge of WB stations in possession of the historical series to keep their set up to date.

> weather centers for that theater, the snyopticians (sic) classified the current map by types and then searched the analog files over the past 40 years. The dates of similar weather types were then put into a secret coded message and transmitted to the weather units concerned. The forecaster in the theater could then go through his historical map series to find the analogs that best fit the current date. By comparing these maps with whatever data he was able to gather locally and studying the maps for subsequent days, he could make useful inference on the likely weather situation for the next few days."

One of the problems in using analogs every day is that a good analogue will not always be found. Also, initial critical decisions are specifying over what area to form the analogue patterns and what variable to use for the analogues, although pressure has been a predominant choice for the variable. While analogues occasionally raise their head again, they are not in widespread use today.

By the late 1950's, digital computers were being used for developing statistical forecasting systems, and published papers on hand analysis methods and results waned. Even so, a careful analysis can likely produce as good a local technique as computer methods.[13] But computers can produce a lot more!

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[13] While certainly not conclusive, Glahn and Allen (1964) analyzed a rather simple problem with a small data sample, one that might be characteristic of a study that could be done by a field forecaster, and showed that a hand analysis produced a better forecast than discriminant analysis.

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CHAPTER II

EARLY STATISTICAL WEATHER FORECASTING–THE COMPUTERS ARRIVE

Statistical forecasting methods slipped gradually from hand analysis to processing by computer. The scope, also, soon changed; instead of very localized studies, data from groups of stations over a region or even over the whole United States were being analyzed. NWP was in its very early stages. A barotropic model was being run operationally on an IBM 701 by the Joint Numerical Weather Prediction Unit (JNWPU)[1] at Suitland, Maryland. Numerical modelling was being taught in the universities. I was in the Alaskan Weather Center[2] in the mid 1950's when the first "progs" (prognoses) started rolling off the smelly fax machines. When I entered the WB in the fall of 1958, the IBM 701 had been replaced by an IBM 704. One of the first things I did was to enroll in a FORTRAN class, and soon started making use of what I learned. The computer was at Suitland, across town from my office in downtown Washington, D.C. Arrangements were made whereby persons located downtown could send their "cards" in metal boxes by a small courier bus to Suitland, where they would be placed in the IBM 704 card reader. Then the print from the computer run would be sent back the next morning by the same bus. So, we would make sure we "made the bus" at about 3:30 p.m., and would eagerly await the arrival of results early the next morning. If, on occasion, a developer felt sufficiently protective or wanted to make sure the correct tapes were hung, he/she could go over to Suitland and actually insert the cards when the machine was not otherwise busy, hang the tapes, run the program, watch the tapes spin, and then print the output on the IBM 1401 on 14-inch folding paper. Those were heady days; you could feel like you were really accomplishing something!

Federal Office Building No. 4, Suitland, Maryland. This is where the IBM 704, 7090, and 7094 were housed that we used for development. (Photo from the National Archives.)

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[1] JNWPU, a joint effort by the WB, the Air Weather Service of the U.S. Air Force, and U.S. Naval Weather Service, started operation July 1, 1954 (WB 1954; Shuman 1989, p, 287). In 1958, JNWPU was divided into three organizations, the WB portion becoming the National Meteorological Center along with the National Weather Analysis Center and the Extended Forecast Section of the Office of Meteorological Research (WB 1958a; 1961).

[2] The Alaskan Weather Center was part of the 7th Weather Group of the U.S. Air Weather Service located at Elmendorf Air Force Base in Anchorage.

For the next decade after the arrival of computers, persons interested in developing statistical forecasting systems experimented with various techniques. Nothing had been put into WB operations, and there was no process for doing so.

The arrival of computers boosted the possibility of using analogues. Lund (1963) used an IBM 704 for "map pattern classification," finding analogues over the northeastern CONUS by simple correlation. However, he concludes, "Since the map types are based on pressure values only, they are not intended for use in forecasting future pressure distributions unless other information (for example pressure tendencies) is also considered."

The IBM 029 punch machine by which we transferred FORTRAN code and data onto punch cards. (From IBM Reference Manual, IBM 29 Card Punch, eighth edition, 1971.)

The Travelers Research Center (TRC), created in 1954 by the Travelers Insurance Company (Weatherwise 1954), was a leader in the statistical forecasting field. Their work, supported by the Federal Aviation Administration (FAA), the U.S. Air Force, and to a lesser extent the WB, was mainly in short-range forecasting of aviation-related variables, especially ceiling height and visibility. "Short-range" was then understood to be only a few hours into the future. Joseph (Joe) G. Bryan and Robert (Bob) G. Miller were there, and they led the action in the private sector, at least as it affected WB work. Bob published more than Joe, but Joe was at the forefront of new work. Several cutting-edge reports resulted.

Bob Miller's (1958a) TRC report, "The Screening Procedure" laid out the stepwise selection of predictors in linear regression.[3] Bob says this was originally proposed by Bryan in 1944, but the process was probably developed multiple times, as Wherry et al. (1940) and Lubin and Summerfield (1951) had discussed it earlier.[4] The time was now ripe for this process, with computers and programming languages able to handle the calculations. The predictor selection can be either forward (adding a predictor from a set of possibilities one at a time, which was what Bob proposed), backward elimination (all possible predictors put into the regression, then eliminated one by one if they are not useful), or a combination. The criterion for adding or dropping is the incremental reduction of variance (RV) attributable to the predictor being considered. This procedure involves a decision as to whether or not the incremental RV is large enough for a predictor to be included in the regression equation. Bob proposed a modification to the F-test (Miller 1958a, p. 95), the basic test not being appropriate (at a specific significance level) because the predictors were not randomly selected, but rather selected because they were "best" according to the same criterion on which the F-test is based—reduction of variance. The significance of this report is not that it was the first to propose "screening," as others had done so earlier, but that it brought screening to the attention of the meteorological community; members of SRFDS certainly took note. It was probably the first time the term "**screening**" had been applied to this process of predictor selection. While Bob had available an IBM 704, he was still programming in "machine language" and, of course, using magnetic tapes (Miller 1958b).

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[3] This selection method for regression is also described in Miller (1962) as Appendix A.

[4] I find no evidence the TRC group was aware of Wherry et al.'s or Lubin and Summerfield's work.

It was shortly after this that I prepared for use in SRFDS a FORTRAN II screening regression program 20G (Glahn 1961a) for the IBM 704 and documented it for use on the 7090 which replaced the 704 in 1961 at the National Meteorological Center (NMC). As mentioned earlier, Glenn Brier's office and staff were next door to SFRDS; I was aware of their statistical work, and secured a regression program from Morris Frankel, who worked for Brier, which I revised and tailored for our use. It is my belief that the program had been adapted from one written by Frank Lewis. FORTRAN could not perform all tape manipulation functions needed, so some elements of FAP (FORTRAN Assembly Program) had to be used. Vestiges of this 20G FORTRAN code can be found in the most recent of MDL's regression programs. The stopping procedure was not the F-test, but rather just a value x furnished by the user that when an additional predictor did not provide an additional x percent reduction of the total predictand variance, the selection stopped. This stopping procedure seemed as good as any other and has served as the basis for selection in all TDL/MDL screening programs.


Robert G. (Bob) Miller of the Travelers Research Center. (Photo via Allan Murphy and Ed. Epstein.)

About the time I arrived in Allen's branch, the WB began an expanded agricultural weather service in the Mississippi Delta (Glahn 2012; WB 1958b), and a project was soon started in SRFDS to study the problem of rainfall prediction there. The Delta is a rich agricultural plain between the Mississippi River on the west and the bluffs along the Yazoo River on the east. The name of our group was changed in 1961 from the SRFDS to the Short Range Forecast Research Project (SRFRP).[5] The first paper to come out of SRFRP using computers documented some of the results of forecasting the probability of rain in the Delta for the next day based on data observed a few hours before (Glahn 1962). The experiment was woefully short on data, as we now know, comprising only 184 cases. This was the classical technique whereby the RF of rain over the Delta was forecast for the following day by using observed surface and upper air predictors. The screening procedure does not necessarily select the best set of predictors. For instance, if six are selected, there may be a set of six that is better. It is almost prohibitive to try to find the unique best set because of computer resources needed, but screening by pairs is feasible, and we tried that. Ed Lorenz (1956) had earlier developed empirical orthogonal functions (EOF) as a way of specifying a large percentage of the variance of a set of variables with a small number of functions.[6] Lorenz had provided a worked example from which I was able to program the


Card tray with binary punched cards ready for loading into a computer. (Photo by Bob Glahn.)

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[5] Memo from J. J. Davis, Chief, Personnel Management Division dated February 3, 1961, to H. R. Glahn informing of the change of name from Short Range Forecast Development Section to Short Range Forecasting Research Project, Meteorological Research Projects Branch. These were elements of the Office of Meteorological Research headed by Harry Wexler.

[6] EOFs had earlier been called principal components. This is another example of something having been independently developed more than once.

method (Glahn 1961b), and I included EOFs as predictors in the Delta study. The forecasts were evaluated by RV and Thompson's C/L utility diagram (Thompson 1955). The forecasts were also compared to subjective forecasts made by three meteorologists in the SRFDS. Overall, the results of the objective forecasts were not encouraging. The equations were not stable on test data. The statistical techniques were not the problem, but rather the amount and type of data available, and the way they were presented to the technique; all data were tabulated by hand and put onto IBM punch cards, and resources and time were limited. Screening by pairs did not show improvement over screening singly. There was some indication that the equations using EOFs were more stable than others. One conclusion was, "It is possible that some method which attempts to consider advection parameters and parameters derived from dynamic models such as vertical velocity as nonlinear operators would be more successful than the completely linear techniques . . ."

Klein, being in the Extended Forecast Division of the WB located at Suitland, Maryland, had early access to the IBM 704 there and followed up on his earlier work to forecast 5-day mean temperatures at 30 cities in the CONUS (Klein et al. 1959). This was the first of several papers by him and his collaborators (Frank Lewis, Billy Lewis, Isadore Enger, Jim Andrews, C. W. Crockett, and others) (e.g., Klein 1966; Klein et al. 1967). He used the screening procedure to relate the temperature at a city to mean station temperature and 5-day mean 700-mb heights centered 2 days earlier at two specific gridpoints. He noted that ". . . regression equations tend to 'hedge' by not forecasting the extremes as often as they are observed. One method of correcting this tendency is to 'inflate' the objective forecasts so that the variability of observed and predicted values is approximately the same." He then explained that dividing the forecasts by the correlation coefficient would do that. Actually, it is the forecast deviations from the mean that should be divided by the correlation, not the forecasts themselves unless the predictand is deviations from the mean. Klein credits Isadore Enger, a co-author, with suggesting the **inflation** procedure. Inflation has its positive and negative points. It was discussed in the literature then (Glahn and Allen 1966) and since (Maraun 2013, 2014; Glahn 2016). In practice, neither the forecast 5-day mean temperatures nor the 700-mb heights are known, so for testing the equations, Klein used a combination of previously observed temperature, temperatures forecast by the WB District Offices, and the 700-mb forecasts from the barotropic model. A conclusion was "Thus, the objective forecasts were nearly as skillful as a good set of official forecasts." This type of work was used for a number of years in the Extended Forecast Division and was an example of the "**perfect prog**" (PP) technique.[7] Perfect prog is a method that develops relationships, usually correlations, between the predictand and one or more observed predictors at, or nearly at, the same time, then in operation the predictors have to be estimated. Already at this early date, the estimates were being based, at least in part, on NWP. The assumption is that the predictors can be forecast perfectly, hence the term perfect prog. This was truly a "transition" paper; equations were developed on the IBM 704, but a portion of the work was done on desk calculators (Klein et al. 1959., p. 678).

Another landmark paper by Miller (1962) was "Statistical Prediction by Discriminant Analysis." Here again, this cannot really be claimed as original work, but it hit the

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[7] Klein et al. (1959) was the first paper to appear that used the perfect prog technique. Klein attributes the name perfect prog to Keith Veigas, a member of TRC.

meteorological statistical community full force and made the method readily available.[8] In the foreword to Miller's monograph, Thomas Malone states, "The meteorological prediction problem is probably one of the most difficult and challenging scientific problems of our times." He continued, ". . . encouraging progress has been made in recent years in dealing quantitatively with meteorological prediction. This progress has been along two converging paths." Then he characterizes the dynamical approach and the statistical approach. It is not clear why he used the term "converging." Actually, it became more like two trains on parallel tracks. Occasionally, the statistical train would grab something from the dynamical train if it happened to be at the right place at right time, but the dynamical train was at the time only peripherally aware of the statistical train.

The problem addressed by multiple discriminant analysis (MDA) is forecasting one of two or more classes of a predictand. This can be either a variable which divides itself naturally into classes, for instance type of precipitation, or a continuous variable for which classes, or groups, can be defined that are meaningful, for instance certain ceiling heights of importance to aircraft operations. For G groups, a set of G-1 or fewer discriminant functions are defined which when evaluated give values indicative of group membership. Unfortunately, even though the functions "discriminate," there is still the problem of determining probabilities of the groups or selecting the best one. Forecasts from these functions are characteristically not multinormal, so some empirical procedure must be used to find the probabilities or single value forecast, and Miller explained and used one due to Fix and Hodges (1951). Basically, this is plotting the data points on a graph with the discriminant functions as axes, finding for each point others in its vicinity defined by their distances on the diagram, and computing the RF of the event over those points. This works well for two functions, and can be easily visualized, but becomes cumbersome with more than two, even when done by computer.

Possibly to offer a better solution than MDA for finding the probability of an event, Miller (1964) provided another TRC report, "Regression Estimation of Event Probabilities." This has caught on so well that his acronym **REEP** (Miller 1964, p. 1) has become near-universal in meteorological statistics. Again, the method was not really new; it had been published by Lund (1955) and Suits (1957). Any reference to REEP is almost always to Miller; given that Lund published in 1955, why is this? I believe it is due to there actually being an acronym, and that TRC was heavily involved in statistical work which led directly to a number of reports dealing with a subject of great interest to the WB. TRC also shared data and expertise with members of the WB for the WB's own studies.

There are similarities between MDA and REEP. In fact, if there are only two categories, MDA and REEP give identical results, in that the coefficients of the MDA equation (with G = 2, there is only one) are proportional to those in the REEP equation. The two equations are not necessarily identical, because the variance of the predictions from the MDA equation is not bounded as it is from the REEP equation. The relationships among regression, MDA, and canonical correlation are described in Glahn (1968).

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[8] Joe Bryan had laid out the method in his 1950 Harvard University Ed. D. Dissertation, "A Method for the Exact Determination of the Characteristic Equation and Latent Vectors of a Matrix with Applications to the Discriminant Function for More Than Two Groups" (Bryan 1950).

These three publications by Miller had a tremendous influence on how statistical work advanced in the WB and later in the National Weather Service (NWS), not only in SRFRP and TDL, but also in other parts of the WB, such as the National Hurricane Center (NHC).[9] REEP was found to have considerable advantage over MDA. REEP is just linear regression with a binary predictand, and there can be as many predictands as needed to represent the range of the variable being forecast. When the groups being represented by the binaries are exhaustive and mutually exclusive, then for the probabilities over the groups to add to unity, the same predictor variables must be used in each of the equations. The forecasts produced by REEP are not bounded by zero and one--not a theoretically pleasing characteristic if they are to represent probabilities. However, the values can easily be "normalized" by setting all values > 1 to 1, all values < 0 to 0, and dividing the resulting estimates over the groups by their sum.

Bob Miller, Joe Bryan, and others at the Traveler's Research Center were very influential in statistical weather research in the 1950's and 1960's.

Another area of experimentation was the use of "adaptive logic." Several such papers and reports appeared in the 1959 to 1964 time period. The authors were mostly from MIT (Mattson 1959) and Stanford University (Ridgway 1962), and the latter were collaborating with one of the WB Research Forecasters, Hal Root (Hu and Root 1964). This seemed a worthwhile technique to investigate, so it was programmed and tested in SRFRP. This method maps binary inputs to binary outputs (categories of the predictand), adjusting the coefficients for the mapping iteratively. The summation of the products of the inputs and weights are categorized, and if in the training the category matches the binary predictand, the weights are not adjusted. If they do not match, the weights are adjusted "a bit" so that the output is closer to the desired outcome. This process the authors called an ADALINE (adaptive linear neuron). There can be more than one ADALINE, so that one feeds into another ADALINE; that was called a MADALINE. As one might imagine, the success hinges on the adaption process, as well as the exact arrangement of ADALINES and the binary coding procedures. So any test cannot be conclusive, but only apply narrowly to the setup tested. What was then called a MADALINE is today called a neural network.

I compared some configurations of the adaptive logic ADALINES with results of MDA, and found that MDA provided better results. One has to question an adaptive approach unless it is more appropriate for the last sample point encountered to have a larger effect on the developed process than one farther back in the sample. One thing that did come into focus at about this time was the importance of the binary coding. Consider the two methods of coding a variable that is in, or has been put into, categories, as indicated in Table II-1 reproduced from Glahn (1964). Each coding scheme contains exactly the same total information, but it seems relationships between predictand and predictor ought to be better with Code 2. Duda and Machanik (1963) explain that all of the points in an ADALINE input space that indicate a positive response should be "close" to each other, where "close" is defined in terms of Hamming

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[9] There was active statistical work going on in relation to hurricanes, both at TRC and at the NHC For instance, Veigas et al. (1958) produced an objective method for predicting the behavior of hurricanes in the western Atlantic and Gulf of Mexico that was subsequently used operationally by the NWS (Glahn, 1965, p. 121).

distance. Hamming distance between two binary numbers is defined as the number of changes of bits in one number necessary to make it equivalent to the other number. One also can conclude that those points that give a negative response ought to be a large distance from those that give a positive response. In Code 1, each number is hamming distance 2 from each of the others. For Code 2, each category is 1 hamming distance from its neighbors, but is 2 or greater for non-neighbors. Therefore, Code 2 is better. We have used Code 2 almost exclusively in TDL/MDL especially for predictors, and I think that has contributed to our success. This is a departure from much of the work at TRC (for instance, see Miller 1964).

Table II-1. Two possible binary codes for converting a variable in five categories into binary variables. All four of Code 2 or any four of Code 1 furnish all the information.

Category	Code 1					Code 2			
	Binary Variable Number					Binary Variable Number			
	1	2	3	4	5	1	2	3	4
1	1	0	0	0	0	0	0	0	0
2	0	1	0	0	0	1	0	0	0
3	0	0	1	0	0	1	1	0	0
4	0	0	0	1	0	1	1	1	0
5	0	0	0	0	1	1	1	1	1

A method for developing conditional relative frequencies suggested by Gringorten (1955) and Panofsky and Brier (1958, p. 185) was the use of contingency tables. These suggestions were made before computers were widely in use, and the precise method of using them varied. It seemed, now that computers were available, this ought to be a viable method. Consequently, I programmed and tested it against other techniques (Glahn 1963). The idea is to divide one or more predictors into categories that should be meaningful in predicting the event needing a prediction, and then to compute the relative frequency (RF) of the categories of the predictand for each combination of predictor groups. Essentially, this is a multi-dimensional (multi-celled) contingency table, and the computations are straightforward. The major problem is that some cells will be empty or have so few cases that an RF computed would be meaningless. So, some smoothing is needed, at least in parts of the table. The problem, then, is how much to smooth and over which dimensions. For a table of many dimensions, the process and computations become laborious, but they can be done. One could use this process for finding the probabilities associated with MDA functions. Results of testing were not encouraging for using contingency tables; for instance, MDA was more efficient and more predictors could be profitably used.

Several persons in the Office of Meteorological Research were now using computers to devise objective aids. For instance, Pore (1964) used regression to relate extratropical storm surges at Atlantic City, New Jersey, to wind and pressure with various time lags. A regression equation was presented for possible operational use.

By the mid 1960's, there were no statistical forecasts being prepared centrally and communicated for use by field forecasters. In fact, there were no statistical forecasts *ready* for distribution except possibly Bill Klein's mean temperature forecasts for a few stations which were being used internally at NMC. Statistical forecasting was not really being taken seriously by WB higher management. But foundation techniques and software had been developed, experience gained, and statistical work was spreading.

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CHAPTER III

THE SUBSYNOPTIC ADVECTION MODEL—PREPARING FOR MOS

One of the organizational elements in the Meteorological Research Projects Branch, Office of Meteorological Research (OMR), besides Allen's Short Range Forecast Research Project (SRFRP), was the Aviation Forecasting Research Project (AFRP). It was more recently formed and was headed by Charles F. Roberts, recently from the U.S. Air Force. Charlie asked me to transfer to the branch, with a promotion, and develop a short-range mesoscale model. The transfer was effective May 10, 1964. As indicated in the following paragraph, OMR soon ceased to exist.

On October 1, 1963, Dr. Robert White became chief of the WB, replacing Dr. Francis Reichelderfer (WB 1963). He soon brought change. The Office of Meteorological Research, of which we were a part, was abolished, and the new Systems Development Office headed by Merritt Techter inherited us (WB 1964a; 1964b). The Techniques Development Laboratory was formed in 1964, and although the people were not moved into it until October, it was operating under that structure by mid-August. Our work was in the Mathematical and Physical Techniques Section, of which I was chief, reporting to Roger Allen as chief of the Techniques Development Branch. Charles Roberts was named as acting TDL Director. Quoted from Glahn (1989):

> "Page No. 22 from Weather Bureau Transmittal Memorandum No. 906 (WB 1964c) shows the Techniques Development Laboratory (TDL) as an element of the Systems Development Office (SDO) with an effective date of July 17, 1964, the structure of SDO being recommended by J. C. Thompson and approved by Dr. Robert M. White. The structure within TDL was recommended by D. S. Fordham and approved by Merritt Techter, with an effective date of September 18, 1964 (op. cit., pp. 24-26). TDL was to have two branches, 1) the Techniques Development Branch consisting of the Synoptic Techniques Section, the Mathematical and Physical Techniques Section, and the Observations and Measurements Section and 2) the Techniques Evaluation Branch, consisting of the Computer Services Section and the Test and Evaluation Section (op. cit., pp. 159-166). The earliest transfer of personnel into TDL was probably October 11, 1964, but the organization was operating under the new structure by mid-August, as existing memoranda show."

The statistical use of numerical model output was beginning, but no distribution of products to the field forecasters was even being planned. Bill Klein and associates in the Extended Forecast Division were using the PP technique to produce guidance to be used internally in their division. But the relationships developed between near concurrent upper air *observations* and surface variables did not hold well when applied to upper air *forecasts*, even though the results were useful. It seemed a no brainer that the relationships should be developed between actual NWP upper air *forecasts* and surface variables at the desired projections.[1] However, building such relationships was not possible because a lengthy sample of an operational model would be needed, and the models were undergoing rapid change. Moreover, there was no upper level

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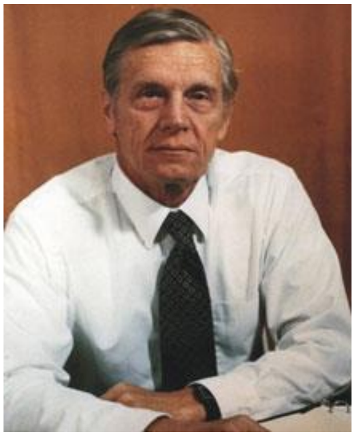
[1] The term "projection" to mean "time into the future" was becoming well entrenched. The term likely came from the WB headquarters group. Certainly, Roger Allen supported it. Bill Klein used "into the future," and projection was not being used in the early TRC reports or the Irv Gringorten and Iver Lund papers.

management interest in developing a process whereby a suitable sample could be collected and used for this purpose.

At this time, NMC's operational model had a grid spacing of 381 km at 60° N on a polar stereographic map, which is about 340 km at the mid latitudes of the CONUS. Certainly, weather processes occur on a much smaller scale, and surface observations would support a smaller grid length. Roberts wanted me to build a smaller-scale model, a tall order for someone without modelling experience and who had only received a "C" in Norm Phillips numerical weather prediction class at MIT! But fortunately, a couple of models had been developed that seemed suitable. After visiting Fred Sanders at MIT and George Platzman at the University of Chicago, I embarked on the task. Dale Lowry soon joined the project in 1965, transferring from the Analysis Division in NMC. George Hollenbaugh also joined as a programmer and that exactly tripled my null experience in such matters. Jackie Hughes and Elizabeth Booth also joined the project as meteorological technician support for the many processes being carried out by hand, such as tabulating and plotting data, drafting figures, and punching data and FORTRAN statements onto cards. George and I did all the programming for the project.

The author's work space in December 1965 in the Old Annex at 24th and M Streets as the new project was getting underway. Note the large cabinet for punched cards. (Photo by Bob Glahn.)

The Environmental Science Services Administration (ESSA) was formed in 1965 with Dr. White as Administrator. The Weather Bureau retained its name with Dr. George P. Cressman as Director (ESSA 1965). Within a few months, he brought Dr. William H. Klein over from the Extended Forecast Division to head TDL as its first permanent director. This was a good move. Bill was aggressive, had experience, knew Cressman well, and with his interest in statistics, such work now had more status than previously. The project we had started under Roberts to build a subsynoptic NWP model continued.



Dr. George P. Cressman, director of the Weather Bureau, then later the National Weather Service from 1965 to 1979. (NOAA photo.)

Quoted from Glahn and Lowry (1972):

> "The system [at NMC] then in operation (Fawcett 1962) was geared to the upper air observation times of 0000 and 1200 GMT. No hourly data (Teletype Service A) and little if any surface synoptic data (Teletype Service C) were input to the numerical models. The grid length was 381 km at 60° latitude, which may be adequate to describe and project to 36 hr most features at 500 mb. However, some detail is lost, and certainly the small-scale features of the sea level pressure field defined by the relatively dense hourly surface reports cannot be captured with so coarse a mesh.

> "Therefore, we wanted the new system to have the following characteristics:
>
> - The forecast cycle would be determined by the needs of the field forecasters rather than upper air observation times.
> - All data routinely available, including hourly, would be used.
> - A mesh length commensurate with the spacing of observation stations would be employed.
> - Numerical and statistical models would be combined to forecast actual weather variables such as cloudiness, surface winds, probability of precipitation, and maximum temperature.
> - The numerical model portion of the system had to be rather simple so that computer time would not be excessive.
>
> "In addition to requiring the system to have the above characteristics, we wanted to adapt existing models, rather than develop completely new ones, so that implementation could be achieved more quickly. With these things in mind, we chose to adapt two existing numerical models—the Reed (1963) sea level pressure model and the SLYH precipitation model (Younkin et al. 1965). The combination and modification of these two models we call the Subsynoptic Advection Model or SAM.[2]"

Richard Reed had spent a year at NMC and developed the sea level pressure model. This is a bit of a misnomer; it was really to predict the 1,000-mb height. We figured if Dick Reed developed it, it ought to be good. Reed tested it in the usual, at the time, Eulerian framework, and also in a Lagrangian framework, mimicking graphical methods he (Reed 1960) and others had previously used (e.g., Fjortoft 1952; Oakland 1962). By using the 500-mb height and a rather smooth "equivalent advecting wind" from the operational barotropic model, he found the characteristic errors in the Eulerian framework to be reduced in the Lagrangian. There is no indication this was ever run on a grid finer than 381 km. Fred Shuman (1989) was later to say about accuracy of forecasts at NMC: "The error at sea level continued to decline, and for the 5 years from 1962 to 1966 the decline was attributed largely to Reed's model." Quoted from Glahn and Lowry (1972) concerning Reed's model:

> "This model has been in continuous use at NMC since about 1963 on the hemispheric, 1977-point grid. Since the advent of NMC's primitive equation (PE) model (Shuman and Hovermale 1968) in June 1966, the Reed model has been used for a 'preliminary' forecast package for extended range guidance."

Essentially the downstream (forecast) 1,000-mb height was the upstream 1,000-mb height modified by (1) the change in 500-mb height (a deepening term) over the trajectory, the change in latitude over the trajectory, and (3) the terrain change over the trajectory, each of these with an appropriate coefficient. One of the weaknesses noted by Reed (1963) was the over-intensification of anticyclones, and under certain conditions, these high pressure areas would develop into a "tear drop" shape. To try to solve this problem, we constructed trajectories with the model's equivalent advecting wind, and then constructed trajectories that would give a perfect forecast. Analysis of these trajectories indicated that an advective wind with a smaller

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[2] Competing acronyms were LAM, SLAM, SLIC, SLIP, and SLAP.

meridional component than the equivalent wind we were using would give a better result. After experimentation, we substituted a heavily smoothed advecting wind, and got significantly better results.

The 381-km distance between gridpoints came to be called a "Bedient" after Art Bedient a technological genius at NMC. This term was probably coined by John Stackpole (1978, p. 2), a denizen of NMC for many years. This exact value was used because it was ½ inch on a 1:30 million polar stereographic map projection true at 60°N. The one-half inch was exactly the distance of 5 print wheels on the IBM 1401 lineprinter used for gridprinting zebra maps (Hoke et al. 1981, p. 42).

Besides the 500-mb forecast from NMC, we were going to use the surface observations of pressure converted to sea level (SLP). It seemed that the spacing of stations reporting SLP would support a ¼ Bedient gridlength, so we chose that scale such that every fourth gridpoint was an NMC gridpoint. This was a lot of gridpoints in those days, so we concentrated on the eastern United States. The 35 x 35 gridpoint area covered is shown in Fig. III-1. Our intent was to develop a model, run it, and build up a history so that we could relate weather to its forecasts.

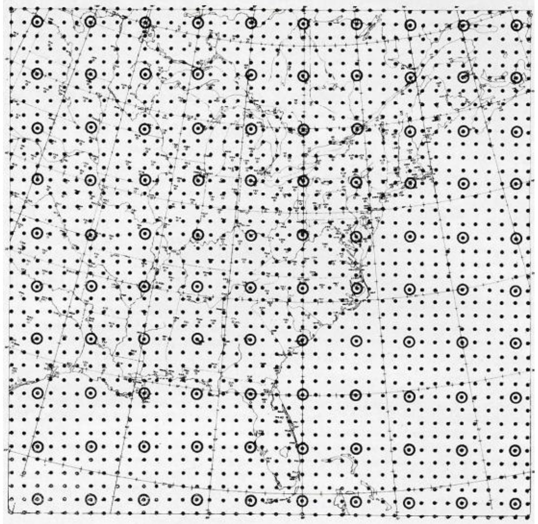
Fig. III-1. The SAM grid shown by dots at gridpoints. The NMC gridpoints are at the circles. (From Glahn and Lowry 1972.)

Several weather variables we wanted to forecast, such as clouds, precipitation, and visibility, require some measure of moisture to be forecast, such as relative humidity. Quoted from Glahn and Lowry (1972):

> "The first 'wet' numerical model used routinely at NMC was initially developed for graphical use by Russell Younkin and Jerry LaRue. Later, Fred Sanders presented theoretical justification for its success. John Hovermale programmed the model for computer use and it was put into operation in September 1964. The name SLYH derives from the last name initials of the four persons mentioned above."

This model was solved in a Lagrangian manner, being similar in that respect to the Reed SLP model, and suited our needs. Our use of it would be similar to its use in NMC, except we would use a mesh length ¼ that used by NMC. The moisture parameter in the model was saturation deficit (Sd). For our purposes, saturation deficit was the thickness between 1,000 and 500 mb that would have to be reduced (cooled) to produce precipitation, given the amount of moisture in the column. The downstream (forecast) Sd was equal to the upstream Sd modified by the change in thickness over the trajectory and the change in terrain height, each with an appropriate coefficient.

Plans for our model were reported in Glahn and Lowry (1969). For the model, we needed an SLP and an Sd analysis at that scale, and none existed. Shared databases had not been established, so we wrote software to decode hourly observations (Hollenbaugh et al. 1969) and to analyze them (Glahn et al. 1969b). In the decoding, we got guidance from a TRC report (Marx and Shroyer 1961). By this time, the computer being used was a CDC 6600, a 60-bit word-length machine. The data to be decoded came from magnetic tapes collected from the communication circuits on the IBM 360-40 by NMC[3].

After experimenting with a method to analyze upper level heights by fitting mathematical functions to data in local areas and interpolating to gridpoints (Gilchrist and Cressman 1954), George Cressman, Director of JNWPU (WB 1954) and later of NMC, recognized the power of an analysis method put forth by Bergthorssen and Doos (1955), made a few enhancements, and implemented it at 500 mb (Cressman 1959). We adopted this method and refined it for analyzing sea level pressure and saturation deficit. Observations of wind can assist in the analysis of geopotential heights at upper levels, where NMC was interested, through the geostrophic relationship, but we did not use wind at the surface. Essentially, the analysis process is to start with some "first guess" value at each gridpoint, then modify the gridpoint values in the vicinity of each observation based on the difference between the observed value and the gridpoint values interpolated to the observation point. This is done for more than one pass through the data, each time reducing the radius over which the observations modify the gridpoint values. If the difference between the observation and the current analysis is greater than a threshold that varies by pass over the data, the observation is declared in error, and is not used for that pass. For sea level pressure, which is spatially continuous, a very good analysis could be made with the available observations and the gridlength being used. An example is shown in Fig. III-2. Good visualization techniques were not available, and the isobars, or contours at 500-mb, were depicted by "zebra maps." These charts had alternating bands of letters and blanks between neighboring isobars; an example is shown in Fig. III-3. Fig. III-2 was hand drawn by tracing from a zebra map.

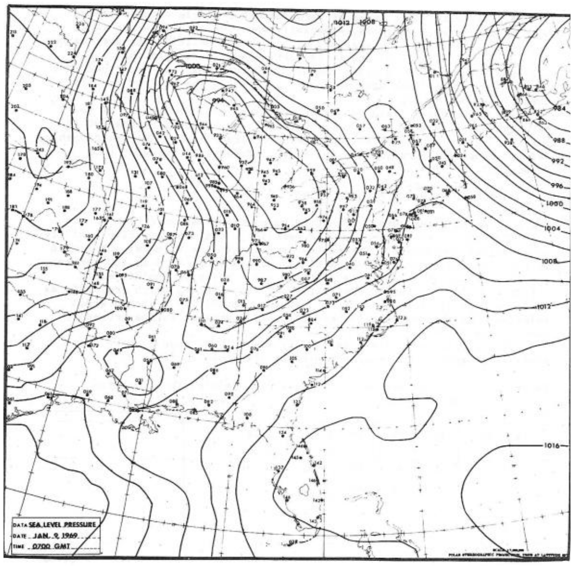

Fig. III-2. Sea level pressure map analyzed at ¼ Bedient on the SAM grid for 0700 UTC January 9, 1969. (From Glahn et al. 1969b.)

Sd is not observed, so we estimated it from other surface weather variables that were observed. Total column water can be calculated from upper air reports, but we needed an estimate on a smaller time and space scale. Regression equations were derived which specified the natural logarithm (ln) of total column precipitable water as a function of surface dew point, weather, and clouds (Lowry and Glahn 1969). Considerable work went into this study; data were gathered for 1200 UTC for 56 stations in the eastern CONUS over 2 years from the Service A teletype reports. Precipitable water values were those computed at NMC from radiosonde reports. Numeric code values for weather and clouds were devised for use in the regression.

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[3] Glahn et al. (1969a) state these were IBM 360-40s. However, Fenix (circa 1998) states that IBM 360-30s were purchased in 1966 and used until IBM 360-40s were purchased in 1970.

Approximately 86% of the variance of the ln of precipitable water could be explained by the equations. Regional and seasonal stratification added only a small improvement. Further analysis allowed the saturation thickness at stations to be specified from the estimate of precipitable water and elevation (Lowry 1972). This regression estimate of the saturation thickness could be made each day. The Sd could be computed as the difference between the saturation thickness and actual thickness; it then needed to be analyzed.

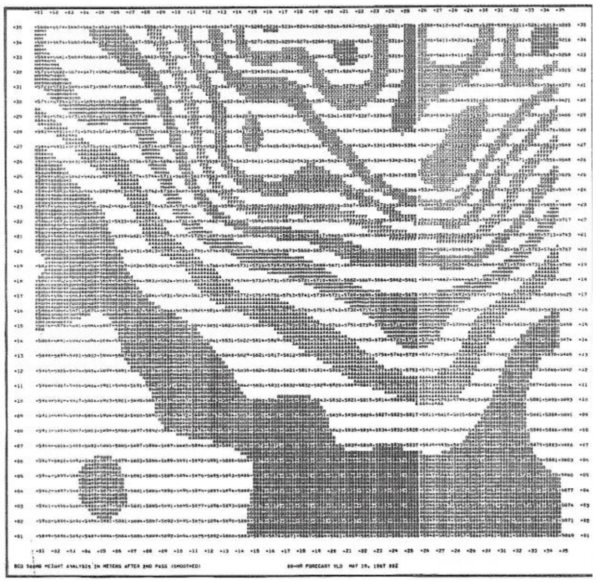


Fig. III-3. An example zebra map depicting the analysis of 500-mb height for 0000 UTC May 18, 1967. (From Glahn and Hollenbaugh 1969.)

Analysis of Sd is a bit trickier than sea level pressure, primarily because the values are bounded at zero. The values of Sd are zero by definition when precipitation is occurring, and never go negative. The analysis process tends to spread the positive values into the zero areas. Therefore, the Sd values were coded to get a good demarcation between the zero and non-zero areas (see Glahn et al. 1969b for details). After coding, the Sd could be analyzed essentially the same way as sea level pressure (see Fig. III-4).

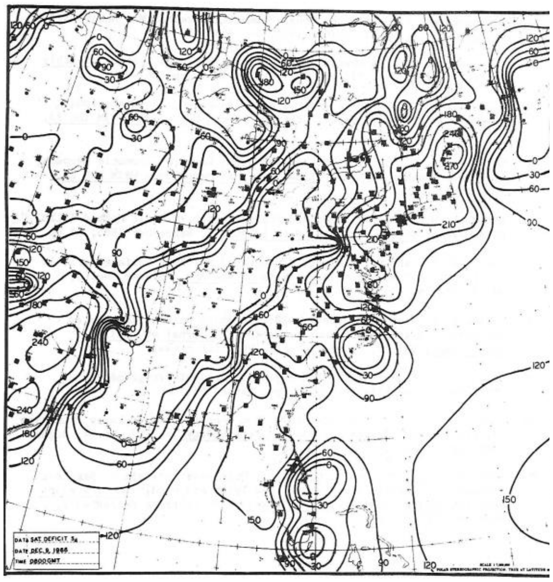


Fig. III-4. An example saturation deficit analysis for 0800 GMT, December 9, 1966. The dots are stations with precipitation and the squares are stations without precipitation. The areas with no contours, along a northeast to southwest oriented frontal boundary and to the far northwest, are the areas with precipitation and zero saturation deficit. (From Glahn et al. 1969b.)

We found, to our surprise after looking closely, the PE model contained high-amplitude gravity waves at 500 mb that needed to be filtered out before input to SAM (Glahn 1970). Some variables output from the PE had been time-smoothed by NMC, but the heights at constant pressure surfaces had not. Fig. III-5 shows the hourly values of 500-mb height for three PE gridpoints at projections 1 through 36 h. At each of the gridpoints, 3rd, 4th, and 5th order polynomials fitted to the data are plotted. After examining plots at several gridpoints, we concluded (Glahn 1970):

> “The heights are very noisy. The forecast change in 1 hour (due to gravity waves) may be greater than the ‘real meteorological’ change in 36 hours.

> “The larger amplitude gravity waves have a period of about 6 hours. This checks roughly with previous studies. There is also a higher frequency wave indicated with a period of about 3 hours.”

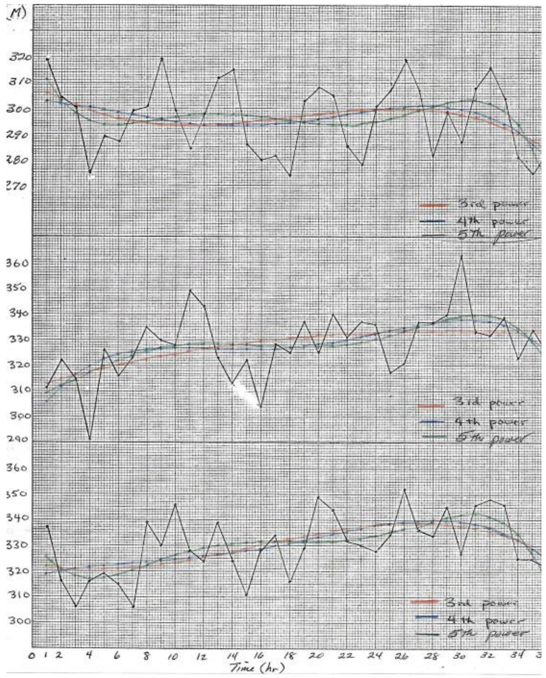


Fig. III-5. PE 500-mb heights at three gridpoints, with 3rd (red), 4th (blue), and 5th (green) degree polynomials plotted. (From Glahn 1970.)

For most gridpoints studied, there was not a lot of difference in the 3rd, 4th, and 5th degree fits. What also became clear (diagrams not shown) was that to get reasonable results, the PE output needed to be at hourly intervals, instead of the 3-hourly being produced. Eventually, the PE output was furnished hourly, and we used a 3rd degree fit to obtain the values to go into SAM.

As stated earlier, the decoding of observations, estimation of Sd, analyses, and SLP and moisture models were put together in a package we called the Subsynoptic Advection Model (SAM) (Glahn et al. 1969a; SDO 1969). SAM was run for nearly 30 cases and extensive verification carried out. Quoted from Technical Procedures Bulletin No. 6 (WB 1967) concerning the tests:

> “The results of these tests indicate that SAM apparently has a capability of predicting the occurrence of precipitation during the twelve-hour ‘Today’ period beginning four hours after initial data time with a degree of skill which is equivalent to that of the subjective forecasts now issued by NMC. The forecasts appear to be slightly better than those derived from the 6-layer model predictions. This apparent increase in skill is probably due to the use of a smaller grid length (and the accompanying greater detail in the initial moisture and sea level pressure fields) and the use of surface data several hours after the initial data of the PE model.”

The Technical Procedures Bulletin (TPB) series was started by Charlie Roberts, who initially acted as TDL Director when it was first formed but was now Chief of the Technical Procedures Branch, Weather Analysis and Prediction Division, Office of Meteorology (OM). The purpose of the TPB series was to inform the WB forecasters, and others using WB products, of the changes occurring in the centrally produced and distributed product suite. The series started in July 1967, and lasted until around 2000, a better than average run for almost anything, some organization names having changed multiple times during that period. While the TPBs were not under the purview of the Committee on Analysis and Forecast Technique Implementation (CAFTI), they were closely tied, because for CAFTI to recommend implementation of a product, it mandated that a TPB had been written covering the product. CAFTI was formed in 1966 when Merritt Techter, Director of the Systems Development Office (SDO), parent of TDL, saw a need for a mechanism that would facilitate the implementation at NMC of techniques developed within SDO. This foresight by Techter undoubtedly contributed heavily to TDL’s success in getting products implemented at NMC; before CAFTI, there had been resistance. The first members of CAFTI were Bill Klein of SDO, chair; Charlie Roberts of OM; and Harlan Saylor of NMC. Because of the critical importance of CAFTI to TDL's getting products implemented, a summary of CAFTI from its beginning until 1990 is included as appendix B. CAFTI was disestablished in 2000 by Gen. John (Jack) Kelly, NWS director, and the TPBs soon stopped.

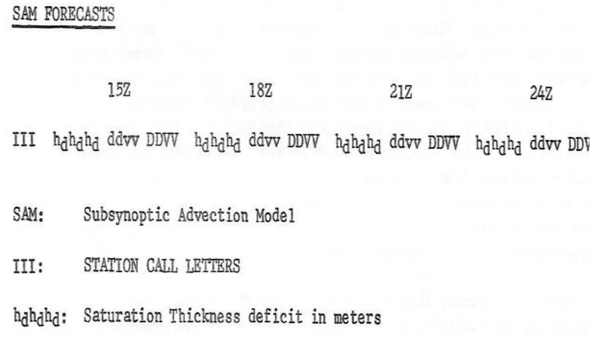
According to WB (1967), a 6-month implementation test of SAM started September 6, 1967. Forecasts of saturation deficit and 1000-mb geostrophic wind were furnished for 25 stations for projections of 3, 6, 9, and 12 h. The Sd forecasts covered the 3-h periods ending at the projection times, and were derived from 1-h values.

The test was completed, and the results led to the recommendation (WB 1968) for operational implementation in June 1968 twice daily starting from 0700 and 1900 UTC data. Quoted from WB (1968):

> "The operational forecasts will be relayed to each of the four RAWARC (radar report and warning coordination) circuits (23420, 23421, 23422, and 23423) on an unscheduled basis in the first available time following 0820Z and 2020Z. The bulletin heading will be FOUS WBC, and the format will be nearly the same as that used in the test program except that a statistically derived estimate of the surface wind direction and speed will be provided in addition to the geostrophic wind direction and speed."

SAM, implemented in June 1968, was the first numerical model to run at NMC with a grid spacing of less than 381 km. The surface wind was the first forecast statistically derived from model output and provided to field forecasters.

Note the addition of the statistically derived wind. This was the first operational distribution of statistical forecasts to field offices and the first MOS product, although it was not yet called MOS; it occurred on or about June 10, 1968 (see Fig. III-6). A rather inauspicious start, but a start. Within about a 4-year period, we had planned and initiated a new project; decoded and collected hourly surface observations; written an objective analysis program that could analyze SLP, saturation deficit, and upper air heights; coded, improved, tested, and implemented, two advective models; written verification routines; derived wind prediction equations by regression; coordinated with CAFTI; and implemented the system at NMC.



SAM FORECASTS

15Z 18Z 21Z 24Z

III $h_dh_dh_d$ ddvv DDVV $h_dh_dh_d$ ddvv DDVV $h_dh_dh_d$ ddvv DDVV $h_dh_dh_d$ ddvv DDV

SAM: Subsynoptic Advection Model

III: STATION CALL LETTERS

$h_dh_dh_d$: Saturation Thickness deficit in meters

Fig. III- 6. Format of SAM bulletin with saturation deficit, geostrophic wind, and surface wind. The surface wind forecasts DDVV were the first product where the statistical relationships were derived from a numerical model. (From WB 1967.)

At the beginning of this project, we were using the IBM Stretch (7030) computer located at the Geophysical Fluid Dynamics Laboratory at 615 Pennsylvania Ave., downtown D.C. (WB 1962). The shuttle bus that had previously connected us to the computer at Suitland was shifted to this location, and cards were sent nightly. There were some differences in the setup of jobs between the IBM 7094 at Suitland and the 7030, but the change was relatively painless.

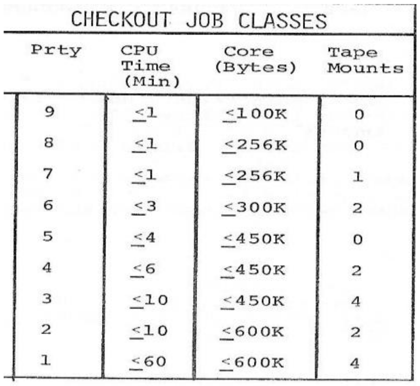
During this period, NWS headquarters moved from downtown D.C. to Silver Spring, Maryland; TDL moved in April 1966. The new site was the Gramax building, and TDL was on the 12th floor. It was new, so we built out the floor according to need. A few permanent walls were built, and work spaces were formed by using free-standing partitions. It was much better than the Old Annex we had been in previously, but still was not "modern" by today's standards. For instance, the windows could be opened and the heating and cooling were by radiators under windows with a fan switch. Switching between cooling and heating was usually done only twice per year.


The Weather Bureau and then the National Weather Service headquarters building at 2400 M Street from 1941 when it was built until 1966 when the headquarters moved to Silver Spring, Maryland. The building used prior to 1941 came to be called "Old Main" and its annex, where we worked, was called the "Old Annex." A second-floor walkway connection between the Old Main and the Old Annex can be seen at the far left. (Photo from National Archives.)


The Gramax building, the NWS's new headquarters at 8060 13th Street in Silver Spring, Maryland. TDL was on the 12th floor. Bill Klein has a spacious office on the northwest corner (leftmost here). (Photo by Bob Glahn 1989.)

There was in the Gramax on the 8th floor a computer and lineprinter for communicating with Suitland, so we no longer had to use a shuttle; we could feed in cards and get printout at the Gramax. Most of the time there was an attendant who kept the paper torn and filed by job. This was a considerable step up in development capability; we could usually get more than one turn-around per day. But we were still very limited in core (memory), and jobs greater than 100K bytes would get a lower priority in the queue. A job requiring 600K was a <u>big</u> job (see Fig. III-7). This is not meg or gig, but K!

With the completion and implementation of SAM in 1968, we had achieved the goal set by Charlie Roberts to build a short-range mesoscale model, although it was running over only the eastern CONUS. Actually, the components of the "model" were not new, but rather implementations of existing models with a smaller mesh length than had previously been used for them.



CHECKOUT JOB CLASSES

Prty	CPU Time (Min)	Core (Bytes)	Tape Mounts
9	≤1	≤100K	0
8	≤1	≤256K	0
7	≤1	≤256K	1
6	≤3	≤300K	2
5	≤4	≤450K	0
4	≤6	≤450K	2
3	≤10	≤450K	4
2	≤10	≤600K	2
1	≤60	≤600K	4

Fig. III-7. Priority of jobs (9=high). (From *PMCS* 1975.)

We were then ready to build a substantial statistical processing system with SAM as its input. The primary NWP model at NMC was still the PE running at 1 Bedient (381 km at 60°N) with little or no surface data input. SAM was at ¼ that resolution, was initialized with surface reports of pressure and moisture, and was running at a time more appropriate to support the WB Eastern Region forecasters. The statistical system would also have as input meteorological variables observed at the surface. SAM, together with its statistical component, was a prototype to demonstrate the viability of such a system.

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CHAPTER IV

THE BARRIER IS BROKEN—TDL IMPLEMENTS PRODUCTS AT NMC

The estimates of surface wind, as well as for geostrophic wind, in the SAM bulletin implemented twice a day on or about June 10, 1968, were for 105 stations in the eastern U.S. and were distributed on four RAWARC teletype circuits. The forecasts were based on 0700 and 1900 UTC data, the times being chosen to be helpful to the forecasters in producing their official forecasts. The surface wind estimates were extremely simply derived. The U (eastward) and V (northward) components were each computed from a regression equation of three terms: a constant and the U and V geostrophic winds from the SLP model of SAM (see Glahn 1970a for a discussion of wind prediction models). Because only a few months of developmental data were available, the equations were derived by pooling all stations together to get a large enough sample to be meaningful. In addition, the relationships were based on data valid at only 1200 UTC, but were applied to all projections. Nevertheless, it was a start, and proved that a group outside of NMC could develop a product, write the implementation software, and get it run regularly by NMC. It must have been a joy to Charlie Roberts to see this happen, as he had instigated the project a few years earlier. Charlie, through his role in CAFTI, was also helpful in the implementation process, and incidentally, he as Chief of the Technical Procedures Branch of the Weather Analysis and Prediction Division, Office of Meteorology, signed TPB 14 (see Chapter III) announcing the implementation.


Harry R. Glahn, co-developer of SAM and MOS.

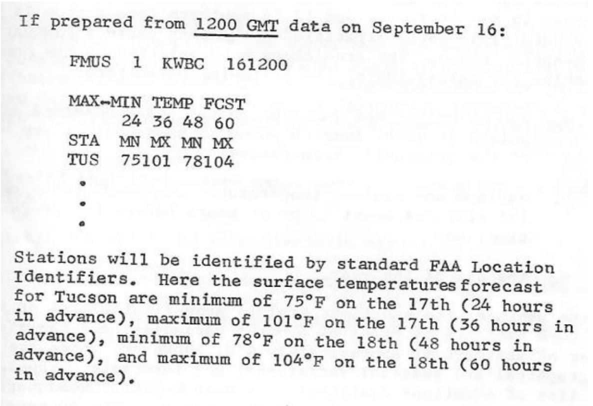

Dale A. Lowry, co-developer of SAM and MOS.

TDL had been formed in 1964 and within a few months Dr. Cressman, now director of the Weather Bureau, brought Dr. William (Bill) H. Klein over from the Extended Forecast Division (EFD) of NMC to head TDL. In the interim, either Charlie Roberts or Roger Allen acted in the capacity of director. The formation of TDL and naming of Klein, with his interest and history of statistical analysis, had a tremendous impact on the future of statistical weather forecasting. This brought together, along with others, the groups formerly headed by Allen and Roberts with a laboratory director who cared about the work. Previously, Harry Wexler, the director of the Office of Meteorological Research, was much more interested in NWP than statistics and was influential in bringing operational NWP into existence.

Soon after arriving at TDL, Bill printed Weather Bureau Research Paper No. 46 (Klein 1965**)** which was essentially work he and others had done at EFD. It gives a quite comprehensive summary of the research applications of PP, including cloudiness and precipitation as predictands. This work is also reported in Klein et al. (1965).

Bill and a small group in TDL were diligently working on temperature prediction in the same manner as Bill had been doing in the Extended Forecast Division. Through this work, twice daily PP forecasts of maximum (max) and minimum (min) temperature for projections 24 to 60 hours were implemented at NMC on or about September 19, 1968. These forecasts were for 131 cities over the CONUS and were distributed over national teletype, Service C (WB 1968a). Although inflation (see Chapter II) had been in use, it was dropped for implementation, evidently to improve verification[1] (WB 1968a, p. 7). The developmental process followed that described in Klein et al. (1967; 1969) and Klein and Lewis (1970). This was the first CONUS-wide (Alaskan and Hawaiian stations were not included) statistical product to be widely distributed. The product format is shown in Fig. IV-1.

These forecasts were made by applying what are essentially specification equations relating surface temperature to upper air variables and to previous observed values of temperature, the word "specification" having been used in previous studies (Klein 1963).[2] The predictors were from NMC's barotropic and Reed SLP models. The equations were applied iteratively, where the NWP forecasts were used at the appropriate projections, and the surface temperatures were those forecast in the previous iteration. Another difference between Klein's work and that in SAM was that in SAM the model predictors were from the exact location of the forecast, but Klein's screening regression could select gridpoints from essentially anywhere over the CONUS, and interpolation of the predictors to the station location was not done. This reflected his extended range forecasting experience and techniques in use in the Extended Forecast Division.



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If prepared from 1200 GMT data on September 16:

     FMUS  1  KWBC  161200

     MAX-MIN TEMP FCST
          24 36 48 60
     STA  MN MX MN MX
     TUS  75101 78104
      •
      •
      •

Stations will be identified by standard FAA Location
Identifiers.  Here the surface temperatures forecast
for Tucson are minimum of 75°F on the 17th (24 hours
in advance), maximum of 101°F on the 17th (36 hours in
advance), minimum of 78°F on the 18th (48 hours in
advance), and maximum of 104°F on the 18th (60 hours
in advance).
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Fig. IV-1. Format of the max/min temperature bulletins issued. Note the "in advance" terminology. (From WB 1968a.)

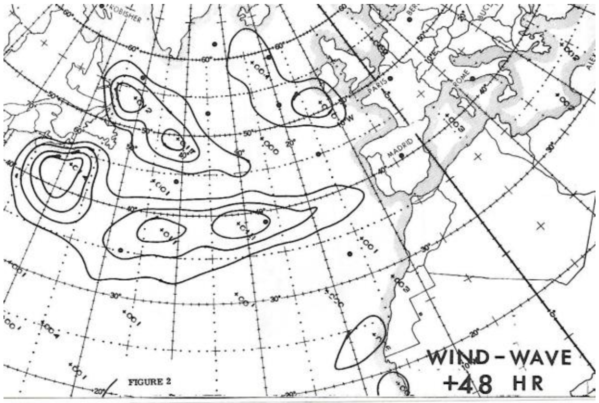

Fig. IV-2. Example wind wave chart. Contours are at 3-ft intervals, and the maximum is printed in the center of closed contours. (From WB 1968b.)

Not to be outdone, TDL's marine group provided for implementation, a system that forecasted 24- and 48-h wind waves, swell, and combined wave (Fig. IV-2) based on the NMC six-layer primitive equation (PE) model (Shuman and Hovermale 1968). The prediction equations were based on the PE 1000-mb wind, and according to WB 1968b, "Studies have indicated that the surface wind is represented best by taking 86% of the 1000-mb wind speed and backing the direction 20°." Consideration of fetch and the relationship of waves and swell to surface wind makes this a rather involved, physically-

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[1] Not surprising, because verification was undoubtedly by mean absolute error, and inflation increases mean absolute error.

[2] Klein states that the word specification was introduced in 1956 by Malone and colleagues (Malone et al. 1956).

based PP technique. This followed work by the U.S. Navy and at JNWPU [see Pore and Richardson (1967) for background and details]. The system was implemented on or about October 1, 1968 (WB 1968b), and is attributed to N. A. Pore and W. S. Richardson. This technique was applied to the Atlantic and Pacific Oceans, and NMC's "curve follower" was used to generate contours for the maps that were distributed by facsimile [see Fawcett (1962), Fig. 3, for a picture of the curve-follower].

N. Arthur Pore, Marine Branch Chief, 1972. (Photo furnished by Art's family.)

Also on October 1, 1968, wind forecasting equations were changed in the SAM product from those based on summer data to those based on winter data,[3] and more importantly, perhaps, was the addition of 3-hourly precipitation forecasts for four consecutive periods (ESSA 1968). These forecasts were based on areas of negative Sd in SAM and were depicted by X's on a map (see Fig. IV-3). Quoted from WB 1968c, "The edge of the X-covered area can be considered as the 50% probability of 0.01 inch or more of precipitation line." The wind equations were different from those initially implemented in that each regression equation had no constant term. When the geostrophic wind is very light, a constant term in the regression equations for u and for v may indicate a direction which is unrealistic when compared to the direction of the geostrophic wind (see Glahn 1970a).

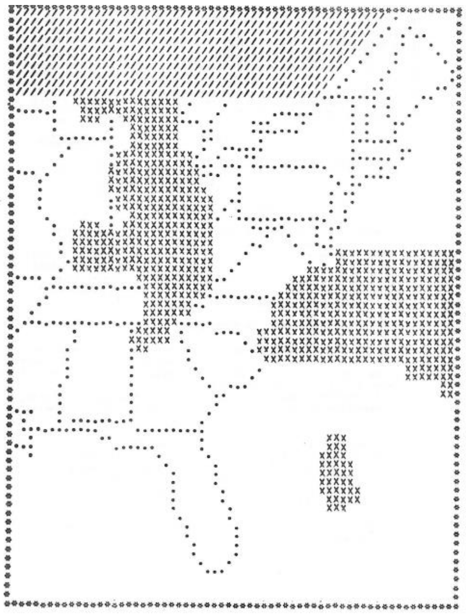

Fig. IV-3. The precipitation chart produced by SAM starting October 1, 1968. (From WB 1968c.)

In approximately one year, between the time the first SAM test bulletin was released in late 1967 until late 1968, we have seen three different methods of model interpretation: Forecasts from SAM, which would later be called MOS; Klein's method of specification/PP; and the more physically-based marine PP product. Now comes another type of interpretation. Danielsen (1961) and others had emphasized that cloud patterns and convection evolve in a Lagrangian manner, and a cloud forecast model based on this concept had been under development since 1962 by the Air Weather Service. Edson et al. (1967) had achieved significant improvements in accuracy of temperature and moisture forecasts using such a model. Following the Air Force's lead, Ron Reap (1968) developed a trajectory model based on the horizontal and vertical wind forecasts from the six-layer primitive equation model (Shuman and Hovermale 1968). This NMC model was running at 1 Bedient mesh length and that is the resolution Reap used except he used topography at ½ Bedient to improve trajectory accuracy. Backward trajectories gave parcel starting points, and the initial values of temperature and dew point were estimated by a method

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[3] TDL has primarily used two seasons for deriving statistical relationships: April through September and October through March. Initially, these were called summer and winter seasons, respectively. Later Gary Carter promoted a name change to warm and cool seasons, respectively.

of interpolation from radiosonde data originally developed by Endlich and Mancuso (1968). Reap found the trajectory model gave better 24-h forecasts of temperature at gridpoints than did the PE model (the PE model did not forecast dew point for comparison). This model was developed primarily to aid in severe weather forecasting, and it was implemented on or about December 17, 1968 (WB 1968d). Temperature and dew point were displayed together on one chart on FOFAX (Forecast Office Facsimile Circuit), and the trajectory 24-h net vertical displacement and relative humidity on another chart. Like the wave chart, the NMC curve follower was used to draw the lines (see Fig. IV-4).

The products from each of these methods of interpretation were modified several times over the course of their lifetimes. These changes are followed here in roughly chronological order to emphasize the evolutionary nature of interpreting numerical model output and the effort necessary to keep up with changing models.

SAM was running daily and we were archiving the forecasts. Our attention had now turned to developing forecasts of specific surface weather elements. Simple generalized wind equations had been developed and implemented earlier. Of prime importance was the probability of precipitation (**PoP**)[4] and the conditional (on precipitation occurring) probability of frozen precipitation [PoFP(P)]. The yes/no precipitation chart shown in Fig. IV-3 was not statistically derived, but was a representation of Sd directly out of the model. Other studies had related precipitation occurrence to observed variables and those predictors were used in making the forecasts (the classical method) or to observed variables and forecasts of those variables were used with NWP in making the forecasts (the PP method). For instance, Russo et al. (1966) of the Travelers Research Center, under contract to TDL, had developed specification equations relating the occurrence of measurable (i.e., ≥ 0.01 inch) precipitation in a 12-h period to observed upper level heights. The predictand values "... were obtained from the Weather Bureau's data center in Ashe-

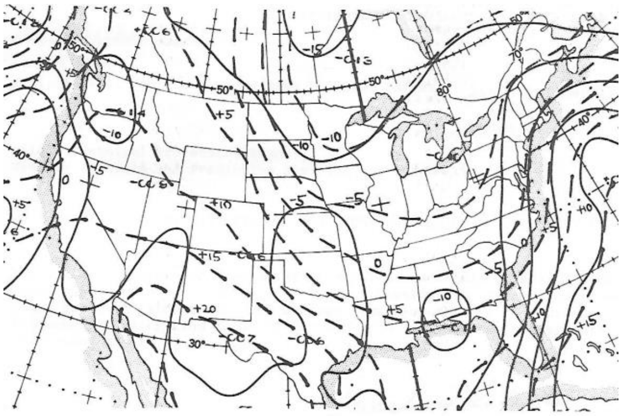

Figure 1a: 24-hr 850mb temperature (dashed lines) and dewpoint (solid lines) forecast in degrees Celsius.

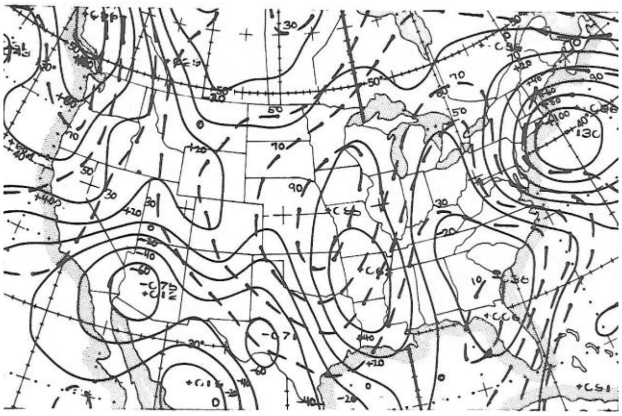

Fig. IV-4. Example temperature (dashed) and dew point (top) and 24-h net vertical displacement (solid) and relative humidity (bottom) from the trajectory model. (From WB 1968d.)

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[4] The Weather Bureau definition of probability of precipitation is "The probability of ≥ 0.01 inch of precipitation at a point over a stated period of time." The acronym PoP was not used initially when the probability forecasting program was started on an experimental basis in 1965 (Cressman 1965). The earliest use of the acronym may have been in in TPB 21 (WB 1969a) dated Feb. 3, 1969, based on material supplied by Dale Lowry**.** It also appeared in ESSA News (ESSA 1969) on February 14 and Glahn and Lowry (1969) in October that same year. After that, it slowly became standard terminology.

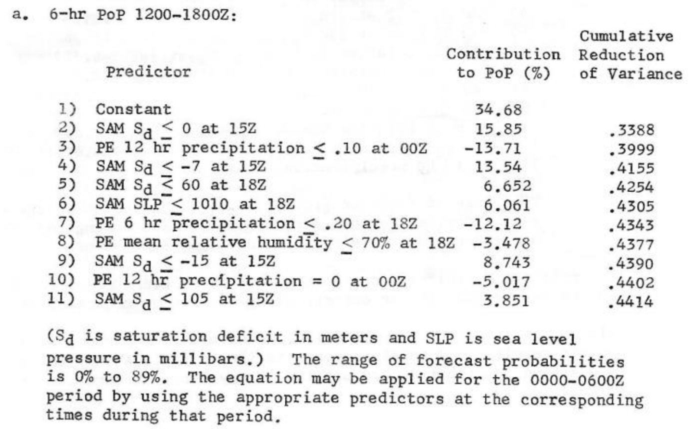
ville for 29 U.S. stations. . . .” (op.cit.) for a 4-year period from April to December. They state, “Only large data samples of observed height fields were available for the developmental phase of this study. For this reason, observed heights were used in the derivation of the forecast equations (“perfect prog” concept). . . ., while the prognostic heights, which are used in actual practice, were employed for evaluation.” Bill Klein was acknowledged for his technical guidance and assistance. Note there were no direct moisture-related predictors used in the derivation. Perhaps the reason was that the primary NMC model did not forecast moisture; the PE with the SLYH embedded moisture formulation was not implemented operationally until June 1966.

Not only did SAM forecast a moisture variable, but TDL had expanded its daily data collection to include output from NMC’s PE model and also TDL’s trajectory model. These data provided an adequate sample, so we developed regression equations to predict PoP based on variables forecast by SAM and the PE model (Glahn and Lowry 1969). This was the first use of the acronym **MOS**. Equations were developed for winter and for summer, but one of the sets was used for both the morning and afternoon runs.

Acronym MOS introduced for Model Output Statistics in 1969.

The output from SAM was modified a number of times over the next couple of years. On February 12, 1969, the content and format of the transmission was revised to include sea level pressure and 1000-500 mb thickness, probability of precipitation, and conditional probability of frozen precipitation forecasts (WB 1969a). The sea level pressures were direct output from SAM. The probability of precipitation was provided by a new set of REEP regression equations derived from the output of both the SAM and the PE model. The conditional probability of frozen precipitation equations were also derived from the output of the two models.

The PoP forecasts were based on regression equations where the predictors were picked by screening from a large set. The predictors were cumulative binary from SAM and the PE. Climatology as categories of the relative frequency of precipitation in 6- and 12-h periods was also included. The first 6-h equation is shown in Fig. IV-5. Data from 80 stations were combined into generalized equations for one 12-h and two 6-h periods. Only one set of equations was derived that was used for both cycles.[5] Noticeably, no climatological variables were selected. It was clear that



a. 6-hr PoP 1200-1800Z:

	Predictor	Contribution to PoP (%)	Cumulative Reduction of Variance
1)	Constant	34.68	
2)	SAM $S_d \le 0$ at 15Z	15.85	.3388
3)	PE 12 hr precipitation $\le .10$ at 00Z	-13.71	.3999
4)	SAM $S_d \le -7$ at 15Z	13.54	.4155
5)	SAM $S_d \le 60$ at 18Z	6.652	.4254
6)	SAM SLP ≤ 1010 at 18Z	6.061	.4305
7)	PE 6 hr precipitation $\le .20$ at 18Z	-12.12	.4343
8)	PE mean relative humidity $\le 70\%$ at 18Z	-3.478	.4377
9)	SAM $S_d \le -15$ at 15Z	8.743	.4390
10)	PE 12 hr precipitation = 0 at 00Z	-5.017	.4402
11)	SAM $S_d \le 105$ at 15Z	3.851	.4414

(S_d is saturation deficit in meters and SLP is sea level pressure in millibars.) The range of forecast probabilities is 0% to 89%. The equation may be applied for the 0000-0600Z period by using the appropriate predictors at the corresponding times during that period.

Fig. IV-5. The PoP prediction equation for the first 6-h period used for both run times. Each predictor was cumulative binary and derived from SAM saturation deficit (Sd), prior 12-h observed precipitation, SAM SLP, PE precipitation amount, or PE mean relative humidity. (From WB 1969a.)

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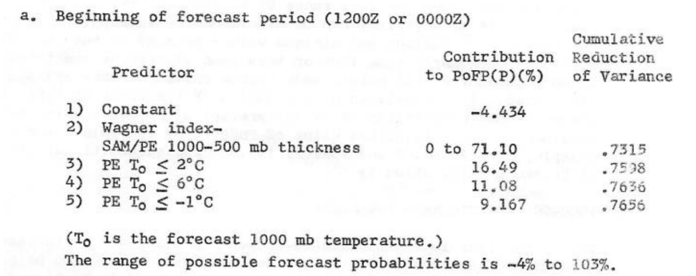
[5] WB (1969a) gives one equation for 6-h Pop 1200-1800 UTC, another for 1800-0000 UTC, and another for the 12-h period 1200-0000 UTC, each with predictor coefficients. The statement is made that infers each equation can be used for the other cycle. Evidently, the developmental system was not yet efficient enough to develop a different set of equations for each cycle.

moisture relating to this specific time was more important than some broad-brush climatological value.

The conditional probability of frozen precipitation equations (conditional on precipitation occurring) were also derived by screening regression. One equation was for the beginning of the first 6-h period (1200 UTC for the 0700 UTC run, shown in Fig. IV-6), and the other for the end of the 12-h period (0000 UTC). The cases in the developmental sample included only those when precipitation occurred. The climatology predictor was replaced by a predictor based on the work of Wagner (1957) which related probability of frozen precipitation to 1000-500 mb thickness. This derived predictor was chosen first, and there was only slight improvement by including temperature binaries.



a. Beginning of forecast period (1200Z or 0000Z)

Predictor	Contribution to PoFP(P)(%)	Cumulative Reduction of Variance
1) Constant	-4.434	
2) Wagner index- SAM/PE 1000-500 mb thickness	0 to 71.10	.7315
3) PE $T_o \leq 2°C$	16.49	.7598
4) PE $T_o \leq 6°C$	11.08	.7636
5) PE $T_o \leq -1°C$	9.167	.7656

(T_o is the forecast 1000 mb temperature.)

The range of possible forecast probabilities is -4% to 103%.

Fig. IV-6. The PoFP(P) equation for the beginning of the forecast period. The predictors are the Wagner Index applied to the SAM/PE thickness and the PE 1000-mb temperature. (From WB 1969a.)

The forecasts were transmitted in graphical form as a 4-panel chart on FOFAX, as shown in Fig. IV-7) for the 0700 UTC start time:

Upper left panel—Isopleths of PoP for the 12-h period 1200-0000 UTC as solid lines and sea level pressure as dashed lines valid at 1200 UTC.

Upper right panel—Isopleths of 1000-500 mb thickness as solid lines with sea level pressure as dashed lines valid at 1800 UTC.

Lower left panel—Isopleths of PoP for the first 6-h period as solid lines with PoFP(P) depicted as dashed lines valid at 1200 UTC.

Lower right panel—Isopleths of PoP for the second 6-h period as solid lines with PoFP(P) depicted as dashed lines valid at 0000 UTC.

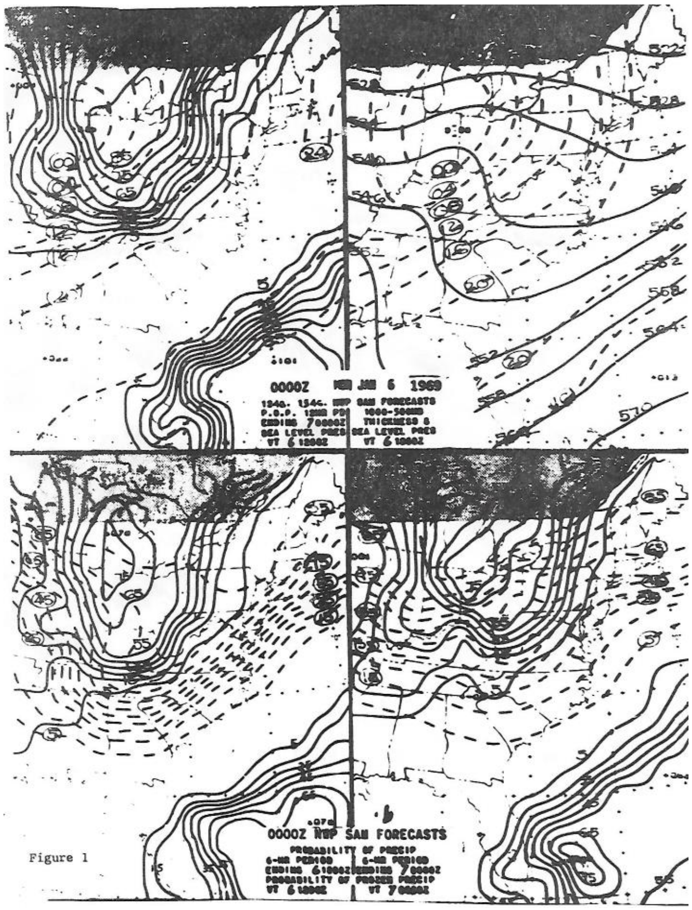


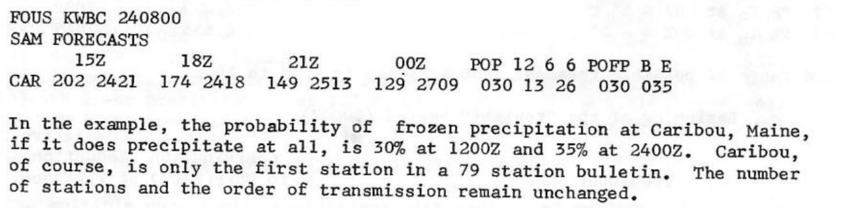
Fig. IV-7. Four panel fax chart transmitted with sea level pressure, 1000-500 mb thickness, PoP, and PoFP(P) (see text for details). (From WB 1969a.)

A similar chart was transmitted for the 1900 UTC start time. As with the initial implementation, one set of regression equations was used for both start (cycle) times.

This fax depiction lasted nearly a year until December 8, 1970, when some changes were instituted (see NWS 1970c for details).

The wintertime PoP equations described above were replaced by summertime equations on April 1, 1969, but the PoFP(P) equations for the winter remained in use. WB 1969b contains the caveat, “Most of the time the isopleths of PoFP(P) will be well to the north of the forecast area. When they appear, the forecasts may be less reliable than they were during the period for which they were derived.” At this time, the estimates of surface wind were dropped from the SAM teletype bulletin. Wind equations had now been derived for both seasons, and were given in TPB 23 (WB 1969b) so that they could be used on station applied to the SAM geostrophic wind, which was still transmitted.

PoP and PoFP(P) equations were rederived with another year of data. Also, seasonal PoFP(P) was added to the service “C” teletype bulletin (see Fig. IV-8). Wind equations were not rederived, and it was suggested the previous ones be continued for use on-station (WB 1969d).



