NOAA Technical Memorandum NWS TDL 72

EXPERIMENTAL WIND FORECASTS FROM THE LOCAL AFOS MOS PROGRAM

Techniques Development Laboratory
Silver Spring, Md.
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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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Atmospheric Administration
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Harry R. Glahn

ABSTRACT

The Techniques Development Laboratory has a project called the Local AFOS MOS Program (LAMP). The purpose of the project is to provide Model Output Statistics (MOS) forecasts to a Weather Service Forecast Office (WSFO) for essentially all locations for which the WSFO makes routine forecasts. These forecasts will be for most weather elements and for projections of 1 to about 20 hours. Inputs will include centralized MOS forecasts; hourly observations; a few forecast fields from the National Meteorological Center's (NMC's) primary short-range guidance model; and, when available, radar and satellite data.

This report describes the development of an experimental surface wind forecast system for WSFO Washington that could provide guidance for projections of 1 to 20 hours from the start times of 0800 and 1300 GMT. Regression equations were developed for each of 32 stations and for each hour out to 20 hours. Predictors were the U- and V-wind components and speed from (1) the station observation, (2) centralized MOS wind guidance, (3) geostrophic winds computed from a simple sea level pressure prediction model, and (4) objective analyses of wind observations.

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.

1. INTRODUCTION

The recent implementation of the Automation of Field Operations and Services (AFOS) (AMS, 1978) by the National Weather Service (NWS) has placed mini-computers in each Weather Service Forecast Office (WSFO). AFOS is presently being enhanced, and a new second generation system is being designed. Computers in field offices can be used for many purposes, including the running of programs which will provide assistance in preparing short range forecasts.

The Techniques Development Laboratory (TDL) has a project called the Local AFOS MOS Program (LAMP) (Glahn, 1980). The purpose of the project is to provide Model Output Statistics (MOS) forecasts to a WSFO for essentially all locations for which the WSFO makes routine forecasts. These forecasts will be for most weather elements and for projections of 1 to about 20 hours. Inputs will include centralized MOS forecasts; hourly observations; a few forecast fields from the National Meteorological Center's (NMC's) primary short-range guidance model, such as the Limited-area Fine Mesh (LFM) model (Gerrity, 1977); and, when available, radar and satellite data.

LAMP includes three rather simple forecast models--(1) a sea level pressure (or 1000-mb height) model (Unger, 1982) based on Reed's (1963) formulation, (2) a moisture model based on the SLYH model (Younkin, et al.),[1] and (3) a trajectory model called CLAM (Grayson and Bermowitz, 1974). These models are driven by a 500-mb height forecast from an NMC model. They are basically initialized by analyzing surface data. Output from these models is then combined statistically with hourly observations and centralized MOS forecasts to produce updated MOS guidance forecasts.

The requirement for a forecast guidance system such as LAMP can be seen from Figs. 1 and 2. Fig. 1 indicates the relationships between the 0000 GMT cycle LFM run time (the present primary NMC short-range guidance model), the observation used in centralized MOS forecasts, the valid period of the centralized MOS guidance, and the valid periods of the early morning official public and aviation terminal (FT) forecasts. In preparing the public and FT forecasts, the forecaster has available 0800 GMT, and quite likely the 0900 GMT, local observations. Therefore, centralized MOS guidance is based on observations made 5 to 6 hours before--and on a model initialized 8 to 9 hours before--observations available to a forecaster preparing the official forecast. LAMP can use 0800 GMT observations to produce guidance for the early morning public and FT forecasts.

Fig. 2 shows similar relationships for the mid-morning update of the public forecast and another of the three scheduled FT forecast release times. Since no new LFM or MOS forecasts are available by the time these mid-morning forecasts are released, the available guidance is even more out of date. LAMP can use 1300 GMT observations to produce guidance for these forecasts.

The periods over which LAMP will furnish guidance are also shown in Figs. 1 and 2. These periods cover the first 18 hours of the FT--the period for which the forecast is quite specific. For the 0800 GMT data input time, all of the so-called "first period" of the public forecast is covered (Fig. 1); for the 1300 GMT data input time, the remainder of the first period and 9 of the 12 hours of the "second period" are covered (Fig. 2).

Although the weather forecast process is continuous (a new forecast should be prepared when it would serve a user's needs better than the current one) and LAMP can be tailored for any initialization time, guidance to support scheduled forecast release times is more important than guidance provided at other specific times.

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[1]These first two models also furnished the basis for the Subsynoptic Update Model (SAM) developed by Glahn and Lowry (1972).

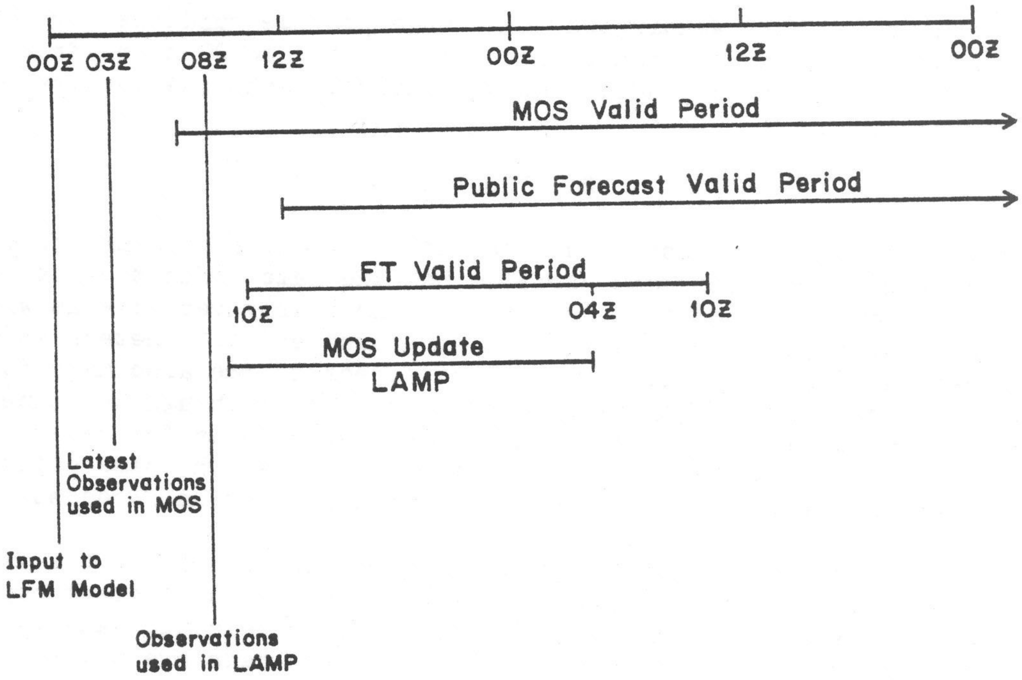

Figure 1. Relationships between inputs to the LFM model, MOS, and LAMP and the valid periods for the early morning forecasts.

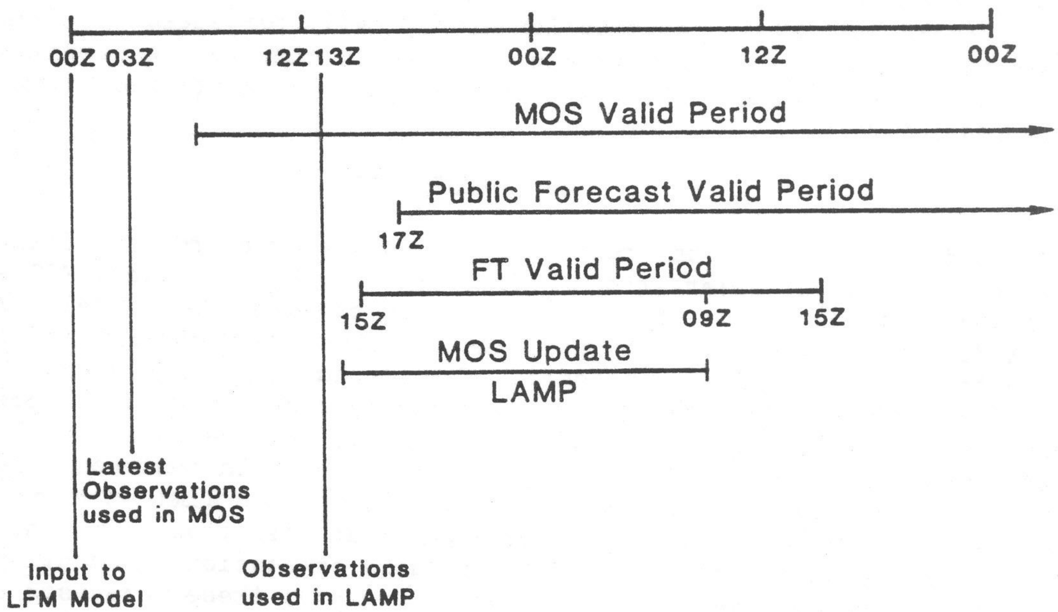

Figure 2. Same as Fig. 1, except for the forecasts issued later in the day, about 1400 GMT.

This report describes the development of an experimental surface wind forecast system for WSFO Washington that could provide guidance for the periods indicated in Figs. 1 and 2--projections of 1 to 20 hours from the start times of 0800 and 1300 GMT. The statistical technique used was multiple linear regression.

2. PREDICTAND

One of the important elements contained in an aviation terminal forecast is the surface wind. This forecast variable has the same definition as the observation of surface wind that is put into the hourly report--the wind measured at a specific place and time at an elevation of 10 meters and averaged over a 1-min period. Surface wind forecasts are also made for other purposes, and the same definition is generally used, although the time and place the forecasts are made for may not be as specific as for aviation purposes. The predictand in these wind experiments has the same definition as does the wind in the hourly observation and in the aviation forecast.

We conducted our experiments for those stations in and around the Washington D.C. WSFO (WBC) area of responsibility for which we had sufficient hourly observations to develop regression equations. The predictand data were taken from TDL's hourly data archive (Glahn, 1974). These data are collected in real time and are then subjected to an automated error checking process. In the case of wind observations, we found it necessary to manually check large wind speeds and discard those judged to be in error.

Of the 46 stations in our archive in and around the WBC WSFO area, 32 had sufficient observations for each hour of the day to provide meaningful results. These stations are indicated in Appendix I. The predictands were the U- and V-components and the speed, S, at each of the hours 1 through 20 after the input times of 0800 and 1300 GMT for each of the 32 stations. Since a speed forecast computed from regression estimates of U- and V-components is biased toward low values, an equation specifically for speed was developed. Forecasts of the U- and V-components are used to compute the forecast direction. (See Glahn, 1970, for a further discussion of predicting a vector by regression.)

3. PREDICTORS

The predictors used in the regression equations came from the following sources: (1) hourly observations (Obs), (2) centrally produced MOS wind forecasts, and (3) output from the sea level pressure (SLP) model. Note that no LFM fields are included. Rather, the information of the LFM forecasts is transmitted through the MOS forecasts of wind components and speed. The centrally produced MOS forecasts of wind may be based on up to 20 predictors (usually 12 or less) derived from the LFM model, observations 2 or 3 hours after LFM initialization time, and day of the year. In contrast, the LAMP equations should be as simple as possible because only limited computer resources are available on-station to support an operational system, and LFM fields in grid-point form may not be available on-station in quantity. Also, LAMP should produce true update guidance forecasts; these forecasts should depart from the central MOS guidance only because of new information, not because a different set of LFM predictors is used. Therefore, LFM fields are excluded as input.

A. Hourly Observations

The observed wind is a powerful predictor for the very short-range--up to, say, 3 hours. Although some information for wind prediction is contained in other elements in the hourly observation, the amount is small compared to the observed wind, MOS forecasts, and geostrophic winds computed from the SLP model. For this reason, and to keep the equations relatively simple, predictors from the surface observation were limited to the U- and V-components and speed.

However, a forecast system based (partly) on the initial observation at a station must be prepared to make a forecast in case the observation is missing in real time for any reason. (Note that of the 46 stations in and around the Washington WSFO area, 14 did not regularly take observations throughout the night during the sample period used.) Therefore, we also developed equations in which winds from analyses of the observed U- and V-components were used as predictors instead of the observations themselves. The speed predictor from these analyses was computed from the U- and V-components; that is, speed was not analyzed separately. It should be understood that the analyses were made with all available observations--that is, for the stations verified, an observation was usually available in making the analysis. It is believed this did not significantly bias the verification results, because of the inherent smoothing in objectively analyzing the winds on a 95-km grid and then interpolating back to the station location.

B. MOS Forecasts

Three predictors were used from the centrally produced MOS guidance--the U- and V-components and speed, the latter being inflated since that is the way it is received on station (NWS, 1983).[2]

C. SLP Model Output

Two classes of predictors were computed from the SLP model. The first class was composed of geostrophic U- and V-wind components and speed. The other class was composed of geostrophic vorticity, advection of the geostrophic vorticity by the geostrophic wind, and 1000-500 mb thickness advection by a geostrophic wind computed from an average of the 1000- and 500-mb height gradients. The 500-mb heights were from the LFM model--the same ones used to drive the SLP model (see Unger, 1982).

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[2]The inflation technique introduced by Klein et al. (1959) renders the variance of regression-produced estimates equal (on the developmental sample) to the observed variance. The formula

$$\hat{\hat{Y}} = \frac{\hat{Y} - \bar{Y}}{R} + \bar{Y}$$

is used, where $\hat{Y}$ is the regression estimate, $\bar{Y}$ the predictand mean, R the multiple correlation coefficient associated with the regression analysis, and $\hat{\hat{Y}}$ the inflated estimate.

D. Space Interpolation

In order to make LAMP forecasts at each of 32 stations, we needed predictor values at those stations. The observations posed no problem--we had assured that by selection of the stations. Also, computations could be made for any station from the SLP model. However, MOS forecasts were available at only 15 of the 32 stations. Therefore, we used a weighted average of MOS forecasts for surrounding stations to arrive at estimates for non-MOS stations. More sophisticated interpolation schemes could have been used, but it was thought unnecessary. The weighted averages used are shown in Appendix I.

E. Time Interpolation

Since hourly forecasts were to be made, it was desired to have MOS and geostrophic wind forecasts valid each hour as input. The SLP model output was saved for each hour, so the geostrophic winds could be computed for each hour. However, MOS wind forecasts are currently available only every 6 hours. Therefore, a linear interpretation was used to produce MOS forecasts at intermediate hours. This was done after the necessary space interpolation.

4. DEVELOPMENT OF EQUATIONS

A large number of regression equations are necessary to predict the U- and V-components and speed at each of 32 stations for each of 20 projections--namely, 1920. It would likely be prohibitive to develop each single station equation independently of the others by screening regression. Not only would a large amount of computer time be required, but also evaluation of the equations on-station would tax computer resources. It has long been a practice in TDL to include the same predictors in each U, V, and S equation for a specific projection and station (see Carter, 1975). This helps insure consistency of the three forecasts.

Similarily, it seems even more desirable to include the same predictors for each projection when the projections are only 1 hour apart to help insure consistency in time, except that the predictor projections would vary along with the predictand projections. That is, for predictand projection i, i = 1, 20, the MOS (and SLP) predictors could have corresponding projections i, i = 1, 20, or, if tests proved it desirable, the MOS (and SLP) predictors could have corresponding projections i, i = 2, 21, say, provided all such predictor projections were available. In fact, both sets of predictors could be used. For example, for a 5-h forecast, MOS (and/or SLP) predictors with both 5- and 6-h projections could be used.

Also, a predictor useful at one station is likely useful at another station in the same locale, and using the same predictors for all stations in the same geographic region will help insure consistency in space.

For the above reasons, a screening regression program was written that develops single station (or regionalized) equations for up to 24 projections and several predictands simultaneously. The same predictors are put into each equation, except that the positions in space match those of the predictands and the projections bear a specified relationship to the predictand projections.

In these wind prediction experiments, the screening option was not used; rather, certain predictors were specified, and equations were generated with these predictors. Four 6-mo periods October through March, starting October 1, 1977 and ending March 31, 1981, were used for development. Sample sizes ranged from about 350 to 620, most being 500 to 600. Table 1 shows the combinations of predictors for which equations were developed for input data times of 0800 and 1300 GMT. See Section 3.C for a definition of the predictors computed from the SLP model.

Table 1. Combinations of predictors for which equations were developed.

Experiment No.	Types of Predictors				
	U, V, S from Hourly Obs	U, V, S from Analyses	U, V, S, from MOS	U, V, S, from SLP Model	Computed from SLP model
1	X				
2		X			
3			X		
4	X		X		
5	X		X	X	
6	X		X	X	X
7		X	X	X	

5. RESULTS AND EVALUATION

It is sometimes appropriate to verify wind forecasts in terms of vector error. For instance, it is the vector error that is important for flight level winds for aircraft. Vector errors of surface winds in the FT are also of interest. However, we believe many users of surface wind forecasts tend to think in terms of direction and speed, rather than their combination. Also, the direction and speed are predicted by different equations, and it is interesting to know how various combinations of predictors fare against pure persistence or MOS guidance in terms of both direction and speed. For these reasons, vector errors were not computed, but rather scores for direction and speed separately.

All speed forecasts were inflated before verification. This technique, mentioned earlier in connection with centralized MOS forecasts, spreads the forecasts away from the mean, and, specifically, produces more forecasts of the important, strong speed categories. This actually increases the root mean square error, but experience has shown the biases by category[3] are improved and the Heidke skill score (NWS, 1982) remains about the same (Carter, et al., 1983).

[3]Bias is defined as the number of forecasts in a particular category divided by the number of observations in that category. Therefore, a bias of near unity is usually desirable. A bias >1 (<1) indicates overforecasting (underforecasting).

Although a number of scores were computed, we basically show in this report one score for speed--the Heidke skill score--and one score for direction--the relative frequency of forecasts correct to within 30°. In some cases, the relative frequencies of forecasts correct to within 20° and 10° are also shown. Biases for categories of wind speed were also computed, and some results are shown for these. Most results shown are for a one season independent data sample, October 1, 1981 to March 31, 1982, the only exception being a small sample of 13 cold front cases.

The categories for speed used to compute biases and skill scores are basically consistent with those in the National Verification Plan (NWS, 1982).[4] These are: ≤7, 8-12, 13-17, 18-22, 23-27, 28-32, and ≥33 kt.

The frequencies in the test sample at four times of the day for these categories are shown in Table 2. (These frequencies are for the matched samples for the 0800 GMT start time; the frequencies were slightly different for the 1300 GMT start time.) It can be seen that winds ≥18 kt occurred infrequently--about 1% to 4% of the time, depending on the time of day. Also, winds in the upper two categories were never observed for most hours. Winds ≤7 kt occurred about 40% to 65% of the time. Sample sizes for wind speed verification were on the order of 4300 cases.

Table 2. Frequency of wind speeds in the independent sample.

Hour (GMT)	Category (kt) ≤7	8-12	13-17	18-22	23-27	28-32	≥33	Total
0900	2949	1139	313	51	7	1	0	4460
1300	2714	1195	387	77	8	0	0	4383
2000	1638	1770	676	154	32	0	0	4270
0000	2592	1272	367	66	2	0	0	4299

Most direction errors shown were computed for only those observed winds of ≥10 kt. The sample size varied by projection, being between 900 and 2000 cases for the 32 stations combined. Matched samples were used for all

[4]The upper four categories agree exactly. The National Verification Plan specifies two categories for public wind forecast verification below 18 kt (p. 15) and also two categories for aviation terminal wind verification below 18 kt (p. 25), but the cateogories are not the same. We have used three categories in the range 0 to 17 kt to verify this experimental system.

comparisons,[5] and persistence was defined to be the initial (0800 or 1300 GMT) observed wind.

[5]It is possible samples for computing direction errors did not match exactly. Whenever an observed wind was $\geq$10 kt, a forecast of that wind was verified if the matching sample (or samples) also had a forecast. However, one (or more) of the forecasts could have been of zero speed and, therefore, a direction was not available and could not be verified.

A. Predictors from Observations

Wind Speed

Figs. 3 and 4 compare skill scores of speed for the equations that contain only the initial observation--the U, V, and S--with persistence. At 1 hour, regression beat persistence slightly at 1300 GMT but not at 0800 GMT.

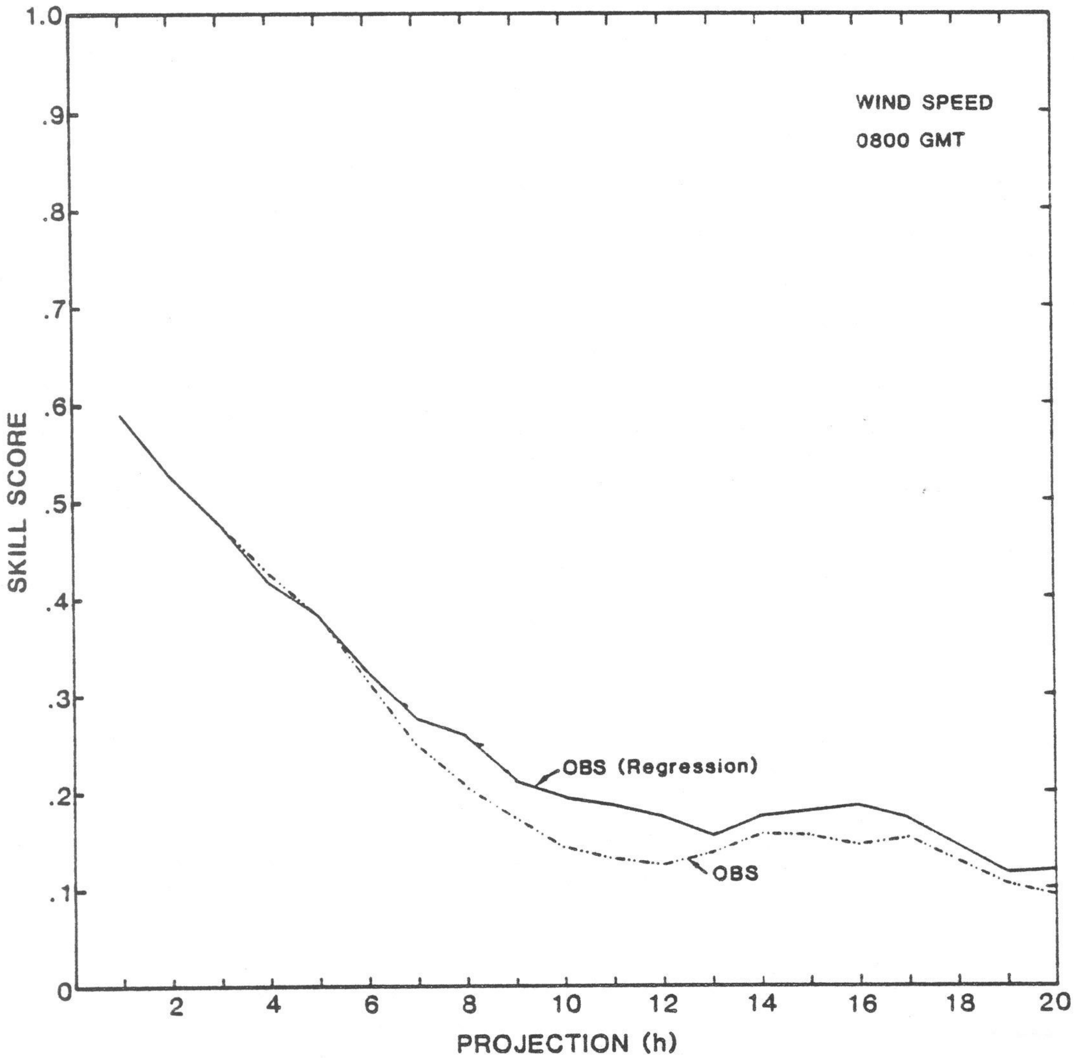

Figure 3. Skill scores for persistence (OBS) and regression forecasts based on the initial observation for the 0800 GMT start time.