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FOUS KWBC 240800
SAM FORECASTS
     15Z        18Z        21Z        00Z      POP 12 6 6 POFP B E
CAR 202 2421  174 2418  149 2513  129 2709  030 13 26  030 035
```

In the example, the probability of frozen precipitation at Caribou, Maine, if it does precipitate at all, is 30% at 1200Z and 35% at 2400Z. Caribou, of course, is only the first station in a 79 station bulletin. The number of stations and the order of transmission remain unchanged.

Fig.IV-8. Format of SAM bulletin, explaining the new conditional frozen precipitation probabilities. Before them are the 12-h and two 6-h PoPs, the geostrophic wind ddss (e.g., 2421), and the saturation deficit (e.g., 202). (From WB 1969d.)

Slight changes were made to the wind/wave fax chart on April 29, 1969, to correct unrealistic gradients near the coast (WB 1969c). After a year of running, a change was made in the calculation of swell propagation and attenuation on November 1, 1969 (WB 1969e), and another change was made to the propagation rate on May 18, 1970 (WB 1970e).

On approximately March 18, 1970, the input to the max/min equations was switched to the PE from the previously used barotropic and Reed models. Also, reported max and min temperatures, predictors in the equations, were now 6 h later than previous; this was possible because waiting for the PE delayed the run by about an hour. The equations were not changed (WB 1970b). This is an advantage of the PP technique—a better model comes along, use it and the max/min forecasts should improve. And verification showed that they did improve to about the accuracy of the temperatures produced subjectively by NMC’s Analysis and Forecast Division (AFD). Following that verification, the objective max/min temperatures replaced the previous NAFAX product produced by AFD on April 1. The fax chart had values plotted for each of 131 U.S. cities and seven cities in Canada. The product went directly from the CDC computer to the facsimile circuit, thereby saving staff hours (WB 1970c). This was

The PP max/min temperatures replaced the NMC person-produced product in April 1970.

the first time a statistically derived product replaced a subjectively produced one at NMC. Isotherms were not included but were added on October 19, 1970 (NWS 1970b), and at that same time changes were made in the teletype bulletin. A scheme was devised and implemented to indicate missing or likely erroneous forecasts. The isotherms were formed by first finding values at gridpoints by the Bergthorssen and Doos (1955) analysis scheme, although it was not identified as such, then the contours were drawn by interpolating biquadratically between the gridpoints.[6] Monitoring of the forecasts showed that record breaking temperatures were sometimes forecast because of bad input data, so a process was put in place on approximately March 8, 1971, to constrain the forecasts to near the daily record values (see NWS 1970d for the exact procedure[7]). A list of stations having truncated forecasts was provided as part of the teletype bulletin.

On October 29, 1969, a "laminated moisture feature" was introduced into the PE model. From WB (1970a):

> "Verification figures through September 1, 1969, from TDL and NMC show the mean relative humidities and precipitation amounts forecast by the laminated PE model to show a strong bias on the dry side over the eastern United States. This strong bias may or may not hold true for other areas.
>
> "The effect of the laminated moisture PE predictors on the machine produced PoP forecasts, of course, is to make them drier than desired. NMC is continuing to verify the products and this may or may not lead to a future adjustment in the PE model moisture. In the meantime, we feel it will be advantageous to revise the program by dropping the PE predictors from the objective forecast procedure and carrying only SAM predictors. . . . They were introduced into the operational program at 1200 GMT on December 5, 1969."

It is noted that the new equations have lower reductions of variance and lower range of forecasts than the ones that included the PE, showing the PE was initially important before the change to the way the moisture was handled.

This hurried change indicates that changes were made in the primary NWP model being run at NMC without testing what effect they would have on a final statistical product. It also indicates the TDL statistical system was now efficient enough that new equations could be generated for both cycle times rather quickly and put into operations.

Changes were made to the PE model on March 19, 1970, but a half month of verification still showed a pronounced bias, so PoP and PoFP(P) equations for the summer continued to not contain PE predictors (WB 1970d). PoFP(P) forecasts were removed from the teletype bulletin on May 15 to return on October 1.

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[6] This analysis process had been used in NMC for years (Cressman 1959). It is not stated whether this was a new coding of the process, or whether NMC's code was used. It is likely the code was new because the interpolation routine was identified as NMC's, while no such attribution was made for the analysis code.

[7] TPB 59 indicates the large amount of work the Extended Forecast Division (EFD) did to make this adjustment possible. This shows the tight connection of Klein's max/min forecasts to his previous work at EFD.

Other changes to the PE were made that it was thought would eliminate the PE dryness, so equations were implemented on September 30, 1970, that contained both SAM and PE predictors (NWS 1970a). Then on April 1, 1971, summertime equations based on 3 years of data (1967-1969) were implemented. The 1970 data were not used because of the PE dryness (NWS 1971a). The sample had now grown to respectable size.

Both PoP and PoFP(P) equations for the next winter were again rederived. The PoP equations were based on 3 years of data for the daytime run and 2 years for the nighttime run. The P0FP(P) equations were based on 4 years of data for the daytime run and 3 years for the nighttime run. The wind equations were the same as used the previous winter (NWS 1971c).

In the meantime, the geostrophic winds were replaced with surface winds in the teletype bulletin. Previously, the surface winds were computed by very simple generalized operator equations. We thought that enough data had been collected that robust single-station equations could be developed, so we did a test on 10 stations. Equations were developed for each component of the wind and for wind speed. The predictors screened were the geostrophic winds and the initial observed winds on summertime data of 1967 and 1968. Forecasts were made for each day of April and May 1969, and compared to wind forecasts in the NWS terminal forecasts (FT). The accuracy of the MOS equations was as good as or better than the FTs (Glahn 1970a). Therefore, single-station equations were implemented on or about July 1, 1970 (WB 1970f).

WB 1970a also indicates that the SAM statistical forecasts were made on the grid for the curve follower to use, and then the station values were arrived at by interpolation. It was recognized that the interpolated values might not be exactly what would be produced if the equations were applied directly to station locations, but it was believed ". . . the interpolation procedure neither helps nor hurts the forecasts, on the average" (op. cit.).

The NMC models were still running at 1 Bedient. We experimented with a ½-Bedient barotropic model and 500-mb analysis, thinking the combination at that resolution might improve SAM. However, testing indicated little or no reason to implement this higher resolution option (Bermowitz 1971). Also, in that regard, Jim Howcroft (1971) was now in the process of tailoring the PE model to run on a limited area at ½-Bedient mesh length.

The 3-dimensional trajectory model implemented in 1968 was improved with the addition of the effects of air-sea interactions within the oceanic boundary layer (Reap 1971). This change became operational on or about June 1, 1971 (NWS 1971b, Reap 1972).

Throughout the period 1968 to 1971, the statistical products consisted of the nationwide PP max/min temperatures (for years thereafter and continuing today, called "the Klein Temperatures");[8] the trajectory forecasts of temperature and dew point; ocean wind waves and swell; and SAM forecasts of wind, PoP, and PoFP(P). The PP temperatures, designed, fostered, and documented by Bill Klein, were developed primarily by Frank Lewis, Fred Marshall, George

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[8] Klein temperatures, sometimes called the Klein-Lewis temperatures) are still being used in the Climate Prediction Center. They were produced by TDL for many years. At some point, the "leapfrogging temperature input (using the previous forecast as input) was changed from PP forecasts to MOS forecasts. This reduced the variance of the longer-range forecasts and increased accuracy. Interestingly, the PP forecasts had MOS input! Later, the running was turned over to the Climate Prediction Center (Paul Dallavalle, email dated 1/17/18).

Casely, and Gordon Hammons located at FOB4 in Suitland, Maryland. The trajectory forecasts were primarily the work of Ron Reap. The waves and swell were developed and implemented by the marine group; primary contributors were Art Pore, William Richardson, and Herman Perrotti. The SAM team consisted of myself, Dale Lowry, George Hollenbaugh, Elizabeth Booth, Jackie Hughes, and Evelyn Boston.


Frank Lewis, developer and branch chief at TDL.


Gordon Hammons, developer at TDL. Surface temperature was a main interest.

These products were updated either as improvements to the process of producing the forecasts, improving or augmenting the dissemination media or formats, or redeveloping equations as more data accumulated. None of these products was left to flounder; the developers were always there to strive for improvements.

This was a productive period, TDL having gone from no statistically derived products in early 1968 to several in 1971. Just as importantly, the process of implementation had been established with the introduction of the Technical Procedures Bulletins to announce changes of dissemination of products from NMC and the formation of CAFTI to recommend changes and to insist on verification before implementation. Charlie Roberts was the moving force behind the TPBs. Merritt Techter instigated CAFTI, and Bill Klein bulldogged its formation and operation at Techter's behest. NMC was responsible for the daily running of the products, but the software was written by the developers, members of TDL.[9]

It was also a stable period. The CDC 6600 was being used the whole time, so no expensive computer conversions were necessary. We were building and documenting our development system along with developing and implementing products. It became clear the implementation and developmental software needed to be coordinated and actually be the same insofar as possible, and we began working toward that concept.

During this period, I also experimented with another form of interpretation: the computer worded forecast (CWF) (Glahn 1970b, 1970c). Because the final form of surface weather forecasts provided to the public was usually a worded message, why should we not provide a stab at what that would be? Of course, the input should be the official NWS forecasts, but these were not handily available in the quantity and form needed, so I used statistically developed forecasts as input. I also wanted to demonstrate that it was possible to turn out a forecast in essentially the form being currently issued completely by computer. With the data we had in the SAM project, we developed regression equations for four stations for estimating surface wind, cloudiness, maximum temperature, PoP, and PoFP(P). The predictors were from SAM (0700 UTC cycle) and the PE model (0000 UTC cycle). SAM only supported the first (today) period from 0700 UTC, so that is what we demonstrated.

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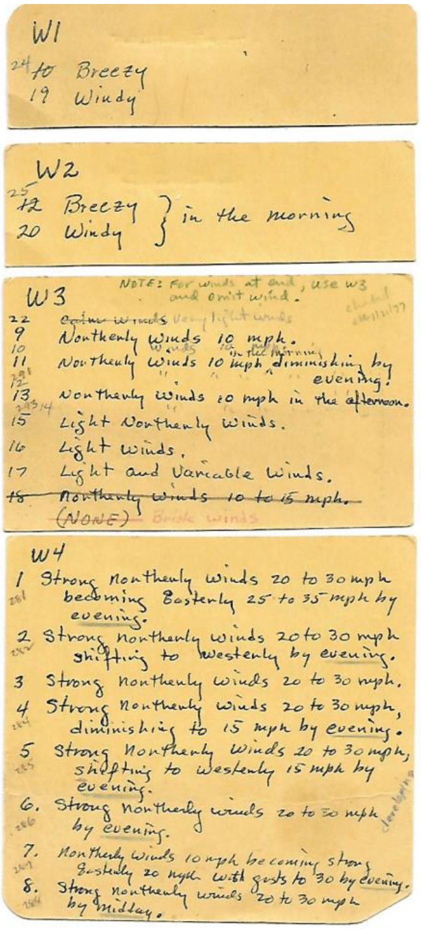
[9] The programs made use of NMC data and "system" routines.

The format I chose to emulate was what we could hear on the telephone on the well-known (at the time) number WE6-1212. The weather element deemed most important was put first in the forecast; otherwise, the order of the elements depended somewhat on the forecasts themselves and how they best fit together. An "important" or "significant" element was defined to be: wind of 20 mph or greater, probability of precipitation of 35% or greater, maximum temperature 10°F above or below yesterday's maximum, or maximum temperature near yesterday's maximum but 8°F or more below the climatological maximum.

The ordering of the elements was the most challenging. The actual words, phrases, and punctuation that were arranged into the forecast are shown in Figs IV-9 and IV-10. Hours spent at the kitchen table produced a reasonable result. Figure IV-11 shows three examples. The lead-in is, of course, arbitrary and redundant. This work was not encouraged by my



W1
24 ~~10~~ Breezy
19 Windy

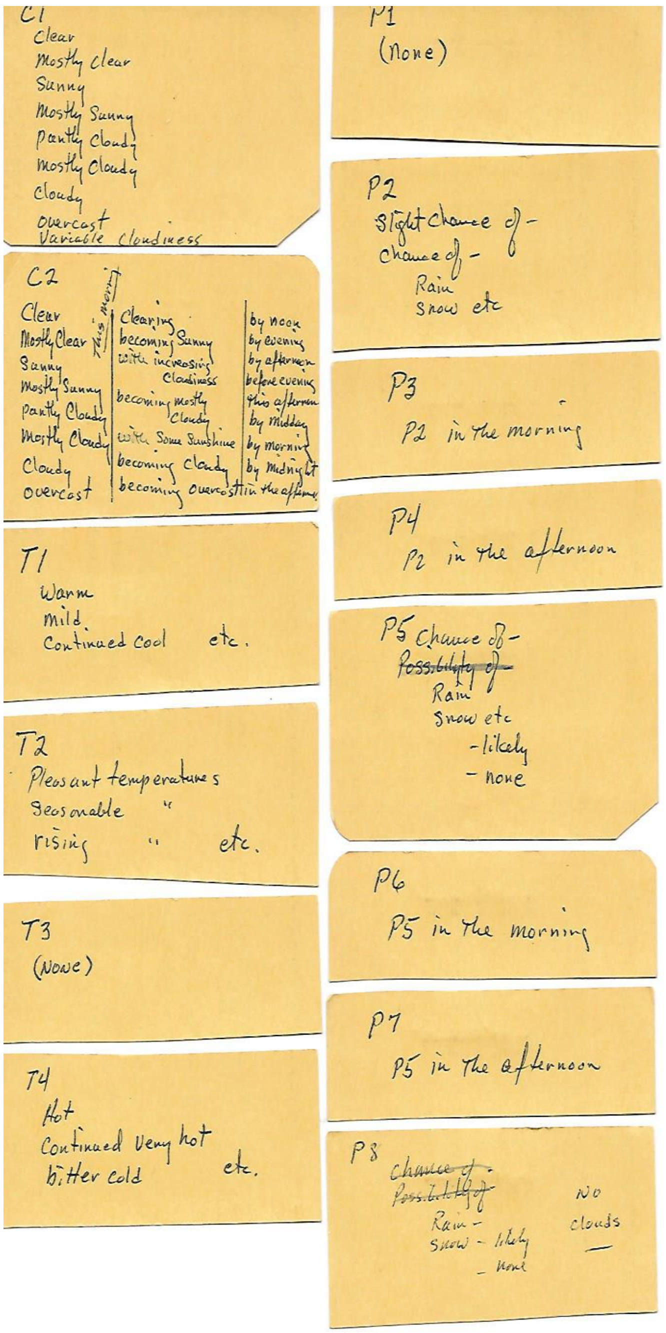
W2
25 ~~12~~ Breezy } in the morning
20 Windy }

W3
NOTE: For winds at end, use W3 and omit wind.
22 ~~Calm winds~~ Very light winds
9 Northerly winds 10 mph.
10
11 Northerly winds 10 mph in the morning diminishing by evening.
12
13 Northerly winds 20 mph in the afternoon.
14
15 Light Northerly winds.
16 Light winds.
17 Light and Variable winds.
~~18 Northerly winds 10 to 15 mph.~~
~~(NONE)~~ Brisk winds

W4
1 Strong northerly winds 20 to 30 mph becoming Easterly 25 to 35 mph by evening.
2 Strong northerly winds 20 to 30 mph shifting to westerly by evening.
3 Strong northerly winds 20 to 30 mph.
4 Strong northerly winds 20 to 30 mph, diminishing to 15 mph by evening.
5 Strong northerly winds 20 to 30 mph, shifting to westerly 15 mph by evening.
6. Strong northerly winds 20 to 30 mph by evening.
7. Northerly winds 10 mph becoming strong Easterly 20 mph with gusts to 30 by evening.
8. Strong northerly winds 20 to 30 mph by midday.

developing

Fig. IV-9. Wind words and phrases used in building computer worded forecasts.



C1
Clear
Mostly clear
Sunny
Mostly Sunny
Partly Cloudy
Mostly Cloudy
Cloudy
Overcast
Variable Cloudiness

C2
This morning
Clear
Mostly Clear
Sunny
Mostly Sunny
Partly Cloudy
Mostly Cloudy
Cloudy
Overcast
Clearing
becoming Sunny
with increasing Cloudiness
becoming mostly Cloudy
with Some Sunshine
becoming cloudy
becoming overcast
by noon
by evening
by afternoon
before evening
this afternoon
by midday
by morning
by midnight
in the afternoon

T1
Warm
mild
Continued cool etc.

T2
Pleasant temperatures
Seasonable "
rising " etc.

T3
(None)

T4
Hot
Continued Very hot
bitter cold etc.

P1
(None)

P2
Slight Chance of -
Chance of -
Rain
Snow etc

P3
P2 in the morning

P4
P2 in the afternoon

P5 Chance of -
~~Possibility of~~
Rain
Snow etc
- likely
- none

P6
P5 in the morning

P7
P5 in the afternoon

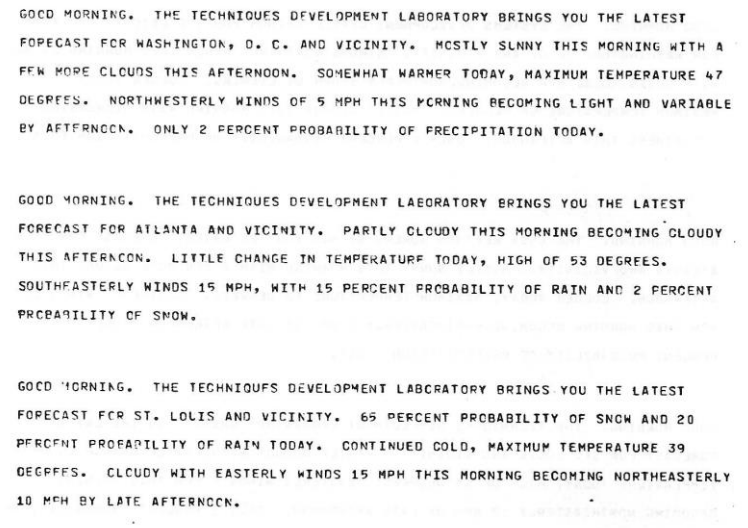
P8
~~Chance of~~
~~Possibility of~~
Rain -
Snow - likely
_ none
No clouds
—

Fig. IV-10. Cloud and temperature (left) and precipitation words and phrases used in building computer worded forecasts.

management, even to it being called a fetish. Fred Sanders disparaged it (Sanders 1971), it was questioned as a legitimate endeavor on an AMS conference floor, and you can imagine how the field forecasters felt about it. George Cressman (1970), in discussing the published examples, said, ". . . they may prove useful to the forecaster after further improvement." Obviously, he was thinking of guidance, not a final product. Yet, essentially all such forecasts are today produced by computer from digital forecasts.

If a forecast could be produced for the today period, it could also be produced for tonight and tomorrow, the extent of the public forecast at the time. Later, official forecasts were in a format where periods could be combined, which was even more of a challenge. Progress was made on combing periods, but the preferred format was switched back to separation by period.

The computer worded forecast was introduced in 1970.



```
GOOD MORNING.  THE TECHNIQUES DEVELOPMENT LABORATORY BRINGS YOU THE LATEST
FORECAST FOR WASHINGTON, D. C. AND VICINITY.  MOSTLY SUNNY THIS MORNING WITH A
FEW MORE CLOUDS THIS AFTERNOON.  SOMEWHAT WARMER TODAY, MAXIMUM TEMPERATURE 47
DEGREES.  NORTHWESTERLY WINDS OF 5 MPH THIS MORNING BECOMING LIGHT AND VARIABLE
BY AFTERNOON.  ONLY 2 PERCENT PROBABILITY OF PRECIPITATION TODAY.


GOOD MORNING.  THE TECHNIQUES DEVELOPMENT LABORATORY BRINGS YOU THE LATEST
FORECAST FOR ATLANTA AND VICINITY.  PARTLY CLOUDY THIS MORNING BECOMING CLOUDY
THIS AFTERNOON.  LITTLE CHANGE IN TEMPERATURE TODAY, HIGH OF 53 DEGREES.
SOUTHEASTERLY WINDS 15 MPH, WITH 15 PERCENT PROBABILITY OF RAIN AND 2 PERCENT
PROBABILITY OF SNOW.


GOOD MORNING.  THE TECHNIQUES DEVELOPMENT LABORATORY BRINGS YOU THE LATEST
FORECAST FOR ST. LOUIS AND VICINITY.  65 PERCENT PROBABILITY OF SNOW AND 20
PERCENT PROBABILITY OF RAIN TODAY.  CONTINUED COLD, MAXIMUM TEMPERATURE 39
DEGREES.  CLOUDY WITH EASTERLY WINDS 15 MPH THIS MORNING BECOMING NORTHEASTERLY
10 MPH BY LATE AFTERNOON.
```

Fig. IV-11. Examples of the computer worded forecast. (From Glahn 1970c.)

There were many improvements that could be made to our products. The max/min temperatures were for only 131 specific sites, albeit there was a graphic from which forecasts for other points could be found. More importantly, SAM MOS forecasts were for only the eastern part of the United States. Some of us believed MOS was the way of the future, and had been collecting data and forecasts from the PE model over the CONUS since October 1969. So, on January 1, 1972, the first CONUS MOS product was implemented, and took the place of the formerly subjectively prepared product (NWS 1971d). Details of this product and other implementations are the subject of the next chapter

It is noted that Charlie Roberts, Chief of the Technical Procedures Branch, had moved on and Duane Cooley was by February 1970 chief of the branch and was signing the TPBs.

It is also noted that the TPBs are referenced as WB (Weather Bureau) up to and including TPB No. 52, and are thereafter referenced as NWS (National Weather Service) after it was so named.

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CHAPTER V

MOS GOES CONUS

As stated earlier, a breakthrough occurred when a statistical product replaced one that had been previously prepared by forecasters. This occurred on April 1, 1970, when the PP temperatures replaced the NAFAX NMC product. A similar breakthrough occurred on January 1, 1972, when the MOS PoP forecasts replaced the manual product on NAFAX (NWS 1971). Four panels, each of 12-h periods, covered the periods 12-24, 24-36, 36-48, and 48-60 h (Fig. V-1). The MOS PoP used predictors from the PE and trajectory (TJ) models, so the product was dubbed PEATMOS PoP.

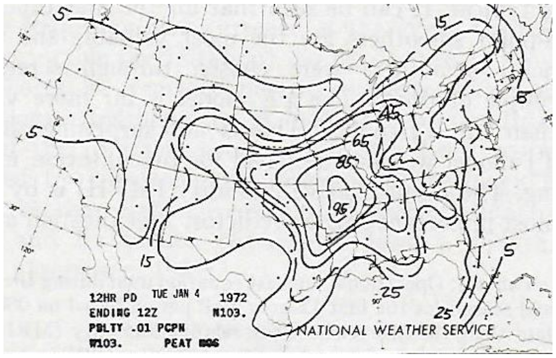


Fig. V-1. One panel from the 4-panel PoP fax chart for Jan. 4, 1972. (From Lowry and Glahn 1976.)

MOS PoP forecasts replaced the NMC forecaster-produced product in January 1972.

The 2-season (October-March and April-September) equations were each based on one season of developmental data ending October 1970. We developed generalized equations over regions (later called regional equations). The regions were determined by combining stations that had similar relative frequencies of precipitation observed when the forecast PE mean relative humidity was ≥ 75%. Over a 1-year test period, the PEATMOS PoPs were compared to local forecasts and to those produced by NMC. The measure of accuracy was Brier skill score, where the baseline climatology was relative frequency by month and station determined over a 15-year sample. PEATMOS beat NMC, and except for the first period was about as good as the local forecasts. I credit Harlan Saylor, a prominent forecaster and manager at NMC, for recognizing the quality of MOS and the potential saving of NMC resources in replacing the manually-produced product. Three years of operations of this product are detailed in Lowry and Glahn (1976). The wintertime equations were replaced with summertime equations on April 12, 1972 (NWS 1972b). The regions used for these equations are shown in Fig. V-2.

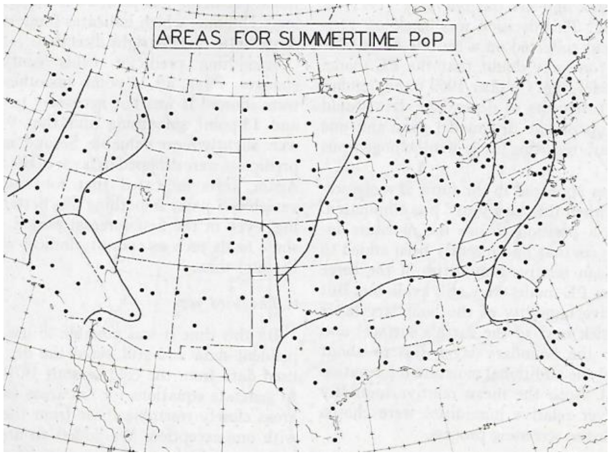
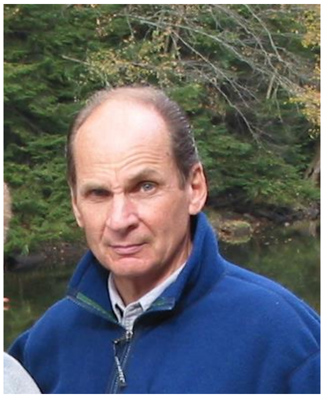


Fig. V-2. Stations and regions used for summertime PoP equations. (From Lowry and Glahn 1976; also in NWS 1972b.)

At the end of March 1972, two twice-daily teletype bulletins were implemented consisting of information from the trajectory model. The bulletins contained 24-h forecasts of temperature, dew point, and the K index (George 1960) for each of 70 stations, along with 6-houly positions for trajectories terminating at the surface, 850 mb, and 700 mb. With this information, the actual parcel trajectories could be approximated. The two bulletins contained stations selected in consultation with the NWS regions. The K index was especially important; Bonner et al. (1971) found it to be the best, in a linear sense, of all predictors tested for general convection (op. cit., p. 41)[1]

Even though PoP forecasts based on the PE and TJ models had been implemented for the CONUS, the SAM products for the eastern U.S. were still maintained. Summer PoP equations were installed on April 4, 1972 (NWS 1972a). They were based on only one season of data (1971). Data for 1970 were not used because of the dry bias of the PE explained in Chapter IV. Data for the years 1967-1969 could have been used; however, it was believed that an accumulation of small changes in the PE model over a period of several years could present a problem when the equations were applied to an independent sample. This illustrates the difficulties with "keeping up" with a changing model. Joe Gerrity, a researcher at NMC, coined the phrase, "A developing model gathers no MOS." While not completely accurate, certainly MOS grows thicker on a mature model. SAM winter PoP equations were introduced on October 2, 1972; they were also based on only one season of data. The same PoFP(P) and surface wind equations used the previous winter were reintroduced (NWS 1972c). The summer equations were reintroduced on April 2, 1973 (NWS 1973a); equations were not rederived because priority was being given to transitioning SAM into the Subynoptic Update Model and extending it to cover the CONUS.


Joseph (Joe) Bocchieri, developer at MDL 1970-1982. Joe's specialty was forecasting precipitation type, snow amount, and ceiling height.

Significant changes were made to the PEATMOS product. The detailed changes are in NWS (1972d); only the most important are given here. The fax charts in operations beginning January 1, 1972, had hand-drawn contours fitting the points where there were forecasts. These were converted to DFI (digital facsimile interface) products, thereby eliminating the hand analysis step. Copies of the equations were sent to the Scientific Services Division (SSD) in each NWS region. The most important change was the introduction of conditional probability of frozen precipitation (PoFP(P)) forecasts (Bocchieri and Glahn 1973; Glahn et al., 1973; Glahn and Bocchieri 1975). The process followed closely that implemented for SAM in 1969, and because nearly the same procedure has been used by TDL in all subsequent PoFP(P) work, it is explained here in some detail.

The method of making the PoFP(P) forecasts was much like that reported by Wagner (1957) and might be considered an extension of his work. Basically, the development of the technique consists of two steps. First, a "50-percent" value was found for each predictor considered for

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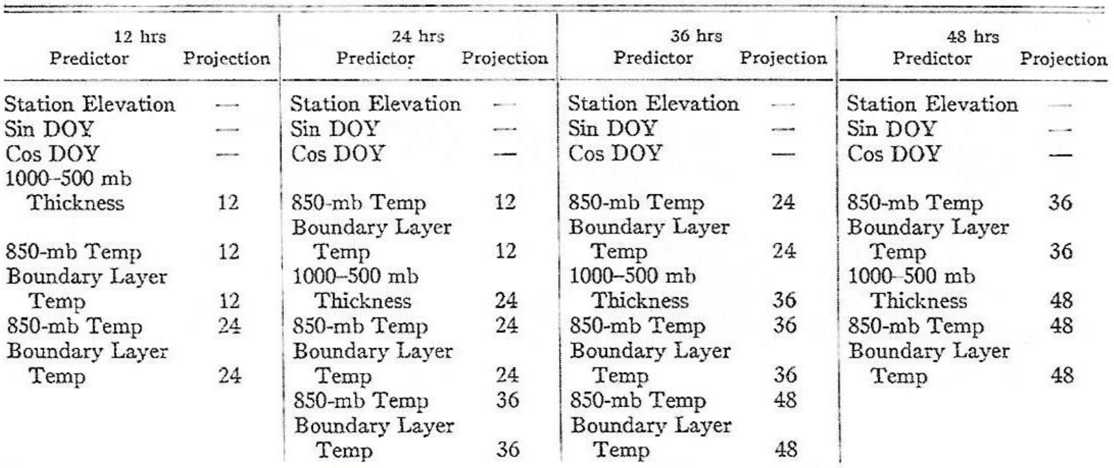
[1] Although Bonner et al. (1971) used the PEATMOS data (op. cit., p. 36) and the MOS screening regression program (op. cit., p. 41), they called the study the "imperfect prog" approach, referencing Klein (1970). The MOS acronym was seemingly not locked in yet, even in TDL. However, by 1974, the loop in Klein (1970) called "imperfect prog" was replaced by "Model Output Statistics (MOS)," and Klein was an avid supporter of MOS (Klein and Glahn 1974).

each station for which we had data available. For instance, we needed to know what value of 1000-500 mb thickness indicated a 50-50 chance of frozen precipitation at a particular station, provided precipitation occurred. (The category "frozen" consisted of snow and/or sleet; the category "liquid" contained rain, drizzle, mixed rain and snow, and/or freezing precipitation.) Next, we computed the deviations of the 1000-500 mb thickness from this 50-percent value for each station for a sample of data and determined the relative frequency (for those cases when precipitation occurred) of frozen precipitation as a function of this new variable.

We determined 50-percent values for three meteorological variables forecast by the NMC PE model—1000-500 mb thickness, 850-mb temperature, and boundary-layer temperature—for each of 182 stations using the winter seasons of 1969-70 and 1970-71 (September 1 through April 30). Our PEATMOS data collection contained data for 234 stations, but only 182 of them had sufficient frozen precipitation for a 50-percent value to be determined. A difference in our development and Wagner's is that he used observations at radiosonde stations, while we used PE forecasts interpolated to stations. We felt there was not enough data in the two-season sample to determine a 50-percent value for each forecast projection, so we pooled[2] data for projections of 12, 24, and 36 h and for the two PE run times, 0000 and 1200 UTC. The 50-percent values were determined by using the logit model which fits an S-shaped curve to a yes-no predictand as a function of a continuous predictor (Brelsford and Jones, 1967).[3]

After the deviations from the 50-percent values were determined for each station, the data for the 182 stations were pooled and the logit model again used to get the final forecast relationships. In addition to screening the three meteorological variables at various projection times, we used station elevation and the sine and cosine of the day of year (DOY) as predictors. (These latter three were not used as deviations from a 50-percent value.) Separate equations were determined for each of the projection times 12, 24, 36, and 48 h for each of the PE run times. The number of predictors in each equation was either 8 or 10 as indicated in Table V-1 (from Bocchieri and Glahn 1973).

Table V-1. Predictors in the PoFP(P) equations for each of the four projections. (From Bocchieri and Glahn 1973.)



12 hrs		24 hrs		36 hrs		48 hrs	
Predictor	Projection	Predictor	Projection	Predictor	Projection	Predictor	Projection
Station Elevation	—	Station Elevation	—	Station Elevation	—	Station Elevation	—
Sin DOY	—	Sin DOY	—	Sin DOY	—	Sin DOY	—
Cos DOY	—	Cos DOY	—	Cos DOY	—	Cos DOY	—
1000-500 mb Thickness	12	850-mb Temp	12	850-mb Temp	24	850-mb Temp	36
850-mb Temp	12	Boundary Layer Temp	12	Boundary Layer Temp	24	Boundary Layer Temp	36
Boundary Layer Temp	12	1000–500 mb Thickness	24	1000–500 mb Thickness	36	1000-500 mb Thickness	48
850-mb Temp	24	850-mb Temp	24	850-mb Temp	36	850-mb Temp	48
Boundary Layer Temp	24	Boundary Layer Temp	24	Boundary Layer Temp	36	Boundary Layer Temp	48
		850-mb Temp	36	850-mb Temp	48		
		Boundary Layer Temp	36	Boundary Layer Temp	48		

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[2] Joe Bocchieri was the first to use the term "pooled" in this context.

[3] Dick Jones gave me a copy of his FORTRAN logit code I didn't understand it well, but made it work.

Although adequate data were available for determining the 50-percent values at only 182 stations, 50-percent values were estimated for the remainder of 234 stations so that forecasts could be made for the entire CONUS. An example fax chart is shown in Fig. V-3.

The PoP equations were switched to summertime effective April 24, 1973; these equations were based on two seasons of data, 1971 and 1972 (NWS 1973c). So, we were using a season of data in operations the next season, including the modification of regions. This may be optimum for "keeping up with the model."

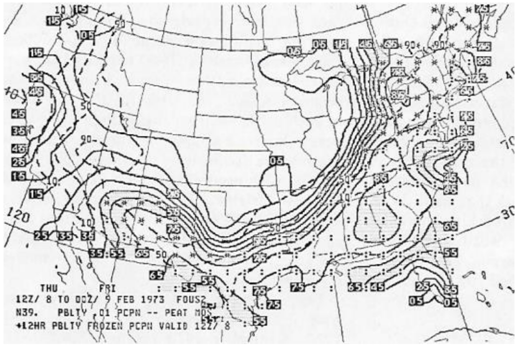

Fig. V-3. An example PoP/PoFP(P) fax chart. PoP isopleths are solid lines and PoFP(P) isopleths are dashed. Areas where liquid (frozen) precipitation may be expected are shown by dots (stars). (From Bocchieri and Glahn 1973).

The method of determining the wind input to the wave and swell program as a function of the PE 1000-mb wind forecasts was modified, based on a longer sample of data. Changes went into effect approximately January 2, 1973[4] (see NWS 1972e for details). This product is a hybrid. It is not clearly MOS, but certain constants have been determined by associating PE forecasts with observations.

A number of changes were made to the PEATMOS PoP products (NWS 1972f), some of them due to errors discovered. In addition to the stations for which PoFP(P) and/or PoP forecasts were available on Teletype Service C, forecasts were also available for additional stations by request-reply through the Kansas City Switch.[5] This capability not only supplied guidance forecasts, but also supported the NWS verification program. An implementation error was discovered and was corrected on February 1, 1973. The conversion of units of precipitable water had been done incorrectly, and a problem had also been discovered in using the precipitation amount. The packing and then unpacking of data does not always produce exactly the same floating-point value. For PE precipitation amount, a threshold of zero indicates the precipitation/no precipitation line. A slight difference in the unpacked value can mean the difference between PE precipitation and no precipitation. As a temporary fix, equations were rederived for which a threshold of zero was not used.

The problems discussed above highlight the errors that are more likely to occur when the development and implementation are done by different groups. It also shows the desirability of having the development and implementation software linked together to the maximum extent possible. The process that was currently in place was for the equations to be developed then turned over to another group for implementation. The implementation consisted of modifying an existing program to accommodate the current set of equations. That is, there was no general implementation program that could accommodate a new set of equations just by using different data sets. This process spawned many programs, largely undocumented, similar in nature, but different enough to harbor errors. This process needed to be changed.

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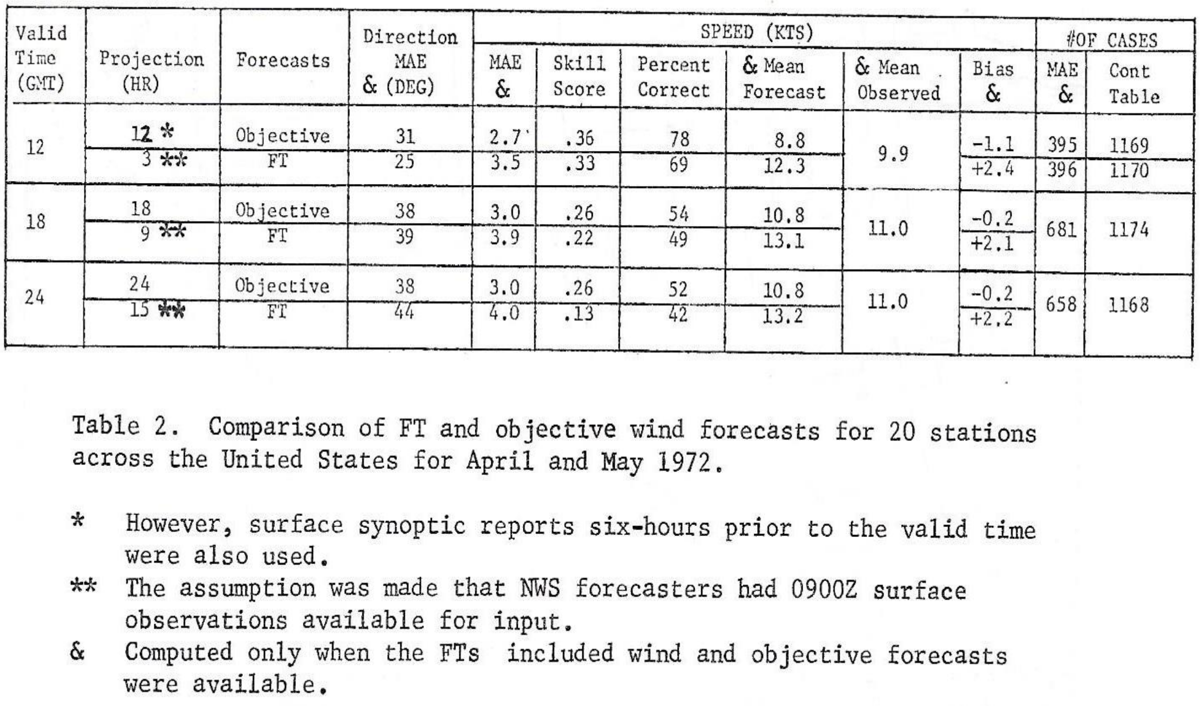
[4] The dates of changes announced in TPBs are only approximate. Delays may have been encountered for various reasons. The exact dates were announced by GENOTs, which are no longer available. (GENOTs contain "General notices" or information of use in meteorology or the airline industry.)

[5] Shorthand routinely used for FAA Weather Message Switching Center in Kansas City, Missouri (Fenix c. 1998).

The PEATMOS system was extended to surface winds, with implementation in May 1973. Heretofore, surface wind guidance was available from the SAM and PE models for 79 stations in the eastern United States, but with this implementation, forecasts for 233 stations over the CONUS based on the PE model (NWS 1973b) were available by the request/reply capability of Service A. Primary predictors screened were the PE wind components and speed. For the 6-h forecast, observed wind components, wind speed, and cloud cover were also screened. For the cases in which the observation was not available, a backup set of equations was used that did not have the observed predictors. To test the system, equations were developed on warm season data from 1970 and 1971 (0000 UTC PE model run) and verified for April and May of 1972. Also verified were the corresponding wind forecasts in the aviation terminal forecasts (FT).

Since the FTs did not mention wind if the speed is expected to be less than 10 kt, the comparison was done in two ways. For all those cases where the FTs included wind and for which objective forecasts were available, the mean absolute error (MAE) of direction (computed from the U and V equations) and speed (direct from the speed equation) and the bias (mean forecast minus mean observed) of speed were computed. Also for all cases when the FTs and objective forecasts were available, contingency tables for speed were prepared by considering the FT forecast of wind to be under 10 kt when the wind was not mentioned. For these contingency tables, which had categories of < 10, 10-12, 13-17, 18-22, and > 22 kt, skill scores and percent correct were computed. These scores are shown in Table V-2.

Table V-2. Verification of wind forecasts. Reproduced from Table 2 of NWS (1973b).



Valid Time (GMT)	Projection (HR)	Forecasts	Direction MAE & (DEG)	SPEED (KTS)						#OF CASES	
				MAE &	Skill Score	Percent Correct	& Mean Forecast	& Mean Observed	Bias &	MAE &	Cont Table
12	12 *	Objective	31	2.7	.36	78	8.8	9.9	-1.1	395	1169
	3 **	FT	25	3.5	.33	69	12.3		+2.4	396	1170
18	18	Objective	38	3.0	.26	54	10.8	11.0	-0.2	681	1174
	9 **	FT	39	3.9	.22	49	13.1		+2.1		
24	24	Objective	38	3.0	.26	52	10.8	11.0	-0.2	658	1168
	15 **	FT	44	4.0	.13	42	13.2		+2.2		

Table 2. Comparison of FT and objective wind forecasts for 20 stations across the United States for April and May 1972.

* However, surface synoptic reports six-hours prior to the valid time were also used.

** The assumption was made that NWS forecasters had 0900Z surface observations available for input.

& Computed only when the FTs included wind and objective forecasts were available.

As shown in Table V-2, the objective forecasts were superior to the FTs for both direction and speed at 1800 and 2400 UTC. The FT forecasts of direction were better than MOS at 1200 UTC, but MOS was better for speed. More detail is given by Carter (1973) in the newly established TDL Office Note series.[6] The verification of forecasts from the cool season equations led to the same conclusions when they were implemented (NWS 1973i).

For efficiency, the format of the teletype messages for the wind forecasts was changed on July 5, 1973. The cases in which backup equations were used were now identified in the message (NWS 1973g).

Ron Reap, a TDL developer 1966-1999. He developed the trajectory model and thunderstorm and severe weather products.

A new product consisting of the probability of thunderstorms and of severe weather was implemented on May 16, 1973 (NWS 1973d). The predictand data came from the manually digitized radar data valid at 0000 UTC prepared by the National Severe Storms Forecast Center (NSSFC) and covered the eastern and central CONUS. One generalized equation was developed for general thunderstorms and was applied operationally over the whole CONUS. Two regions were used for the conditional (on thunderstorms occurring) probability of severe thunderstorms and for two time periods: April-June (spring) and July-September (summer). Probabilities along the border between the two regions were smoothed to give a smooth transition. These were applied only over the area that the predictand data covered. Predictors came from the PEATMOS archives stored on magnetic tapes. The forecasts were displayed on a one-panel chart valid at 0000 UTC once per day. An example is shown in Fig. V-4. The spring equations for severe thunderstorms implemented in May were replaced by summer equations on July 2, 1973 (NWS 1973f).

Two new products were implemented in June 1973 (NWS 1973e). Each was to forecast surface winds over the Great Lakes. The first related winds observed over Lakes Erie and Ontario to SAM surface winds at nearby cities. Different equations for the speed and the two components were derived for each lake location. The second product related winds over all five Great Lakes to PE boundary layer winds. In distinction to the first method, the PE winds were interpolated to the lake locations and a generalized operator approach was used. The PE-based forecasts were for projections 6 to 36 h at 6-h intervals. More detail is given on the first method in Barrientos (1970) and on the second by Feit and Pore (1978). Both of these products were distributed by RAWARC.

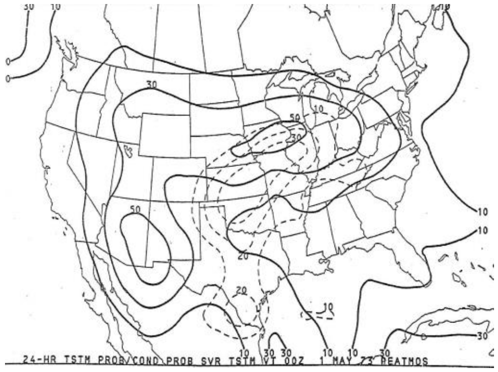


Fig. V-4. 24-h thunderstorm probabilities (solid lines) and conditional probabilities for severe thunderstorms (dashed lines). (From NWS 1973d.)

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[6] TDL's office note series was established in 1973. I wanted the numbering system to just be sequential like the NMC series. Jim Kemper who was working in TDL at the time and had been given a role in establishing the series, insisted the numbering system include the year (e.g., 73-1). I am glad he prevailed, as that has been very convenient.

Following some work by Annett et al. (1972) (see also Glahn et al 1971), another milestone occurred in 1973; the PP method of producing and transmitting calendar day max and min temperature forecasts implemented in 1968 was shifted to MOS in early August for the first four periods; the 5th period forecast was still based on the PP method. Retaining the 5th period was because we had not archived the PE forecasts for projections sufficient for a 5th period MOS. It is believed the CDC 6600 MOS system we had by this time developed was used. This new temperature system continued to produce fax charts, and text forecasts for 93 stations were on the Kansas City Switch. Bill Klein, who along with Gordon Hammons furnished the material for TPB 94 (NWS 1973h) announcing the change, was now calling the method MOS rather than imperfect prog (Klein and Hammons 1973). Although the PP max and min temperatures had been improving each year of operation (Klein 1972), verification presented for 49 cities over a 3-month period showed about 0.5°F MAE improvement for MOS over PP for each of today's max, tonight's min, and tomorrow's max and min. Bill was now MOS's most vocal supporter (e.g., Klein and Glahn 1974).

MOS max and min temperature forecasts replaced the PP system in 1973.

In the approximate 2-year period 1971-1973, we had implemented several CONUS-wide MOS products, namely PoP, PoFP(P), wind speed and direction, thunderstorms, and max/min temperatures. Severe thunderstorms were for the eastern and central U.S. (where predictand data were available), and the SAM products were maintained and improved. Also, by this time the SAM model had been updated and converted to cover the entire CONUS and renamed the Subsynoptic Update Model (SUM) (Grayson and Bermowitz 1974), so the SAM products would be phased out.

In late 1973, NOAA began phasing out the CDC 6600 computers and installing the IBM 360/195 system (Glahn, 1974, p. I-1). By this time, we had developed a rather complete CDC 6600 MOS processing system (Glahn 1973); that now had to be converted to the IBM system. The next chapter describes the CDC 6600 system.

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CHAPTER VI

THE DEVELOPMENT OF A MODEL INTERPRETATION SYSTEM

When we started our SAM products, the data sets were few and small. Feeding them into a regression routine was relatively easy. As the predictand and predictor data sets grew in number and size, we needed a way to exercise options, so a predictor and predictand identification system was designed. Statistical development differed from development of NWP models in several ways, one being the amount of data involved. Especially with the low bit density of mass storage at that time, data needed to be stored efficiently.

The source of model predictor data was the SAM and NMC archived grids. The NMC scheme for packing data was to put five values into one CDC 6600 60-bit word; that is, 12 bits were allocated to hold one value. Before packing each value, the average of the values in the dataset was subtracted, usually making the numbers to pack smaller (of course, the average had to be saved also). We adopted that scheme and used NMC routines for packing, unpacking, reading, and writing. We, as well as NMC, wrote in FORTRAN, switching to “machine language” only if absolutely necessary.

Initially, programs were written to deal with the SAM and PE combination of predictors. This was for a specific set of stations in the eastern U.S. With the expansion to the CONUS, the programs were revised to handle the larger domain and number of stations. These programs were sufficient to develop regression equations, make forecasts, and verify them, but neither the SAM-oriented nor the PE-oriented set consisted of a well-constructed, documented, and expandable system. Quoted from “The TDL MOS Development System CDC 6600 Version” (Glahn 1973):

> “As other models were developed, it became clear that we needed a more general system which would accept data, and allow the merging of data, from several models. It would have to be flexible enough so that output from new models, as they are developed, could be accommodated. Planning for this new system started in March 1972. Although changes will always be necessary in any set of computer programs that must meet the changing needs of an organization, the MOS Development System is now complete enough so that it can be effectively used. Its development has been a joint effort of many people in TDL and several have actively contributed to the programming. In this latter group I want especially to mention Frank Globokar, George Hollenbaugh, Frank Lewis, Ron Reap, and Tom Grayson.”

Our first fully functional MOS development system was in place by 1973.

Frank Globokar was an Air Force liaison officer working in TDL, George Hollenbaugh had been with the group from the beginning of the SAM project, Frank Lewis was branch chief overseeing the implementation, Ron Reap had developed the trajectory model, and Tom Grayson was a recent addition to the team.

The planning started in March 1972 and the system was documented in an office note dated October 1973, so the development, including documentation, took about 20 months. During this time, we were also developing and implementing products, as detailed in the previous chapter.

The programs involved and flow of data are shown in Fig. VI-1. The primary person responsible for each program is also shown. A program naming convention had been implemented; each main program was named Mxxx where xxx fell within a number range specified for that program's function.

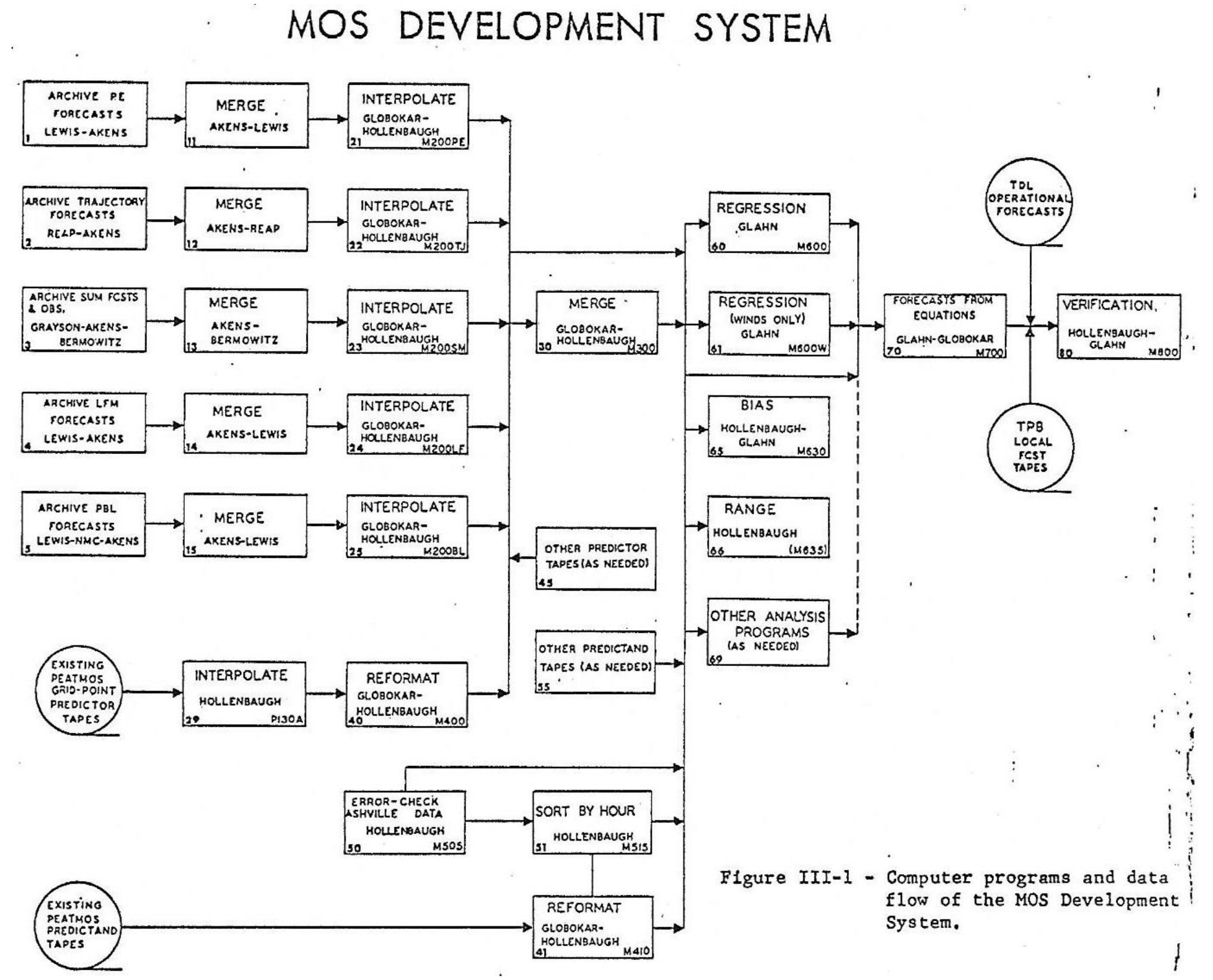

Figure VI-1. Programs and data flow in the CDC 6600 MOS development system. (From Glahn 1973.)

The numbering scheme is shown in Fig. VI-2.

We arranged to archive data from five models, the PE (NMC primitive equation; Shuman and Hovermale 1968), TJ (TDL trajectory; Reap 1972), SUM (TDL subsynoptic update),[1] LFM (NMC limited area fine mesh; Howcroft 1971), and PBL (NMC planetary boundary layer; Gross et al., 1972)[2] models. Each required an archiving program because of differing grids, and the

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[1] The SUM was an outgrowth of SAM and will be discussed in the following chapters.

[2] TDL also had a boundary layer model under development starting in 1972, but it was not ready for use.

metadata were not stored with the grids. The daily archives were merged into one archive per model (the M1xx series of programs, shown in Fig. VI-2).

Our process was to interpolate into the grids to station locations to get the predictors for the regression. Because the grids were not self describing, we had separate versions of the interpolation for each model (the M2xx series). Once the predictors were in "vector" form (a value for each station) we could merge them together (the M3xx series). The existing PEATMOS grids also had to be interpolated and reformatted to get them into condition they could be merged with the other interpolated values (the M4xx series). Also, in this series of programs was the reformatting of predictand data.

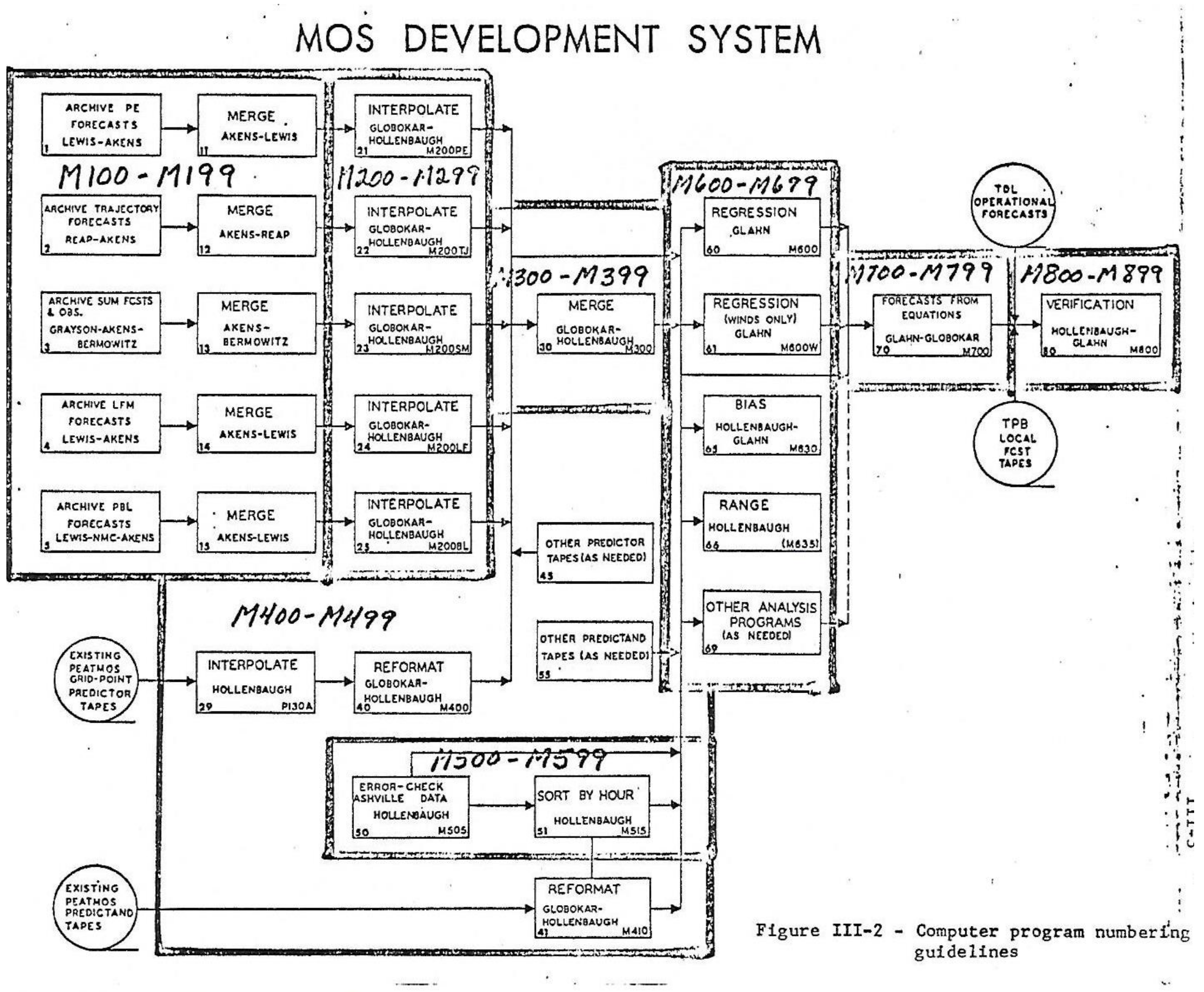

Figure VI-2. Computer program numbering guidelines in the CDC 6600 MOS development system. (From Glahn 1973.)

Our predictand data were the observations obtained from the National Weather Records Center (NWRC)[3] at Asheville, North Carolina. We bought 17 types of data (e.g., temperature,

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[3] NWRC has had a variety of names in its lifetime. Its current name is National Centers for Environmental Information.

dew point) for 255 stations from NWRC for several years until we established our own archive of real-time data. Stations in Alaska, Hawaii, and Puerto Rico were included as well as in the CONUS. The format, of course, was unique, and the data were put into the form used by the processing programs (e.g., regression) by the M5xx series of programs.

Various processing programs that related predictands to predictors were in the M6xx series, notably the regression programs, one for general use and one for concurrently[4] developing relationships for the wind components and speed. This latter program assured that all three equations (U, V, and speed) for a specific projection had the same predictors. Once the equations were developed, forecasts could be made from them by M700, and they could be verified by M800.

We established a software library called TDLLIB according to the NMC convention and structure. We provided for potential users a write-up for each routine with a numbering system "TDLLIB No. x" where x was one or more digits. A series of TDL Library Notices was written and disseminated containing instructions and standards. For instance, Notice No. 3 provided the standards for program write-ups. Writeups appearing in this TDLLIB have authors Thomas Grayson, H. Michael Mogil, Harry. R. Glahn, George Murphy (NMC), George H. Hollenbaugh, Frank T. Globokar, and Thomas D. Bethem (TDL 1972).

Our need to keep storage to a minimum with efficient input/output (IO) contributed to the design. We also wanted to use NMC's routines wherever possible. The packing of model data came naturally; we used the NMC format and associated software. A record consisted of five identification words, then the following gridpoint values packed five values per 60-bit word. The first value was the lower left point on the grid. Scanning was then by column (upward) from left to right. A missing datum was indicated by all 12 bits set to 1. These data were on 7-track tapes in 800 bpi (bits per inch, longitudinally) density.[5]

The PE archive consisted of four grids in the same record, one grid covering each of CONUS, Alaska, Hawaii, and Puerto Rico (Fig. VI-3). We wanted to be able to develop for each of these areas, but felt one grid covering the entire area was too much data to store. This arrangement of four grids in one record complicated certain programs, but was workable. We were quite selective in what we archived. We saved 27 different variables at 6-h intervals (the frequency of the NMC output) from 6 to 84 h, but less often for other variables.

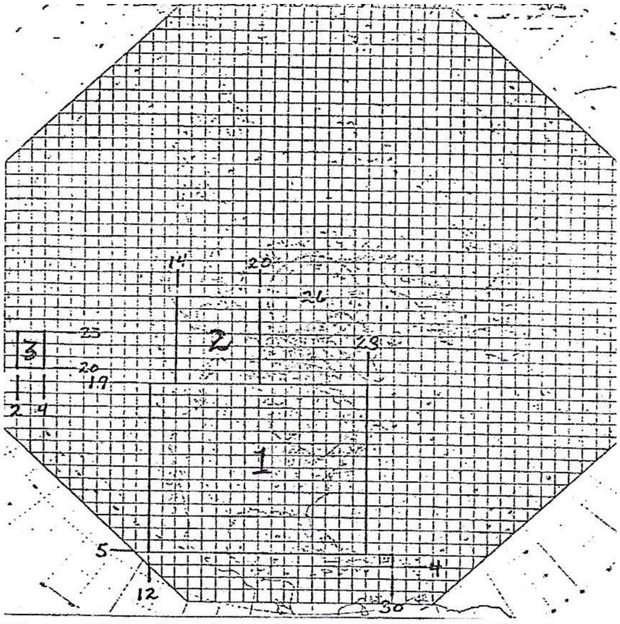

Figure VI-3. The four grids saved from the PE octagonal grid. 1 = CONUS, 2 = Alaska, 3 = Hawaii, and 4 = Puerto Rico. (From Glahn 1973.)

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[4] "Concurrently" was the term used. Later we used "simultaneously."

[5] Previous densities used were 200 and 556 bpi.

Variables saved were geopotential height, temperature, relative humidity, wind components (relative to the grid), vertical velocity, and precipitation amount. The total number of fields saved was 194 (125) at 0000 (1200) UTC. The grid was polar stereographic oriented on 80° W with a resolution of 381 km at 60° N (1 Bedient).

The LFM archive consisted of much the same information as the PE archive but went out to only 24 h. The total number of grids saved was120. The LFM grid was also polar stereographic but was oriented on 105° W and had a resolution of ½ Bedient.

The TJ model furnished forecasts at the 24-h projection. Variables included temperature, dew point, relative humidity, and net vertical displacement at the surface, 850 mb, and 700 mb. The grid was over the CONUS on the LFM grid, but not the exact area of the LFM archive.

The PBL archive was also on the LFM grid and over the same area as the LFM archive. Variables saved included wind components, moisture, and temperature at various levels above the terrain up to 1,600 m at 3- or 6-h increments out to 24 h.

The SUM archive contained 1000-mb height, mean relative humidity, 3-h precipitation amount, ceiling, visibility, and sky cover at 3- or 6-h increments out to 18 h. The grid was the same as the LFM, but at ¼ Bedient. The SUM archive also (redundantly to the predictand archive) contained observations.[6]

The NMC packing scheme for grids used five words, each of 20 octal digits, for identification. TDL followed that scheme and used the first two words for variable identification.

The ID scheme for interpolated (predictor) data, now in vector (non-grid) form, also used a variant of the NMC scheme. The first five words identified the data. But now there was a header record on each tape that contained information about the stations on the tape. This allowed different stations to be on different tapes. Figure VI-4 gives in some detail the ID system used.

The format and ID scheme for predictand data were not the same as for predictor data. The predictand data for each date/time were in a 255 x 17 (stations x types of data) matrix. This format was designed primarily for packing efficiency; each type of data had a specific number of bits allocated for packing, in distinction to 12 bits for each predictor value. Variables were identified by a 10-digit number in octal. If it had the form 70000000xx, the data were to come from column xx (in octal) of the predictand matrix. If xx was > 21 ($21_8 = 17_{10}$), then a subroutine YXCMPUT was used to compute the predictand from the matrix. The stations were identified by their 5-decimal digit WBAN (Weather Bureau Army Navy) numbers, a numbering system used at NWRC (see Fig. VI-5 for more details).

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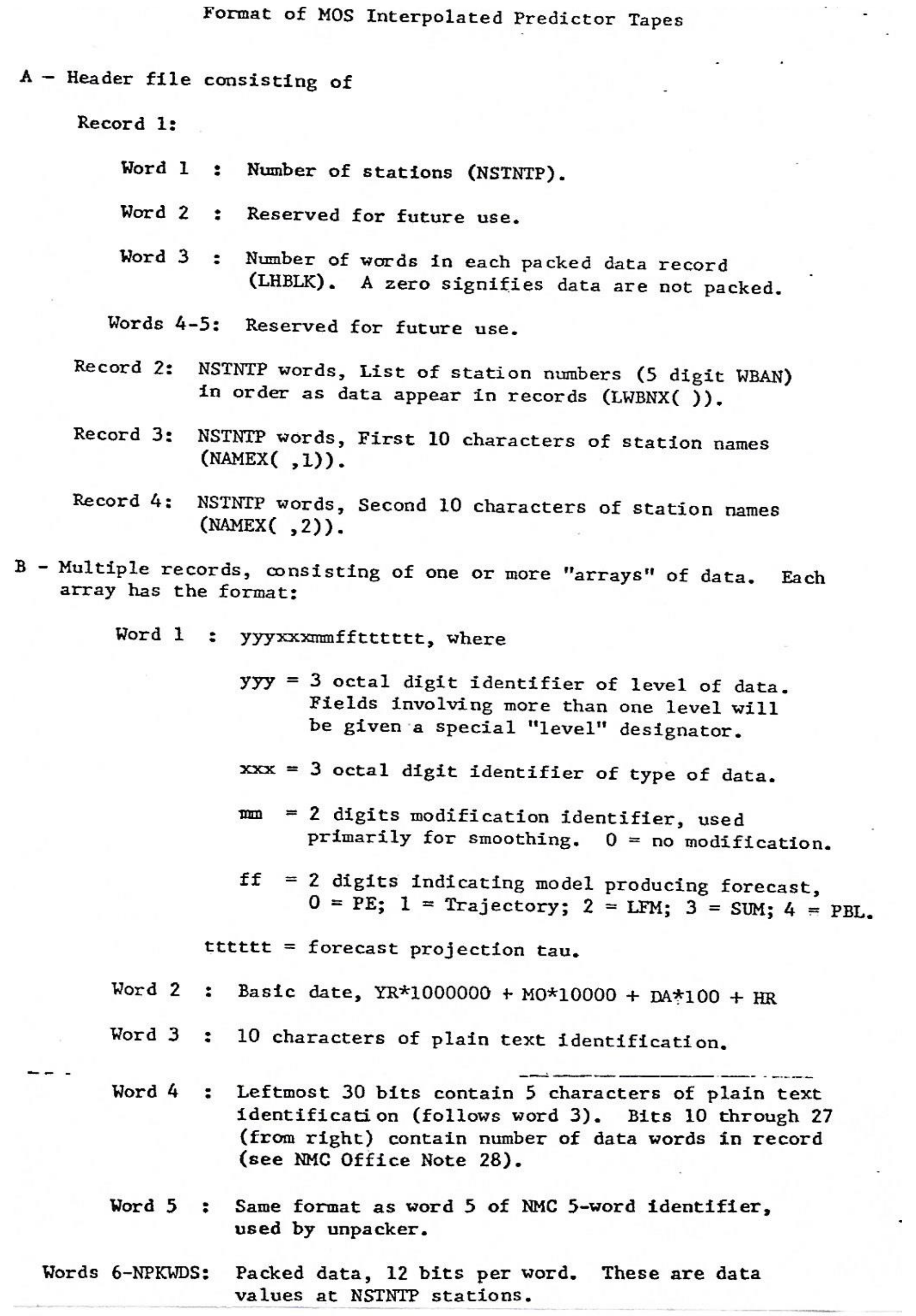
[6] This was an artifact of this system treating predictors and predictands differently. The Asheville observations were to be used as both predictors and predictand, so they were put onto a predictor tape as well as being on a predictand tape.



Format of MOS Interpolated Predictor Tapes

A – Header file consisting of

Record 1:

Word 1 : Number of stations (NSTNTP).

Word 2 : Reserved for future use.

Word 3 : Number of words in each packed data record (LHBLK). A zero signifies data are not packed.

Words 4-5: Reserved for future use.

Record 2: NSTNTP words, List of station numbers (5 digit WBAN) in order as data appear in records (LWBNX( )).

Record 3: NSTNTP words, First 10 characters of station names (NAMEX(,1)).

Record 4: NSTNTP words, Second 10 characters of station names (NAMEX(,2)).

B - Multiple records, consisting of one or more "arrays" of data. Each array has the format:

Word 1 : yyyxxxmmfftttttt, where

yyy = 3 octal digit identifier of level of data. Fields involving more than one level will be given a special "level" designator.

xxx = 3 octal digit identifier of type of data.

mm = 2 digits modification identifier, used primarily for smoothing. 0 = no modification.

ff = 2 digits indicating model producing forecast, 0 = PE; 1 = Trajectory; 2 = LFM; 3 = SUM; 4 = PBL.

tttttt = forecast projection tau.

Word 2 : Basic date, YR*1000000 + MO*10000 + DA*100 + HR

Word 3 : 10 characters of plain text identification.

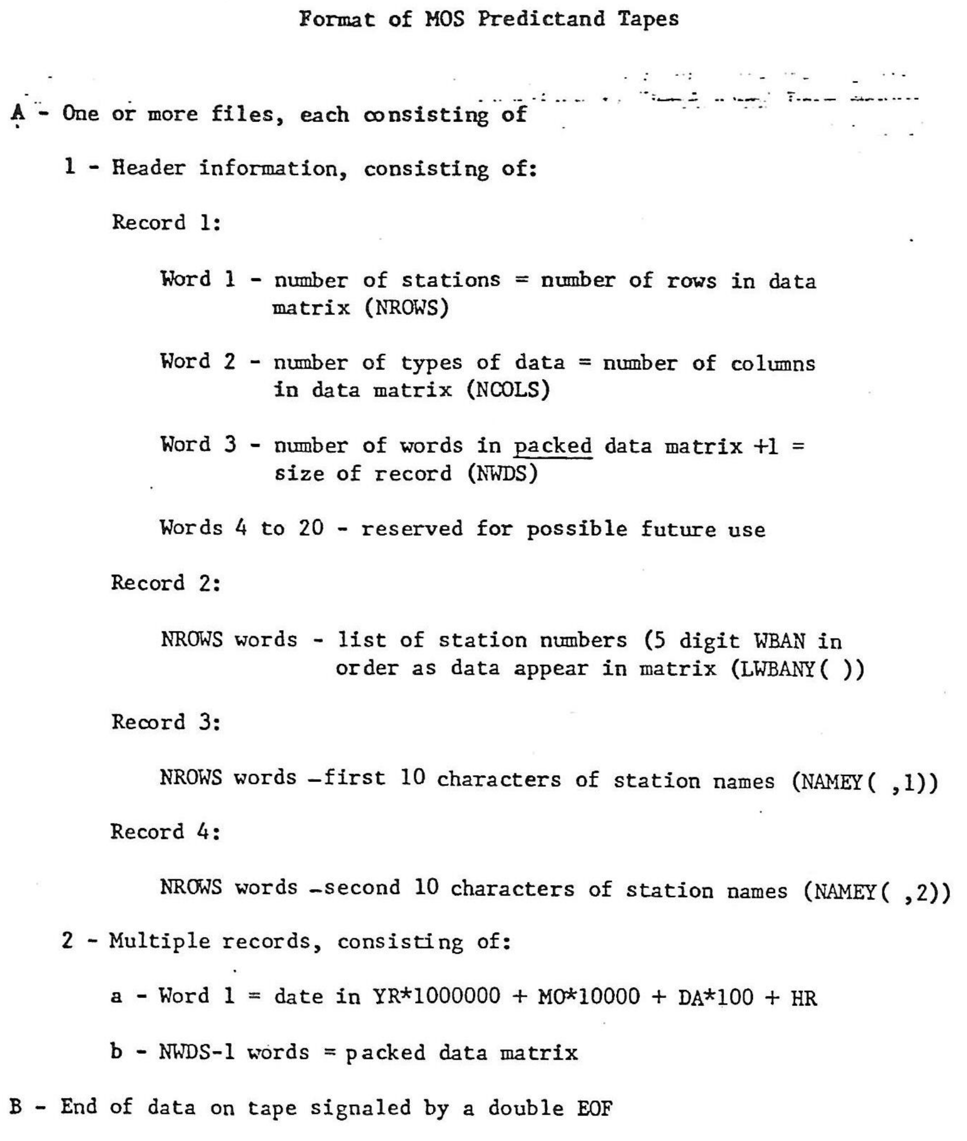
Word 4 : Leftmost 30 bits contain 5 characters of plain text identification (follows word 3). Bits 10 through 27 (from right) contain number of data words in record (see NMC Office Note 28).

Word 5 : Same format as word 5 of NMC 5-word identifier, used by unpacker.

Words 6-NPKWDS: Packed data, 12 bits per word. These are data values at NSTNTP stations.

Figure VI-4. Format of the interpolated predictor tapes. (From Glahn 1973.)

A plain language format was established. It consisted of 15 BCD (binary coded decimal) characters. The first two identified the model (e.g., PE for the PE model). The third was blank, for easy reading. Characters 4-11 identified the variable. Number 12 was blank. Numbers 13, 14, and 15 were reserved to indicate what smoothing was done. It had become customary to smooth with a 5-, 9-, or 25-point smoother.



Format of MOS Predictand Tapes

A - One or more files, each consisting of

  1 - Header information, consisting of:

    Record 1:

      Word 1 - number of stations = number of rows in data matrix (NROWS)

      Word 2 - number of types of data = number of columns in data matrix (NCOLS)

      Word 3 - number of words in <u>packed</u> data matrix +1 = size of record (NWDS)

      Words 4 to 20 - reserved for possible future use

    Record 2:

      NROWS words - list of station numbers (5 digit WBAN in order as data appear in matrix (LWBANY( ))

    Record 3:

      NROWS words –first 10 characters of station names (NAMEY(,1))

    Record 4:

      NROWS words –second 10 characters of station names (NAMEY(,2))

  2 - Multiple records, consisting of:

    a - Word 1 = date in YR*1000000 + MO*10000 + DA*100 + HR

    b - NWDS-1 words = packed data matrix

B - End of data on tape signaled by a double EOF

Figure VI-5. Format of predictand tapes. (From Glahn 1973.)

A format for the equations that could be punched on cards or written to tape was established. It allowed for single-station or generalized operator equations, and a variable number of predictors. Part of the ID was the threshold for binary predictors. For single-station equations, 20 characters of the station name were included. This format was output by M600 and M600W.

A special collection of digitized radar data was archived in the predictand format. This collection was for thunderstorm and severe thunderstorm prediction. The data came from teletype reports from individual radars and were collected into this archive—a massive job.

We wrote all the so-called main programs (designated as programs Mxxx) as subroutines called by a matched driver DRMxxx. The dimensions of most variables were defined in the driver. This allowed dimensions (sizes of arrays) to be changed without modifying the main program. The dimensions were in terms of variables in PARAMETER statements with names such as NDX where X was a 1 or 2-digit number. These dimensions were then passed through the call and used wherever needed. In those days, allocating the storage needed at the beginning would cause the program to stop immediately if space were not available. Allocating space after much of the data processing was done and then running into space issues wasted computer and clock time—very important. The importance of this has waxed and waned as computers and operating systems have changed.

This CDC system was used but only for a short time until it had to be converted to the new NOAA IBM 360/195 system. The 32-bit IBM word, as well as different IO processes, meant massive changes not only for TDL but also for NMC for their software, especially because we were making much use of bit- and octal-oriented definitions. All data tapes had to be converted. I remember the day Lena Loman came over from NMC and told me of the impending switch. I was so upset. The converted system, to be explained later, was up and running by December 1974 (Glahn 1974).

Many of the concepts established in this CDC system have persisted until today, usually with modification. For instance, if a field needed to be computed before interpolation, control was routed to the correct computation routine through a “switcher” called OPTION. The reading of the IDs of the fields needed has been dispensed with as memory became less of an issue, but the use of OPTION remains. The use of 5-, 9-, and 25-point smoothers, as well as the basic program naming/numbering convention and the use of drivers for main programs, has remained. The format for program writeups has changed very little.

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_____, 1974: The TDL MOS development system, IBM 360/195 version. *TDL Office Note* **74-14**, Techniques Development Laboratory, National Weather Service, NOAA, U.S. Department of Commerce, 22 chapters.

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CHAPTER VII

THE SUBSYNOPTIC UPDATE MODEL AND NEW PRODUCTS

The Subsynoptic Advection Model (SAM) covered only the eastern part of the CONUS. One of the tasks of Tom Grayson was to extend SAM to cover the CONUS and to improve it if possible. He developed a model, called the Subsynoptic Update Model (SUM) that made more use of the driving model (e.g., the PE or LFM[1]) than had SAM. It was also more “numerical” in nature, like other NWP models, than the “advective” SAM. NWS (1973b) gives considerable detail on SUM that was to be implemented in September 1973.

Thomas Grayson was a TDL branch chief and developed the SUM model.

Because the model was more compute intensive than SAM and because it now covered a much larger area, the SLP portion of the model was ½ Bedient instead of ¼ Bedient for SAM. However, the ¼ Bedient mesh was retained for the precipitation prediction calculations. The grid was oriented on 105° W, as was the LFM. Like SAM, SUM was to be run at 0700 and 1900 UTC to furnish “update” guidance to the PE or LFM run on 0000 and 1200 UTC data. Fig. VII-1 shows the rationale for running SUM, and also shows the input from the PE or LFM as the driving NWP model. The diagram is essentially like a similar one for SAM except for the driving model input. The 5-h (17-h) SAM and SUM forecasts verified at the same time as the 12-h (24-h) PE and LFM forecasts. See Grayson and Bermowitz (1974) for more details.

Verification of SUM was limited. shows the score computed on March

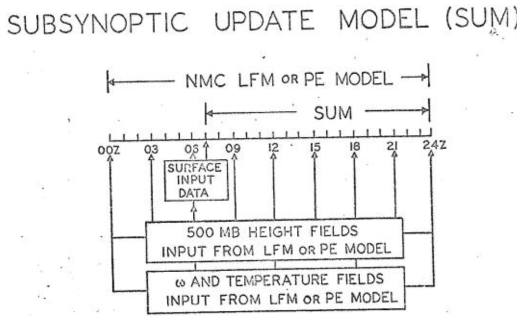

Figure VII-1. Relationship between SUM and the PE or LFM model during a forecast cycle from 0000 UTC. The arrow at 0600 UTC indicates surface data were used as input to SUM at this time. The other arrows indicate the PE or LFM predictions of 500-mb height, vertical velocity, and temperature were used as input at the times shown. (From NWS 1973b.)

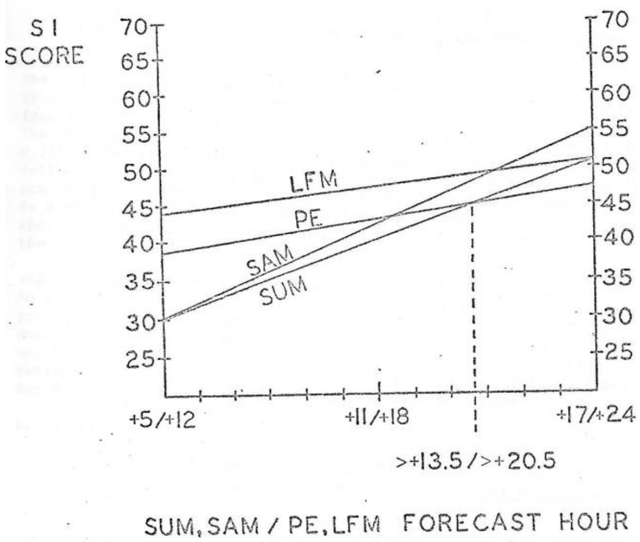

Figure VII-2. S1 score for 32 SUM, SAM, PE, and LFM SLP forecasts during March 1973. The crossover between SUM and PE forecasts was about 13.5 (20.5) h after the initial SUM (PE) data time. (From NWS 1973b.)

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[1] The limited-area fine-mesh model (LFM) (Howcroft 1971) was similar in design to the PE model run with a gridlength ½ that of the PE. The LFM model was implemented September 1971 (Fawcett 1977).

1973 data for the PE, LFM, SAM, and SUM for the two projection points indicated and the skill crossover point. The S1 score (Teweles and Wobus 1954) measures pressure gradient error and is negatively oriented; that is, a lower score is better. According to this limited verification, SUM was better than SAM, the PE did not improve on SUM until SUM projections > 13 h, and the LFM did not improve on SUM within the 24-h LFM forecast period.

By this time, the LFM was running at ½ Bedient, but only at 0000 and 1200 UTC. SUM updated the last NMC run with new surface data, and precipitation was forecast at ¼ Bedient resolution. The SUM forecasts replaced the SAM fax charts, and the SAM teletype output was discontinued. The SUM forecasts were not transmitted on teletype. This ended SAM (Glahn and Lowry 1972a), a project that had been started in 1964 and by which the MOS concept was proven to be viable (Glahn and Lowry 1972b).

SUM replaced SAM facsimile charts in the fall 1973. SAM teletype was discontinued.

In September 1973, the fax charts from the TDL trajectory model were materially revised to provide more clearly readable information; the model itself was not revised (NWS 1973c). Fig. VII-3 shows one panel that depicts forecast trajectories ending at gridpoints.

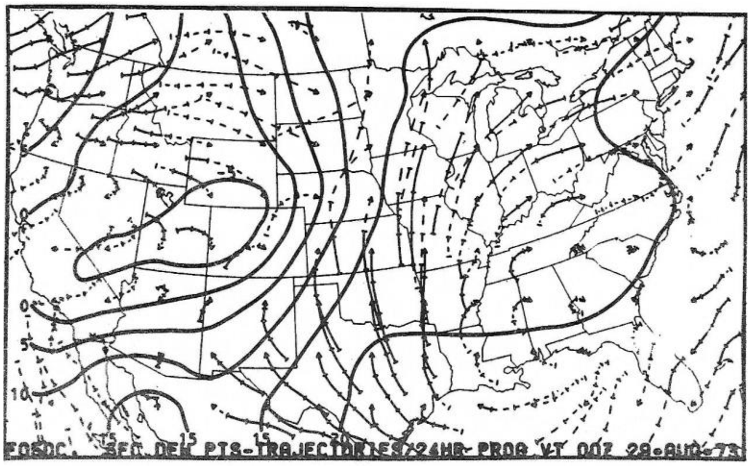
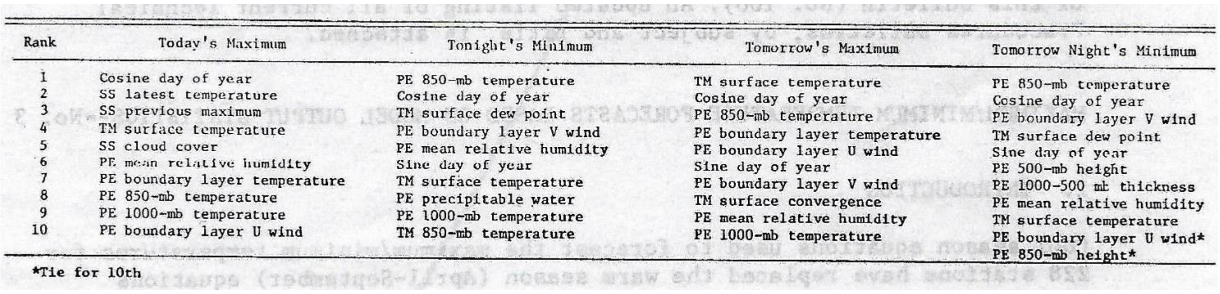


Figure VII-3. 24-h forecast of surface dew point (°C) (solid) and parcel trajectories valid at 0000 UTC Aug. 29, 1973. Six-h parcel positions are denoted by tick marks. Arrows are placed at terminal gridpoints to indicate direction of flow. Rising (sinking) motions for each 6-h segment are indicated by solid (dashed) lines. (From NWS 1973c.)

The MOS max/min temperature equations had in them the observed temperature for the first period forecast. When this was missing, a backup equation was used that did not have the observed temperature. An "M" was inserted into the message to indicate the backup equation was used (NWS 1973d). Cool season equations replaced warm season equations. Fig. VII-4 shows the frequency of predictor selection over all 228 single-station equations for cool season 0000 UTC data.



Rank	Today's Maximum	Tonight's Minimum	Tomorrow's Maximum	Tomorrow Night's Minimum
1	Cosine day of year	PE 850-mb temperature	TM surface temperature	PE 850-mb temperature
2	SS latest temperature	Cosine day of year	Cosine day of year	Cosine day of year
3	SS previous maximum	TM surface dew point	PE 850-mb temperature	PE boundary layer V wind
4	TM surface temperature	PE boundary layer V wind	PE boundary layer temperature	TM surface dew point
5	SS cloud cover	PE mean relative humidity	PE boundary layer U wind	Sine day of year
6	PE mean relative humidity	Sine day of year	Sine day of year	PE 500-mb height
7	PE boundary layer temperature	TM surface temperature	PE boundary layer V wind	PE 1000-500 mb thickness
8	PE 850-mb temperature	PE precipitable water	TM surface convergence	PE mean relative humidity
9	PE 1000-mb temperature	PE 1000-mb temperature	PE mean relative humidity	TM surface temperature
10	PE boundary layer U wind	TM 850-mb temperature	PE 1000-mb temperature	PE boundary layer U wind* PE 850-mb height*

*Tie for 10th

Figure VII-4. Importance of PE and TJ predictors on the basis of frequency of selection in 10-term equations for minimum and maximum winter temperatures at 228 stations (0000 UTC data). (From NWS 1973d.)

The MOS wind speed forecasts were produced from a speed equation. Previously, Glahn (1970) showed that a speed computed by $S = (U^2 + V^2)^{1/2}$ would in general underestimate the speed when the U and V were regression estimates. Even so, the regression estimates of speed did not capture the stronger winds, so a modification was made. The larger of the speed computed from the equation above or the speed directly from the speed equation was forecast. Verification showed the new process scored slightly better than the one previously used (NWS 1973e).

In April 1974, the summer MOS PoP equations were updated, being developed on 3 years of data instead of 2 used previously (NWS 1974a). The years 1971, 1972, and 1973 were used for 1974, again demonstrating we could collect data from one season, develop equations, and use the equations the next year, 6 months after the end of the developmental season. Equations were developed for 24 regions, 4 projections, and 2 runs per day (a total of 192), each with 12 predictors. The screened list varied by projection, but was the same otherwise. The winter equations were updated later in the year in a similar manner based on 4 years of data (NWS 1974c).

In June 1972, the Director of the NWS Eastern Region requested that a method be developed to produce wind forecasts along the east coast. TDL was given the task of developing such a system. In consultation with the Eastern Region, eight light stations[2] along the east coast (see Fig. VII-5) were identified for which we could obtain data. The system was developed in much the same way as previous MOS wind systems, with equations for U, V, and S. Three years of predictand data were obtained from NOAA's Environmental Data Service. Stratification was by the usual summer (April through September) and winter seasons. Forecasts were produced at 6-h increments out to 42-h. The implementation, probably late summer 1974, was over RAWARC, the date to be announced by ALSYM (NWS 1974b).

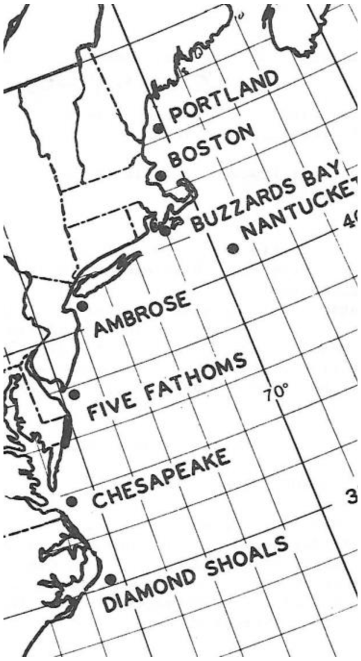


Figure VII-5. The locations of the eight light stations. (From NWS 1974b.)

Two new types of forecasts were implemented in September 1974 or shortly thereafter. These were ceiling height and prevailing visibility, and were specifically to support aviation interests. Much work had been done in past years at the Travelers Research Center (e.g., Enger et al. 1964) and later in the Weather Bureau (e.g., Allen 1970; Crisci 1973; Crisci and Lewis 1973) to predict these variables by statistical means with only initial observations as predictors (the so-called classical method). The existence of archived model forecasts now allowed models to contribute in the prediction equation. The distributions of ceiling and visibility are extremely non-normal, and in addition, the less frequent values of low ceiling and low visibility are the most important ones. So, the usual regression techniques applied to temperature and wind are not adequate.

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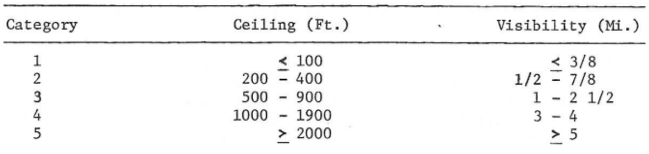
[2] Light stations were ships or towers off the coast having special nautical duties including taking meteorological observations (NWS 1974b).

We wanted, if possible, to forecast a continuous distribution of the predictand, so we tried various transformations to try to linearize the problem. We were disappointed with the results, so we tried the REEP approach where the predictand was divided into a number of categories that were meaningful to the potential customer and then predicted the probability of each category; these categories are shown in Fig. VII-6. Then we transformed the probability forecasts into a "best" categorical forecast by several methods. We concluded that the use of SAM and PE predictors improved the forecasts over using only the initial observation and that REEP was superior to the continuous formulation (Bocchieri and Glahn 1972; Bocchieri et al. 1973).



Category	Ceiling (Ft.)	Visibility (Mi.)
1	≤ 100	≤ 3/8
2	200 - 400	1/2 - 7/8
3	500 - 900	1 - 2 1/2
4	1000 - 1900	3 - 4
5	≥ 2000	≥ 5

Figure VII-6. The categories of ceiling and visibility used for the forecasts. (From NWS 1974d.)

The predictors for the implemented products were from the PE and TJ models; note that the SUM model was not included even though SAM had been used in the testing; SUM had not run long enough to generate a viable sample. Regional equations were developed; the regions for summer equations are shown in Fig. VII-7 with the stations shown as dots. The forecasts were produced for 6-, 12-, 18-, and 24-h projections.

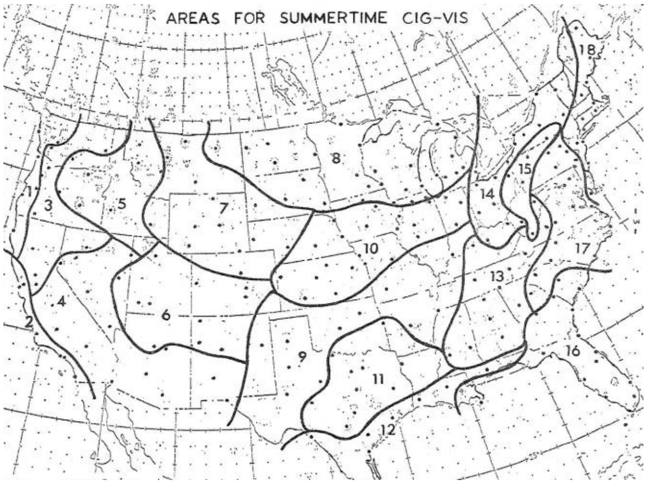
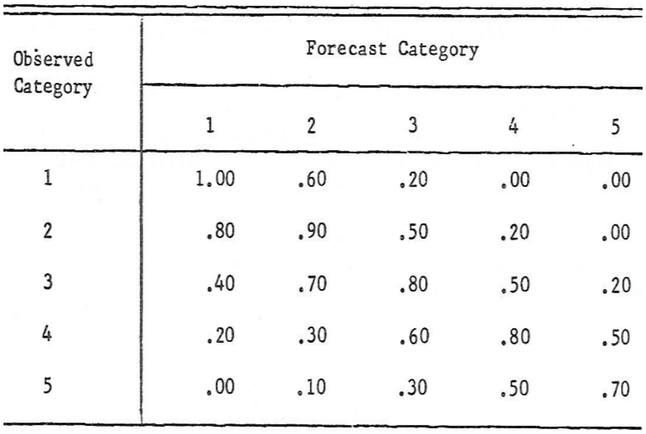


Figure VII-7. The regions used for summer cig/vis equations and the stations as dots. (From NWS 1974d.)

A specific value forecast was made by transforming the probability forecasts to maximize the NWS matrix score (MS). Quoted from NWS 1974d:

> "The NWS scoring matrix is the result of efforts going back some 10 years to acquire information on the utility of ceiling and visibility forecasts to aviation users. On November 30, 1972, the NWS Task Group on Aviation Forecasting approved the NWS scoring matrix. The resulting NWS Aviation Forecasting Score ("MS") is now the primary verification score used by NWS."



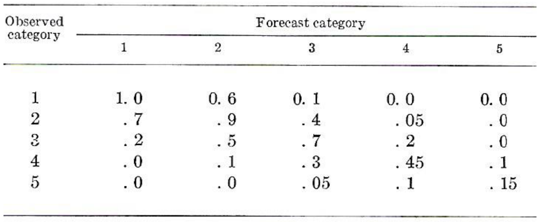
Observed Category	Forecast Category				
	1	2	3	4	5
1	1.00	.60	.20	.00	.00
2	.80	.90	.50	.20	.00
3	.40	.70	.80	.50	.20
4	.20	.30	.60	.80	.50
5	.00	.10	.30	.50	.70

Figure VII-8. NWS scoring matrix for ceiling and visibility forecasts as of 1974. (From NWS 1974d.)

This scoring matrix is shown in Fig. VII-8. Forecasts were verified on independent data for 2 winter months for 20 stations in the eastern CONUS for the three valid times 1200, 1800 and 0000 UTC. These times were 2-, 8-, and 14-h projections for the NWS terminal forecasts (FT) and 4-, 10-, and 16-h projections for MOS. Generally, the FTs were better at 1200 UTC, but MOS was better for 1800 and 0000 UTC for both percent correct and the NWS MS.[3] However, the biases were extremely low for both the FTs and MOS for the low categories. This is not surprising for MOS, because the probabilities were transformed into categorical values by applying the scoring matrix, and while the weights are a bit higher for the low categories than the high ones, not nearly enough so to make many low forecasts.

Bocchieri and Glahn in their study did not use the matrix shown in Fig. VII-8, but rather the one shown in Fig. VII-9. According to Glahn (1964):

> “. . . (it) was devised by R. A. Allen after consultation with forecasters at several aviation forecast centers. It is thought that this matrix may not be far different from that of an actual utility matrix of an airline and it was used by Enger, Reed, and MacMonegle for the purpose of evaluating ceiling height forecasts at seven terminals. . . .”



Observed category	Forecast category				
	1	2	3	4	5
1	1. 0	0. 6	0. 1	0. 0	0. 0
2	. 7	. 9	. 4	. 05	. 0
3	. 2	. 5	. 7	. 2	. 0
4	. 0	. 1	. 3	. 45	. 1
5	. 0	. 0	. 05	. 1	. 15

Figure VII-9. The Allen utility matrix. (From Bocchieri and Glahn 1972.)

MOS ceiling height, cloud amount, and visibility forecasts were introduced in the fall of 1974.

The Allen matrix seems more appropriate than the one in Fig. VII-8, but was evidently rejected by a ruling group. If unbiased probability forecasts were used with it to make forecasts, they would have better bias characteristics than if the NWS one were used, but the forecasts would probably still be biased toward the high categories. See Bocchieri et al. (1974) for more information. Other methods are used today for transforming probability forecasts into categorical ones.

New max/min temperature equations were implemented for the 1974-75 winter based on 5 years of data; this supplanted those for the previous winter based on 3 years of data (NWS 1974e). The max/min system is chronicled in Klein and Hammons (1975).

A method for forecasting cloud amount was developed, and forecasts from it were sent to Houston by fax to support the NASA Project SKYLAB (Glahn 1974). The warm and cool season single-station equations were developed with REEP for 231 stations in the CONUS on 4 years of data. The forecasts were in terms of the probability of each of four categories, roughly clear (clear, partial obscuration, and thin scattered), scattered, broken (thin broken, broken, and thin overcast), and overcast (overcast and obscured). Forecasts from 0000 UTC were used to forecast for 1800 UTC the same day; forecasts from 1200 UTC were used to forecast for 1800 UTC the next day.

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[3] The 2-h difference in projections for the FTs and MOS represented the difference in input data times. It was thought the forecasters would have 2-h later data in making their forecasts because of the time it took to collect data, make the MOS forecasts, and get the forecasts into the hands of the forecasters. This practice of treating the automated forecasts as guidance and it having to be in the hands of the forecasters when they make their forecasts for a comparative verification to be done still exists today.

Initially, the categorical forecasts were made by choosing the category with the highest probability. This gave almost no forecasts of scattered and less than desired of broken. We found that if we multiplied the warm season probability forecasts of the four categories by 0.84, 1.20, 1.04, and 0.94, respectively, and then chose the category with the highest value, the forecasts were relatively unbiased. Other transformation factors were applied to the cool season forecasts.

Five fax maps composed the twice daily transmission to Houston, four of them were for the probability of occurrence of each of the four cloud categories, and the fifth was for the categorical forecast. An example of each type of chart is shown in Fig. VII-10.

Shortly thereafter, the cloud system was updated for widespread distribution. Another year of data was added and forecasts were made at 6-h intervals from 12-h to 48-h projections.

The process of making the categorical forecasts was modified. First, the probability forecasts were inflated, then a transformation matrix (see Fig. VII-11) was applied that differed from the one defined above for the NASA product. Quoted from TPB 124 (NWS 1974f):

> "In order to determine the best category forecast, each of the inflated probabilities was multiplied by the values in the matrix on a column basis, and the category with the highest computed value was selected."

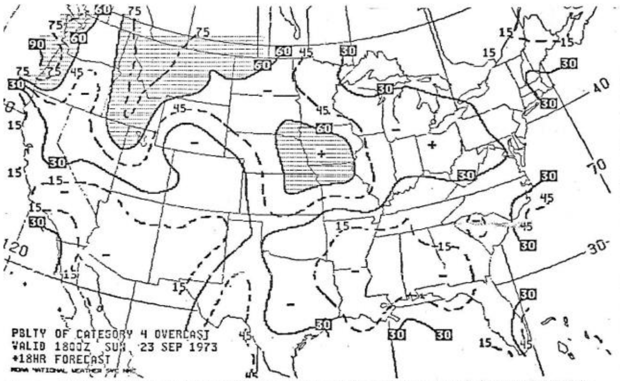


Fig. 1. An 18-hr forecast of the probability of occurrence of cloud category 4 (overcast) valid at 1800 GMT on September 23, 1973. Labels are in percent; values greater than 60 percent are shaded.

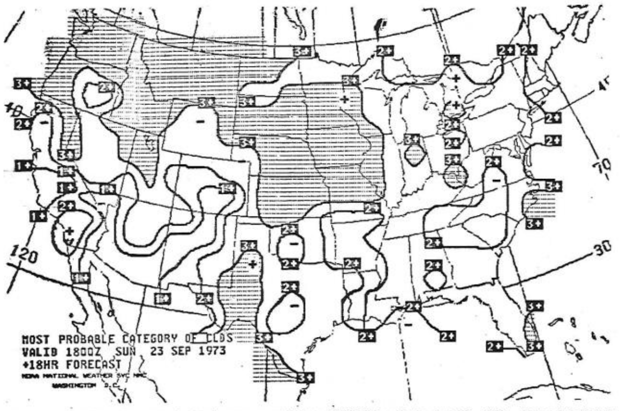
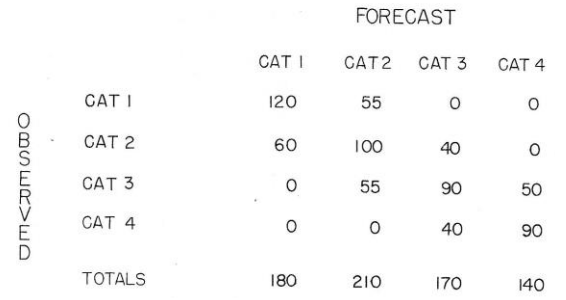


Fig. 2. An 18-hr forecast of cloud category valid at 1800 GMT on September 23, 1973. Lines labeled 1+ divide the category 1 and category 2 areas, etc. Category 4 (overcast) areas are shaded.

Figure VII-10. An example of a cloud probability forecast (top) and a categorical forecast. (From Glahn 1974.)

The initial matrix (Fig. VII-11) was based on very limited data, and was revised on more dependent data, which actually resulted in one for 0600 and 1200 UTC valid times and one for 1800 and 0000 UTC valid times. The forecasts were much improved by this double adjustment procedure as shown in NWS (1974f), NWS (1974g), and Carter (1975). The comparative verification showed the MOS forecasts measured up well with the official forecasts. The cool season 10-term equations were replaced by warm



		FORECAST			
		CAT 1	CAT 2	CAT 3	CAT 4
OBSERVED	CAT 1	120	55	0	0
	CAT 2	60	100	40	0
	CAT 3	0	55	90	50
	CAT 4	0	0	40	90
	TOTALS	180	210	170	140

Figure VII-11. Transformation matrix for cloud amount probabilities to make a categorical forecast. (From NWS 1974f.)

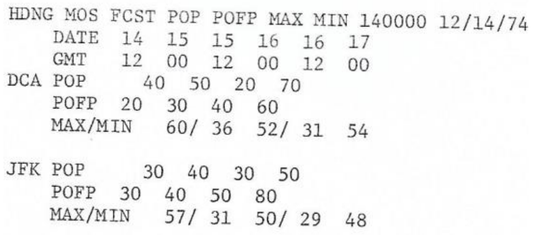
season 12-term equations in April 1975 (NWS 1975a). NWS (1975b) indicates that these new equations included as predictors observations at the initial time, and that the inclusion of observations improved the predictions.[4]

In July 1974, Bermowitz and Grayson (1974) reported on a full winter season of SUM forecasts compared to the PE and LFM at 58 cities over the CONUS in terms of the S1 score and MAE. The results were similar to those presented earlier. The PE was better than the LFM. SUM was best initially, and the skill crossover point for the PE was 12.5 h for S1 and 15.1 h for MAE. Scores were also presented for precipitation in terms of measurable precipitation for the period January to March 1974. SUM tended to have a wet bias, being 1.6 for both 6-h periods (the first 5-h SUM period did not exactly fit the standard 6-h periods). Summarized by Bermowitz and Grayson (1974):

> "SUM precipitation forecasts for the period January to March 1974 generally have better verification scores than the PE and about the same scores as the LFM for the first 5 hr SUM period. Second period SUM forecasts, in general, have about the same verification scores as the PE and slightly worse scores than the LFM. The LFM had better verification scores than the PE for both periods."

Late in 1974, wave forecasts were produced for 64 points in the Great Lakes. The wave forecasts were based on the automated wind forecasts being made for the lakes (see NWS 1973a). For each forecast point, fetch lengths were determined. The effective fetch was calculated as a function of the effective wind speed and duration time. Significant wave height was calculated by the Bretschneider (1970) method. The method of producing the wave forecasts is explained in detail by Pore (1977) who gives the implementation date as January 1975. The forecasts were put on the RAWARC circuit (NWS 1974h). Much later, March 18, 1981, two more points were added in Lake Michigan at the request of Weather Service Forecast Office at Milwaukee (NWS 1981).

Each of the CONUS automated MOS and PP products that had been implemented was in one or more bulletins dedicated to only that product. In late 1974, a new bulletin was created that contained MOS PoP, PoFP(P), and max/min temperatures. This was the beginning of the "matrix" products that were later issued that had over a dozen elements in one bulletin (NWS 1974i).



```
HDNG MOS FCST POP POFP MAX MIN 140000 12/14/74
     DATE  14   15   15   16   16   17
     GMT   12   00   12   00   12   00
DCA  POP        40   50   20   70
     POFP  20   30   40   60
     MAX/MIN    60/  36   52/  31   54

JFK  POP        30   40   30   50
     POFP  30   40   50   80
     MAX/MIN    57/  31   50/  29   48
```

Figure VII-12. Example first matrix type MOS bulletin for two stations. (From NWS 1974i.)

MOS forecasts for several weather elements were issued in matrix form starting in 1974.

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[4] It was about this time that the 2-season stratification terminology was being changed from winter and summer to cool season and warm season. This change was spearheaded by Gary Carter, and he led the nationwide development of the cloud forecasting system.

In 1974, we switched from using the CDC 6600 to the IBM 360/195. As mentioned earlier, we had to convert our CDC 6600 processing system to the IBM. The next chapter summarizes the new system that was to last from 1974 until 2000.

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CHAPTER VIII

THE IBM 360/195 PROCESSING SYSTEM

The CDC 6600 had been used the entire time we had been implementing products up until 1974, and we had over time developed a fairly complete development system (Glahn 1973). About the time we got it completed, NOAA switched to an IBM 360/195 system,[1] so we had to convert our system. Although FORTRAN, which we used almost exclusively, largely works on any system, there are "extensions" in every system that may not be supported in another system. There are some rules that are not hard and fast in one compiler system, but may be in another.

Two primary concerns with the conversion were the input/output (IO) capabilities and our ID system for meteorological variables. The CDC 6600 was a 60-bit machine, and both we and NMC had some connections to octal and binary numbers. We had made use of NMC IO and packing and unpacking routines, and these were materially different on the two systems.

But the concepts we used for the CDC 6600 were used for the new system; there were certain functions that had to be performed and in generally the same order. The new system was documented in TDL office note TDL 74-14 (Glahn 1974), which became a living document. We continued our naming convention; main programs were named Myxx where "y" denoted the "family" of programs, and "xx" the specific function. The original programs and flow diagram were much like that for the old system shown in Fig. VI-1, and evolved as the system grew. What is shown here as Fig. VIII-1 is what it was in July 1983. The system developed in 1974 had major contributions by Frank Globokar, George Hollenbaugh, Al Forst, Don Foster, Fred Marshall, and myself. During its lifetime, there were contributions by many others including Gary Carter, Paul Dallavalle, and John Jensenius. Carter and Dallavalle contributed substantially and were each responsible when they were branch chiefs for major parts of the system. The description in this chapter summarizes what the system had grown into from the initial documentation in Glahn (1974).

From the diagram in Fig. VIII-1, it can be seen, on the left, that several data sources were accommodated; the actual archiving programs are not shown. The "local forecasts" and "NWS verification archive" were data associated with our evolving role in verification of the public and aviation products. We established a real-time archive of hourly data so that we would have data for many stations and not just a limited set we had previously bought from "Asheville." The M1xx series was for basic inventorying, summarizing, and merging data and files.

The workhorse in the M2xx series was M201. Its original purpose was to interpolate into the gridpoint data to get values at specific sites, usually stations, where we had predictand data. However, through its "option" routine, subroutines could be written to calculate almost any variable needed if the basic data were available. Many subroutines were written for M201.

The M5xx series was to deal with predictand data. Extensive error checking routines were written for the data from Asheville and our hourly archive.

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[1] NMC had been testing and using the IBM 360/195 since 1972 (Dallavalle 2020).

The M6xx series was for methods of relating predictands to predictors, but expanded a bit to include other programs that logically fell into this place in the data flow. The M600 regression and its sibling M602, written specifically for LAMP,[2] were used heavily because regression was our primary way of developing forecasting relationships. We also had logit programs M653 and M654. M660 for copying selected datasets became a favorite.

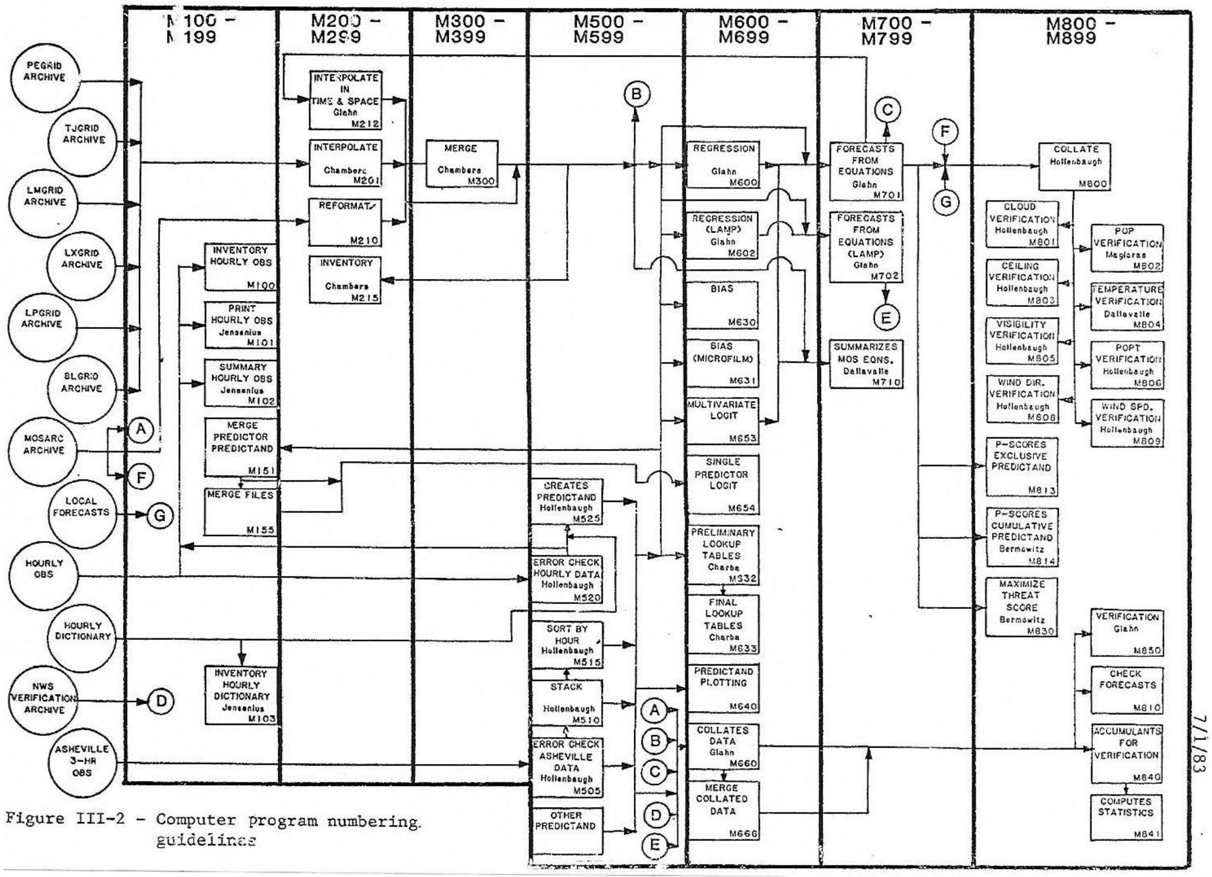

Figure VIII-1. Programs, data flow, and computer numbering guidelines in the IBM 360/195 development system. (Evolved from Glahn 1974.)

The M7xx series was for making forecasts from whatever relationships were established in the M6xx series. M701, and M702 for LAMP, would make forecasts from regression equations.

The M8xx series was for verification. A set of verification programs was put in place, each for either specific metrics (scores) or weather elements. For instance, wind was rather unique in its verification processing. Forecasts and verifying data could come from a variety of sources and could be merged by M800 in order to have matched samples. The diagram shows two alternate data flows to verification. The set in the upper part of M800-M899 is composed of individual programs for specific purposes that grew up as the need arose. The four at the bottom

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[2] LAMP is the Local AFOS MOS Program designed for short range forecasting. It was born in 1979, and was intended for implementation locally on the NWS processing system AFOS (Automation of Field Operations and Services). LAMP programs and archives were additions to the original conversion to the IBM 360/195 system and to the original TDL 74-14 office note.

resulted from consolidating the various functions into one program M850 with multiple capabilities; this capability was not there in 1974 and was written specifically for LAMP but could be used for other forecasts as well.

We established a software library MOSLIB. Each program or routine that had a separate writeup was given a number "MOS OP NO. xxx," where each new writeup number was sequential. "xxx" was the number by which the writeup was filed in a notebook. By 2000, this file had grown to MOS OP NO. 186 and filled three large 2½-inch notebooks (Glahn et al., eds. 1975). These were kept up to date, indexed both by MOS OP number and alphabetically, and tabbed by number. George Hollenbaugh was initially named the MOSLIB librarian. Authors of the write-ups include (in the order they first appear in the MOS OP numbered writeups) George W. Hollenbaugh, Harry R. Glahn, Al Forst, John E. Janowiak, Thomas D. Bethem, Donald S. Foster, Paul J. Banas, Frederick Marshall, Timothy L. Chambers, Frank T. Globokar, Gary M. Carter, Gordon Hammons, Joseph R. Bocchieri, David B. Gilhousen, J. Paul Dallavalle, Edward A. Zurndorfer, Robert J. Bermowitz, David P. Ruth, Thomas H. Grayson, Jerome P. Charba, Anna E. Booth, Frank Lewis, George J. Maglaras, Karl R. Hebenstreit, John S. Jensenius, Stephan M. Burnam, William K. Griner, David M. Garrison, Rob Washenko, Lawrence D. Burroughs, Herman Perrotti, Paul Osborne, James P. Stefokivich, Andrew L. Miller, Valery Dagostaro, Mary C. Murphy, David A. Unger, and Joseph M. Palko. These contributors included contractors, U.S. Air Force officers, and cooperative education students, as well as full-time government employees over the 25-year period of the system's use.

NMC members had designed a 12-word ID system for their gridpoint data, which we adopted. The data were 2-packed, that is two values in the 32-bit word, the first value in the leftmost 16 bits. The first value was the lower left gridpoint value, and scanning was then by column (upward) from left to right. Our archive was on tape, and as of 1983 was on 9-track tapes written at 6250 bpi density. The order of the fields on the tape, chronological by hour, was immaterial, but the order had to be maintained on that particular tape. For the PE model, the same four areas were archived at 1-Bedient (381-km) mesh length as in the CDC 6600 system (see Fig. VI-3 for a map), the areas being the CONUS, Alaska, Hawaii, and Puerto Rico. Consistency of archive of gridded model data was maintained as much as possible with our previous CDC 6600 archive.

Originally, there was a SUM archive, but it was dropped.[3] During the 1980's, archives were started for the LAMP model over the CONUS; the TDL Boundary Layer Model over the eastern CONUS; the Nested Grid Model (NGM) over the CONUS, Alaska, and Canada; and the Medium Range Forecast (PE/MRF) Model.

A format for predictand data, much like the one in the previous system, was established that maintained compact packing and allowed flexibility in the number and order of stations and the number of types of data. Optionally, packing information could be included, and special predictand tapes could be created with only a few predictands. Digitized radar data and severe storm reports were archived in predictand format. Much effort went into acquiring quality controlled observations. Errors could occur in NMC's handling of the reports, and we had limited insight into this process or when it was changed. Our quality control codes were quite complicated. Inconsistencies can occur within an observation (e.g., fog with large temperature-dew point

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[3] When the LFM became operational, it fulfilled the role that had been envisioned for SUM.

spread), from observation to observation (large temperature change), or between the synoptic observation and the hourly observation, and it is often not obvious whether or not there is an error, and if so which of the values is correct.

The IDs used for predictor data, data usually interpolated from the gridded archives, consisted of two words of octal digits and the projection. Because these records were vector (station-oriented) rather than gridded, information about location was needed that was not needed for gridded data. Such information was contained in seven header records. What followed could be packaged with a 12-word header followed by data, like the gridpoint data. This ID system was largely a holdover from the previous system, but an ID was now accommodated in two 32-bit words, rather than one 60-bit word (see Fig. VI-4).

The speed of IO functions is very important, especially in operational programs. When a search for the CDC 6600 replacement was underway, IBM created a set of reading and writing routines for random access files called FORTXDAM to be used with FORTRAN. The word on the street was that IBM put their best people on this and the resulting efficiency of FORTXDAM was in large measure the reason for the IBM 360/195 being selected. In any case, it was efficient and we used it to advantage. Eventually, we and NMC converted to another file system, VSAM.

Many of our MOS forecast equations had one or more observations as predictors. If the observation was missing when the job was run to make the forecasts, a backup equation was used that did not include the observation. Especially for the first few projection hours, the backup forecast was expected to be less accurate. In order to keep track of whether the primary or backup equation was used, we used the least significant bit in the floating point word to indicate the status. If bit number 31 was zero, the primary equation had been used; if the bit were “one,” the backup equation had been used. We could use this information when verifying forecasts and for transferring the information to the teletype bulletin used to provide the forecasts to the field forecasters.

Figure VIII-1 relates to development and testing and does not contain programs for making operational forecasts. However, such programs did exist, the primary one being M900, to mirror somewhat M700 used for making forecasts in the development system. The programs and data flow for the operational system is shown in Fig. VIII-2. The transition to M900 was gradual, as Frank Lewis and his branch had their own set of routines that they sometimes preferred to use.

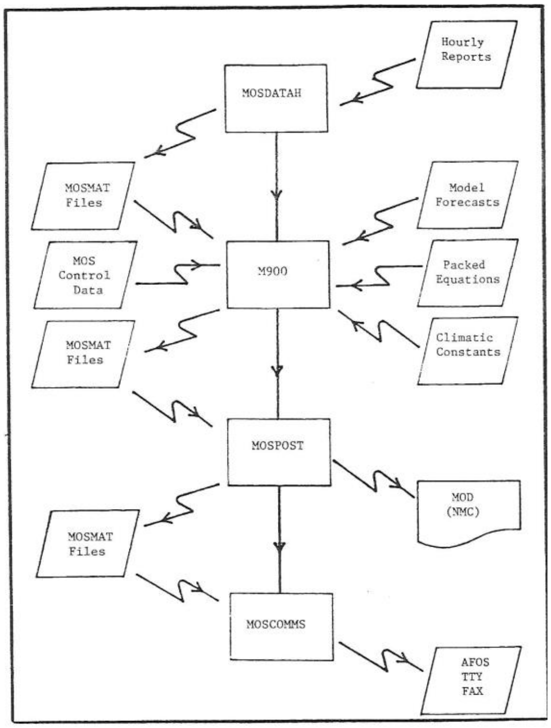

Figure VIII-2. Programs and data flow for making operational forecasts. (From Glahn 1974 as revised.)

Over the lifetime of a system such as described here, many changes occur, both because of increasing requirements for forecasts, and because of changing "system" software, which in our case included NMC routines and standards. The LAMP project was started after our IBM 360/195 system was designed. LAMP made forecasts each hour out to 20 hours, and we wanted them to be consistent in time. A specialized regression program, M602, was written to help assure this. One such "system" change was the change from FORTXDAM to VSAM files mentioned previously. FORTRAN itself has changed over time. In 1974 we were using FORTRAN66; around 1990, we switched to FORTRAN77. Also, the formats in which to disseminate the forecasts changed. The system was constantly monitored for its effectiveness.

We had established early-on that a value 9999 would represent a missing value and that 9997 would represent a probability forecast that could not be made and should be interpreted as zero. In packing and unpacking, these values might not be maintained exactly, so checking for them as exact values might not work. Frank Lewis[4] modified the NMC packers and unpackers to recognize these values and return them exactly. These new routines had to be inserted and used.

The CYBER 205 supercomputer was introduced around 1983, with CRAY machines replacing the CYBER in 1991. However, we continued to use the IBM 360/195 and the subsequent mainframes until about 1997 when they were removed. Operational codes had to be switched to the CRAY and substantial changes were necessary to file formats and their use to keep products flowing. Ironically, it was soon after that that the IBM supercomputer came in.

The ID structure we set up for variables was extended until it was bursting at the seams. The predictand matrix structure and naming convention differed from that of the predictors and had proved to be limiting. After about 20 years, it was obvious we needed a new system, and planning for it started in 1993.

The 1974 MOS system served us well for 25 years.

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[4] Memo from Thomas Bethem, who was at that time the MOS librarian, to all MOS users, dated December 1, 1980.

CHAPTER IX

EXPANSION OF THE CONUS MOS PRODUCTS

We were now in full swing using our IBM 360/195 software. Several persons had gotten familiar with our software system and data archives and could use them efficiently. Frank Lewis had effectively organized the implementation of TDL products going back to the PP temperatures with software he had built. He retired in 1975 and Tom Grayson became branch chief; the implementation was thereafter with the MOS system software. However, other regression programs existed in other TDL branches and not all specialized products used the documented system. I became director of TDL in 1976 after Bill Klein moved up to head the Systems Development Office[1], TDL's parent organization.

Gary Carter was a TDL branch chief and developed wind, cloud, and temperature forecast systems.

1975-1976 was also the period TDL headquarters was moved from the 12th floor of the Gramax Building at 8060 13th Street into a nondescript building at 7915 Eastern Ave. called the William Building about a block or two away. Space was needed in the Gramax building, and TDL was about the right size to alleviate the problem. TDL occupied portions of the 3rd and 5th floors. A line printer with a person to tear and file paper was provided. After about 2 years, the NOAA Library, which was largely the old Weather Bureau Library, moved from the 8th floor of the Gramax to NOAA headquarters in Rockville, Maryland. That freed up space for TDL to move back to the Gramax, this time to the 8th floor. The move back was in November 1976. It was mostly open space, so we could build a few walls. The TDL director's office was on the northwest corner, directly below where it had been on the 12th floor. One branch of TDL had been co-located with NMC in FOB4 in Suitland, Maryland. In late 1974, that branch and NMC moved to the new World Weather Building at 5200 Auth Rd. in Camp Springs, Maryland (Fig. IX-1).

Figure IX-1. World Weather Building at 5200 Auth Rd., Camp Springs, Md. (Picture from web, 2018.)

A new product was implemented on April 9, 1975, consisting of the probability of severe weather (tornado, hail, and/or damaging surface winds) in rectangles about 90 nm by 135 nm. It was issued three times per day based on data at 1500, 1800, and 2100 UTC. The forecasts were for 3-h valid periods starting 2 h after data time. For this specialized product, the predictand was based on severe weather reports. The predictors were instantaneous or 3-h tendencies of surface temperature, dew point, and wind components; SLP; and the 500-mb temperature from the LFM (Charba and Livingston 1973; Charba 1974).

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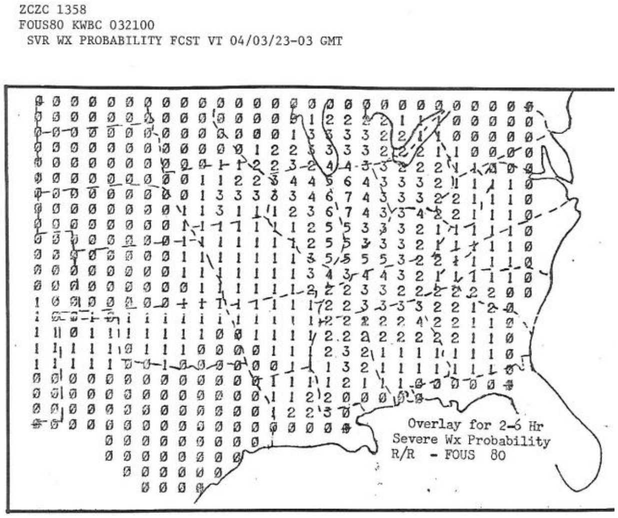
[1] At some point, the Systems Development Office became the Office of Systems Development.

The forecasts were available in a teletype request/reply bulletin. The values shown represented probabilities in tens of percent of the predictand at points on a map, the location of which could be determined by using a transparent map overlay (Fig. IX-2). This was a rather unique product, quoted from NWS (1975b):

> "Users should bear in mind that each number is associated with a rectangular area offset somewhat to the east (right of the page in Fig. IX-2). In other words, we have not provided for shifting the positions of the numbers so that they would be positioned at the centers of the imaginary boxes for which they are valid. On the other hand, we presume that field forecasters would rather displace the gridpoint values in a manner appropriate to each weather situation. For instance, the forecaster should apply a 4-h extrapolation based on past movements of important surface map features."

Jerome Charba specialized in convection, severe weather, lightning, and precipitation occurrence and amount products. He ended a 49-year career in TDL/MDL in 2021.

The PoP equations were updated for the summer season of 1975 by increasing the developmental sample from 3 to 4 years and revising the regions now numbering 26. Forecasts were made for 4 periods, namely projections 12-24, 24-36, 36-48, and 48-60 h. Predictors for the first two projections came from the PE and TJ models and the last two from only the PE (NWS 1975c).



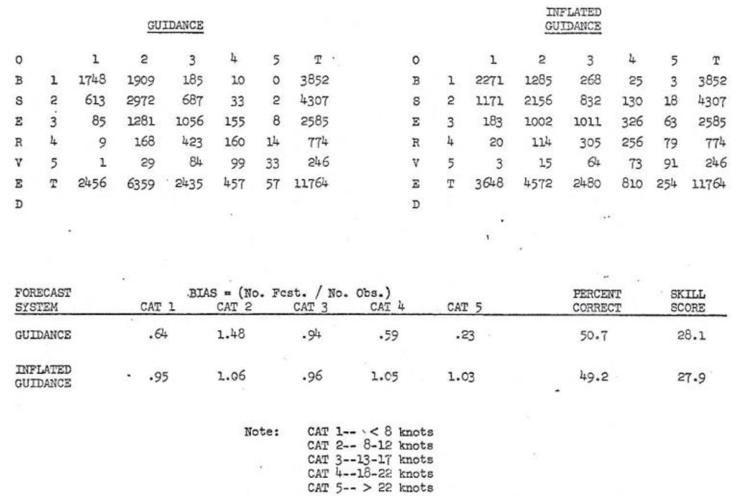
ZCZC 1358
FOUS80 KWBC 032100
SVR WX PROBABILITY FCST VT 04/03/23-03 GMT

Figure IX-2. Example request/reply teletype bulletin showing the probability of severe weather in tens of percent, with a map superimposed. (From NWS 1975b.)

The MOS warm season wind prediction system was improved and implemented in May 1975 (NWS 1975d). New predictors were added, and 5 seasons of data were used for development. The processing of the speed forecasts to produce more strong winds than came directly from the regression equations consisted of inflation only and not the process that had been used earlier and described in NWS (1973). The effects of this inflation can be seen in Fig. IX-3. The bias characteristics were much improved, although the percent correct and Heidke skill score were reduced a bit. The wind prediction system is fully explained in Carter (1975a). Verification of the 1973-74 wintertime forecasts is contained in Carter et al. (1974).

The severe weather probabilities and thunderstorm products described in an earlier chapter were revised to give much better resolution (NWS 1975e). The predictand was based on a new manually digitized radar (MDR) sample of data. The radar echoes were coded for boxes approximately 40-45 km on a side and covered the CONUS roughly east of the Rocky Mountains. Values > 3 were used as indicative of thunderstorms.

One equation was developed for the entire season and area. The severe weather equations were developed by considering both MDR data and severe storm reports. Given the occurrence of a thunderstorm (MDR > 3), the equations for severe thunderstorms predicted the conditional probability of tornadoes, hail, wind gusts, or radar-indicated severe convective cells. For severe weather, two equations, conditional on thunderstorms occurring, were developed, one for the spring (April-June) and one for the summer (July-September) seasons. The details of editing and archiving the MDR data are given in Foster and Reap (1973). Figure IX-4 is an example of the product.



GUIDANCE

		1	2	3	4	5	T
O							
B	1	1748	1909	185	10	0	3852
S	2	613	2972	687	33	2	4307
E	3	85	1281	1056	155	8	2585
R	4	9	168	423	160	14	774
V	5	1	29	84	99	33	246
E	T	2456	6359	2435	457	57	11764
D							

INFLATED GUIDANCE

		1	2	3	4	5	T
O							
B	1	2271	1285	268	25	3	3852
S	2	1171	2156	832	130	18	4307
E	3	183	1002	1011	326	63	2585
R	4	20	114	305	256	79	774
V	5	3	15	64	73	91	246
E	T	3648	4572	2480	810	254	11764
D							

FORECAST SYSTEM	BIAS = (No. Fcst. / No. Obs.) CAT 1	CAT 2	CAT 3	CAT 4	CAT 5	PERCENT CORRECT	SKILL SCORE
GUIDANCE	.64	1.48	.94	.59	.23	50.7	28.1
INFLATED GUIDANCE	.95	1.06	.96	1.05	1.03	49.2	27.9

Note: CAT 1-- < 8 knots
CAT 2-- 8-12 knots
CAT 3--13-17 knots
CAT 4--18-22 knots
CAT 5-- > 22 knots

Figure IX-3. Contingency tables for the 18-h projection for the regression and inflated regression forecasts of wind speed over the 1973-74 season. (From NWS 1975d.)

An entirely new type of product was implemented in June 1975 (NWS 1975f). It was a fax chart depicting three-category flight weather IFR, MVFR, and VFR (see Fig IX-5); surface wind; and cloud amount. Four panels were provided, one for each of the projections 12, 18, 24, and 30 h. This was a new depiction of cloud (NWS 1975a) and wind (NWS 1975d) described previously, and ceiling and visibility forecasts combined into three-category flight weather forecasts. An example fax chart is shown in Fig. IX-6.

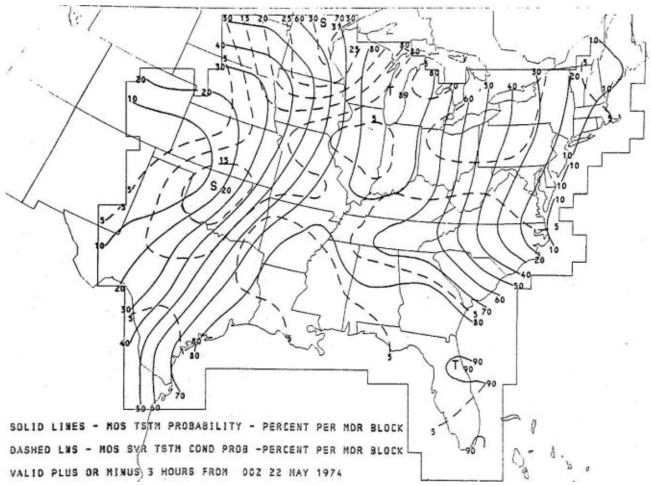
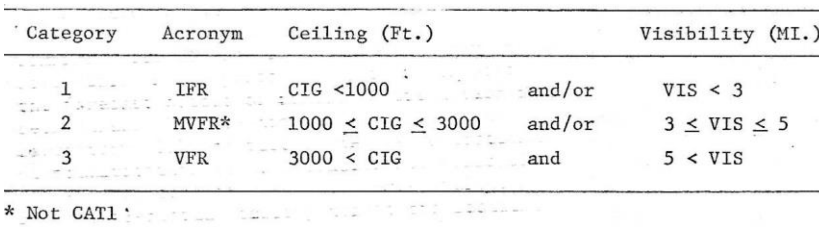


Figure IX-4. Example of 6-h probability of thunderstorms (solid) and conditional probability of severe thunderstorms (dashed). (From NWS 1975e.)

The reprogramming of SUM for the IBM 360/195 was completed by July 1975, and the new version put into operation (NWS 1975g). The SLP portion now ran at ¼ Bedient, the same as the original SAM; it had been degraded to ½ Bedient to run on the CDC 6600. This version was at ½ the mesh of the LFM. The initialization time was also changed to 0600 and 1800 UTC vice the previous times of 0700 and 1900 UTC. This was to assure the output was available for the Eastern Region forecast schedule (see Fig. VII-1).



Category	Acronym	Ceiling (Ft.)		Visibility (MI.)
1	IFR	CIG <1000	and/or	VIS < 3
2	MVFR*	1000 ≤ CIG ≤ 3000	and/or	3 ≤ VIS ≤ 5
3	VFR	3000 < CIG	and	5 < VIS

* Not CAT1

Figure IX-5. Definition of flight categories IFR, MVFR, and VFR. (From NWS 1975f.)

Frank Globokar, a U.S. Air Force officer stationed at TDL 1971-1975 developed aviation related products. He later was transferred to Offutt AFB, Nebraska, and led the development of a MOS system for the U.S. Air Force.

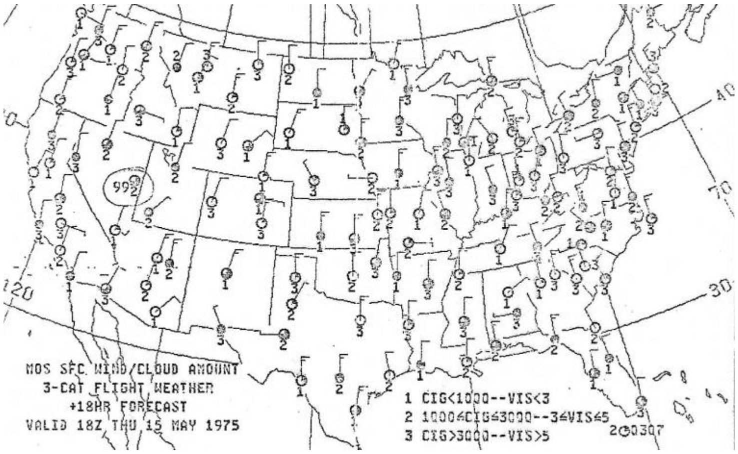


Figure IX-6. Example wind, cloud, and flight category map. Cloud and wind are plotted in the conventional manner and the flight category is under the station. (From NWS 1975f.)

NWS (1975h) announced that the max/min temperatures would now be based on 3-month equations rather than 6-month equations. Standard errors on development data were smaller, but it was noted testing on independent data had not been done. The summer equations for the months June-August became operational late in the period in 1975, but were followed each 3 months with the appropriate equations. The potential predictor set was modified, and a 25-point smoother was added to the PE and TJ model predictors; previously smoothing of predictors was limited to 5- and 9-point. Two harmonics of the day of the year, latest surface observations, and the appropriate observed max and min were also screened. NWS (1975i), NWS (1975l), and NWS (1975o) announced the implementation of the fall, winter, and spring equations for the months September-November, December-February, and March-May, respectively, on schedule. The revised system was fully explained in Hammons, et al. (1976).

New conditional probability of frozen precipitation (conditional on precipitation occurring), equations were developed and implemented for the 1975-76 winter season (NWS 1975j). The acronym was changed from PoF(P) to PoF. The development was done in a similar manner to that of the equations previously described. Predictors into the logit model were deviations from 50-percent values, also determined by the logit model; a few 50-percent values had to be estimated because the number of snow cases was too few to determine reliable 50-percent values with the logit model. The deviations from 50-percent values were used to allow for differences in predictor/predictand relationships over a region, largely due to elevation differences. A major change was the implementation of an "early guidance" package derived from the LFM as well as one from the PE, the standard package. The LFM PoF package was developed on 2 seasons of data, the PE package on 5 seasons of data. Also, the 50-percent values obtained with PE data were used without change for the LFM package. Teletype messages were available for both the LFM and PE systems, but only the PE had a facsimile package. See Bocchieri and Glahn (1976) for details.

An early guidance package based on the LFM was initiated, in addition to the standard PE-based package.

The TDL suite of products continued to grow. There were now two PoP systems, one based on only the LFM model (an early package) and one based on the PE and LFM models (NWS 1975k). The latest surface variables were now for the first time being used as predictors. Considerable testing of the LFM in this role had been done by Glahn and Bocchieri (1975). A total of 233 stations were used in the development, partitioned into 18 regions.[2] The regions were developed based on the relative frequency of measurable precipitation conditioned on the LFM forecasting $\geq$ 0.01 in of precipitation. The relative frequencies were averaged for the first 12-h period for both the 0000 and 1200 UTC initial data times. Fig IX-7 shows the relative frequency map subjectively analyzed from station values, and Fig. IX-8 shows the resulting regions subjectively determined.

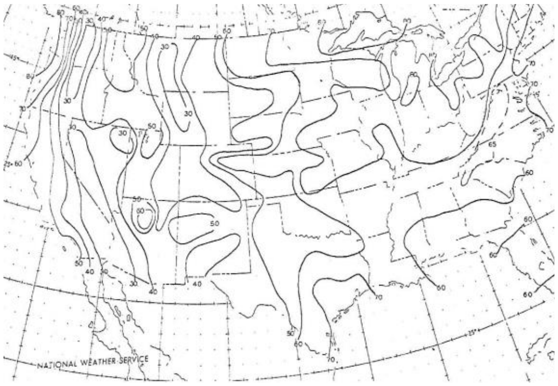


Figure IX-7. Relative frequencies of measurable precipitation when the LFM forecast $\geq$ 0.01 in precipitation in the 12-24 h period, averaged for the 0000 and 1200 UTC cycles. (From NWS 1975k.)

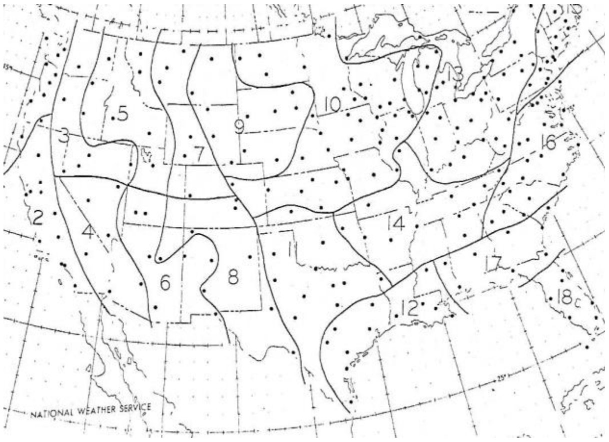


Figure IX-8. The 18 regions for developing PoP based on the conditional relative frequencies shown in Fig. IX-7. (From NWS 1975k.)

The MOS guidance had become well entrenched in the preparation of official forecasts by field forecasters, as well as being used by forecasting activities within NMC. NWS (1975m) announced a number of schedule changes and provided a good summary of the public-related (non-marine) weather elements being provided in the FOUS bulletins. To quote:

> "Presently, the FOUS12 bulletin contains (1) Probability of Precipitation (PoP) forecasts for 267 cities in the conterminous United States for four 12-hour periods, 12-24, 24-36, 36-48, and 48-60 hours; (2) Probability of Frozen Precipitation (PoF) forecasts for 234 cities for four specific projections 12, 24, 36, and 48 hours; and (3) calendar day maximum/minimum temperature forecasts for 228 cities valid approximately 24 hours after the initial cycle time, and every 12 hours thereafter out to 72 hours from 0000 GMT and out to 60 hours from 1200 GMT.
>
> "The FOUS22 bulletin contains cloud amount, surface wind, ceiling, and visibility forecasts for 233 stations in the conterminous United States. The estimates of cloud amount and surface wind are for projections 12, 18, 24, 30, 36, 42, and 48 h in advance of the 0000 GMT

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[2] We were calling this "generalized operator development within regions." Later we would call it "regional development."

and 1200 GMT forecast cycles. The ceiling and visibility forecasts only cover the projections out to 30 hours."

"The objective with regard to the use of forecast models in the future is to work towards a 12- to 48-hour LFM as the primary conterminous U.S. guidance model and the 8 Layer Global Model as the guidance model for the longer range and the larger area forecasts.

"With this as our goal, an "early" MOS guidance bulletin based on only the LFM model and (and the 0200 (1400) GMT observations) will be produced. We would like to include all the elements in one bulletin, like FOUS12, but it is not possible to generate the maximum/minimum temperature forecasts at the same time due to restraints imposed by the predictors used in the MOS equations. Therefore, two bulletins, FOUS12 and FOUS22 will have to be produced.

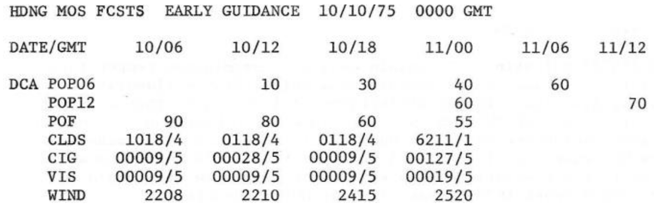
"The FOUS12 (FO12) bulletin will consist of forecasts of PoP, PoF, clouds, ceiling, visibility, and surface wind. The PoP and PoF forecasts will be for 6-hour and 12-hour periods for 267 and 234 cities respectively in the conterminous United States. Probability of precipitation (PoP) forecasts are for periods like 12-18 or 12-24 hours. PoP can be any one of the following values: 0, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100. Probability of frozen precipitation (PoF) forecasts are valid at specific times, that is at 6, 12, 18, etc. hours after data-time. PoF is expressed to the nearest percent.

"Cloud amount, ceiling, visibility, and surface wind forecasts are made for 6-hourly increments for 233 cities in the United States. The forecasts of cloud amount and surface wind go out to 48 hours. The forecasts of ceiling and visibility go out to 30 hours.

"There will be an EARLY and a FINAL FOUS12 bulletin. The EARLY FOUS12 bulletin will include only the LFM model output and the 0200 (1400) GMT surface observations. The bulletin should be available as soon as possible after the completion of the LFM run, certainly by 0400 (1600) GMT."

An example EARLY FOUS12 is shown in Fig. IX-9. Quoted from NWS (1975m):

"The FINAL FOUS12 bulletin will be based on forecasts from the LFM, Primitive Equation (PE) and Trajectory (TRAJ) models and the 0500 (1700) GMT surface observations. The bulletin should be available by 0600 (1800) GMT."



```
HDNG MOS FCSTS   EARLY GUIDANCE  10/10/75  0000 GMT

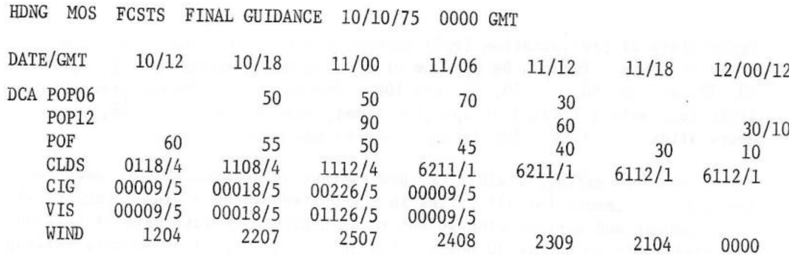
DATE/GMT      10/06      10/12      10/18      11/00      11/06    11/12

DCA POP06                   10         30         40         60
    POP12                                         60                  70
    POF          90         80         60         55
    CLDS     1018/4     0118/4     0118/4     6211/1
    CIG     00009/5    00028/5    00009/5    00127/5
    VIS     00009/5    00009/5    00009/5    00019/5
    WIND       2208       2210       2415       2520
```

Figure IX-9. Example early FOUS12 bulletin for a particular station. (From NWS 1975m.)

An example FINAL FOUS12 is in Fig. IX-10. The indicators for missing observations were discontinued. Additional details are in NWS (1975m).

The FOUS 22 contained only max/min temperature. The forecasts were for 228 cities in the CONUS. The 72-h forecasts at 0000 UTC continued to be based on the perfect prog equations, which were available for only 126 stations. There was an early and a final bulletin; both had the same format shown in Fig. IX-11. The early had predictors from the trajectory and PE model and was released at approximately 0500 UTC. The final FOUS22 had those predictors pus the latest surface observations and the last appropriate observed max or min temperature. The indicators for missing observations were not retained, but backup equations without observations were used when observations were missing.

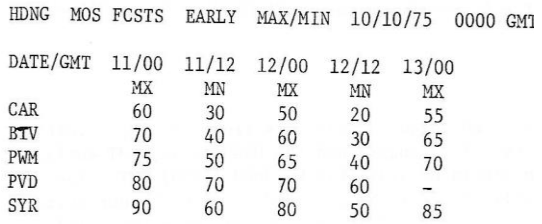


```
HDNG  MOS  FCSTS  FINAL GUIDANCE  10/10/75  0000 GMT

DATE/GMT    10/12     10/18     11/00     11/06     11/12     11/18     12/00/12

DCA POP06               50        50        70        30
    POP12                         90                  60
    POF        60       55        50        45        40                  30/10
    CLDS    0118/4    1108/4    1112/4    6211/1    6211/1      30        10
    CIG    00009/5   00018/5   00226/5   00009/5              6112/1    6112/1
    VIS    00009/5   00018/5   01126/5   00009/5
    WIND      1204      2207      2507      2408      2309      2104      0000
```

Figure IX-10. Example final FOUS12 bulletin for a particular station. (From NWS 1975m.)



```
HDNG  MOS FCSTS  EARLY  MAX/MIN  10/10/75  0000 GMT

DATE/GMT  11/00  11/12  12/00  12/12  13/00
            MX     MN     MX     MN     MX
CAR         60     30     50     20     55
BTV         70     40     60     30     65
PWM         75     50     65     40     70
PVD         80     70     70     60     -
SYR         90     60     80     50     85
```

Figure IX-11. Example FOUS 22 bulletin for the stations listed on the left. (From NWS 1975m.)

Considerable testing went into deciding what predictors should be used in the regression equations. For instance, Gilhousen (1976) and Glahn and Bocchieri (1976) conducted testing for forecasting PoP. The results were in some cases perplexing, perhaps indicating that small differences in P-score can be caused by factors impossible to control. It was determined that the first harmonic of the day of the year should be included. Gilhousen (op. cit.) showed that equations for the two 6-h periods contained within a 12-h period should use the same predictors as for the 12-h period for better consistency of the 6-h and 12-h PoPs.

Usually when a new product was implemented, we had evaluated it on “independent” data. If enough data were available, one season was held back from the developmental sample for this testing. If the new equations were only the result of adding one more season of data, testing on independent data was not really necessary and not always done. Many times, we verified the actual operational forecasts and put the results into a TDL office note. Examples of this documentation of our forecasts are in Carter (1975b), Carter and Hollenbaugh (1975), and Carter et al. (1975). This verification was done in collaboration with the Technical Procedures Branch of the Office of Meteorology and Oceanography. This branch was in charge of the NWS verification program, and furnished us the local forecasts. The NWS verification results are in a series of NOAA Technical Memoranda with a numbering system NWS FCST-xx; specific examples are Roberts et al. (1967) and Sadowski and Cobb (1973). (The numbering was slightly different before NOAA was formed.) Gerry Cobb spent many hours punching the local forecasts onto cards for machine processing. The NWS verification program was another activity Charlie Roberts strongly supported and evolved when he was Chief of the Technical Procedures Branch. Duane Cooley succeeded him in 1969 and continued the Technical Procedures Bulletins and the verification work.

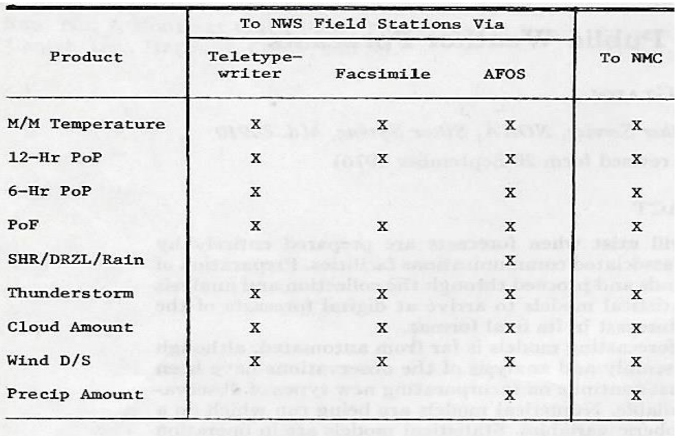
New cool season equations to predict wind were derived based on the LFM (NWS 1975n). Independent data testing was done for the 12- and 18-h forecasts for 20 widely distributed stations. It was found the LFM equations, even though developed on less data (2 seasons) than the

PE equations (3 seasons), were just slightly better that the PE-based equations. Forecasts from these equations became part of the early package discussed above. Warm season equations were implemented on schedule (NWS 1976d).

A quantitative precipitation forecast (QPF) system was devised. The development generally followed the pattern of development for other weather elements. The forecasts were for 6- and 12-h intervals for several projections for both the 0000 and 1200 UTC runs. In the REEP framework, the regression produced probability forecasts for categories ≥ 0.25, ≥ 0.5, ≥ 1.0, and ≥ 2.0 in. There was an early package based on the LFM and one available about 2 hours later based on the PE and TJ models. There was an "unconditional" and a "conditional" system developed. The first used all the cases in development, and the latter used only precipitation cases. The conditional system forecast the categories, given that precipitation would occur. The forecasts were provided to the Quantitative Precipitation Branch (QPB) of NMC and were compared to the QPB's forecasts. Development and verification details are contained in Bermowitz (1975) and Bermowitz and Zurndorfer (1975). Verification results on a very short 1-month sample were mixed. Generally, the subjective forecasts were better than the objective ones, but not always. Of special note, the LFM forecasts were better than both the objective and subjective forecasts.


Robert Bermowitz worked on SUM, the computer worded forecast, and precipitation and other forecast systems.

Initially to support the development of the computer worded forecast (Glahn 1979), which had been extended to three periods, systems were developed for both warm and cool seasons to forecast thunderstorms or severe weather and to forecast the type of liquid precipitation (drizzle, rain, or showers), conditioned on precipitation occurring (Carter 1974; 1975c). These were for projections 18, 30, and 42 h after 0000 UTC. The thunderstorm and severe weather forecasts extended in projection those described previously. These forecasts were not distributed to field forecasters at this time, but we expected they would be distributed over AFOS which was being developed.[3]



Product	To NWS Field Stations Via			To NMC
	Teletypewriter	Facsimile	AFOS	
M/M Temperature	X	X	X	X
12-Hr PoP	X	X	X	X
6-Hr PoP	X		X	X
PoF	X	X	X	X
SHR/DRZL/Rain			X	
Thunderstorm	X	X	X	X
Cloud Amount	X	X	X	X
Wind D/S	X	X	X	X
Precip Amount			X	X

Figure IX-12. Availability of MOS forecasts to NWS field stations and NMC. AFOS was not operational at this time, but expected. (From Glahn 1976, courtesy of AMS.)

The public weather forecasts being produced automatically by MOS were summarized by Glahn (1976). Figure IX-12 shows their availability to forecasters. This summary does not include aviation- or marine-specific products; the public weather forecasts were the ones that fed the computer worded forecast.

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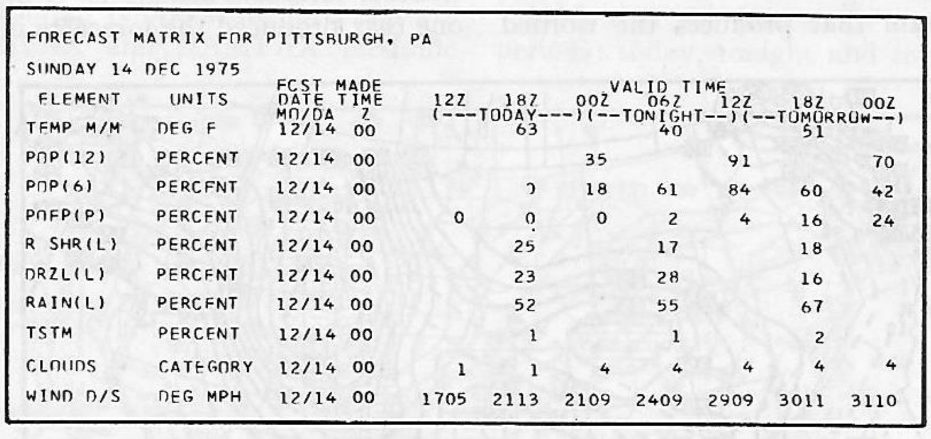
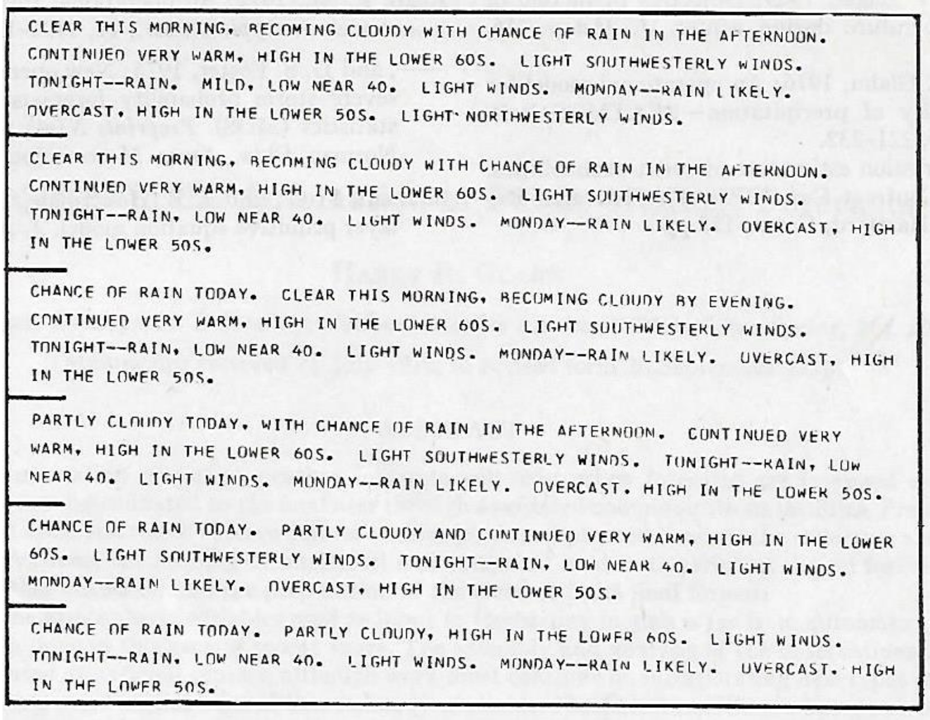
[3] AFOS (Automation of Field Operations and Services) was the first computer-based system that digitally linked together the NWS field components.

Fig. IX-13 shows a forecast matrix and Fig IX-14 shows the worded forecasts that were made from the forecasts in the matrix. The CWF software had controls on the degree of complexity one wanted in the worded forecast (Glahn 1978a, b).



```
FORECAST MATRIX FOR PITTSBURGH, PA
SUNDAY 14 DEC 1975
                        FCST MADE                      VALID TIME
 ELEMENT     UNITS      DATE TIME     12Z   18Z    00Z    06Z    12Z    18Z    00Z
                        MO/DA   Z    (---TODAY---)(--TONIGHT--)(--TOMORROW--)
TEMP M/M    DEG F       12/14  00           63            40             51
POP(12)     PERCENT     12/14  00                  35            91             70
POP(6)      PERCENT     12/14  00            0     18     61     84     60     42
POFP(P)     PERCENT     12/14  00       0    0      0      2      4     16     24
R SHR(L)    PERCENT     12/14  00           25            17             18
DRZL(L)     PERCENT     12/14  00           23            28             16
RAIN(L)     PERCENT     12/14  00           52            55             67
TSTM        PERCENT     12/14  00            1             1              2
CLOUDS      CATEGORY    12/14  00       1    1      4      4      4      4      4
WIND D/S    DEG MPH     12/14  00    1705  2113   2109   2409   2909   3011   3110
```

Figure IX-13. Forecasts from which the forecasts in Fig. IX-14 were produced. (From Glahn 1976, courtesy of AMS.)



```
CLEAR THIS MORNING, BECOMING CLOUDY WITH CHANCE OF RAIN IN THE AFTERNOON.
CONTINUED VERY WARM, HIGH IN THE LOWER 60S.  LIGHT SOUTHWESTERLY WINDS.
TONIGHT--RAIN.  MILD, LOW NEAR 40.  LIGHT WINDS.  MONDAY--RAIN LIKELY.
OVERCAST, HIGH IN THE LOWER 50S.  LIGHT NORTHWESTERLY WINDS.