Both persistence and regression on the observation lose skill rapidly with time. The slight peaks at about 2200-2300 GMT are probably due to diurnal wind variability. Regression beats persistence at many projections but somewhat erratically and not by large amounts. The skill at 1300 GMT drops more rapidly at the shorter projections than it does at 0800 GMT; this is undoubtedly due to more rapid wind changes shortly after 1300 GMT than after 0800 GMT.

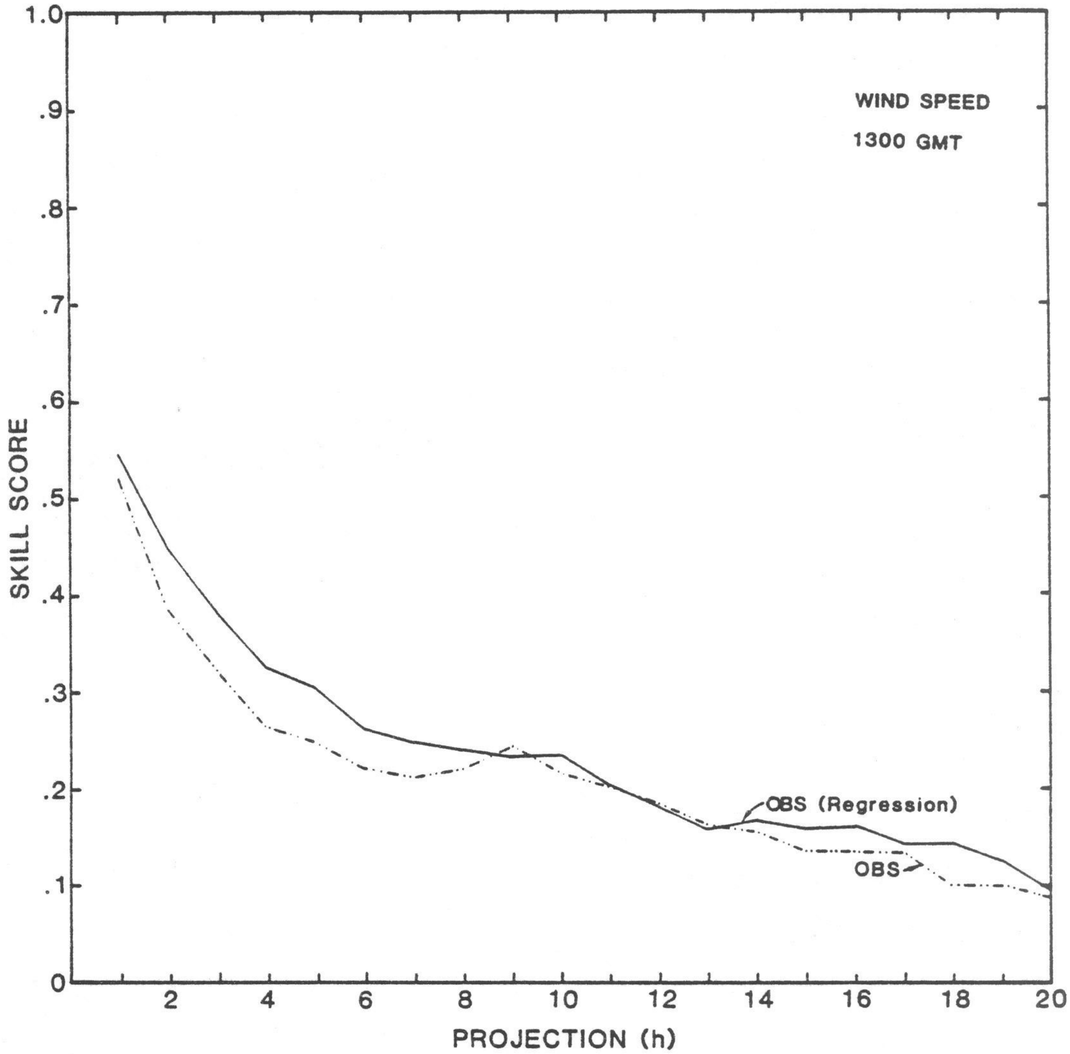

Figure 4. Same as Fig. 3 except for the 1300 GMT start time.

Wind Direction

Figs. 5 and 6 compare the wind direction forecasts made from the equations described above with persistence. At 1 hour, about 95 to 96% of the forecasts have direction errors $\leq 30^{\circ}$ when the observed speed is $\geq$ 10 kt. As with speed skill, the direction accuracy drops rapidly. Regression rather

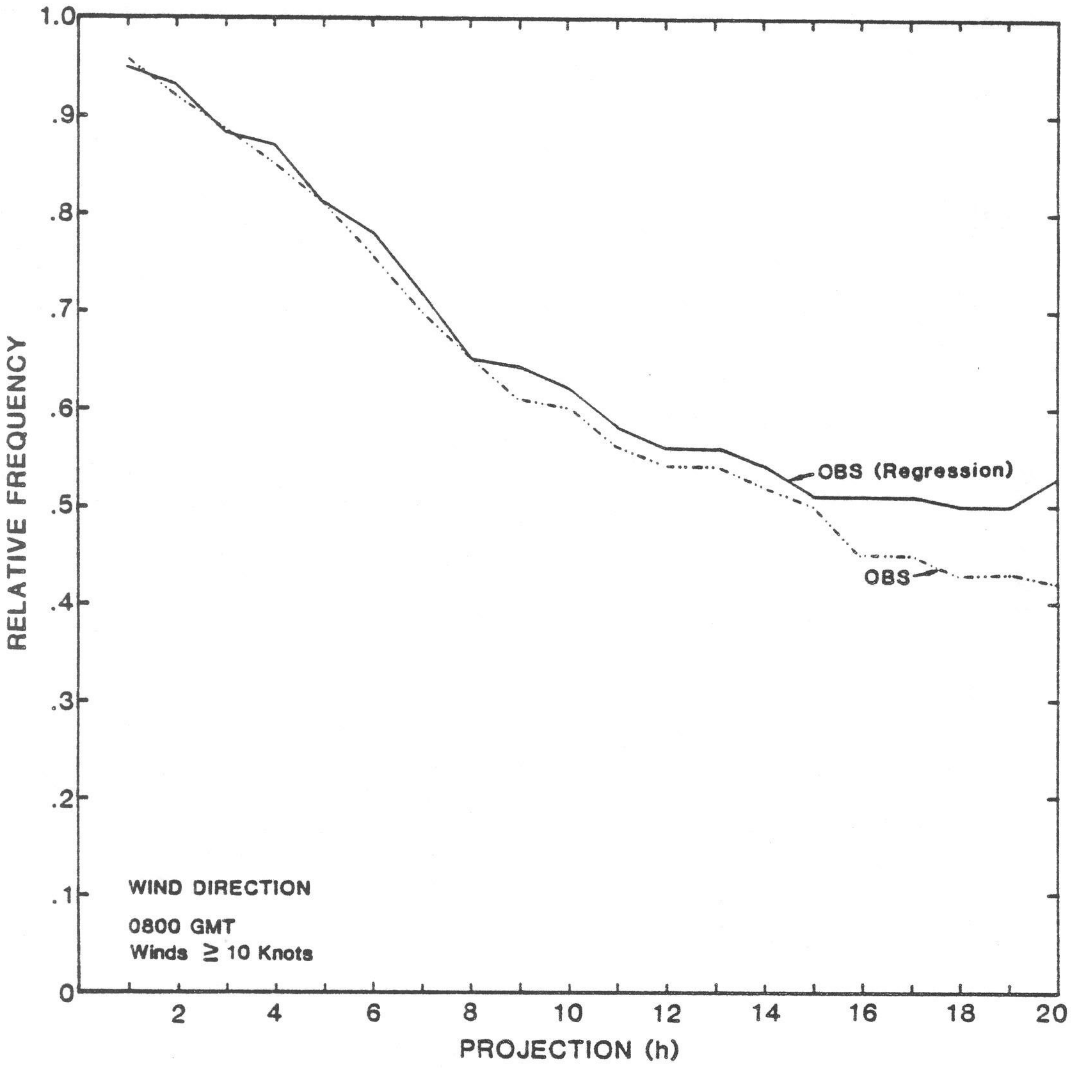

Figure 5. Relative frequency of wind direction forecasts correct to within 30° for observed wind speeds of ≥10 kt for persistence (OBS) and regression forecasts based on the initial observation for the 0800 GMT start time.

consistently beats persistence but not by much except for large projections. The results for 0800 and 1300 GMT are similar, except the accuracy drops more rapidly in the early projections at 1300 GMT; as with speed, this is undoubtedly due to more rapid wind changes shortly after 1300 than after 0800 GMT.

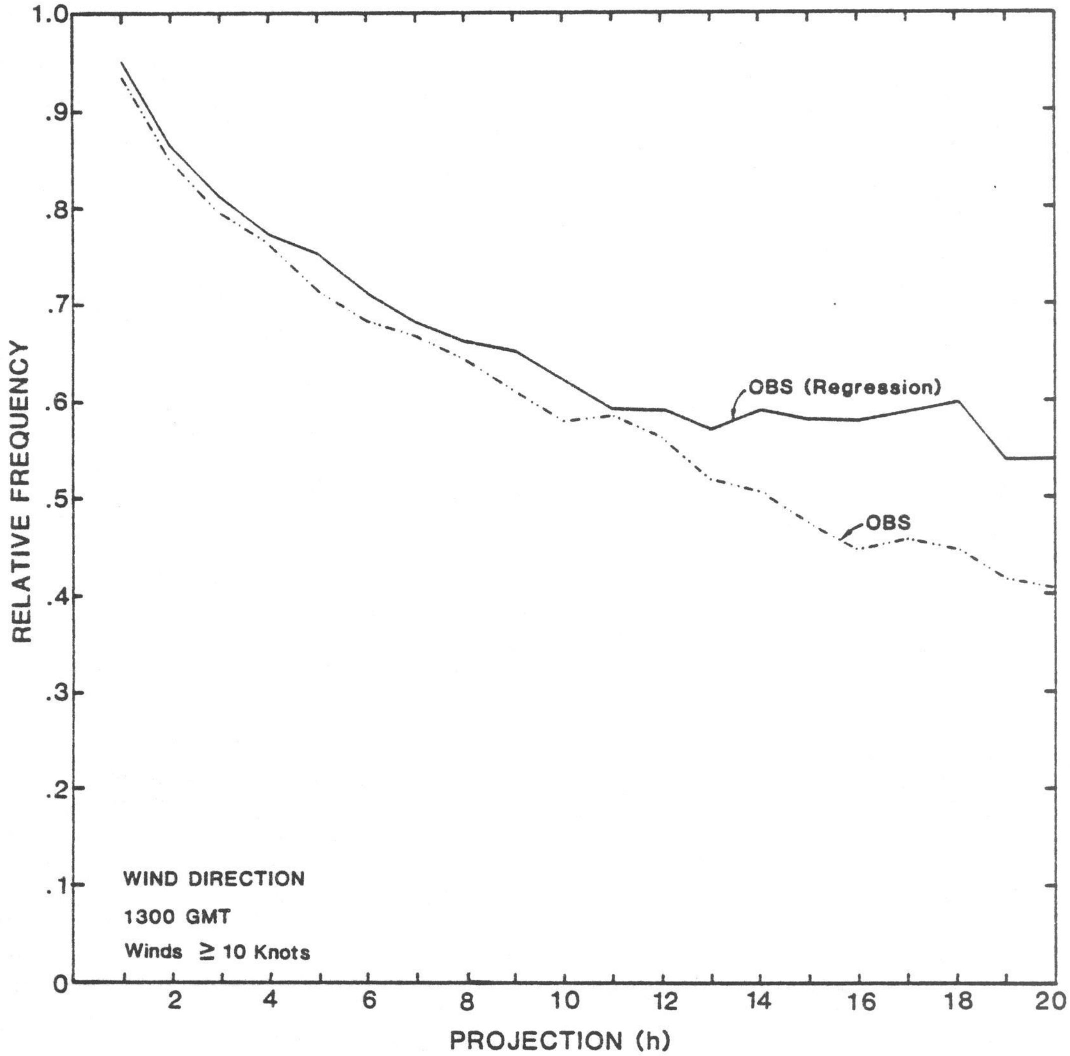

Figure 6. Same as Fig. 5 except for the 1300 GMT start time.

B. Predictors from Wind Analyses

Wind Speed

Figs. 7 and 8 show skill scores computed from "persistence" forecasts taken from the objective analyses of U- and V-wind components (the speed is computed from the components) and regression forecasts based on those same

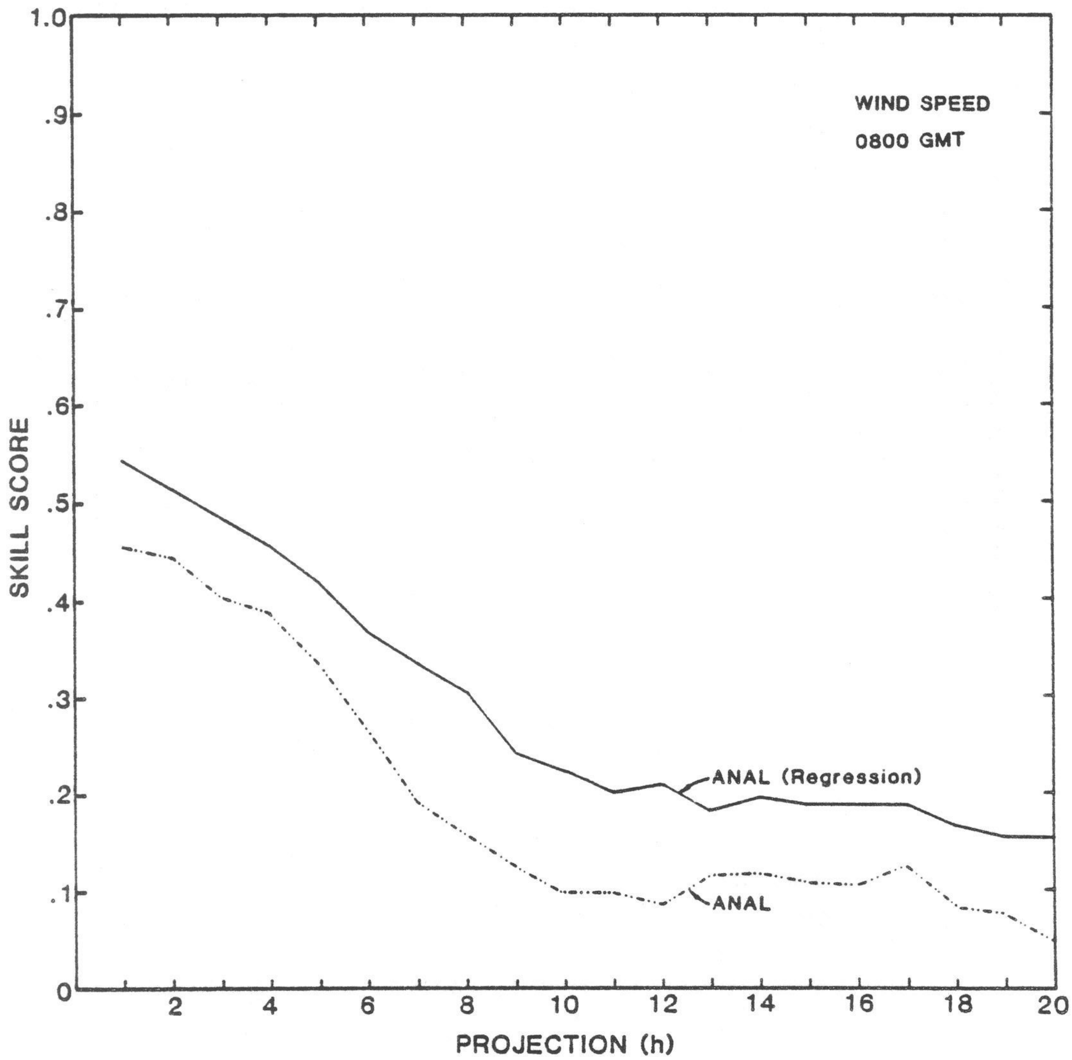

Figure 7. Skill scores for analyzed values used as persistence forecasts and regression forecasts based on those analyzed values for the 0800 GMT start time.

three variables. The improvement of regression over the analysis used as persistence is consistent with projection and quite significant. The analysis process smooths the observations and then the analyzed values at stations must be found by interpolation. These two processes render the analysis values generally less useful for a persistence forecast than the observation itself. The skill decreases with projection more rapidly at 1300 GMT than at 0800 GMT.

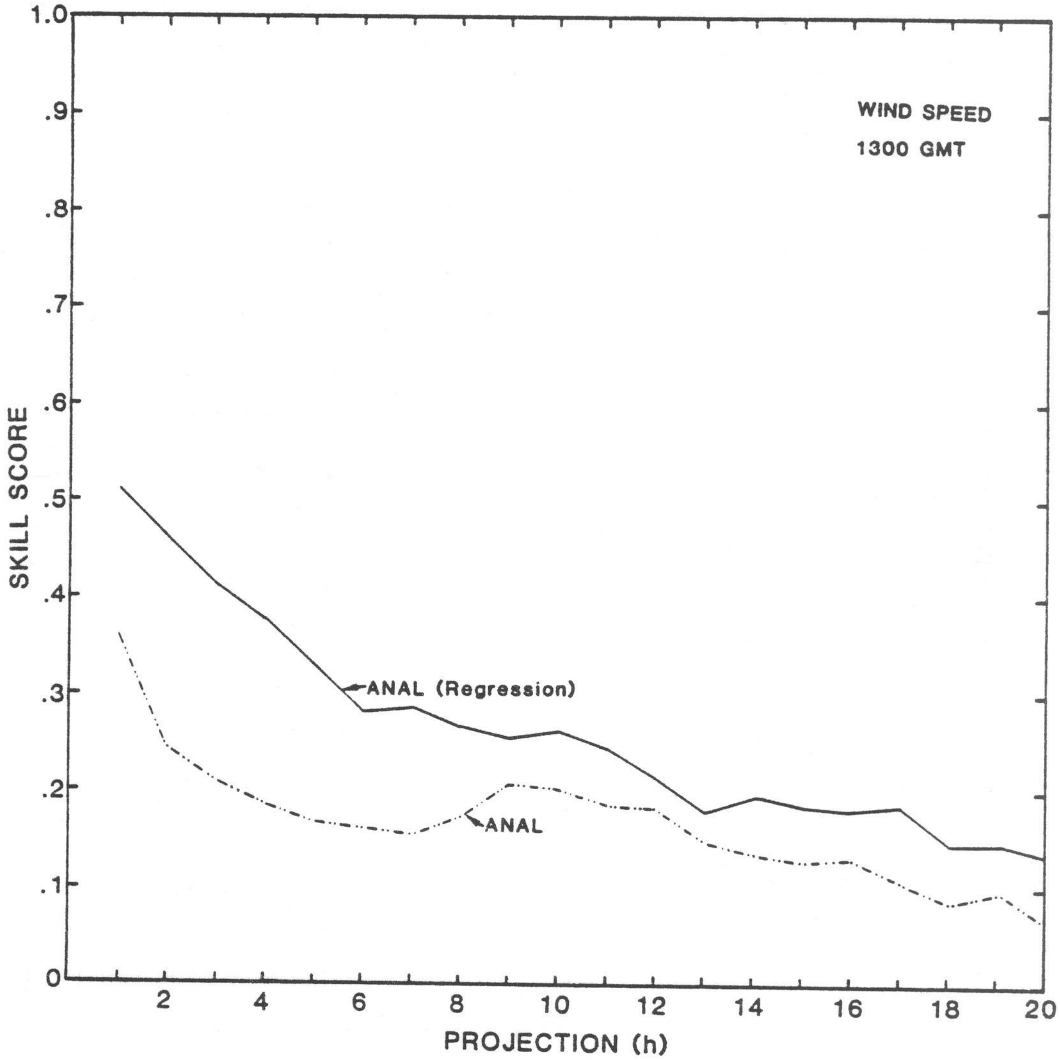

Figure 8. Same as Fig. 7 except for the 1300 GMT start time.