CLEAR THIS MORNING, BECOMING CLOUDY WITH CHANCE OF RAIN IN THE AFTERNOON.
CONTINUED VERY WARM, HIGH IN THE LOWER 60S.  LIGHT SOUTHWESTERLY WINDS.
TONIGHT--RAIN, LOW NEAR 40.  LIGHT WINDS.  MONDAY--RAIN LIKELY.  OVERCAST, HIGH
IN THE LOWER 50S.

CHANCE OF RAIN TODAY.  CLEAR THIS MORNING, BECOMING CLOUDY BY EVENING.
CONTINUED VERY WARM, HIGH IN THE LOWER 60S.  LIGHT SOUTHWESTERLY WINDS.
TONIGHT--RAIN, LOW NEAR 40.  LIGHT WINDS.  MONDAY--RAIN LIKELY.  OVERCAST, HIGH
IN THE LOWER 50S.

PARTLY CLOUDY TODAY, WITH CHANCE OF RAIN IN THE AFTERNOON.  CONTINUED VERY
WARM, HIGH IN THE LOWER 60S.  LIGHT SOUTHWESTERLY WINDS.  TONIGHT--RAIN, LOW
NEAR 40.  LIGHT WINDS.  MONDAY--RAIN LIKELY.  OVERCAST. HIGH IN THE LOWER 50S.

CHANCE OF RAIN TODAY.  PARTLY CLOUDY AND CONTINUED VERY WARM, HIGH IN THE LOWER
60S.  LIGHT SOUTHWESTERLY WINDS.  TONIGHT--RAIN, LOW NEAR 40.  LIGHT WINDS.
MONDAY--RAIN LIKELY.  OVERCAST, HIGH IN THE LOWER 50S.

CHANCE OF RAIN TODAY.  PARTLY CLOUDY, HIGH IN THE LOWER 60S.  LIGHT WINDS.
TONIGHT--RAIN, LOW NEAR 40.  LIGHT WINDS.  MONDAY--RAIN LIKELY.  OVERCAST. HIGH
IN THE LOWER 50S.
```

Figure IX-14. Automated worded forecasts prepared from the information in Fig. IX-13 with different degrees of complexity. Maximum complexity is at the top and decreasing downward. (From Glahn 1976, courtesy of AMS.)

The equations for the thunderstorm and severe weather products that had been implemented for the spring and summer seasons described in NWS (1975e) were replaced by cool season equations valid January through March (NWS 1976a). The cool season equations were based on

162 days in 1974 and 1975. The number of individual predictor/predictand comparisons over the grid was about 120,000. Besides the fax graphic shown in Fig. IX-4, the forecasts were available by teletype. The probability values were printed such that a transparent map could be overlain to depict the approximately 40-km boxes to which the forecasts applied. Because of the area and the teletype message width, there were two messages, one for the eastern and one for the midwestern U.S. An example of the midwest bulletin with the map overlain is shown as Fig. IX-15. As can be deduced from Figs. IX-2 and IX-15, getting the forecasts to the forecasters was a challenge, and even these innovative products required map overlays for the forecaster to use (Reap 1977).

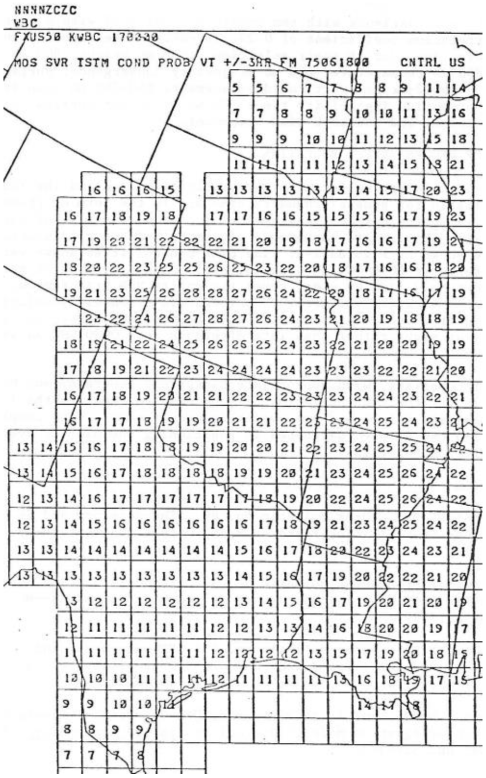


Figure IX-15. Sample teletype message for probability of thunderstorms with map overlay. (From NWS 1976a.)

A wind forecast system had been developed for east coast light stations at the request of the Director of the Eastern Region and implemented as described in NWS (1974). In a similar manner, the Director of the Western Region requested forecasts be made for stations along the west coast. Six coastal sites, shown in Fig. IX-16, were identified where suitable data existed. Wind forecast equations were developed in the usual manner, and the forecasts were put into a teletype message. Predictors were from the PE model. Forecasts were made at intervals of 6 h out to 42 h (NWS 1976b; Pore 1976).

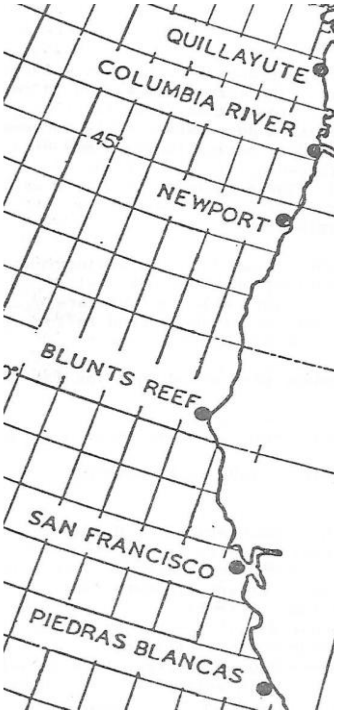


Fig. IX-16. The west coast points for which wind forecasts were made. (From NWS 1976b.)

The short-range severe weather product was updated with more recent data (NWS 1976c). The predictand was a bit more specific. The characteristics of the disseminated products were the same as before. However, a significant change in the interpretation of the probabilities was that they were representative of the points shown, and a spatial translation by the user was not necessary. In addition, the probability of general thunderstorms was added. The format of both the severe storms and general thunderstorm products continued to be as shown in Fig. IX-2 and were to be used with a clear plastic map overlay furnished by TDL. Equations were developed separately for the two areas shown in Fig. IX-17. Backup equations were used in case manually digitized radar (MDR) predictors were missing. Also, equations were developed for general thunderstorms. These products are described in Charba (1975, 1977a, b, c).

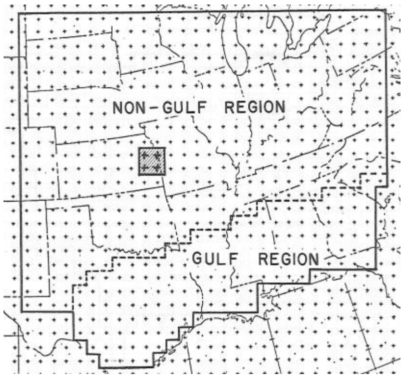


Figure IX-17. Areas over which the predictor-predictand relationships were developed for severe weather. (From NWS 1976c.)

The PoP equations for the early and standard guidance packages to be used for the warm season 1976 are discussed in NWS (1976e). Juggling among the various model inputs (LFM, PE, TJ) for the different projections (out to 60 h) and forecast coverage periods (6- and 12-h) to get the best quality was challenging. The forecast projections, periods, and models used are shown in Fig. IX-18. New regions were determined. New to the list of screened predictors was the relative frequency of ≥ .01 in of precipitation during a 12-h period averaged over the 6-month season at each station. This variable was included to introduce climatic differences between stations within regions. This predictor was important for the regions encompassing Florida, but was of little use elsewhere. Also for the first time, the surface observations at the forecast site were screened.

The cloud system was enhanced for the warm season. New was an early package based on the LFM. Three warm seasons of data were available for development. The predictors included observations taken 3 h after the LFM data input time. The predictand definition was also changed from total sky cover to opaque sky cover. So for this season, the definitions of sky were different between the early and standard guidance, as the standard guidance had not switched to opaque sky. Considerable testing was done to determine the best way to define a categorical forecast from the probabilities. It was determined that for the early package inflation of the forecasts and then choosing the highest probability gave reasonable skill and considerably better bias characteristics than choosing the highest probability without inflation. It was determined for the standard package that inflation without the minimum bias matrix that was currently being used was acceptable and the minimum bias matrix procedure was dropped. See Carter (1976a, b, c), Carter and Hebenstreit (1976), and NWS (1976f) for details.

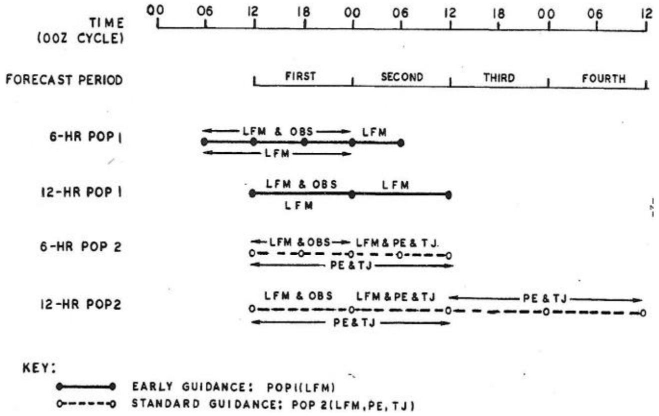


Figure IX-18. The forecast was valid for the interval between circles. The predictor types above (below) the line are for the primary (backup) equations. (From NWS 1976e.)

It was believed an early LFM-based max/min temperature package would be useful to the field, but we had not developed LFM-based equations. The PE and TJ based equations were tested with LFM and TJ predictors, where the TJ model had been run based on the LFM. It was determined the LFM-based guidance was slightly less accurate than the PE-based guidance, but the accuracy seemed to be high enough to warrant implementation, as max/min guidance would be available about an hour earlier than at present. However, forecasters were cautioned (NWS 1976g):

> "We believe that the field forecasters should monitor the product closely. While there will be only small differences in most cases between the early and final guidance, there may be certain times when the discrepancies are quite large. With careful study, forecasters may be able to determine certain synoptic situations when either the early or the final guidance will be the superior products. We also advise forecasters in the western United States to use the early guidance with a great deal of caution since LFM input to the PE equations caused the greatest degradation in the West."

New LFM-based PoF equations were derived in a similar manner to previous derivations. The major difference from the previous LFM-based system was that 50-percent values for the predictors were derived from the LFM, whereas previously the PE-based 50-percent values were used for the LFM. There were significance differences in the two sets of 50-percent values, so it was thought the forecasts would be improved. No testing on independent data was reported (NWS 1976h). The equations were implemented for the 1976-77 season.

By 1976, 4 years after the first CONUS MOS product, MOS forecasts for more than a dozen weather elements were being provided to field forecasters twice per day, most of them with both early and final packages (Klein and Glahn 1974; Glahn 1976).

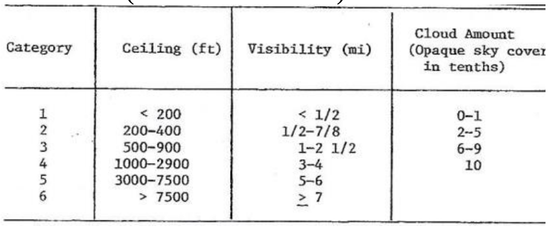
New PoP equations were developed for both the early LFM-based package (PoP1) and the final (PoP2) package based on the LFM, PE, and TJ models. The number of regions was increased to 26 and new predictors were screened. The new predictors, LFM upper-level wind components and boundary layer moisture convergence, were frequently selected by screening. According to NWS (1976i), this makes the PoPs ". . . less exclusively moisture based and more consistent with upper-level wind forecasts." The regions were based on two analyses. One was based on the relative frequency of precipitation of ≥ 0.01 in. in a 12-h period when the LFM 18-h mean relative humidity forecast was ≥ 65%. The other was based on the same relative frequency when the 12-h LFM precipitation amount between 12 and 24 h was ≥ 0.01 in. The 12-h period PoPs were derived simultaneously with the two imbedded 6-h PoPs to help assure consistency. Four seasons of data were available for both the LFM- and PE-based systems. The same operational structure as shown in Fig. IX-18 was used for the 1976-77 cool season.


William Richardson, a marine specialist, developed wind, wave, erosion, and storm surge products.

A new product that qualitatively forecast beach erosion (Richardson 1978) was made available on request/reply on a trial basis (NWS 1976j). Forecasts were made for the coasts of Maine through Virginia. Beginning with March 1962 and continuing through April 1973, all winter *Storm Data* volumes were scanned for mention of beach erosion or wave damage along those coasts. The erosion was given an intensity value of 1 through 4 according to the categorization of erosion as minor, moderate, major, or severe, respectively. The predictors of this erosion scale for the regression analysis were the maximum observed tide height, maximum storm surge height, and storm duration. The PP forecasts were in terms of none, minor, moderate, major, or severe.

Procedures for producing ceiling, visibility, and cloud amount forecasts were revised, and an early, LFM-based system was developed for those elements for the first time. The final product was also updated. The number of categories of ceiling and visibility was increased from five to six; the number of categories of cloud amount remained four. The ceiling and visibility categories were coordinated with the four CONUS regions. These categories are shown in Table IX-1 (see NWS 1977a). Initial implementation was for the cool season; the warm season system followed (NWS 1977e). Twenty-one regions were defined encompassing 233 CONUS stations based initially on similar relative frequencies of ceilings below 500 ft. and below 2000 ft., conditioned on the LFM boundary layer relative humidity of ≥90%. These were then adjusted based on cloud frequencies, topography, and synoptic climatology. The regions are shown in Fig. IX 19. Forecasts were valid every 6 h out to 48 h. Ceiling and cloud equations were derived simultaneously. For all projections and cycles, backup equations were derived without surface observations as predictors.

Table IX-1. Categories used for ceiling, visibility and cloud. (From NWS 1977a.)



Category	Ceiling (ft)	Visibility (mi)	Cloud Amount (Opaque sky cover in tenths)
1	< 200	< 1/2	0-1
2	200-400	1/2-7/8	2-5
3	500-900	1-2 1/2	6-9
4	1000-2900	3-4	10
5	3000-7500	5-6	
6	> 7500	≥ 7	

The equations gave probability forecasts, and categorical forecasts were made from them. For cloud amount, the first step was to sum the probabilities of the first two categories and to sum the probabilities of the last two categories. The two categories with the smallest sum were eliminated for becoming the categorical forecast. The probabilities of each of the remaining pair of forecasts were adjusted by an enhanced inflation technique. In addition to dividing the departure of the forecast from the dependent sample mean by the correlation coefficient, that value was multiplied by a factor F before adding the result to the dependent sample mean. The factor F ranged from 1 for a 6-h forecast to 2 for a 48-h forecast. The member of the pair with the largest enhanced probability was chosen as the categorical forecast. This method is fully explained in NWS (1977a) and departed from that reported by Carter and Glahn (1976).

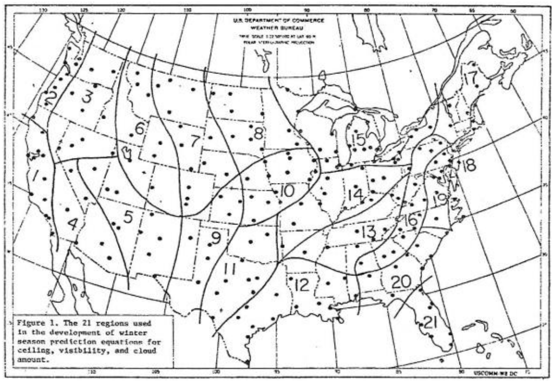


Fig. IX-19. The 21 regions used for developing cool season prediction equations for ceiling, visibility, and cloud amount. (From NWS 1977a.)

The categorical ceiling and visibility forecasts were found by a variation of thresholding, explained in some detail in NWS (1977a). Basically, a threshold was subjectively determined for each category, for each projection and for both cycles. We wanted to make categorical forecasts that had about the same bias as the forecaster-produced ones. Starting at the lowest category, when the threshold was tripped, that became the forecast. This was more effective in producing forecasts for the lower categories than the NWS scoring matrix used previously.

Three flight categories were defined from the ceiling and visibility categories rather than having separate equations for flight categories as had been done before. This supported the weather charts described above (see Fig. IX-6).

By 1976, we had collected enough PE data for the longer ranges to develop 72-h max/min temperature equations. Heretofore, the 72-h forecasts had been PP. We had 4 years of data for 226 stations, about double the number of stations for which we had PP forecasts. For testing, we developed on 3 years of data for 49 stations and tested on one year of data. Surprisingly, the MAE for PP was 0.01°F lower than MOS. The development was done on 3-month seasons, and this testing indicated a marginal sample size for single-station equations. However, the PP forecasts were not pure PP at that point, as the previous cycle MOS was used as input, as it was in operations, instead of the previously forecast PP temperature.

We felt the increase in number of stations compensated for the possibly slight decrease in accuracy and implemented in December 1976. See Dallavalle and Hammons (1977) for more details. These forecasts were later extended to include the summer and fall seasons (Dallavalle 1977).

Most MOS forecasts were made for approximately 230 cities scattered over the United States. Some organizations had a specific need for more spatially detailed forecasts. One such organization was the Bonneville Power Administration (BPA), who funded TDL to develop a system to forecast PoP, PoPA, (probability of precipitation amount) and max/min temperature for as many sites as possible over the Columbia River basin (Bermowitz et al. 1976a).

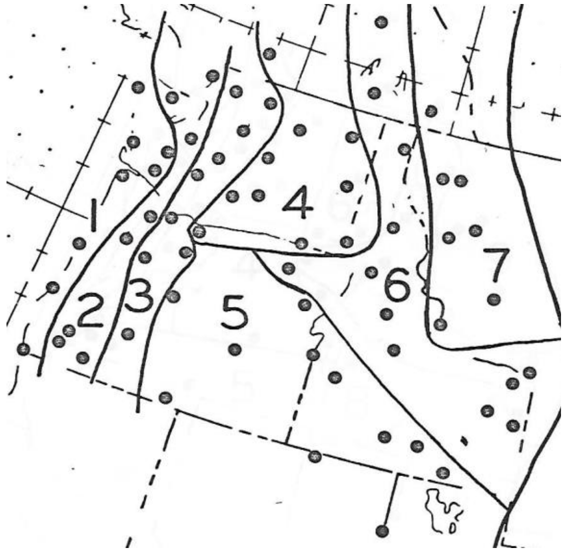


Fig. IX-20. Stations and regions for PoPA for the Columbia River basin in support of the Bonneville Power Administration. (From Bermowitz et al. 1976a.) A similar set was used for PoP.

TDL acquired warm season max/min temperatures and 24-h amount of precipitation data from the National Climatic Data Center in Asheville, North Carolina, for 77 stations over a 5-year period. Unfortunately, these observations, mainly from climatological sites, lacked uniformity in reporting times, so 70 stations were used for temperature and 65 stations were used for PoP and PoPA. Single-station regression equations were developed for max/min temperature and regional equations were developed for PoP and PoPA for the regions shown in Fig. IX-20. Projections for PoP and PoPA were for 24-h periods out to 96 h after 0000 UTC and out to 60 h after 1200 UTC. The temperature predictions were for similar projections. Predictors came predominately from the PE and TJ models. Forecasts from these equations were transmitted to the Portland office of the BPA via a Bureau of Reclamation computer in Denver. These forecasts were to be used for improved streamflow forecasts and, therefore, improved scheduling of power.

A similar system was developed for the cool season (Bermowitz et al. 1976b). The next year, the warm season equations were updated with an additional season of data, and at the request of BPA we increased the forecast sites to 93 for both temperature and precipitation. Twenty-six Canadian stations in the Columbia River drainage basin were now included. The equations were updated in 1979 with 2 more years of data and forecasts were produced for an additional 20 stations (Bermowitz et al 1977a, b). Later in 1981, equations were again updated and LFM predictors included. Finally, 20 more stations were added (Dallavalle and Bermowitz 1981). At that time, MOS temperature forecasts were made for several levels in the atmosphere and for specific times of the day. Also, several changes were made in transmission of the messages at the request of BPA. These messages were transmitted until the IBM-type mainframes were turned off in the summer of 1997.

Our BPA work culminated in a final Phase V report by Dallavalle and Bermowitz (1981). In all, surface forecasts were made for 114 stations. We also made forecasts at various levels above the surface based on data at the 10 radiosonde stations in the area. Transmissions were to the Portland office of BPA via the Department of Interior computer in Denver. At BPA's request, and with their funding, we also formulated other specialized bulletins with hourly observations.

At the request of the NWS Eastern Region, PP equations were developed for forecasting storm surge at Essexville and Lakeport, Michigan. In operations, the LFM sea level pressure forecasts were the predictors. The forecasts were disseminated by adding them to the Lake Erie storm surge teletype bulletin (NWS 1977b).

In a similar manner to the wind wave forecasts developed for the Atlantic and Pacific oceans in 1968 described in Chapter IV, wind wave forecasts were developed and implemented for the Gulf of Mexico. Here, as described by NWS (1977c), the input was the LFM rather than the PE model. The method of computing the wave forecasts is given by Pore (1977).

In the early (LFM) package, the wind forecasts were extended to 30 and 36 h (NWS 1977d). The process was essentially the same as that explained previously for the earlier projections. A backup set of equations was developed based on the PE model. The speed forecasts were inflated to get more strong winds.

Most of TDL's products were CONUS-wide once the MOS method was demonstrated. However, as a joint project with the NWS Western Region, Carter and Jensenius (1977) developed and implemented a system to forecast the rate of pan evaporation (RPE) at 66 stations in the Western Region. Developmental data were available for 4 years, July through October, 1973-1976. Predictors were from the PE, LFM, and TJ models. The cosine of the day of the year and twice the day of the year were also made available for screening.

Interestingly, the cosine of the day of the year was overwhelmingly the best singular predictor of the RPE, probably because this variable is (inversely) highly correlated with the amount of incoming solar radiation during this July to October period. Teletype bulletins of the forecasts were transmitted over the RAWARC circuit.


John Jensenius lecturing at the WMO Training Workshop in Wageningen, The Netherlands, 1991. He was TDL section chief and developed grid binary predictors and numerous forecast products.

NWS Western Region forecasters criticized the forecasts for being too highly determined by climatology and seldom predicted rapid changes in the RPE. Several things were tried to improve these characteristics, including inflation of the regression forecasts, adding the previous RPE (persistence), and leaving out the climatic variables. Little improvement was achieved, but new equations based on 5 years of data were the basis of continuing teletype messages for the 30 stations (Jensenius and Carter 1978a).

Another joint project with the Western Region was predicting convective gust potential (CGP) at each of 10 stations (Carter and Grayson 1977). The predictand was the occurrence of a surface wind gust of ≥25 kt within ± 4 h of 0000 UTC. Two sets of single-station regression equations were developed, one set with only LFM predictors from the 1200 UTC run (MOS PROB) and one with surface and upper air observed predictors as well as LFM forecasts (MOS-RS-OBS). The surface predictors were observed at 1500 UTC and the upper air at 1200 UTC. All equations contained seven or eight terms. The reductions of variance for this fairly rare event ranged from about 20 to 35%.

Forecasts from the MOS PROB equations were sent to the stations by teletype. Partial MOS-RS-OBS forecasts were also sent that contained contributions from only the LFM. The forecasters were provided the equations, and they could use the partial forecasts and complete the forecasts with the observed data when they became available.

With the aim of assisting the NWS in forecasting for agricultural purposes in Indiana and Michigan, TDL developed forecasting systems for probability of ground condensation (GC) in three categories (light, moderate, and heavy of either dew or frost) and for Michigan the conditional probability of frost given that GC occurs (Jensenius and Carter 1978b). These forecasts were available for 27 sites in Michigan and 19 in Indiana as shown in Fig. IX-21. Predictors were from the PE model. The primary ones chosen by the screening regression were relative humidity, wind speed, geopotential layer thickness, and climatological factors. Verification by the P-score on independent data indicated the forecasts were better than climatological forecasts. These forecasts were part of a specialized package that included objective forecasts of several other agricultural weather elements (Jensenius et al. 1978).

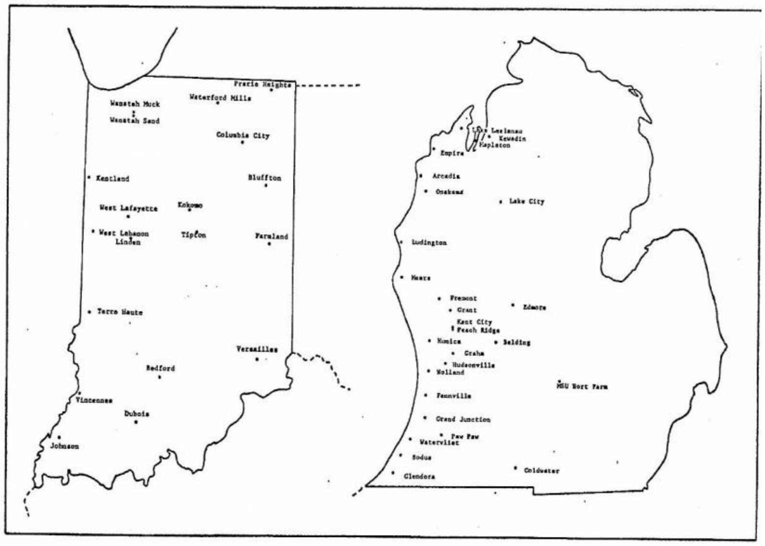


Fig. IX-21. Sites in Indiana and Michigan for which a specialized agricultural package was provided. (From Jensenius and Carter 1978b.)

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CHAPTER X

MOS GOES ALASKA

Our concentration in the first few years of MOS development, after initially proving the concept with SAM, was to produce forecasts for several weather elements for stations in the CONUS, and to provide both early and final guidance packages, the early being based on the LFM and the final being based primarily on the PE model. For some weather elements, the trajectory model was used and sometimes the LFM was also used in the final package.

The Alaska Region was anxious to have temperature guidance for Alaskan sites, and Dick Hanas from Alaska came and worked with TDL to develop and implement max/min temperatures for Alaska (Hanas 1975). The process was the same as for the CONUS, and forecasts based on the PE model were produced for 14 stations for four periods, approximately 24, 36, 48, and 60 h after the initial times of 0000 and 1200 UTC. The forecast equations contained 10 terms and were developed on the same warm and cool seasons as the CONUS products (warm = April-September). These forecasts were made and transmitted to Alaska starting in January 1975. This implementation included a special communication arrangement with the Alaskan Region and did not go through CAFTI; there is no TPB regarding it.

J. Paul Dallavalle was a TDL branch chief and a prime developer of our MOS systems and their documentation. He also developed temperature and precipitation forecast products.

In April 1977, surface wind forecasts for the same 14 stations were added to the Alaska max/min FMAK 1 bulletin (NWS 1977a). In contrast to the temperature equations, the wind equations were based on 3-month seasons (spring = March-May; summer = June-August; fall = September-November; winter = December-February). The forecasts were for the two earth-oriented wind components and wind speed. The equations were developed simultaneously, so the same predictors were in each equation for a particular station and projection. Most equations contained 12 terms; the criterion for predictor selection was RV > .0075 for at least one of the predictands. They were based on data from 1969 through 1976. The speed forecasts were adjusted by inflation, following the procedure used in the CONUS. Forecasts were for projections each 6 h from 12 through 48 h. For three of the seasons, four stations were comparatively verified with the official NWS forecasts for MOS projections 18, 36, and 48 h (see Carter 1976; 1977a, b, c). The guidance forecasts were not available to the forecasters for the test, but more recent data were available to them than went into the MOS equations. In general, the official forecasts were more accurate at 18 h, but MOS was more accurate at 36 and 48 h.

Our first MOS forecasts for Alaska were made in 1975.

The 2-6 h severe weather product, the probability forecasts of tornadoes, large hail, and damaging surface winds, in operation over the CONUS since 1974 was updated for the 1977 convective season. In addition, forecasts of general thunderstorms were made and disseminated

(NWS 1977b). These forecasts were transmitted four times per day, namely from data at 1500, 1800, 2100, and 0000 UTC. General thunderstorms were defined as the occurrence of an MDR value $\geq$ 4 in an MDR-sized box (40-45 mi square) in a 4-h period. Four such boxes exactly fit within a severe weather predictand box. Note that the convective weather predictands were tied to the MDR grid being used. Many predictors to be screened were defined from LFM forecasts and surface observations, some of them "interactive," that is, the predictor was composed of a combination of other predictors, usually a nonlinear combination that was thought to have a linear relationship to the predictand. Further explanation of the developmental process is in Charba (1977a), and Charba and Burnham (1978a, b; 1979) provide verification of the forecasts. The system as it was in operation in the 1977 convective season is described in Charba (1977b).

TPB 194 (NWS 1977b) referenced above was superseded by TPB 228 (NWS 1978c). In addition to the probability of general thunderstorms in an MDR-sized box, probabilities of severe weather in an area the size of four MDR boxes were provided. The forecast area (grid) was expanded slightly, and meaningful predictors were devised. The forecasts were still transmitted as a grid of single-digit numbers representing tens of percent (see Chapter IX), and plastic overlays were necessary to supply the geography, one for thunderstorms and one for severe weather. These numbers on the grid represented the forecasts for the locations of the displayed values.

For the 1977 summer season, the PoP equations for the final package were rederived for projections longer than 36 h. All other equations were unchanged and dissemination of products remained the same (NWS 1977c**;** Gilhousen 1976).

In response to a longstanding request, TDL developed for the first time 72-h PP minimum temperature equations from the 1200 UTC model run time. Although not explicit in TPB 198 (NWS 1977d), undoubtedly the reason for using PP rather than MOS was due to not having archived model data far enough in advance for MOS to be the best option. In operations, predictors came from the 60-h PE forecasts from 1200 UTC, and the MOS surface temperature forecasts valid approximately 60 h after 1200 UTC. The product was really a combination of MOS and PP, and the forecasts were inserted into the existing MOS bulletin. The new forecasts were implemented in May 1977. The PP system was still being run for the original 126 stations.

Several changes were introduced into the development of thunderstorm and severe weather probabilities. The editors of the TPB series had introduced the policy of fully explaining the product to which a TPB referred, and not just describing the changes. Therefore, NWS (1977e) rendered TPB 89, TPB 92, and TPB 138 obsolete. These older TPBs can be consulted for details not repeated here. The changes included using:

1) an interactive severe local storm predictor which incorporated severe local storm relative frequencies computed from a 7-year sample,
2) an interactive thunderstorm predictor which incorporated mean daily thunderstorm relative frequencies obtained from radar data,
3) a separate forecast equation to give conditional probabilities for major or family tornado outbreaks, and
4) the development of a statistical relationship for each grid block based on the interactive thunderstorm predictor.

The first two had a dual role: to simulate *seasonal* variation in thunderstorm and severe local storm occurrence and to modulate the climatology by the daily synoptic situation. The last two were incorporated into the generalized thunderstorm equation to take into account *local* variation in thunderstorm occurrence. The definition of a major tornado outbreak was seven or more tornadoes within a 5 x 5 array surrounding any MDR grid block with a thunderstorm (MDR code value of ≥ 4). A longer sample of data was used, and the changes were implemented in April 1977. The development of the equations and evaluation of the major tornado outbreak forecasts are given by Reap and Foster (1977), and verification is contained in Foster and Reap (1978).

The bulletin for Alaska that contained max/min temperatures and wind was expanded to include 6- and 12-h PoP (NWS 1977f; Gilhousen 1977a, b) in June 1977. The forecasts were for the same 14 stations (see Fig. X-1). The 6-h PoPs were for 12-18, 18-24, 24-30, and 30-36 h periods for both the 0000 and 1200 UTC cycles. The 12-h periods were 12-24, 24-36, 36-48, and 48-60 h. The values in the bulletins could be any one of the values 0, 2, 5, 10, 20, 30, . . . 90, and 100. The usual REEP screening regression approach was used.

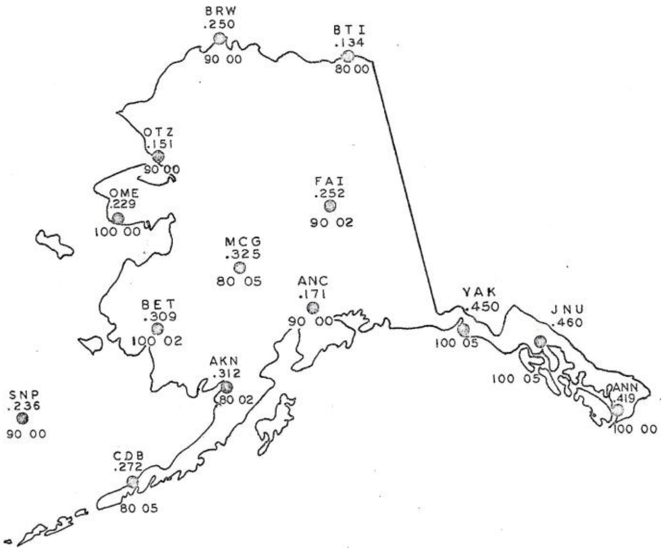
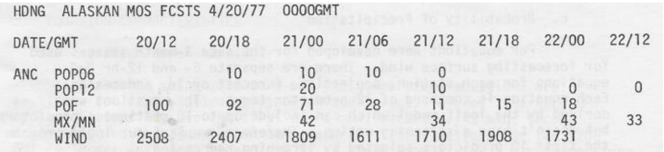


Figure X-1. The 14 stations in Alaska for which forecasts were made. (From Gilhousen 1977a.)

Not long thereafter, about September 1977, forecasts of the probability of frozen precipitation (PoF) were added to the bulletin. This, too, was done in the same way as for the CONUS. The logit model was used in a two-step procedure. For each station, the 850-mb height was found that gave a 50-50 chance of frozen precipitation when precipitation occurred—the so-called 50-percent values. The deviations from these 50-percent values became 850-mb predictors. The 14 stations were divided into three regions for the final logistic regression. The 50-percent values give station-specific information within the regions. A sample FMAK 1 bulletin, for one station, is shown in Fig. X-2 (NWS 1977h). Consult Gilhousen (1977c) for further details.



```
HDNG  ALASKAN MOS FCSTS 4/20/77  0000GMT

DATE/GMT       20/12    20/18    21/00   21/06   21/12   21/18   22/00   22/12

ANC  POP06                10       10      10      0
     POP12                         20              10              0       0
     POF        100       92       71      28      11      15      18
     MX/MN                         42              34              43      33
     WIND      2508     2407     1809    1611    1710    1908    1731
```

Figure X-2. An example FMAK 1 bulletin for Anchorage. (From NWS 1977h.)

A new product for the CONUS, that of heavy snow, was developed and implemented in October 1977 (NWS 1977i; Bocchieri 1977, 1979c). Heavy snow was defined as ≥ 4 inches at a station in a 12-h period. Both conditional (conditional on ≥ 0.1 in of snow or sleet) and unconditional probability forecasts were made for the 12-24 h period following the 0000 and 1200 UTC cycles of the LFM, on which the forecasts were based. Because of the rarity of heavy snow, the development was over rather large regions determined by relative frequencies conditioned on LFM forecasts. The odd-shaped regions are shown in Fig. X-3. In addition to the probability forecasts, a threshold developed for each region and cycle was used to make categorical yes/no forecasts. The thresholds were determined by choosing the one that gave the highest threat score on the developmental sample within a bias range of 1.0 to 1.5. Verification for the 1977-78 season was provided by Bocchieri (1978c).

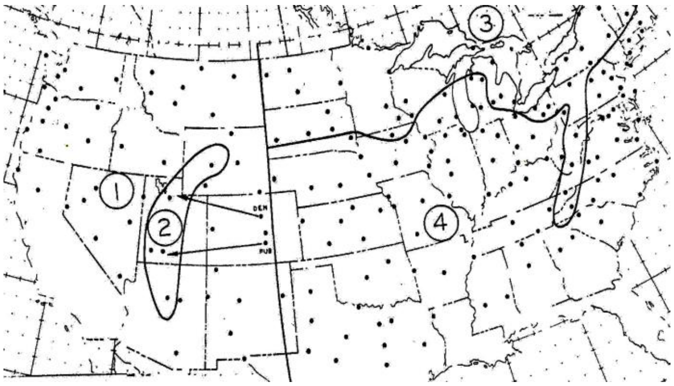


Figure X-3. The four regions used for heavy snow and the stations used in defining them. (From NWS 1977i.)

Forecasting heavy snow was the first use of maximizing the threat score to choose thresholds.

The threat score was devised by Palmer and Allen (1949) to compute the fraction of correct forecasts of an event when there was a "threat" of the event, threat being defined as those cases in the sample when there was either a forecast of the event or it occurred. It was devised for quantitative precipitation, but could be used on other threatening events.[1] The software that was in use at the time iterated through the sample of forecasts and verifying observations, computing the threat score for a series of thresholds. Besides the output of the computed threat scores as a function of the threshold, the bias was provided. The developer would scan the printout and pick the desired threshold, considering both the threat scores and the biases. It was thought the bias should not depart too far from unity. This process had to be done for each season, each projection, each region, and each category of precipitation (or, for instance, ceiling height), so the time consumed could be considerable. This prompted Bob Miller, Bob Bermowitz, Larry Best and others to try to find a less labor-intensive way to arrive at the thresholds.

Miller and Best (1978) looked at various statistical models and proposed computing a threshold that depended on the relative frequency of the event (its climatology) "C," the correlation coefficient "R" of the regression equation predicting the event, and a factor "F" that could be adjusted according to "the desired verification effect." They statistically derived F to be 0.698 to maximize the threat score based on threat scores for precipitation cases provided by Bermowitz. They tested the method on categories of visibility and sky cover. For visibility, the threat event was visibility < 6 mi which had a C of 0.20. These equations were generalized over all of Alaska. Their method worked well for this category. No evidence was presented on testing for the rarer and more important categories of 3 miles, or of 1 mile.

For sky cover, the "threat" event was "clear," and the equations were single-station for the 14 stations in Alaska. Therefore, the results presented are an amalgamation for the 14 stations. Some results were unexpected, which led to a more in-depth study, with the conclusion that the empirical value of F of 0.698 might not be best for this sample of data.

---

[1] Unfortunately, perhaps, the threat score has been used by some indiscriminately whether or not the event could legitimately be perceived as a rare event threat. The threat score is the same as the critical success index used by the severe storm community for severe weather, a legitimate threat.

Following that, Bermowitz and Best (1978a, b), derived two equations by regression to compute a threshold for maximizing the threat score, one based on R and one based on R and C. They tested these and the Miller and Best method on four sets of precipitation data. From their testing, it seems their models performed better than the Miller and Best model, and performed about as well as the operational (iterative) method. Because the aim was to arrive at a method which would be as good and use less computer and developer time, they claimed success. Quoted from their office note:


Larry Best, a member of the U.S. Air Force team at TDL, helped develop decision models, and MOS products.

> "There is a question that remains concerning which model—R, RC, or M&B—to use. For example, in forecasting precipitation amount, the R model performed the best. On the other hand, M&B appears to be the choice in forecasting thunderstorms. Perhaps the safest answer, therefore, is that potential users of this method do their own testing to determine which model to use. One thing is certain, however, is that the R model is the only one that can be used if a reliable climatology is not available."

Given these caveats, no universal method was derived. Both methods were used by some developers for a while instead of the iterative method, but they eventually faded, especially after much more user-friendly software was written by Dave Radack and Paul Dallavalle that did not require as much user interaction. Probability forecasts still had to be made, but one could not be sure of good results with the statistical models without doing that and checking results anyway. The iterative method attacks the problem more directly and became the method of choice.

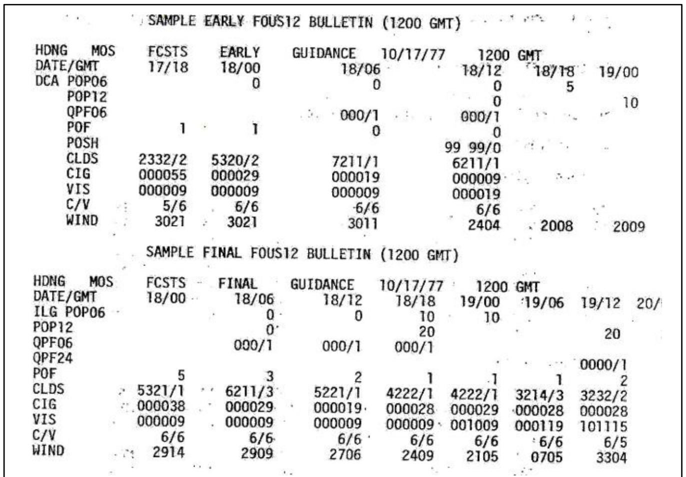
Another new product for field forecasters in the CONUS hit the streets in the fall of 1977—probability and categorical forecasts of precipitation amount. A similar product had been developed and the forecasts provided to NMC forecasters, but not transmitted widely (see Chapter IX). The PoP forecasts were for the lowest amount category ($\geq$ 0.01 inch); the categories were extended to $\geq$ 0.25, $\geq$ 0.50, $\geq$ 1.0, and $\geq$ 2.0 inches (NWS 1977j). Forecasts for 233 stations for the early run were based on both cycles of the LFM and were made for 6- and 12-h periods out to 60 h. The same stations and regions were used for the final run based on PE and TJ predictors. In order to make categorical forecasts, thresholds were developed for all categories for each region and projection. The criteria for threshold selection was the threat score, the primary score used for precipitation amount verification at NMC. This was done for all categories, for both seasons and both early and late runs. Categorical forecasts were made with many different thresholds, and the threshold that gave the highest TS was chosen, conditional on the bias being within a small range near 1.0. Thresholds could not always be determined nor categorical forecasts made for the larger amounts in dry regions.

Regarding precipitation amount forecasting, considerable work was done investigating how many predictors to select, the RV cutoff predictor selection criterion, and whether to use both continuous and binary predictors (Zurndorfer and Bermowitz 1976). While any study such as this is limited to the specifics of the situation, some conclusions were reached:

1) twelve terms in the equations were sufficient,
2) continuous predictors in addition to binary were useful, and
3) an RV cutoff of 0.005 limited the equations to fewer terms (about 7) and allowing more terms was better.

TPB 210 discussed above (NWS 1977j) was rendered obsolete by TPB 227 (NWS 1978b) because each TPB described the total QPF MOS forecast system and not just changes from the previous TPB. The system expected to be implemented in April 1978 seems to have included one more season of data for the warm season, making it now 5 seasons for both early and final runs and warm and cool seasons. Only one set of regions was changed.

NWS (1977k) presents the status of the early and final FOUS 12 bulletins and NWS (1977n) does the same for the FOUS 22 bulletins. and show, respectively, examples of these bulletins.



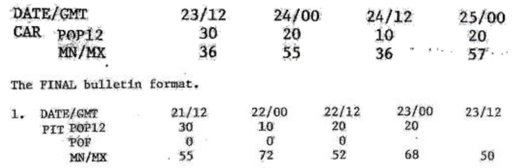
```
                SAMPLE EARLY FOUS12 BULLETIN (1200 GMT)

HDNG    MOS     FCSTS     EARLY     GUIDANCE   10/17/77    1200 GMT
DATE/GMT        17/18     18/00          18/06         18/12     18/18    19/00
DCA POP06                     0              0             0         5
    POP12                                                  0                  10
    QPF06                                000/1         000/1
    POF             1         1              0             0
    POSH                                             99 99/0
    CLDS       2332/2    5320/2         7211/1        6211/1
    CIG        000055    000029         000019        000009
    VIS        000009    000009         000009        000019
    C/V           5/6       6/6            6/6           6/6
    WIND         3021      3021           3011          2404      2008     2009

                SAMPLE FINAL FOUS12 BULLETIN (1200 GMT)

HDNG    MOS     FCSTS     FINAL     GUIDANCE   10/17/77    1200 GMT
DATE/GMT        18/00     18/06     18/12     18/18     19/00    19/06    19/12   20/
ILG POP06                     0         0        10        10
POP12                         0                  20                          20
QPF06                     000/1     000/1     000/1
QPF24                                                                    0000/1
POF                 5         3         2         1         1        1        2
CLDS           5321/1    6211/3    5221/1    4222/1    4222/1   3214/3   3232/2
CIG            000038    000029    000019    000028    000029   000028   000028
VIS            000009    000009    000009    000009    001009   000119   101115
C/V               6/6       6/6       6/6       6/6       6/6      6/6      6/5
WIND             2914      2909      2706      2409      2105     0705     3304
```

Figure X-4. Example of the early (top) and final FOUS 12 bulletins for 1200 UTC as of November 1977. (From NWS 1977k.)



```
DATE/GMT            23/12      24/00      24/12      25/00
CAR  POP12            30         20         10         20
     MN/MX            36         55         36         57

The FINAL bulletin format.

1.  DATE/GMT        21/12     22/00     22/12     23/00     23/12
    PIT POP12         30        10        20        20
        POF            0         0         0
        MN/MX         55        72        52        68        50
```

Figure X-5. Example of the early (top) and final FOUS 22 bulletins, as of December 1977. (From NWS 1977n.)

The 7-layer PE, now running at ½ the previous resolution, took longer to run than previously, and was available for MOS later than before (see next page). To quote from NWS (1977o):

> "Transmitting the charts at the new, later times will make the data available too late for use by meteorologists in the Eastern and Central Time Zones in preparing forecasts to meet press release deadlines. Similarly, the FOUS12 and FOUS22 bulletins would arrive too late by the Request/Reply System.
>
> "To make the forecasts available in time for use by meteorologists, the Techniques Development Laboratory (TDL) is making the EARLY GUIDANCE PRODUCTS nearly as complete as the FINAL GUIDANCE PRODUCTS are at present. This was accomplished by applying some equations derived from the Primitive Equation (PE) model to the new LFM II Model. This technique will be used on an interim basis until TDL can implement new sets of PoP and MAX/MIN temperature equations derived from the LFM output alone."

NWS (1978a) explains the forecasting of extratropical storm surge at 12 east coast stations with PP equations. The message with the forecasts was already in operation for 11 stations and one more station was added, namely, Avon, North Carolina. Predictands were calculated by subtracting the astronomical tide from tide gage data obtained from the U.S. Army Corps of Engineers. Predictors were sea level pressures at PE gridpoints. In operations, the LFM II forecasts of sea level pressure were applied. These PP forecasts were at 6-h intervals out to 48 h.

The early surface wind guidance was extended to projections 42 and 48 h (NWS 1978d). The LFM was the driving model. The wind speed equations continued to be inflated as routine verification continued to show inflation produced more strong forecasts with ". . . very little decrease in the overall skill of the objective forecasts (Zurndorfer et al. 1978)."[2] These equations, as with many others in the MOS suite of products, included terms not only valid at the predictand time but also before and/or after that time to allow for possible timing errors in the model. Many predictors were spatially smoothed; including more than one projection time also essentially time-smoothed them. In those years, models sometimes became known as "slow" or "fast;" this helped to compensate. The equations were developed with observed surface predictors 3 h after nominal model time. When these observations were not available, and in those days this occasionally happened, then the 2-h obs were used instead with no adjustment in the equations. For operations, both the LFM and PE had changed. The LFM, now called the LFM-II, ran at a mesh length 2/3 of that of the original LFM (NWS 1977g).[3] The six-layer PE model (6LPE) morphed into a seven-layer model (7LPE) run at half the original resolution (NWS 1977l, 1977m). Archives of these models were not available for development. Preliminary testing showed that using these new versions in operations had minimal impact on the MOS surface wind forecasts.

For the 1978 summer season, the PoP equations for the early package were rederived and all PoP equations were applied to the LFM-II and the 7LPE model (NWS 1978f). The character of the output products remained the same; one example is shown in Fig. X-6.

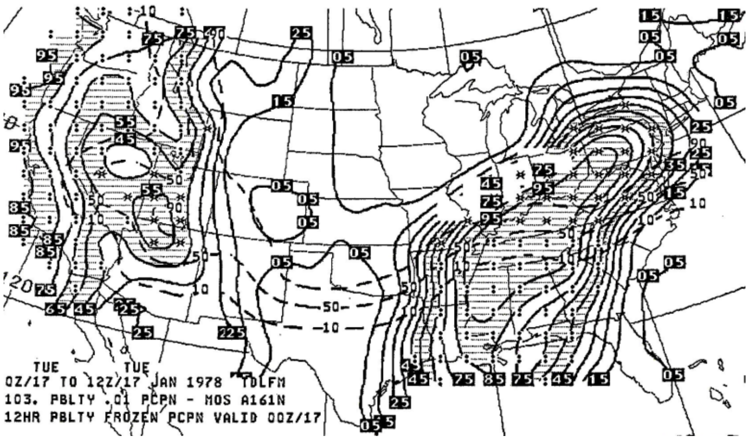


Figure X-6. An example of an operational fax chart showing PoP and PoF forecasts. PoP lines are in solid at 10% intervals. Values between 45 to 65% and > 85% are shaded. The PoF lines are dashed and are for 10, 50, and 90 %. Categorical rain (**:**) and snow (*****) forecasts are also shown. (From NWS 1978f.)

The MOS system for predicting ceiling, visibility, and cloud amount continued with a few changes. The principal differences, as quoted from NWS (1978g) were:

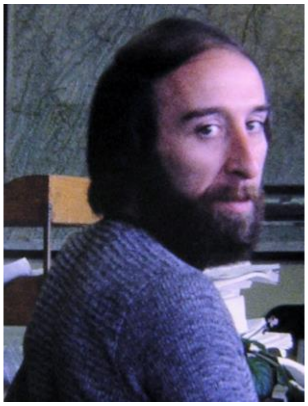
> "The 'early' guidance package of aviation forecasts is now available for projections 6-, 12-, 18-, 24-, 30-, 36-, 42-, and 48-h from the model runtimes of 0000 and 1200 GMT.
>
> "Predictand categories, for which there were too few

---

[2] The MAE increases a bit with inflation, but the Heidke skill score is significantly higher.

[3] Products from the LFM became available to the NWS field offices on September 29, 1971, and continued in operation until August 31, 1977, at which time the LFM was replaced by the new LFM-II. NWS (1978e) gives a good description of the LFM.

occurrences of the event to develop a stable equation, in a particular geographical region, will now be flagged with an 'X' in place of the probability value in both the early and final FOUS12 bulletins. Such predictand categories can never be selected as a 'best' category."



Richard Crisci specialized in aviation-related forecast products for the NWS and the Federal Aviation Administration.

The lower categories of ceiling and visibility are very rare and difficult to predict. A study by Crisci (1976) had shown that the biases could be greatly improved by the use of thresholding rather than the NWS scoring matrix, and this had been implemented in 1977 and continued in 1978. Thresholds were determined based on desired biases for each category [see NWS (1978g) for details].

The thunderstorm forecasts for three 12-h periods from 0000 UTC continued with some enhancements (NWS 1978h). In addition, forecasts were available from the 1200 UTC cycle, and LFM and LFM-based TJ forecasts were used as predictors. Figure X-7 shows the reliability of the forecasts had been improving over the previous 3 years.

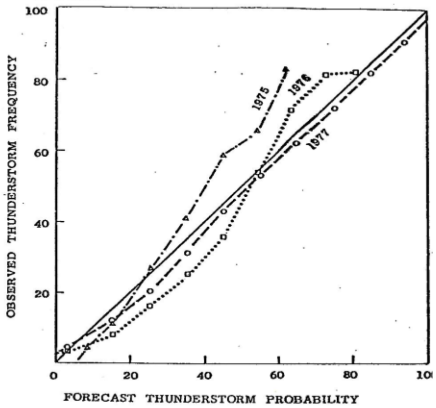


Figure X-7. Thunderstorm operational forecast reliability for 3 years. (From NWS 1978h.)

Wind forecasts over the Great Lakes based on the PE model had been in operation since 1973. The equations were rederived with LFM predictors, and the LFM-based forecasts replaced the PE-based forecasts in May 1978. The predictands were the winds observed by anemometer-equipped vessels at approximately 20 m above the lake surface. The lakes were divided into sectors (Fig. X-8), and the maximum observed wind in the sector was used as the value at the center of the sector at the 6-h observation times. In operations, the LFM-II forecasts were used as input to the regression equations for U, V, and speed [see NWS (1978i) or Feit and Pore (1978) for more details].

Figure X-8. The 12 sectors for which wind forecasts were made. (From NWS 1978i.)

Calendar day max and min PP temperature forecasts had been made available to field forecasters since 1968. In August 1973, most forecast guidance out to 60 h was switched from PP to MOS. Initially, the MOS equations were for 6-month seasons, but 3-month equations were put into operations in July 1975, all based on the PE model. Also, in the summer of 1976, LFM predictors were input to the PE-derived equations to produce an "early" guidance package in addition to the PE-driven "final" package. A few more changes involving the 72-h forecasts were introduced in 1977 and 1978 (see NWS 1978j). At that time, the LFM-II drove the early package, and the final package relied primarily on the 7LPE model.

In June 1978, new MOS max/min equations and, for the first time, temperatures valid every 3 h were implemented for the early package (Dallavalle 1977; Dallavalle and Grayson 1978; Carter et al. 1978, 1979; Grayson and Dallavalle 1977). The equations were derived simultaneously over projection ranges to achieve a greater degree of consistency among the forecasts. These new equations were for 232 stations, and were based on the TDL "standard" 6-month seasons (warm season = April through September). The 3-h temperatures were added to the early FOUS12 bulletin. Max and min temperature maps were provided; an example is shown in Fig. X-9.

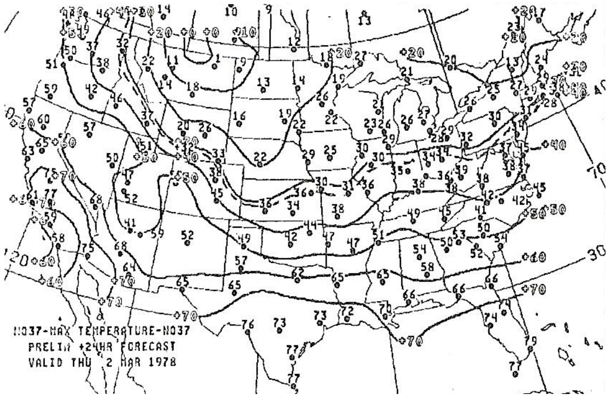


Figure X-9. Example max temperature chart. (From NWS 1978j.)

Dallavalle et al. (1979) described a number of challenges in developing the temperature equations for the next cool season. For the first time, they screened predictors derived from existing (observed) snow cover; this possibility had been investigated earlier by Dallavalle and Carter (1979). In an attempt to get consistency among the max, min, and 3-hourly values, development was done in groups as shown in Fig. X-10. Three sets of 3-hourly values

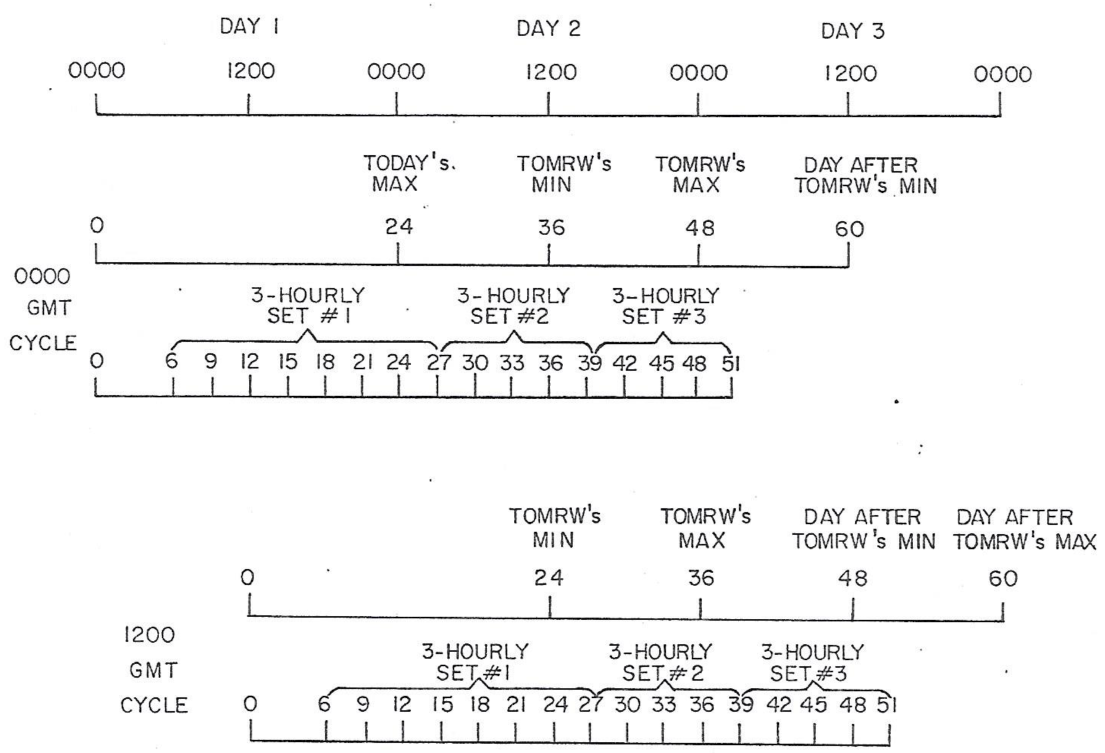


Fig. X-10. Forecast periods associated with the early guidance temperature prediction equations. During development, the predictands were grouped into three sets that each contained 3-hourly temperatures and one max or min. The equations to predict the fourth period max or min were developed separately. (From Dallavalle et al. 1979.)

were defined to screen simultaneously along with the max or min that fell within the 3-h forecast range. The final (60-h) max or min was screened for separately. Archived LFM data were in short supply. There were differing amounts of LFM data for different projections; this constrained development somewhat. The screening was stopped at a maximum of 10 terms or sooner if no additional predicter reduced the variance by > 0.01%.

MOS three-hourly temperature forecasts were provided for the first time in June 1978.

For the winter 1978-79 season, the PoF (conditional probability of frozen precipitation) became PoPT (conditional probability of precipitation type) forecasts. The categories of the predictand were frozen (snow or ice pellets), freezing (freezing rain or drizzle) and liquid (rain). For development, seven regions were used (only four for projections ≥ 30 h because of sample size), whereas only one had been used for PoF. New interactive predictors were devised, and categorical forecasts were made; PoF had no accompanying categorical forecast. Logistic regression continued to be used for the predictand/predictor relationships, but screening linear regression was used to select the predictors because our logit program did not have screening capability (see NWS 1978k and Bocchieri 1978a, b, 1979a, b for more details).

Our MOS bulletins and graphics products were continually changing, many times in response to the changes in NMC models. We also developed new products, expanded existing products, or redeveloped predictor-predictand relationships with larger data samples. The LFM-II had replaced the LFM. The PoP system was revised resulting in the portrayal in Fig. X-11 (NWS 1978l). We found that the trajectory model did not improve the results, so it was dropped (refer to Fig. IX-18). Backup equations were used when the initial obs were not available. Regions were formed in much the same manner as explained in Chapter IX.

Fig. X-12 shows the predictors that were screened for PoP. Fig. X-13 shows the first 6 predictors chosen by screening for the 12-predictor equation for two of the regions. The RVs in Fig. X-13 are the additional RVs contributed by the chosen variable at that step in the selection. As indicated, predictors were used in both continuous and binary form. The smoothing was either a 5-point or 9-point square, or as indicated in the figure as a 1-point, meaning no smoothing. A type of predictor could be selected for more than one projection and more than one binary threshold. For instance, LFM mean relative humidity was selected with a threshold of ≤ 85% at the 12-h projection and with a threshold of ≤ 75% at the 24-h projection for Region 9 (Northern Rockies).

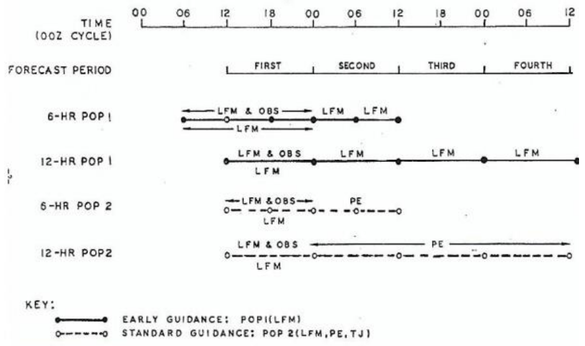


Fig. X-11. The PoP products for the winter 1978-79. The forecast was valid for the intervals between circles. The items listed above (below) each forecast interval are the predictor types of the primary (backup) equations. (From NWS 1978l.)

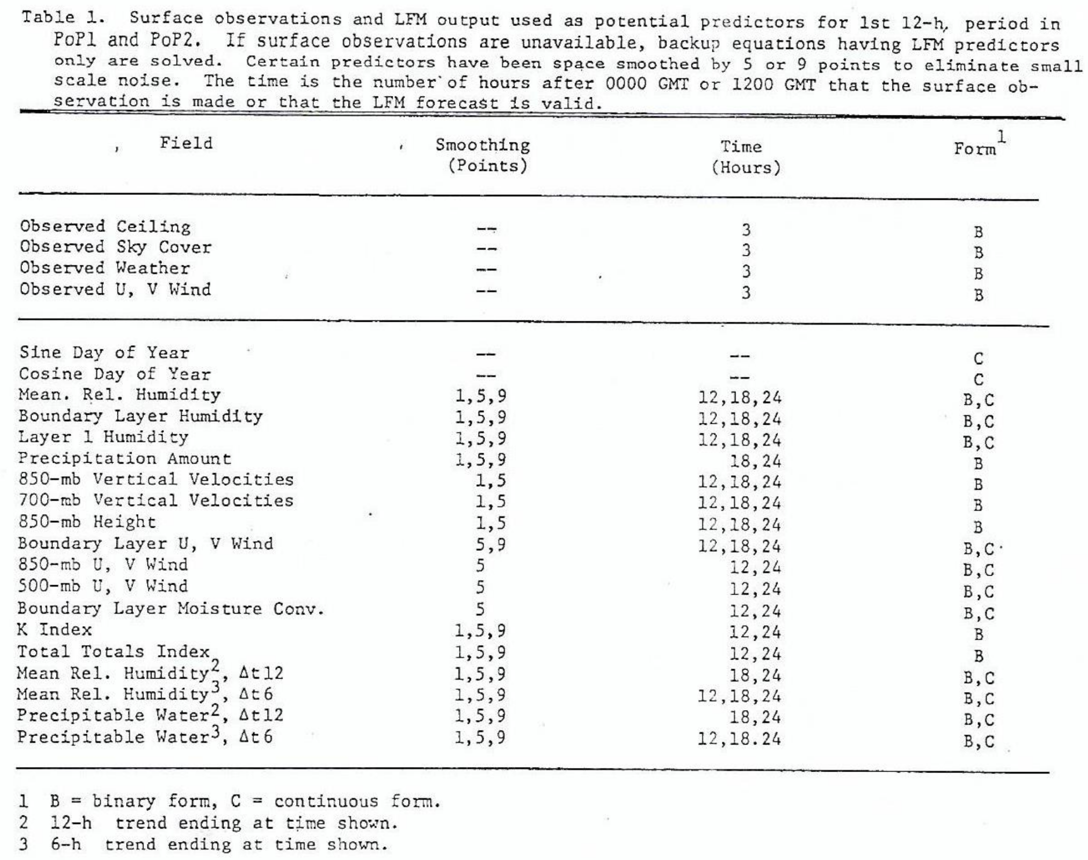
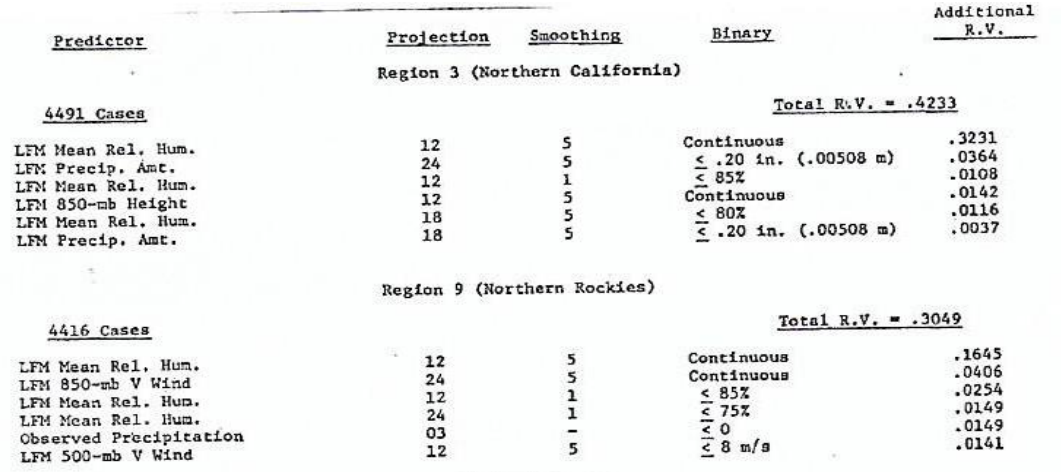


Table 1. Surface observations and LFM output used as potential predictors for 1st 12-h, period in PoP1 and PoP2. If surface observations are unavailable, backup equations having LFM predictors only are solved. Certain predictors have been space smoothed by 5 or 9 points to eliminate small scale noise. The time is the number of hours after 0000 GMT or 1200 GMT that the surface observation is made or that the LFM forecast is valid.

Field	Smoothing (Points)	Time (Hours)	Form[1]
Observed Ceiling	--	3	B
Observed Sky Cover	--	3	B
Observed Weather	--	3	B
Observed U, V Wind	--	3	B
Sine Day of Year	--	--	C
Cosine Day of Year	--	--	C
Mean. Rel. Humidity	1,5,9	12,18,24	B,C
Boundary Layer Humidity	1,5,9	12,18,24	B,C
Layer 1 Humidity	1,5,9	12,18,24	B,C
Precipitation Amount	1,5,9	18,24	B
850-mb Vertical Velocities	1,5	12,18,24	B
700-mb Vertical Velocities	1,5	12,18,24	B
850-mb Height	1,5	12,18,24	B
Boundary Layer U, V Wind	5,9	12,18,24	B,C
850-mb U, V Wind	5	12,24	B,C
500-mb U, V Wind	5	12,24	B,C
Boundary Layer Moisture Conv.	5	12,24	B,C
K Index	1,5,9	12,24	B
Total Totals Index	1,5,9	12,24	B
Mean Rel. Humidity[2], Δt12	1,5,9	18,24	B,C
Mean Rel. Humidity[3], Δt6	1,5,9	12,18,24	B,C
Precipitable Water[2], Δt12	1,5,9	18,24	B,C
Precipitable Water[3], Δt6	1,5,9	12,18.24	B,C

[1] B = binary form, C = continuous form.
[2] 12-h trend ending at time shown.
[3] 6-h trend ending at time shown.

Fig. X-12. Potential predictors screened for PoP (see text). (From NWS 1978l.)



Predictor	Projection	Smoothing	Binary	Additional R.V.
		Region 3 (Northern California)		
4491 Cases			Total R.V. = .4233	
LFM Mean Rel. Hum.	12	5	Continuous	.3231
LFM Precip. Amt.	24	5	≤ .20 in. (.00508 m)	.0364
LFM Mean Rel. Hum.	12	1	≤ 85%	.0108
LFM 850-mb Height	12	5	Continuous	.0142
LFM Mean Rel. Hum.	18	5	≤ 80%	.0116
LFM Precip. Amt.	18	5	≤ .20 in. (.00508 m)	.0037
		Region 9 (Northern Rockies)		
4416 Cases			Total R.V. = .3049	
LFM Mean Rel. Hum.	12	5	Continuous	.1645
LFM 850-mb V Wind	24	5	Continuous	.0406
LFM Mean Rel. Hum.	12	1	≤ 85%	.0254
LFM Mean Rel. Hum.	24	1	≤ 75%	.0149
Observed Precipitation	03	-	≤ 0	.0149
LFM 500-mb V Wind	12	5	≤ 8 m/s	.0141

Fig. X-13. The first six predictors selected for two of the regions (see text). (From NWS 1978l.)

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CHAPTER XI

THE SUITES OF LFM– AND PE–BASED PRODUCTS CONTINUE AND EXPAND

The method used to qualitatively forecast beach erosion was overhauled (NWS 1978a; Richardson 1980). In addition to the erosion predictand having a linear scale representing none, minor, moderate, major, and severe, erosion was also regressed with a powers of 2 scale. Expanding the scale at more severe erosion allowed higher values to be forecast. The decision process to arrive at the final forecast involved forecasts on both scales. If by the powers of 2 scale, the forecast was moderate or greater, that was used as the forecast. Otherwise, the forecast was according to the linear scale. This combination allowed the more serious events to be forecast without greatly overforecasting the minor and no erosion events.

The MOS heavy snow forecast system was updated with almost 2 years more data (NWS 1978b). The sample contained 195 stations. Forecasts were made for the 12- to 24-h period after model run time. Regional equations were developed. The regions were formed by analyzing the relative frequency of heavy snow at observing stations when the LFM predicted ≥ 0.1 in of precipitation. Also considered were the climate of snowfall and of the snow-to-liquid equivalent at the stations. The resulting regions are shown in Fig. XI-1. As before, the conditional system was conditional on (pure) snow occurring. Then a forecast of conditional precipitation amount was made, conditional on precipitation occurring. Forecasts were also made of PoP (measurable precipitation occurring). The unconditional probability was the product of those three forecasts. A final categorical forecast was made by using thresholds determined by maximizing the threat score; the thresholds were calculated for each region and forecast cycle. NWS (1978b) and Bocchieri (1978) give verification scores, but unfortunately there was nothing to compare them to. Interestingly, the prefigurance and postagreement are given, the old Brier terminology in Panofsky and Brier (1958).

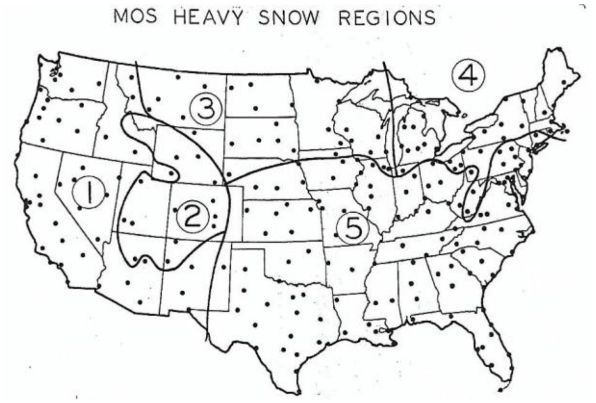

Fig. XI-1. The five regions used for heavy snow development. (From NWS 1978b.)

Progress in the statistical interpretation of NWP output as of 1978 is given by Glahn et al. (1978). Work had continued on the computer worded forecast (CWF) (Glahn 1979a). Software running at NMC could produce a three-period forecast based on MOS forecasts. It was recognized (see Glahn 1978) that for the CWF to be successful, three things would be necessary:

1) objective forecasts of acceptable accuracy of all weather elements contained in a public weather forecast;
2) adequate computer, display, and communications equipment; and
3) flexible software.

For about 2 years, TDL had been producing MOS forecasts that essentially fulfilled 1). It was anticipated that AFOS (Automation of Field Operations and Services) would fulfill 2). We believed we had software that could be used to fulfill 3). In anticipation, a user's guide was written by Heffernan and Glahn (1979) that greatly expanded on previous documentation of the CWF software.


Mary Glackin Heffernan worked on the computer worded forecast, AFOS applications, and other developmental projects.

The 12-h thunderstorm forecasts were updated for both 0000 and 1200 UTC cycles for projections 12-24, 24-36, and 36-48 h (NWS 1979a). For the first time, LFM and LFM-based trajectory model predictors were used exclusively in deriving the prediction equations. The predictand continued to be based on MDR data in accordance with a code that was originally developed by Moore and Smith (1972). The forecasts were based on 3 years of data and covered the period March 15 through September 15 for the country generally east of the Rocky Mountains. The forecasts were valid for blocks 75-80 km square. Analysis of the forecasts and thunderstorms reported at stations showed that a forecast at a point within the block could be found by using one-half the block forecast. The most important predictor was the interactive KF formed by multiplying the large-scale stability index K by the daily thunderstorm relative frequency F obtained from MDR data. An excellent status of this work is in Reap and Foster (1979).

The short-range thunderstorm and severe storm forecasts were also updated (NWS 1979b). These forecasts were also valid roughly east of the Rocky Mountains (see Fig. XI-2) and were issued four times per day after 1500, 1800, 2100, and 0000 UTC in the spring and summer months. The input data are shown in relation to the release time based on 1800 UTC data in Fig. XI-3. Another year of data was added to the development, and the sample was divided into the three areas shown in Fig. XI-2. Forecasts for thunderstorms were for boxes 75-80 km on a side, and forecasts for severe storms were for boxes of double those dimensions (see Fig. XI-2).

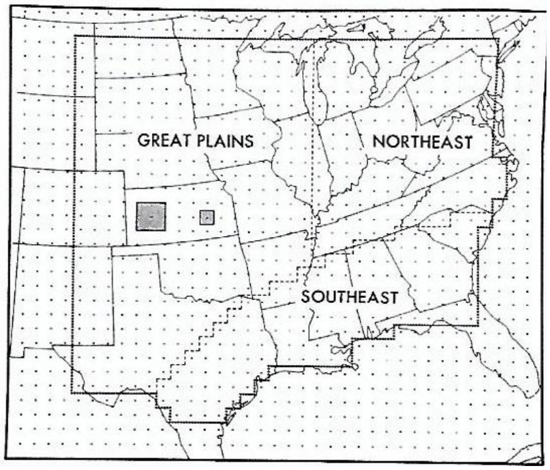

Fig. XI-2. Computational and forecast grid. The thunderstorm (severe storms) forecasts were valid for an area indicated by the small box (large box). (From NWS 1979b.)

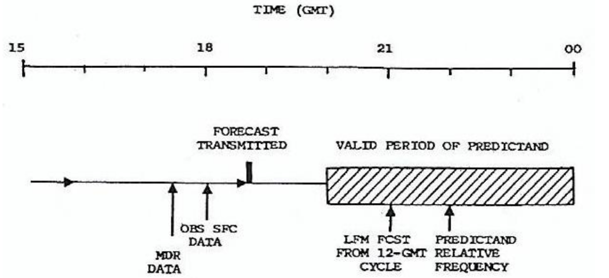

Fig. XI-3. Types of input to the thunderstorm and severe storm equations and their valid times relative to the 2000-0000 UTC predictand period. (From NWS 1979b.)

The MOS bulletin for Alaska underwent a major makeover involving several weather elements (NWS 1979c). The calendar day max/min temperature forecasts were now for 3-month seasons; the predictors were from the coarse mesh (1-Bedient) PE model, mixed as to the 6-layer and 7-layer versions. The sample extended over 6 years. Projections were out to 72 (60) hours from 0000 (1200) UTC. Surface observations were also screened, as well as daily insolation and two harmonics of the day of the year. Dallavalle (1979) describes the temperature development and testing in more detail. The wind equations were for the same 3-month season stratification. As usual, the U and V components and speed were forecast with the same predictors in each equation for each of the four projections, 12, 18, 24, and 30 h, and for each station. Inflation was used for the speed. Carter (1977) describes the wind development and testing in more detail for the fall season. The PoP equations were also for the same 3-month seasons. They were single-station, derived by the logit model. The 10 predictors used in the logit model were selected by linear regression screening, because the logit software did not have a screening option. The PoP equations for 12-h periods were derived simultaneously with the two inclusive 6-h periods. PE predictors were from the years 1970 through 1976. Surface observations were also screened. Gilhousen (1977) describes the PoP development and testing for the fall season in more detail. Conditional probability of frozen precipitation (PoF) was done in the usual way by finding the 50-percent value for each PE model variable at each station, computing the deviations, and then combining stations in three regional pools to get stable results with a multivariate logit model. Note that the logit was used in two ways. The deviations from the 50-percent values particularized the regional equations to stations.

The Great Lakes wind forecasts distributed over Request/Reply as FZUS4 were modified by inflation. According to NWS (1979d), the equations were the same as used previously, but the speeds were inflated. However, the uninflated winds were still used as input to the wave forecasts as it was not yet known the effect inflation would have on them. The automated wave guidance for the Great Lakes is described in Pore (1979).

Convective gust potential forecasts had been available for the past two summers for 10 stations in the western U.S., as discussed in Chapter IX. Recently, seven more stations were added (NWS 1979e). High level thunderstorms in the West may produce little or no rain, but sometimes produce gusty winds at the surface, a hazard to aviation. The predictand in the MOS equations was the occurrence, within ± 4 h of 0000 UTC, of a surface wind gust of ≥25 kt in conjunction with virga or towering cumulus at, or in the vicinity of, the station. To obtain the predictand, microfiche copies of the WBAN10 coding forms for the observations were searched. The period of record was May through September of 1973-78. For the 0000 (1200) UTC run time, the forecast projection was approximately 24 (12) h. Two more seasons of data were used in the development than in the original equations. More detail is given in Carter (1979) and Grayson et al. (1978).

TDL was producing rather comprehensive verification statistics for each 6-month season, and many developers were contributing in their specific areas. For instance, Hebenstreit et al. (1979) is one such report. Comparison with local forecasts was made when possible. PoP forecasts had been comparatively verified since 1970, and verification for other elements started a few years later. Trends in accuracy and skill were reported in Zurndorfer et al. (1979). For instance, the locally-prepared 12-24 h PoP forecasts were definitely better than MOS, but there was little difference for the 36-48 h forecasts.

Developers were continually trying different methods of arriving at a forecast. For instance, the probability of a precipitation category (e.g., ≥ 1 in) could be arrived at by developing an unconditional forecast directly by REEP using all cases in the sample; this was the basis of the operational system. An alternative was to develop a conditional system by using only those cases when measurable precipitation occurred and also to develop equations for predicting the occurrence of measurable precipitation (PoP). The unconditional probability is then the product of the two. Following earlier work by Bermowitz (1975), Zurndorfer (1979) tried both ways and found the two-step process slightly better. However, the added difficulties of transforming the probability into a categorical forecast led to the continuation of the unconditional system. The operational system is described in Bermowitz and Zurndorfer (1979).

From time to time, another governmental organization would support us to do some developmental work. For instance, the Department of Energy asked us to develop a MOS wind forecasting system that would be useful in case of a nuclear incident at their Savannah River plant (SRP). The predictand data came from a TV tower instrumented to 330 m. Wind equations were developed for the U and V components and speed and also for the vertical and horizontal components of turbulence intensity, all provided from an instrumented tower for three levels of data—10, 91, and 243 m above ground (Gilhousen 1979, 1980). Forecasts were transmitted to the site from the 0000 and 1200 UTC LFM runs, and SRP incorporated them into the plant's emergency response computer system (Pendergast and Gilhousen 1980). MOS forecasts were available only twice per day and their effectiveness deteriorated with time after issuance. A modified MOS was devised that combined persistence and MOS, called adjusted MOS. Pendergast and Gilhousen (1980) conclude:

> "A technique was developed and tested to use the 30-hour MOS forecasts of wind and turbulence issued twice daily into SRP's emergency response program. This study showed the technique for combining MOS forecasts, persistence, and an adjusted MOS forecast . . . can be used to generate good forecasts at any time of day. Wind speed and turbulence forecasts have been shown to produce smaller RMSE than forecasts of persistence for time periods over about two hours. For wind direction, the adjusted-MOS forecasts produce smaller RMSE than persistence for times greater than four hours. The adjusted-MOS forecast technique is fully implemented into the SRP emergency response program."

In developing a set of programs that make up a "system," it is important to follow an established set of standards. This includes user documentation and coding standards. Documentation standards had been established in 1975 (see Chapter VIII). Each programmer left to his/her own devices will establish some, usually loose, standards, which will vary greatly from person to person. The goal for the MOS system was to have a set of coding standards that would make it largely indeterminate, except for the name in the header, who wrote the code. That is, it would be a "TDL" code and not a "person" code. To this end, coding standards were

Coding standards were defined for the MOS system in 1979.

established as detailed in Glahn (1979b). Some persons were unhappy with certain elements of the standards, but they were largely followed. Details could have been different, but the adhering to documentation and coding standards greatly contributed to the MOS system's success over many years.

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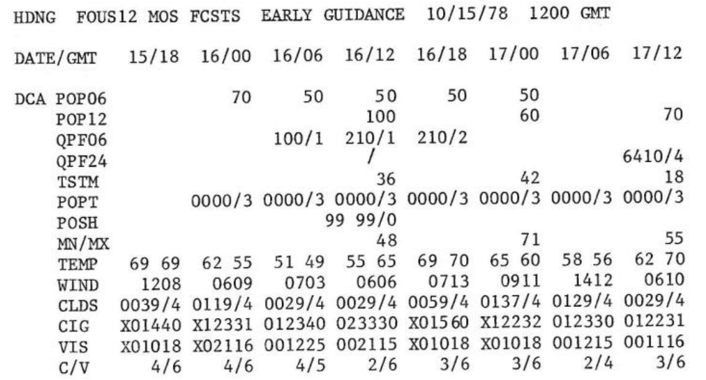
CHAPTER XII

THE LFM RULES

Heretofore, the FOUS12 bulletin had been issued in two versions, an “early” one in which the forecasts were based on the LFM-II model and a “final” one in which the forecasts were based on the 7L PE model. TPB 270 (NWS 1979a) states that the final FOUS12 bulletin was no longer issued and only the early version remained. This decision was based on extensive verification, most of it recorded in TDL office notes. Figure XII-1 shows an example early FOUS12 bulletin for the 1200 UTC run cycle. It was available on both Request/Reply and the KCRT system for 267 CONUS stations.



```
HDNG   FOUS12 MOS FCSTS   EARLY GUIDANCE   10/15/78   1200 GMT

DATE/GMT    15/18  16/00  16/06  16/12  16/18  17/00  17/06  17/12

DCA POP06             70     50     50     50     50
    POP12                          100            60            70
    QPF06                 100/1  210/1  210/2
    QPF24                            /                      6410/4
    TSTM                            36            42            18
    POPT          0000/3 0000/3 0000/3 0000/3 0000/3 0000/3 0000/3
    POSH                     99   99/0
    MN/MX                           48            71            55
    TEMP    69 69  62 55  51 49  55 65  69 70  65 60  58 56  62 70
    WIND     1208   0609   0703   0606   0713   0911   1412   0610
    CLDS   0039/4 0119/4 0029/4 0029/4 0059/4 0137/4 0129/4 0029/4
    CIG    X01440 X12331 012340 023330 X01560 X12232 012330 012231
    VIS    X01018 X02116 001225 002115 X01018 X01018 001215 001116
    C/V       4/6    4/6    4/5    2/6    3/6    3/6    2/4    3/6
```

Fig. XII-1. An example early FOUS12 bulletin for the 1200 UTC cycle. (From NWS 1979a.)

Our screening regression program stopped selecting predictors when the added reduction of variance of all of the predictands fell below a threshold set by a user, but it was still possible to select predictors that were highly correlated with each other. This near-collinearity would sometimes produce erratic results. A modification was made to the screening algorithm that kept a predictor from being selected if it were nearly a linear function of the predictors already selected.[1] This helped to reduce the occasional non-meteorological results that could occur with small developmental samples. The modified program, M600, was used to rederive the MOS wind equations, which according to TPB 271 were implemented on or about October 3, 1979 (NWS 1979b). Inflation continued to be used. Quoted from TBP 271:

> “Verification results . . . show that inflation increases the number of forecasts of strong winds with only a small decrease in the overall skill of the objective forecasts. Generally, the strong winds are forecast only in conjunction with the organized synoptic scale weather systems; high winds associated with special situations such as thunderstorms, tornadoes, or hurricanes are not well predicted. Objective forecasts of surface wind gusts are not provided either, since sufficient quantities of the data necessary for derivation of such equations are not yet available in our predictand data archive.”

In addition to the FOUS12 bulletin, surface wind, cloud amount, and 3-category flight weather forecasts were shown on a four-panel fax chart depicting projection times of 12, 18, 24, and 30 h for 134 stations. An example is shown in Fig. XII-2.

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[1] An original test was basically to keep from dividing by zero in the matrix inversion. After the test put in on July 2, 1979 (memo from H. R. Glahn dated June 21, 1979), the regression program M600 did not select a predictor if 99% of its variance was “explained” by the predictors already selected. This test was changed to 95% of the variance on January 11, 1984 (memo by Gary Carter dated January 20, 1984) after problems were again noted. In MOS-2000 (the system implemented in 2000; see Chapter XIV), the regression programs now have this percentage as a variable that can be specified by the user.

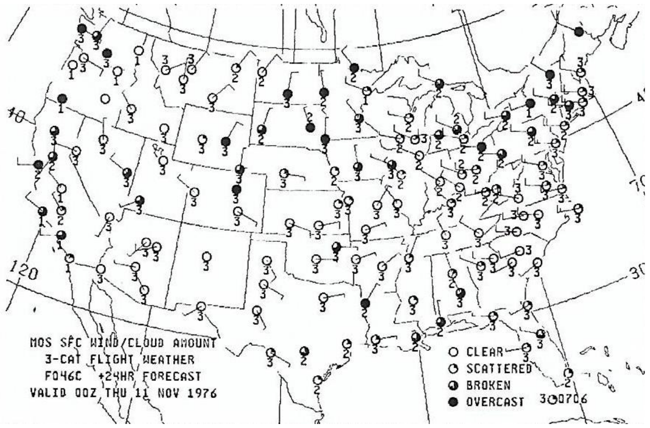


Fig. XII-2. One panel of a four-panel fax chart showing wind, cloud amount, and 3-category flight weather forecasts. (From NWS 1979b.)

The wind forecast equations for eight light ship stations along the east coast in operations since January 1975 were redeveloped based on LFM rather than PE predictors (NWS 1979c). Several other changes were necessary because of data availability. Forecasts covered projections out to 36 h at 3-h intervals. The winds were inflated, and transmission was in another bulletin, FZUS3, instead of FZUS5.

Storm surges were forecast for four points on the Great Lakes, two each for Lakes Erie and Huron. Surge forecasting for the lakes was requested by the Eastern Region and started in 1977 (see Chapter IX). The surges for Essexville and Lakeport on Lake Huron were forecasted by statistical means. In operations, LFM predictors were used; it is not clear from the documentation (NWS 1979d), but it appears from NWS (1980f), the equations were MOS. The forecasts for the Lake Erie points were made by using an impulse response function developed by the Great Lakes Environmental Research Laboratory (Schwab 1978); MOS uninflated winds were used as input. See Richardson and Schwab (1979) for verification of Lake Erie forecasts.

The west coast marine wind forecasts continued at the original six sites, but the wind speed forecasts were inflated. These had PE and LFM predictors. MOS equations with LFM predictors were developed for four additional sites and the speeds were inflated. Because of the completion times of the LFM and PE models, the forecasts for the four new stations could be sent out earlier than the original six sites (NWS 1979e).

The PP equations that were forecasting qualitative beach erosion were redone with a few changes (NWS 1980a). The erosion for Maine and Massachusetts had been forecast too high. This was traced to the duration predictor. The overforecasting is discussed by Richardson (1980). The states were put into two groups for development, Maine and Massachusetts in one group and the others in another group. The duration predictor was omitted and the powers of 2 scale was not used for the first group. NWS (1980a) can be consulted for more detail.

The MOS probability of thunderstorms and severe storms covering the period 12-36 h had been implemented for the warm season (see Chapter XI). These were now extended to the cool season (NWS 1980b). Evidently there had been confusion as to what was a “block,” for which the forecasts were valid, and an addendum dated April 25, 1980, attempted to straighten things out. It seems the grid had previously been related to the MDR (manually digitized radar) definition but now was with respect to the LFM/PE grid.

The precipitation amount forecast product was improved in April 1980. Quoted from TPB 283 (NWS 1980c):

> “In the past, PoPA guidance has been provided for 6- and 24-hour projections. These 24-hour projections have been replaced by 12-hour projections. By providing forecasts for 12-hour periods, the 12-hour PoPA guidance is consistent with the 12-hour period probability of precipitation (PoP) guidance given in the FOUS12 bulletin. In addition, the number of 6-hour PoPA forecast projections has been increased to be consistent with the number of 6-hour PoP guidance periods.”


Karl Hebenstreit developed obstructions to vision and several other aviation-related products.

Categorical forecasts were made from the PoPA probabilities by using thresholds developed to maximize the threat score. The equations were developed for regions, the regions being different in the warm and cool seasons. They were determined by an analysis of the conditional frequency of occurrence of observed precipitation amounts for various amounts forecast by the LFM model.

A new product, the occurrence and type of nonprecipitating obstructions to vision, was developed with the assistance of the U.S. Air Force liaison team stationed at TDL (NWS 1980d; NWS 1981a). The predictand, the obstruction event, was divided into four categories: 1) none, 2) smoke or haze, 3) blowing phenomena, and 4) fog. Predictors were from the LFM; surface-based observations; geo-climatic variables such as latitude, longitude, and harmonics of the day of the year; and climatic relative frequencies of the ceiling/visibility condition less than 1,500 ft and/or 3 mi. One set of regions was used for both the warm and cool seasons, and for the CONUS follow closely the fog regions suggested in Byers (1959) (see Fig. XII-3). Equations were developed for projections 6 to 48 h at intervals of 6 h. Following the pattern of several other developments, there was a “primary” set of equations that included observed variables, and another “backup” set that had no observed variables. The latter set was used in operations when an observed variable was not available. Thresholds were developed for determining a categorical forecast from the probabilities by the Miller/Best method (see Chapter X).

Fig. XII-3. The 10 (2) regions used for developing the obstructions to vision equations in the CONUS (Alaska) area. (From NWS 1980d, 1981a.)

A new set of LFM-based equations to forecast calendar day max/min; surface temperature; and, for the first time, surface dew point (NWS 1980e) was developed. These were all MOS single-station equations for 3-month seasons. Various checks were made among the forecasts to insure consistency. For instance, if the dew point forecast exceeded the temperature, the average was used for both. Besides the forecasts in FOUS bulletins, facsimile charts were also made available; Fig. XII-4 shows one such chart. Although the predictor emphasis was now on the LFM, the final guidance based on the PE was still available. Also, PP forecasts of max/min were used to fill in where MOS was not available. Because Dallavalle and Carter (1979) had shown that snow cover used as a binary predictor was somewhat helpful in temperature prediction, it was used in this and some future developments. NWS (1980e) gives a good history of the temperature guidance since its beginning in 1965, as well as its current status as of May 1980. Also, Dallavalle et al. (1980) provides a status of temperature guidance and Klein and Dallavalle (1980) review the evolution of MOS and PP in forecasting maximum surface temperature.

MOS forecasts of dew point were introduced in 1980.

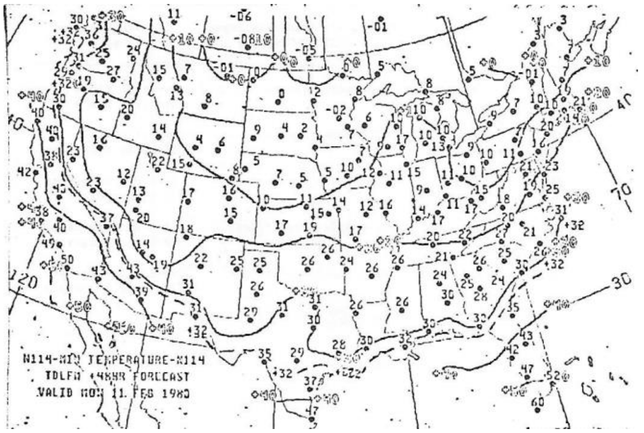


Fig. XII-4. Example panel for the LFM-based max/min forecast facsimile chart produced from 1200 UTC data on Feb. 9, 1980. (From NWS 1980e.)

The LFM-based MOS wind equations for the 12 sectors of the Great Lakes were redeveloped with more data (NWS 1980f). They differed from previous equations in basically two ways. First, projections of 42 and 48 h were added, and second, a separate set of equations was used for western L. Superior and another (generalized) set for all other sectors. Previously, one set had been used for all sectors. The speed forecasts continued to be inflated.

New LFM-based equations for both the warm and cool seasons and for both the 0000 and 1200 UTC run cycles were redeveloped for predicting wind (NWS 1980g) in the CONUS. The development sample included a mix of LFM and LFM-II forecasts. Sample sizes varied between 2 and 5 years of data, depending on projection. Selection of predictors with strong correlations with other already selected predictors was inhibited, and it was hoped this would improve the sometimes unrealistic forecasts. In addition, generalized operator equations were produced for a few stations that had insufficient data for single-station equations. The predictors most often selected for the 12-h forecast were the observed U and V wind components and speed. For the other projections, the LFM boundary layer winds were most often selected east of the Rocky Mountains, and in the West the 850-mb winds were most often selected. The forecast speeds continued to be inflated.

NWS (1980h) defines the early, LFM-based PoP system in place for the 1980-81 cool season. Although the FOUS12 containing the final, PE-based forecasts had been discontinued, the PoPs were still available in FOUS22. PoPs based on the LFM were extended to the 42- and 48-h projections. Figure. XII-5 shows the availability of the PoP guidance and the inputs. Regions for LFM-based development were subjectively defined based on two charts. One chart was the relative frequency of precipitation in the first 12-h period (averaged over both cycles) when the LFM forecast of mean relative humidity was $\geq$ 65% at 18 hours. The other was the same relative frequency of precipitation when the LFM forecast precipitation of $\geq$ 0.01 inches in the 12- to 24-h period. Twenty-six regions resulted. Equations for the PE-based PoPs were also redeveloped. In August 1980, the 7LPE model was replaced by the spectral model. Therefore, these PE-based equations had spectral model input in operations. Testing indicated some deterioration of the MOS PoP forecasts for some stations in Alaska. A full description of the contents of FOUS12 is given in NWS (1980i). This cool season system was followed by warm season equations in time for the warm season (NWS 1981b).

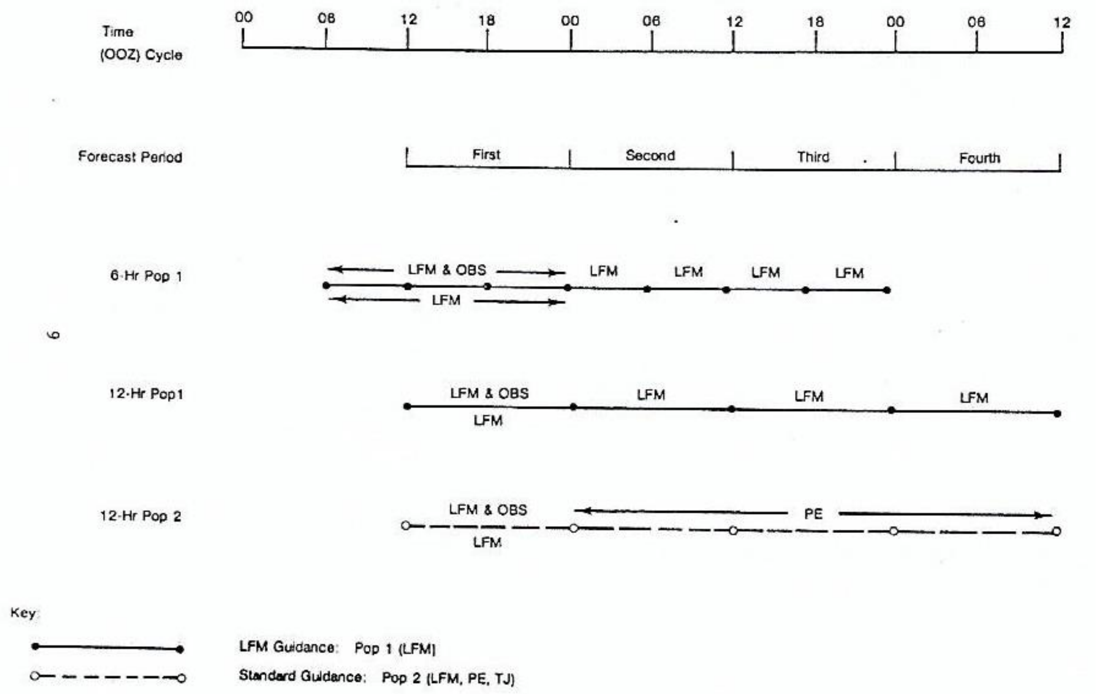
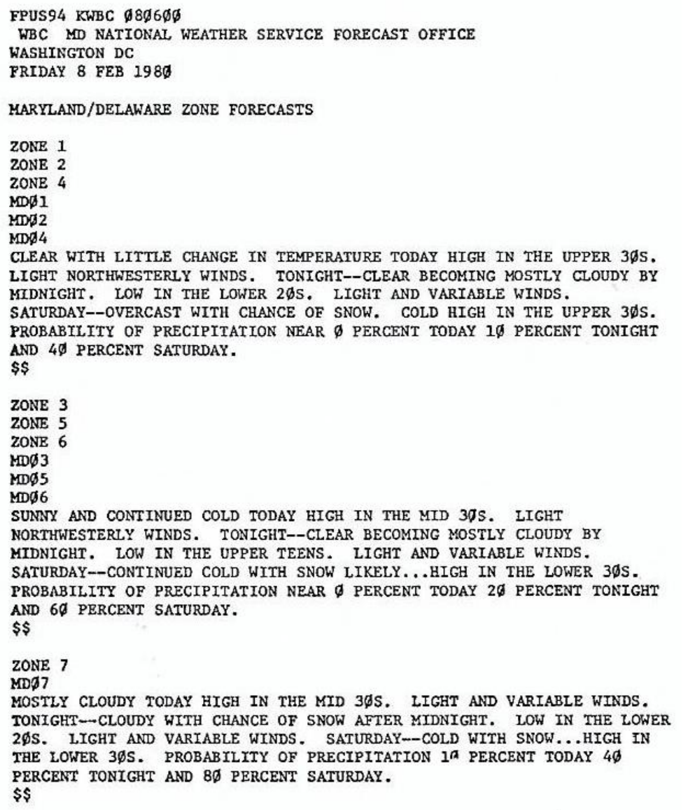


Fig. XII-5. The availability of the PoP forecasts by forecast period and the model inputs. The inputs shown above the line are for primary equations, and those below the line are for the backup equations to be used when the observations were not available. (From NWS 1980h.)

The change from spring to summer of the 2- to 6-h probabilities of thunderstorms and severe local storms was announced in NWS (1980j).

Work continued on the computer worded forecast. The following is summarized from Bermowitz et al. (1980). For about 5 years, TDL had been producing three-period CWFs on a daily basis for cities in the conterminous U.S. for the 0000 UTC cycle. This was expanded to the 1200 UTC cycle in February 1980 and included the fourth period. The purpose of the CWF was to save forecasters' time by providing a start on their city or zone forecasts. The format matched as closely as possible the locally-produced forecasts. One version of the CWF program ran on the NOAA IBM 360/195, and forecasts were distributed from it over both the NWS KCRT system and the AFOS test loop. Another version could be run on the AFOS minicomputer at a Weather Service Forecast Office. This gave the forecaster the control needed over the final product. For example, one option allowed the forecaster to alter the digital forecasts appearing in a matrix that accompanied the CWF and to rerun the program on the minicomputer. The result was a new CWF that more closely reflected the forecaster's meteorological input. Also, the CWF text could be edited directly.

The most recent changes to the CWF included it being produced for zones (combinations of counties) as well as for cities. Examples are shown in Fig. XII-6. These were also distributed after being produced on the 360/195, packaged by state for each WSFO, and disseminated on the AFOS National Distribution Circuit. The zone forecasts were a combination of the forecasts for cities in them. Algorithms were in place to judge whether zones could be combined, as was the practice when the weather was similar across zones. These algorithms used parameters that could be set by the forecasters for each station to allow for different climatic conditions and forecaster preference. Lists could be made that specified certain zone combinations that were preferred and combinations that should never be made. An attempt was made to make the software flexible enough to be useful and provide a good forecast. At that time, combining periods (e.g., today, tonight) in the forecasts to shorten them when justified by the weather was encouraged; we were beginning on algorithms to do this combining and also to add warnings.



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FPUS94 KWBC 080600
 WBC  MD NATIONAL WEATHER SERVICE FORECAST OFFICE
WASHINGTON DC
FRIDAY 8 FEB 1980

MARYLAND/DELAWARE ZONE FORECASTS

ZONE 1
ZONE 2
ZONE 4
MD01
MD02
MD04
CLEAR WITH LITTLE CHANGE IN TEMPERATURE TODAY HIGH IN THE UPPER 30S.
LIGHT NORTHWESTERLY WINDS.  TONIGHT--CLEAR BECOMING MOSTLY CLOUDY BY
MIDNIGHT.  LOW IN THE LOWER 20S.  LIGHT AND VARIABLE WINDS.
SATURDAY--OVERCAST WITH CHANCE OF SNOW.  COLD HIGH IN THE UPPER 30S.
PROBABILITY OF PRECIPITATION NEAR 0 PERCENT TODAY 10 PERCENT TONIGHT
AND 40 PERCENT SATURDAY.
$$

ZONE 3
ZONE 5
ZONE 6
MD03
MD05
MD06
SUNNY AND CONTINUED COLD TODAY HIGH IN THE MID 30S.  LIGHT
NORTHWESTERLY WINDS.  TONIGHT--CLEAR BECOMING MOSTLY CLOUDY BY
MIDNIGHT.  LOW IN THE UPPER TEENS.  LIGHT AND VARIABLE WINDS.
SATURDAY--CONTINUED COLD WITH SNOW LIKELY...HIGH IN THE LOWER 30S.
PROBABILITY OF PRECIPITATION NEAR 0 PERCENT TODAY 20 PERCENT TONIGHT
AND 60 PERCENT SATURDAY.
$$

ZONE 7
MD07
MOSTLY CLOUDY TODAY HIGH IN THE MID 30S.  LIGHT AND VARIABLE WINDS.
TONIGHT--CLOUDY WITH CHANCE OF SNOW AFTER MIDNIGHT.  LOW IN THE LOWER
20S.  LIGHT AND VARIABLE WINDS.  SATURDAY--COLD WITH SNOW...HIGH IN
THE LOWER 30S.  PROBABILITY OF PRECIPITATION 10 PERCENT TODAY 40
PERCENT TONIGHT AND 80 PERCENT SATURDAY.
$$
```

Fig. XII-6. Examples of forecasts for zones in the Maryland area near Washington D.C. transmitted for use by forecsters. (From Bermowitz et al. 1980.)

Public and aviation MOS products were produced twice per day for 3-h projection intervals. The resolution of the LFM on which MOS was based was at that time approximately 107 km over the CONUS. Forecasts were needed more often and at finer time and space resolution, especially for aviation interests. There were also radar and other data available but not used in the operational NMC models that could be used to make more accurate short-range forecasts. TDL had developed SAM that ran over the eastern U.S. at nominal 80 km and output forecasts every hour. By expansion and improvement, SAM became SUM. SUM had been discontinued in favor of the LFM when the LFM became a primary NMC model. In 1979, TDL embarked on a project to reprogram the SAM model for the CONUS and to develop MOS forecasts from it to be run on a local station's AFOS minicomputer (Glahn 1980). That way, the forecasters could have control of their weather-related inputs. The surface analyses, input to the model, could be run with quality-controlled data based on locally available data sources and algorithms appropriate to the forecast office. TDL would maintain the model and generate MOS forecasts from it. This new effort was called the Local AFOS MOS Program (LAMP) (see Chapter XVIII).

LAMP was started in 1979.

In the fall of 1981, new prediction equations were implemented for ceiling, visibility, cloud amount, and obstructions to vision (NWS 1981c). The new system differed from the previous one in the following ways:

1) The best category of cloud amount was obtained by using the thresholding technique rather than the previous method.
2) Three more years of data were used in the development, bringing the total to 7 years.
3) Forecasts greater than 24 h for ceiling, visibility, and cloud amount were based on LFM/LFM II model output rather than PE model output (the LFM II became operational in August 1977).
4) Visibility and obstructions to vision equations were derived simultaneously resulting in common predictors for the 10 predictands (categories).

Development continued to be regional and new regions were defined. Thresholds for the "best" category were defined in the following ways:

1) For cloud amount and obstructions to vision—unit bias for each category.
2) For ceiling and visibility, categories 1 and 2—maximum threat score with bias in range 0.7 to 1.3.
3) For ceiling and visibility, categories 3 to 6—unit bias for each category.

The 3-category flight weather forecasts were continued (see Chapter IX). Besides bulletins, graphics continued to be provided by fax and over AFOS. Also, both probability and categorical 3-category flight forecasts were provided to the Aviation Weather Branch of NMC four times daily for 236 civilian and approximately 140 U.S. Air Force terminals by a special computer printout to be used in preparation of the low-level significant weather facsimile charts.

A new product, solar energy guidance, was instituted in October of 1981 (NWS 1981d). Specifically, it was the amount of extraterrestrial radiation reaching a horizontal plane at the earth's surface during the daytime. The predictand was defined at the 30 stations in the NOAA Solar Radiation Network. Primary predictors were MOS forecasts of cloud cover and observations of dew point. Consult NWS (1981d) and Jensenius (1983) for more details.

A new solar energy forecast was implemented in 1981.

The product was a two-panel chart showing the solar energy in kilowatt-hours per square meter multiplied by 10. The forecasts were valid for the daylight period approximately 24 and 48 hours after 0000 UTC and 36 and 60 hours after 1200 UTC. An example is shown in Fig. XII-7. Note that the forecasts were based on MOS forecasts, which in turn were based on the LFM model. The equations were developed for the 6-30 h projection from 0000 UTC, but were applied to all other projections and to the 1200 UTC start time. Even though there was predictand data at only 30 stations, the generalized equations were applied to about 230 stations.

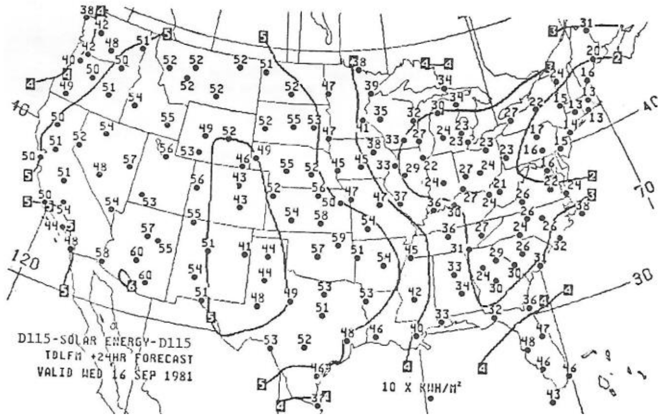


Fig. XII-7. One panel of a two-panel fax chart showing solar energy in kilowatt-hours per square meter multiplied by 10 (from 1981d). In late 1982, the contours, but not the plotted values, were modified to represent percent of possible energy (NWS 1982g.)

The sample of data for developing the new product was 2 years. In the spring of 1982, the equations were rederived with 4 years of data (NWS 1982b).

The coastal wind forecasts were updated in 1981 (NWS 1981e). The equations continued to be single-station and the predictors came from the LFM. The equations for the 23 stations that currently had such guidance were updated, and 45 new stations were added. The predictand data came from the National Climatic Data Center, the Los Angeles WFO, Oregon State University, and NMC. Data samples varied from 2 to 7.5 years. To indicate the varied nature of the data collection tasks, the forecasts were for seven light stations, 35 marine stations, 10 buoys, five platforms, five Navy stations, two FAA stations, one WFO, one Marine Corps base, one Army airfield, and one cooperative observing station. This system was again updated in the fall of 1982 (NWS 1982i). One station location was corrected and the samples increased. Changes also occurred in transmission modes.

John Janowiak, a developer at TDL, studied the effectiveness of model predictors.

The wind prediction system for 236 stations in the CONUS was updated with more data (NWS 1982a). The process was nearly identical to the previous, except the boundary layer and surface pressure variables were omitted. A study by Janowiak (1981) showed that the predictions were about as good without these predictors as with them, and because a model change was more likely to affect these variables than others higher in the atmosphere, it was deemed a risk to use them, and they were dropped. Inflation of the speeds had been used to make more forecasts of strong winds. This also makes reduced forecasts of winds below the mean, and they had been found to have a low bias. Partial inflation, where only the winds above the mean were inflated, had been discussed, and Schwartz and Carter (1982) investigated what effect this would have on the accuracy. They found that overall the fully inflated forecasts were slightly better than the partially inflated ones, so the process of inflation was left intact.

A major upgrade of the Alaska guidance was made in the fall of 1982. Whereas the current guidance equations had been developed on the PE model and were evaluated on the spectral model that had supplanted the PE, the new guidance was based on the LFM. Also, the number of stations was increased from 14 to 30. The elements for which guidance was generated were

PoP, PoF, calendar day max and min temperature, surface temperature and wind, and probability of cloud amount categories. Except for PoF, which had two 6-month seasons, four 3-month seasons of data were used for development. Fig. XII-8, reproduced from NWS (1982c) shows some of the equations' characteristics. Some equations included the surface observation of the element being predicted taken 3 h after the model run time; in these cases, backup equations were developed to use if the observations at 3 and 2 h after run time were missing, the 2-h observation being used as a substitute for the 3-h if necessary.

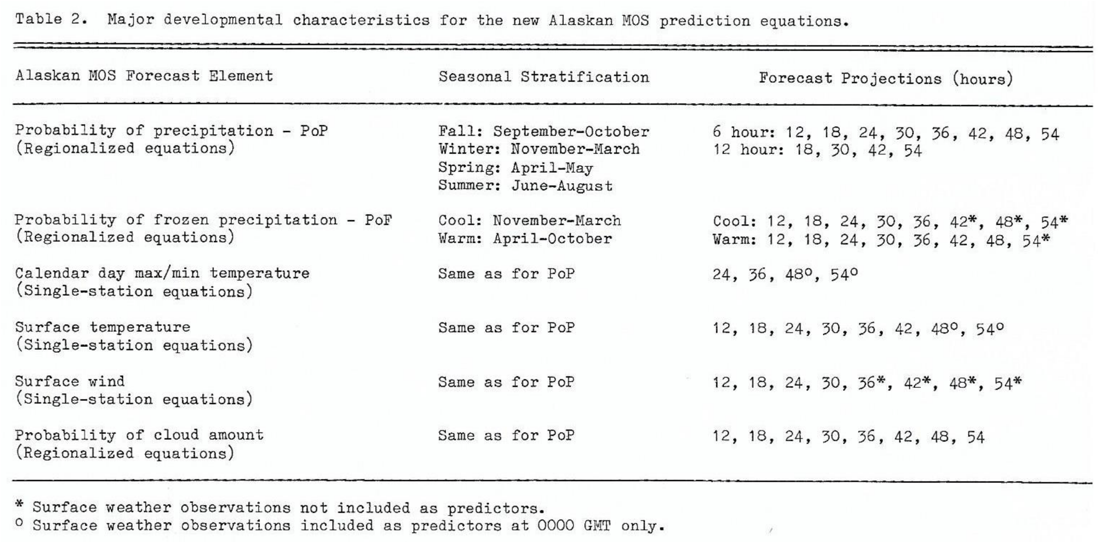


Table 2. Major developmental characteristics for the new Alaskan MOS prediction equations.

Alaskan MOS Forecast Element	Seasonal Stratification	Forecast Projections (hours)
Probability of precipitation - PoP (Regionalized equations)	Fall: September-October Winter: November-March Spring: April-May Summer: June-August	6 hour: 12, 18, 24, 30, 36, 42, 48, 54 12 hour: 18, 30, 42, 54
Probability of frozen precipitation - PoF (Regionalized equations)	Cool: November-March Warm: April-October	Cool: 12, 18, 24, 30, 36, 42*, 48*, 54* Warm: 12, 18, 24, 30, 36, 42, 48, 54*
Calendar day max/min temperature (Single-station equations)	Same as for PoP	24, 36, 48°, 54°
Surface temperature (Single-station equations)	Same as for PoP	12, 18, 24, 30, 36, 42, 48°, 54°
Surface wind (Single-station equations)	Same as for PoP	12, 18, 24, 30, 36*, 42*, 48*, 54*
Probability of cloud amount (Regionalized equations)	Same as for PoP	12, 18, 24, 30, 36, 42, 48, 54

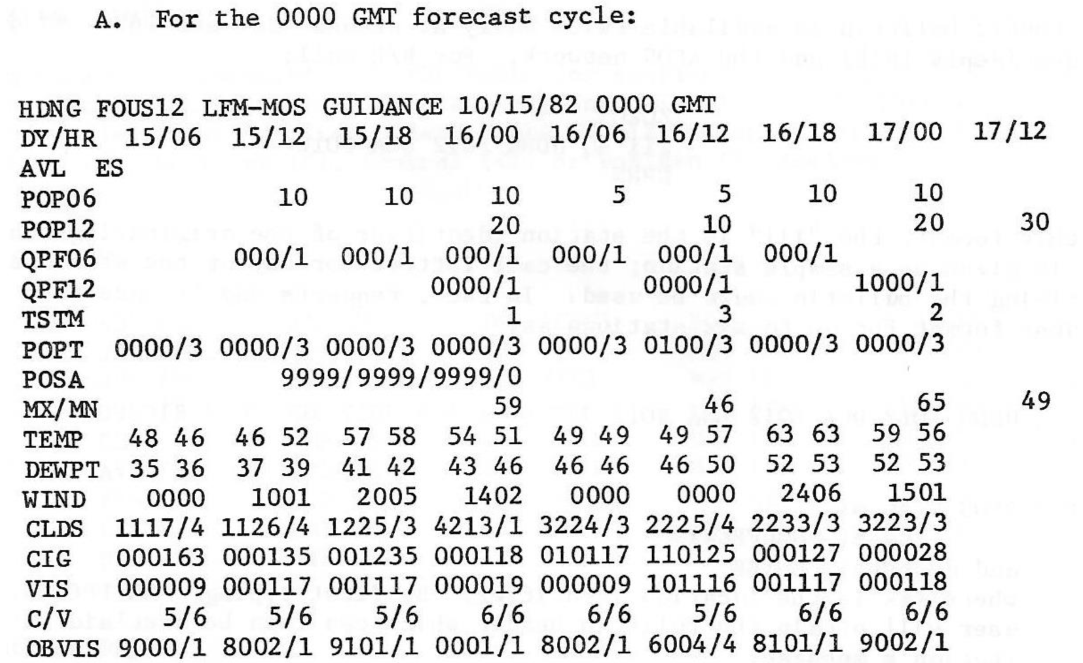
* Surface weather observations not included as predictors.
° Surface weather observations included as predictors at 0000 GMT only.

Fig. XII-8. Characteristics of equations for Alaska, taken from TPB 317 (NWS 1982c).

The CONUS snow amount prediction system was updated in 1982 (NWS 1982d). Both conditional (on precipitation occurring) and unconditional forecasts were provided. The process was essentially the same as reported previously. Details of the development can be found in Bocchieri (1982a, b) as well as NWS (1982d). Bocchieri used a novel approach to defining regions for the regional approach. First, he derived conditional probability of snow amount (PoSA) equations for 195 stations (the generalized approach). Then he computed for each station and snow category the [average (PoSA) – RF] / RF, where PoSA had been evaluated for all 195 stations. The category RF of snow was specific to the station. These relative differences were plotted on a map, and regions subjectively defined by similar values. The forecasts were made available on the request/reply teletypewriter circuits, the KCRT system, and AFOS.

The probability of precipitation type system was also updated with 3 to 4 more years of data (NWS 1982e). Slight changes were made to the valid times of the forecasts on the facsimile chart, and a forecast for the 6-h projection was added to the FOUS12 bulletin. The FOUS12 bulletin was modified to contain a 48-60 h period PoP forecast and a fourth period maximum temperature (NWS 1982h). Changes were also made so that the bulletins could be regionally routed. A sample message as now constructed is shown in Fig. XII-9.

The coastal wind prediction system was again updated and 24 stations were added. The stations span the coasts of the United States including Alaska (NWS 1982f, i); they are shown in Fig. XII-10.



A. For the 0000 GMT forecast cycle:

```
HDNG FOUS12 LFM-MOS GUIDANCE 10/15/82 0000 GMT
DY/HR      15/06     15/12     15/18     16/00     16/06     16/12     16/18     17/00     17/12
AVL   ES
POP06                    10        10        10         5         5        10        10
POP12                                        20                  10                  20        30
QPF06                 000/1     000/1     000/1     000/1     000/1     000/1
QPF12                                    0000/1              0000/1              1000/1
TSTM                                          1                   3                   2
POPT      0000/3    0000/3    0000/3    0000/3    0000/3    0100/3    0000/3    0000/3
POSA                9999/9999/9999/0
MX/MN                                        59                  46                  65        49
TEMP       48 46     46 52     57 58     54 51     49 49     49 57     63 63     59 56
DEWPT      35 36     37 39     41 42     43 46     46 46     46 50     52 53     52 53
WIND        0000      1001      2005      1402      0000      0000      2406      1501
CLDS      1117/4    1126/4    1225/3    4213/1    3224/3    2225/4    2233/3    3223/3
CIG       000163    000135    001235    000118    010117    110125    000127    000028
VIS       000009    000117    001117    000019    000009    101116    001117    000118
C/V          5/6       5/6       5/6       6/6       6/6       5/6       6/6       6/6
OBVIS     9000/1    8002/1    9101/1    0001/1    8002/1    6004/4    8101/1    9002/1
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Fig. XII-9. A sample FOUS12 bulletin. This shows the breadth of the MOS aviation/public forecasts available in the CONUS from the LFM. (From NWS 1982h.)

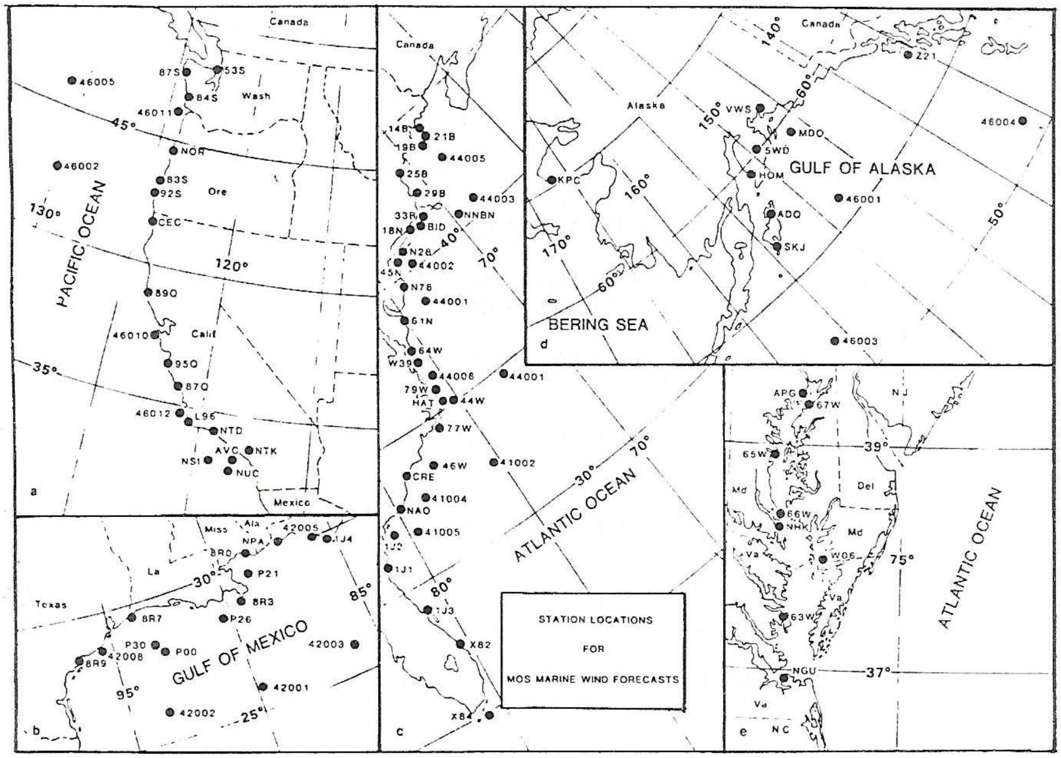

Fig. XII-10. The coastal wind stations—the west coast, the east coast, the Gulf of Mexico coast, Alaska coasts, and Chesapeake Bay. (From NWS 1982i.)

A major change occurred in the fall of 1982 when the Alaska forecasts were shifted to the LFM from the coarser model. This system was updated in early 1983 with the addition of more data, which led, in some cases, to the adjustment of regions (NWS 1983a).

The wind forecast equations for the Great Lakes described in a previous chapter were rederived. The principle changes were that more data and new stability-related predictors were used, and boundary layer predictors were not used (NWS 1983b). The forecasts were for sections of the Great Lakes as shown in Fig. X-8 and were implemented in March 1983. The predictand data were from anemometer-equipped vessels, the anemometers being situated approximately 20 m above the lake surface. The wind speed forecasts were inflated. Wave forecasts were derived from the uninflated wind forecasts by a process defined in NWS (1974). Subsequently, errors were found in some subroutines, and the corrected equations, without some of the new stability variables, were re-implemented in June 1983 (NWS 1983d).

The thunderstorm equations were updated (NWS 1983c). Generally, the development followed that explained in Chapter IX. The probability was based on a radar value of VIP level 3 or greater within a block roughly 75-80 km on a side in a 12-h period. The forecasts, implemented in the spring of 1983[2], were valid for three, 12-h periods and covered the entire conterminous states. Past forecasts had been quite reliable as shown in Fig. XII-11.

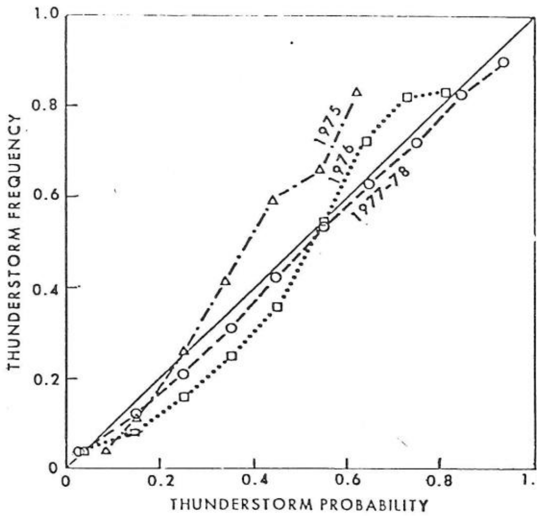

Fig. XII-11. Observed thunderstorm relative frequency as a function of thunderstorm probability forecasts for the years 1975-78. (From NWS 1983c.)

The equations for predicting surface wind were refreshed in 1983 with a longer data sample (1977-1982) and for 27 additional stations (NWS 1983e). Essentially, the same process was used as was used previously. Single-station equations were developed for wind speed and for the two wind components from which the direction was computed. Each of the three equations had the same predictors for a specific station and forecast projection. LFM predictors screened included horizontal and vertical wind components, constant pressure heights, temperature, dew point, and relative humidity for various levels of the atmosphere. Computed variables for screening included divergence, relative vorticity, and pressure change. Most predictor fields were smoothed over 5, 9, or 25 points. Also, surface reports and the first and second harmonics of the day of the year were screened. Boundary layer and surface pressure fields continued to be excluded to avoid possible changes in LFM boundary-layer forecasts. See Janowiak (1981) for a discussion of the usefulness of LFM boundary-

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[2] Initially, the Technical Procedures Bulletins contained an expected implementation date of the product. This was approximate, and implementation was sometimes delayed. However by 1983, the TPBs did not contain an implementation date and just stated that “Implementation of forecasts will be announced by an ALSYM on RAWRC and an AFOS Change Notice.” The implementation dates here are now estimated from the date on the TPB. Also, at about this time, the TPBs were designed to completely explain what was in operation at the time. Previously, a TPB might describe only the changes being implemented and relate them to the previous product. This change to a more complete TPB makes it harder to determine the changes that were made.

layer fields in MOS wind forecasts. In operations, the speed forecasts were inflated to increase the number of strong winds (Carter 1975).

Both production and development continued for the CWF, and the current status as of 1983 is rather completely explained in NWS (1983f). The CWFs were being produced centrally on the IBM 360/195 for 111 stations for the 0000 and 1200 UTC cycles and for the zones of 18 WSFOs for the 0000 UTC cycle. Forecasts were prepared from the digital MOS forecasts in 12-h segments (e.g., today, tonight), but segments were combined when they were similar enough to warrant it. MOS forecasts for zones were made by combining forecasts for stations within the zones, and the periods within the zones could also be combined. Software that could be run by forecasters on the local AFOS computers was also made available. Control constants (such as what constitutes a normal temperature) could be tailored by station by forecasters (see NWS 1983g). Complexity of phrasing could be controlled by station and forecast projection. Each worded forecast was accompanied by a matrix of MOS digital forecasts, called original digital guidance (ODG). Reference to this work has been given earlier (Bermowitz et al. 1980); also, see Heffernan and Glahn (1979) for implementation details. To assess the usefulness of the CWF and to guide further development, evaluations were carried out both internally (Waldstreicher and Bermowitz 1984) and NWS-wide (Bermowitz and Miller 1983).

Since September 1982, twice-daily, LFM-based MOS forecasts of probability of precipitation, probability of frozen precipitation, surface temperature, surface wind, and cloud amount had been available for 30 stations in Alaska in the FMAK1 teletype bulletin (NWS 1984a; Schwartz 1983; Dallavalle and Murphy 1983). Starting about February 1, 1984, probabilistic forecasts of ceiling height, visibility, and obstructions to vision were implemented in the FMAK2 bulletin. Previously, forecasts for these latter three variables based on the coarse-mesh PE model were included in the FMAK1 bulletin but were discontinued in September 1982. Besides the LFM predictors (gridpoint values interpolated to the station locations), surface observations taken 3 h after the LFM run time were used in the primary equations; backup equations without the observations were developed and used in operations when the observation was missing. The developmental data set, consisting of about 4 or 5 years of data, was divided into 4 seasons.

All new equations were derived for regions, grouping the stations within the regions. Ceiling height and cloud amount equations were derived simultaneously to help keep the forecasts consistent. Similarly, the obstruction and visibility equations were derived simultaneously. The regions were different for the four seasons, but were the same for all elements; an example is shown in Fig XII-12. Equations produced probabilities for the discrete categories shown in Fig. XII-13, but forecasts for only the cumulative categories, which can be calculated from the discrete categories, shown in Fig. XII-14 were disseminated.

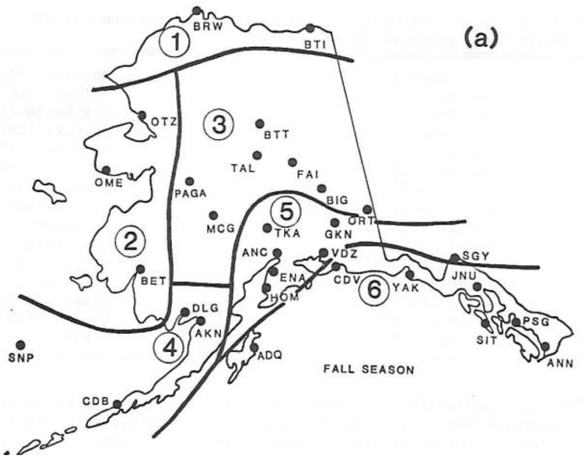


Fig. XII-12. The regions used for all aviation-related variables for the fall season. (From NWS 1984a.)

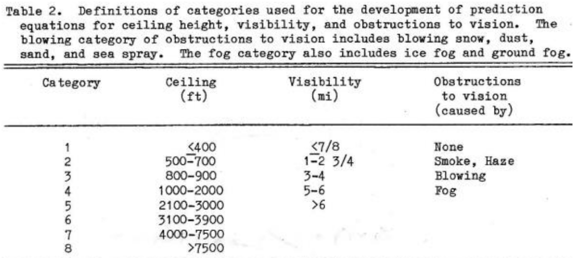


Table 2. Definitions of categories used for the development of prediction equations for ceiling height, visibility, and obstructions to vision. The blowing category of obstructions to vision includes blowing snow, dust, sand, and sea spray. The fog category also includes ice fog and ground fog.

Category	Ceiling (ft)	Visibility (mi)	Obstructions to vision (caused by)
1	≤400	≤7/8	None
2	500-700	1-2 3/4	Smoke, Haze
3	800-900	3-4	Blowing
4	1000-2000	5-6	Fog
5	2100-3000	>6	
6	3100-3900		
7	4000-7500		
8	>7500		

Fig. XII-13. Discrete categories used in development. (From NWS 1984a.)

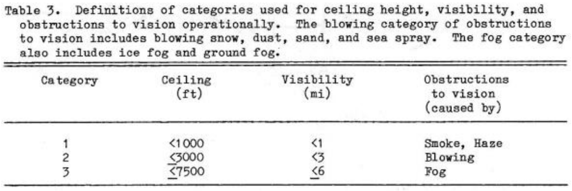


Table 3. Definitions of categories used for ceiling height, visibility, and obstructions to vision operationally. The blowing category of obstructions to vision includes blowing snow, dust, sand, and sea spray. The fog category also includes ice fog and ground fog.

Category	Ceiling (ft)	Visibility (mi)	Obstructions to vision (caused by)
1	<1000	<1	Smoke, Haze
2	≤3000	<3	Blowing
3	≤7500	≤6	Fog

Fig. XII-14. Cumulative categories used for dissemination. (From NWS 1984a.)

Forecasts were made out to the 42-h projection at 6-h intervals starting at 12 h.

The formats of the bulletins transmitting the wind forecasts for marine sites along the coasts were compressed (NWS 1984b) to provide communication space for a new product—wave forecasts for six sites in Chesapeake Bay (NWS 1984c). At the same time, in March or April 1984, the number of wind forecast sites was increased from 68 to 91 (see Fig. XII-10 for the original sites). The wind forecasts continued to be based on the LFM II model and were inflated. Forecasts were made for projections every 3 h from 6 to 48 h. The wave forecasts were based on the Sverdrup-Munk-Bretschneider method (Pore 1983a, b) and depended on wind speed, fetch length, duration time, and water depth for the shallow bay. The actual equation is given in NWS (1984b). Later, in December 1990, the input was changed for the Chesapeake Bay wind and waves from the LFM to the NGM (NWS 1990). The six sites with wave forecasts are shown in Fig. XII-15, taken from a supplement to TPB 340 (NWS 1984d) issued in June 1984.

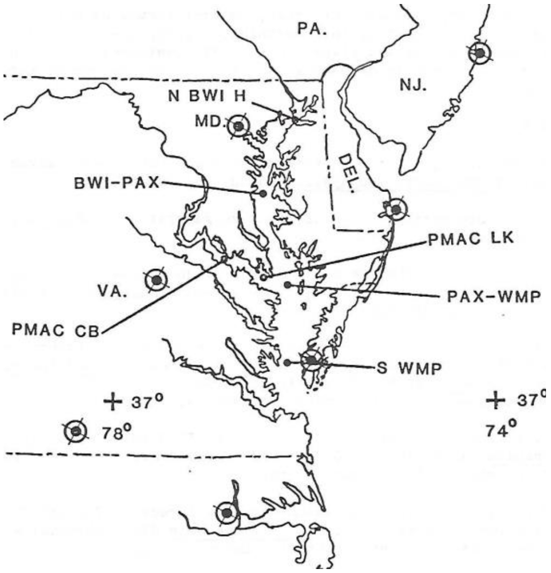


Fig. XII-15. The six sites (labeled) for which wave forecasts were made and distributed. (From NWS 1984d.)

The general thunderstorm and severe weather probabilities for the eastern and central CONUS 2 to 6 h in advance were continued (NWS 1984e; Charba 1977, 1979a, b). More data were available for development (5 years for spring and summer equations), and the product was extended to the cool season (2 years of data), so the probabilities were available for all months. The thunderstorm predictand was defined as the occurrence or nonoccurrence of a manually digitized radar (MDR) intensity code value of three or more within square areas 75 to 85 km on a side during a 4-h period (see Fig. IX-17). Because four MDR boxes fit inside areas this size, the predictand was defined as the highest MDR value in the four boxes included. The severe storms predictand was defined as the occurrence or nonoccurrence during a 4-h period of one or more tornadoes, hail ¾ inch or greater in diameter, surface wind gusts greater than 50 kt, or wind damage in an area four times the area for thunderstorms.

Great care was taken in defining the predictors. As a last step, each predictor was "linearized" with respect to the predictand relative frequency. A linearized variable was developed by first deriving, from the dependent sample, a histogram that related the predictand relative frequency to the predictor variable. The linearized variable was then evaluated by referring to the histogram to obtain the predictand relative frequency corresponding to the value of the variable. This procedure was applied separately for each predictand and each geographic region. Thresholds were derived to apply to the probabilities to make categorical forecasts that maximized the threat score. Biases ranged generally from 1.0 to 1.5. One of the methods of providing the information to forecasters was in a graphic produced for AFOS; an example is shown in Fig. XII-16.

From 1965 until August 1973, the NWS used perfect prog regression equations to produce maximum (max) and minimum (min) temperature guidance. Since then, most of the temperature guidance out to 60 h was generated by the MOS method. As of October 1984, MOS equations based on the LFM were used to produce max and min guidance and also temperature and dew point guidance at 3-h intervals from 6 to 51 h after model run time. Perfect prog was still used for 72-h max/min forecasts as our sample of LFM forecasts did not extend to 72 h. Max and min temperatures were for calendar-day periods. Equations were for 3-month seasons for MOS and 2-month periods for perfect prog.

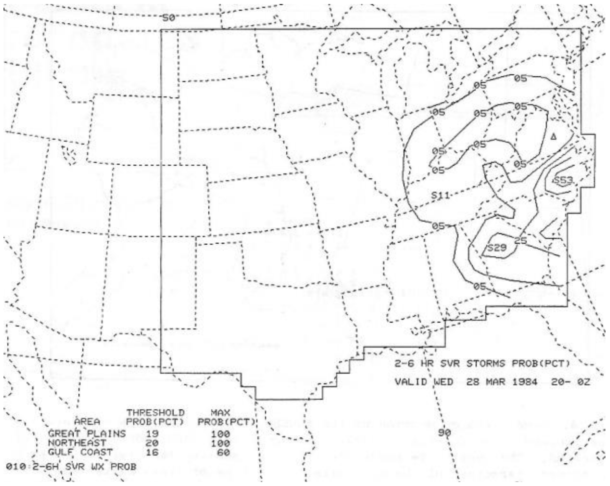


Fig. XII-16. An example of the 2-6 h severe storms probability chart on AFOS valid 2000-0000 UTC March 28, 1984. Labeled maximum values are preceded with the letter "S." The maximum possible and threshold probabilities are given in the legend. (From NWS 1984e.)

Equations for max and min and for the 3-h forecasts were developed simultaneously so that the forecasts would tend to be consistent. However, consistency is not guaranteed by the process, and if max or min was inconsistent with the 3-h values, the inconsistent max or min was corrected to agree; details are given in NWS (1984f). Dallavalle (1984) discusses performance during a record-breaking cold spell. Primary equations included observed values, and to make forecasts when the observation was missing, backup equations were used that omitted the observation.

The surface wind prediction system was updated in 1983 with data from the years 1977-82 (NWS 1985a). The predictors were from LFM II, but for the last couple of years, the LFM involved fourth-order computations, so the sample was mixed in that regard. The first and second harmonics of the day of the year were screened, as well as the observations taken 3 h after model run times of 0000 and 1200 UTC. The practice of adjusting the speed forecasts by inflation was continued. Most equations for the 267 stations were single-station, but for a few stations where an adequate sample was not available, a regional equation was used. Forecasts were produced at 6-h intervals from 6 through 48 h. The FOUS messages and "flight weather" graphics (Fig. XII-2) were continued.

Maintenance of the costal wind prediction system was being done by NMC after a TDL employee transferred there, but the TDL software system and archives were still being used. All equations were rederived because of changes to the input LFM II model (NWS 1985b). A few locations were added. In conjunction with this update, a system to predict Santa Ana wind conditions was developed and a separate bulletin created (Burroughs 1983). The six sites in this specific application of surface winds is shown in Fig. XII-17 (NWS 1985c).

Fig. XII-17. The six sites (black dots) for which Santa Ana wind forecasts were developed. (From NWS 1985c.)

In 1985, the max/min temperature forecasts for the CONUS became daytime/nighttime. Previously, forecasts were for calendar day max and min, defined to be from local midnight to midnight; this definition was for convenience. Synoptic reports, from which the observations were initially taken were in terms of UTC. Observations were not taken with reference to daytime and nighttime (sunrise and sunset). For this new definition, "daytime" and "nighttime" had to be defined. For this purpose, for the cool season (October-March), daytime was defined as 9 a.m. to 7 p.m. local standard time (LST); nighttime was from 7 p.m. to 9 a.m. LST. For the warm season, daytime was defined as 8 a.m. to 7 p.m. and nighttime from 7 p.m. to 8 a.m. LST. An algorithm was devised to derive the pertinent predictand value from a series of surface temperature reports at 3-h intervals and from the corresponding calendar day max/min reports (NWS 1985d).

Calendar day max/min temperature forecasts became daytime/nighttime in 1985.

Extensive evaluation (Reap 1986) of cloud-to-ground lightning strike reports from the Bureau of Land Management's (BLM) automated network clearly showed the ability of the lightning strike data to accurately delineate convective activity over the western United States. These lightning data were used as predictands in developing 6-h thunderstorm probability forecasts for the West that appeared on AFOS (NWS 1985e). They were for the intervals 0-6, 6-12, 12-18, and 18-24 h after 0000 UTC. They were for blocks ¼ the areal size (~47 km in each direction) as the 12-h thunderstorm forecasts based on MDR data (NWS 1983c). A thunderstorm was defined as a block in a 6-h period having two or more lightning strikes. Predictors were from the LFM model and TDL's LFM-based three-dimensional trajectory model. The sample consisted of data from 3 summer seasons 1983-85.

Lightning strike data were used as a proxy for thunderstorms.

Generalized, 12-predictor equations for the four time periods were derived simultaneously; each equation had the same predictors with appropriate projections. The most important predictor was the linearized K stability index times the daily relative frequency of two or more lightning strikes within the 47-km box. Linearizing, to assure the relationship between the predictor and predictand was linear, was done in the same manner described above for the

2- to 6-h thunderstorm and severe weather probabilities. An example graphical forecast with verifying counts of lightning strikes is shown in Fig. XII-18. The forecasts were provided for each gridpoint, then contoured with an AFOS applications program on-station.

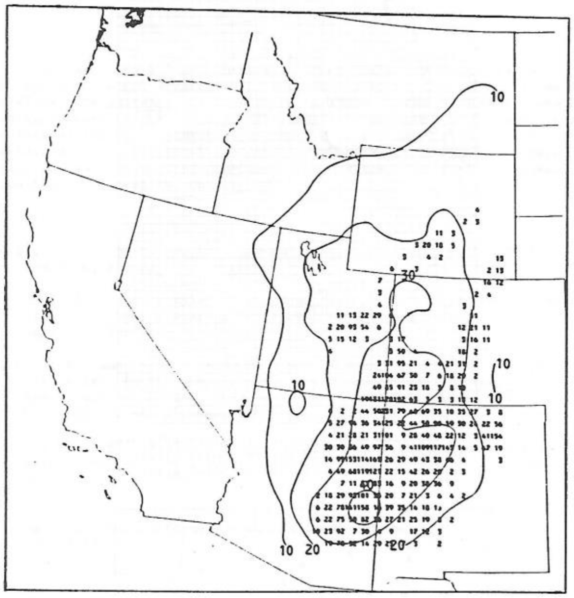
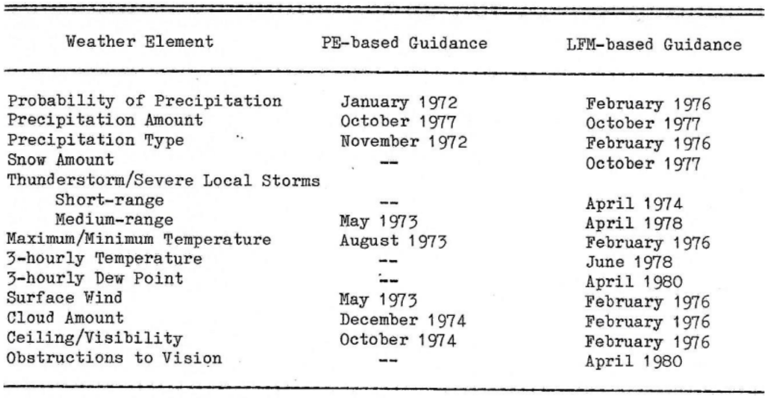


Fig. XII-18. Forecasts of the probability of two or more lightning strikes during the 18-24 h projection on September 15, 1985, following 0000 UTC. The number of observed strikes is plotted in each grid box when ≥ 2. (From NWS 1985e.)

TDL started producing guidance forecasts in 1968. The first MOS forecasts were for the eastern United States and were based on the TDL SAM model. In that same year, perfect prog max and min temperatures were implemented nationwide. In 1972, the transition had started to produce forecasts based on NMC's primitive equation (PE) model. While the PP products were still produced, the primary guidance for max and min shifted to MOS. Most forecasts were migrated to the LFM model (essentially the same as the PE model, but run with a smaller grid spacing over a smaller area). The year each weather element was first produced on the PE and LFM models is shown in Fig. XII-19, reproduced from Carter et al. (1983). That same publication contains a bibliography of papers dealing with statistical guidance up to that date. In 1987, the guidance began to shift to the Nested Grid Model (NGM). A vital adjunct to the development and implementation of the guidance products was the consistent and comprehensive verification documented in semi-annual reports of the public and aviation forecasts produced by TDL guidance.



Weather Element	PE-based Guidance	LFM-based Guidance
Probability of Precipitation	January 1972	February 1976
Precipitation Amount	October 1977	October 1977
Precipitation Type	November 1972	February 1976
Snow Amount	--	October 1977
Thunderstorm/Severe Local Storms		
Short-range	--	April 1974
Medium-range	May 1973	April 1978
Maximum/Minimum Temperature	August 1973	February 1976
3-hourly Temperature	--	June 1978
3-hourly Dew Point	--	April 1980
Surface Wind	May 1973	February 1976
Cloud Amount	December 1974	February 1976
Ceiling/Visibility	October 1974	February 1976
Obstructions to Vision	--	April 1980

Fig. XII-19. Approximate month and year of operational implementation for types of MOS guidance for the CONUS. (From Carter et al. 1983.)

For several years, starting in 1976 (Carter et al. 1976), TDL comparatively verified for 6-month seasons TDL's guidance and the official local forecasts in the aviation and public programs. This series of reports ended with the 16th being printed in 1984 (Carter et al. 1984a). This verification was done in collaboration with the Technical Procedures Branch of the Office of Meteorology and Oceanography in conjunction with the combined aviation/public weather verification system then in operation (NWS 1973). The local forecasts were made by forecasters at the Weather Service Forecast Offices. They were recorded daily for the purpose of verification under instructions that the value recorded be ". . . not inconsistent with. . . ." the official weather forecasts. Surface observations as late as 2 h before the first verification time may have been used in their preparation. The observations used to verify the forecasts were, at least initially, obtained from the National Weather Records Center in Asheville, North Carolina.

The objective forecasts were from the "final" package produced by MOS; these forecasts were based on NMC's PE and/or LFM models, and possibly on TDL's trajectory model. Verification statistics were provided for opaque sky cover, precipitation type, surface wind, ceiling height, and visibility over 6-month seasons for 92 of the 233 stations for which TDL provided guidance forecasts.

The first such report concluded:

> "This verification shows that, overall, TDL's aviation/public weather guidance forecasts compare very favorably with local forecasts produced at WSFO's. In particular, automated guidance is substantially better than local predictions for opaque sky cover and surface wind for the 30- and 42-hour projections, and for precipitation type for all projections. While both the objective and subjective estimates of ceiling and visibility are generally poorer than persistence forecasts for the initial (12-hour) projection, they are generally more accurate for longer periods. However, the bias characteristics of the objective estimates require improvement to meet the needs of users of these two products."

Valery Dagostaro played an important role in verifying MDL guidance and official forecasts.

A number of changes occurred over the course of the 9 years covered by these 16 reports; the changes can be found in the individual office notes. The comparative quality of the official and guidance forecasts varied by weather element, cycle time (0000 or 1200 UTC), and projection of the forecasts. Suffice to say, this series of reports caught the attention of forecasters and management and undoubtedly contributed to the success of TDL's guidance forecasts.

In the same year as the 16th and last such report (Carter et al. 1984a), a new verification series was started (Carter et al. 1984b) based on another verification process that utilized the AFOS verification system to which TDL had contributed, and would contribute, substantially (Heffernan 1983; Heffernan et al. 1980, 1983; Ruth and Alex 1987). A National Verification Task Team (NVTT) had been formed by the NWS Deputy Director Bill Bonner in 1980, and a report, the *National Verification Plan* (NWS 1982j), resulted in 1982.[3] Software was written that had both central and local AFOS components. The processing of data and computation of metrics

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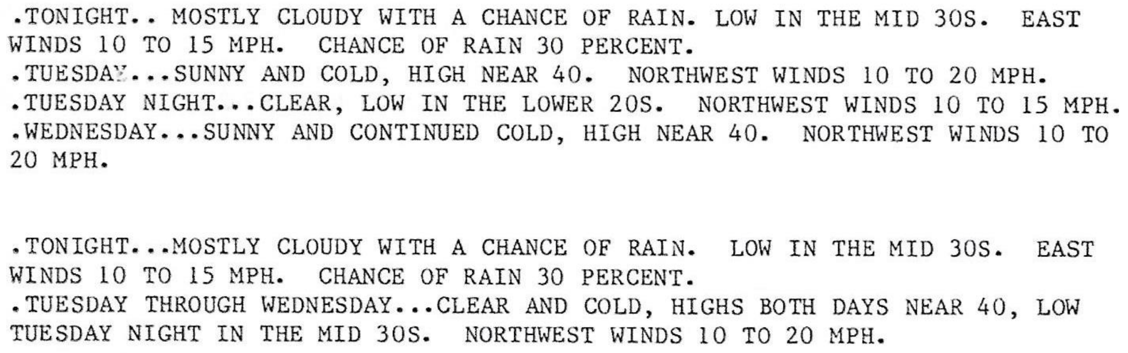
[3] The NVTT morphed into the NWS National Verification Committee (NVC), and the NVC held its first meeting in Seattle in July 1982. The NVC was in existence and held regular meetings for approximately 10 years. It guided the NWS verification of local forecasts during that time. It ceased to function as a committee soon after funds for the centrally funded meetings were not made available. Its 14th and last formal meeting was in September 1989. A full set of committee meeting notes is filed in MDL. The committee's influence lasted for years after its demise.

followed this national plan. Verification reports were published by TDL in the office note series and by the Office of Meteorology and Oceanography in the FCST series (e.g., Polger 1983).

By 1985, work had been completed to combine periods in the CWF, and Bermowitz (1987) reported that after almost 2 years of twice daily running, the selected criteria for combining “work quite well.” Criteria for combining, or not, are quite complex. It was decided to base the combining decisions on the phrases chosen for making the forecast before the period-combining step instead of looking at the values of all the individual weather elements. An example four-period forecast with and without combining provided by Bermowitz (1987) is shown in Fig. XII-20.



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.TONIGHT.. MOSTLY CLOUDY WITH A CHANCE OF RAIN. LOW IN THE MID 30S.  EAST
WINDS 10 TO 15 MPH.  CHANCE OF RAIN 30 PERCENT.
.TUESDAY...SUNNY AND COLD, HIGH NEAR 40.  NORTHWEST WINDS 10 TO 20 MPH.
.TUESDAY NIGHT...CLEAR, LOW IN THE LOWER 20S.  NORTHWEST WINDS 10 TO 15 MPH.
.WEDNESDAY...SUNNY AND CONTINUED COLD, HIGH NEAR 40.  NORTHWEST WINDS 10 TO
20 MPH.


.TONIGHT...MOSTLY CLOUDY WITH A CHANCE OF RAIN.  LOW IN THE MID 30S.  EAST
WINDS 10 TO 15 MPH.  CHANCE OF RAIN 30 PERCENT.
.TUESDAY THROUGH WEDNESDAY...CLEAR AND COLD, HIGHS BOTH DAYS NEAR 40, LOW
TUESDAY NIGHT IN THE MID 30S.  NORTHWEST WINDS 10 TO 20 MPH.
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Fig. XII-20. Four-period CWF with periods separate (top) and with combined periods (bottom). (From Bermowitz 1987.)

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CHAPTER XIII

THE NGM MAKES ITS PLAY

The NWP models in operations at NMC changed as improvements were made. This might be modest changes within an existing model, or it might be a new model. The model that implemented the "primitive equations" developed primarily by Fred Shuman (Shuman and Hovermale 1968) replaced earlier models. The limited area version of it, called the Limited Area Fine-Mesh (LFM) model developed by Jim Howcroft (NWS 1971)[1] ran in parallel with the PE and by constant attention surpassed the PE as a better source of input to MOS. Later still, Norman Phillips developed the Nested Grid Model (Phillips 1979)[2] and it was implemented in March 1985 as part of the Regional Analysis and Forecast System (RAFS) (DiMego 1988; Hoke et al. 1989). We intended to migrate MOS to it. Unfortunately, for the first implementation, a sufficient sample of NGM data was not available to support MOS development, so a modified perfect prog method was used (NWS 1987a; Erickson 1988, Erickson et al. 1992). The weather elements included in this development were daytime/nighttime max/min temperature, probability of precipitation, cloud amount, and surface wind; implementation was in May 1987 (Carter et al. 1989) for about 200 stations. This was an interim solution used to supplement the complete LFM MOS package (Dallavalle 2020).

Mary Erickson was a section chief and a developer of MOS and PP forecast systems in TDL.

After some discussion and experimentation, Norm Phillips and Jim Hoke became convinced of the need for NGM MOS guidance. Consequently, Hoke established a mechanism whereby TDL MOS developers could rerun the NGM on the Cyber 205 supercomputer for a 1-year sample of October 1986 through September 1987 (Dallavalle 2020). Reruns began in August 1988 and were completed by December that same year. The development of MOS warm season equations based on 2 years of data started immediately. This was a milestone, marking the first time that an operational NWS model was rerun to support statistical development (Dallavalle 2020).

NGM reruns were made to support statistical development in 1988.

A new very short-range precipitation forecasting system was implemented in May 1987 (NWS 1987b). The predictands were amounts in cumulative ranges ≥ 0.25, ≥ 0.50, ≥ 1.00, and ≥ 2.00 inches in each of the two overlapping 6-h periods, 0-6 and 3-9 h after the synoptic times 0000 and 1800 UTC. The initial implementation was for "spring" equations; equations were implemented for the other three seasons at the appropriate times. The system was later expanded to issuance times of 0600 and 1200 UTC. The forecasts were for boxes approximately 40 n mi on a side, the boxes being within seven regions for equation

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[1] Howcroft was a U.S. Air Force officer assigned to NMC and was charged by George Cressman, Weather Bureau Chief, with developing a smaller scale version of the PE. This was not without difficulties, but eventually the effort paid off. Documentation was provided by Newell and Deaven (1981).

[2] It was called affectionately by punsters at NMC Norm's Good Model.

development. Eight years of data were available. The amounts of precipitation came from the climatological network consisting of approximately 3,000 stations over the CONUS. The specific value in each box was the percentage of all stations in the box having the specific amount of precipitation in the categories stated above. Predictors were from (1) objectively-analyzed surface variables observed hourly, (2) 6-18 h forecasts from the LFM model, (3) manually digitized radar reports, and (4) local climatological relative frequencies of the predictand categories. The equations gave a probability forecast in each box for each amount. The probabilities were transformed into a specific amount forecast by maximizing the threat score. This operational product followed the experimental system described by Charba (1983). Other details are contained in Charba (1987, 1990), Charba and Moeller (1989), and Charba et al. (1988).

A problem showed up with LFM-based MOS cloud predictions for the CONUS. Occasionally, clear skies would be forecast in the middle of areas of heavy precipitation. This was traced to the use of LFM precipitation as a continuous predictor. Regression coefficients allowed this to happen in this very sparse data region (collinearity). As a consequence, the equations for forecasting opaque cloud amount were rederived omitting LFM precipitation as a continuous variable and including it only as a binary (NWS 1988). The sample was also increased; eight cool and nine warm seasons of data were used ending in 1987. The predictands were for the discrete categories clear, scattered, broken, and overcast. Fifteen regions were defined for each of the cool and warm seasons to house 204 stations. From the probabilities of these categories made from the regression equations over the developmental sample, thresholds for clear, scattered, and broken were derived such that when the probability of clear exceeded its threshold, clear would be forecast. When it didn’t, thresholds developed for clear plus scattered and clear plus scattered plus broken were used. If the clear plus scattered plus broken threshold was not exceeded, overcast was forecast. Forecasts were implemented in February 1988 for both 0000 and 1200 UTC cycles for projections every 6 h from 6 to 60 h. Observations were included when available for projections up though 24 h. The same modes of dissemination were used as were used previously. In distinction to the previous development for cloud, equations were not developed simultaneously with ceiling. Therefore, the cloud and ceiling forecasts were less likely to be in agreement than previously.

Networks to record lightning strikes were being implemented across the country. Previously, a system for making thunderstorm forecasts had been implemented for the West. Now a very similar procedure was used to make thunderstorm forecasts for four 6-h periods over the Kansas/Oklahoma area and the northeast U.S. (NWS 1990a). The lightning data for those two areas were acquired from the National Severe Storms Laboratory (NSSL) and the State University of New York at Albany (SUNYA), respectively. The forecasts provided were probabilities of two or more strikes within a 47-km box and a 6-h period. Fig. XIII-1 shows the FAR, POD, and CSI for various thresholds to convert the probabilities into a categorical forecast of a thunderstorm (proxied by two strikes). The plotted biases along the POD line show that to maximize the CSI, the bias should exceed unity. This is a well-known empirical rule; a small increase in bias over unity tends to maximize the CSI. The rule is not exclusive to thunderstorm prediction.

The LFM-based PoP forecast system that had been in place for several years was replaced. New regions were defined and a full 10-year sample of data was available. Forecasts were for 6- and 12-h periods out to 60 h. Equations for some predictands were developed simultaneously to enhance consistency across forecast ranges (6- and 12-h) and projections. The usual warm and cool seasons were used to develop regression equations, and surface observations were used as predictors to screen for projections ≤ 24 h. Preimplementation tests indicated improvement over the replaced system of a few percent. NWS (1990b) indicates the forecasts were distributed widely in both alphanumeric and graphical forms: (1) on AFOS in FOUS12, (2) AFOS graphic NMC-GPH04P (etc.), (3) FOUS22, and (4) DIFAX D068 (etc.).

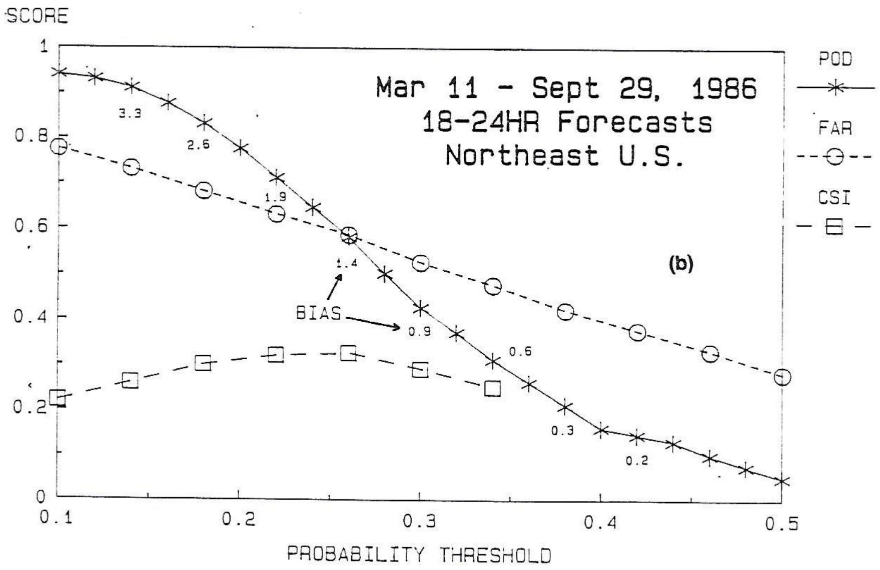

Fig. XIII-1. POD, FAR, and CSI for the 18-24 h thunderstorm forecasts with various thresholds shown along the abscissa. Biases are plotted along the POD line. (From NWS 1990a.)

Eli Jacks was a developer of forecast systems in TDL.

The NGM data, which came from reruns and operational runs that ended in December 1988 (discussed above), were used for development of an NGM CONUS MOS package and implemented for the warm season in July 1989 and the cool season in October (NWS 1990c; Jacks et al. 1990). This consisted of daytime/nighttime max/min temperature, probability of precipitation, cloud amount, and surface wind for the same 204 stations used previously. This new package replaced the NGM PP package implemented in May 1987. Development of each element basically followed past practices. Note the short time between the last rerun date (December 1988) and the implementation date (July 1989).

First NGM-based MOS package was implemented in July 1989.

Starting in February 1990, 12-24, 24-36, and 36-48 h net vertical displacement fields from the TDL NGM-based trajectory model (NWS 1978; Reap 1972) were transmitted on the AFOS communications system. These displacement fields were designed for use with 850-mb temperature forecasts as input to a technique that predicted both the occurrence of snow and snowfall amounts (NWS 1990d; Chaston 1989). The technique, originally developed at WSFO Milwaukee, Wisconsin, was dubbed "the magic chart."

TDL trajectory model was input to the magic chart.

The Alaska Region of the NWS requested that TDL supply thunderstorm forecasts for Alaska to help them identify regions of potential wildfire activity caused by lightning. Using methods developed for the western U.S., TDL implemented thunderstorm forecasts in May 1991 (NWS 1991; Reap 1990). As in previous work, BLM lightning strike data were the basis of the predictand data over 47-km blocks. Based on 1200 UTC NGM predictors, the forecasts were for the projection periods 6-18 and 30-42 h; based on 0000 UTC NGM predictors, the forecasts were for the projection period 18-30 h. Forecasts were provided for the May 15 to September 15 warm season. The forecasts were transmitted via high-speed digital line to the PR1ME computer at WSFO Anchorage and were fanned out from there.

TDL's trajectory model[3] had been running at NMC/NCEP for over 2 decades. At present, two versions were being run. One was driven by wind forecasts from the LFM and producing forecasts at a 24-h projection. The more recent version was driven by wind forecasts from the NGM and was run twice daily producing forecasts for projections of 24, 36, and 48 h after initial time. Since the initial TPB on the subject, numerous improvements had been made. NWS (1992) describes the current model as it was being run in 1992. Backward trajectories were computed, separately for each valid time. Air-sea energy exchanges were added to give better forecasts along the coasts. Trajectories were not allowed to intersect the earth's surface and were displaced by the underlying terrain. The beginning points of the trajectories were calculated by an algorithm that emphasized flow along the trajectories. Output from the model had numerous applications to forecasting.


David Miller was a U.S. Air Force officer stationed at TDL. He developed wind, ceiling height, and other aviation-related MOS weather forecast systems.

The initial NGM CONUS MOS forecast package implemented in 1989 for 204 stations was based on 2 years of data. Portions of it were soon updated. For instance, wind forecast equations were implemented for 666 stations in October 1991 (NWS 1993a). The increase in number of stations was made possible by using TDL's hourly data archive instead of data purchased from NWRC in Asheville. Also, using the new archive, we increased the projections from every 6 h to every 3 h out to 60 h. By this time, we had over 4 years of NGM forecasts for development. Significant with this development, also, was the inclusion of single-station equations for several military stations. The Air Force, through its team stationed at TDL, prepared predictand data for military sites which made possible the switch to single-station equations from regional equations based on other than military sites (Glahn 1983). A special bulletin was established for the Air Force. Forecasts were needed at some stations that did not have enough

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[3] TDL's initial trajectory model was largely based on one developed by Joe Friday and staff at the Global Weather Center, U.S. Air Force, Offutt, Nebraska (Collins 1970).

data for single-station equations, so regional equations were also developed; these could be applied to any location. Equations for the two earth-oriented wind components and for speed were developed simultaneously for each projection, and the speeds were inflated. Speed forecasts were verified on independent data for 203 stations and compared to the previous NGM-based forecasts and to LFM MOS forecasts in terms of Heidke skill score. The results, shown in Fig. XIII-2, indicate the new forecasts were more skillful.

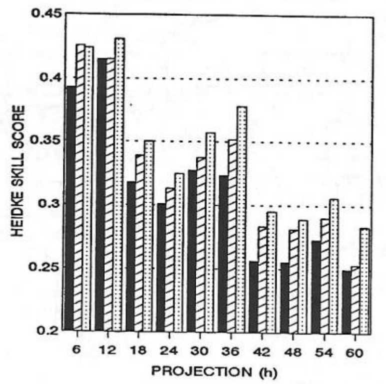
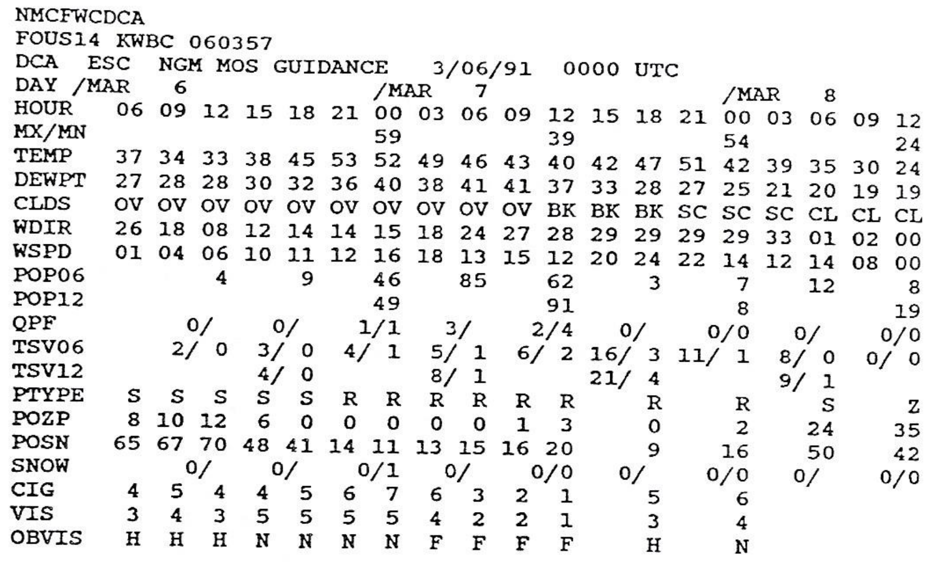


Fig. XIII-2. Heidke skill scores for LFM (black), old NGM (checked), and the new NGM (dotted) MOS wind speed forecasts. (From NWS 1993a.)

TPB 408 (NWS 1993b) briefly documents the enhanced NGM package for the CONUS; each element is addressed although compete documentation of individual elements was written later and is summarized in this chapter in the order the TPBs were written. The weather elements described in TPB 408 are daytime/nighttime max/min temperature; surface temperature and dew point; opaque cloud cover; surface wind speed and direction; PoP for 6- and 12-h periods; quantitative precipitation for 6- and 12-h periods; probability of thunderstorms and the conditional probability of severe thunderstorms for 6- and 12- periods; conditional probability of precipitation type (freezing, snow, or liquid) and a corresponding category; snow amount; and categories of ceiling height, visibility, and obstruction to vision. The example reproduced from TPB 408 is shown in Fig. XIII-3. The QPF system was eventually documented in TPB 461 (NWS c. 2000).



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NMCFWCDCA
FOUS14 KWBC 060357
DCA   ESC   NGM MOS GUIDANCE   3/06/91  0000 UTC
DAY /MAR    6            /MAR    7                   /MAR    8
HOUR     06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
MX/MN                      59          39          54          24
TEMP     37 34 33 38 45 53 52 49 46 43 40 42 47 51 42 39 35 30 24
DEWPT    27 28 28 30 32 36 40 38 41 41 37 33 28 27 25 21 20 19 19
CLDS     OV OV OV OV OV OV OV OV OV OV BK BK BK SC SC SC CL CL CL
WDIR     26 18 08 12 14 14 15 18 24 27 28 29 29 29 29 33 01 02 00
WSPD     01 04 06 10 11 12 16 18 13 15 12 20 24 22 14 12 14 08 00
POP06           4     9    46    85    62     3     7    12     8
POP12                      49          91           8          19
QPF           0/    0/    1/1   3/    2/4   0/    0/0   0/    0/0
TSV06         2/ 0  3/ 0  4/ 1  5/ 1  6/ 2 16/ 3 11/ 1  8/ 0  0/ 0
TSV12               4/ 0        8/ 1       21/ 4        9/ 1
PTYPE     S  S  S  S  S  R  R  R  R  R  R     R     R     S     Z
POZP      8 10 12  6  0  0  0  0  0  1  3     0     2    24    35
POSN     65 67 70 48 41 14 11 13 15 16 20     9    16    50    42
SNOW          0/    0/    0/1   0/    0/0   0/    0/0   0/    0/0
CIG       4  5  4  4  5  6  7  6  3  2  1     5     6
VIS       3  4  3  5  5  5  5  4  2  2  1     3     4
OBVIS     H  H  H  N  N  N  N  F  F  F  F     H     N
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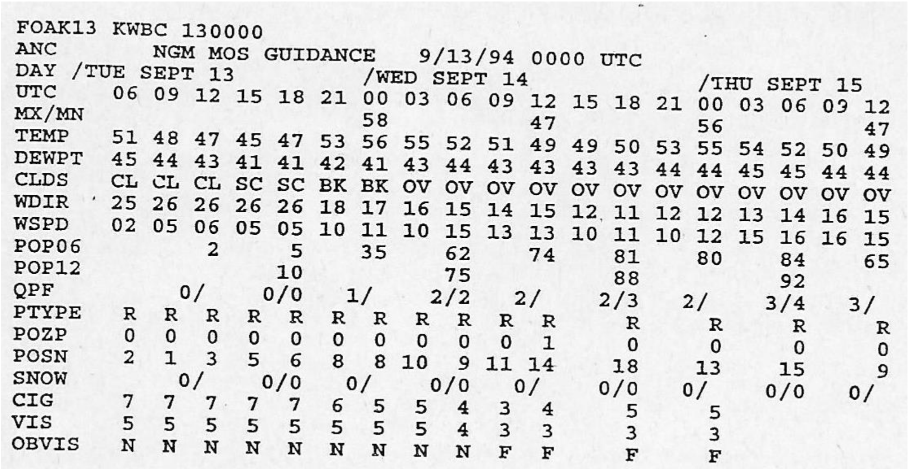
Fig. XIII-3. Example NGM-based MOS bulletin FOUS14 for the CONUS. (From NWS 1993b.)

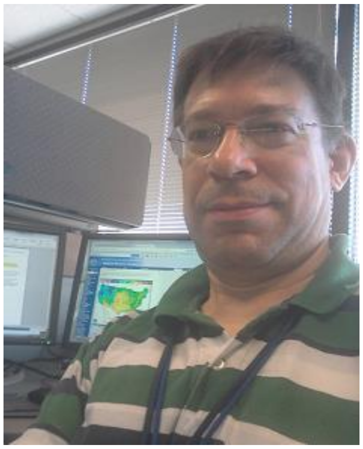
Very similar to TPB No. 408 that pertained to the CONUS, TPB No. 425 (NWS 1995a) was written that pertained to Alaska. These were overarching documents that briefly explained the whole bulletins, and were written before detailed TPBs could be written about each weather element. More detail on wind development is given in TPB 439 (NWS 1997b). An example bulletin for Alaska is shown in Fig. XIII-4.