Wind Direction

Figs. 9 and 10 show how analysis values as forecasts and regression on those values fare with respect to wind direction. The improvement of regression

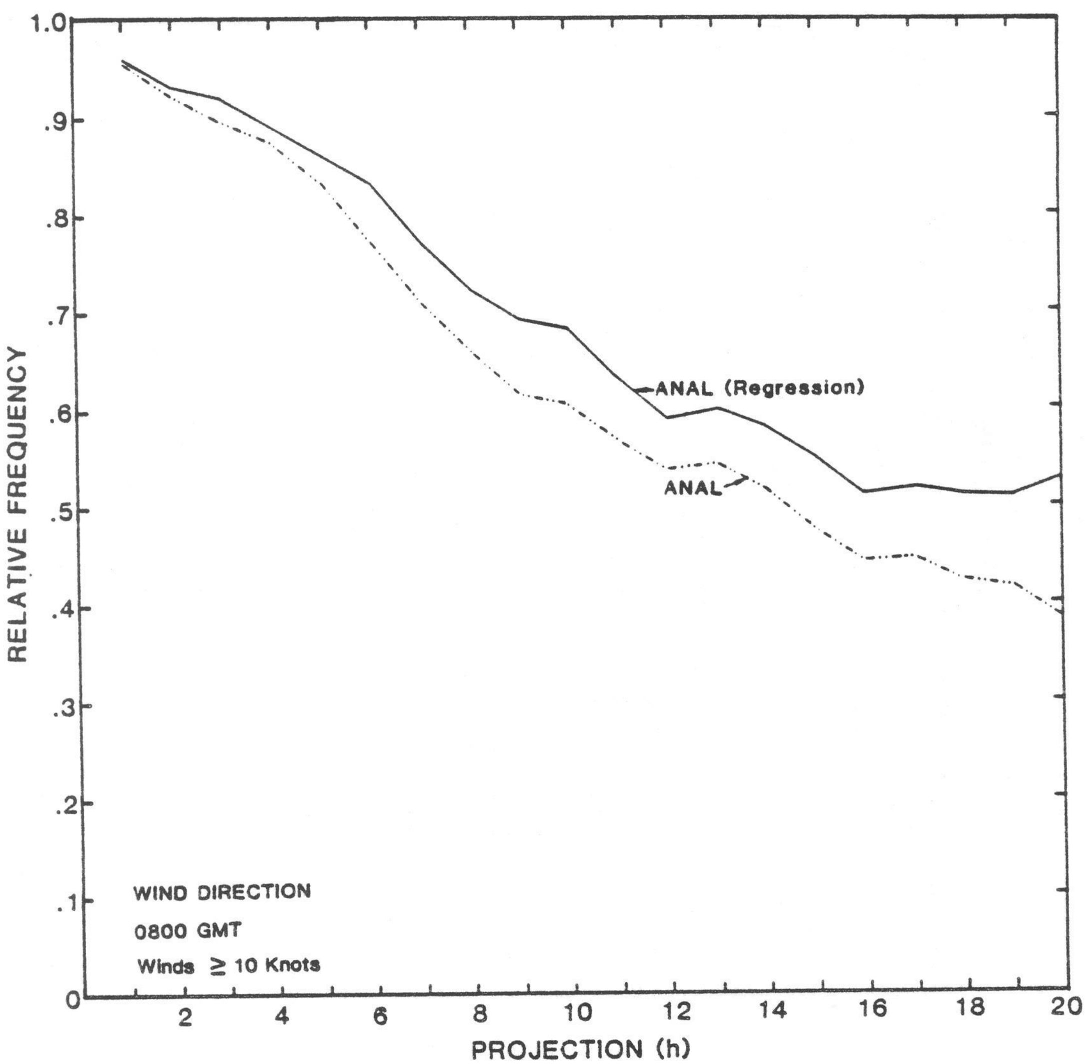

Figure 9. Relative frequency of wind direction forecasts correct to within 30° for observed wind speeds ≥10 kt for analyzed values used as persistence and regression forecasts based on those values for the 0800 GMT start time.

over analysis used as persistence is considerable, except for the very short projections. The improvement is greater at 1300 GMT than at 0800 GMT. The accuracy decreases with projection more rapidly at 1300 GMT than at 0800 GMT.

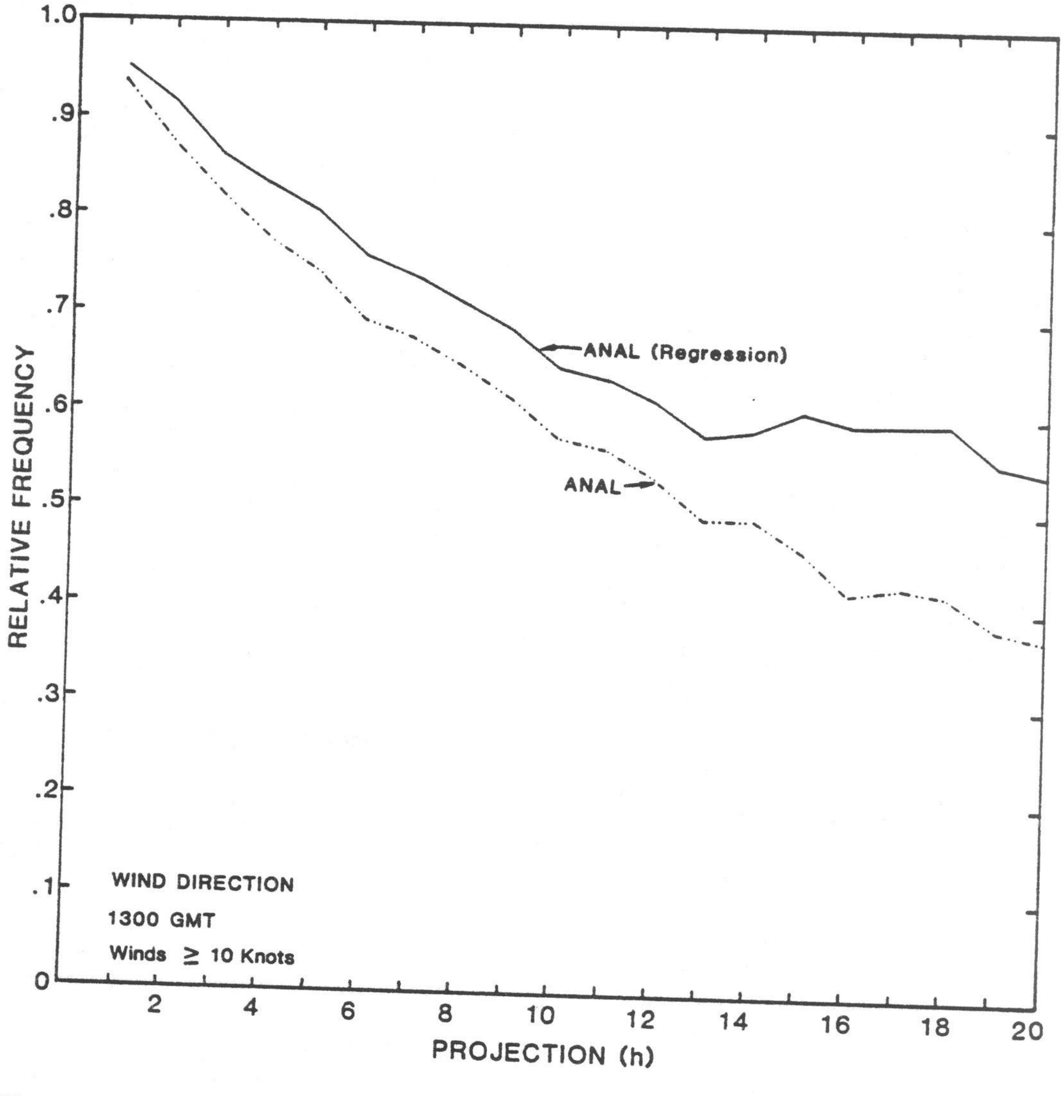

Figure 10. Same as Fig. 9 except for the 1300 GMT start time.

C. Comparison of Regression on Observations and Analyses

Wind Speed

Figs. 11 and 12 compare the regression speed forecasts made with the wind observations as input with those made with the wind analysis values as input.

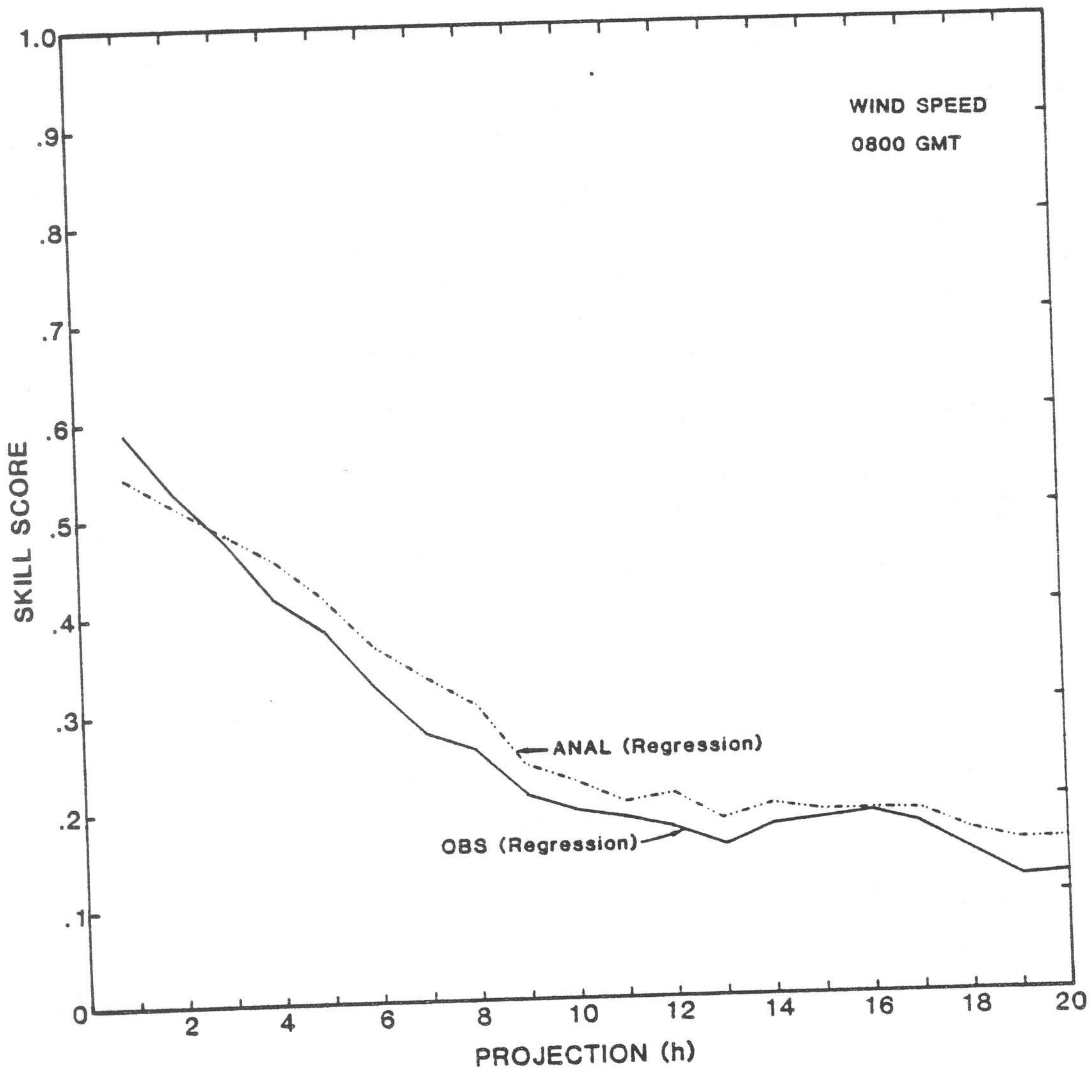

Figure 11. Skill scores for regression forecasts based on the initial observations and on analyzed values for the 0800 GMT start time.

(The skill curves are the same as those in Figs. 3, 4, 7, and 8.) It can be seen that the analysis values furnish slightly better input to regression than the raw observation except for the first 1 or 2 hours.

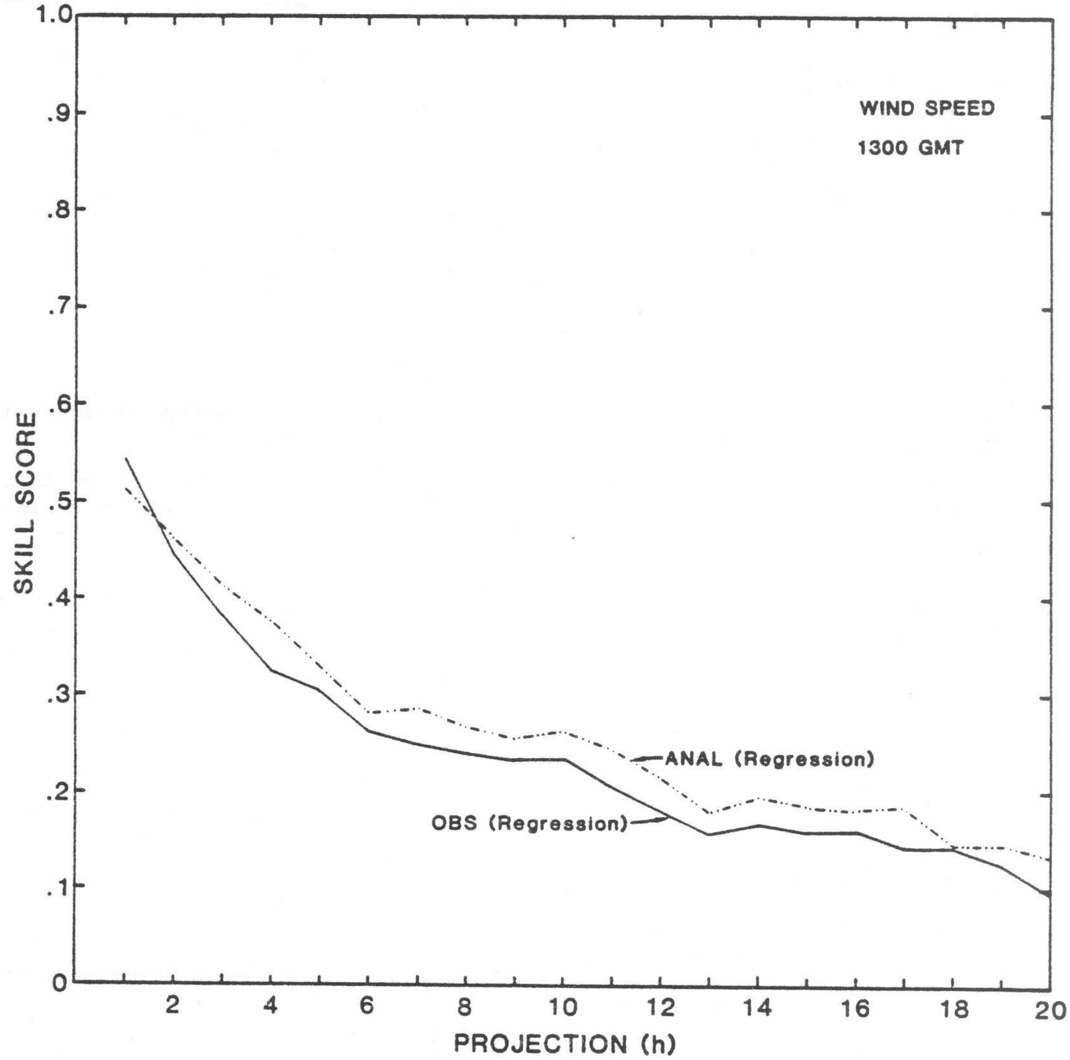

Figure 12. Same as Fig. 11 except for the 1300 GMT start time.

Wind Direction

Figs. 13 and 14 compare the regression direction forecasts made with the wind observations as input with those made with the wind analysis values as input. (The accuracy curves are the same as those in Figs. 5, 6, 9, and 10.) As with speed, the analysis input is better than the observations as input, especially for projections of 2 to 14 hours. These speed and direction results show that information contained in observations at stations around the

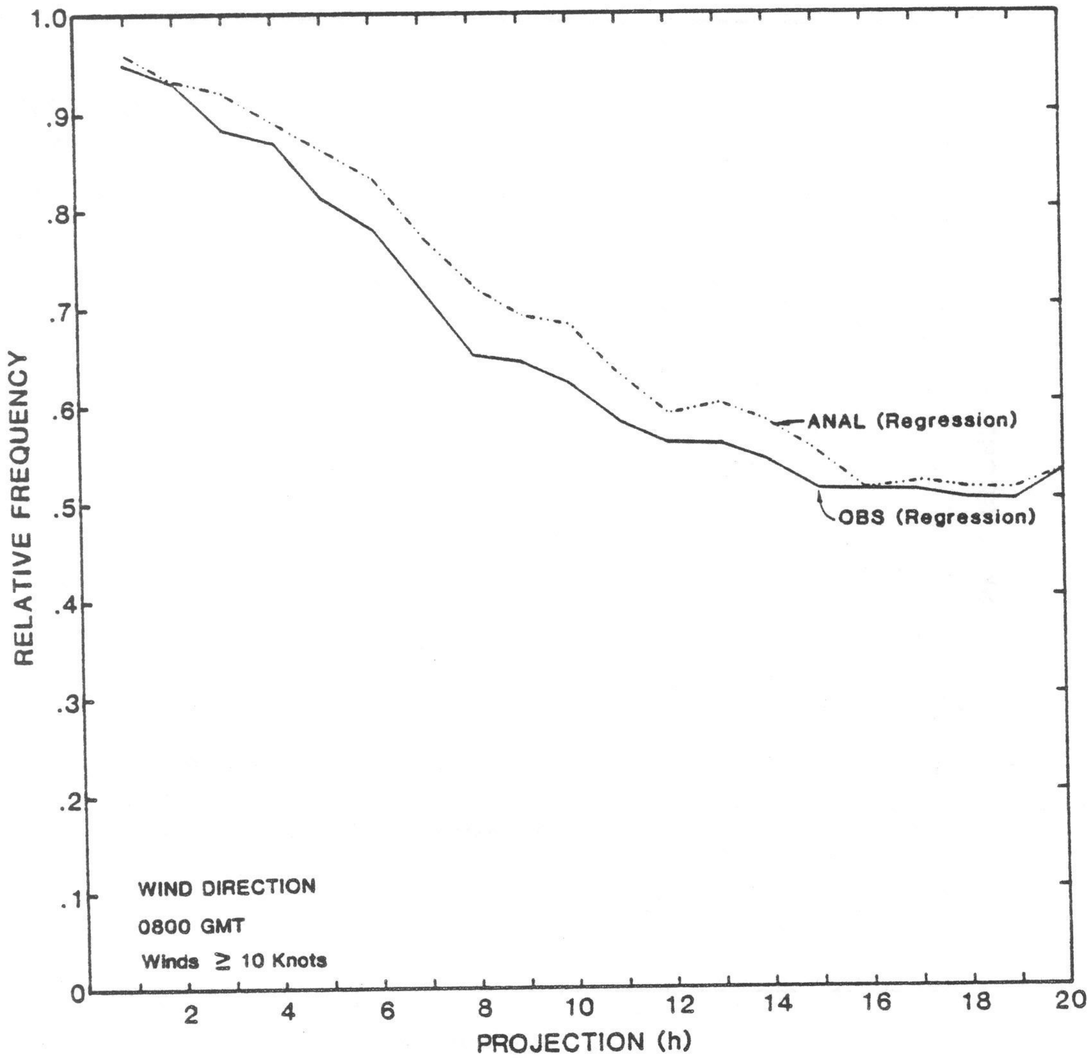

Figure 13. Relative frequency of wind direction forecasts correct to within 30° for observed wind speeds ≥10 kt for regression forecasts based on observations and on analysis values for the 0800 GMT start time.

predictand station is useful in this very simple wind prediction model, especially for projections longer than 2 hours.

Further tests showed, however, that the analysis information was more redundant with the geostrophic winds computed from the SLP model than was the information contained in the raw observations. Therefore, analysis input was not used in the final LAMP wind prediction equations. However, a backup system that can be used whenever the observation at a station is missing was derived.

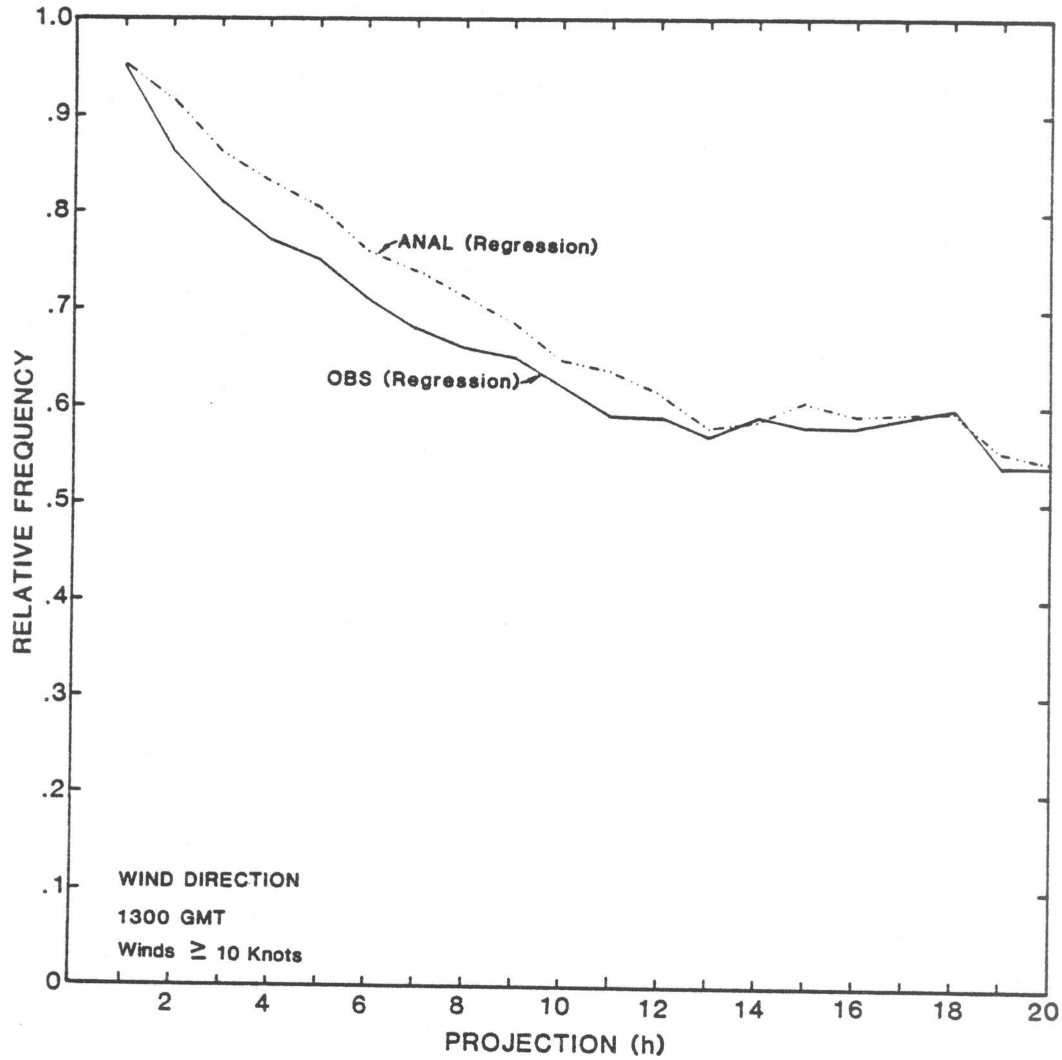

Figure 14. Same as Fig. 13 except for the 1300 GMT start time.