```
FOAK13 KWBC 130000
ANC          NGM MOS GUIDANCE   9/13/94 0000 UTC
DAY /TUE SEPT 13           /WED SEPT 14           /THU SEPT 15
UTC       06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
MX/MN                       58          47          56          47
TEMP      51 48 47 45 47 53 56 55 52 51 49 49 50 53 55 54 52 50 49
DEWPT     45 44 43 41 41 42 41 43 44 43 43 43 43 44 44 45 45 44 44
CLDS      CL CL CL SC SC BK BK OV OV OV OV OV OV OV OV OV OV OV OV
WDIR      25 26 26 26 26 18 17 16 15 14 15 12 11 12 12 13 14 16 15
WSPD      02 05 06 05 05 10 11 10 15 13 13 10 11 10 12 15 16 16 15
POP06            2     5    35    62    74    81    80    84    65
POP12                 10          75          88          92
QPF              0/   0/0    1/   2/2    2/   2/3    2/   3/4    3/
PTYPE      R  R  R  R  R  R  R  R  R  R  R     R     R     R     R
POZP       0  0  0  0  0  0  0  0  0  0  1     0     0     0     0
POSN       2  1  3  5  6  8  8 10  9 11 14    18    13    15     9
SNOW             0/   0/0    0/   0/0    0/   0/0    0/   0/0    0/
CIG        7  7  7  7  7  6  5  5  4  3  4     5     5
VIS        5  5  5  5  5  5  5  5  4  3  3     3     3
OBVIS      N  N  N  N  N  N  N  N  N  F  F     F     F
```

Fig. XIII-4. Example NGM-based MOS bulletin FOAK13 for Alaska. (From NWS 1995a.)

The process for developing NGM-based thunderstorm and severe weather probability forecasts changed appreciably, predominantly in defining the predictand (NWS 1993c). Previously, the predictand had been defined by MDR or lightning strike data, and the development had been grid-based. That is, a forecast was made for grid blocks. Forecasts were needed for stations throughout the conterminous U.S. While extremely useful, radar and lightning data pose problems in coverage, consistency over the U.S., and being a reliable proxy for thunderstorms and severe local storms. A new station-based predictand was formed whereby a thunderstorm was defined as either an SAO report of a thunderstorm, an MDR report of VIP3 or greater anywhere in a 9-block area around the station, or a SELS log report of a severe thunderstorm occurrence within the same area (Reap 1993). A severe thunderstorm was defined as either an SAO report of a severe thunderstorm or a SELS log report of a severe thunderstorm. Given that the definition was station-based, the development proceeded much like that for other weather elements. The data were stratified into regions and three seasons—spring (March 16-June 30), summer (July 1-October 15), and cool (October 16-March 15). Forecasts were for 6- and 12-h periods out to 60 h. Equations for each 12-h period and the encompassed two 6-h periods were derived simultaneously to enhance consistency. Specific forecasts were made by using thresholds based on maximized the CSI. This approach gave forecasts directly for stations which were put into the alphanumeric bulletins.



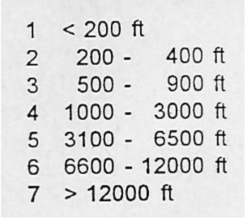
Mark Antolik of TDL developed precipitation and other MOS products.

A new station-based process was used to forecast thunderstorms and severe thunderstorms.

New NGM-based PoP equations were implemented for the CONUS in the fall of 1992 (NWS 1993d). The data sample was increased to 5 years. The use of our hourly data archive gave us 399 stations for development. Use of regional equations allowed us to disseminate forecasts for 717 stations. The usual definition of precipitation was used: ≥0.01 inches of liquid equivalent precipitation within a stated period. Forecasts for 6- and 12-h periods were made for projections out to 60 h. Regions were determined by cluster analysis on correlation coefficients between predictand and specific predictors, but were adjusted significantly for meteorological consistency into 22 regions for the warm season and 25 for the cool season (Su 1993). A new type of predictor, named grid binary, was used. Usually, a binary predictor would take the value of 1 when initially it was above a particular threshold and zero otherwise. A grid of these would be all zeros and ones. Interpolation into this field to a location gives a rather abrupt shift from zero to one across the boundary. The grid binary process was to smooth this binary field before interpolation to give a smooth transition of values between zero and one around the transition zone. Grid binaries were first used by Jensenius (1992).

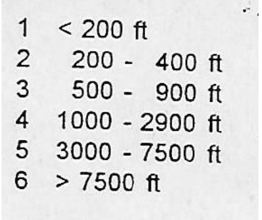
Grid-binary predictors came into use.

Ceiling height forecasts based on the NGM were developed for the CONUS and implemented in January 1993 (NWS 1995b). Forecasts were at 3-h intervals out to 42 h, then every 6 h out to 60 h. The predictands were seven discrete binaries shown in Fig. XIII-5; these differed slightly from those used previously for LFM-based guidance (see Fig. XIII-6). The changes were partly based on the ASOS observation of ceiling height being limited to 12,000 ft. The predictors screened for selection are shown in Fig. XIII-7. This list is shown to indicate the diversity of information considered, which was typical of MOS developments. Most model predictors were smoothed with 5-, 9-, or 25-point smoothers. Predictors were continuous, cumulative point binary, or cumulative grid binary. Regions were based largely on the relative frequency of ceilings < 1,000 ft. Equations for all categories for a specific projection were developed simultaneously. Predictor selection continued until 15 were chosen or until the next best reduced any category variance by < 0.1 %. While the probabilities of the 7 categories sum to 1.0, an individual category can be < 0 or > 1.0. We set all values to within the definitional limits of probability, then divided each value by the resulting sum. This "standardized" the probabilities, a process used for many elements forecast in



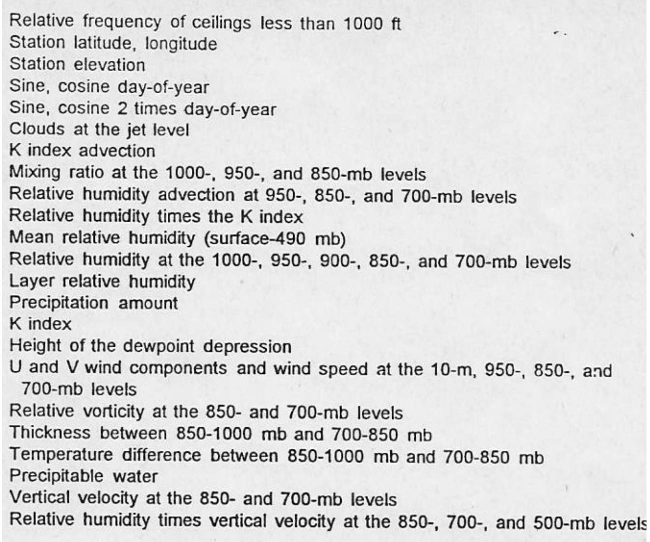
1	< 200 ft
2	200 - 400 ft
3	500 - 900 ft
4	1000 - 3000 ft
5	3100 - 6500 ft
6	6600 - 12000 ft
7	> 12000 ft

Fig. XIII-5. Ceiling height categories for NGM MOS. (From NWS 1995b.)



1	< 200 ft
2	200 - 400 ft
3	500 - 900 ft
4	1000 - 2900 ft
5	3000 - 7500 ft
6	> 7500 ft

Fig. XIII-6. Ceiling height categories for LFM MOS. (From NWS 1995b.)



Relative frequency of ceilings less than 1000 ft
Station latitude, longitude
Station elevation
Sine, cosine day-of-year
Sine, cosine 2 times day-of-year
Clouds at the jet level
K index advection
Mixing ratio at the 1000-, 950-, and 850-mb levels
Relative humidity advection at 950-, 850-, and 700-mb levels
Relative humidity times the K index
Mean relative humidity (surface-490 mb)
Relative humidity at the 1000-, 950-, 900-, 850-, and 700-mb levels
Layer relative humidity
Precipitation amount
K index
Height of the dewpoint depression
U and V wind components and wind speed at the 10-m, 950-, 850-, and 700-mb levels
Relative vorticity at the 850- and 700-mb levels
Thickness between 850-1000 mb and 700-850 mb
Temperature difference between 850-1000 mb and 700-850 mb
Precipitable water
Vertical velocity at the 850- and 700-mb levels
Relative humidity times vertical velocity at the 850-, 700-, and 500-mb levels

Fig. XIII-7. Predictors screened for the ceiling regression equations. (From NWS 1995b.)

multiple categories. Categorical forecasts were made by comparing each probability, starting at the low ceiling end, to a threshold devised to give unity bias to cumulative from below categories, cumulative categories being devised from the discrete category probabilities.

New gridded NGM-based thunderstorm and severe local storm forecast equations were developed (NWS 1994a). The predictand for thunderstorms was lighting strike data obtained from SUNYA, NSSL, and BLM; combined they covered the conterminous United States. Predictand blocks were approximately 48 km on a side. The predictand for severe local storms came from the NSSFC event logs. Procedures for development were much like those used previously for the LFM-based product. From the forecasts, an automated convective outlook chart was prepared (Reap 1983, Reap et al. 1982). This was done to aid NSSFC in preparing their convective outlooks.

Snow amount forecasts based on the NGM were implemented for over 500 sites in the CONUS in 1993 and for 60 sites in Alaska in 1994 (NWS 1994b). The forecasts were in categories of no snow, amounts ≥ trace to < 2 in., 2 to < 4 in., 4 to < 6 in., and ≥ 6 in. for 12-h periods, and for no snow, amounts ≥ trace to < 2 in., and ≥2 in. for 6-h periods. However, for development, cumulative from below categories were used to better correlate with predictors that were, when binary, cumulative. The predictand data were those from NCDC. Equations were developed for one "snow" season, which was different for Alaska and the CONUS. Thresholds were developed to produce high threat scores with the bias in an acceptable range.

TPB 421 (NWS 1995c) and Erickson (1992) describe the development and implementation of conditional precipitation type forecasts. Three discrete binary variables were defined from observations--snow, liquid, and freezing. The freezing category included ice pellets and all pure and mixed freezing rain and drizzle. Snow included only pure snow events. Liquid included pure rain and drizzle as well as liquid and snow mixed. These definitions were changed from those used in developing LFM-based MOS, in that ice pellets was moved from frozen to freezing. Logit transformations were applied to the 850-mb temperature, 1000-500 mb thickness, and 850-700 mb thickness to form additional predictors. Quoted from NWS (1995c):

> "Logit transformations were used because they provide a good method of fitting a binary predictand with a continuous predictor. In our particular application, a separate logit relationship was determined between the occurrence of snow and each of the thermal variables mentioned previously. In addition, separate logit transformations were derived for each station available in the developmental sample. When performing each logit analysis, NGM forecasts interpolated to a station and the corresponding surface observations for 18 and 24 hours after both 0000 and 1200 UTC were combined into one sample. The result of the logit transformations was the creation of predictors which essentially provide a single-station conditional probability of snow based on the NGM forecasts of the 850-mb temperature, 1000-850 mb thickness, or 850-700 mb thickness."

Logit transforms as a way of making regional equations specific to stations became standard practice for snow amount and precipitation type predictands.

The developmental sample consisted of 474 stations in the CONUS and 39 in Alaska. The equations for the three types were developed simultaneously and the forecasts normalized. Some predictors were surface observations; when in operations an observation was missing, a backup equation that did not use the observation was used. Thresholds chosen on the basis of unity bias were used to make the categorical forecasts, starting from the rarest freezing category. Verification showed the NGM-based forecasts to be better than the LFM-based forecasts. Comparison with local official forecasts, provided through the national AEV forecast program, showed that the objective forecasts were as good as, and in some cases better than, the locally made forecasts.

MOS forecasts of CAT were provided to AWC and HPC starting in 1995.

A completely new type of product was developed and implemented—the probability and categorical forecasts of non-convective clear air turbulence (CAT) (NWS 1996a; Reap 1996). This element was especially difficult, starting with the difficulty of obtaining observations for the predictand. Pilot reports of CAT in PIREPS were in categories 1 through 8 indicating smooth or light to severe. What is reported depends on the weight and other characteristics of the aircraft. Some CAT is due to convection and some is not. Pilots try to stay away from turbulence, and there are few aircraft flying at night, so CAT is underreported. Nevertheless, reports were acquired from the Aviation Weather Center (AWC) for a 3-year period. The PIREP CAT level considered to be CAT for prediction purposes depended on aircraft weight and flight level. CAT reports due to convection were screened out by using lighting data; contemporaneous reports of lighting were considered to indicate convection. Stratification was by warm (March 15-September 30) and cool seasons, high (> 10,000 ft) and low level, eastern and western U.S., and model run time (0000 and 1200 UTC). Forecasts were made for the four projection times (2-8, 8-14, 14-20, and 20-24 h) and for categories of CAT $\geq$ 3 and $\geq$ 5. The forecast probabilities were so low that they were scaled X 20 for display. By careful definition of predictors based on the NGM[4], areas of greatly enhanced likelihood of CAT were produced as shown in Fig. XIII-8. Verification showed the forecasts to be reliable, although the threat score was very low. The forecasts were available to AWC and HPC (Hydrometeorological Prediction Center) beginning in August 1995. AWC was responsible for issuing operational AIRMETS and SIGMETS which are inflight advisories for use by the aviation community.

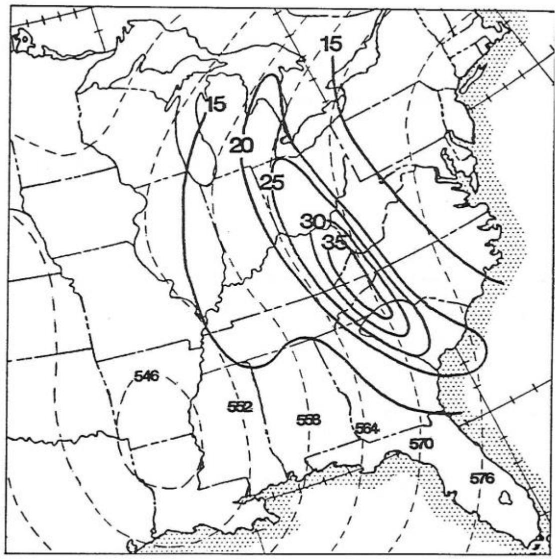


Fig. XIII-8. High band scaled (X20) probabilities (solid lines) for $\geq$ category 3 CAT in 48-km grid blocks 8-14 h from 1200 UTC on Jan. 14, 1995. 500-mb height contours for initial data time are shown in dashed lines. (From NWS 1996a.)

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[4] For instance, one predictor was the 300-mb total deformation times the 300-mb wind speed. Another was the 1000-500 mb mean relative humidity times the K stability index.

NGM-based MOS forecasts of visibility and obstructions to vision had been in operation since 1993. NWS (1996b)[5] describes the development. Probability forecasts of visibility were in five categories of visibility and three categories of obstructions with a "best category" forecast based on probability thresholds derived to maximize the threat score while keeping the bias within an acceptable range. The visibility and obstructions equations were derived simultaneously and up to 18 terms were allowed. The categories are shown in Fig. XIII-9. Verification showed these NGM forecasts to be much better than the previous LFM-based forecasts.

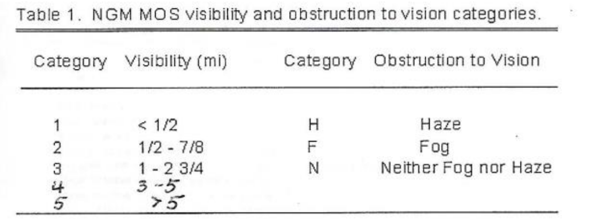

Table 1. NGM MOS visibility and obstruction to vision categories.

Category	Visibility (mi)	Category	Obstruction to Vision
1	< 1/2	H	Haze
2	1/2 - 7/8	F	Fog
3	1 - 2 3/4	N	Neither Fog nor Haze
4	3 - 5		
5	> 5		

Fig. XIII-9. Categories of visibility and obstructions to vision. (From. NWS 1996b.)

The development of a new product, non-convective aircraft icing, was quite similar to the development of the non-convective CAT described above. The predictand was obtained from the same sample of PIREPS and was subject to the same limitations. This product was produced for AWC and HPC and was implemented during the cool season 1996-97 (NWS 1997a; Reap 1997). In keeping with AWC's practice, icing was considered to have occurred if the report was category 4 (light to moderate) or greater. As with CAT, if a report had more than one location, icing was considered to have occurred between the two reports as well. Because the forecasts were for relatively small areas (~47-km blocks) and were unconditional and underreported, the probabilities were very small and were scaled X 20 (as with CAT) for display. Even with the difficulties of observation, coherent patterns forecast by NGM predictors emerged.

MOS forecasts of non-convective aircraft icing were provided to AWC and HPC starting in 1996.

This essentially brought to a close new statistical development based on the NGM. Other models were by this time running operationally at NMC. The Global Spectral Model replaced the PE, and the Eta model had replaced the LFM in 1993 (NWS 1995d, Black 1994) for short-range forecasting. However, products that were based on the LFM had to be shifted to the NGM. This included marine forecasts such as the Great Lakes wind, waves, and surge (NWS 1996c, d) and coastal beach erosion and winds (NWS 1996e). TDL developed and implemented an abbreviated MOS package based on the Eta (Hughes 2002; Maloney 2002, 2004). Development methods were essentially the same as for previous developments based on the LFM and NGM; development for PoP and QPF are described in NWS (2002b). The status of Eta MOS development in 2002 is described in NWS (2002a). The Eta MOS bulletin contained max/min temperature, temperature, dew point, wind, PoP, QPF, total sky cover, and thunderstorm/severe weather. MDL (2005)[6]

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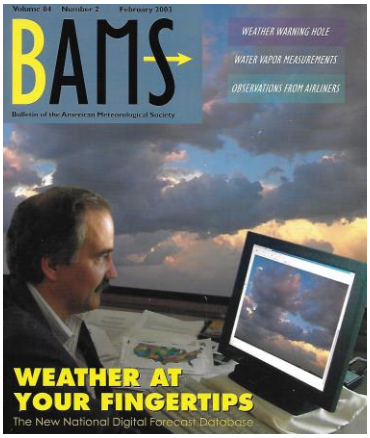
[5] Starting with TPB 431 (NWS 1996b), issue dates were omitted, and there is no way to accurately ascertain them. The responsibility for the TPBs seems to have changed. No. 430 (NWS 1996a), with a date of February 2, 1996, was signed by Joe Bocchieri, Chief, Science and Training Core, Office of Meteorology. No. 431, and several thereafter with no date, were signed by Leroy Spayd, Chief, Training and Professional Core, Office of Meteorology.

[6] The Technical Procedures Bulletins (TPB) were started in 1967 and continued until about 2003 shortly after CAFTI was disbanded. The office that had been issuing them stopped the process. TDL, now MDL, continued to write TPBs for its products for a few years. These are referenced to MDL rather than NWS. While the care of preparation was high for the MDL bulletins, and in fact, the NWS ones were many times written by the same persons who

shows that the Eta message had by 2005 grown to a full package containing many of the same weather elements as the GFS (Global Forecast System) package.

Work continued throughout this period on the CWF and what it had become. Originally, it was a way of providing statistical forecasts to forecasters in a format close to forecaster-produced products, although the concept was broader than that. The forecasts were for stations, and later were produced for zones (Bermowitz et al. 1980). In 1985, the CWF was produced centrally and distributed via AFOS for 111 stations and zones of 22 WSFO's twice daily based on the 0000 and 1200 UTC model run cycles. The forecasts for zones were interpolated from forecasts for stations (Miller and Glahn 1985). Making forecasts for zones moved the concept closer to the NWS operational mainstream, as the zones were the NWS's flagship product (Ruth and Peroutka 1993).



Dave Ruth developed interactive techniques for the IFPS and managed the National Digital Forecast Database. (*BAMS* cover **84(2)** 2003)

By 1985, the CWF concept was moving away from central production to forecasters operating interactively with digital forecasts, and from June 1986, evolving versions of the Interactive Computer Worded Forecast (ICWF) had been used at several WSFOs. Formatting of other products, such as the aviation FTs (Vercelli and Ruth 1989, Vercelli et al. 1985, Oberfield and Ruth 1997) and fire weather (Peroutka et al. 1997) was investigated. Cutting-edge experiments were being carried out on how to structure a digital database, how to represent certain weather variables in it, and on techniques for forecasters to modify it (e.g., Ruth 1993, 1998, 2000, 2002, 2004; Ruth and Du 1997). Some of the work was done in collaboration with NOAA's Forecast Systems Laboratory (e.g., Ruth et al. 1998).


Dave Vercelli concentrated on aviation-related weather elements including ceiling height and visibility.

MDL proposed the "Digital Database/Product Preparation" (DD/PP) (Glahn 1991) concept whereby a digital database would be generated by forecasters manipulating guidance forecasts, and products would be prepared from it, but the acronym never found favor from higher management. The same concept later became the AWIPS Forecast Preparation System (AFPS). MOS products continued to feed the system, giving the forecaster a possible starting point. The thread of statistically processed NWP leads through these systems and the products from them (Peroutka et al. 1998) into the National Digital Forecast Database (NDFD) (Ruth and Glahn 2003, Boyer and Ruth 2003, Glahn and Ruth 2003), to become NWS's flagship service (Glackin 2007).

Through the ICWF and AFPS, the national digital forecast database (NDFD) became operational in 2003.

(continued) wrote the MDL ones, the MDL bulletins cannot be considered to have quite the official status of the NWS bulletins. MDL was trying to fill the gap left by the demise of CAFTI and the TPBs.

By 2004, the Aviation Forecast Preparation System (AvnFPS) that had been in development since 2002, had reached a state of maturity, and it was being used by field forecasters (Peroutka et al. 2004). It combined previously developed functions of assisting in the preparation of TAFs (Terminal Aerodrome Forecast) and TWEBs (Transcribed Weather Broadcast) and in their monitoring and verification. Observations of various kinds and MOS forecasts flowed into AvnFPS. Improvements included the ingest of LAMP (see Chapter XVIII) hourly probabilistic forecasts to update the existing TAF (Oberfield et al. 2008).

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CHAPTER XIV

MOS-2000

By the early 1990's, it was obvious that both of our development and operational subsystems for delivering statistical products needed to be overhauled. The current system had been in place for nearly 20 years and in many respects reached back further than that. We needed the capacity to provide forecasts for many more stations, more projections, more weather elements, and with predictors from more sources than the present system could handle. The variables' identifications (ID) needed to be vastly improved. The predictor and predictand data formats were different and they needed to be standardized. Communication among the various programs needed to be improved. After some hesitation to start such a major undertaking, a memo was sent out in 1993 to members of TDL asking for suggestions. Many were received, but by and large the high-level requirements were what our current 1974 system already addressed, but we needed more flexibility, more expandability, more consistency across software modules, and more efficiency. Many existing features were good and could be adopted. For instance, the basic functions and data flow of the existing system would remain. There are certain computations that have to be done in about the same order in any such system, and this is laid out in Chapter VIII describing our 1974 system. However, nearly all software for MOS-2000 was new (Glahn and Dallavalle 2002). A rather complete description is in Glahn and Dallavalle (2000a).

The environment in which we were working had been quite stable since 1974. However, in 1995, NMC declared a moratorium on operational changes and announced a major effort to port all operational processes, all necessary software, and all datasets used in operations to the CRAY computer.[1] This conversion required a major effort, all the while MOS-2000 was being developed. Yet, by June 1997, when NMC turned off the IBM type machines,[2] TDL's operational code had been converted and was running. Because MOS-2000 was being developed, the developmental portion of the 1974 system was not converted to the CRAY or used again.

A portion of MOS-2000 was being developed on 32-bit word-length HP workstations[3]. Most code developed on HP, or later IBM, workstations would run on the 64-bit CRAY with the 32-bit FORTRAN compiler option. However, there was a problem with the word length in binary IO, so a feature was included in MOS-2000 to indicate whether a 32-bit or a 64-bit machine was being used. This solved the problem, and because the IBM machines came back into use, this feature was not long needed.

So, MOS-2000 was developed on HP workstations and the CRAY, and both developmental and operational components became operational on IBM Class 8 supercomputers.

Another complication during this 1995-2000 period was the switch from manual observations and their reporting in surface airways observation (SAO) code (OFCM 1988) to predominantly automated reporting (e.g., ASOS; NOAA, FAA, and USN, 1992) in the METAR international code as modified in the United States. ASOS ceilometers did not report clouds above 12,000 ft,

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[1] Much of the information about this period was furnished by Paul Dallavalle (2020) and personal emails from him.

[2] IBM or essentially an IBM clone (e.g., Hitachi, NAS 9000).

[3] There was an HP workstation available, because that was the equipment initially furnished for AWIPS.

so high ceilings or even total cloud cover could not be determined. TDL did studies to ascertain whether satellite observations could be used effectively to augment the METARs for cloud cover (Unger 1992). It seemed feasible to use a product produced by NESDIS called the satellite cloud product (SCP); Hughes (1996) discussed how TDL planned to use it. Fiebrich et al. (1997) studied false reports of small amounts of precipitation generated by ASOS under certain conditions of dew formation or snowmelt. This led to an algorithm implemented within TDL to check automated reports of precipitation amount. Cooperative observer observations were obtained from NCDC and incorporated (Cosgrove and Sfanos 2004).

Major features of the new MOS-2000, which is still being used as of this writing, are detailed below.

ID Structure

The computer being used at NMC in 1993 was an IBM 360/195 clone, a 32-bit word-length machine. It was desired to use no more than four 32-bit words for the ID, for reasons that proved groundless. A team within TDL led by Paul Dallavalle designed a four-word ID as follows:

CCC FFF B DD　　V LLLL UUUU　　T RR O HH ttt　　WXXXXYY I S G

The ID primarily identified the variable, but also defined some processing that was either to be done or had been done. In the first word, the **CCC** was the class of variable (e.g., 003 was moisture), **FFF** was the subclass (e.g., 210 was the 6-h accumulated total precipitation in mm), **B** was a binary indicator (e.g., 0 = the variable was not binary), and **DD** indicated the model or lack thereof providing the data (e.g., 06 = the NGM model).

The second word indicated the lower (**LLLL**) and upper (**UUUU**) levels of the data and the processing (**V**) related to those levels.

The third word, except for **T** which indicated processing (e.g., 2 = square root), related to time. For instance, **ttt** was the projection in hours and **RR** indicated the hours back in time the ID applied from the basic date/time NDATE. That is, the data being processed were for the date/time NDATE, but this particular variable was for NDATE – **RR** hours. **HH** and **O** operated together and added capabilities for dealing with complicated time issues; they are seldom needed or used.

The first part (**WXXXXYY**) of the fourth word was a threshold, severely compressed. **I** indicated the type of interpolation, **S** indicated the smoothing, and **G** was reserved. **G** has been carefully guarded, and has only occasionally been used internally within a program.

In making decisions based on the ID, the whole 4-word ID, individual words, or portions of a word could be used. For instance, **CCC** could be obtained by dividing **CCCFFFBDD** by 1000000. To facilitate use within a program, the ID was immediately broken up into 15 integer values plus the floating-point threshold and carried around that way as well as was the total ID.

Packing of Data

Previously, TDL had followed, to the extent possible, NMC's data format and used its packing routines. For gridpoint data, GRIB was used, and packing was two data values per 32-bit word.[4] Better schemes existed. The World Meteorological Organization (WMO) had defined a packing scheme (i.e., second-order packing) that separated the data into groups, then packed the groups using only enough bits to exactly represent the scaled data after subtracting the minimum. This was efficient, especially if there were "runs" in the data that varied little compared to the total field. But there was no suggestion as to how the groups would be determined. I had been analyzing the packing being used at NMC and the possibilities for a different packing method within GRIB and devised a method of finding groups and tested it on various kinds of data (Glahn 1992, 1993, 1994, 1995, 1997, 1998). Combined with that was a second-order differencing scheme that had been proposed (OFCM 1990). I devised a new data structure and packing method that came to be called TDLPack.[5] I had been trying to get WMO to adopt a more flexible coding scheme, but without success. We would have used GRIB as our format for gridded data if it had met our needs, but it did not, so we devised our own. While in some respects it was similar to GRIB, it was substantially different. The arrangement of the identifying metadata was such to be efficient for statistical processing. In addition, it could also be used for vector (non-gridded) data; for vector data, there just needed to be a record identifying the location of each datum, whereas for gridded data, the definition of the grid itself specified the locations of the data points. TDLPack is explained in Glahn and Dallavalle (2000a, Chapter 5).

Sequential Data Files

Most data used for processing in MOS-2000 were on sequential files in the TDLPack structure. The only order of the records necessary was that they be chronological. There was no differentiation of predictor and predictand data as there was in the older systems. We established real-time archives of model data and converted existing archives to the new format. Initially, these files were on tape, but most working files were migrated to solid-state devices.

The model archives were on the same grid in use by NMC and generally at the same resolution. For instance, for the NGM, the map projection was north polar stereographic oriented on 105° W with a grid spacing of 190.5 km (1/2 Bedient) at 60° N. A standard file-naming convention was established. The extent of the grids was established to meet our processing needs. For instance, the aviation model archive covered the CONUS, Puerto Rico, Hawaii, and Alaska. Gridpoint archives are explained in Chapter 12 (op. cit.).

Vector files had at their beginning a "dictionary record." It defined in 8-character words (non-packed, 32 bits) the name of the location of each value on the data files. For instance, if the 10th value was "KDENbbb" in the dictionary, then the 10th value in each following record was for Denver. This correspondence lasted until a trailer record was encountered. A trailer record could signal the end of the data on the device or could be followed by another dictionary record, thereby allowing the order of data in the records to be changed within the archive.

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[4] Packing had been five values per 60-bit word on the earlier CDC 6600 machine.

[5] I believe Mary Erickson bestowed that name.

A real-time archive of METAR observations was in place starting December 1996. Before that, the archive had been of SAOs and synoptic reports. A number of quality control checks were performed on these data, for example, see Allen (2001). The differences between METARs and SAOs were substantial, further complicating our conversion to a new system. We also archived snowfall and precipitation data in the supplemental climatic data (SCD) reports, satellite data from the satellite cloud product (SCP), and lightning and severe weather reports. Vector archives are explained in Chapter 13 (op. cit.).

External Random Access Files

Some data, such as climatologies are static and may be referenced many times in a program. There are thresholds that pertain to transforming probability forecasts into categorical forecasts. It is convenient to have such data on a random access file. MOS-2000 has such a system of files, called the external random access system (ERAS), and one or more can be accessed within a program for reading and/or writing. It accommodates large records and a large number of records. This system became useful in operations where forecasts are made by one or more programs, then need to be accessed in a somewhat random order in other programs. This file system is fully explained in Chapter 7 (op. cit.). A different identification structure is used for these data than that explained above. For instance, for a relative frequency, the period of time over which it applies must be specified (op. cit., Chapter 14).

Station Dictionary File

Most of the development has been for points (not on a grid) that are defined by ≤ 8 characters (e.g., station call letters). Information is needed about these locations, such as elevation, latitude and longitude, and name. We established a file with information needed within the system that could be accessed by any program. This not only absolved each user from obtaining or manufacturing such information, but also standardized it across the system (op. cit., Chapter 10).

Variable Constants File

Information about the weather elements is needed that is not contained in the 4-word ID. This information, such as variable name and the scaling to be used in packing, is contained in a variable constants file (op. cit., Chapter 11). Like the station dictionary file, this file relieved each user from defining such information and just as importantly standardized certain information. For instance, in packing, the values must be whole numbers, so fractional values must be scaled by some positive number. Precipitation of 0.15 inches would become 15 with a 10^2 scaling, but there would be no use in scaling it by 10^4, and to do so would waste space. By specifying the desired scaling in this file, the user usually need not worry about the packing.

Equation File

A format for regression equations, either linear or logistic, was established that could be used for either single-station or regionalized equations; it included enough information that inflation of forecasts could be done without access to other files (op.cit., Chapter 15).

Forecasts and Matching Observations

TDL had been responsible for collecting and comparatively verifying with MOS forecasts the official NWS forecasts made locally in the AFOS-era verification (AEV) program. The AEV archive was built for the 1974 system and presented challenges for MOS-2000 uniformity. This was maintained for some years until the collection of the local forecasts and verifying observations shifted to the Office of Meteorology and Oceanography (op. cit., Chapter 16).

Software Standards

Many years of experience had been gained by members of TDL in writing software for interpretation of model output. Just as it is important to have a format for published papers, it is important to follow a set of rules in programming. NMC and TDL almost exclusively used FORTRAN for their computer intensive software. That was a given. Detailed standards were prescribed concerning both coding and internal and external documentation. A goal was to have the MOS-2000 code written in one “style” and not each code be written in an individual programmer’s style. While there was a bit of grumbling initially, the standards were not too different from what had been the practice, so they were generally followed. This standardization of code contributed greatly to the success of MOS-2000.

To the extent practicable, users were expected to use agreed-upon variable names. For instance, STALAT( ) was the name for the array of station latitudes, and ORIENT was the longitude orientation of the grid being used.

Control of diagnostic information was handled by a series of variables IPxx, where xx was a 2-digit number. The main program would read 25 of these early in its execution. Each number read designated the FORTRAN unit number to be used for that IP number. When it was zero, the diagnostic was not written for this IPxx. That way, a one-line input could control nearly all of the diagnostic output and was very effective in differentiating output between a checkout run and a long development or operational run.

Readers and Writers, Packers and Unpackers

Routines were provided for all to use for input/output functions. The arrangement of metadata in TDLPack made it possible to quickly tell whether a record was needed (four ID words plus the date/time word) before reading the entire record, thereby saving IO and unpacking time.

Space Allocation

Most programs were written with a driver whose main function was to set the dimensions of large arrays, the size of which may need to vary from run to run. The user must estimate the maximum size of the array for this instance of the program. The arrays’ sizes may vary tremendously from run to run, and a reasonable array size was important for conserving space and to a lesser extent computer time. The use of a driver, which could be compiled and linked in at run time, allowed this allocation without the user becoming involved with the main program, which could be in a library and not have to be changed.

Internal Random-Access File

The large volume of data needed for statistical development resided on sequential files. Various programs needed the data in a somewhat random sequence. This was accommodated by defining in most main programs an internal binary file that would hold either vector or gridded records, packed or unpacked, of varying size, and maintaining in memory a 12-word key to each record. This file functioned as an internal random access file system (IRAS).[6] In a program, for the first date/time that was processed, all sequential data from a designated set of inputs for that date/time would be written to the IRAS. If any date/time after the first was needed, then all data up to and including that date/time were also read and saved in IRAS. If records before the date/time being processed were needed, then all data for the earliest record and all intervening date/times were also read and saved in IRAS.

The first date/time was processed and records were read from IRAS as needed. Notation was made in the key record when a data record was used. At the end of processing that date/time, all records in IRAS that would not be needed again were purged and those that might be needed were kept.

As the second and following date/times were being processed and the records were being read from the inputs, it was known from the key record whether or not the input record was needed. If it were not needed, it would be bypassed and the next record processed. If it were needed, then it would be used immediately, if possible, and if it were not to be used again, it was not put into IRAS. On the other hand, if that input record was going to be needed again, it would be saved. This arrangement kept voluminous data from being read and unpacked if not needed.

The OPTION Option

The MOS-2000 programs provide for input and output and a structure for performing certain functions. Many times, because of a requirements change or just the desire of a developer to compute a predictor not previously used, the code must be augmented For instance, in U201 which performs the basic computation of predictors and predictands for input to the regression programs, the basic functions of smoothing **(S** above), interpolation (**I** above), and simple transformations (**T** above) are performed without code change. For example, the V-wind from a particular model designated by **DD** (see above) could be smoothed and interpolated from the model grid to the set of stations provided for the run by just setting the appropriate values in the ID. But if one wanted to compute the wind speed from the U- and V-wind components, it would be done in a subroutine. If such a capability had not already been used, it would have to be added. A CCCFFF would be defined for such a variable. U201 would try to find that CCCFFF in the input data. If it were not there, then a switching subroutine named OPTION would be called. That subroutine would call another subroutine to compute the speed (call it SPEED) when that specific CCCFFF was encountered. So, to add a computational capability, three things would be done: (1) a subroutine would be written and linked into U201 to perform the function, (2) a call to that subroutine, such as SPEED, would be inserted into OPTION passing in needed information, and (3) the new variable ID with its associated information would be inserted

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[6] It was actually an in-memory array of size specified by the user. If this allocated space became full, a file was automatically opened and used for the overflow.

(numerically) into the variable constants file. SPEED would access the IRAS to get the gridded data needed to do the computation. Then, any smoothing, interpolation, and transformation designated by **S**, **I**, and **T**, respectively, would be automatically done. If smoothing were to be done on the wind components *before* the speed computation, that would be handled in SPEED, calling the same smoothing routines otherwise used by U201. Note that no change to the main program would be needed.

OPTION could deal with either gridded or vector data. A less capable switching routine OPTX was used in programs dealing with only vector data.

Developmental and Operational Software Correspondence

Although a goal in the 1974 system, MOS-2000 further enhanced the use of the same modules in both development and operations areas of the system. While some differences were unavoidable, lower level subroutines were standardized. Modules were built to bundle IO functions for ease of use.

Regression Programs

By far, the most relationships between predictands and predictors were determined by regression programs. A danger in developing coefficients in a regression equation with many predictors is that near-collinearity of the predictors can result in unstable equations. For instance, two predictors could have quite large coefficients, but with opposite signs. This means that small differences in those predictor values can have an undue influence on the value computed from the equation. U600[7] has a number of checks, under control of the user, to minimize the chance of unstable equations being developed.

In the LAMP project, we were additionally concerned about the forecasts from the regression equations being consistent from hour to hour. Predictors in LAMP included observations and MOS forecasts. We were concerned an observation (or a MOS forecast) would be in an equation for a particular projection, but not be in the equation for a projection plus or minus one hour. Guarding against such contingencies was outside the capability of U600, so U602 was written for LAMP.

Logistic regression is also provided for by U655. The logit solution is found iteratively, as there is no analytic solution, and the screening capability was not built into it. The Newton Raphson solution follows that laid out in Wilks (2011, p. 238-242).

Criticism is frequently voiced about MOS-2000 using “linear” regression. It is true the equation itself is linear in its predictors, but those predictors are carefully chosen and computed by the developer so that the predictand will have a near-linear relationship to the predictor, even to the extent of “linearizing” the predictors (see Chapter XII, pp. XII-13,14). This allows meteorological knowledge to play an important role in predictor definition and selection.

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[7] User documentation for U600 and other MOS-2000 programs is contained in Glahn and Dallavalle (2000b).

Forecasts from Equations

Mirroring our previous system, U700 and U710 provide for making the forecasts from equations in a development environment, and U900 and U910 play that same role in operations. Output is in TDLPack vector format on either sequential files or in ERAS. Logistic, as well as linear, regression equations are accommodated.

Thresholds

The distribution of several of the weather variables we wished to forecast do not lend themselves to linear processes without a transformation of some sort. MOS-2000 deals with this primarily by dividing the predictand into several binary variables, usually cumulative from below but they can be discrete or cumulative from above.**[8]** The forecasted value of the binary is considered to be its probability of occurrence. These probabilities of the categories can be provided to a user, but a user may also want a definitive value. Such a "best" forecast is computed by developing a threshold for each binary predictand that when used to make a discrete forecast from the probabilities, the forecasts exhibit desirable characteristics in terms of threat score and/or bias. Program U830 surveys the forecasts made over the developmental sample and provides thresholds that can produce forecasts with either user specified bias or that maximize the threat score within a user specified bias range.

Verification

Verification of the MOS forecasts can be done with U850 for vector data or U855 for gridpoint data. A number of scores can be computed, such as threat score, Heidke skill score, Brier score, bias, and continuity score (Ruth et al. 2009). U850 can be used for comparing sets of forecasts, and always computes on a matched sample. For instance, if a forecast is missing in one set, that case will not be in the verification statistics.

Missing Values

Missing data values are designated by 9999. Also, 9997 is reserved for a probability value that is to be treated as zero. This can come from U700 or U900 when the regression equation could not be computed for lack of data. The packers and unpackers recognize these as primary and secondary missing values and pack them efficiently.

Efficiency of Operation

Very careful consideration was given to implementing the "updatable MOS" concept that had been first discussed by Ross (1987)**[9]** and put into operations in Canada (Wilson and Vallee 2002). Our predictand set was so diverse that we judged this would have more drawbacks than

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[8] Predictands can be discrete, cumulative from above (good for precipitation amount), or cumulative from below (good for ceiling height), but predictors can, by convention, be only cumulative from above. This restriction on predictor orientation does not affect its predictive power, but only its visual and cognitive utility.

[9] Basically, the process would be automated so that the data would be collected and the redevelopment/ implementation done perhaps as often as daily.

advantages. The necessary use of thresholds to calculate specific values from probability forecasts, thresholds based on the developmental data, complicated the picture. Data for some predictands don't have real-time access, and the sample has to be collected later in batches and QCed. If models are changed, it is not always immediately obvious whether or not the old and new outputs should be merged. Based on our experience, the computer system and operational guidelines provided to us, and the data availability, we decided not to implement a constantly changing system.

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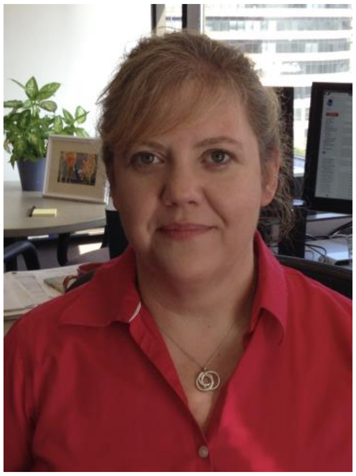
CHAPTER XV

THE MRF AND AVN RUNS OF THE GLOBAL FORECAST SYSTEM

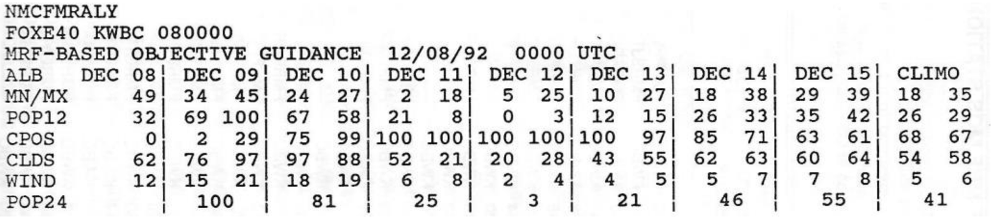
Technical Procedures Bulletin No. **411** titled "The MRF-Based Statistical Guidance Message" announced this was the first bulletin on this subject (NWS 1993). The NGM was the basis for statistical guidance out to 60 h (see Chapter XIII). The Medium-Range Forecast model, part of the NMC global data assimilation and forecast system (Kanamitsu 1989), was now the basis for guidance out to 192 hours (8 days). These forecasts were mainly to provide guidance for longer-range projections, and it was expected forecasts $\leq$ 48 h from the NGM would be superior. Also, the forecasts were available only once per day and were not available until about 0900 UTC, so lagged those from the NGM by several hours.



Kathy Hughes Gilbert was a branch chief and developer of thunderstorm and other forecast systems.

In this message, starting December 10, 1992, forecasts for the contiguous United States and Alaska were available for daytime max and nighttime min temperature, PoP for 12- and 24-h periods, conditional probability of snow for 12-h periods, and mean wind speed for 12-h periods. In general, the forecasts were available for each 12-h period between 12 and 192 h. For comparison, the normal climatic values for the 96- to 120-h period were included in the transmitted message. The forecasts were made by applying various techniques (Jensenius et al. 1992). A sample message is shown in Fig. XV-1.

The MRF forecast package was implemented in 1992.



```
NMCFMRALY
FOXE40 KWBC 080000
MRF-BASED OBJECTIVE GUIDANCE   12/08/92   0000 UTC
ALB     DEC 08| DEC 09| DEC 10| DEC 11| DEC 12| DEC 13| DEC 14| DEC 15| CLIMO
MN/MX       49| 34  45| 24  27|  2  18|  5  25| 10  27| 18  38| 29  39| 18  35
POP12       32| 69 100| 67  58| 21   8|  0   3| 12  15| 26  33| 35  42| 26  29
CPOS         0|  2  29| 75  99|100 100|100 100|100  97| 85  71| 63  61| 68  67
CLDS        62| 76  97| 97  88| 52  21| 20  28| 43  55| 62  63| 60  64| 54  58
WIND        12| 15  21| 18  19|  6   8|  2   4|  4   5|  5   7|  7   8|  5   6
POP24         |  100  |   81  |   25  |    3  |   21  |   46  |   55  |   41
```

Fig. XV-1. A sample message for the MRF-based guidance for Albany (ALB). The abbreviations for the weather elements along the left side are recognizable. (From NWS 1993.)

The forecasts were passed through a calibration procedure that minimized the mean square error based on previous verification data. This procedure made the forecasts tend toward normal climatic conditions as the skill of the guidance decreased.

The MRF model was also run twice a day out to 72 h to furnish forecasts for the aviation industry and was called the AVN model. TDL fielded guidance based on the AVN for both the 0000 and 1200 UTC runs out to 72 h (NWS 1994). The forecasts were for the same elements as the MRF message except the PoP for the 24-h period and wind were omitted for this August 1994 implementation. Forecasts were MOS except 12-h PoP was perfect prog. The same calibration techniques were used as were used for the MRF package. Calibration makes minimal changes to MOS forecasts, but can have significant effect on PP forecasts. The message was similar to the first three columns of Fig. XV-1.

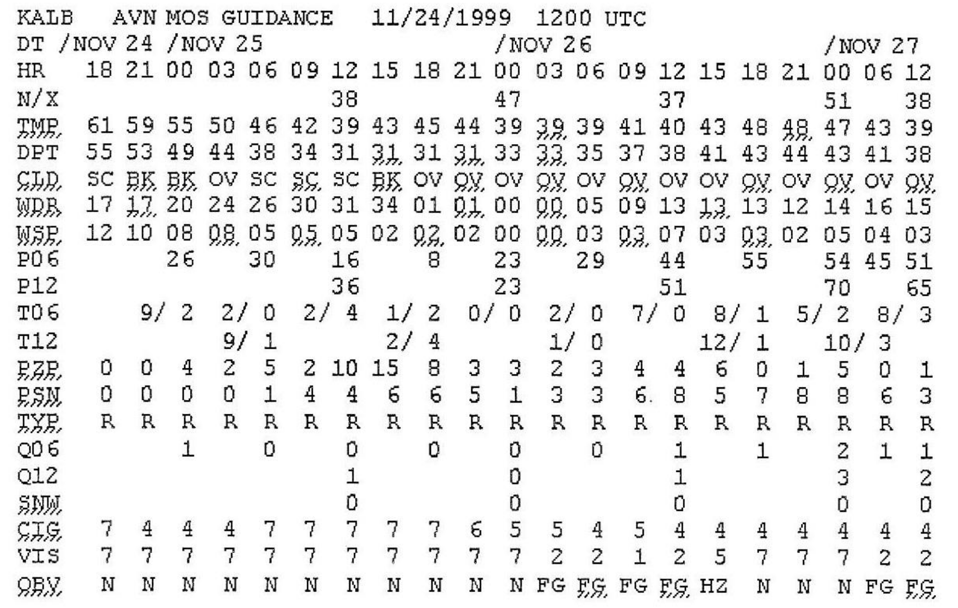
The AVN forecast package was implemented in 1994.

The MRF-based guidance was enhanced in May 2000 (NWS 2002a; Erickson 1999). The messages now contained forecasts of the daytime/nighttime max/min temperature, time-specific 2-m temperature and dew point (Carroll and Maloney 2004), mean total sky cover, maximum sustained surface wind speed, PoP for 12- and 24-h periods, probability of thunderstorms for both 12- and 24-h periods, conditional probabilities of freezing precipitation type categories, quantitative precipitation for 12- and 24-h periods, and snowfall amount. All elements except the temperature and dew point were valid over at least a 12-h period. Guidance was provided for projections of 24 to 192 h for most weather elements. This product had many changes from the original MRF MOS message. New definitions for the wind, sky cover, and precipitation type elements were made to increase the utility of the guidance. Also, for the first time, the medium-range MOS messages contained categorical precipitation amounts, temperature, dew point, the probability of thunderstorms, and a categorical snowfall amount.

The wind was not for specific values, but represented one of four operationally significant categories—light (5 = 0-12 kt), breezy/brisk (15 = 13-21 kt), windy (22 = 22-33 kt), or strong (40 = ≥34 kt) The climatic values of temperature and PoP were included for two times of the day. Quantitative precipitation was also shown in terms of categories. Thunderstorm predictands were based on lightning flash data but were unavailable for Alaska, Hawaii, and Puerto Rico. As of August 2001, the guidance was available for 1060 stations, and plans were to add 346 sites later in the year. In addition, messages for 273 stations were distributed to the U.S. Air Force. More detail is available in NWS (2002a).

The AVN-based guidance was also enhanced in May 2002 (NWS 2002b; Erickson et al. 2002; Dallavalle et al. 2004). Issued twice daily, the message now contained daytime/nighttime max/min temperature; time-specific surface temperature and dew point; total sky cover; surface wind direction and speed; PoP for 6- and 12-h periods; probability of thunderstorms and conditional probability of severe thunderstorms for 6- and 12-h periods (Hughes 1999, 2001); conditional probability of precipitation type (freezing, snow, or liquid) and a corresponding category; categories of quantitative precipitation for 6- and 12-h periods (Lenning and Antolik 1999); snowfall amount; and categories of ceiling height, visibility, and obstruction to vision. Guidance was provided for projections of 6 to 72 h for most weather elements. Specific time forecasts were for every 3 h to 60 h then every 6 h to 72 h. Forecasts were in terms of categories for several elements (e.g., ceiling in 7 categories). A sample message is shown in Fig. XV-2.

TPB 474 (NWS 2002c) gives details of the wind development. Procedures follow previous developments closely. Equations were developed simultaneously for the earth-oriented U- and V-wind components and speed for both the warm and cool seasons. The predictands came from the METAR observations of direction and speed; the direction components were calculated from the direction and speed. Predictors included model variables and initial observations. Single-station equations were developed. Predictor selection stopped when either nine were chosen or no screened predictor added ≥ 0.5% to the RV of any one of the three predictands. Initial observations were important for the first few projections, and then the model variables were the most important. Backup equations without the observations were used in operations when the observations were not available. Independent data verification in terms of Heidke skill score for speed and percent of wind direction errors ≤ 30 degrees are shown in Figs. XV-3 and XV-4, respectively. Direction was verified when the observed speed was ≥ 10 kt. Clearly, the GFS[1] guidance was a major step up in skill. Verification of other weather elements also showed improvement.



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KALB    AVN MOS GUIDANCE   11/24/1999  1200 UTC
DT /NOV 24 /NOV 25                /NOV 26                 /NOV 27
HR   18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 06 12
N/X                    38          47          37          51    38
TMP  61 59 55 50 46 42 39 43 45 44 39 39 39 41 40 43 48 48 47 43 39
DPT  55 53 49 44 38 34 31 31 31 31 33 33 35 37 38 41 43 44 43 41 38
CLD  SC BK BK OV SC SC SC BK OV OV OV OV OV OV OV OV OV OV OV OV OV
WDR  17 17 20 24 26 30 31 34 01 01 00 00 05 09 13 13 13 12 14 16 15
WSP  12 10 08 08 05 05 05 02 02 02 00 00 03 03 07 03 03 02 05 04 03
P06        26    30    16     8    23    29    44    55    54 45 51
P12                    36          23          51          70    65
T06     9/  2 2/  0 2/  4 1/  2 0/  0 2/  0 7/  0 8/  1 5/  2 8/  3
T12           9/  1       2/  4       1/  0       12/ 1    10/ 3
PZP   0  0  4  2  5  2 10 15  8  3  3  2  3  4  4  6  0  1  5  0  1
PSN   0  0  0  0  1  4  4  6  6  5  1  3  3  6  8  5  7  8  8  6  3
TYP   R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R
Q06         1     0     0     0     0     0     1     1     2  1  1
Q12                     1           0           1           3     2
SNW                     0           0           0           0     0
CIG   7  4  4  4  7  7  7  7  7  6  5  5  4  5  4  4  4  4  4  4  4
VIS   7  7  7  7  7  7  7  7  7  7  7  2  2  1  2  5  7  7  7  2  2
OBV   N  N  N  N  N  N  N  N  N  N  N FG FG FG FG HZ  N  N  N FG FG
```

Fig. XV-2. A sample message for the AVN-based guidance for Albany (ALB). The weather elements along the left side are mostly recognizable from the text description. (From NWS 2000b.)

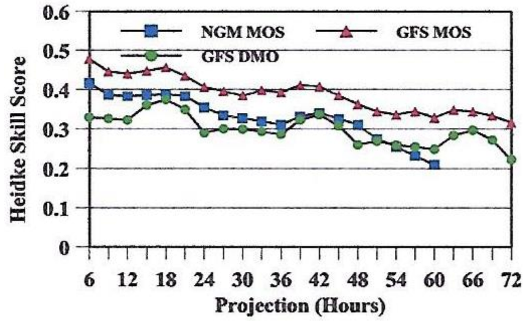

Fig. XV-3. Heidke skill score of wind speed of GFS raw model output (DMO), NGM MOS, and GFS MOS for the cool season, 0000 UTC. (From Dallavalle et al. 2004.)

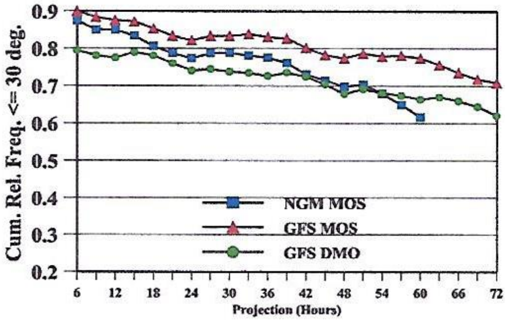

Fig. XV-4. Relative frequency of direction errors ≤ 30 degrees of GFS raw model output, NGM MOS, and GFS MOS for the cool season, 0000 UTC. (From Dallavalle et al. 2004.)

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[1] The AVN was the 72-h early run of the Global Forecast System (GFS), and the MRF was the 8-day run of the GFS. Verification in Figs. XV-3 and XV-4 are from the AVN run.

Details are given in NWS (2002d) about the development for the precipitation type guidance from the AVN. The development was done in much the same way as it was for the NGM. The three predictands were freezing, frozen, and liquid, conditional on precipitation occurring. Each of the freezing and frozen categories was treated as a binary predictand. The liquid category was redundant, and did not need a prediction equation. Regions were made for the conterminous United States and for Alaska based on climatic and geographic similarity. There were 611 stations in the CONUS and 32 in Alaska with useable data for most of three cool seasons (September 16-May 15 for the CONUS and September 1- May 31 for Alaska). A portion of California and of Florida, as well as Hawaii and Puerto Rico, did not have sufficient cases of frozen precipitation to develop equations. Also, equations to predict freezing rain could not be developed for some stations in Alaska. Some predictors came from single-station, single-predictor regression equations, and thereby brought local effects into the process.[2] Surface observations were used as predictors for some projections, and for those projections, backup equations were developed to use in operations when the observation was missing. Predictors included both point binary and grid binary model predictions. Equations were developed simultaneously. Thresholds were developed to use in making categorical forecasts from the probability forecasts. Verification on test data indicated that the AVN precipitation type guidance had skill comparable to that of the NGM MOS guidance.

The development of ceiling height and cloud cover based on the AVN model is explained in NWS (2002e). The development for ceiling guidance was much like that for the NGM noted in Chapter XIII. The predictand categories were the same. However, distinct from the NGM development, ceiling and opaque cloud amount were done simultaneously to strive for more consistency between the forecasts [a later development again separated them (Yan and Zhao 2009)]. The cloud categories were clear, scattered, broken, and overcast. Most observations used for the predictand were from ASOS and did not indicate clouds above 12,000 ft., so the satellite cloud product was used to help estimate cloud coverage. Probabilities from the equations were normalized to the 0 to 100 percent range. Note that the predictand was discrete rather than cumulative categories. Thresholds were determined such that the bias of each cumulative from below category (computed from the discrete categories) was near unity. Persistence of the observation played a major role in the accuracy up to the 12-h projection. There were not enough cases for the lower two categories of ceiling to develop equations for all projections for Hawaii and Puerto Rico, and in the warm season for the southwest CONUS. Verification showed the AVN ceiling product to be clearly superior to the NGM product. Because the cloud observational system changed between the development of the NGM and AVN equations, comparison of the cloud forecasts was problematic.

Wei Yan developed ceiling height, sky cover, and other weather element forecasts.

The MRF precipitation type guidance is detailed in NWS (2002f). These forecasts were for 12-h periods, so the 13 hourly observations bracketing the 12-h period were used to characterize the period. For a case to be used, at least seven of the 13 possible observations had to be present

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[2] Although the not large number of cases of the rare categories would not support *multiple*-predictor, single-station development, it was thought that *single*-predictor equations developed on data from a single station would be stable.

and at least three of them had to represent precipitation. For every valid case, four mutually exclusive binary predictands were formed, each taking a value of 1 or 0 for freezing/no freezing, snow/no snow, rain-snow mixed/no rain-snow mixed, and rain/no rain. An equation was developed for each, and the result of applying the equation was interpreted as the probability of the particular event. This is in distinction to the AVN guidance where the forecasts were for specific times and were based on a single observation. Predictors from the MRF at both the beginning and end of the 12-h period were screened. Similar to the AVN, the probability of snow at individual stations based on single-station regression equations was offered. To determine a specific forecast from the probabilities, thresholds were developed that maximized the threat score within a bias of 0.98 to 1.02.

Lightning strike data were used to define the predictands, and the GFS model provided major predictors for a set of equations to forecast the probability of thunderstorms and severe storms (Hughes 2004). Developmental and forecast points were on a 20-km grid over the CONUS. All points were considered together (the generalized approach) to enhance equation stability. Most MOS forecasts had been for points (stations with observations); this was, by contrast, a gridded product possible because the predictand could be defined on a grid as easily as being defined at stations. Closely related work was in progress in LAMP to be addressed in Chapter XVIII. An example forecast and verifying map are shown in Fig. XV-5.

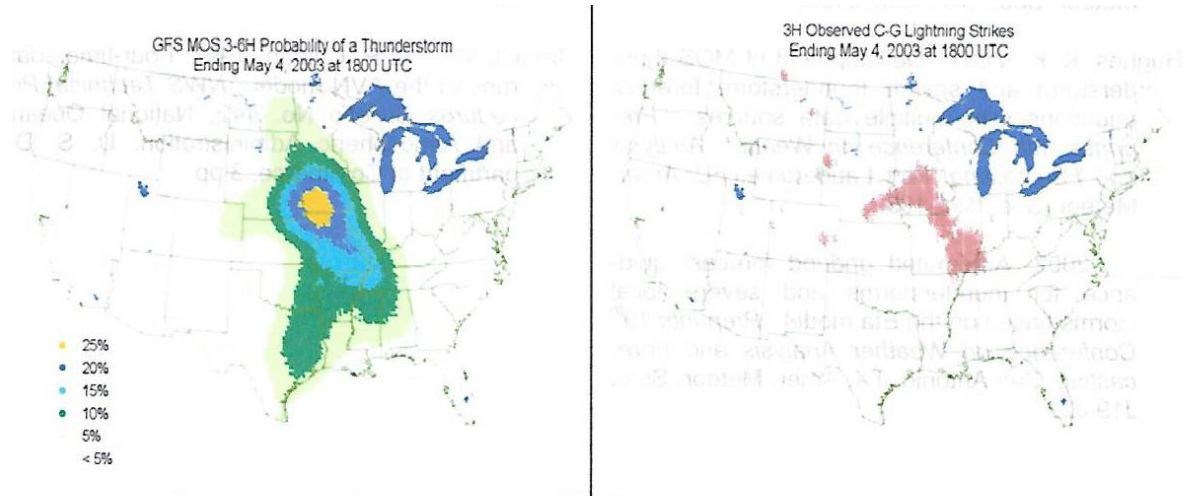

Fig. XV-5. MOS thunderstorm probability forecast contoured in percent (left) and corresponding lighting strikes in red (right) for the 3-h period ending at 1800 UTC on May 4, 2003. (From Hughes 2004.)

Later, lightning strike data were obtained for Alaska from the Bureau of Land Management and the thunderstorm forecasts were extended to Alaska (Shafer and Gilbert 2008). Implementation was in May 2008.

The Committee on Analysis and Forecast Technique Implementation (CAFTI) was disbanded in approximately 2002 when Gen. Kelly was Director of the NWS. While CAFTI was not responsible for the Technical Procedures Bulletins, it played a major role in them being written and distributed. The official TPBs under the purview of the Office of Meteorology stopped in about 2003. For a time, MDL wrote TPBs and distributed them to interested parties; they were named MDL

Technical Procedures Bulletins.[3] The remainder of this chapter is largely based on them and brief change logs kept by MDL.


Phil Shafer developed MOS and LAMP rainfall, thunderstorm, and other forecast systems.

As of June 2005,[4] a message was being generated and distributed containing MOS forecasts for about 13 sites in the western Pacific area. Initially, only surface wind was available; as other weather elements became available they were to be added to the message. Plans were to include time-specific forecasts from 6 to 72 h of surface temperature and dew point, total sky cover, and PoP for 6- and 12-h periods, as well as the surface wind direction and speed.[5] The structure of the bulletin was essentially the same as for the CONUS (MDL 2005a, Su 2005).

The area where these Pacific sites are located is between 15°S and 30°N and between 130°E and 170°W. Stratification into 2 seasons was usual, but the seasons were different from other developments, being June through September (the monsoon season) and October through May (the dry season). Primary wind predictors were from the GFS at isobaric levels smoothed on the grid over a 25 by 25 gridpoint box. Observed wind components were also used, as well as the 1st and 2nd harmonics of the day of the year. Twelve predictors were selected unless no remaining unselected predictor reduced the variance of either the U, V, or S predictands by at least 0.5%. As usual, the wind speed forecasts were inflated (MDL 2005b).

As explained earlier, the so-called AVN and MRF models were both part of the GFS system. Since September 2002, the AVN had been referred to as the GFS (MDL 2005c). Since October 2001, guidance had been available for the "off" cycles of 0600 and 1800 UTC (MDL 2005d). These two references present examples of messages and the same guidance appears to be available for all cycles. Some definitions had changed in May 2004. For cloud, the scattered category was broken into few and scattered, giving five categories. The ceiling height category 1,000 to 3,000 ft was broken into two categories 1,000 to 1,900 and 2,000 to 3,000 ft, giving eight total categories. Some categories of visibility were also adjusted. For those variables dealt with in a categorical manner, the categories are shown in Figs. XV-6 and XV-7. As of January 2004, the MOS forecasts were available for 1,524 stations, and messages for 272 sites were transmitted to the military.