D. Predictors from MOS

Wind Speed

Figs. 15 and 16 show the skill scores of the centralized MOS guidance and also those from three-predictor regression equations using as input those same MOS forecasts. Results are for all 32 stations; interpolations in time and space were performed, where necessary. (Portions of the curves on these two figures are nearly identical, the differences being due to slightly different samples used in verifying the 0800 and 1300 GMT forecasts.) Two things are apparent--regression improves over raw MOS, and the skill does not deteoriate much with time. Also, it seems the linear interpolation in time is a valid procedure; there are no noticable peaks at the specific MOS valid times

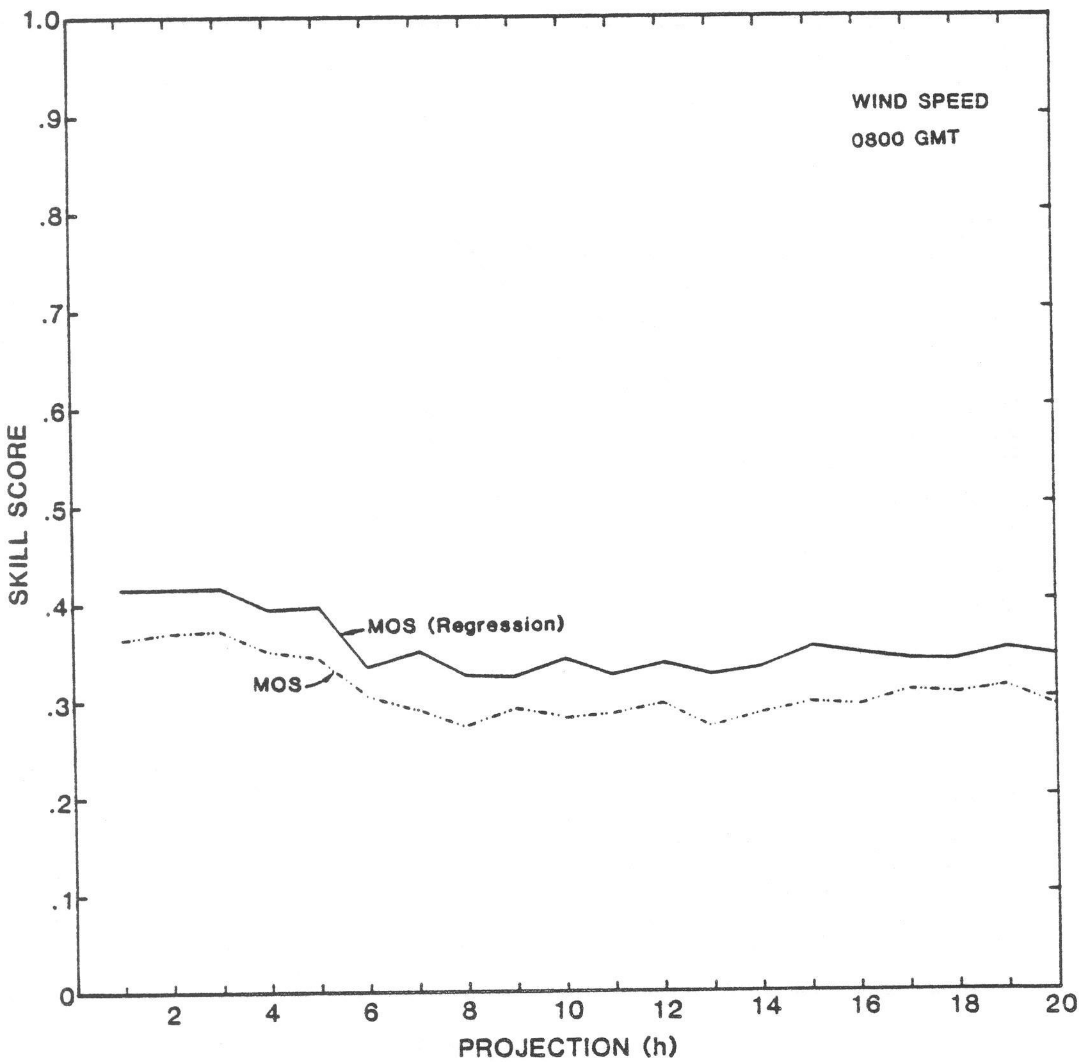

Figure 15. Skill scores for MOS forecasts and regression forecasts based on MOS for the 0800 GMT start time.

(projections 4, 10, and 16 in Fig. 15 and projections 5, 11, and 17 in Fig. 16). The validity of space interpolation is discussed later.

It is a little surprising that the MOS forecasts do not deteriorate more rapidly with time. It is possible some of the skill is due to the aggregation of data for all stations into one contingency table before computing the skill score. However, this component is quite small compared to the general level of skill. For instance, at the 20-h projection from 1300 GMT, the MOS regression forecasts had a skill score of .323 computed from the combined table, while the average of the individual station skill scores was .305. (Two of the 32 stations had no verifying data and one station had only two observations. The sample sizes for the other 29 stations ranged from 140 to 160. The 29 station scores were weighted by sample size to arrive at the average.)

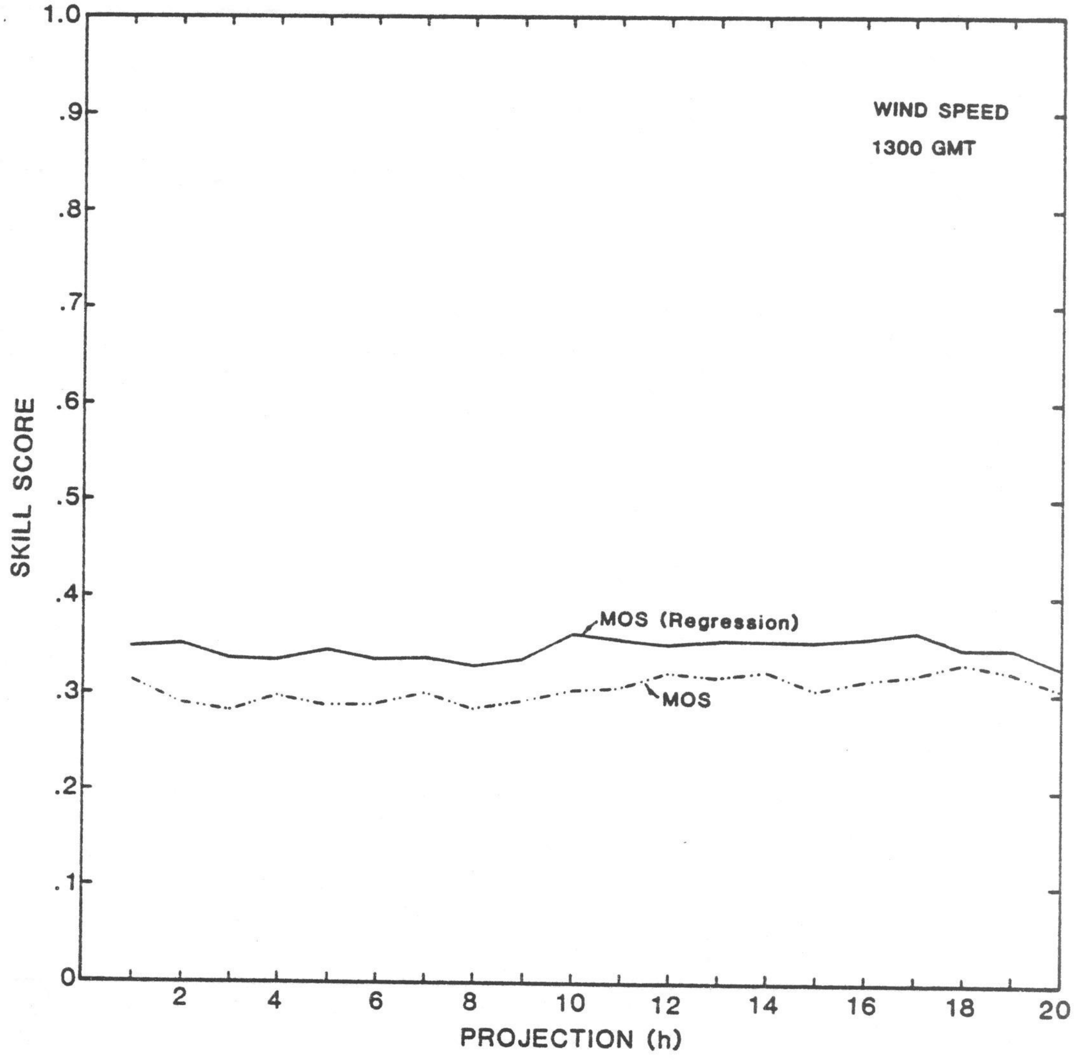

Figure 16. Same as Fig. 15 except for the 1300 GMT start time.

Wind Direction

Figs. 17 and 18 show the direction accuracy of MOS and MOS-based regression forecasts. Here, regression improves on MOS only slightly, if at all, and the

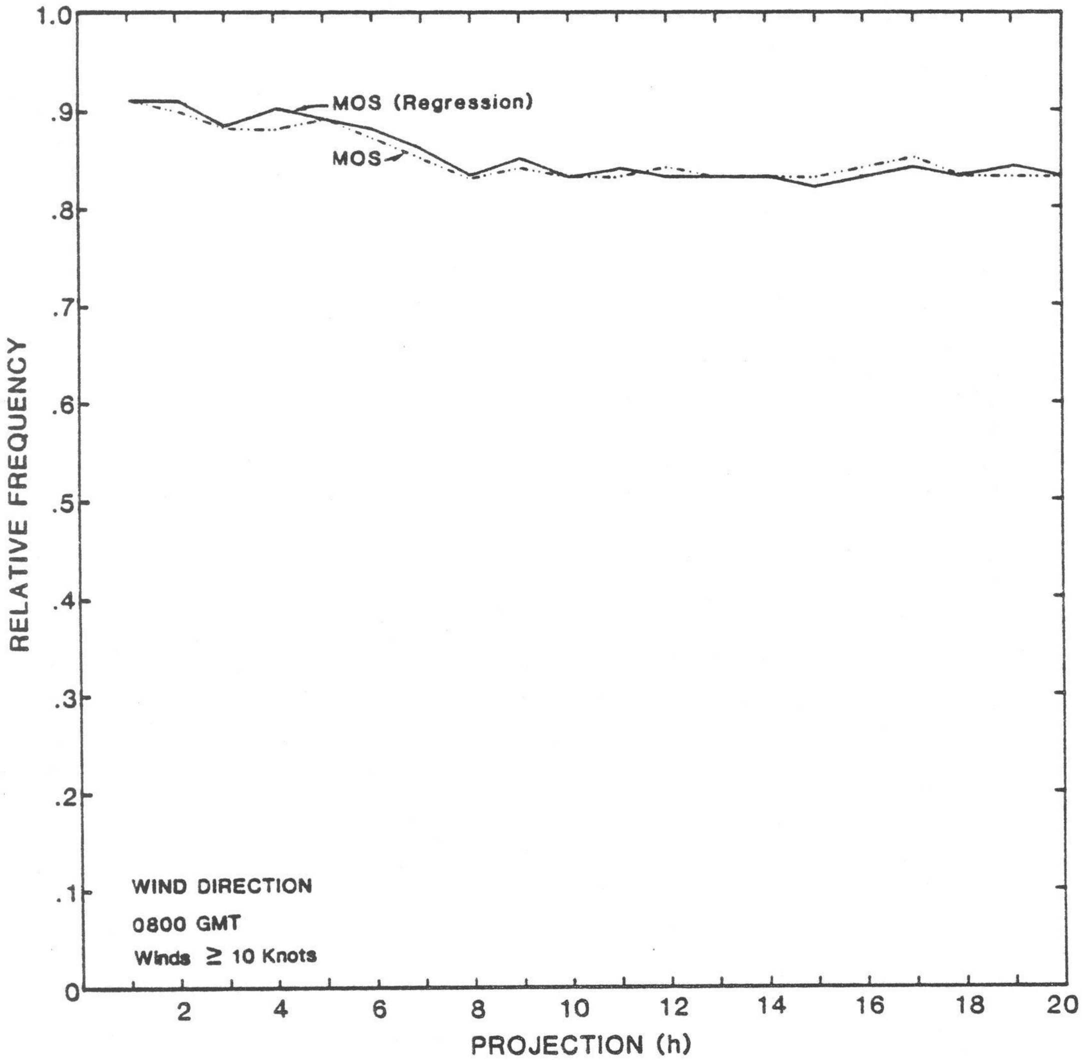

Figure 17. Relative frequency of wind direction forecasts to within 30° for observed wind speeds ≥10 kt for MOS and regression forecasts based on MOS for the 0800 GMT start time.

accuracy deteriorates little with time, especially after about 1600 GMT (8-h projection from 0800 GMT and 3-h projection from 1300 GMT).

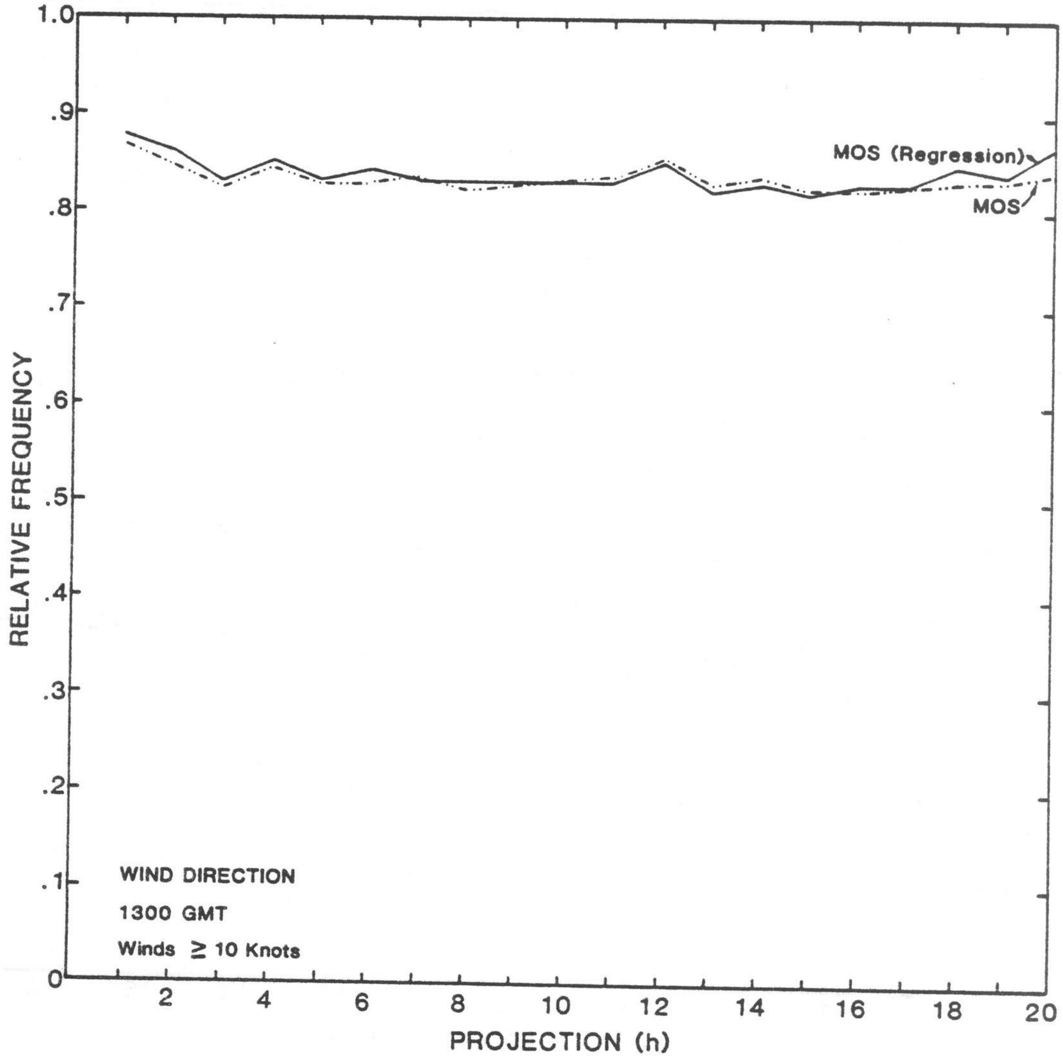

Figure 18. Same as Fig. 17 except for the 1300 GMT start time.

E. Comparison of MOS and Regression based on MOS at MOS stations

Wind Speed

Fig. 19 is similar to Fig. 16 except Fig. 16 pertains to all 32 stations and Fig. 19 to only the 15 MOS stations. It is apparent that regression on MOS does not improve nearly as much on MOS alone for the MOS stations as for all stations combined at 1300 GMT. (Similar results were found for 0800 GMT.) This implies that space interpolation to non-MOS stations does not provide speed forecasts of accuracy equal to those at the MOS stations and, therefore, regression can improve on those interpolated values. The LAMP regression forecasts for all 32 stations have about the same level of skill as those forecasts at only the 15 MOS stations.

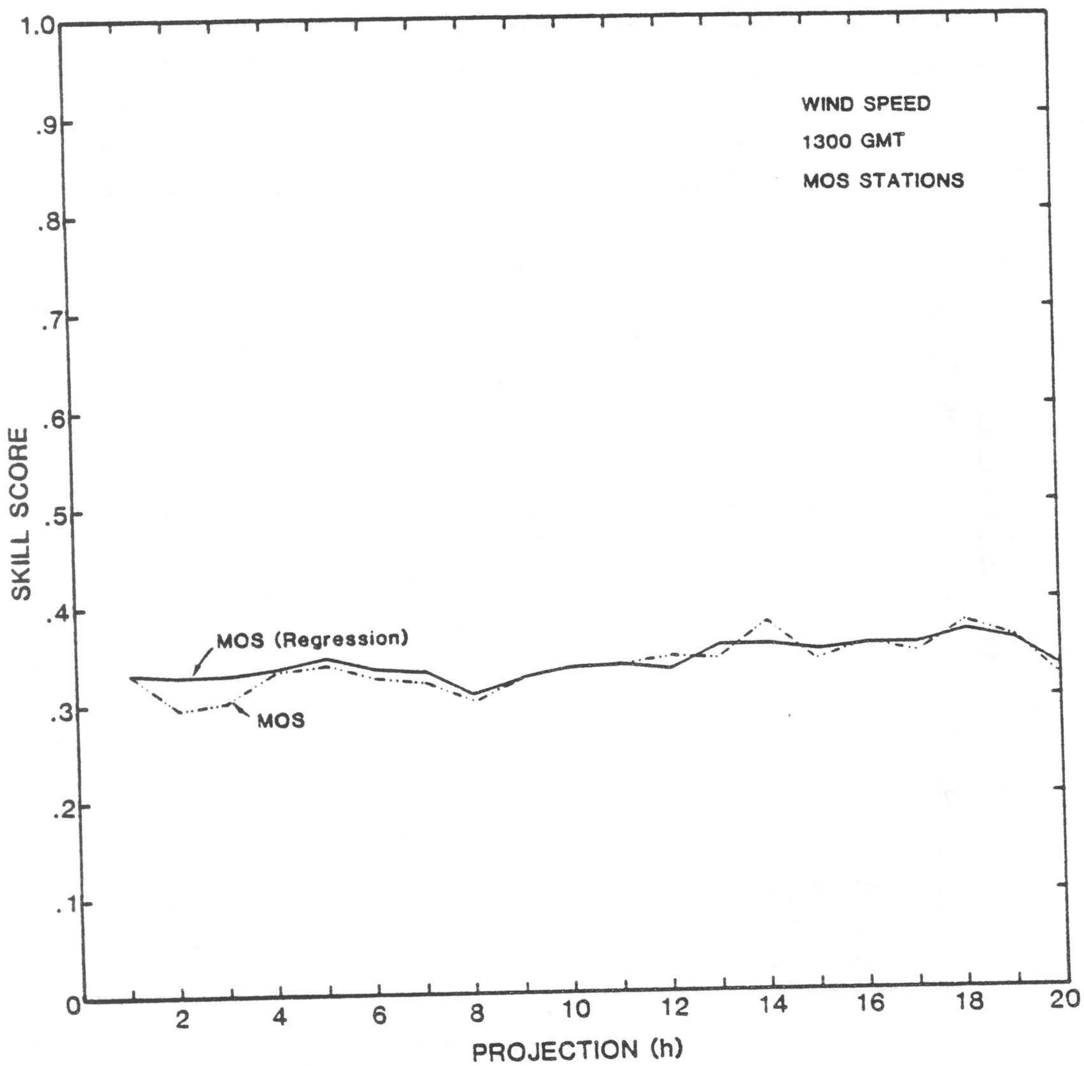

Figure 19. Skill scores for MOS forecasts and regression forecasts based on MOS for only MOS stations for the 1300 GMT start time.

Wind Direction

Fig. 20 is similar to Fig. 18 expect that Fig. 18 pertains to all 32 stations and Fig. 20 to only the 15 MOS stations. Regression on MOS does not improve on MOS alone for direction for these MOS stations. However, the level of skill of both MOS and regression on MOS forecasts is slightly higher at MOS stations then at non-MOS stations. It is not clear whether this is a result of the space interpolation procedure, or whether the non-MOS stations either have more noise in their observations or are more difficult to forecast for.

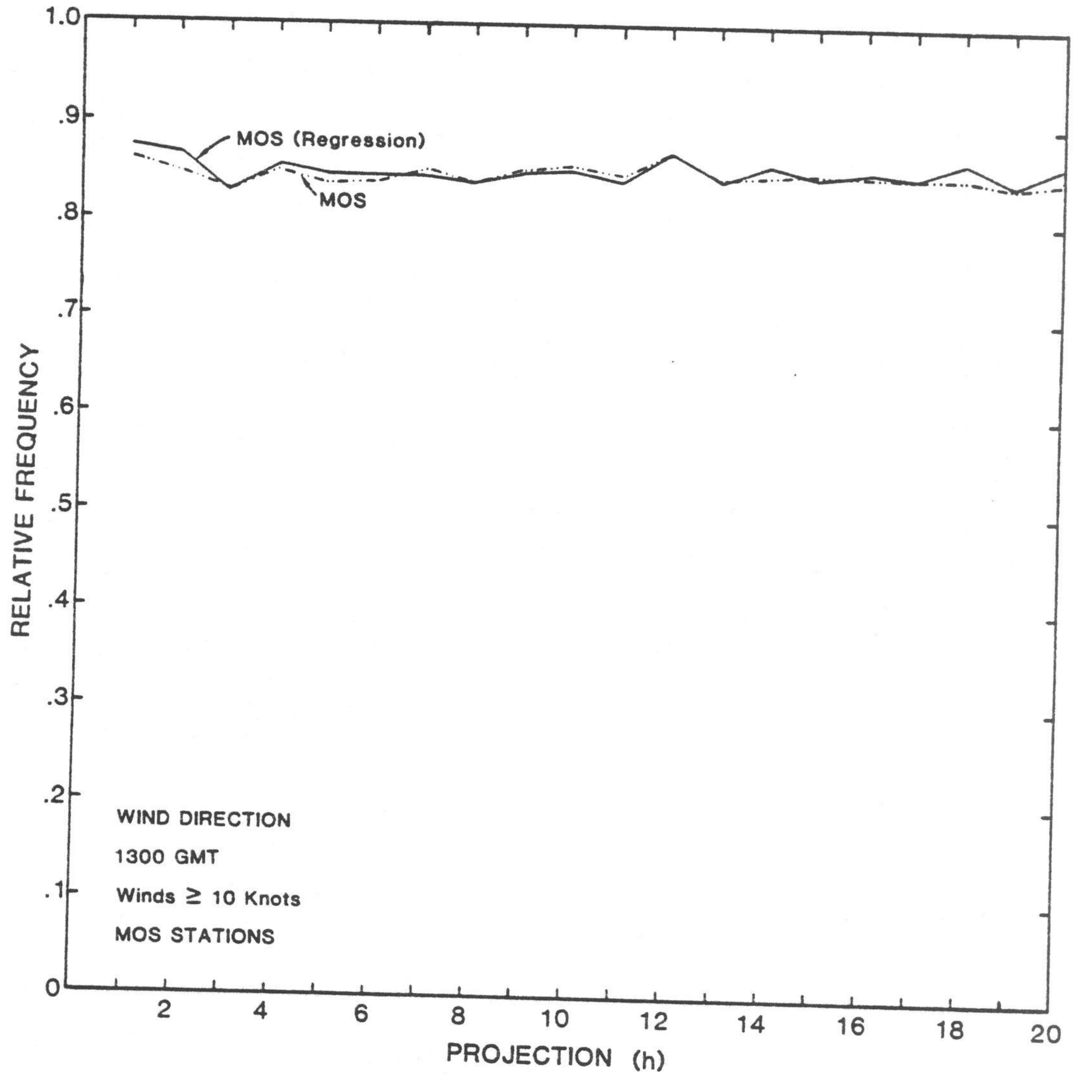

Figure 20. Relative frequency of wind direction forecasts correct to within 30° for observed wind speeds ≥10 kt for MOS and regression forecasts based on MOS for only MOS stations for the 1300 GMT start time.

F. Observations, MOS, Geostrophic Winds, and Computed Variables as Predictors

Wind Speed

Figs. 21 and 22 compare skill scores for various regression forecasts. The curves for regression on Obs alone and MOS alone were shown previously. Although these figures are based on data from all 32 stations, results for only the 15 MOS stations would probably be similar, since regression on MOS was about equally skillful for MOS and non-MOS stations.

In the early projections, the observations control the skill, while MOS is dominant for later projections. Improvement afforded by MOS and the SLP model is very small at projections of 1 and 2 hours. However, for projections of

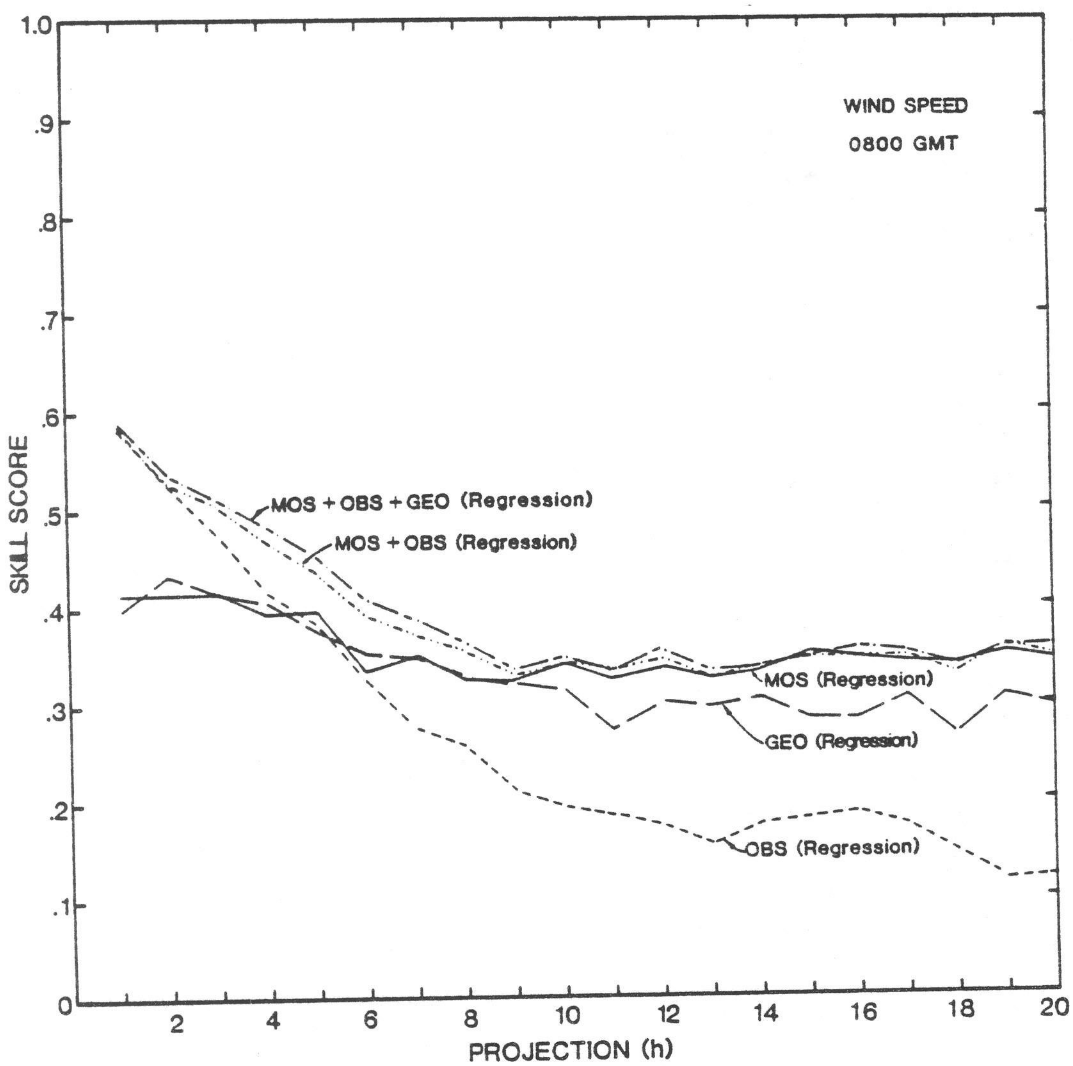

Figure 21. Skill scores for regression forecasts based on observations, MOS, geostrophic winds from the SLP model (GEO), and certain combinations for the 0800 GMT start time.

3 to 9 hours for 0800 GMT and 3 to 16 hours for 1300 GMT, the 9-predictor equations (MOS + Obs + geostrophic winds from the SLP model) are better than either Obs alone or MOS alone. Regression forecasts from the SLP model alone do not compete favorably with Obs alone at the early projections or MOS alone at later projections. Especially at 1300 GMT, the addition of observations as predictors improves on MOS predictors alone, and the addition of geostrophic winds further improves the results.

In addition to the 9-predictor equations, 12-predictor equations were evaluated (graphs not shown). These equations had the same nine predictors plus three computed predictors (see Section 3.C. and Table 1). Although there was no loss of skill with the added predictors, showing the stability of the equations, there was also no appreciable gain.

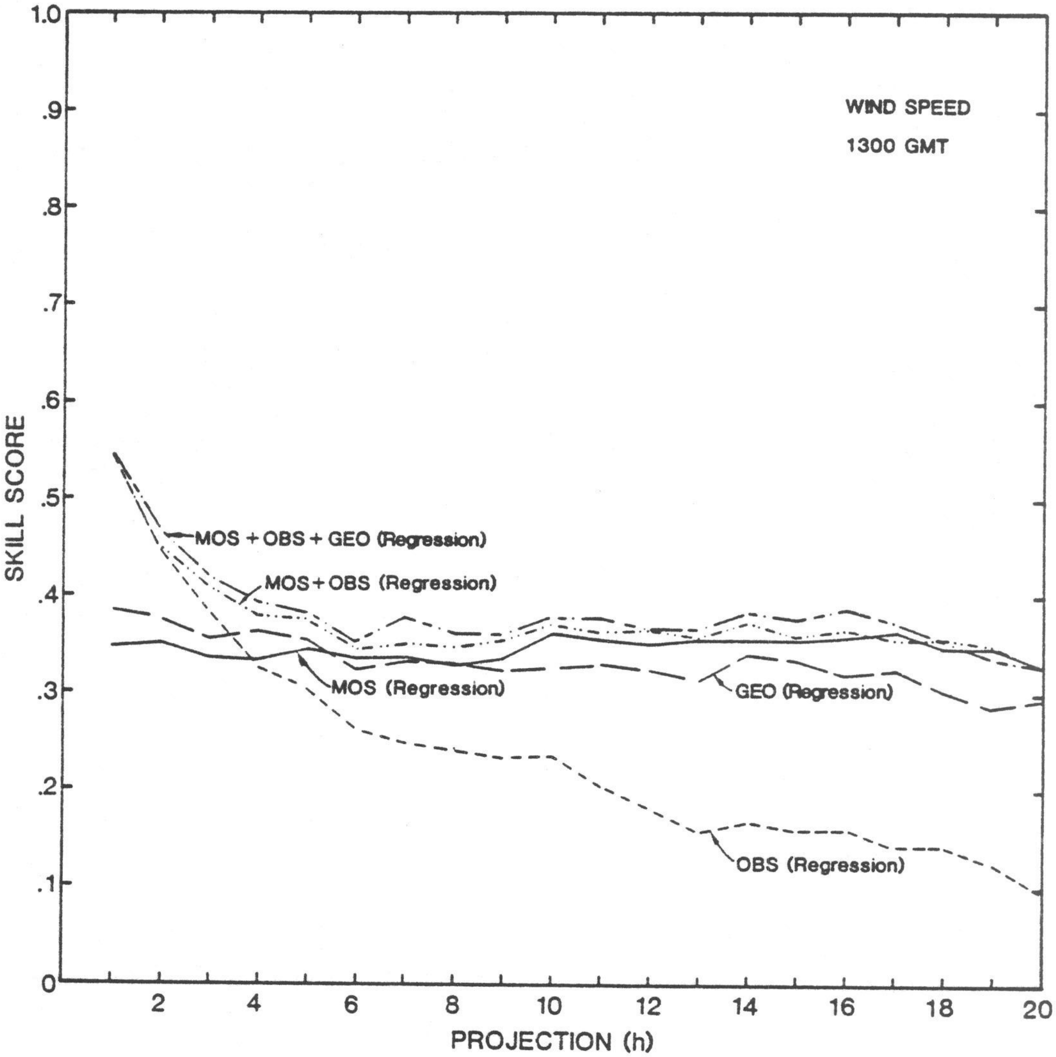

Figure 22. Same as Fig. 21 except for the 1300 GMT start time.

Wind Direction

Figs. 23 and 24 are similar to Figs. 21 and 22, respectively, except they are for wind direction instead of wind speed. In contrast to speed, the addition MOS and geostrophic winds to observations as predictors improves the direction forecast for 1 and especially 2 hours. The addition of observations and geostrophic winds improves on MOS predictors alone out to 16 hours at

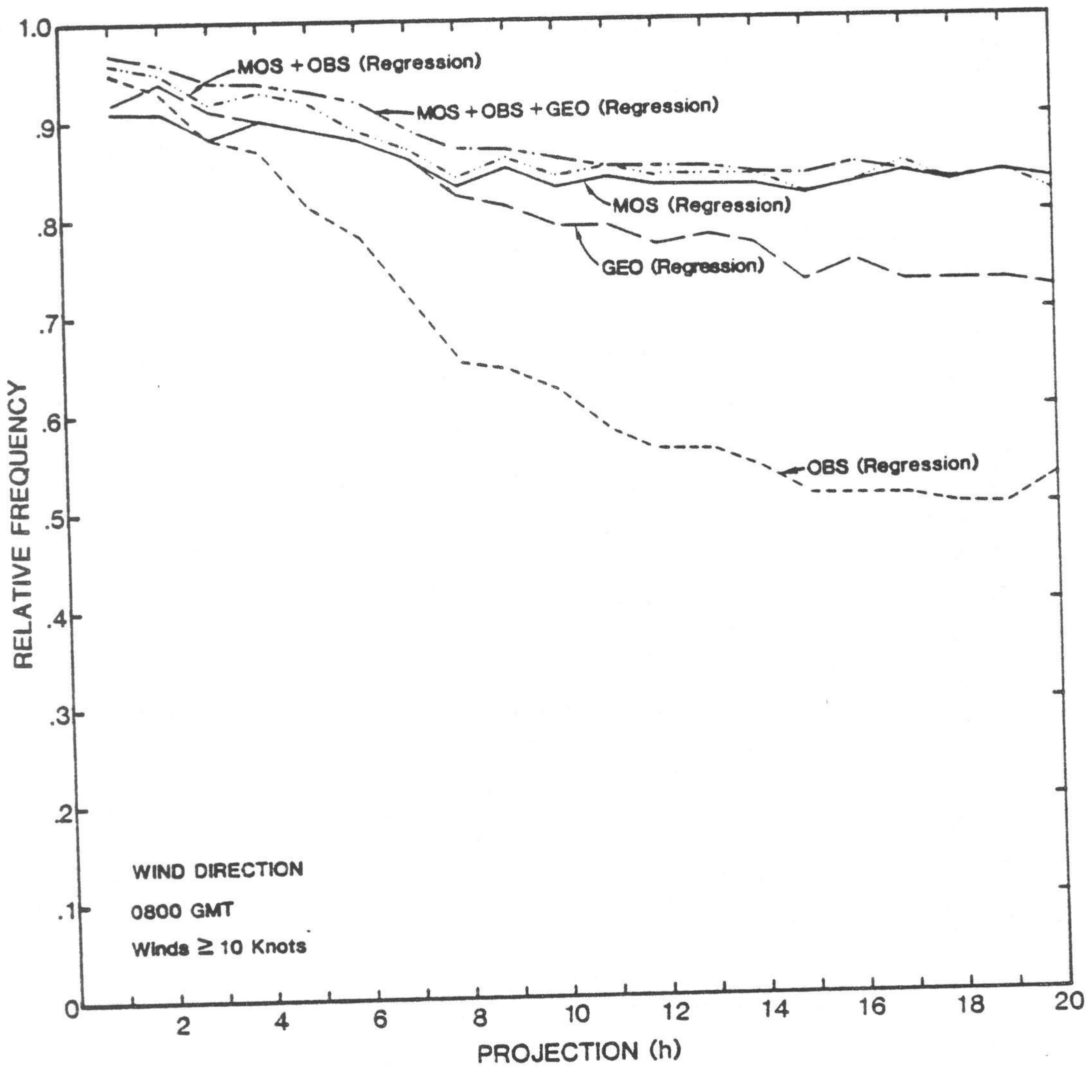

Figure 23. Relative frequency of wind direction forecasts correct to within 30° for observed wind speeds ≥10 kt for regression forecasts based on observations, MOS, geostrophic winds from the SLP model (GEO), and certain combinations for the 0800 GMT start time.

0800 GMT and to 11 hours at 1300 GMT. Geostrophic winds alone do not compete well with observations alone at 1 hour, but are better at all other projections. Also, geostrophic winds alone are better than MOS alone for about 1 to 4 hours.

The computed predictors (see Section 3.C. and Table 1) did not contribute to the direction accuracy (graphs not shown).

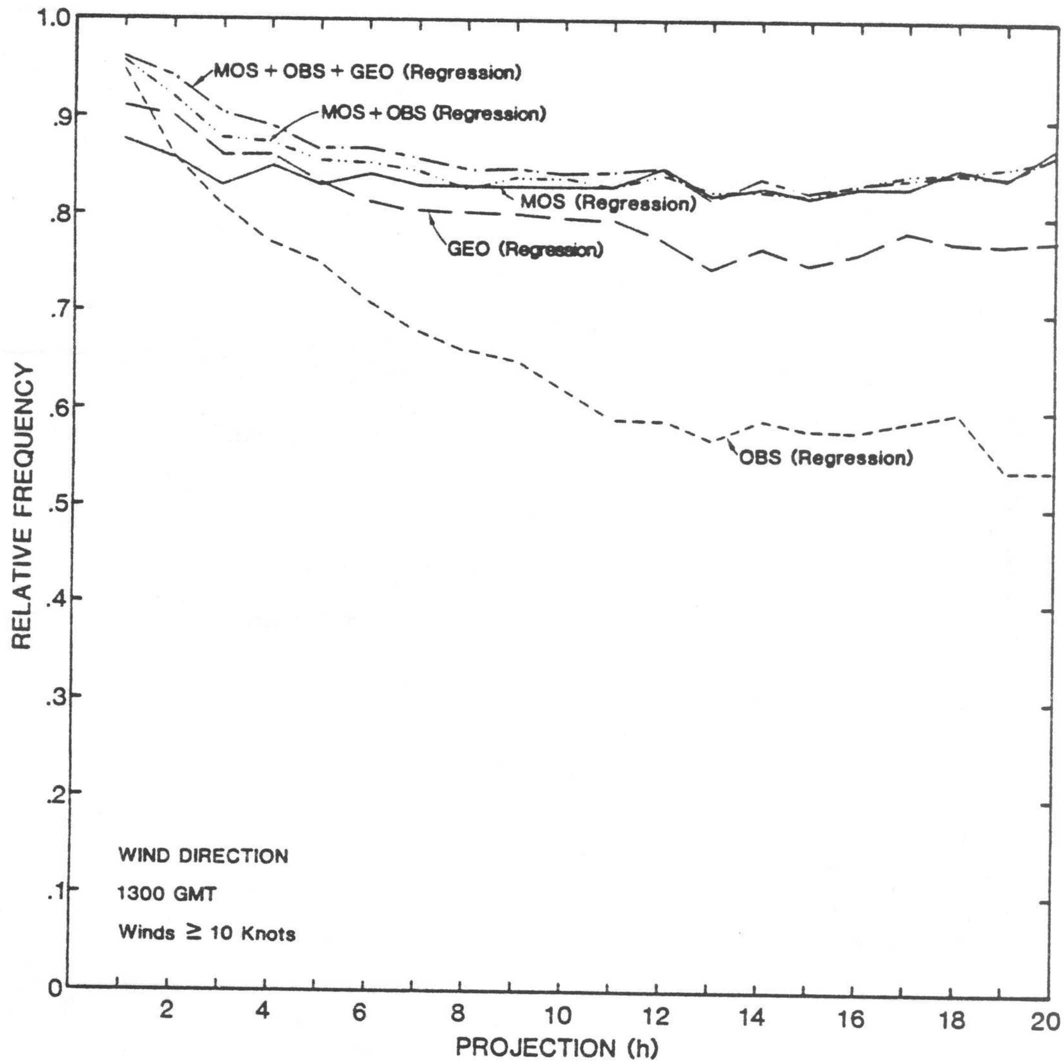

Figure 24. Same as Fig. 23 except for the 1300 GMT start time.

G. Wind Direction Verification for All Wind Speeds

Figs. 25 and 26 are similar to Figs. 23 and 24, respectively, except that the latter pertain to verification of wind directions when the speed is ≥10 kt

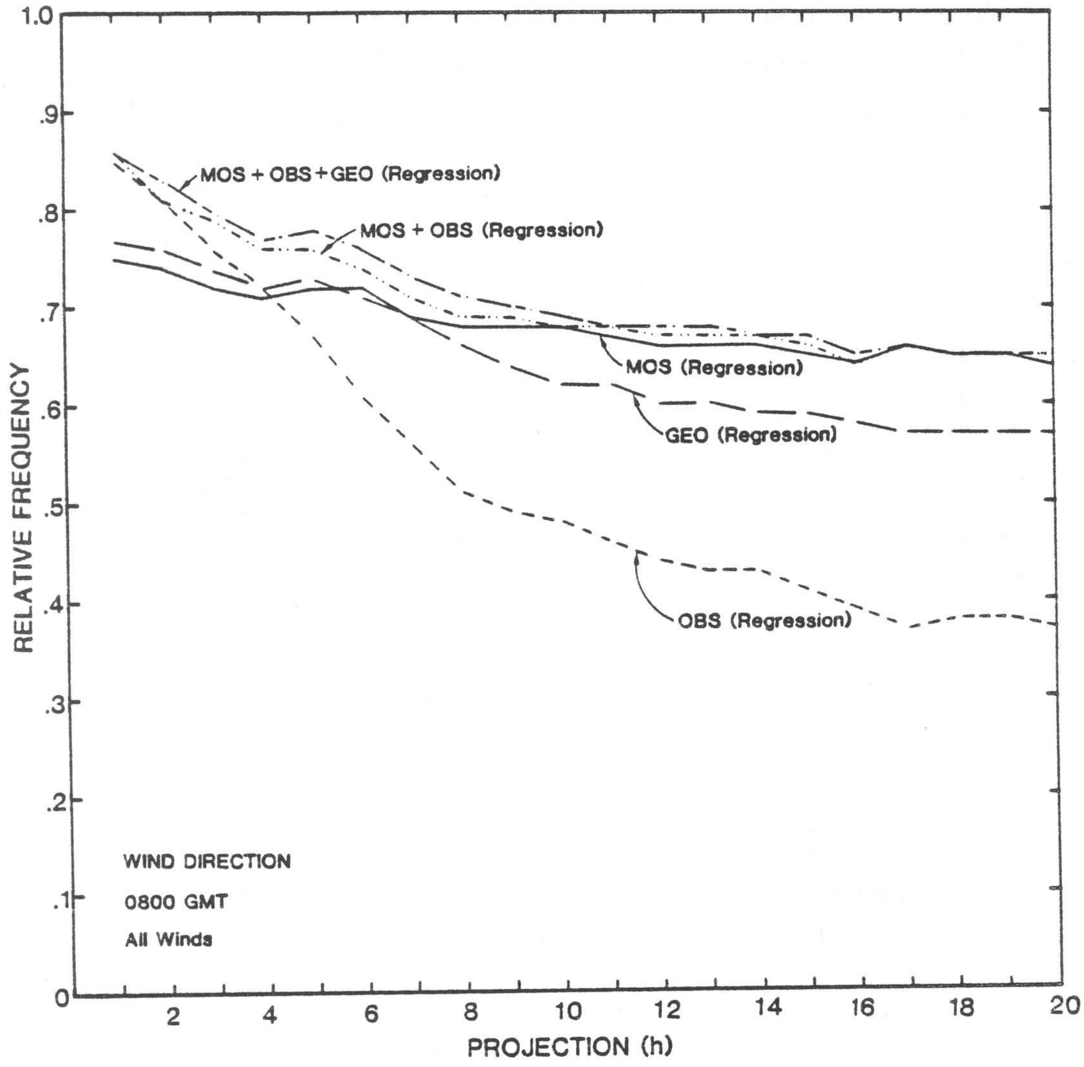

Figure 25. Same as Fig. 23 except all winds (except calm) were verified rather than just those ≥10 kt.

while the former pertain to all wind speeds (except, of course, calm). The percents correct (within 30°) are lower when all winds are verified, as would be expected, but other conclusions reached by verifying only winds ≥10 kt still generally hold.