Single-station, daytime/nighttime max/min temperature and time-specific temperature and dew point regression equations were derived for the CONUS, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands and were implemented in December 2003 (MDL 2005e). Development details remained the same as before. Of the over 1,500 stations, the max/min forecasts for 330 in the CONUS and Alaska were verified for the 0000 UTC cycle. The MAE verification showed that for both max and min and for warm and cool seasons, there was skill out to day 8, and for the short-range projections, the GFS forecasts were better than those from the NGM.

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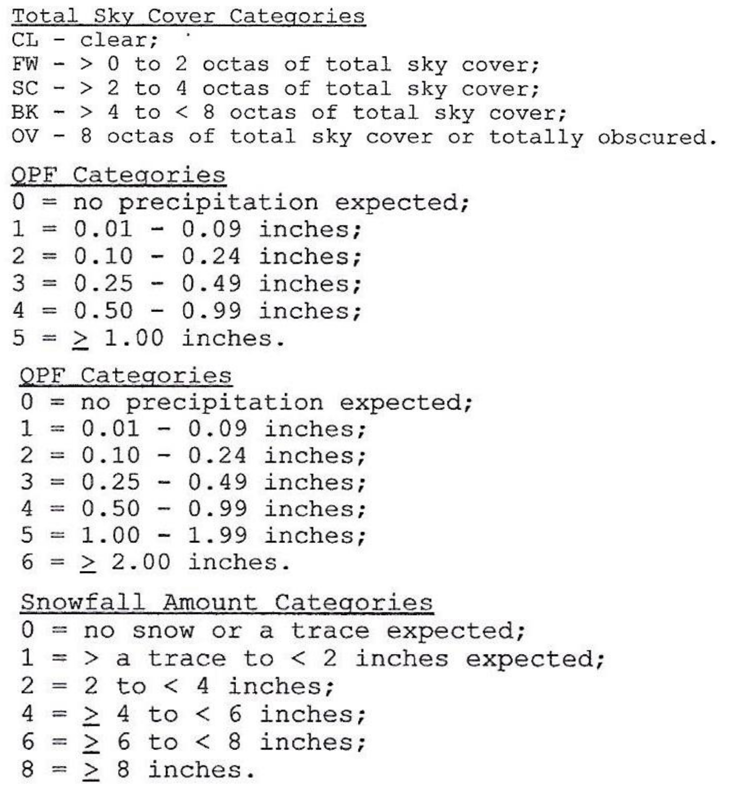
[3] There was also a series named MMAB Technical Procedures Bulletins written by another organization.

[4] MDL MOS change log.

[5] Temperature and dew point were added September 2008 (MDL MOS change log). Su (2007) presents the development for precipitation.



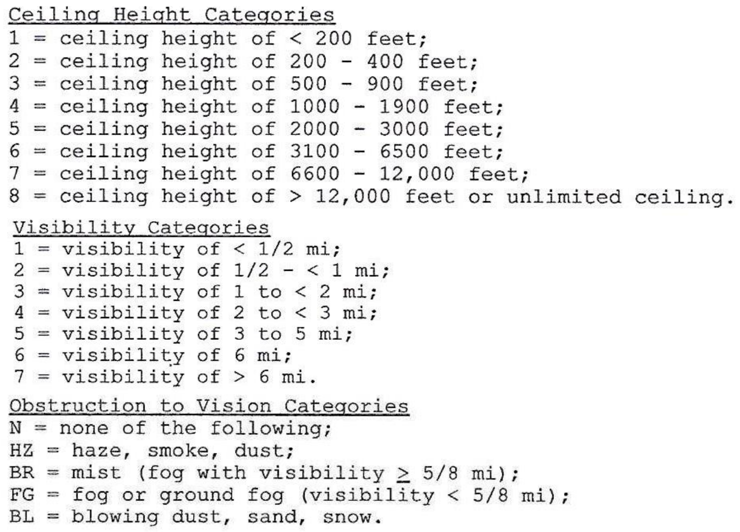
Total Sky Cover Categories
CL - clear;
FW - > 0 to 2 octas of total sky cover;
SC - > 2 to 4 octas of total sky cover;
BK - > 4 to < 8 octas of total sky cover;
OV - 8 octas of total sky cover or totally obscured.

QPF Categories
0 = no precipitation expected;
1 = 0.01 - 0.09 inches;
2 = 0.10 - 0.24 inches;
3 = 0.25 - 0.49 inches;
4 = 0.50 - 0.99 inches;
5 = ≥ 1.00 inches.

QPF Categories
0 = no precipitation expected;
1 = 0.01 - 0.09 inches;
2 = 0.10 - 0.24 inches;
3 = 0.25 - 0.49 inches;
4 = 0.50 - 0.99 inches;
5 = 1.00 - 1.99 inches;
6 = ≥ 2.00 inches.

Snowfall Amount Categories
0 = no snow or a trace expected;
1 = > a trace to < 2 inches expected;
2 = 2 to < 4 inches;
4 = ≥ 4 to < 6 inches;
6 = ≥ 6 to < 8 inches;
8 = ≥ 8 inches.

Fig. XV-6. The categories of the predictands, top to bottom: Total sky cover, 6-h QPF, 12-h QPF, and snowfall amount. (From MDL 2005c.)



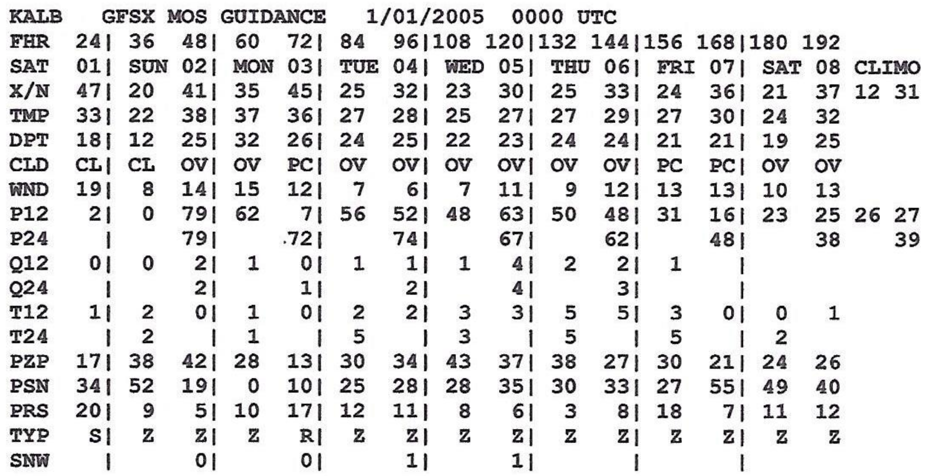
Ceiling Height Categories
1 = ceiling height of < 200 feet;
2 = ceiling height of 200 - 400 feet;
3 = ceiling height of 500 - 900 feet;
4 = ceiling height of 1000 - 1900 feet;
5 = ceiling height of 2000 - 3000 feet;
6 = ceiling height of 3100 - 6500 feet;
7 = ceiling height of 6600 - 12,000 feet;
8 = ceiling height of > 12,000 feet or unlimited ceiling.

Visibility Categories
1 = visibility of < 1/2 mi;
2 = visibility of 1/2 - < 1 mi;
3 = visibility of 1 to < 2 mi;
4 = visibility of 2 to < 3 mi;
5 = visibility of 3 to 5 mi;
6 = visibility of 6 mi;
7 = visibility of > 6 mi.

Obstruction to Vision Categories
N = none of the following;
HZ = haze, smoke, dust;
BR = mist (fog with visibility ≥ 5/8 mi);
FG = fog or ground fog (visibility < 5/8 mi);
BL = blowing dust, sand, snow.

Fig. XV-7. The categories of the predictands, top to bottom: ceiling height, visibility, and obstruction to vision. (From MDL 2005c.)

The extended GFS 0000 and 1200 UTC bulletins are described in MDL (2006a) as they existed in September 2005, except the mean total sky cover and precipitation type for the 1200 UTC message would be added later. The 0000 UTC example message is shown in Fig. XV-8.



```
KALB   GFSX MOS GUIDANCE   1/01/2005  0000 UTC
FHR  24| 36  48| 60  72| 84  96|108 120|132 144|156 168|180 192
SAT  01| SUN 02| MON 03| TUE 04| WED 05| THU 06| FRI 07| SAT 08 CLIMO
X/N  47| 20  41| 35  45| 25  32| 23  30| 25  33| 24  36| 21  37 12 31
TMP  33| 22  38| 37  36| 27  28| 25  27| 27  29| 27  30| 24  32
DPT  18| 12  25| 32  26| 24  25| 22  23| 24  24| 21  21| 19  25
CLD  CL| CL  OV| OV  PC| OV  OV| OV  OV| OV  OV| PC  PC| OV  OV
WND  19|  8  14| 15  12|  7   6|  7  11|  9  12| 13  13| 10  13
P12   2|  0  79| 62   7| 56  52| 48  63| 50  48| 31  16| 23  25 26 27
P24    |     79|    .72|     74|     67|     62|     48|     38    39
Q12   0|  0   2|  1   0|  1   1|  1   4|  2   2|  1    |
Q24    |      2|      1|      2|      4|      3|       |
T12   1|  2   0|  1   0|  2   2|  3   3|  5   5|  3   0|  0   1
T24    |  2    |  1    |  5    |  3    |  5    |  5    |  2
PZP  17| 38  42| 28  13| 30  34| 43  37| 38  27| 30  21| 24  26
PSN  34| 52  19|  0  10| 25  28| 28  35| 30  33| 27  55| 49  40
PRS  20|  9   5| 10  17| 12  11|  8   6|  3   8| 18   7| 11  12
TYP   S|  Z   Z|  Z   R|  Z   Z|  Z   Z|  Z   Z|  Z   Z|  Z   Z
SNW    |      0|      0|      1|      1|       |       |
```

Fig. XV-8. An example GFS-based extended-range MOS bulletin for 0000 UTC as it existed in September 2005. (From MDL 2006a.)

A brief explanation of the rows in Fig. X-8 is below. For categorical forecasts, the category numbers are the same as in the short-range bulletin (see above).

X/N -- Alternating nighttime min and daytime max temperatures. Climatological values are given at the end of the line. For the 0000 (1200) UTC cycle, the NCDC “normals” are used for the 96-120 (84-108) h projection.

TMP – Temperature every 12 h.

DPT – Dew point every 12 h.

CLD – Mean cloud cover over 12-h periods. CL = mostly clear; PC = mixed clear and cloudy; OV = mostly overcast. These are averages of 3-h probability values with thresholds applied.

WND – Maximum sustained wind over 12-h periods. This is the largest of five, 3-h forecasts over the period.

P12 – PoP for 12-h period.

P24 – PoP for 24-h period.

Q12 – Quantitative precipitation in categories (e.g., 1 = 0.01 to 0.09 in) over 12-h period.

Q24 – Quantitative precipitation in categories over 24-h period.

T12 – Probability in percent of thunderstorms in 12-h period.

T24 – Probability in percent of thunderstorms in 24-h period.

FZP – Conditional (on precipitation occurring) probability in percent of freezing precipitation in 12-h period.

PSN – Conditional (on precipitation occurring) probability in percent of snow in a 12-h period.

PRS – Conditional (on precipitation occurring) probability of mixed rain and snow in a 12-h period.

TYP -- Type of precipitation (if precipitation occurs). Z = freezing; S = snow; RS = rain and snow mixed; R = rain.

SNW – Categorical snowfall amount accumulated in a 24-h period (e.g., 2 = 2 to < 4 in).

Developing the snowfall guidance was particularly difficult for a number of reasons. For one thing, the reporting systems had changed. With the advent of AFOS and adhering to METAR standards, the reporting of snowfall at most sites was discontinued (Cosgrove and Sfanos 2004). The solution was to use reports from cooperative observers of which there were about 8,000 active in the CONUS and Alaska. But not all sites reported at the same time or did not report for a sufficiently long record, and there were other observational problems, including the moving of a station perhaps to a different elevation. Extensive quality control of the data was required. Finally, 5,994 stations were selected for development. These were put into eight regions in the CONUS and two in Alaska. Portions of California, and Florida did not have enough cases of snow to be included. Equations were developed for both the 0000 and 1200 UTC cycles, out to 132 and 84 h, respectively. Snowfall amount was divided into the categories shown in Fig. XV-6.

A snowfall forecasting system was developed and implemented.

Rebecca Allen Cosgrove developed snow forecasts and other weather forecast systems.

There were three predictands, in addition to the amount being broken into categories. They were: (1) precipitation/no precipitation (PoP); (2) conditional, on precipitation occurring, probability of snow (CPOS); and (3) conditional on snow occurring, the amount (CSNOW). According to Cosgrove and Sfanos (2004):

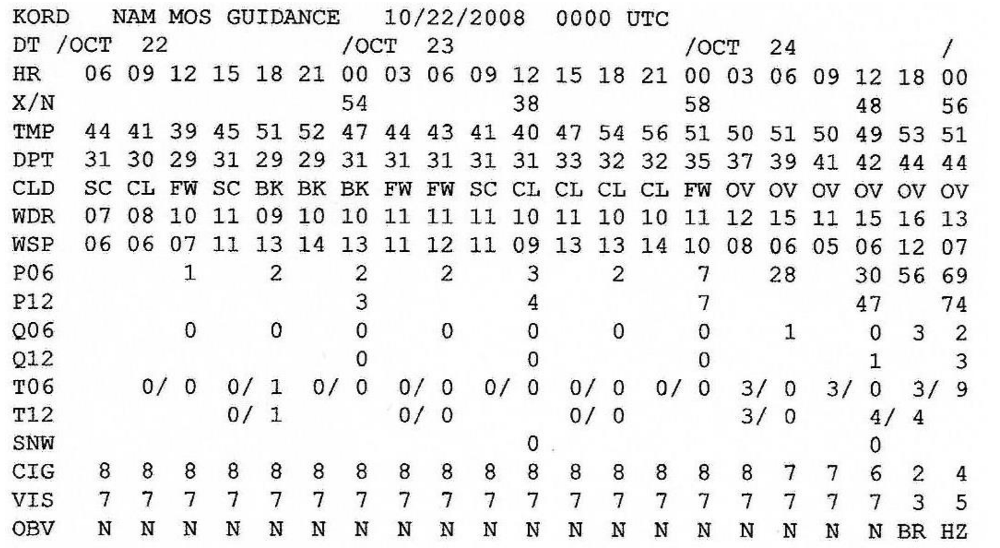
> "When the forecast equations are evaluated, the PoP, CPOS, and CSNOW probabilities are combined statistically to create the final unconditional snowfall probabilities. First, the PoP and CSNOW are multiplied together to produce the unconditional probability of snow occurring. This probability is then multiplied by each of the CSNOW probabilities to give the unconditional probability of exceeding that amount of snow."

Thresholds developed by maximizing the threat score within a bias range of 0.9 to 1.1 were compared to the unconditional probabilities to get a categorical forecast category; the category was put into the bulletin (see Fig. XV-8).

According to MDL (2006b), wind gust guidance based on the GFS was developed to support its inclusion in the NDFD. Many METAR wind reports were searched, and it was determined that the "vast majority of the observed wind gusts occurred when the wind speed was greater than or equal to 14 knots." So, a wind speed of ≥ 14 kt was considered necessary for a gust, but not sufficient for the wind to be gusty. For the screening regressions, two predictands were defined. One was binary. When the speed was ≥ 14 kt and there was a gust, the predictand value was 1. When the speed was ≥ 14 kt and there was no gust, the predictand value was 0. When the speed was < 14 kt, the value was set to 9999 (the MOS 2000 universal value for "missing"). The equation would give the probability of a gust when the speed was ≥ 14 kt. Thresholds were developed with which to separate the probabilities into gust and no gust. The other predictand was the wind gust speed. When it was < 14 kt, or when it was not a gust, it was set to 9999. The equation for this predictand gave the value of a gust, conditional on there being a gust and the speed was ≥ 14 kt. Single-station equations were developed when enough gusts occurred; otherwise, a regional equation was developed. The forecasted gust speeds were partially inflated (inflated above the mean but not below). There were restrictions put on the magnitude of the gusts.

A wind gust forecasting system was developed and implemented in 2006.

MDL continued to make changes to its guidance in keeping with changes in the NCEP model suite. The eta model was replaced by the NAM and a rather complete MOS package based on the NAM (Maloney et al. 2009) was implemented in December 2008 (MDL 2008);[6] an example is shown in Fig. XV-9. The eta bulletin (see Chapter XIII) was discontinued. At the time of implementation, some but not all forecast equations had been developed from NAM output and some equations were based on the eta model but applied to the NAM. Those based on the eta were to be rederived on the NAM.



```
KORD   NAM MOS GUIDANCE   10/22/2008  0000 UTC
DT /OCT  22            /OCT  23                /OCT  24           /
HR    06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 18 00
X/N                     54          38          58          48    56
TMP   44 41 39 45 51 52 47 44 43 41 40 47 54 56 51 50 51 50 49 53 51
DPT   31 30 29 31 29 29 31 31 31 31 31 33 32 32 35 37 39 41 42 44 44
CLD   SC CL FW SC BK BK BK FW FW SC CL CL CL CL FW OV OV OV OV OV OV
WDR   07 08 10 11 09 10 10 11 11 11 10 11 10 10 11 12 15 11 15 16 13
WSP   06 06 07 11 13 14 13 11 12 11 09 13 13 14 10 08 06 05 06 12 07
P06          1     2     2     2     3     2     7    28    30 56 69
P12                      3           4           7          47    74
Q06          0     0     0     0     0     0     0     1     0  3  2
Q12                      0           0           0           1     3
T06      0/  0 0/  1 0/  0 0/  0 0/  0 0/  0 0/  0 3/  0 3/  0 3/  9
T12            0/  1       0/  0       0/  0       3/  0    4/  4
SNW                                  0                       0
CIG    8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  8  7  7  6  2  4
VIS    7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  3  5
OBV    N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N BR HZ
```

Fig. XV-9. Example NAM MOS message for Chicago on October 22, 2008. (From MDL 2008.)

The extended-range message (one for each of 0000 and 1200 UTC) first implemented in May 2000 was based on the Medium Range Forecast (MRF) model which was the long run of the Global Spectral Model (GSM). By 2010, it had grown to 1,693 stations in the CONUS, Alaska, Pacific, and Caribbean (MDL 2010). In addition, forecasts were furnished for 273 stations for the U.S. Air Force. All weather elements except temperature and dew point were valid over 12-h periods. The projections ranged from 24 through 192 h.

Appendix A in MDL (2010) details the decade of changes, with dates, to the bulletin. Fig. XV-10 is an example of both the 0000 and 1200 messages.

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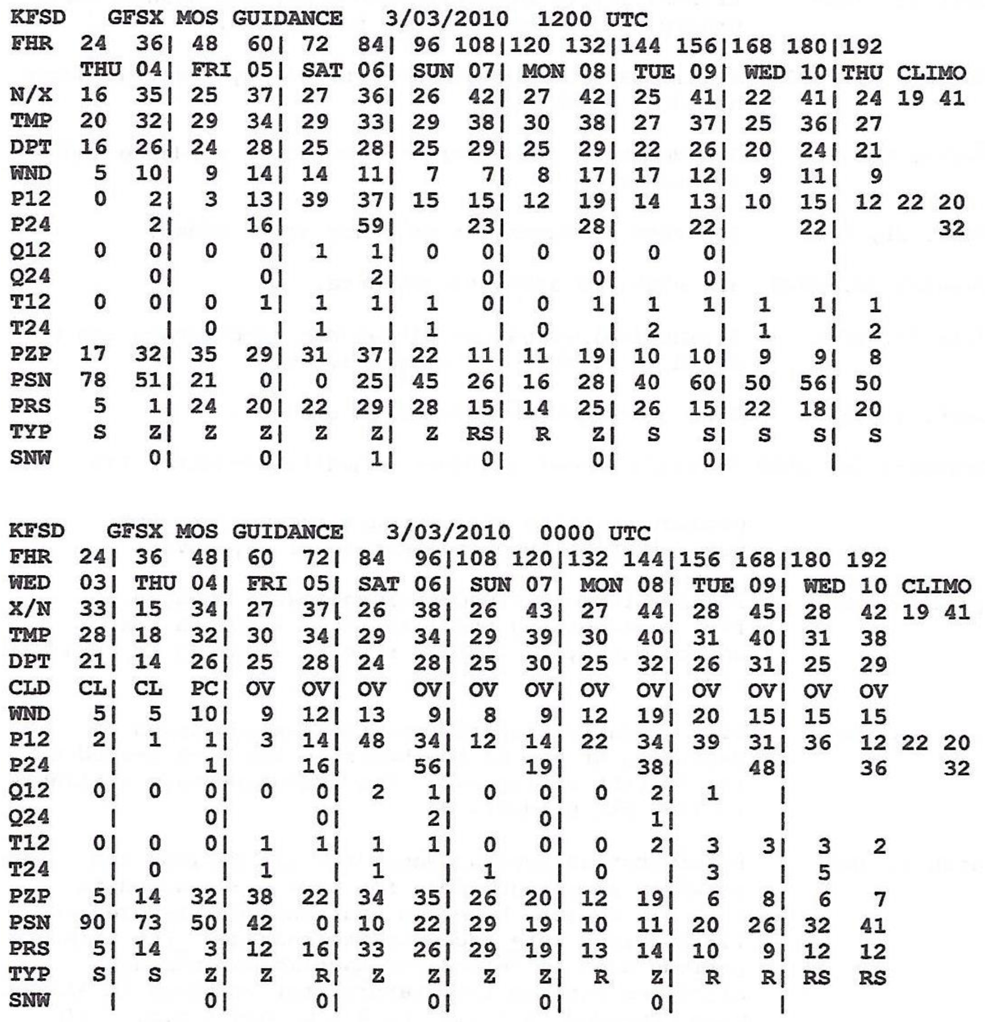
[6] MDL change log.



```
KFSD   GFSX MOS GUIDANCE   3/03/2010  1200 UTC
FHR  24  36| 48  60| 72  84| 96 108|120 132|144 156|168 180|192
     THU 04| FRI 05| SAT 06| SUN 07| MON 08| TUE 09| WED 10|THU CLIMO
N/X  16  35| 25  37| 27  36| 26  42| 27  42| 25  41| 22  41| 24 19 41
TMP  20  32| 29  34| 29  33| 29  38| 30  38| 27  37| 25  36| 27
DPT  16  26| 24  28| 25  28| 25  29| 25  29| 22  26| 20  24| 21
WND   5  10|  9  14| 14  11|  7   7|  8  17| 17  12|  9  11|  9
P12   0   2|  3  13| 39  37| 15  15| 12  19| 14  13| 10  15| 12 22 20
P24       2|     16|     59|     23|     28|     22|     22|       32
Q12   0   0|  0   0|  1   1|  0   0|  0   0|  0   0|       |
Q24       0|      0|      2|      0|      0|      0|       |
T12   0   0|  0   1|  1   1|  1   0|  0   1|  1   1|  1   1|  1
T24        |  0    |  1    |  1    |  0    |  2    |  1    |  2
PZP  17  32| 35  29| 31  37| 22  11| 11  19| 10  10|  9   9|  8
PSN  78  51| 21   0|  0  25| 45  26| 16  28| 40  60| 50  56| 50
PRS   5   1| 24  20| 22  29| 28  15| 14  25| 26  15| 22  18| 20
TYP   S   Z|  Z   Z|  Z   Z|  Z  RS|  R   Z|  S   S|  S   S|  S
SNW       0|      0|      1|      0|      0|      0|       |


KFSD   GFSX MOS GUIDANCE   3/03/2010  0000 UTC
FHR  24| 36  48| 60  72| 84  96|108 120|132 144|156 168|180 192
WED  03| THU 04| FRI 05| SAT 06| SUN 07| MON 08| TUE 09| WED 10 CLIMO
X/N  33| 15  34| 27  37| 26  38| 26  43| 27  44| 28  45| 28  42 19 41
TMP  28| 18  32| 30  34| 29  34| 29  39| 30  40| 31  40| 31  38
DPT  21| 14  26| 25  28| 24  28| 25  30| 25  32| 26  31| 25  29
CLD  CL| CL  PC| OV  OV| OV  OV| OV  OV| OV  OV| OV  OV| OV  OV
WND   5|  5  10|  9  12| 13   9|  8   9| 12  19| 20  15| 15  15
P12   2|  1   1|  3  14| 48  34| 12  14| 22  34| 39  31| 36  12 22 20
P24    |      1|     16|     56|     19|     38|     48|     36    32
Q12   0|  0   0|  0   0|  2   1|  0   0|  0   2|  1    |
Q24    |      0|      0|      2|      0|      1|       |
T12   0|  0   0|  1   1|  1   1|  0   0|  0   2|  3   3|  3   2
T24    |  0    |  1    |  1    |  1    |  0    |  3    |  5
PZP   5| 14  32| 38  22| 34  35| 26  20| 12  19|  6   8|  6   7
PSN  90| 73  50| 42   0| 10  22| 29  19| 10  11| 20  26| 32  41
PRS   5| 14   3| 12  16| 33  26| 29  19| 13  14| 10   9| 12  12
TYP   S|  S   Z|  Z   R|  Z   Z|  Z   Z|  R   Z|  R   R| RS  RS
SNW    |      0|      0|      0|      0|      0|       |
```

Fig. XV-10. The 1200 (top) and 0000 (bottom) UTC GFS extended messages. The cloud forecasts (missing CLD row) were not yet available for 1200 UTC. (From MDL 2010.)

The bulletin for 15, up from 13, stations in the western Pacific was augmented in August 2006 with PoP and the probability of precipitation occurrence,[7] and in September 2008 with temperature and dew point,[8] By November 2013, the bulletin was complete (MDL 2013) for both 0000 and 1200 UTC. An example forecast for Anderson AFB, Guam, for 0000 UTC is shown in Fig. XV-11. The locations of the 15 stations are shown in Fig. XV-12.

James Su developed forecast systems, especially for the western Pacific islands.

Su (2008) discusses these forecasts for the Pacific islands and notes the stations overlap the tropical western Pacific warm pool. The climate there is, of course, much different than other

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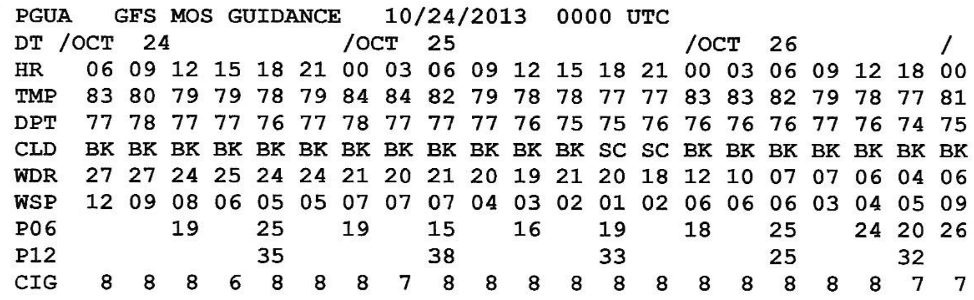
[7] MDL change log.

[8] MDL change log.

areas for which we made MOS forecasts. Verification of PoP, temperature, and dew point at individual stations showed that the forecasts generally matched the low yearly variability shown by the corresponding observations.

Shafer (2010) describes in detail the use of the logit model in defining predictors for precipitation type for current versions of the AVN and MRF bulletins. This elaborates on the explanation presented in Chapter V.



```
PGUA    GFS MOS GUIDANCE    10/24/2013  0000 UTC
DT /OCT  24             /OCT  25                /OCT  26          /
HR    06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 18 00
TMP   83 80 79 79 78 79 84 84 82 79 78 78 77 77 83 83 82 79 78 77 81
DPT   77 78 77 77 76 77 78 77 77 77 76 75 75 76 76 76 76 77 76 74 75
CLD   BK BK BK BK BK BK BK BK BK BK BK BK SC SC BK BK BK BK BK BK BK
WDR   27 27 24 25 24 24 21 20 21 20 19 21 20 18 12 10 07 07 06 04 06
WSP   12 09 08 06 05 05 07 07 07 04 03 02 01 02 06 06 06 03 04 05 09
P06         19    25    19    15    16    19    18    25    24 20 26
P12               35          38          33          25       32
CIG    8  8  8  6  8  8  8  7  8  8  8  8  8  8  8  8  8  8  8  7  7
```

Fig. XV-11. Example message for a western Pacific location, prepared for Anderson AFB on October 24, 2013. (From MDL 2013.)

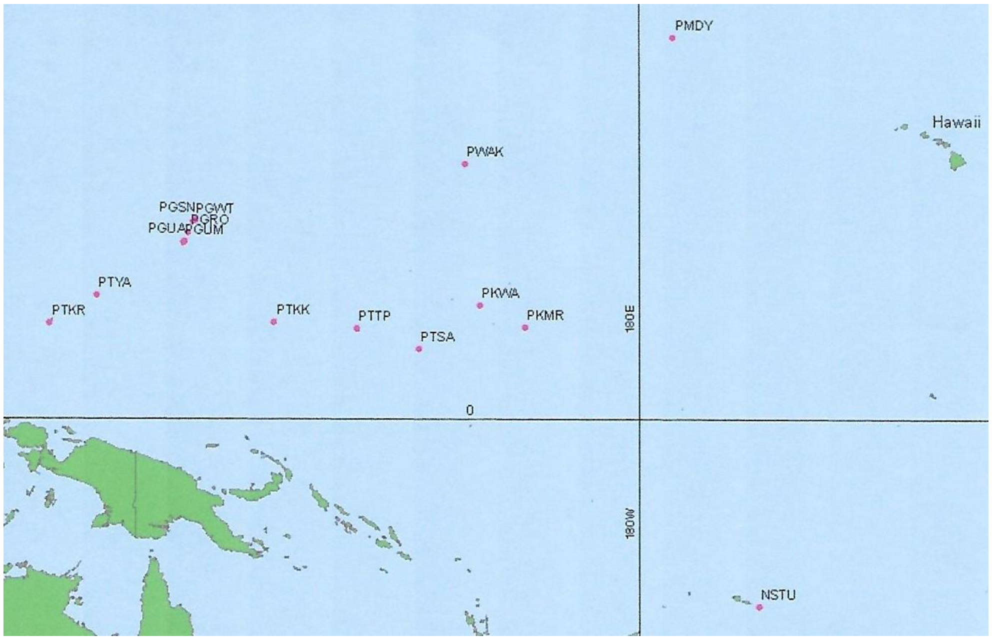


Fig. XV-12. The locations of the 15 western Pacific stations for which MOS forecasts were furnished. (From Su 2008.)

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CHAPTER XVI

ENSEMBLE-BASED MOS

Numerical weather prediction is built on the premise that the atmosphere can be modeled closely enough so the model run forward in time can produce useful predictions, and certainly science and history have proven that. Forecasts with some skill can be made up to a week or more in advance. However, it was always recognized that neither the model nor the input to it would be perfect.

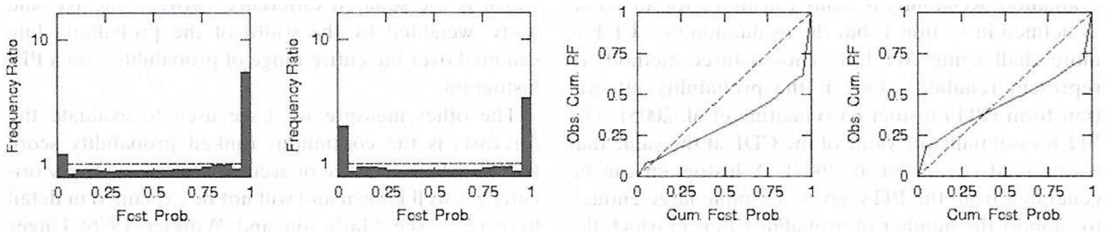
In order to get an "ensemble" of NWP forecasts that together might furnish a better forecast than an individual instance of the model, the model can be run more than once with differing initial conditions or different details within the model. How the initial conditions or the model details are varied are matters for research, but ways have been devised. NCEP started running ensembles of their GFS in a research/experimental mode in 1992 (Toth and Kalnay 1997), and made the results available to users.

Ensembles of that time were notoriously underdispersed. That means the individual members did not encompass the possible outcomes; they were too tightly clustered.


Matthew Peroutka was a branch chief and led the EKDMOS project.

Once the ensemble results were made available to forecasters, there was a clamor for MOS on the individual members. TDL dutifully responded (Erickson 1996), and the MOS equations that had been developed on the base GFS run were evaluated on each member and the results made available, even though it was known the underdispersion of the ensembles would carry forward into the MOS forecasts. Fig. XVI-1 shows the underdispersion of both the raw ensembles and the MOS based on them as well as bias on a 2-year cool season of data in terms of PIT histograms (Gneiting et al. 2005) and cumulative reliability diagrams (CRD) (Glahn et al. 2008, 2009). If the forecasts were unbiased and properly dispersed, the tops of the bars in the PIT histogram would all fall on the unity line. The tall bars at the ends indicate too many observations fell outside the forecasts of the ensemble members in the sample. The taller bar on the right indicates a cool bias, as more verifying observations fell on the warm side than the cool side; the MOS was a little better than the raw ensembles in this regard. The CRDs show that if a user had a specific temperature decision threshold, the MOS would furnish a less biased result.

It became obvious the ensemble process was here to stay and that we needed to develop a processing method specifically targeted to apply to ensembles. For operations, it needed to be relatively simple and not use excessive computer time. Work was started in the mid 1990's and was first documented in 2008 (Glahn et al. 2008). At this time, the sample available was from the global ensemble forecast system (GEFS) starting in May 2004. For our developmental sample, we chose the 2 cool seasons October 2004—March 2005 and October 2005—March 2006. Independent data were available for the 6-month period October 2006 through March 2007. For purposes of illustration, I will discuss our EKDMOS process as first developed for temperature.



(a) (b) (c) (d)

Fig. XVI-1. PIT histograms of temperature of (a) raw ensembles and of (b) MOS applied to the raw ensembles, and CRDs of (c) raw ensembles and of (d) MOS applied to the ensembles. Based on 1650 stations, 2 cool seasons of data from October through March. (From Glahn et al. 2009.)

The first step in the process was to develop single-station MOS equations based on the ensemble means. We used single-station equations rather than generalized operator because our years of previous work showed that samples we had available supported single-station equations, and their accuracy was better than combining stations. Using the means for development of the equations gave better results than developing separate equations on each ensemble member; this has been shown to be preferable (e.g., Unger et al. 2009). This step, shown in the top third of Fig. XVI-2, provided a measure of error and made use of the means of the ensembles, but not their spread.

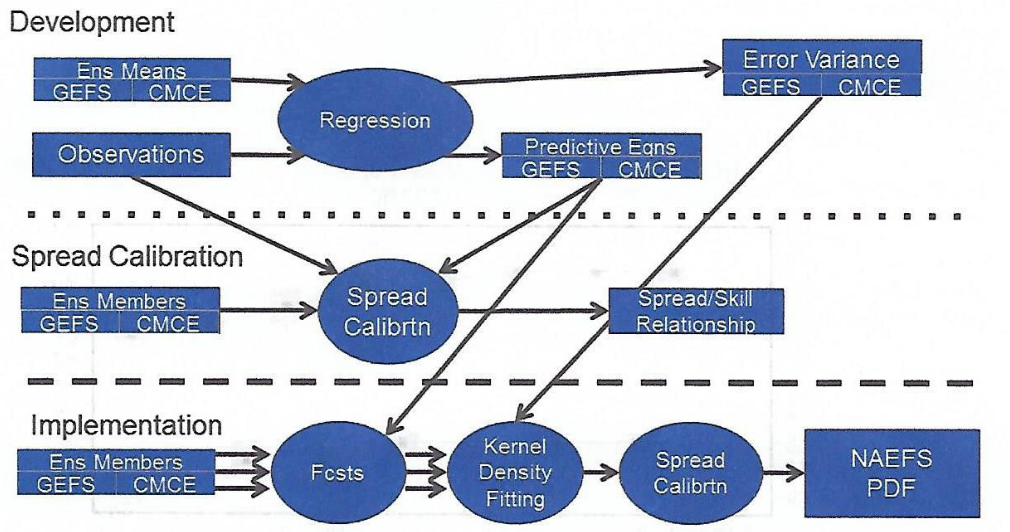
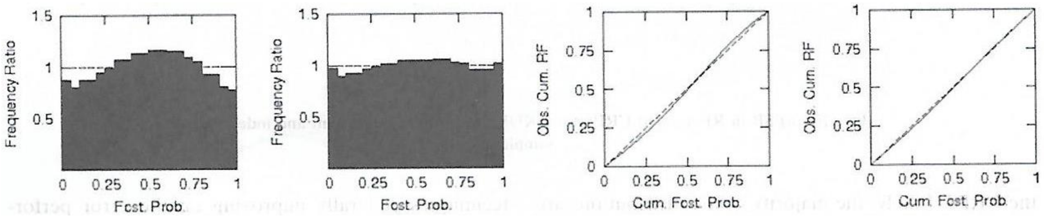


Fig. XVI-2. Diagram of EKDMOS development and implementation steps. Two models are indicated (GEFS and CMCE), but the process can be applied to individual models. (From Peroutka 2015.)

The regression process yields an error estimate of the forecast from the equation [see Glahn et al. (2009) for the equations and application]. We used that estimate and kernel density smoothing [or kernel density estimation (KDE) (Wilks 2011, p. 35)] with a Gaussian kernel to "dress" the forecasts from each of the 11 ensemble members. This gave us a cumulative density function (CDF) for each station which was not necessarily symmetric, and could even be bimodal. Because the error estimate from the regression was reasonable for one member, adding the spread of the members gave overdispersed forecasts.

The second step in the process, the middle section in Fig. XVI-2, was to devise an empirical spread correction that resulted in the members having a better dispersion. This correction is shown as Eq. 16 in Glahn et al. (2009). The adjustment depends on the minimum and maximum of the ensemble forecasts and their standard deviations. It also includes an adjustment factor "sf" that can be used to tune the process as necessary depending on weather element, projection of the forecast, etc. The resulting PIT histograms and CRDs are shown in Fig. XVI-3 for both dependent and independent data.



(a) (b) (c) (d)

Fig. XVI-3. (a) PIT histogram of EKDMOS on dependent data, and (b) same on independent data; (c) CRD of EKDMOS on dependent data, and (d) same on independent data. Note the change in ordinate scale of (a) and (b) from Fig. XVI-1 to Fig. XVI-3. (From Glahn et al. 2009.)

The improvement in the forecasts verified in Fig. XVI-3 over those in Fig. XVI-1 is striking. The square bias in relative frequency and continuous ranked probability score (CRPS) (see Glahn et al. 2008, 2009) show EKDMOS better than raw ensembles and MOS applied to individual members without the EKD (ensemble kernel density) adjustment. This process was tested on maximum and minimum temperature and spot dew point as well as temperature, and the positive results held.

EKDMOS was developed in 2008 and implemented in 2012.

John Wagner was one of the developers of EKDMOS and of other forecast systems.

In March 2006, NCEP implemented operationally the NAEFS system composed of the GEFS and the model developed by the Meteorological Service of Canada, the CMCE (Toth et al. 2006). Each of the models had 11 members. Wagner and Glahn (2010) tested the EKDMOS process on the NAEFS. About two years of both cool and warm seasons of data were available for development. They concluded, based on dependent data, that the NAEFS forecasts were more accurate than the GEFS and the CMCE at every projection hour for both temperature and dew point. EKDMOS was implemented in the CONUS and Alaska in April 2012 and was distributed on the AWIPS SBN starting in April 2015.[1]

Soon, Peroutka et al. (2010) used the EKDMOS process on two variables devised to measure the effect of weather on the human body. One was the heat index (HI) designed to measure the

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[1] MDL EKDMOS change log.

combined effect of heat and humidity. The other was the wind chill (WC) designed to measure the combined effects of cold and wind. Both are computed variables. For convenience, forecasts of HI, WC, and temperature are frequently combined into a single weather element called apparent temperature (Peroutka et al. 2010).

HI development was done for 2,280 stations in the CONUS, Alaska, Hawaii, and U.S. territories. Heat plays an important role only in hot weather, so cases with temperature less than 70°F were omitted and cases with temperature between 70 and 80°F were set to the temperature. The HI can be computed from model output and such was included as a predictor in each equation developed. Equations were developed only if 100 or more cases were available. Because the number of single-station cases in cool areas on the west coast of the CONUS was insufficient for development, some stations were grouped. The number of stations with single-station equations varied by time of day, ranging from 308 to 1,830. Contrary to most MOS developments, stratification by season was not done.


Jerry Wiedenfeld was a developer of EDKMOS, LAMP, and other forecast systems.

EKDMOS was applied to heat index, wind chill, and apparent temperature.

Like for HI, no accounting was done for season in WC development. Cases were omitted when the temperature was greater than 60°F, and the WC was set to the temperature when the temperature was in the range 50 to 60°F. As with HI, some WC equations were single-station (1,440) and some were regional (840).


Greg Zylstra was a developer of the heat index and wind chill EKDMOS and other meteorological products.

Because HI and WC are both bounded on one side, verification is difficult. For instance, the predicted temperature may be too low to make an HI forecast, but the actual temperature allows calculation of the verifying HI. A case such as this ought to be included in the verification, but was omitted for lack of a better solution. The results for HI compared favorably with what had been achieved earlier for temperature. The results for WC were not as good as those for HI, although the EKDMOS scored much better than the raw ensembles.

The temperature, HI, and WC probability distributions were combined in the KDE step of the EKDMOS technique to produce an apparent temperature. First the forecast and prediction intervals of each were computed where possible. The temperature forecast from each member was evaluated to determine whether a kernel should be created from the temperature, HI, or WC forecast/prediction interval. Then the KDE process proceeded by using a set of kernels that could be a mixture of weather elements. Verification of the forecasts was not presented, but the forecasts seemed reasonable. The EKDMOS process that had previously been demonstrated for temperature, dew point, and max and min temperature had now been extended successfully to two derived weather elements and their combination.

The factor developed to adjust the overdispersion of the dressed ensembles mentioned above, the so-called 2nd moment calibration, corrected the overall spread quite well but was not specific to stations. Veenhuis and Wagner (2012) used a technique proposed by Grimit and Mass (2007) to bring that specificity into EKDMOS. They used the NAEFS suite of 42 ensemble members, half from each of the GEFS and CMCE (this number had grown from the original implementation). They used 2303 stations covering the CONUS, Canada, Alaska, Hawaii, and Puerto Rico. Three years of data were available for development and cross validation.

Bruce Veenhuis, meteorologist and statistician, was a developer of EKDMOS.

A spread-skill relationship was added to EKDMOS.

For each case and each station, the forecasts from the 42 members were used to calculate the mean error and the standard deviation. Presumably because the sample for an individual station was not large, a binning technique was used. Bins of standard deviation were defined with at least 100 cases in each bin. Because of sample size, only four bins could be defined. The mean ensemble error was also calculated for each bin. The plots of ensemble mean error vs ensemble member standard deviation usually showed a linear relationship. For instance, see Fig. XVI-4 for Baltimore-Washington International Airport (KBWI) temperature for the 72-h projection. The four means show a positive spread skill relationship, although there is much scatter of the individual members. For each station, a linear line was fit to the four points. Two restrictions were placed on using this relationship. First, the slope had to be positive. Second, a significance test had to show there was a less than 25% probability the positive slope was due to chance. If either of these criteria was not met, the relationship was not used. When this relationship was used for the stations that passed the tests, the results showed that the spread of the

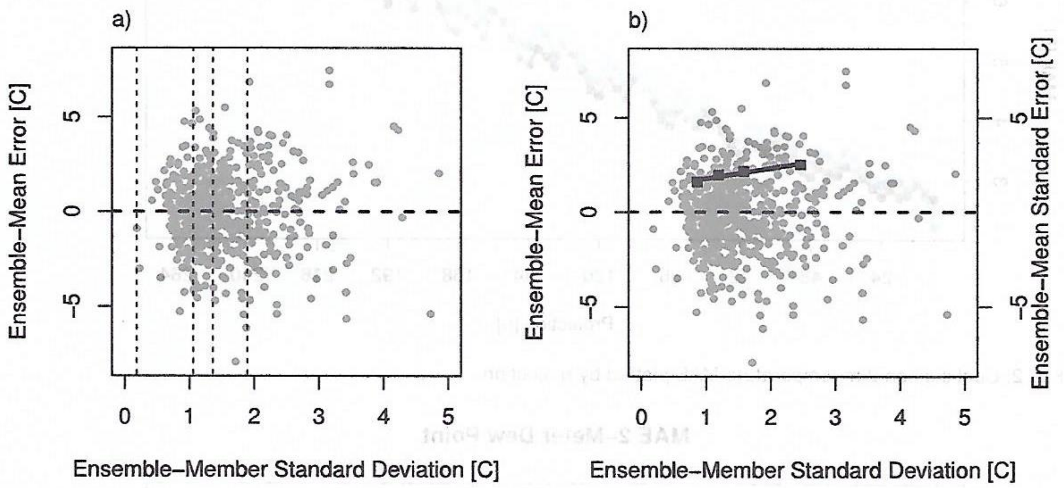

Fig. XVI-4. Ensemble mean error as a function of ensemble member standard deviation. In (a) the bins of standard deviation are indicated (vertical lines) for the four bins. The average mean error in each bin is plotted in (b) at the bin average ensemble member standard deviation. A solid line indicates a linear relationship. (From Veenhuis and Wagner 2012.)

ensembles was significantly increased without degrading the reliability. Forecasts from this method were operationally implemented at NCEP in December 2015 for both the CONUS and Alaska.[2]

The actual data on which the spread-skill relationship was devised are shown in Fig. XVI-4. Veenhuis (2013) devised an alternative to the binning method of specifying the relationship. Instead of binning the data, calculating the means, and deriving a linear relationship, he used a square root transformation and fit the data directly. Forecasts were calculated and verified on a set of 335 stations that had been judged to have reliable data. Although a spread-skill relationship was found for many stations and projections (about 85 to 90% for cool season maximum temperature), it was not found for all. For instance, for dew point forecasts, the percentage of stations with an accepted relationship varied between 60% and 90% for the cool season projections. This new method of developing the spread-skill relationship was shown to be better than the binning method.

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[2] MDL EKDMOS change log.

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CHAPTER XVII

THE GRIDDING OF MOS

The statistical products discussed in the previous chapters, both MOS and PP, were forecasts produced predominantly at stations and provided to users in "bulletins." Usually a bulletin was a matrix of forecasts for an individual station that included forecasts for several weather elements for several projections. The number of stations with forecasts were a few hundred at the start and rose to several thousand, depending on the availability of developmental data which varied greatly by weather element. These bulletins started out as teletype messages and later became encoded for transmission over AFOS or AWIPS communications. Maps for some elements had been prepared by plotting specific values or by contouring the individual values. When this was done, the maps would be transmitted by facsimile, thereby furnishing a picture but not providing values except at the stations plotted.

AWIPS and associated software and techniques made another form of preparation and dissemination desirable. The national digital forecast database had been established in 2003 (Glahn and Ruth 2003). This is a repository for official forecasts in gridded form prepared by forecasters at Weather Forecast Offices (WFO), and later at other places, with AWIPS software in the Interactive Forecast Preparation System (IFPS) (Ruth 2002). In IFPS, forecasters would start from an initial grid and modify it to accommodate their belief of the weather to come. In so doing, they would use forecast guidance from many sources. A gridded representation of MOS forecasts was thought to assist in this process. This means that the MOS forecasts needed to be furnished as gridpoint values on the specific grid (map projection, etc.[1]) used by the NDFD. To house guidance to be used in the forecast process, the national digital guidance database (NDGD) was established by MDL. The grid definitions and access processes were the same for the NDGD and NDFD.

Given that most of the predictand data used for MOS were observations at stations, there were two basic methods of producing a gridded product. One was to use the station-based MOS forecasts in an objective mapping technique. The other was to use objective analysis software on the observations, produce a "grid of observations," and then use the gridpoints in that grid as predictand data to produce MOS equations that could be applied at gridpoints. Note that either of these schemes requires quality objective analysis software. When this requirement rose to the top in MDL, it seemed the first approach was the better of the two. The MOS forecasts already existed, we had only to map them. The other route would have required not only a mapping, but also another development to make forecasts at gridpoints.

There are other alternatives to the two mentioned above. Equations could be developed at stations, and by some assignment of gridpoints to stations, apply the equations at gridpoints. This method sounds attractive, but has its drawbacks. For instance, applying different equations at adjacent gridpoints tends to give discontinuities. Also, observations are many times used as predictors, and this method would require "observations" at gridpoints.

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[1] The characteristics of the grids used by the NDFD and NDGD were adopted from recommendations in a study by Glahn (1988) for the grids to be used by WFOs.

Whenever the predictand data occur naturally on a grid, then an objective mapping of the type discussed above is not necessary, although an interpolation from the observational grid to the forecast grid is usually required. Producing forecasts at gridpoints has been discussed previously (e.g., Charba 1979), but the forecasts were not targeted for gridded dissemination, and usually were provided on teletype or facsimile.

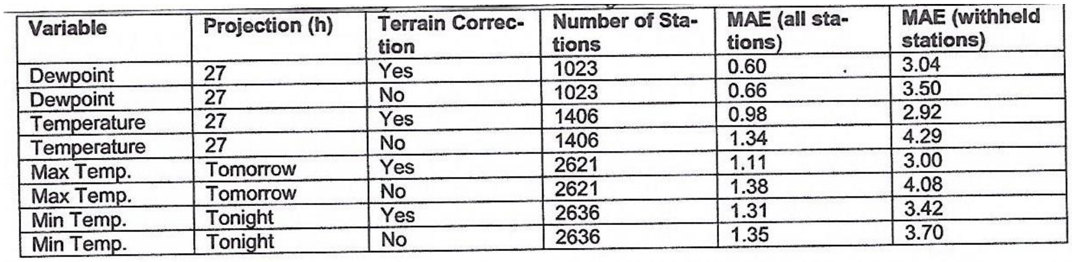
Versions of the Cressman (1959) analysis scheme developed by Bergthorssen and Doos (1955) had been used in TDL/MDL since the 1960's. The method had had considerable tuning and uses associated with LAMP but primarily on 80-km grids (Glahn et al. 1985). At that time, we called the analysis method BCD for the three persons involved in its use (Bergthorssen, Cressman, Doos). At establishment, the NDGD was 5-km resolution, and terrain features needed to be accounted for. Therefore, the in-house version was modified to provide grids of MOS for the NDGD.

The original formulation of the analysis scheme was quite simple. An initial "first guess" grid was modified by making for each datum being analyzed corrections at gridpoints within the datum's vicinity. These corrections depended on the difference between the datum and the value interpolated from the first guess. This process was then repeated as many times as necessary to give a good fit to the data, correcting the grid resulting from the previous pass with the radius of influence being decreased on each pass.

A major challenge was how to account for the terrain. The original use of the BCD method by Cressman (1959) was for upper air geopotential heights and at the levels used, there was no accommodation needed for terrain. However, at the earth's surface, terrain is a major influence on most weather variables. A primary emphasis in MOS was always temperature and dew point near the earth, and these are especially influenced by terrain. Usually, temperature decreases with elevation, but the change varies markedly with weather situation and location, and can even increase with elevation. It seemed the best way to determine the change with elevation was to let the data tell us how. So, to calculate a change to apply at a station, we calculated the average change in temperature between the base station and several other stations divided by the average change in elevation between the pairs of stations. We still needed a way to define the set of stations, for each base station, over which to perform the average. To define the sets of stations can be computer intensive, so that was done in a preprocessor. A set was defined in a way that emphasized a large vertical distance and a small horizontal distance between a station and a neighbor. Details of how this computed change in elevation was used can be found in Glahn et al. (2009).

We started with the western U.S. because of its terrain challenges. We did some withheld data tests of analyses and concluded the process was working well (see Fig. XVII-1). The MAEs in Fig. XVII-1 included the unavoidable error of interpolating from the analysis grid back to the station. In all cases, the average error at both the analysis and withheld stations was less with the terrain correction than without it.

Fig XVII-2 shows a portion of the analysis with and without the terrain correction. As can be seen, the temperature analysis with the adjustment follows the terrain quite well, while the analysis without the adjustment does not. Note especially the Grand Canyon in the upper right.



Variable	Projection (h)	Terrain Correction	Number of Stations	MAE (all stations)	MAE (withheld stations)
Dewpoint	27	Yes	1023	0.60	3.04
Dewpoint	27	No	1023	0.66	3.50
Temperature	27	Yes	1406	0.98	2.92
Temperature	27	No	1406	1.34	4.29
Max Temp.	Tomorrow	Yes	2621	1.11	3.00
Max Temp.	Tomorrow	No	2621	1.38	4.08
Min Temp.	Tonight	Yes	2636	1.31	3.42
Min Temp.	Tonight	No	2636	1.35	3.70

Fig. XVII-1. Mean absolute error (MAE) in degrees F when the analysis was interpolated to all stations and when the analysis was interpolated to stations that had been withheld from the analysis. The column labeled "Terrain Correction" indicates whether or not the terrain correction was used. The column labeled "Number of Stations" denotes the number of sites in the analysis area for which MOS guidance values were available. (From Dallavalle and Glahn 2005.)

Grids were made for max/min temperature and dew point, as well as for temperature. These grids were available on the NWS ftp server and in the NDGD (Glahn and Dallavalle 2006).

After these tests over the western U.S., we immediately extended the method to the CONUS NDGD grid at 5-km resolution. Numerous additions and changes were made to the original BCD code, both going forward and reaching back into our western U.S. tests (Gilbert et al. 2009). Some of them are given here briefly; a somewhat more complete discussion is given in Glahn et al. (2008, 2009). After these extensive modifications and extensions, the analysis method was called BCDG for the primary developers. GIS tools were very useful in this work (Sheets 2007, 2008).

Kari Sheets developed GIS displays for gridded MOS and other techniques.

An analysis system that is to be used operationally in real time needs to have a way of judging the quality of a datum—specifically whether or not to use it in the analysis. This was built in by furnishing the software the maximum difference that would be tolerated between the current analysis (the analysis being corrected) and the datum. This "throw-out criterion" varied by correction pass and by weather element.

The vicinity of a datum in which to correct the gridpoints was within a circle defined by a "radius of influence." Initially, this radius was specified by pass. Obviously, in sparse data areas, the radius would need to be larger than in dense data regions, so that capability was built in by specifying for each correction pass and each datum a radius of influence that was calculated based on data density. This calculation was made in a preprocessor based on "expected" data density.

The first guess could be specified, but for this analysis method, starting with a constant field is quite satisfactory and even preferred. This is not true if there are areas with no data at all; in this case, a good first guess is needed because that will become the final analysis.

The data density for most surface data is much less over water than over land, even to having no values over water. This was handled by doing three analyses in one—one over land, one over the ocean, and one over lakes. Generally, ocean data influenced only the ocean areas, lake data influenced only the lake analysis, and land data influenced only land. However, provision was made for one type of data to bleed into another analysis, fully or partially.

Smoothing was provided for in various ways. One such scheme was a "terrain-following smoother" that did not smooth across markedly different terrain elevations. Eventually, we used what we called a "spot remover" as a selective, larger scale smoother; it was highly effective but computer intensive.

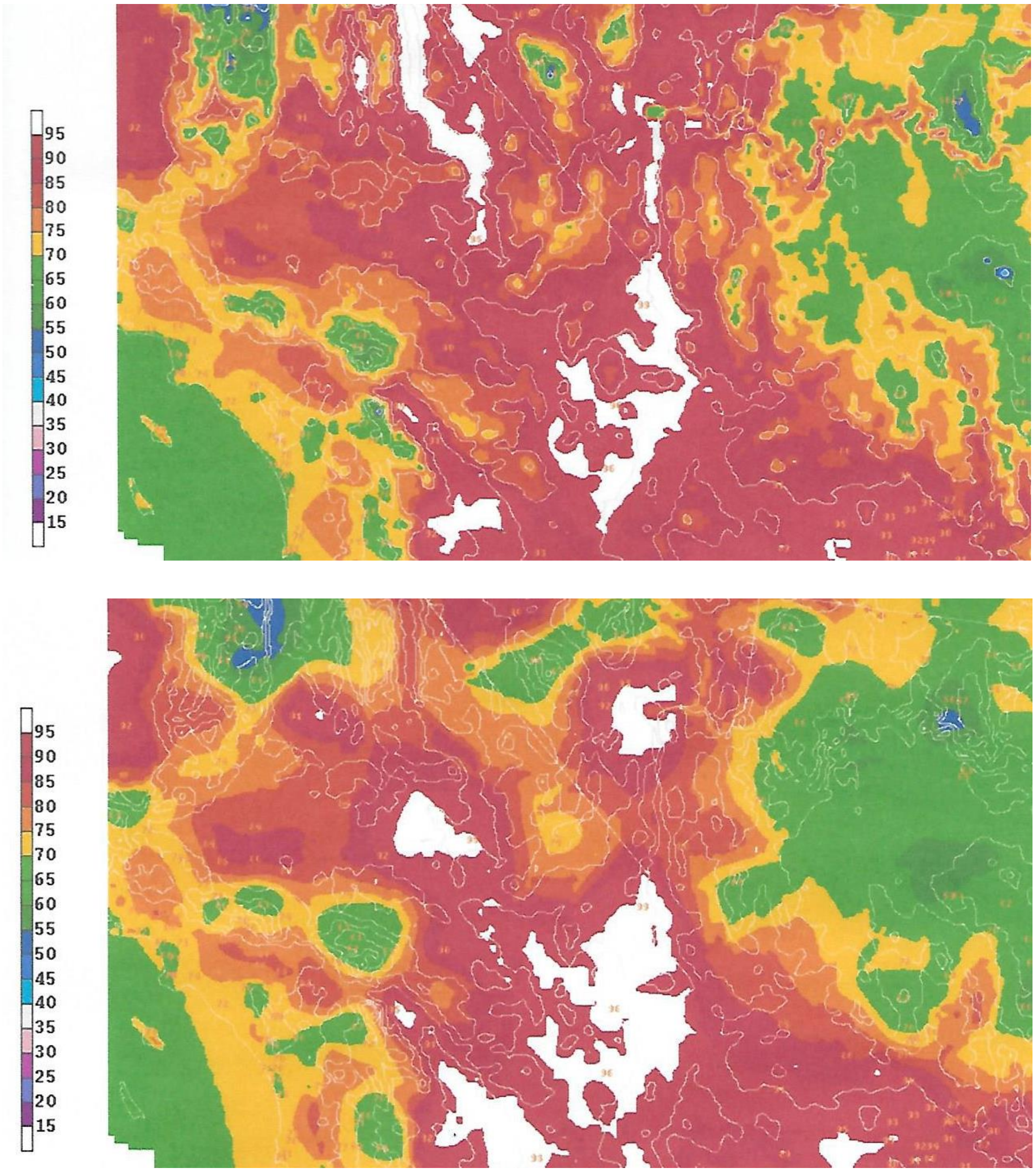


Fig. XVII-2. A portion of the western U.S. used as a prototype for the analysis. Analysis of MOS temperature guidance (°F), 27-h projection, 0000 UTC cycle, July 15, 2004. The top (bottom) map is with (without) the terrain adjustment. (From Dallavalle and Glahn 2005.)

During the period we were developing gridded MOS, there was yo-yoing of the 0000 and 1200 UTC cycles of the driving NWP model. Because that characteristic was in the NWP model, it was also in MOS developed on it, perhaps to a lesser extent. For a time, we analyzed two cycles together. For instance, a 48-h forecast from 0000 UTC would be analyzed with a 36-h forecast made from the 1200 UTC cycle, 12 h later. Cycle averaging caused some undesirable wind analyses, and cycle averaging was dropped for wind on August 12, 2008.[2]

MDL started producing gridded MOS guidance on the CONUS 5-km NDGD grid August 15, 2006, at 1200 UTC.[3] Opaque sky cover, wind gusts, 24-h snowfall, and 6-h and 12-h QPF grids were added June 5, 2007.[4] Verification and comparison of forecasts in the NDGD and NDFD are addressed by Ruth et al. (2009), and they introduce a new score to measure the convergence of forecasts to the verifying value over time.

Gridded MOS was furnished to the NDGD starting in August 2006.

MDL started producing gridded MOS guidance on the Alaska 3-km NDGD grid June 10, 2008, and for the Hawaii 2.5-km grid on November 9, 2010.[5] From this time forward, most MOS was provided in gridded form for most weather elements in addition to the text bulletins. The shift from the 5-km CONUS grid to the 2.5-km grid was started on February 27, 2012.[6]

Examples of analyses are shown in Figs. XVII-3 through XVII-6. The edges are clipped to the NDFD viewing area.

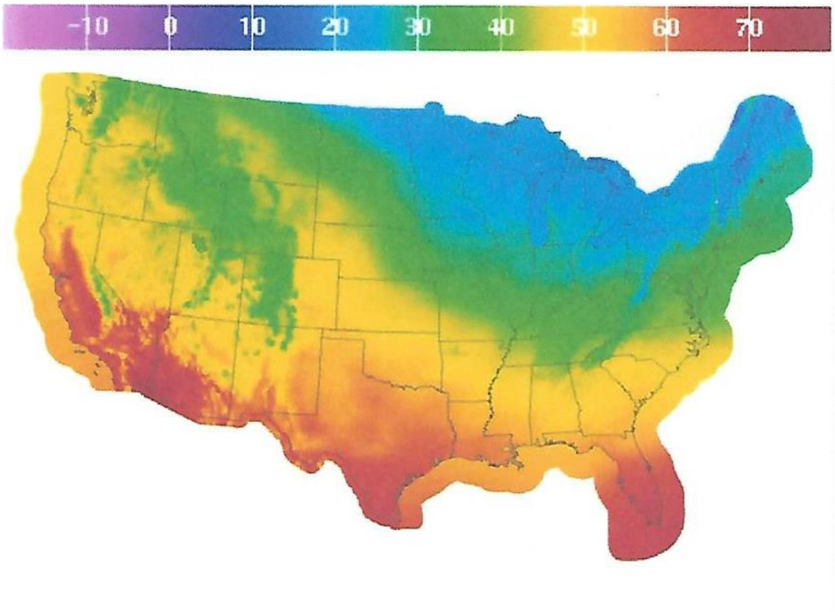


Fig. XVII-3. Analysis of 48-h MOS temperature (°F) based on June 26, 2007, 1200 UTC model run. (From Glahn et al. 2008.)

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[2] MDL MOS change log.

[3] MDL MOS change log.

[4] MDL MOS change log.

[5] MDL MOS change log.

[6] MDL MOS change log.

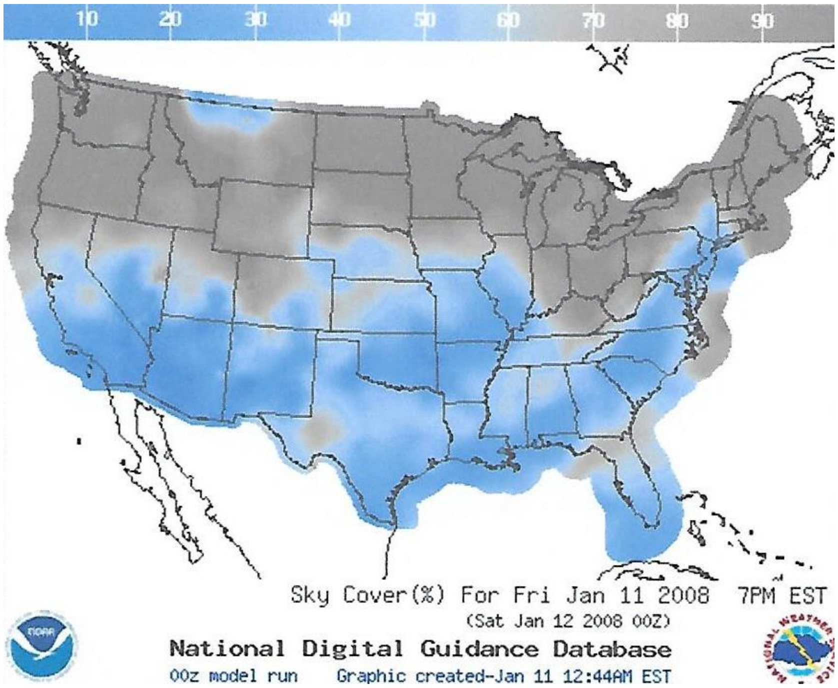

Fig. XVII-4. Analysis of MOS sky cover (%) valid January 12, 2008, 0000 UTC. (From Glahn et al. 2008.)

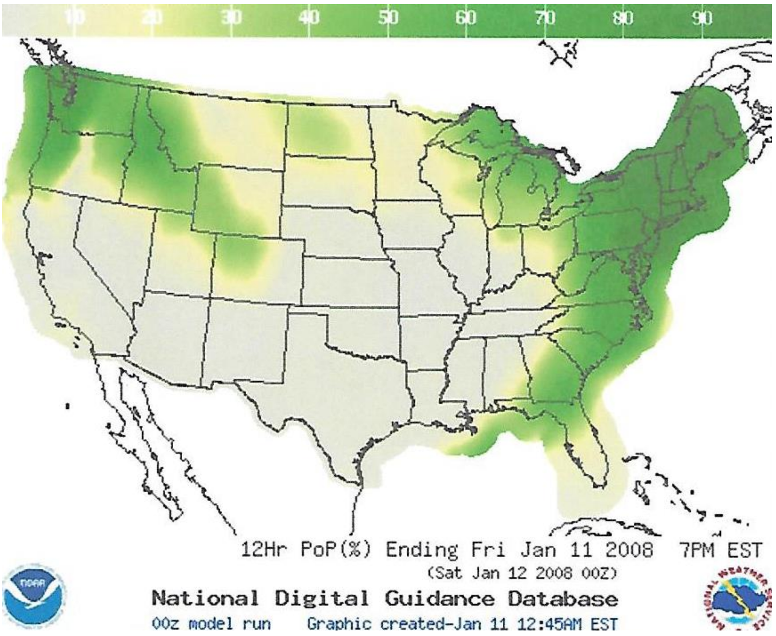

Fig. XVII-5. Analysis of MOS 12-h PoP (%) ending January 13, 2008, 1200 UTC. (From Glahn et al. 2008.)

Usually, the grids in NDGD and NDFD were of individual weather elements, like those presented above. One of the forecaster-prepared grids in the NDFD was the "weather" grid, sometimes called "predominant weather." To provide guidance in the NDGD for the weather grid, Huntemann et al. (2012) presented a method to derive such a grid based on a variety of MOS grids, to wit: 3-h probability of precipitation occurrence; 6- and 12-h PoP; temperature; conditional probability of freezing, frozen, and liquid precipitation; 6-h QPF; 3-, 6-, and 12-h probability of thunderstorm; and 3- and 12-h conditional probability of severe thunderstorm. An example weather grid is shown in Fig. XVII-7.

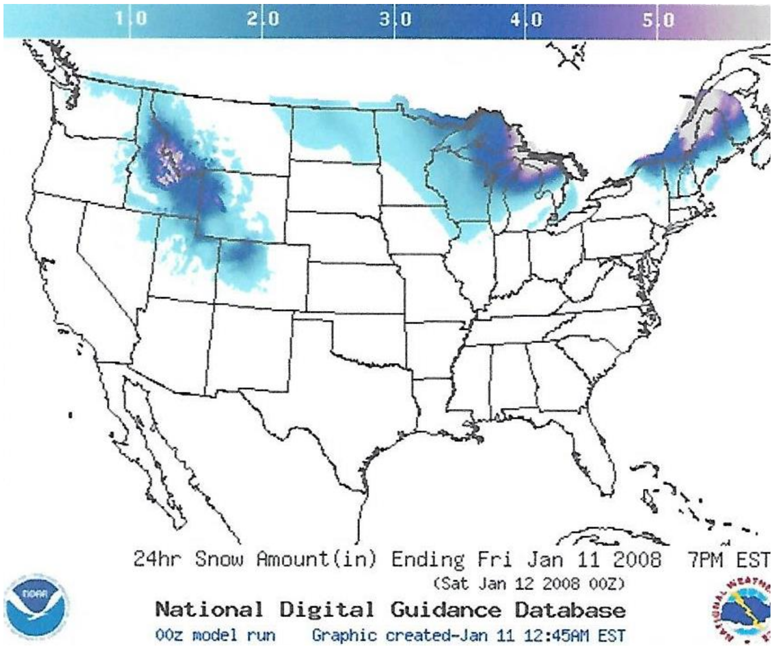

Fig. XVII-6. Analysis of MOS 24-h snowfall (inches) ending January 12, 2008, 0000 UTC. (From Glahn et al. 2008.)

Tabitha Huntemann developed MOS products including the weather grid.

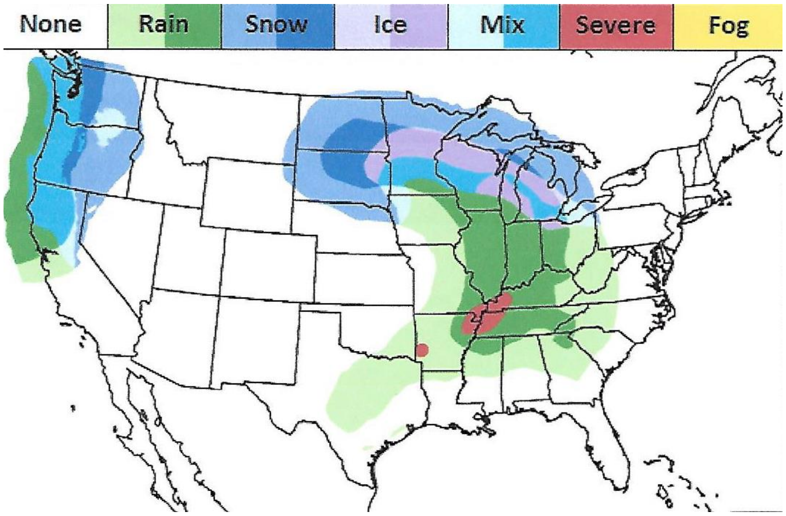

Fig. XVII-7. A 33-h GMOS weather forecast grid valid 0900 UTC 29 Feb. 2012. (From Huntemann et al. 2012.)

Predominant weather, precipitation type, and probability of precipitation occurrence were added to the CONUS 2.5-km NDGD in April 2014.[7]

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[7] MDL MOS change log.

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CHAPTER XVIII

THE LOCAL AFOS MOS PROGRAM (LAMP)

By 1979, a rather complete set of MOS guidance to support the public and aviation forecast programs of the NWS was being produced twice per day based on the LFM II model. The grid length of the LFM was 1/3 Bedient, which was about 127 km at 60°N [116 km at 45° N (NWS 1977)][1]. It was clear that guidance was needed oftener than the twice per day geared to upper air observation times and at a finer resolution. At that time, TDL put forth a rather audacious plan to develop a smaller-scale model and implement it locally within the AFOS system, a model that could run hourly or oftener based largely on data observed hourly or oftener. Justification and plans for this model, which included MOS developed on its output, were laid out in Glahn (1980):

> "Over the past 10 years, the Techniques Development Laboratory has developed and implemented guidance forecasts twice per day for most weather elements contained in public and aviation terminal (FT) forecasts, as well as for some more specialized products. The overall skill of these forecasts is quite comparable to the official National Weather Service forecasts beyond about 18 or 24 hours from the National Meteorological Center's (NMC) run times of 0000 and 1200 GMT. However, because of delays in data receipt, crowded central computer facilities, and the necessity to transmit the guidance forecasts rather early so that receipt can be assured, the shorter-range forecasts are outdated before they are used on station.
>
> "For instance, Fig. XVIII-1 indicates that the MOS guidance forecasts based on the 0000 GMT run of the Limited Area Fine Mesh (LFM) (Gerrity 1977) model cover the 36-h public and the 24-h aviation terminal forecasts. However, the valid periods of these forecasts start 10 to 12 hours after the data input to the LFM and 7 to 9 hours after the latest observations used in MOS. The observation available locally at forecast release time may give better guidance for the next 1 to 12 hours than any centrally produced products presently available."

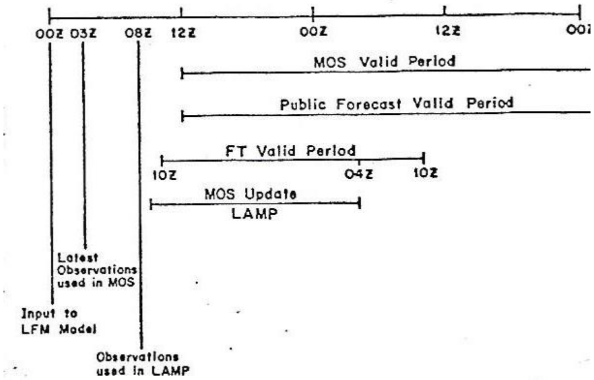

Fig. XVIII-1. Relationships between public and FT forecast valid times, the period covered by current MOS forecasts, and the period to be covered by updated MOS forecasts. These all pertain to the 0000 GMT (00Z) LFM model run time and early morning (approximately 0940 GMT) forecast release times. (From Glahn 1980.)

The plan was to resurrect the SAM model that had run over the eastern third of the CONUS twice per day and reprogram it to run locally each hour on AFOS-like equipment. The MOS developed on its output was also to include an LFM MOS component so that the forecast would be a true update; the forecast for the longest LAMP projection would approach the MOS forecast valid at the same time. We didn't want two completely separate systems giving markedly different results at the longest LAMP projection.

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[1] The LFM ran initially at ½ Bedient grid length (1/2 the larger scale PE model), and about 1977 it was reduced to 2/3 that value (NWS 1977).

Work started in mid-1979 and Dave Unger was hired that year to lead the technical effort. Considerable progress had been made within a couple of years as reported by Glahn and Unger (1982). Although LAMP was to run locally, the development was done on the large computer at NMC. By 1982, the Reed Sea Level Pressure, SLYH Moisture, and CLAM Cloud Advection (Grayson and Bermowitz 1974) models had been reprogrammed for the CONUS. These models are explained in some detail in Chapter III describing SAM.


Dave Unger led the LAMP work for 15 years.

LAMP started in 1979 and was targeted to run locally on AFOS.

The only change to the SLP model was the reduction of the terrain height over the Rocky Mountains and the decrease of 500-mb advective winds when > 41 km/h (see Unger 1982).

For the moisture model, the relationship between the ln of precipitable water W and surface variables that had been used for the eastern U.S. for SAM was redone for the whole CONUS. The regression specifying the ln(W) had only two predictors, the surface dew point and the forecast of precipitable water from the LFM interpolated to the station. Essentially, the surface observation updated the LFM moisture. This study of the estimation of precipitable water and saturation thickness is detailed in Lewis et al. (1985). The many details of the moisture model are in Unger (1985).

To initialize the models, the analysis routines were also retooled for the CONUS. One version was for variables of a continuous nature—sea level pressure, temperature, dew point, U and V wind components, and wind speed. Another was for discontinuous variables—ceiling height, visibility, cloud amount, and three categories of precipitation type. The categories of precipitation type were binary—ones and zeros. For discontinuous variables, each gridpoint was given the value of the closest station—the nearest neighbor concept.

For continuous variables, each datum was compared to the existing analysis and if the difference was too large (criteria set by the user), it might be discarded, but before it was discarded a buddy check was performed, and if the observation agreed sufficiently with one of its two nearest neighbors, it was not discarded.

The U and V wind components and wind speed were analyzed concurrently so that error checking and possible data discards were consistent among these three analyses. Wind speed was analyzed because speed calculated from analyzed U and V components is low biased. A special coding of saturation deficit values was used to give more weight to small values, especially near the areas of zero values. Details of these analyses are given by Glahn et al. (1985). The analyzed saturation deficit field was revised on the basis of MDR (manually digitized radar) reports of precipitation; by definition, saturation deficit is zero if precipitation is occurring.

The models and their analyses were run for a 4-year sample on which to develop the MOS from LAMP. Testing gave similar results to the use of the model in SAM. Because it could be run at the optimal time to furnish guidance and generally several hours after the LFM initialization time, there was a several hour period when LAMP gave better forecasts than the LFM. An evaluation of the models is given by Unger (1983).


Ward Seguin was branch chief and contributor to implementation of LAMP.