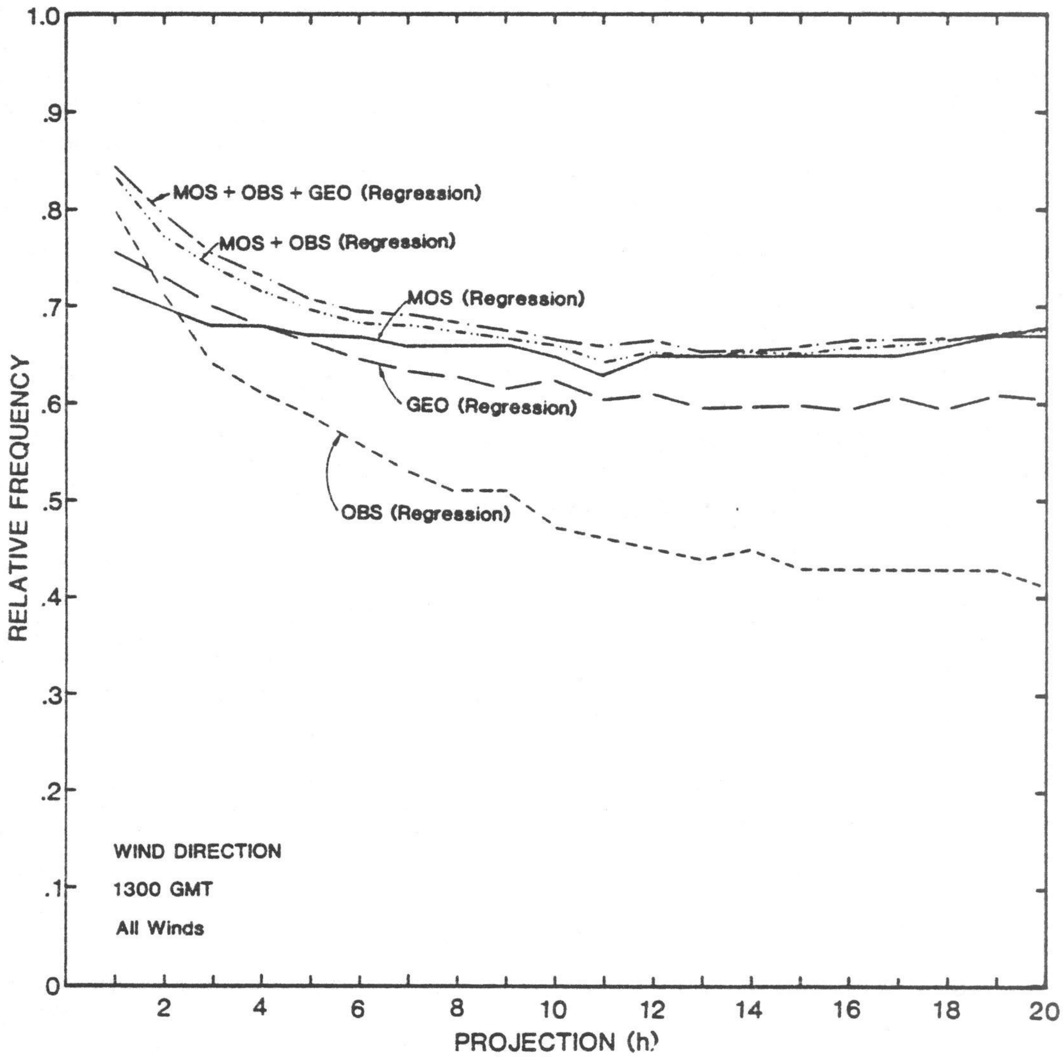

Figure 26. Same as Fig. 25 except for the 1300 GMT start time.

H. MOS and Persistence as Controls

Wind Speed

Figs. 27 and 28 compare the speed forecasts from the final LAMP equations (MOS, observations, and geostrophic winds) with what is currently available--MOS and persistence (the 0800 or 1300 GMT observations). Except for the

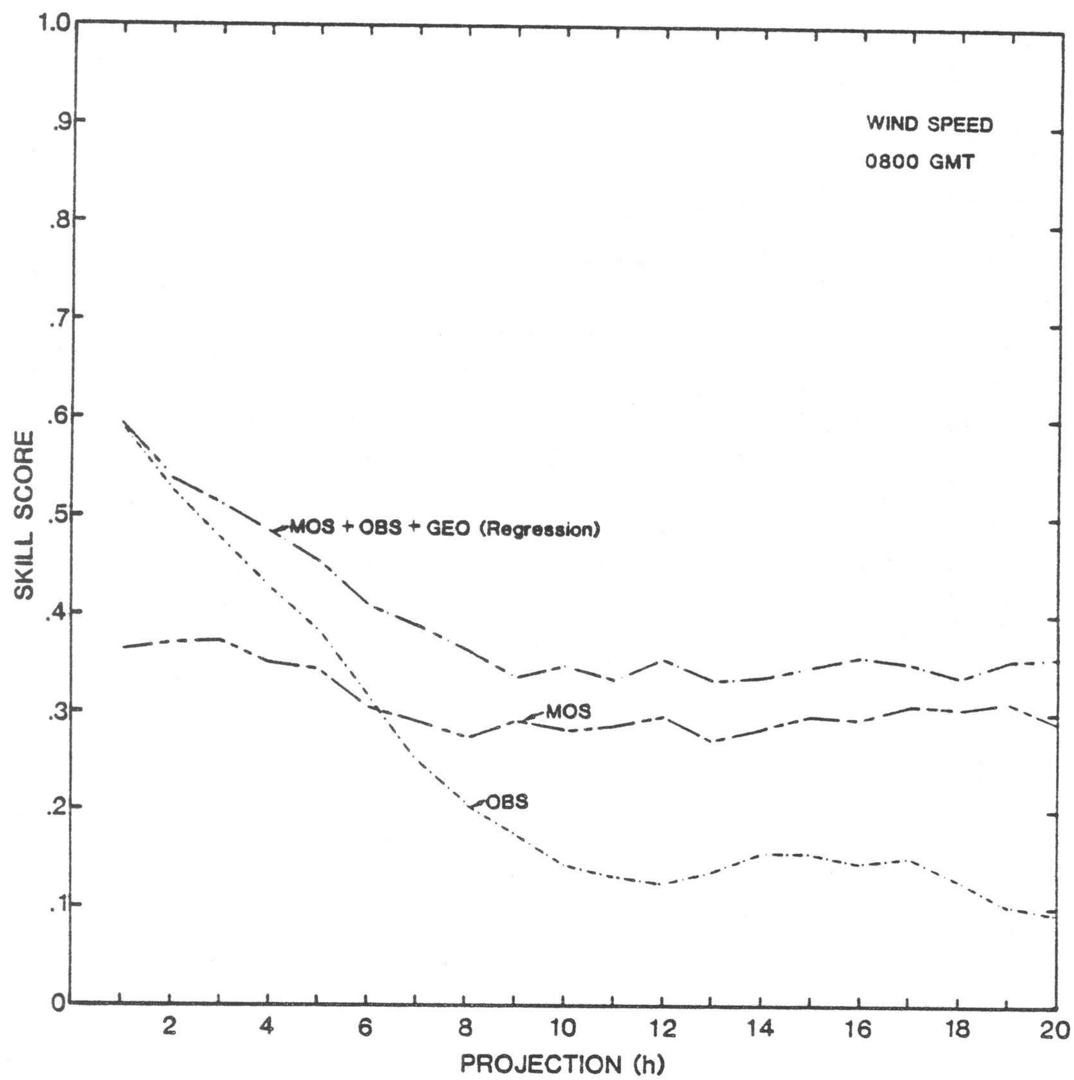

Figure 27. Skill scores for persistence, MOS, and regression forecasts based on the initial observations, MOS, and the geostrophic winds computed from the SLP model for the 0800 GMT start time.

1- and 2-h projections for 0800 GMT, the LAMP forecasts are clearly superior to both controls for all projections. It must be remembered that the MOS forecasts for the non-MOS stations were obtained by interpolation and are not as skillful as the forecasts for the MOS stations. The conclusions stated here are valid provided guidance forecasts are actually needed for a significant portion of the non-MOS stations.

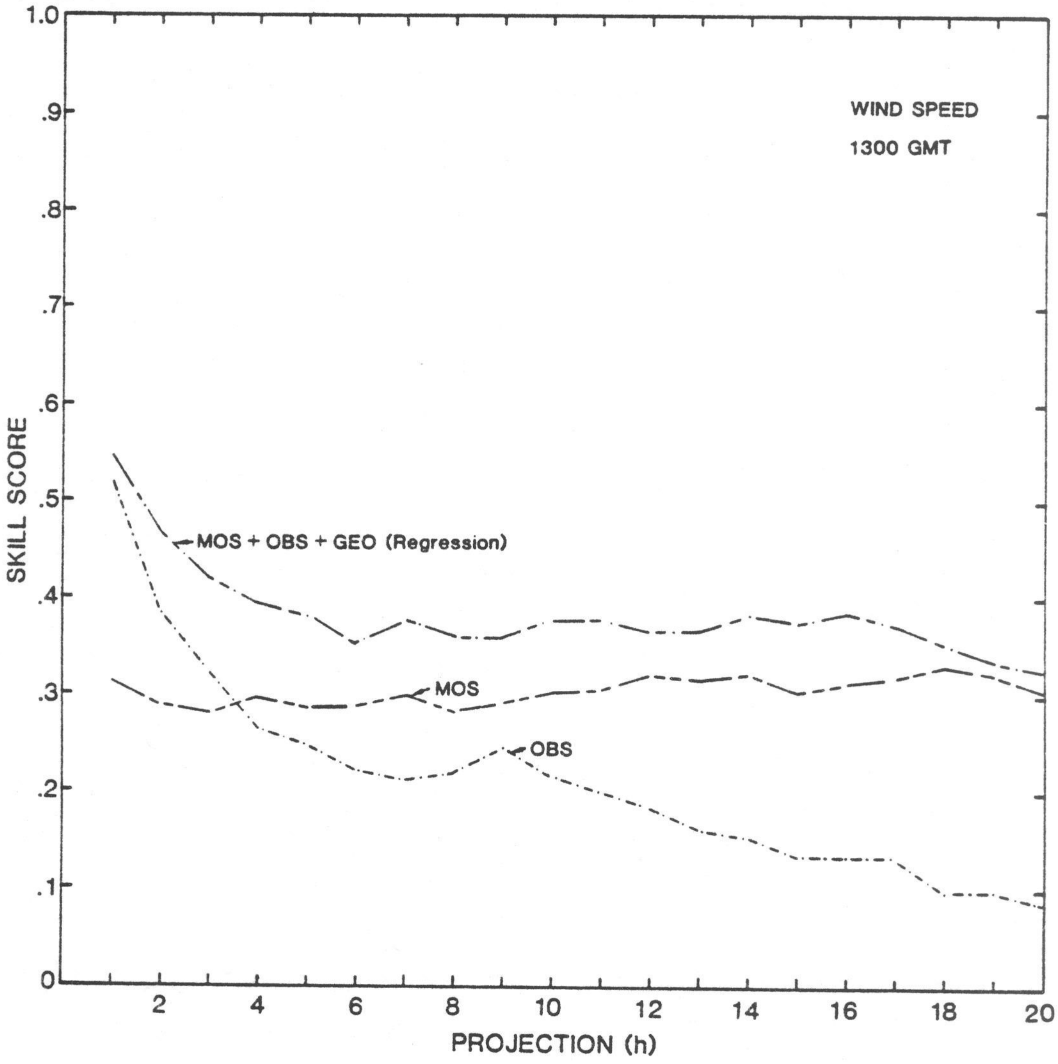

Figure 28. Same as Fig. 27 except for the 1300 GMT start time.

Wind Direction

Figs. 29 and 30 compare the direction forecasts from the final LAMP equations with what is currently available. The LAMP forecasts are clearly

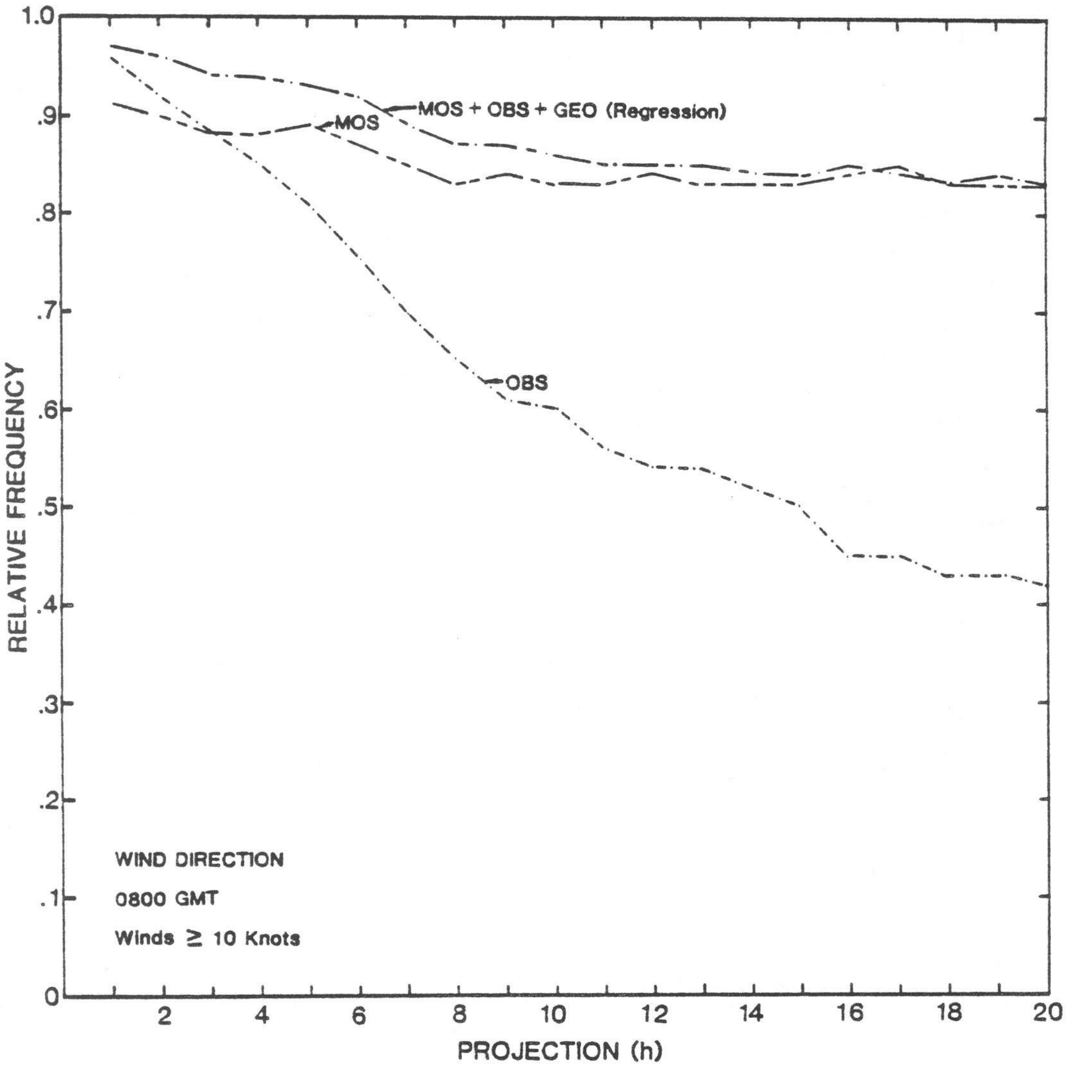

Figure 29. Relative frequency of wind direction forecasts correct to within 30° for observed winds ≥10 kt for persistence, MOS, and regression forecasts based on the initial observations, MOS, and geostrophic winds computed from the SLP model for the 0800 GMT start time.

superior to persistence and superior to MOS out to about 16 hours for 0800 GMT and 11 hours for 1300 GMT. Since the accuracy is approximately the same at MOS and non-MOS stations (see Figs. 18 and 20), this conclusion holds for both groups of stations.

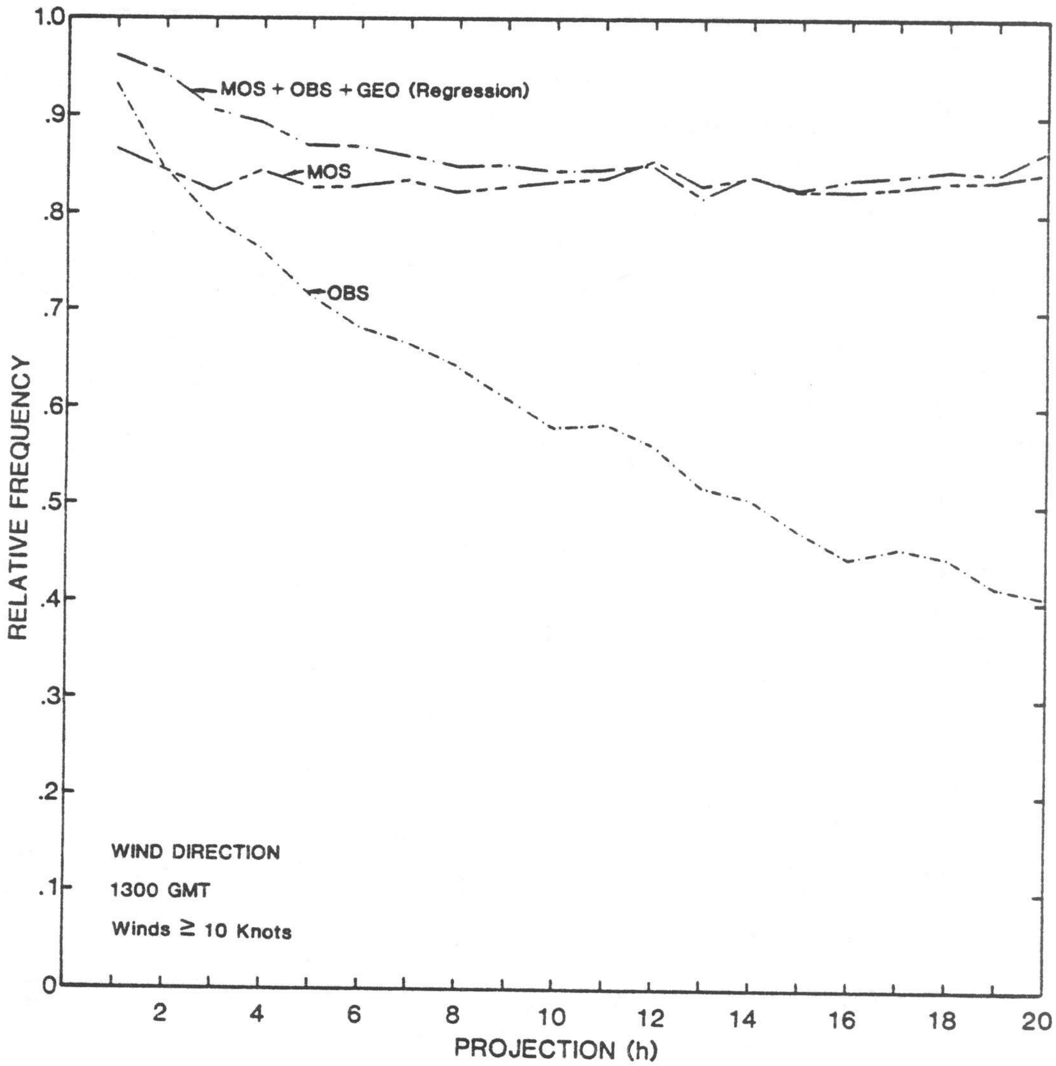

Figure 30. Same as Fig. 29 except for the 1300 GMT start time.

I. Stricter Accuracy Limits for Verifying Wind Direction

Twenty-degree Limit

In all previous figures pertaining to direction, a forecast was counted as correct if it was within 30° of the observed wind. This might be considered a lenient definition, and in fact the percents correct at 1-h are very high. Figs. 31 and 32 show the percents correct when only forecasts within 20° of the observed wind were counted as correct.

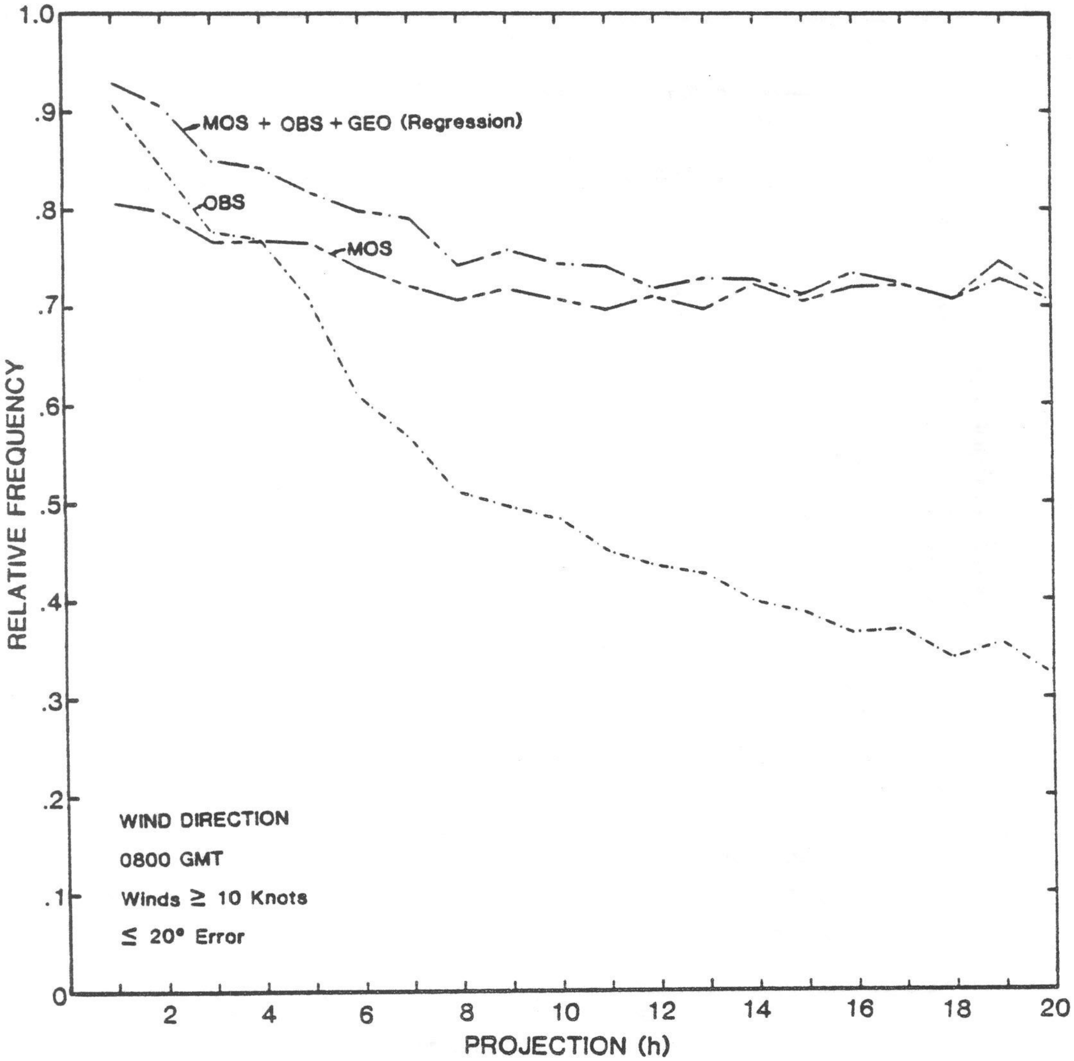

Figure 31. Same as Fig. 29 except the wind direction forecasts were counted as correct if they were within 20° of the observed wind, rather than 30°.

Accuracy is, of course, lower with the stricter limit, but all conclusions reached from the 30° limit still hold. With the stricter limit, the improvements of the LAMP forecasts over MOS and persistence are greater in absolute terms but less in terms of improvement over possible improvement.

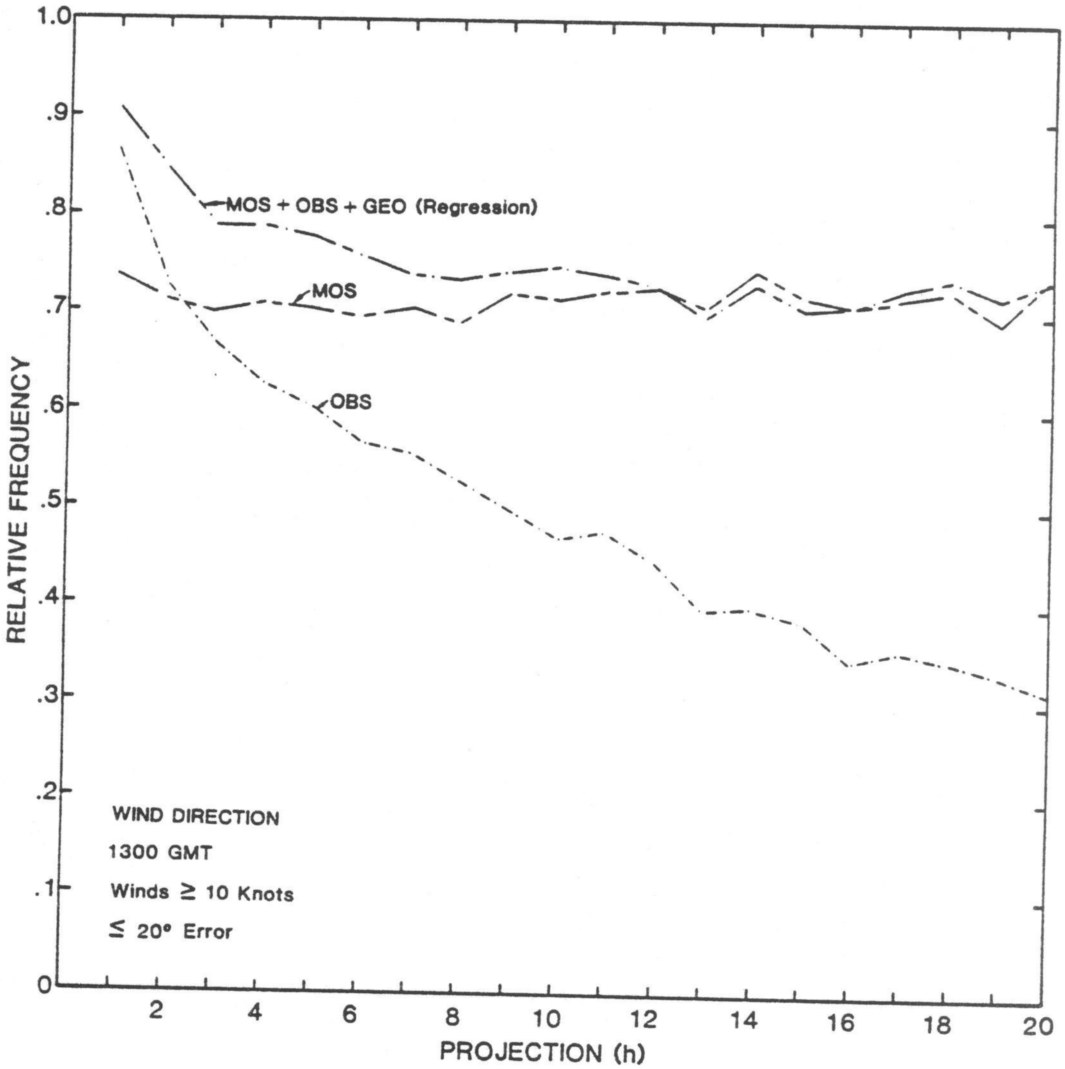

Figure 32. Same as Fig. 31 except for the 1300 GMT start time.

Ten-degree Limit

Figs. 33 and 34 show the percents correct when only forecasts within 10° of the observed wind were counted as correct. Again, the accuracy is lower with the stricter limit. Even so, LAMP 1-h forecasts are correct to within 10° 74 to 80% of the time.

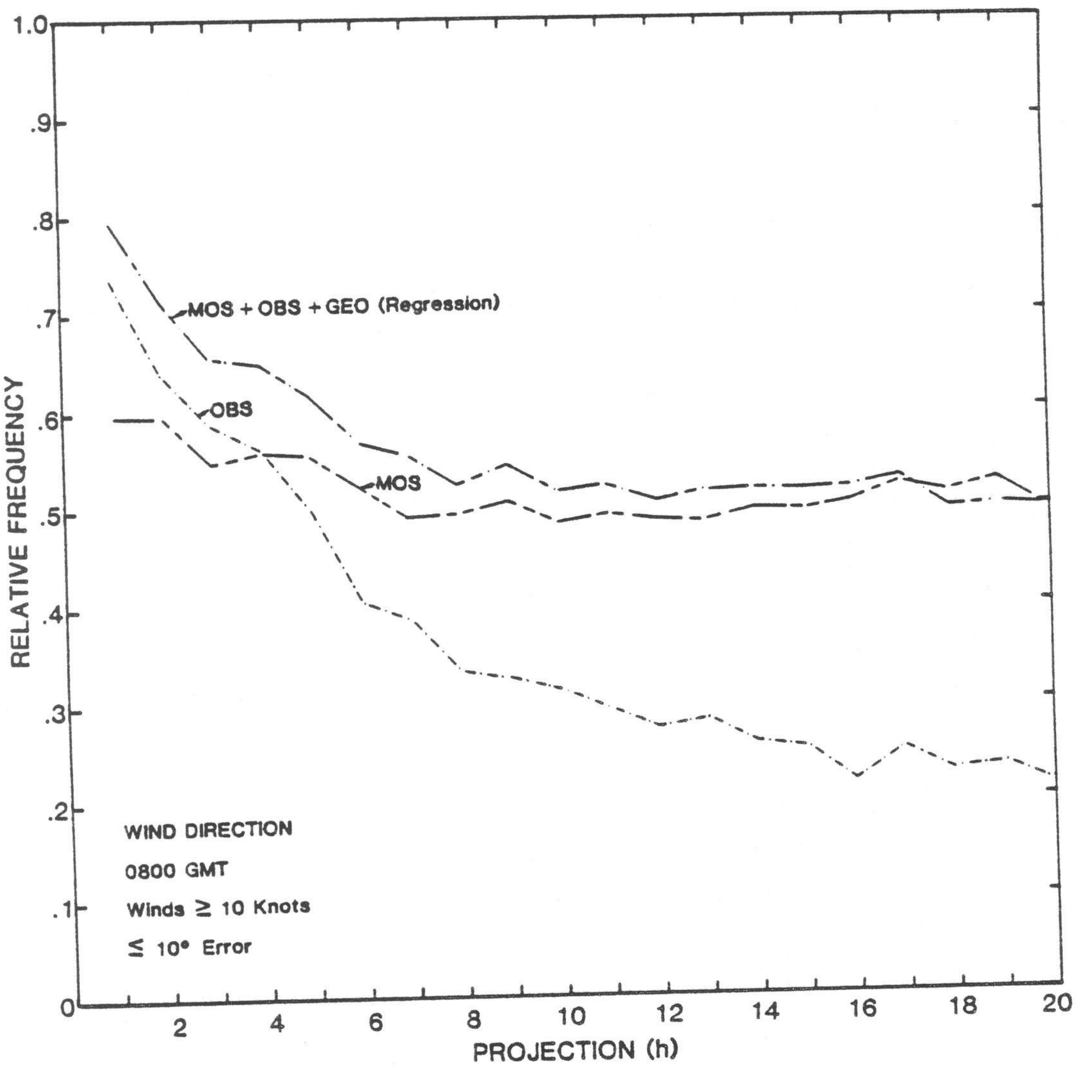

Figure 33. Same as Fig. 29 (Fig. 31) except the wind direction forecasts were counted as correct if they were within 10° of the observed wind, rather than 30° (20°).

It is encouraging that even for the 20-h projection, MOS forecasts alone (as well as LAMP forecasts) are within 30° 84% of the time (Figs. 29 and 30), within 20° 73% of the time (Figs. 31 and 32), and within 10° 50% of the time (Figs. 33 and 34) when winds $\geq$10 kt are considered.

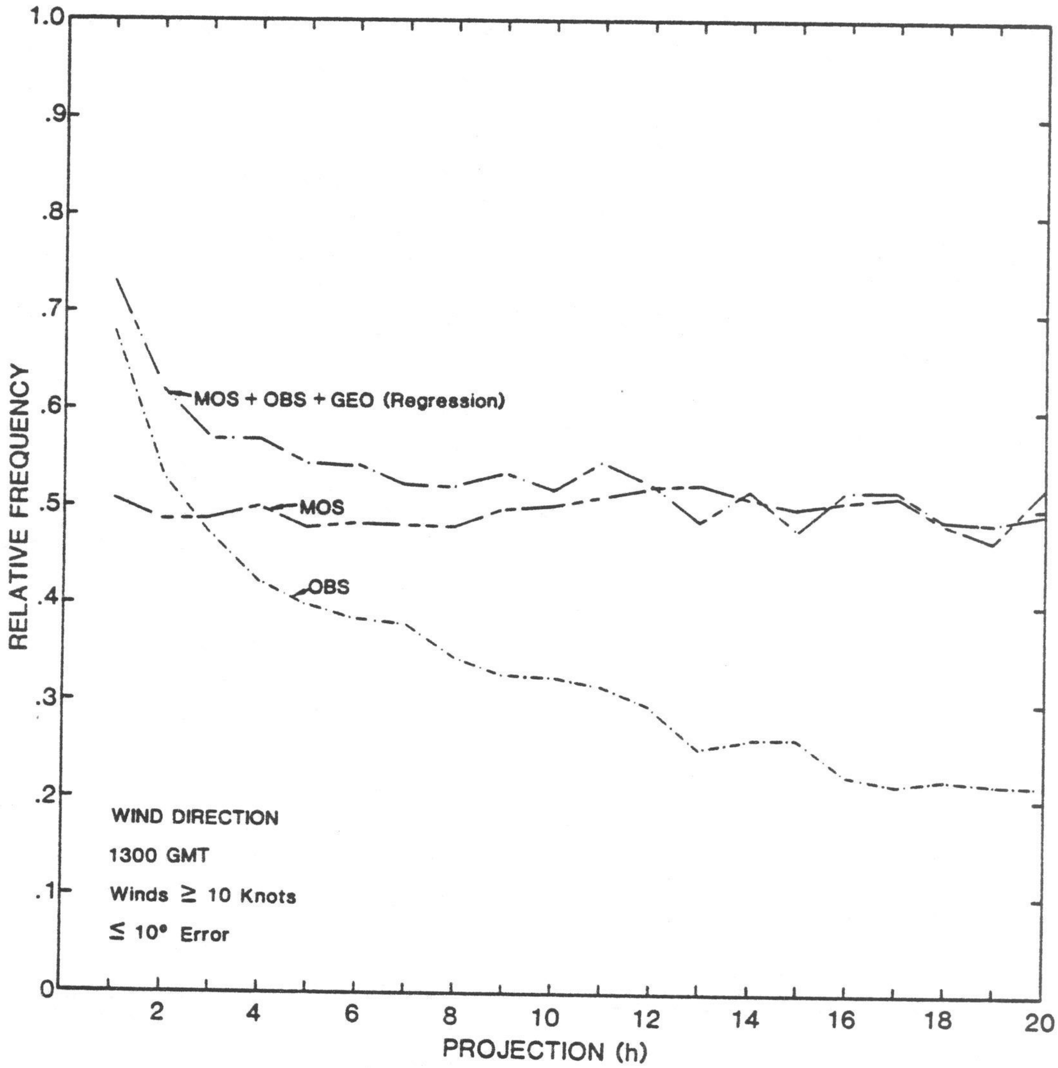

Figure 34. Same as Fig. 33 except for the 1300 GMT start time.

J. Speed Forecast Bias

Figs. 35 and 36 show the biases of the speed forecasts made from the final LAMP equations (based on observations, geostrophic winds, and MOS) for category 1 (≤7 kt) and for categories 5, 6, and 7 combined (≥23 kt). It can be seen that category 1, which contains 40% to 65% of the sample depending on projection, is quite reliable, the number of forecasts always being within a few percent of the observations. The biases for categories 2 and 3 (not shown) are also quite good, usually being between .90 and 1.10.

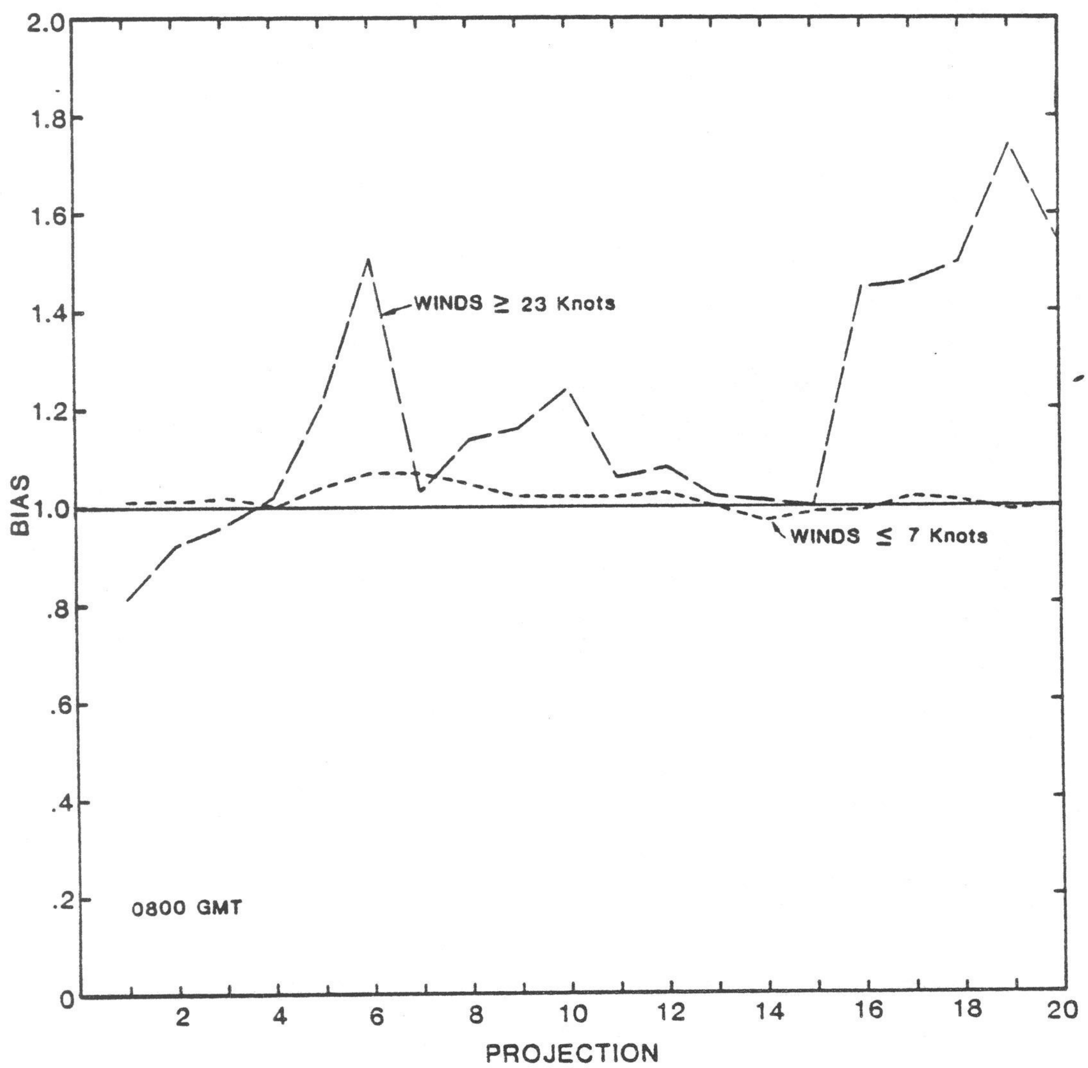

Figure 35. Biases for speed category 1 (≤7 kt) and categories 5, 6, and 7 combined (≥23 kt) for the final LAMP equations from the 0800 GMT start time.

Since there were only about 50 to 200 cases in categories 5, 6, and 7 combined, the biases for forecasts ≥23 kt show more variability. Generally, there is some overforecasting of the higher wind speeds, the bias being above 1.4 for several projections. This is perhaps higher than one would like; however, some overforecasting of the high, more important wind speeds is probably desirable.

Generally, when a speed forecast fell in one of the upper categories, the observation was of a category one or two below that forecast. A typical forecast-observed contingency table is shown in Appendix II.

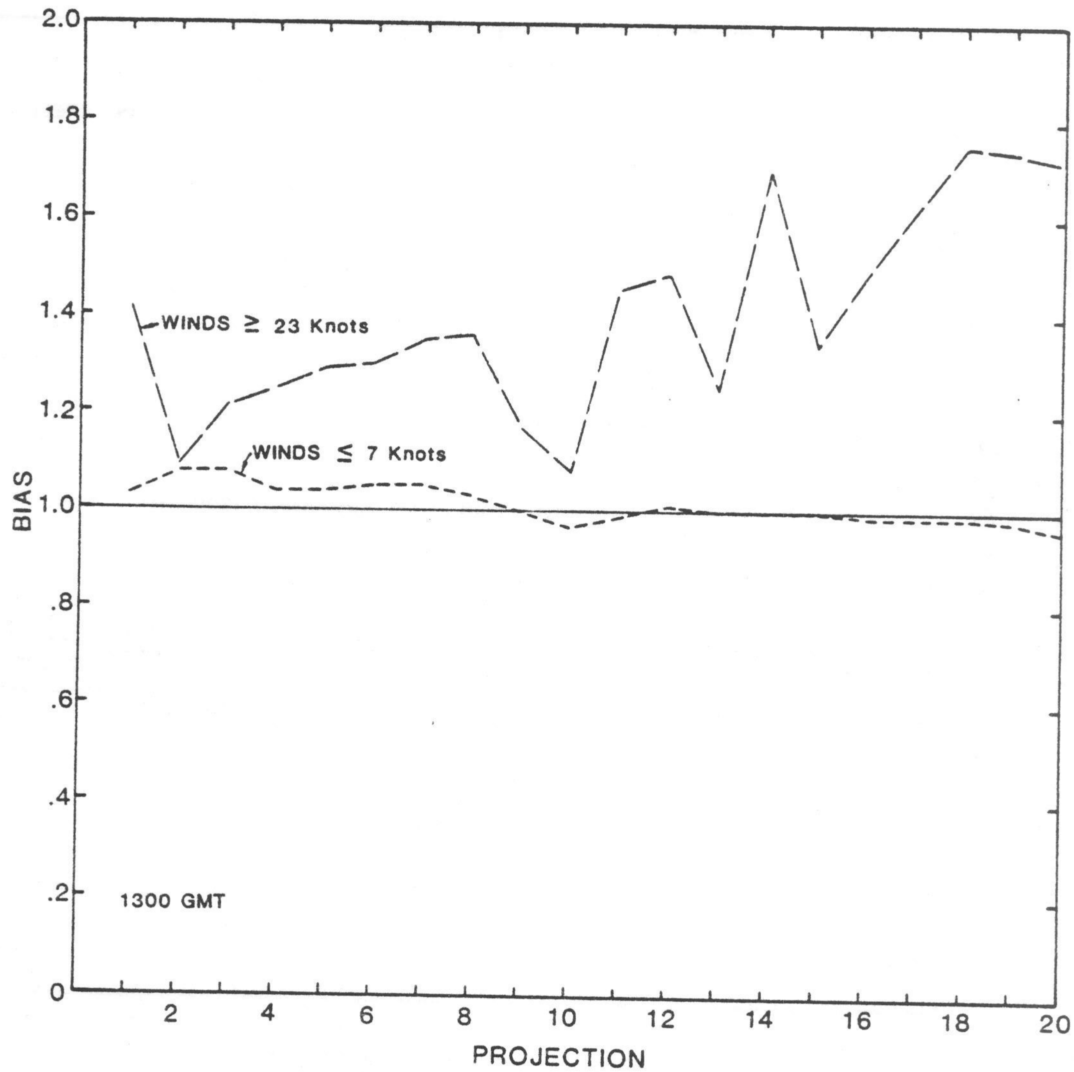

Figure 36. Same as Fig. 35 except for the 1300 GMT start time.