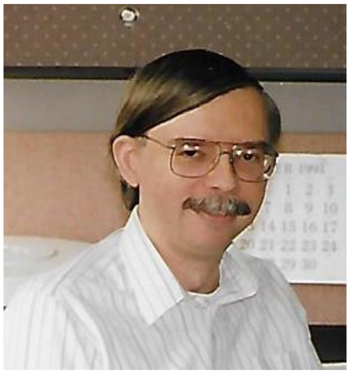
After the software for the analyses and models was completed, along with specialized regression and evaluation software, the first use of the MOS component of LAMP was for surface wind prediction (Glahn 1984a, b, c; Glahn and Unger 1986) and for precipitation type (Bocchieri and Forst 1984). There are many details that cannot be repeated here because of space. In order to promote consistency of forecasts from hour to hour, a regression program that screened and selected predictors partly on the basis of temporal consistency was used. In keeping with the intent of LAMP to be implemented locally at WFOs, this first experiment was for only stations in the Washington D.C. WFO (DCA) area of responsibility. Thirty-two stations were used for wind and 46 for precipitation type, not all of which had MOS forecasts. For those stations not having MOS, an estimate was made as a weighted average of other MOS stations; personnel at DCA helped to guide the work. Our development sample consisted of 4 consecutive cool seasons (October-March), and our test sample was the following cool season, 1981-1982.

Predictands were the U and V wind components and wind speed S for each hour 1 through 20 h. We used two start times, 0800 and 1300 UTC, LAMP being driven in both cases by the 0000 UTC LFM, the most recent NMC model output available at those times. Predictors were from (1) observations at initial time, (2) the LAMP sea level pressure model, and (3) central MOS forecasts. We did not include predictors directly from the LFM model, believing the intelligence of the LFM needed for LAMP would be carried in the MOS. Exclusion of the LFM predictors was primarily so that LAMP would not be tied closely to a specific NMC model. If the model were changed, MOS should not be as susceptible to those changes as the raw model output itself.

For speed, forecasts were verified in terms of Heidke skill score, and for direction, the percent of forecasts whose directions were within 30 degrees of the verifying observation was calculated. Basic conclusions taken from Glahn (1984a) were:

> "It was found that this LAMP system produced forecasts better than persistence, the improvement being quite significant at all projections except, possibly, 1 hour. They were also better than the centralized MOS guidance, the improvement being quite significant for projections of 1 hour to about 12 hours at those stations having MOS guidance and for all projections at those stations for which MOS forecasts could only be inferred from those stations having MOS forecasts."

The LAMP wind forecasts were also compared to those from the Generalized Equivalent Markov (GEM) model developed by Miller (1981). This model, whose input is only the initial observations at the station for which the forecasts are made, could also be implemented locally at stations. Miller provided the forecasts that were compared to LAMP. Rather than being "generalized," he developed single-station equations for the seven stations in the DCA area for which he had the long period of record required for GEM; these are the stations on which the comparison could be made. GEM uses only binary predictors and predictands. The forecasts are probabilities of the binary categories. In order that comparisons could be made in terms of specific values, Miller transformed the forecasts by a method described by Perone and Miller (1983, Section 6.c).



Timothy Chambers worked on LAMP analysis programs and local implementation.

There are many details that contribute to a comparison of this kind; these are discussed by Glahn (1984c). Basically, LAMP performed much better than persistence and GEM, except for the first hour or two where the differences were minor.

We began to concentrate on an area in the central U.S. which encompassed the area planned for the Modernization and Restructuring Demonstration (MARD) (Unger 1987). The modernization, including radar and satellite components, was to furnish a replacement for AFOS, later to be called AWIPS (Automated Weather Interactive Processing System). We had programmed the LAMP system for the AFOS Eclipse minicomputer[2], but for it to run fast enough to be viable in operations, we had to purchase and install a floating-point board. In fact, the board was required to compile the FORTRAN 5 language used on it; FORTRAN 4 was used without the board.

Unger (1987) developed regression equations to predict ceiling height and visibility for an area bounded roughly by 90° and 105° W longitude and 29° and 45° N latitude, shown in Fig. XVIII-2. The development for LAMP paralleled in many ways the development for centrally produced MOS. For ceiling and visibility, the equations calculated the probability of each of several categories, just as for MOS. Verification indicated the use of more recent observations improved the forecasts up through 16 h for ceiling height and 10 h for visibility. The LAMP models were useful in the 4- to 15-h range in the non-mountainous region but not in the mountainous region.

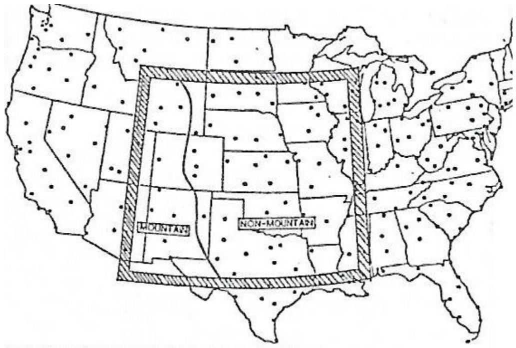


Fig. XVIII-2. The area, within the dashed lines, over which ceiling and visibility equations were developed. For ceiling, two regions, a mountainous and non-mountainous, were used, divided by the solid line. For visibility, the non-mountainous region was divided into two regions. (From Unger 1987.)

Specific values of ceiling and visibility were obtained by another set of equations where the predictand was a non-linear transformation of the ceiling and of the visibility. This process had been extensively tested earlier in two separate efforts and abandoned, but with innovative modifications in implementation, including developing both conditional (conditional on whether or not there was a ceiling at initial time) and unconditional equations, modified inflation, and a persistence adjustment, reasonable results were achieved which seemed to be as good as those achieved with

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[2] The Eclipse minicomputer was rated at one-third MIP (million instructions per second) without floating point hardware.

methods used in MOS of transforming with thresholds the probabilities to categories. This verification was according to the log score, a score defined in the NWS's verification plan (NWS 1982).

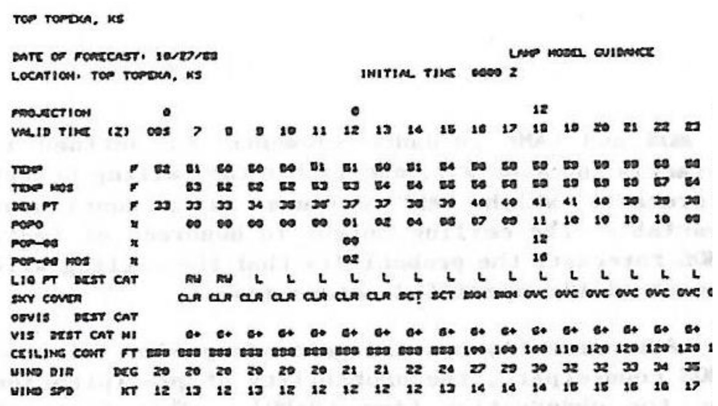
A similar study forecasting hourly temperature, dew point, and maximum temperature out to 20 h was reported by Cammarata (1987). Forecasts for 103 stations in the MARD area were studied, 63 having MOS forecasts and 40 for which the MOS forecasts were interpolated from stations with MOS. The MOS forecasts were available at 3-h intervals, the other hours were linearly interpolated from those values. Four cool seasons were used for development and one season for testing. Cammarata (1987) verified forecasts from regression equations with only MOS predictors (M), with MOS and obs (MO), and with MOS, obs, and LAMP models (MOM). His conclusions were:

> "The greatest potential benefit in using MOM and MO appears to occur at non-MOS stations where the simple linear space interpolation of nearby MOS forecasts is reflected in the poor performance of M. The regression analysis used in the development of MOM and MO appear to effectively calibrate for the errors in M resulting from the space and time interpolations.
>
> "MOM and MO forecasts are strongly dependent upon the initial surface observations during the early projections. As a result, MOM and MO forecasts significantly improve upon M out to about the 7-h projection for both MOS and non-MOS stations. The magnitude of this improvement decreases with increasing projection, reflecting the diminishing utility of the initial observation with time.
>
> "The linear interpolation of MOS forecasts at 3-h intervals to 1-h projections results in relatively large MAE's for M at non-standard MOS projections, especially near the average time of maximum and minimum temperature.
>
> "The MOM and MO forecasts are largely dependent upon the MOS forecast in later projections. If the MOS forecasts for the later projections are in error, MOM and MO will in general exhibit similar errors.
>
> "For MOS stations, the LAMP numerical models add little if any predictive information in addition to that which is already contained in the MO forecast. The LAMP models, however, appear to contribute some useful information for non-MO stations where MOM produces slightly better forecasts than MO at most projections. The LAMP numerical models appear to have their greatest impact in terms of forecast differences between MOM and MO for projections 10-15.
>
> "For MOS stations, there appears to be no strong advantage to using MOM or MO over M as each of these predictive schemes appears to perform equally as well. For non-MOS stations however, MOM and MO clearly outperform M with MOM performing slightly better than MO."

Concurrently, Salem (1987) essentially duplicated for the MARD area the wind forecasting study carried out by Glahn (1984a) for the Washington D.C. area. He used 84 MOS stations and 67 stations for which MOS was derived from MOS stations. In addition to the spatial interpolation, time interpolation was necessary from the 6-hourly MOS values. For verification, the forecast speed was inflated. From the DCA study, it was judged nine predictors were sufficient—the U, V, and S from each of obs, MOS, and the SLP model. This was tested for the MARD area by developing two sets of equations, one set with the nine predictors, and one set with those plus two other screened predictors, the analyzed wind speed and V-wind component. The additional two predictors made little or no improvement over the nine. For both direction and speed, the LAMP forecasts were much better than persistence except for 1-h where there was little difference. The accuracy was a little less than for the DCA area. After the testing, equations were developed on all 5 seasons of data, equations that could be used in operations.

An experimental LAMP system was running at WSFO Topeka in 1988.

By September 1988, a prototype LFM-based LAMP system had been installed and was running in the NWS Weather Service Forecast Office (WSFO) in Topeka, Kansas, with the assistance of Jack May, Meteorologist in Charge, and Mike Heathfield, LAMP focal point in Topeka (Unger et al. 1989). The system was configured as a Weather Service Office (WSO) spur off of WSFO Topeka. The numerical models were not part of the system yet and the forecast equations had only MOS and obs as predictors. Analyses were made and provided to forecasters each hour. In addition to the analyses, several fields of meteorological variables were calculated based on them, as suggested by forecasters at Topeka (e.g., equivalent potential temperature). The LAMP forecasts were initialized at 0600 UTC during the cool season and 0500 UTC during the warm season, the hour difference to support a constant l*ocal* forecast release time.



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TOP TOPEKA, KS

DATE OF FORECAST: 10/27/88                                    LAMP MODEL GUIDANCE
LOCATION: TOP TOPEKA, KS                          INITIAL TIME  0600 Z

PROJECTION              0                    6                            12
VALID TIME  (Z)        OBS   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23

TEMP               F    52  51  50  50  50  51  51  50  51  54  55  58  58  59  59  59  58  58
TEMP MOS           F        53  52  52  52  53  53  54  54  55  56  58  59  59  59  59  57  54
DEW PT             F    33  33  33  34  35  36  37  37  38  39  40  40  41  41  40  39  39  38
POPO               %        00  00  00  00  00  01  02  04  06  07  09  11  10  10  10  10  09
POP-06             %                            00                      12
POP-06 MOS         %                            02                      16
LIQ PT  BEST CAT            RW  RW   L   L   L   L   L   L   L   L   L   L   L   L   L   L   L
SKY COVER                  CLR CLR CLR CLR CLR CLR CLR SCT SCT BKN BKN OVC OVC OVC OVC OVC OVC O
OBVIS    BEST CAT
VIS  BEST CAT MI            6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+  6+
CEILING CONT      FT   888 888 888 888 888 888 888 888 888 888 100 100 100 110 120 120 120 120 1
WIND DIR         DEG    20  20  20  20  20  20  21  21  22  24  27  29  30  32  32  33  34  35
WIND SPD          KT    12  13  12  13  12  12  12  12  12  13  14  14  14  15  15  16  16  17
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Fig. XVIII-3. Example LAMP bulletin prepared at Topeks, Kansas. It contains initial observations and forecasts for projections hourly out to 18 h for temperature; dew point; 6-h PoP; PoPO; probability of liquid precipitation type (best category); probability of precipitation type; best category of sky cover; obstructions to vision; visibility; continuous ceiling height; and wind speed and direction. (From Unger et al. 1989).

Output from the Topeka forecast system was in two forms—graphics for every third projection hour and a matrix or bulletin patterned after the centralized MOS bulletins for each station in the WFO area; an example of the latter is in Fig. XVIII-3. A forecast not contained in MOS is PoPO, the probability of precipitation at the top of the hour. The method of forecasting ceiling height and visibility as reported by Unger (1987) as a specific value was retained for ceiling, but visibility was determined by thresholding the probability values. Equations were derived for cool and warm seasons. They were single-station for temperature, dew point, and wind; otherwise they were regional.

The modernization with AWIPS to replace AFOS brought a change in the LAMP acronym to Local AWIPS MOS Program. Also, the Interactive Forecast Preparation system (IFPS) was

Judy Ghirardelli became leader of LAMP in 1995 and continues today.

progressing (Ruth and Peroutka 1993) and to better support the preparation of worded forecasts, Carroll (1992) developed a five-category conditional type of precipitation forecast which defined mixed types. Previously, precipitation type had been forecasted in three categories, namely, snow or ice pellets, freezing rain or freezing drizzle, and rain (liquid). A nationwide development was done with seven regions. Verification by P-score showed there was skill in creating mixed types. Specifying the type from the probabilities was done with a method developed by Unger (1992). Carroll (1992) also determined that using LAMP temperature and dew point as predictors was better than not using them.

Implementation of LAMP locally on AWIPS at Weather Forecast Offices started in 1997 (Ghirardelli et al. 2004).

Implementation of LAMP on AWIPS at WFOs started in 1997.

In 1998, Charba (1998) reported on a LAMP QPF system for the CONUS. It was unique in several ways. To define the predictand in several overlapping (cumulative) categories (e.g., $\geq$0.10, 0.25), he used data from the U.S. Climatic Hourly Precipitation Network. About 2,500 to 3,000 stations reported hourly measurements, the lowest value being 0.1 in. The reported values were related to a 20-km LAMP grid such that any grid box having one or more observations was given the relative frequency of reported precipitation. Most boxes had no reports and were not used in the development. In development, the REEP regression process was used, the difference being that the event is usually defined as 0 or 1, but in this case could be those values or anywhere in between. Development was done for the points having data, but the relationships were applied for other boxes, as there were predictors for all boxes. Forecasts were made for eight time periods as shown in Fig. XVIII-4, four 1-h periods, sliding from initial time; two 3-h periods; and two 6-h periods, the latter two fixed in UTC time.

The QPF development was done by region, for 2 seasons, eight cycles per day, and projections out to 22 h.[3] The equations were applied to all gridpoints within the region. Predictors were (1) centralized MOS QPF probability forecasts, (2) numerical model forecasts of 850-mb wind, (3) objectively analyzed and advected fields of variables based primarily on conventional hourly surface observations, (4) objectively analyzed and advected fields of 1- and 3-h antecedent precipitation, and (5) high-resolution topography and climatic monthly mean relative frequencies of precipitation categories (Charba et al. 1998). An

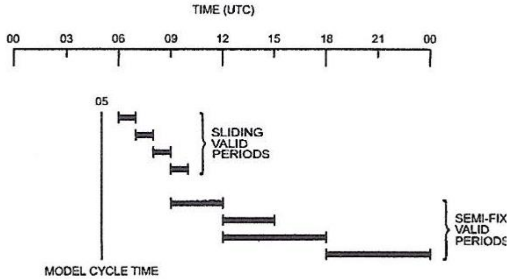

Fig. XVIII-4. Predictand valid periods for the 0500 UTC model cycle time. Sliding 1-h periods change with each hourly cycle time, whereas semifixed 3- and 6-h periods change at 3- and 6-h intervals, respectively. (From Charba 1998.)

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[3] Our initial plan was to run LAMP to "about 20 h;" we increased that to 22 h to support the 18-h TAF, taking into account the time for the guidance to get into the hands of the forecaster. Later, projections were increased to 25 h.

innovative feature was the use of predictors that describe the interaction between mesoscale geoclimatic parameters and the ambient low-level wind, moisture, and MOS QPF variables relative to precipitation occurrence.

This was the first time gridded development and implementation was done for LAMP. Gridded development is convenient when the predictand is on, or can easily be put on, a grid. In 1998, this QPF system was running in TDL on a prototype AWIPS workstation, and graphics were being provided to field stations. The probabilities produced by the equations were transformed into categorical forecasts by the method in Unger (1992).

LAMP was implemented locally at all AWIPS Weather Forecast Offices in the CONUS.

During the next few years, LAMP was implemented at all CONUS AWIPS stations (Kelly and Ghirardelli 1998; Glahn and Ghirardelli 2004). It produced forecasts every 3 hours (eight cycles per day) of the elements temperature, dew point, probability of precipitation occurring at the top of the hour, probability of precipitation in a 6-h period, precipitation type, visibility, obstructions to vision, cloud heights and amounts for up to three layers of clouds, wind speed and direction, and quantitative precipitation (Ghirardelli et al. 2004). While this nearly[4] accomplished the original goal, and basically met the requirement for a locally-run forecast system specified for AWIPS (NWS 1992), there were difficulties. LAMP with its myriad equations and the necessity for it to run fast and frequently became a nightmare to maintain. If operational procedures and forecasts were to be dependent on LAMP, it needed 24x7 support. While it did have that at stations and at the AWIPS Network Control Facility (NCF), the necessary knowledge many times resided only in TDL, and TDL did not operate 24x7. Implementing a new set of equations meant pushing out site-specific data and software to over 100 sites and insuring it was installed. Also, the vision that LAMP would be run under forecaster control when new data arrived and/or were quality-controlled locally, rather than only scheduled hourly, did not materialize, so the main reason for LAMP running locally evaporated. Most data available locally were now available at NCEP.[5] In addition, it was an NWS requirement that all stations be supported equally well, and the current implementation software was built for only the CONUS. LAMP had been based on NGM-based MOS, but the Global Forecast System (GFS)-based MOS now being run was more accurate than the NGM-based MOS (Ghirardelli 2005), so redevelopment was necessary for LAMP to keep its place in the guidance train. Consequently, it was decided, in conjunction with a new MOS-2000 development and implementation system, we would retool the LAMP system, rederive equations based on the GFS MOS with more stations, implement LAMP centrally, and provide the forecasts over the AWIPS Satellite Broadcast Network (SBN). This was the paradigm that had worked well for MOS, and software could be shared with the central MOS system.

Experience and verification had shown that the largest improvement of LAMP over MOS based on older data was for the weather elements that had a close tie to persistence. For instance, surface temperature could be implied fairly well from temperatures forecast by an NCEP NWP model and by MOS, but ceiling height could not. It seemed the NWS program that LAMP could most successfully support was aviation. Therefore, we changed the acronym to replace “AWIPS” with

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[4] The goal had been to run hourly; LAMP was actually running every third hour.

[5] NMC (National Meteorological Center) became NCEP (National Centers for Environmental Prediction) in 1995.

"aviation." Also, because LAMP was not to run locally, the "local" was changed to "localized." So now, LAMP stood for Localized Aviation MOS Program.

Also, during this period, in 2000, the name of TDL changed from Techniques Development Laboratory to Meteorological Development Laboratory in an NWS reorganization by NWS director, John (Jack) Kelly. TDL's mission was expanded with the increase in staff by about 30%.

Also, in the years leading up to 2000, the MOS development and implementation systems were overhauled (see Chapter XIV). This system could be used for LAMP. However, some specifics about LAMP made it desirable to have different regression software. Primarily, this was to maintain more consistency of forecasts from hour-to-hour. The MOS regression allowed simultaneous development for predictands where the same predictors were used in all the predictand equations. We wanted this capability for LAMP, but for the model and MOS predictors to "march" along with the predictand. This is discussed by Glahn and Wiedenfeld (2006). The observations were important for the first few projections. Once an observation was not chosen for a projection, it was not allowed for longer projections. Restrictions were placed on MOS predictors so that predictors could not jump in and out of the equations depending on projection. This was important in LAMP because forecasts were being made for consecutive hours.

The LAMP system was redeveloped from the NGM-based system running locally on AWIPS to a GFS-based system running centrally. The SLP, moisture, and CLAM models were retained. The central system started by running four cycles in July 2006. Cycles were added and all 24 cycles were running by November 2008 (Ghirardelli and Glahn 2010).[6]

LAMP was implemented centrally for all cycles by November 2008.


Dave Rudack was a MOS and LAMP developer of software and forecast systems.

Rudack (2005) documented for the 0900 UTC start time (the first one to be implemented centrally) the development of regression equations for forecasting the probability of six cumulative binary categories of visibility and five discrete categories of obstructions to vision. Six years of data were used (five for development, one for test). 1523 stations were used that covered not only the CONUS but also Alaska, Hawaii, and Puerto Rico. They were put into regions (27 for the warm season and 23 for the cool season). The development was simultaneous to enhance consistency of forecasts. Predictors were from observations, GFS MOS, and advective model output. The same predictors were used for all 25 projections except that the MOS and advective predictors "marched" with the projection; that is, the 20-h forecast had MOS and advective predictors from the 20-h projection. Because visibility and obstructions to vision are many times local in nature, the MOS and obs were the most important predictors, the advective predictors being of minimal use. Thresholds were determined for each category of visibility and obstructions to vision that maximized the threat score within a targeted bias range.

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[6] MDL LAMP change log.

One of the early developments with the new system was for wind (Wiedenfeld 2005). Development was patterned after previous developments. The equations were used for the central implementation.

The status of ceiling height and cloud was recorded by Weiss and Ghirardelli (2005).

Also for the 0900 UTC start time, Charba and Liang (2005) showed that an update to MOS forecasts of thunderstorms could be beneficial. The predictand was defined over the CONUS as the occurrence or non-occurrence of one or more cloud-to-ground lightning strikes in a 2-h period in a 20-km grid box, the boxes being defined by a grid compatible with the NDFD. Predictors were radar reflectivity, cloud to ground (CTG) lightning reports, METAR observations, thunderstorm climatology, topography, and MOS forecasts. Considerable quality control and smoothing was necessary for some predictors. Equations were developed for 13 geographical regions. The 0900 UTC LAMP forecasts were updates to the 0000 UTC MOS forecasts. Fig. XVIII-5 shows the improvement of the updates in terms of Brier score. Especially for a 3-h projection, the improvement is substantial, nearly 18%.

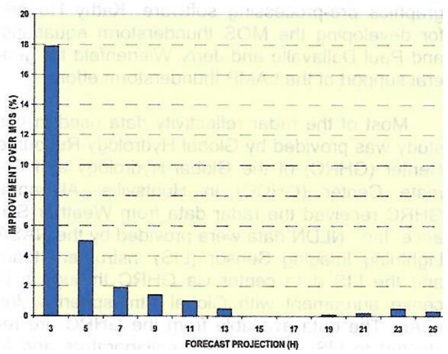

Fig. XVIII-5. Brier score improvement (%) of LAMP 0900 over MOS 0000 UTC thunderstorm forecasts as a function of LAMP forecast projection (3, 5, 7, etc.) for the 1997 summer. (From Charba and Liang 2005.)

After full implementation, this product was further documented by Charba and Samplatsky (2009a). Of importance are the techniques developed to deal with the boundary issue, that is, the inconsistencies that frequently occur at the interfaces of the regions. First, the regions were expanded to produce an overlap of regions, and the regressions were developed on the larger overlapping regions. For implementation, the equations were only applied to the original regions. This helped some, but the discontinuities were still unacceptable. A smoother was then applied that only operated in areas of strong gradients. This reduced the gradients, and after repeated applications, the discontinuities were acceptable. Verification showed that the combined process had a negligible effect on skill. A full documentation of the treatment of regional boundaries is given in Charba and Samplatsky (2011d).

Fred Samplatsky developed and implemented convection, QPF, and other forecasting systems.

Charba and Samplatsky (2009b, 2011a) also developed a gridded QPF product (HRMOS). The method was much like that for thunderstorms discussed above. Like thunderstorms, the predictand lent itself to gridded development, coming from the Stage III precipitation analysis produced on a 4-km grid at NWS River Forecast Centers in the CONUS. The precipitation amounts were put into eight cumulative categories, and REEP was used to forecast probabilities. Also, like for thunderstorms, the 13 regions used were overlapping. After applying each regional equation to its respective non-overlapping region, the overlapping areas were smoothed by a weighted average, the weights being inversely proportional to the distance to the regional boundary. This smoothing was considered to be an improvement over that used for thunderstorms. Comparative verification showed the 6-h categorical forecasts scored slightly better than human-prepared grids from the Hydrometeorological Prediction Center (HPC) and in the NDFD, and strongly better than model-produced girds. These and other findings are in Charba and Samplatsky (2011b). Preliminary results indicated a combination of HRMOS and the forecasts from HPC had higher skill and better reliability than either component separately (Charba and Samplatsky 2011c). Implementation of this HRMOS was in March 2012.[7]

Charba et al. (2011) developed a convection product based on the GFS and NAM models. The predictand was defined as either one or more lightning strikes or an occurrence of $\geq$ 40 dBZ radar reflectivity within a 20-km box and within a 2-h period. A number of conclusions were reached, including: "The skill of LAMP convection probabilities was much higher than that for operational LAMP lightning probabilities at all projections." Implementation was planned for 2011.

LAMP was not the only model providing forecasts for ceiling and visibility. Rudack and Ghirardelli (2008, 2010) comparatively verified forecasts from LAMP, the Global Systems Division's Rapid Update Cycle (RUC) model, NCEP's Weather Research and Forecasting (WRF) Non-hydrostatic Mesoscale Model (NMM), and the Short-Range Ensemble Forecasting (SREF) system. The RUC was producing forecasts on 12- and 20-km grids and the SREF was on a 40-km grid. Model forecasts were interpolated to stations and verified with METAR observations for the period October 2006 through September 2007. The 20-km RUC (RUC20) was used because an archive of the 12-km version was not available. This period was independent of LAMP development. Comparison of RUC, WRF-NMM, and LAMP forecasts were for the 0000 UTC and 1200 UTC cycles; comparison of SREF and LAMP were for the 0900 UTC and 2100 UTC cycles. Rudack and Ghirardelli (2010) concluded:

> "We found that independent of season, the 0000 and 1200 UTC station-based LAMP CIG, VIS, and IFR or lower categorical forecasts are more accurate than RUC20 and WRF-NMM post-processed forecasts when interpolated to stations and then categorized."
>
> "For the 0900 and 2100 UTC forecast cycles and verification periods studied here, LAMP ceiling (< 1000 and $\leq$ 3000 ft) and visibility < 3 mi forecast probabilities exhibit overall better reliability across all probability bins than the SREF probabilities."

In addition to the "bulletin" type method of distributing forecasts (see Fig. XVIII-3), innovative displays were available on MDL web pages. For instance, Fig.XVIII-6 shows flight category forecasts (combinations of ceiling and visibility defined by the Federal Aviation Administration) color coded at stations. Zoom capability allowed showing regional maps. A click on the station would show a meteogram for that station. Example retrospective meteograms are shown in Fig. XVIII-7.

In 2008, with LAMP running centrally for all 24 cycles, attention was turned to gridded output for those weather elements not already gridded, just as had been done for MOS. However, improvements were still being made to the station-based LAMP. GFS MOS was being redeveloped, and since GFS MOS was a primary input to GFS LAMP, redevelopment of GFS LAMP was

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[7] Technical Implementation Notice 12-12, National Weather Service Headquarters, Washington, D.C.

indicated. In addition, the definition for cloud cover was being changed from total cloud to opaque cloud cover. It was also thought that single-station equations could be developed for some stations,

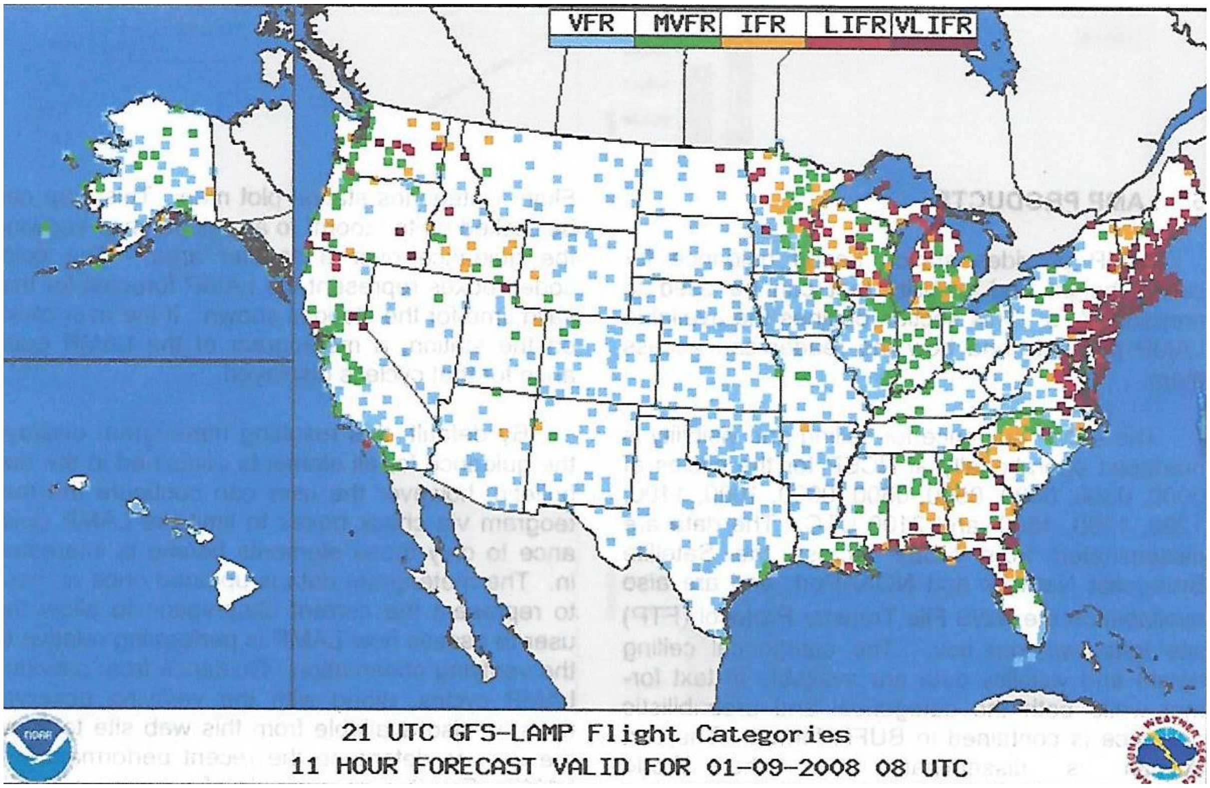


Fig. XVIII-6. Aviation flight categories. Good through poor conditions are represented by the colors in the color bar blue, green, orange, red, and dark red. (From Rudack and Ghirardelli 2008.)

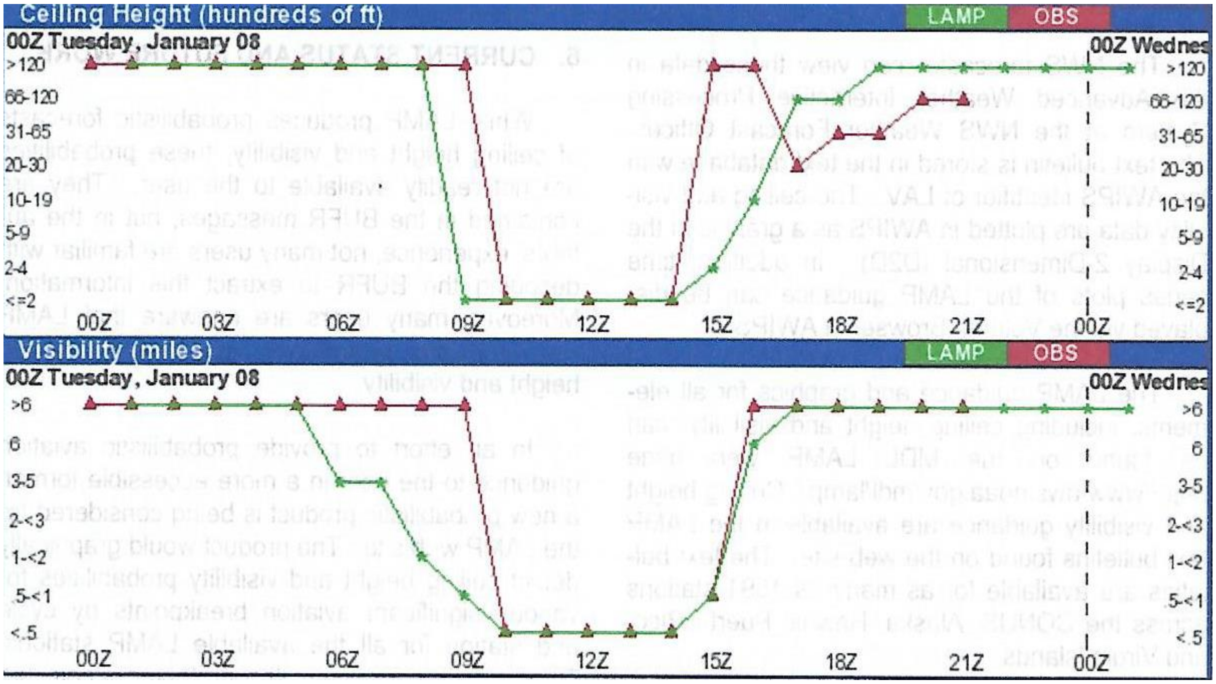
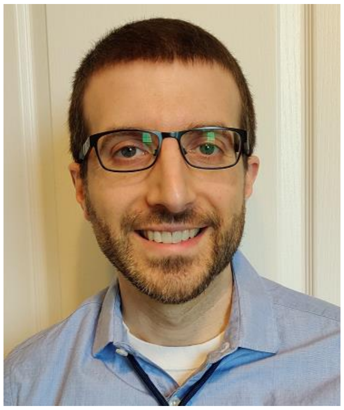


Fig. XVIII-7. Meteograms for ceiling (top) and visibility (bottom) for a cycle of LAMP. The forecasts are in green and the verifying observations (plotted retrospectively) are in red. (From Rudack and Ghirardelli 2008.)

and that possibility needed to be tested. The 1000 UTC LAMP start time was used with the 0600 UTC GFS cycle for testing. A total of 1,591 stations covering the CONUS, Alaska, Hawaii, and Puerto Rico were used. Development followed previous work in most respects. One difference was that for this development cloud cover and ceiling were not developed simultaneously, so those sets of equations could have different predictors. Regional equations were developed for ceiling and also for cloud cover for those stations that did not have an adequate sample of all categories for single-station equations. The probabilities from the REEP equations were transformed into best categories with thresholds. For ceiling, the thresholds were determined by maximizing the threat score within a target bias range. For cloud cover, the criterion was unit bias for each category. The redevelopment gave a 2 to 4% increase in accuracy for ceiling and a slight increase for cloud. Details are given by Weiss and Ghirardelli (2009).

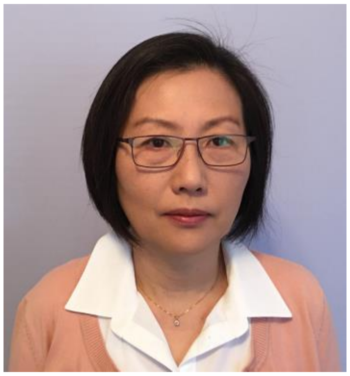

Scott Scallion developed and implemented products for LAMP and MOS.

It is important that the guidance forecasts be consistent. For instance, the dew point should not be higher than the temperature, and checks were made to guard against inconsistencies. It was debated whether or not the onset of precipitation and improving (increasing) ceiling height and/or visibility were inconsistent. Rudack (2009) reported on a study he did to shed light on that. Eight years of cool season observations were used for 1,522 stations in the United States and Puerto Rico. Also, 2 years of LAMP forecasts for the 0900 and 2100 UTC cycles were used. It was found that even though observed and forecast flight conditions deteriorated more frequently than improved with the onset of precipitation, they did improve often enough that such a forecast should not be considered in error.

The gridding of LAMP forecasts and initial observations was done with the same BCDG software used for MOS (see Chapter XVII). However, while the bread and butter weather elements in MOS were temperature, dew point, and wind speed, LAMP emphasized ceiling, visibility, and cloud cover, in addition to convection-related products that were gridded in native form. BCDG was developed for a smoothly-varying field; ceiling and visibility were quite different from that, being somewhat discontinuous. One station might have dense fog with visibility of 0 mi, and the neighboring station might have unrestricted visibility. A number of special features were added to BCDG to deal with such fields (Glahn et al. 2012). For instance, to reclaim the original station value from the nearest gridpoint in the analysis was a very desirable feature. This imposed restrictions on how to smooth the analysis. A smoother called "spot remover" was developed to set a gridpoint to the inverse distance-weighted average of all surrounding gridpoints within a circle for which the elevations were not too different. The circle radius was based on the closest station to the gridpoint. The four gridpoints surrounding a station were left unchanged. This smoother maintained the detail due to terrain and possibly even enhanced it (Glahn and Im 2011a).

An unexpected interpolation issue occurred when a station's elevation was considerably above or below that of all four surrounding gridpoints. To alleviate this problem, the interpolation into the grid when making the station adjustments was modified to include the correction for elevation.

In addition to analyzing the LAMP forecasts, the observations at run initialization time were also analyzed to give, essentially, a persistence forecast. For that, for some analyses, when an observation was missing for the run-time hour, the observation for the past hour was used. Data were used from various sources including METAR, mesonet, synoptic, buoy, C-MAN, and tide-gauge when they existed. Details are given in Im et al. (2010, 2011).



Jung-Sun Im managed observational data for LAMP and developed gridded products.

Questions were raised by users as to the accuracy of specific analyses of observations. To provide an answer to that question, we did a regression study relating error at withheld stations to known possible sources of error. More specifically, temperature and dew point data were analyzed every 5th hour for a 1-year period June 3, 2009, through May 31, 2010, on the 2.5-km LAMP CONUS grid. (Using every 5th hour gives an even distribution of hours without processing all hours.) The predictand (the error) at each withheld station was the absolute difference between the datum at the withheld station and the value interpolated from the analysis. The predictors were measures of spatial data density, spatial data variability, and roughness of terrain in the vicinity of the withheld station.

The regression relationships, one for land and one for water, were computed at stations, but were evaluated, with some assumptions, at gridpoints, which gave a map of errors. An example analysis of temperature and its associated error map are shown in Figs. XVIII-8 and -9. The gridpoints in the western U.S. where the data density is low and the data variability and terrain roughness are high show the most areas of high possible error, and vice versa in the eastern U.S.

While one can question the exact values, spots where there may be more error than in surrounding areas can be easily spotted. For instance, in Fig. XVIII-8, there is a cool spot in southern Texas to the northeast of the “big bend” of the Rio Grande River. It may not garner much attention, but the error map shows there is some question as to its accuracy.

The cool temperatures are supported by four observations of 67, 75, 71, and 71 within the surrounding area of higher temperatures. While the analysis seems to be correct, the analyzed values in the area between an observation of 71°F and a neighboring one of 95° F is uncertain. At least, the error map indicates an area of interest and possible error in the analysis. More detail is contained in Glahn and Im (2011b, 2013) and in the documentation of an earlier and less complete study on a 5-km grid (Glahn and Im 2010). The error maps were made available in the NDGD along with the temperature and dew point analyses.

A history and status of LAMP is given by Ghirardelli and Glahn (2011). Gridded LAMP started running in the NCEP job stream in September 2010. This included both observations and forecasts for temperature, dew point, ceiling height, and visibility. The analyses were at 2.5-km grid-spacing and were put into the NDGD.

Gridded LAMP started running operationally at NCEP in September 2010.

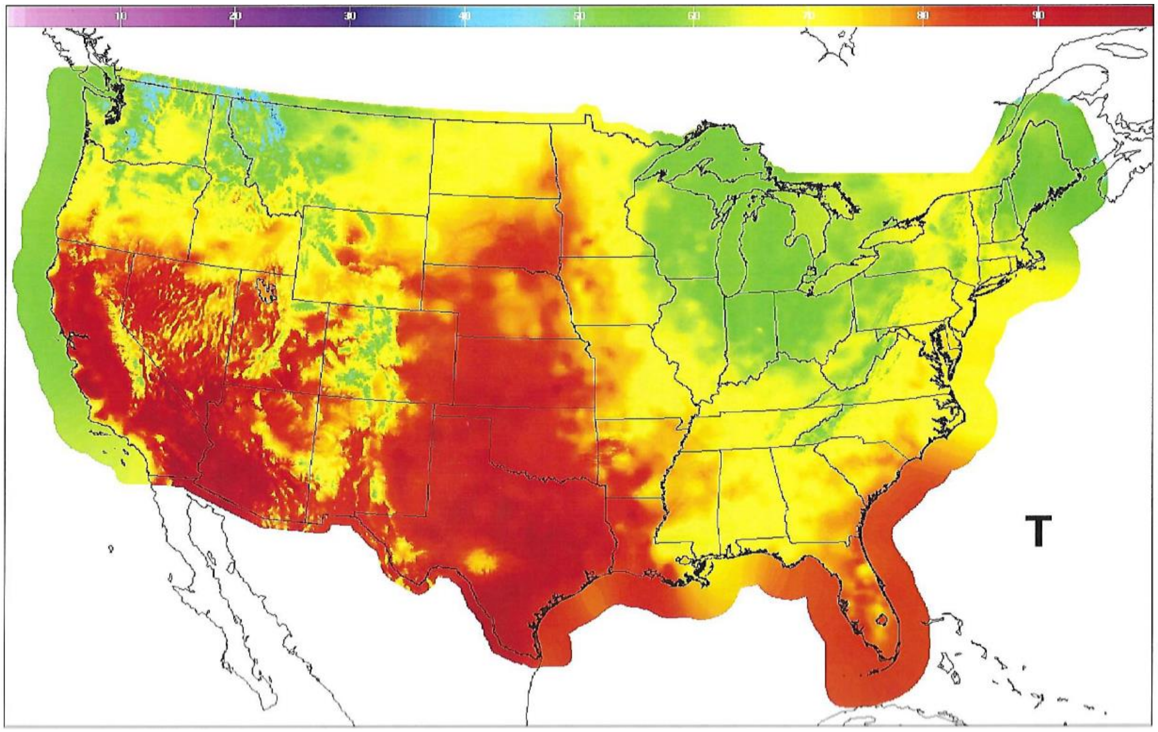


Fig. XVIII-8. BCDG LAMP analysis of temperature (ºF) for 0000 UTC 29 September 2011. (From Glahn and Im 2011b.)

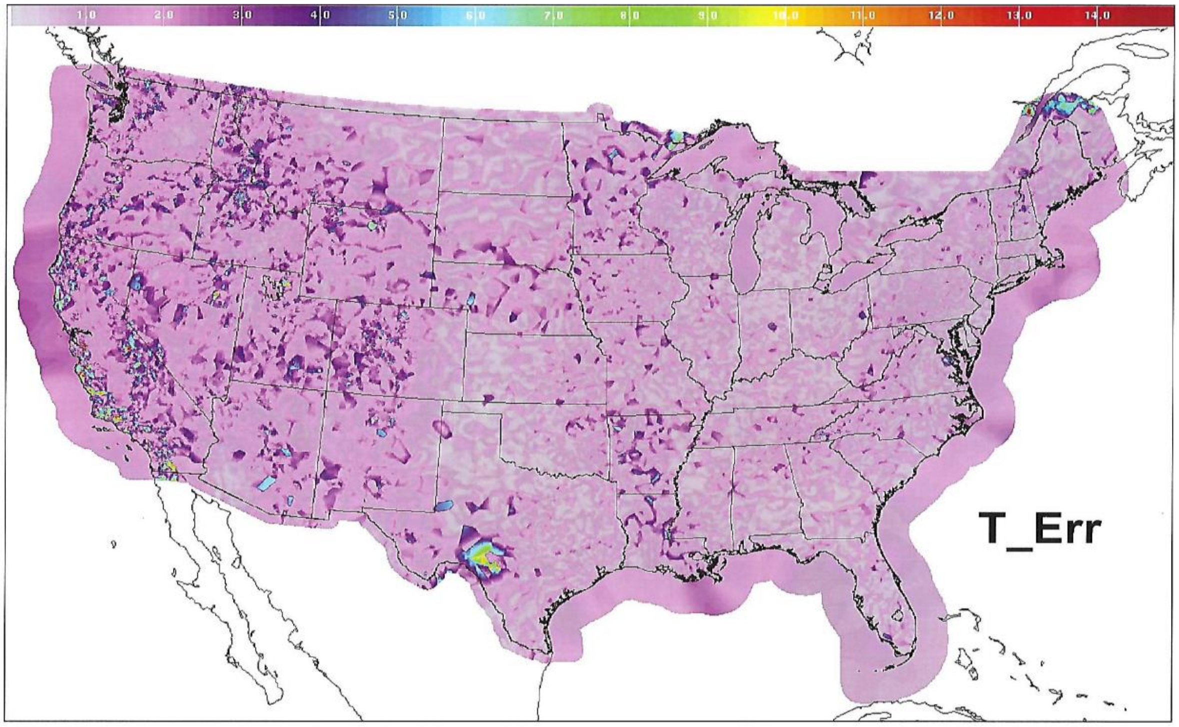


Fig. XVIII-9. Error estimation (ºF) for the temperature analysis in Fig. XVIII-8. (From Glahn and Im 2011b.)

In summary, the original LAMP goal of providing guidance more often than twice per day based on models with a finer resolution than the LFM II was achieved, although the forecast system was running centrally rather than locally. Except for where it was run, the basic plan did not change. AFOS, the initial target platform, had been decommissioned and AWIPS implemented. Anticipated benefits of running LAMP locally did not materialize, and maintenance difficulties of LAMP on AWIPS with the resources available dictated the change to central implementation.

Inputs to LAMP were output from the three advective models, current observations, and central MOS forecasts. Making LAMP forecasts was a two-step MOS process: (1) Developing central MOS from a large-scale numerical model and then (2) developing LAMP with a MOS input. Later, the process would become three-step whereby the basic LAMP forecasts were input together with forecasts from a dynamic small-scale model to form a LAMP Meld.

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CHAPTER XIX

SUMMARY

Three events coincided to elevate statistical weather forecasting into view within the Weather Bureau in the 1960's. Two of these were the development of computer capabilities necessary for running numerical and statistical models and the simultaneous progress in numerical weather prediction. The other was the organizational changes within the Weather Bureau that brought into being the Techniques Development Laboratory. Computers were necessary for both running numerical models and for dealing with the large data sets necessary for statistical models. Statistical forecasts based on lag relationships to observations had not been notably successful. It is doubtful the organizational structure of the WB in the 1950's would have supported the development required for producing the myriad statistical relationships necessary for a robust and lasting cadre of operational products.

Statistical work by the Travelers Research Center in the 1950's and 60's facilitated development in other organizations through application and publication of regression and discriminant analysis methods. Robert G. Miller and others there, supported by government contracts, were at the forefront of statistical forecasting as NWP was being established. Iver Lund and Irving Gringorten of the Air Force Cambridge Research Laboratory were publishing highly relevant work. Lorenz's publication of Empirical Orthogonal Functions caused excitement in the statistical community. There was also interesting research in verification during that period, including innovations by Jack Thompson and Edward Epstein. A new laboratory with a director vitally interested in statistics was a good place to be in the mid to late 1960's and 1970's. It was important that the nucleus for the laboratory existed in Roger Allen's and Charles Robert's WB branches; the statistical interest and experience for the laboratory were already in place.

At that time, there was no one at a high level in the WB who saw the need to bring together the groups primarily interested in NWP and in statistical forecasting. It was apparent our statistical group needed to "go it alone," and did so by adapting advective models until an NMC NWP model was useful and stable and an archive established. Eventually, of course, the NMC models starting with the barotropic became the primary inputs to our statistical work.

There was also no organized process whereby forecast techniques developed throughout the WB could be operationally implemented. NMC was implementing NWP products and forecasts prepared by NMC forecasters; there was no recognized route for TDL to implement its products. Merritt Techter, Director of the Systems Development Office, TDL's organizational parent, soon recognized this and in 1966 caused an NWS committee to be created to facilitate implementation: The Committee on Analysis and Forecast Technique Implementation. Almost immediately, the Technical Procedures Bulletin series was started by Charles Roberts. CAFTI's role was to examine the technique proposed for implementation, to verify its scientific integrity, and to insure a TPB was written to explain it to potential users before it was recommended for implementation by the appropriate operational unit. This process was a strong contributor to TDL's success in getting products implemented in the early days. The TPBs were overseen by the Office of Meteorology from 1967 until 2003 and after that were unofficially continued by MDL for MDL products until 2013. This document could not have been written without the TPB series collected in hard copy and filed by TDL/MDL.

Work leading to the Perfect Prog method had been started by Bill Klein and others even before TDL was formed and could be applied to any NWP model or even forecaster-prepared charts. Obviously, the deficiencies of specific NWP models could not possibly be corrected or at least ameliorated unless the model output was input to the statistical scheme, and the acronym MOS was applied to the process we developed. While most applications of PP and MOS have been with the regression model, MOS and PP are broader than that and do not imply regression; regression is only one statistical method used in MOS and PP. We chose regression after trying a number of techniques in existence at the time, and regression proved to be the best for our purposes, which was to blanket the country with statistical forecasts of many weather variables at many projections.

Almost from the beginning, we were interested in probability forecasts, but users were not ready for them. Also, communication facilities were somewhat limited, and transmitting meaningful probability distributions of forecasts would require more bandwidth than did single specific values. Even so, many weather variables have decidedly non-normal distributions which dictate their being treated in other than a linear regression fashion. For some weather variables, we took the tack of using the REEP application of regression to predict the probabilities of multiple categories of the weather variable, then using those forecasts to determine a “best” category, usually by applying thresholds to the probability forecasts. Verifications focused on the Brier P-Score as well as reliability diagrams for the probability forecasts. For the specific value forecasts, the threat score was used to evaluate forecasts of the elements where threats could be realistically defined, such as ceiling height below 500 ft, but a variety of other scores were also used such as mean absolute error and Heidke skill score. A new score was devised for measuring the convergence of the forecasts to the verifying value over time.

A rather full set of forecasts was being produced and disseminated by 1976 for the conterminous United States; then it became a race to “keep up with the models” as they were improved and at times changed completely, and to extend the forecasts to all 50 states, Puerto Rico, and western Pacific Islands. The number of projections was increased from twice per day to every 3 or 6 hours for the longer-range forecasts and to hourly for the shorter-range forecasts. The frequency of production kept pace with the NWP models, and was increased to hourly production with LAMP. This somewhat repetitive process was facilitated by our adopting the “system” approach to development, verification, and preparing products for distribution; the most complete system and the one in operation as of this writing was developed just prior to 2000 and was named MOS-2000. Even though regression, a linear model, was almost universally used, developers were always trying to improve the forecasts by innovatively pre-processing the NWP forecasts into predictors that had a linear relationship to the predictand, which made the overall process non-linear; human ingenuity and meteorological science were thereby exploited by the statistical model.

A primary and efficient mode of transmitting the forecasts was in “bulletins,” but eventually when gridded forecasts were needed, the forecasts at specific and somewhat random points were analyzed and the resulting grids furnished; these were put into the National Digital Guidance Database, another MDL innovation. Production of worded forecasts composed by computer was encouraged by transmitting such forecasts for possible use by forecasters.

Many persons contributed to the model interpretive work over the 50 years covered by this document. I have tried to indicate this by including pictures of some of the leading contributors and referencing the many publications by TDL/MDL authors. The TDL/MDL branch chiefs and project leads who organized and led the production of the forecasts deserve special mention; their pictures and names are included in previous chapters.

I am especially pleased to acknowledge the assistance of J. Paul Dallavalle, a former MDL branch chief, in writing this document, through personal recollections and for reading an early version; that was very helpful.

APPENDIX A

ACRONYMS AND TERMS

Acronym	Meaning	Chapter	Page
ADALINE	adaptive linear neuron	2	6
AEV	AFOS-era verification	13	9
AFCRL	Air Force Cambridge Research Laboratory	1	7
AFD	Analysis and Forecast Division of NMC	4	7
AFOS	Automation of Field Operations and Services	8	2
AFPS	AWIPS forecast preparation system	13	11
AFRP	Aviation Forecasting Research Project	3	1
AIRMET	airman’s meteorological information	13	9
ALSYM	all systems message	7	3
AMS	American Meteorological Society	1	3
AVN	aviation (model)	15	1
AvnFPS	aviation forecast preparation system	13	12
AWC	Aviation Weather Center	13	9
AWIPS	advanced weather interactive processing system	17	1
BCD	binary coded decimal; Bergthorssen, Cressman, Doos	6; 17	6; 2
BCDG	Bergthorssen, Cressman, Doos, Glahn analysis method	17	3
Bedient	unit of grid spacing = 381 km at 60°N	6	5
BLM	Bureau of Land Management	13	8
BPA	Bonneville Power Administration	9	14
bpi	bits per inch	6	4
C	climatology	10	4
CAFTI	Committee on Anal. and Fcst. Techniques Implementation	3	7
CAT	clear air turbulence	13	9
CDC	Control Data Corporation	3	5
CDF	cumulative density function	16	2
CGP	convective gust potential	9	16
C/L	cost/loss	2	4
CLAM	cloud advection model	18	2
CMCE	Canadian Meteorological Centre global ensemble model	16	3
CONUS	contiguous United States	2	2
CPOS	conditional (on precipitation occurring) of snow	15	9
CRAY	a brand of computer	8	5
CRD	cumulative reliability diagram	16	1
CRPS	continuous ranked probability score	16	3
CSI	critical success index	13	2
CSNOW	conditional (on precipitation occurring) of snow amount	15	9
CTG	cloud to ground (lightning)	18	10
CWF	computer worded forecast	4	10
CYBER	a computer manufactured by Control Data Corporation	8	5
DCA	station identifier for Washington, D. C.	18	3

DD/PP	digital database/product preparation	13	11
DFI	digital facsimile interface	5	2
DIFAX	an NWS digital facsimile circuit	13	3
DOY	day of year	5	3
EFD	Extended Forecast Division	1	5
EKD	ensemble kernel density	16	3
EKDMOS	ensemble kernel density model output statistics	16	1
EOF	empirical orthogonal function	2	3
ERAS	external random access system	14	4
ESSA	Environmental Science Services Administration	3	2
Eta	an NMC numerical model	13	10
F	parameter in decision model; Fahrenheit	10; 17	4; 3
FAA	Federal Aviation Administration	2	2
FAP	FORTRAN assembly program	2	3
FAR	false alarm ratio	13	2
FMAK	header for Alaska alphanumeric bulletin	10	1
FOB	Federal Office Building	4	10
FOFAX	a WB/NWS forecast office facsimile circuit	4	4
PoFP(P)	probability of frozen precipitation in precipitating cases	4	4
FORTRAN	FORmula TRANslation programming language	2	1
FORTXDAM	a FORTRAN input/output package for the IBM 360/195	8	4
FOUS	header for CONUS alphanumeric bulletin	3	8
FT	terminal forecast	4	9
GC	ground condensation	9	16
GEFS	global ensemble forecast system	16	3
GEM	generalized equivalent Markov	18	3
GENOT	general notices	5	4
GFS	global forecast system	13	11
GMT	Greenwich Mean Time	3	2
GRIB	gridded binary (WMO gridded data transmission standard)	14	3
GSM	global spectral model	15	10
h	hour	1	7
HI	heat index	16	3
HP	Hewlett Packard	14	1
HPC	Hydrometeorological Prediction Center	13	9
HRMOS	high-resolution MOS	18	10
IBM	International Business Machines	1	7
ICWF	interactive computer worded forecast	13	11
ID	identification	6	5
IFPS	interactive forecast preparation system	17	1
IFR	instrument flight rules	9	3
IO	input/output	8	1
IRAS	internal random access system	14	6
JNWPU	Joint Numerical Weather Prediction Unit	2	1
K	stability index	12	15

KCRT	an NWS system with a cathode ray tube display	12	1
KDE	kernel density estimate	16	2
km	kilometer	3	2
LAMP	local AFOS MOS program; localized aviation MOS prog.	8; 18	2; 7
LFM	limited area fine mesh (LFM II = 2nd version LFM)	6	2
M	equations with only MOS predictors	18	5
MADALINE	many (more than one) ADALINES	2	6
MAE	mean absolute error	5	5
MARD	modernization and restructuring demonstration	18	4
max	maximum (temperature)	12	14
mb	millibar	1	5
MDA	multiple discriminant analysis	2	5
MDL	Meteorological Development Laboratory	9	2
MDR	manually digited radar	9	2
METAR	meteorological aerodrome report	14	2
min	minimum (temperature)	12	14
MIT	Massachusetts Institute of Technology	1	7
MO	equations with MOS and observations as predictors	18	5
MOM	equations with MOS, observations, and LAMP model pred.	18	5
MOS	model output statistics	1	6
MOSLIB	MOS library (software)	8	3
MRF	medium range forecast	8	3
MVFR	marginal visual flight rules	9	3
NAEFS	North American ensemble forecast system	16	3
NAFAX	a WB/NWS national facsimile circuit	4	7
NAM	North American mesoscale (model)	15	10
NASA	National Aeronautics and Space Administration	7	5
NCDC	National Climatic Data Center	13	8
NCEP	National Centers for Environmental Prediction	13	4
NDFD	national digital forecast database	13	11
NDGD	national digital guidance database	17	1
NESDIS	National Environmental Satellite, Data; and Info. Service	14	2
NGM	nested grid model	8	3
NHC	National Hurricane Center	2	6
NMC	National Meteorological Center	2	3
NMM	non-hydrostatic mesoscale model	18	11
NOAA	National Oceanic and Atmospheric Administration	1	5
NSSFC	National Severe Storms Forecast Center	5	6
NSSL	National Severe Storms Laboratory	13	2
NWP	numerical weather prediction	1	1
NWRC	National Weather Records Center	6	3
NWS	National Weather Service	2	6
OBS	observations	9	16
ODG	original digital guidance	12	12
OFCM	Office of the Federal Coordinator for Meteorology	14	1

OM	Office of Meteorology	3	7
OMR	Office of Meteorological Research	1	5
OPTION	MOS-2000 switching subroutine for vector or gridded data	6	8
OPTX	MOS-2000 switching subroutine for vector data	14	7
PE	primitive equation (model) (7LPE = seven-layer PE model)	3	3
PEATMOS	primitive equation and trajectory based MOS	5	1
PIREP	pilot report	13	9
PIT	probability integral transform	16	1
POD	probability of detection	13	2
PoF	conditional probability of frozen precipitation	10	3
PoP	probability of precipitation	4	9
POPA	probability of precipitation amount	9	14
PoPO	probability of precipitation at the top of the hour	18	6
POPT	conditional probability of precipitation type	10	10
POSA	probability of snow amount	12	9
PP	perfect prog (prognosis)	1	6
PR1ME	a computer company (also PRIME)	13	4
QC	quality control	14	9
QPB	Quantitative Precipitation Branch	9	8
QPF	quantitative precipitation forecast	9	8
R	correlation coefficient	10	4
RAFS	regional analysis and forecast system	13	1
RAWARC	a WB/NWS radar report and warning coordination circuit	3	8
REEP	regression estimation of event probabilities	2	5
RF	relative frequency	2	7
RMSE	root mean square error	11	4
RPE	rate of pan evaporation	9	15
RUC	rapid update cycle	18	11
RV	reduction of variance	2	2
S	speed (wind)	7	3
S1	a verification score dependent on gradients	7	1
SAM	subsynoptic advection model	3	3
SAO	surface airways observation	13	6
SBN	satellite broadcast network	16	3
SCD	supplemental climatic data	14	4
SCP	satellite cloud product	14	2
Sd	saturation deficit	3	4
SDO	Systems Development Office	3	1
SELS	severe local storms	13	6
SIGMET	significant meteorological information	13	9
SLP	sea level pressure	3	4
SLYH	Sanders, LaRue, Younkin, Hovermale Sd moisture model	3	3
SRFDS	Short Range Forecast Development Section	1	4
SRFRP	Short Range Forecast Research Project	2	3
SRP	Savannah River plant	10	4

SSD	Scientific Services Division	5	2
SUM	subsynoptic update model	7	1
SUNYA	State University of New York at Albany	13	2
TAF	terminal aerodrome forecast	13	12
TDL	Techniques Development Laboratory	1	5
TDLLIB	TDL library of computer software	6	4
TDLPack	a data packing format designed and used in TDL	14	3
TJ	trajectory	5	1
TPB	Technical Procedures Bulletin	3	7
TRC	Traveler’s Research Center	2	2
TWEB	transcribed weather broadcast	13	12
U	east/west component of wind, usually earth-oriented	5	5
USN	U. S. Navy	14	1
UTC	Universal Time Coordinated	3	5
V	north/south component of wind, usually earth-oriented	5	5
VFR	visual flight rules	9	3
VIP	video integrator and processor	12	11
VSAM	an input/output software package	8	5
W	precipitable water	18	2
WB	Weather Bureau	1	2
WBAN	Weather Bureau, Army, Navy	6	5
WC	wind chill	16	4
WFO	Weather Forecast Office	17	1
WMO	World Meteorological Organization	14	3
WRF-NMM	wea. res. and forecasting non-hydrostatic mesoscale model	18	11
WSFO	Weather Service Forecast Office	12	6

APPENDIX B

EVOLUTION OF CAFTI

The Committee on Analysis and Forecast Technique Implementation played such an important role in the success of TDL's model interpretation program that a summary of its organization and history over the first 24 years of its existence is included here.[1] The summary was written in 1990 to help maintain the committee's future as an NWS committee and was based on a full set of CAFTI meeting minutes. Without CAFTI's established and approved path to implementation, model interpretation in TDL might have evolved quite differently.

The committee was formed initially to deal with products developed within SDO, but gradually expanded to include products developed in other organizations, principally NMC.

The committee furnished a forum in which members of TDL and the Office of Meteorology (or Office of Meteorology and Oceanography) worked hand-in-hand to meet requirements and to design modes of product dissemination. OM was TDL's primary interface with the NWS field organization. The Technical Procedures Bulletins requested, yea mandated, by CAFTI explained MDL's products to not only field forecasters, but also to many other organizations, both public and private, who used the products.

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[1] As these notes indicate, CAFTI became official July 2, 1969, but was the permanent embodiment of the original Ad Hoc Committee on Implementation in effect since March 8, 1966.

Glahn
10/12/90

THE EVOLUTION OF CAFTI

In late 1965, Merritt M. Techter, Director of the Systems Development Office (SDO), saw a need for a mechanism that would facilitate the implementation at the National Meteorological Center (NMC) of techniques developed within SDO, and particularly the Techniques Development Laboratory (TDL). His memo to Fred Shuman of NMC dated October 14, 1965, almost to the day a year after TDL was formed, with the subject "Implementation of New Techniques Developed by SDO" kicked off the formation of the Ad Hoc Committee on Implementation, the forerunner of the Committee on Analysis and Forecast Technique Implementation (CAFTI). By October 25, Bill Klein, Director of TDL, had drafted Terms of Reference and sent them to Harlan Saylor, Chief of NMC's Analysis and Forecast Division (AFD) and Charlie Roberts, Chief of the Technical Procedures Branch, Weather Analysis and Prediction Division (WXAP), Office of Meteorological Operations (OMO).

After a few iterations, Terms of Reference dated January 21, 1966, were agreed upon and were signed into effect on March 8 by Bob Simpson, Director of OMO; Fred Shuman, Director of NMC; and Merritt Techter, Director of SDO. Membership was designated as Bill Klein, SDO (TDL), chairman, Charlie Roberts, OMO (WXAP), secretary; and Harlan Saylor, NMC (AFD). Committee decisions were to be in "...the form of recommendations for action to the appropriate Program Director." Meetings started immediately, just as Weather Bureau personnel were moving from 24th and M Streets, Washington, D. C., to the Gramax Building in Silver Spring, Md., and were approximately bimonthly. It was about a year later that the Technical Procedures Bulletin (TPB) series was established by Charlie Roberts of WXAP, the first being issued in July 1967. Although not specifically a CAFTI responsibility, the preparation of TPB's and their timely issuance has always been closely tied to the items addressed by CAFTI, and quite likely, the organization of a body such as CAFTI was necessary for the successful substitution of TPB's for the existing NMC Bulletin series, of which 38 had been issued.

This ad hoc committee recommended on May 1, 1969 in a jointly signed memo to the Directors OMO, NMC, and SDO that 1) the committee become permanent and its name be changed to the Committee on Analysis and Forecast Technique Implementation, 2) that the membership be expanded to include a member from NMC's Development Division (DD), and 3) that the Terms of Reference be modified. The original three members would continue to serve along with John Brown of NMC. Alternates were named as Bob Glahn (TDL, SDO), Ed Fawcett (AFD, NMC), John Stackpole (DD, NMC), and Julius Badner (WXAP, OMO). The committee decisions were to be "...in the form of a recommended plan for implementation ... coordinated with the three offices involved (OMO, NMC, SDO) and forwarded to the Director, WB for his approval." Notes by Bill Klein indicate CAFTI became official on July 2, 1969. The first meeting of the committee with its new name was on September 17, 1969. By this time, several other persons were attending regularly and on an as needed basis.

Julius Badner left that summer and Charlie Roberts in the fall. By February 1970, the OMO member and alternate had become Duane Cooley and Fred Ostby, respectively, Harry Foltz having served a brief period. Another change to CAFTI's Terms of Reference was precipitated by Dick Hallgren's April 4, 1973, note to Klein thru Techter, "I would like to see Bill Quinn and John McCallister added as members of the CAFTI Committee." By memo, May 17, 1973, the four members of CAFTI (Klein, Fawcett, Brown, Cooley) petitioned

George Cressman, Director, NWS, that CAFTI's Terms of Reference be changed. According to the new terms dated May 16, "...recommendations will be sent to the Regional offices concerned for comment and presented to the NWS Offices involved for approval and coordination prior to implementation." Membership was to include the Office of Hydrology (OH) and Office of Oceanography (OO). Members and alternates now were:

SDO, TDL - Bill Klein, chairman (Bob Glahn)
NMC, Forecast Div. (FD) - Ed Fawcett (Earl Estelle)
NMC, DD - John Brown (John Stackpole)
OMO, WXAP - Duane Cooley, secretary (Bob Derouin)
OH - John McCallister (Joe Strahl)
OO - Bill Quinn (Dave Eddleman)

The Terms of Reference were approved by George Cressman.

Again on August 15, 1974, membership was enlarged according to a memo signed by Dick Hallgren for George Cressman, the reason being an NWS Headquarters reorganization and the increased role of the NMC Automation Division (AD) in CAFTI. By the reorganization, OMO had become the Office of Meteorology and Oceanography. Members and alternates now were:

SDO, TDL - Bill Klein, chairman (Bob Glahn)
OM&O, Meteor. Services Div. (MSD) - Duane Cooley, secretary (Al Sadowski)
OH - John McCallister (Joe Strahl)
Office of Technical Services (OTS) - Harry Miller (Bernie Rochlin)
NMC, FD - Ed Fawcett (John O'Conner)
NMC, DD - John Brown (John Stackpole)
NMC, AD - Art Bedient (Jim Howcroft)

Terms of Reference were dated July 29, 1974; recommendations were to be handled the same way stated in the May 16, 1970, edition. Chiefs of the Scientific Services Divisions of the NWS Regions were invited to attend all meetings. Also, "The Committee will circulate to Regional and other offices a technical summary (CAFTI Highlights) of meeting sessions."

On July 12, 1976, George Cressman transmitted to Headquarters and Regional Offices new Terms of Reference dated June 15, 1976. Primarily, the change was to add two new members. Members and alternates now were:

SDO - Bill Klein, chairman (Bob Glahn)
SDO, TDL - Bob Glahn (Tom Grayson)
OM&O, MSD - Charlie Sprinkle (Rich Bailey)
OM&O, MSD - Duane Cooley, secretary (Al Sadowski)
OH - John McCallister (Doug Greene)
OTS - Harry Miller (Bernie Rochlin)
NMC, FD - Ed Fawcett (John O'Connor)
NMC, DD - John Brown (John Stackpole)
NMC, AD - Art Bedient (Jim Howcroft)

Al Flanders served for a time instead of John McCallister and by March 27, 1978, membership changes included Gary Carter for Tom Grayson, John Schaake for Al Flanders, Layne Livingston for Harry Miller, Joe DesRoches for Bernie Rochlin, and Ed Carlstead for Ed Fawcett. Later, Roland Loffredo served for Joe DesRoches and Paul Dallavalle for Gary Carter while Gary was on a university assignment.

On January 29, 1980, Charlie Sprinkle proposed by memo to Doug Sargeant, then Director of OM&O, that the Director of OM&O be CAFTI chairman upon Bill Klein's retirement and that a revised Terms of Reference be adopted, which he had prepared and attached. With the retirement of Bill Klein, Dick Hallgren in a memo dated February 26, 1980, named Bob Glahn as chairman, and Hugh O'Neil of OSD's Integrated Systems Laboratory (alternate, Bob Richey) as member, the latter to retain OSD's two votes [the Systems Development Office had become the Office of Systems Development (OSD)]. However, Bill Bonner, Deputy Director of the Weather Service, soon arranged for the chairmanship be put in the Office of Meteorology (OM) "where it belongs" and by a June 5, 1980, memo from Hallgren, signed by Bonner, the membership was revised to reflect Charlie Sprinkle as chairman and Bob Glahn a member. (By that time, Doug Sargeant was Director, OSD and Jerry Petersen was Director, OM.) Also "...recommendations shall be presented to the NWSH Offices involved for coordination prior to approval for implementation by the Associate Director, OM&O. Meetings under the new Terms of Reference commenced on July 15. At that meeting it was announced that material relating to each action item was to be given to the secretary at least a week before the meeting to distribute to members.

As of March 10, 1982, members and alternates were as follows:

OM&O, MSD - Charlie Sprinkle, chairman (Burt Kirschner)
OSD, TDL - Bob Glahn (Gary Carter)
OSD, ISL - Hugh O'Neil (Roland Chu)
OM&O, MSD - Duane Cooley, secretary (Al Sadowski)
OH - John Schaake (Jose Marrero)
OTS - Jim Elliott (R. Morris)
NMC, FD - Ed Carlstead (Bob Derouin)
NMC, DD - John Brown (John Stackpole)
NMC, AD - Art Bedient (Jim Howcroft)

By a January 31, 1983, memo, Dick Hallgren formalized Charlie Sprinkle's resignation as chairman and named Duane Cooley to that position. Duane had already been acting in that capacity for several months. A new terms of reference were also distributed with the January 31 memo. CAFTI's relationship to the AFOS Data Review Group (DRG) was defined, "Scientific product review by CAFTI will take place before being considered by the AFOS Data Review Group for implementation or deletion." Deletion of products was explicitly mentioned. Recommendations of the committee "...will be coordinated with the Director, National Meteorological Center, prior to submission to the Director, Office of Meteorology, for approval." Also, committee recommendations "...may be sent to the Regional Offices concerned for comment and presented to the NWS Offices involved for approval and coordination prior to implementation." The Terms of Reference included the membership (alternate) list, replete with an ex officio member from the AFOS DRG, another OTS (but nonvoting) member, and an executive secretary:

OM, Prog. Requirements and Planning Div. - Duane Cooley, chairman (Ed Gross)
OM, Operations Div. - Ed Gross (Dale Lowry)
OSD, TDL - Bob Glahn (Gary Carter)
OSD, ISL - Hugh O'Neil (Roland Chu)
OH, Hydrologic Services Div. - John Schaake (Jose Marrero)
OTS, Comms Div. - Jim Elliott (Les Gervase)
OTS, AFOS Operations Div. - Bill Brockman (nonvoting)
NMC, FD - Ed Carlstead (Bob Derouin)

NMC, DD - John Brown (John Stackpole)
NMC, AD - Art Bedient (Jim Howcroft)
AFOS DRG chairman - Larry Murphy (Blaine Tsugawa), ex officio, (nonvoting)
Executive secretary - Roland Chu, OSD (Al Sadowski, OM)

The Terms of Reference CAFTI is currently operating under are still substantially those of January 1983, according to a memo from Ron Lavoie dated January 17, 1989. The membership had evolved at that time to:

OM, OM2 - Ron Lavoie, chairman
OM, OM21 - Joe Bocchieri (Steve Zubrick, OM23, secretary)
OM, OM1 - vacant
OH - John Monro
NMC, DD - Euginia Kalnay (Wayman Baker)
NMC, MOD - Bob Derouin (Gale Haggard)
NMC, AD - Jim McDonell (John Stackpole)
OSD, TDL - Bob Glahn (Gary Carter)
Transition Program Office (TPO) - Hugh O'Neil
Office of Systems Operations (OSO) - Jerry Dinges (Andrew Noel), ex officio

In the meantime, Randy Racer had served as a member from OM and Ron McPherson from NMC. Currently, Paul Dallavalle is OSD's alternate; Frank Richards and Ben Weiger are OH's member and alternate, respectively; Bob Embleton is OSO's member; Lou Uccellini and Bob Derouin are the NMC MOD member and alternate, respectively; and Jim Travers is acting chairman, according to the October 3, 1990, CAFTI agenda distribution.

In summary, some of the points to note are:

- o CAFTI is nearing it's 25th anniversary, having started as an ad hoc committee with three members, becoming a permanent committee within 3 years, and growing gradually to 10 members with alternates.

- o It was started to provide a mechanism whereby techniques and products developed in various parts of the NWS, and particularly in SDO, would get adequate consideration for implementation. Its emphasis has always been on scientific merit and has generally insisted on adequate verification in terms of skill and/or accuracy before recommending implementation. Practically, CAFTI was an avenue for SDO to get its products implemented. However, gradually more and more NMC items were considered as action items.

- o The forerunner of CAFTI was signed into being by the Directors of SDO, NMC, and OM&O, not the Director of the Weather Bureau, and recommendations were to be made to the "appropriate Program Directors." When the membership recommended to the three Office Directors (to them, because the ad hoc committee had been created by them) a name change and permanent status, the new Terms of Reference were titled "Terms of Reference for Weather Bureau Committee on Analysis and Forecast Technique Implementation (CAFTI)" and stated that the recommendations would be "forwarded to the Director of the Weather Bureau for his approval." Also, the next membership change and new Terms of Reference were signed by the Director, NWS, and CAFTI has, according to documentation, continued to be a Weather Service committee. The current Terms of Reference attached to Ron Lavoie's memo dated January 17, 1989 term it a National Weather Service Committee.

o The specific duties and bases on which CAFTI was to make recommendations have varied somewhat throughout its existence, as spelled out in the Terms of Reference current at the time. Generally, recommendations concerning techniques/products were to be made on the basis of "comparative skill, user requirements, and operational feasibility," it being made clear in the April 24, 1980 Terms of Reference that the user requirements were set by OM&O or OH. Therefore, although CAFTI is charged with judging scientific merit, recommendations have usually been made with certain other issues in mind, especially AFOS and facsimile traffic loads and NMC computer resources and schedules.

o Perhaps the most interesting evolution has been what CAFTI is supposed to do with its recommendations, being variously over time to "the appropriate Program Director," "the Director of the Weather Bureau," "the NWS offices involved," and eventually to the "Associate Director, OM&O."

o The chairmanship has resided in both OSD and OM, the former primarily because of the way CAFTI came into being. Both OM1 and OM2 have had a turn at the chairmanship. It is noted that all chairmen have had a strong meteorological background--education, development, and/or operations.

o Meetings have always had a formal agenda, but have generally been conducted informally. In its entire existence, a question has actually been put to a vote probably less than a half dozen times. Delivery of recommendations to the appropriate authority has usually been informal (if at all), the agreement at CAFTI generally being what was required to implement. For a period of time under Duane Cooley's chairmanship, all recommendations were presented to the Director, OM&O by memo, and a sign-off secured.

o Most of the items considered by CAFTI have involved adding new products or modifying existing ones. However, more than one concerted effort has been made to recommend deletion, primarily to relieve communication schedules.

o According to the Terms of Reference, ad hoc committee meetings were "...held only when necessary..." CAFTI's first Terms of Reference stated, "Meetings shall be held quarterly, or more often when necessary..." The 1973 Terms of Reference specified, "Meetings shall be held once every two months or as often as necessary..." Subsequent Terms of Reference have included this same intent with only slightly modified wording.

o The ad hoc committee meetings were rotated between the Gramax Building in Silver Spring, Md. and Federal Office Building No. 4 in Suitland, Md. With the formation of CAFTI in 1969, meetings were held almost exclusively in Suitland and later at the World Weather Building in Camp Springs, Md., when NMC moved there. Since 1980 when OM was assigned the chairmanship, meetings have been rotated between the Gramax Building, and now Silver Spring Metro Center No. 2 since the Weather Service Headquarters move to that location, and the World Weather Building.

o <u>CAFTI Highlights</u> have been published since 1974.

o <u>Technical Procedures Bulletins</u>, along with the references quoted in them, furnish a somewhat complete description of the major products and techniques implemented at NMC over the last 23 years. CAFTI agendas and Highlights tell <u>how</u> and <u>why</u> they came into being.