K. Dependence on Initial Data Time

Wind Speed

Fig. 37 shows the relationships of the current MOS guidance to LAMP forecasts from initial times of 0800 and 1300 GMT. (All of these curves appear in previous figures. The MOS scores are the same regardless of LAMP start time, except for slight differences in sample size; the scores for 0800 GMT are shown here.) The "new" forecasts from 1300 GMT are better than those from 0800 GMT for all projections, although the 1-h skill level at 1300 GMT is below that at 0800 GMT, and the skill deteriorates more rapidly at 1300 GMT.

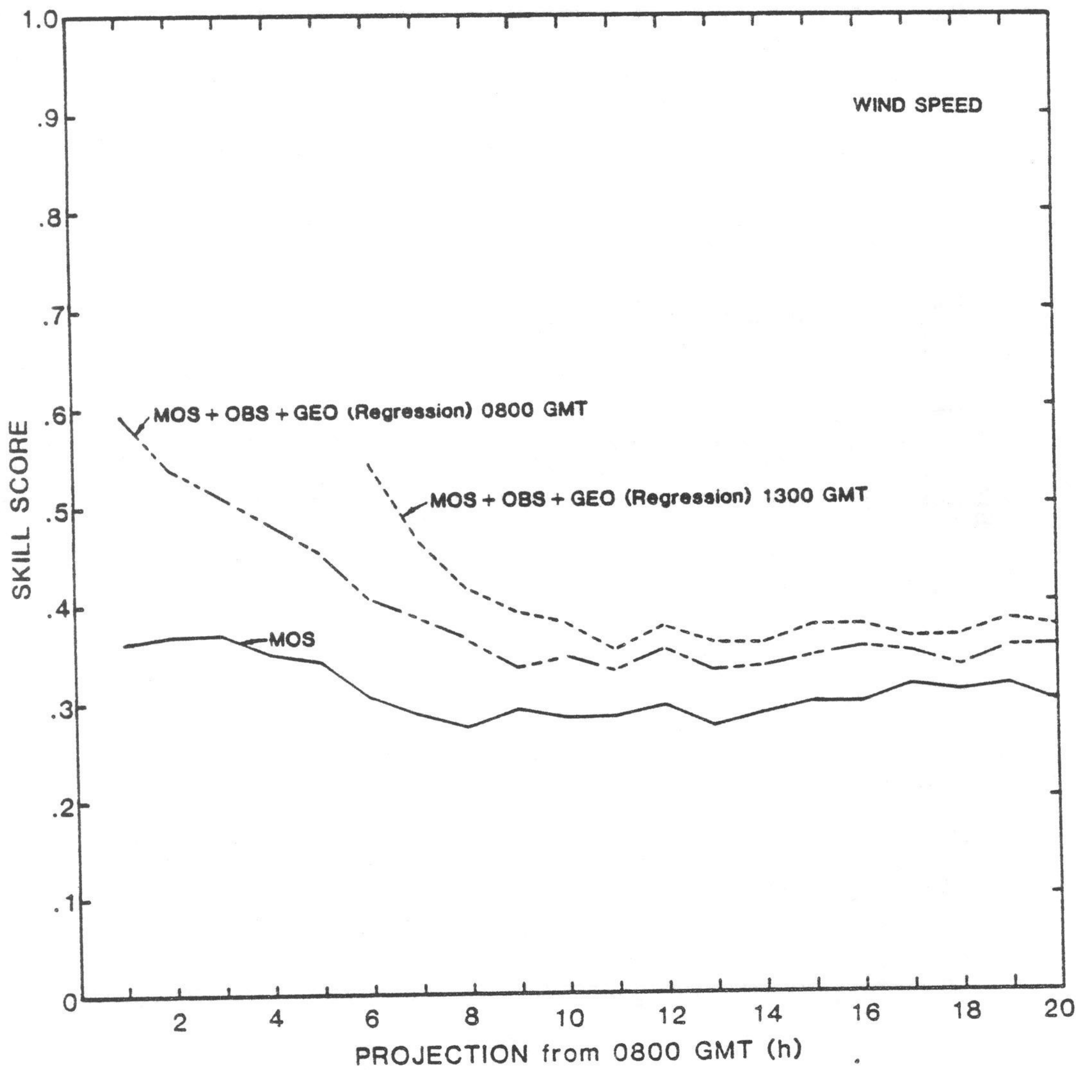

Figure 37. Skill scores for MOS and for LAMP forecasts based on MOS, initial observations, and geostrophic winds computed from the SLP model for start times of 0800 and 1300 GMT. A 6-h projection forecast from 0800 GMT verifies at the same time as a 1-h projection forecast from 1300 GMT, etc.

Wind Direction

Fig. 38 is similar to Fig. 37 except it is for wind direction. The same conclusions reached for wind speed also apply to wind direction, except that by 2100 GMT (a 13-h forecast from 0800 GMT and an 8-h forecast from 1300 GMT) the forecast accuracy from the later start time is no better than that from the early start time.

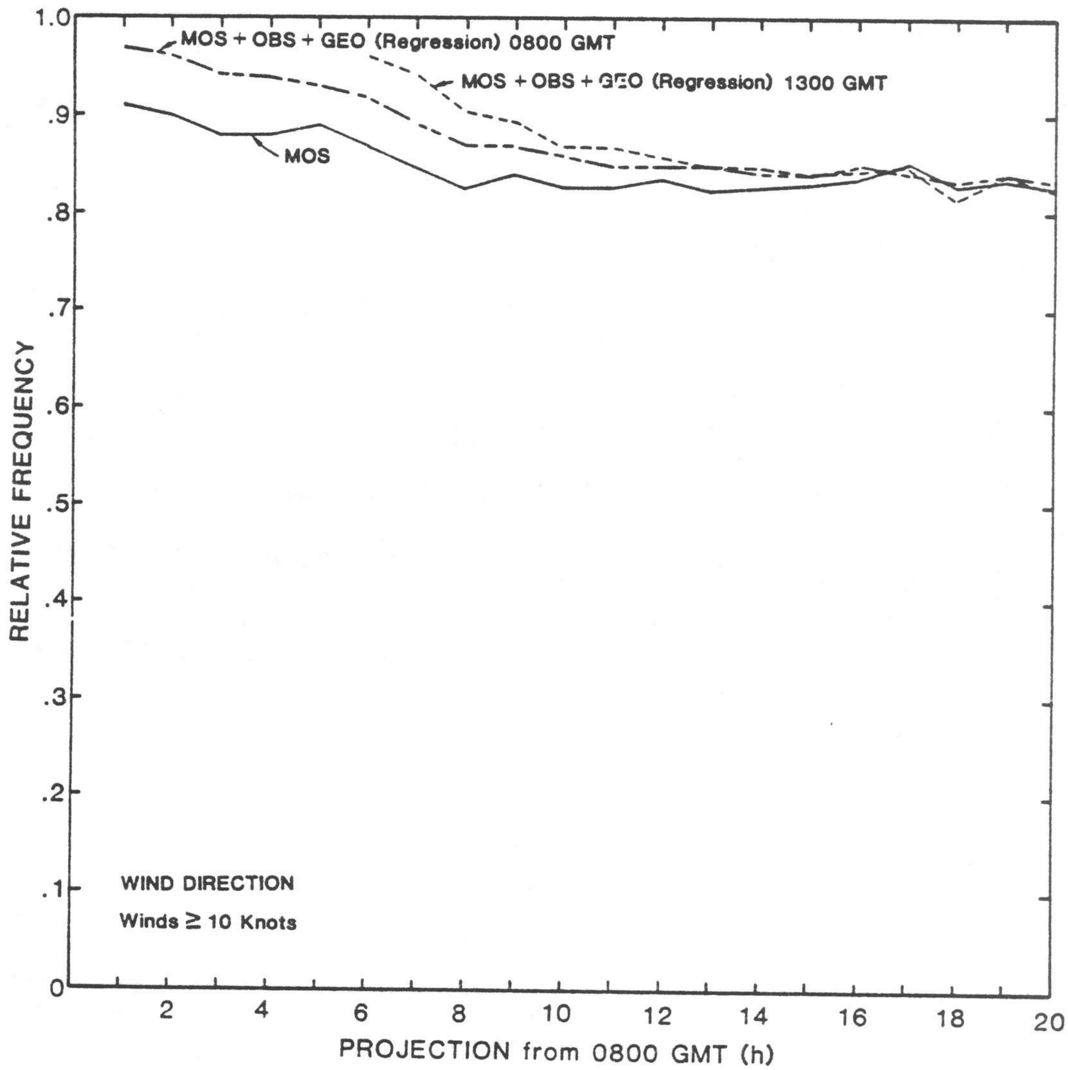

Figure 38. Relative frequency of wind direction forecasts correct to within 30° for observed winds ≥10 kt for MOS and for LAMP forecasts based on MOS, initial observations, and geostrophic winds computed from the SLP model for start times of 0800 and 1300 GMT.

L. Backup Equations Without Observations

Wind Speed

Figure 39 compares regression estimates from LAMP equations having either observations or analyzed winds as predictors together with MOS and geostrophic winds (each equation has 9 terms). At 0800 GMT, there is some loss of skill for projections of 1 to 5 hours for the forecasts based on analyses rather than observations; after that time, the two inputs furnish nearly identical results. At 1300 GMT, there is little difference at any projection, observations being slightly better at 1 hour and analyses being slightly better at hours 3 and 4.

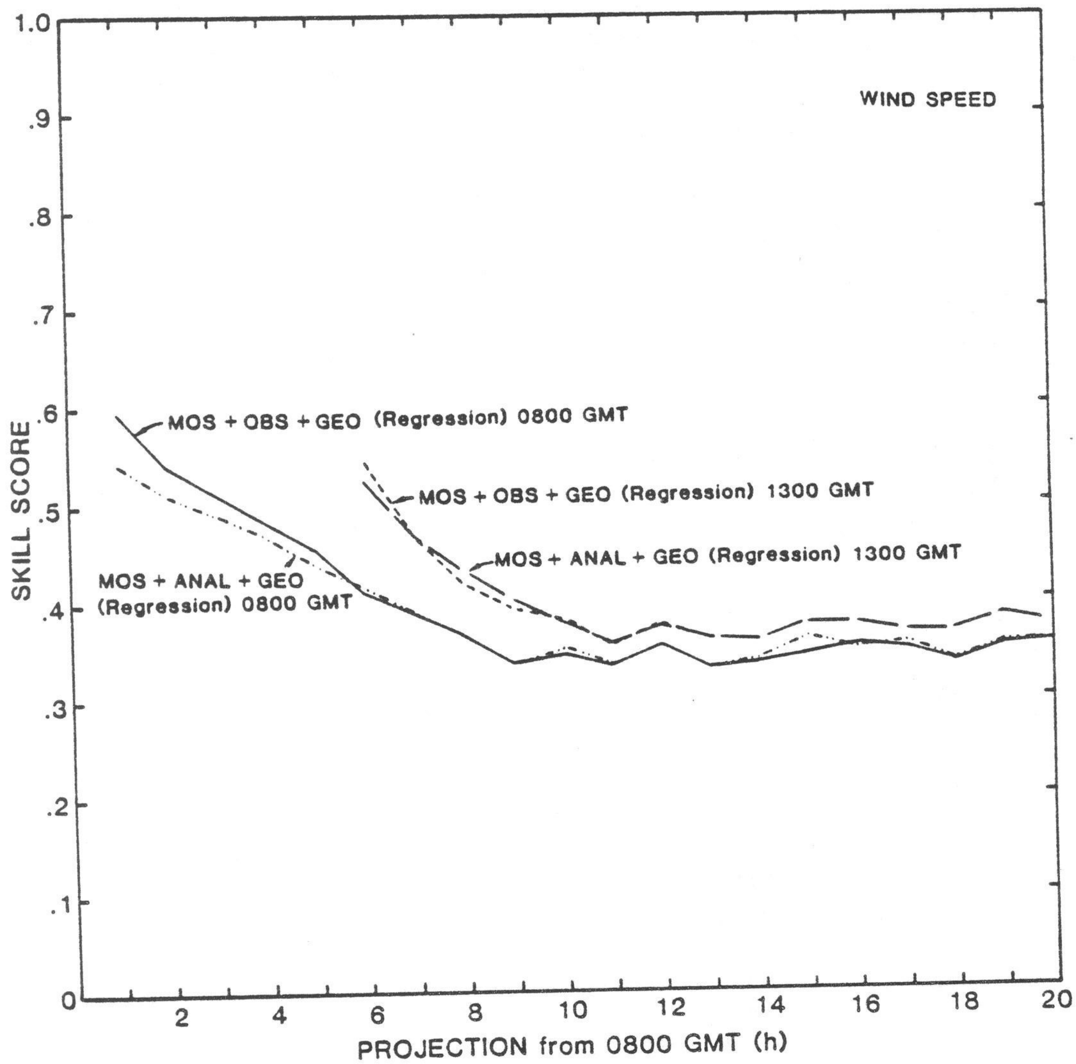

Figure 39. Skill scores for LAMP forecasts based on MOS and geostrophic winds and either initial observations or analyzed winds for start times of 0800 GMT and 1300 GMT. A 6-h projection forecast from 0800 GMT verifies at the same time as a 1-h projection from 1300 GMT, etc.

Wind Direction

Fig. 40 is similar to Fig. 39 except it is for wind direction. At 0800 GMT, there is a slight advantage for the observation for early projections; for later projections and for 1300 GMT, the type of initial wind input is not important.

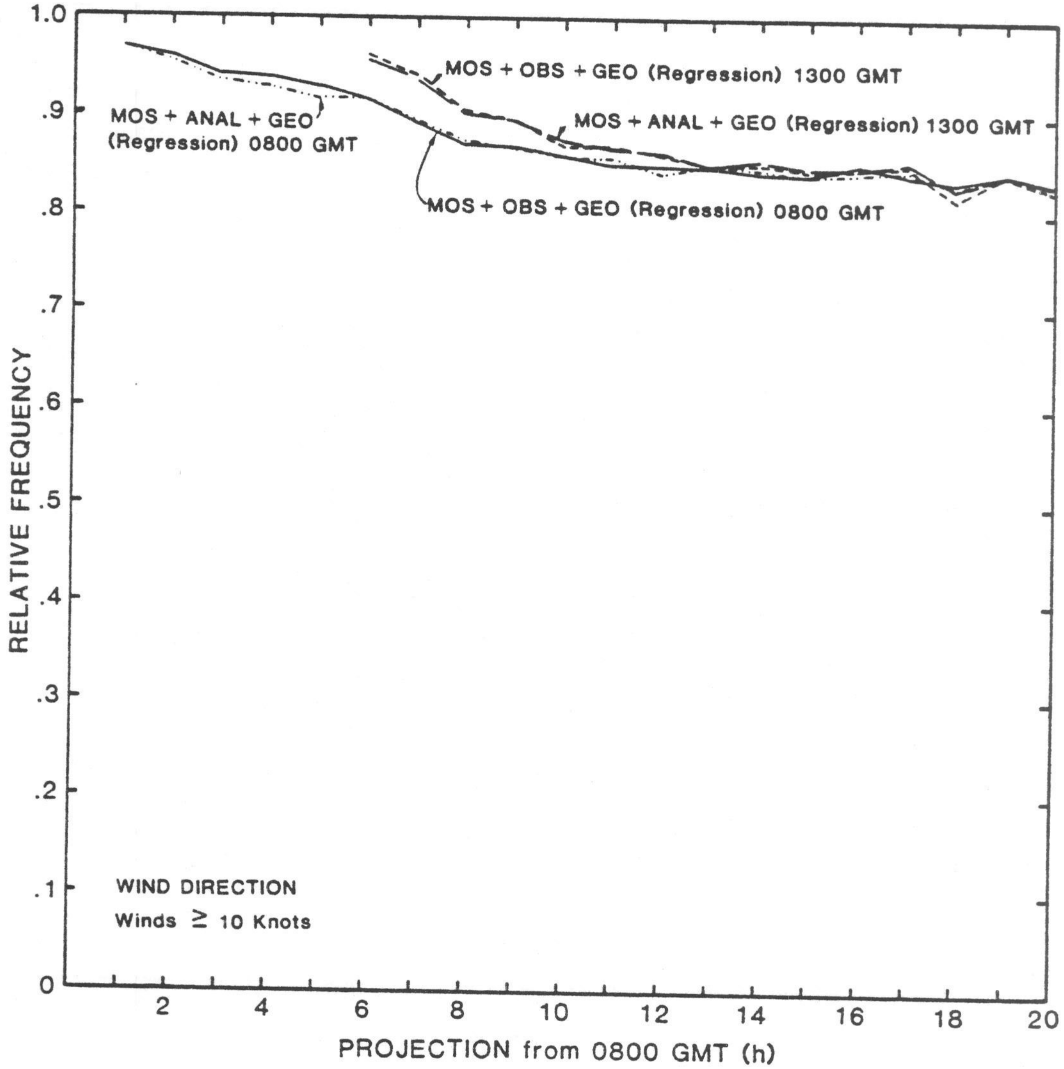

Figure 40. Relative frequency of wind direction forecasts correct to within 30° for observed winds ≥10 kt for LAMP forecasts based on MOS and geostrophic winds and either initial observations or analyzed winds as input for start times of 0800 GMT and 1300 GMT.

M. Cold Front Cases

Thirteen cases were identified in the 1-yr independent data sample when a cold front passed through the Washington D.C. area sometime during the forecast period. Verification of the forecasts for these cases is discussed below.

<u>Wind Speed</u>

Figs. 41 and 42 compare MOS and persistence with regression estimates based on MOS and observations and on MOS, observations, and geostrophic winds. All scores are considerably lower for these cold front cases than scores shown previously for all cases. The general minimum of skill at about 0000 GMT (11-h forecast from 1300 GMT) is due to imperfect timing of speed changes as

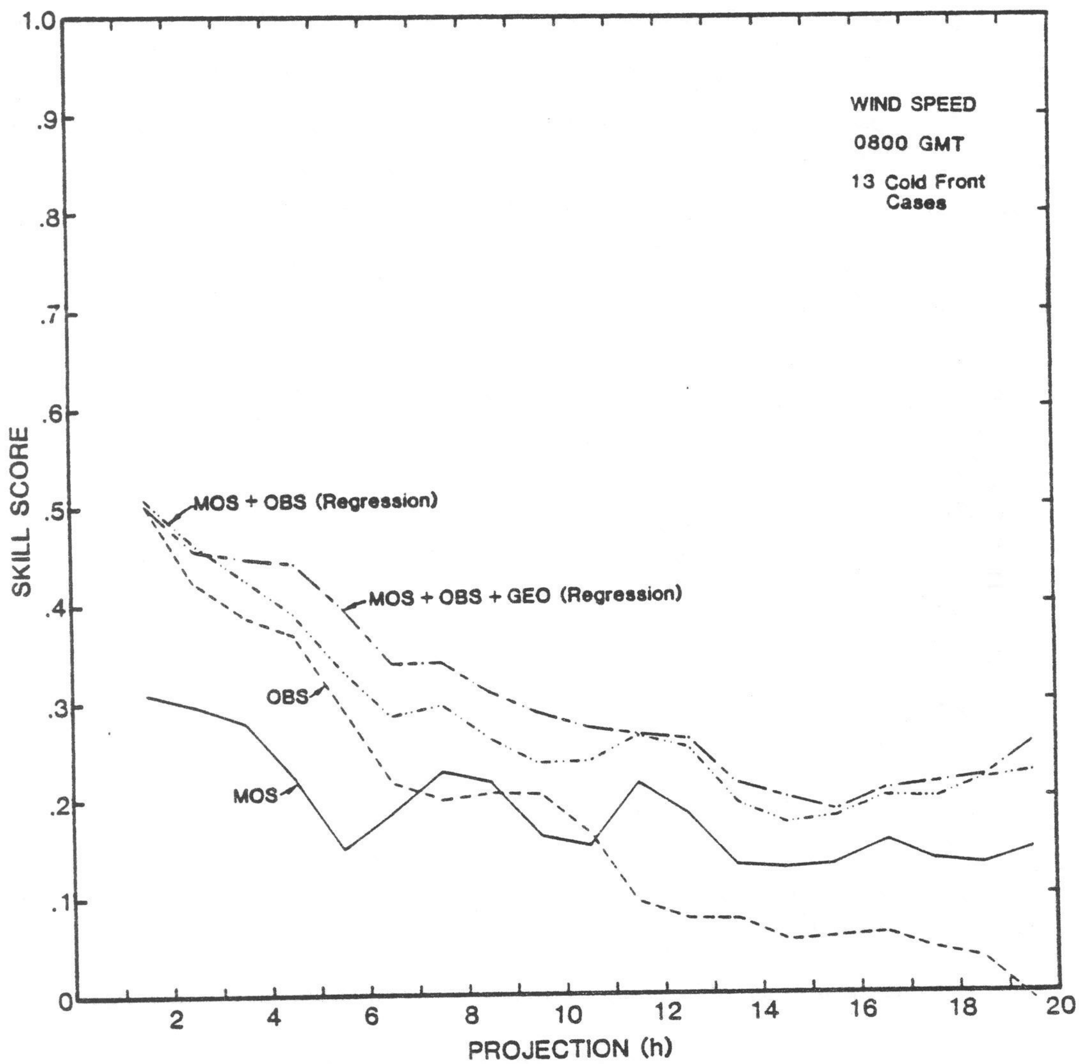

Figure 41. Skill scores for 13 cold front cases for MOS, persistence, and LAMP regression forecasts for the 0800 GMT start time. Scores have been smoothed by plotting the average of scores at two projections at the midpoint between those projections.

the front moves through. By the end of the forecast period from 1300 GMT, the fronts had passed most stations, and the models, regardless of timing problems, forecast them to be past, so the skill is higher than at lesser projections. The shape of the curves, then, is an artifact of the selection of cases. The curves are also not as smooth as previous ones, because of the fewer cases involved, even though they have been smoothed by plotting the average of two projections at the midpoint. For instance, the average score for a 1- and 2-h forecast is plotted midway between those two projections.

The improvement of regression estimates on MOS is somewhat more for the cold front cases than for the full season, and for many projections the geostrophic winds contribute substantially to MOS plus observations.

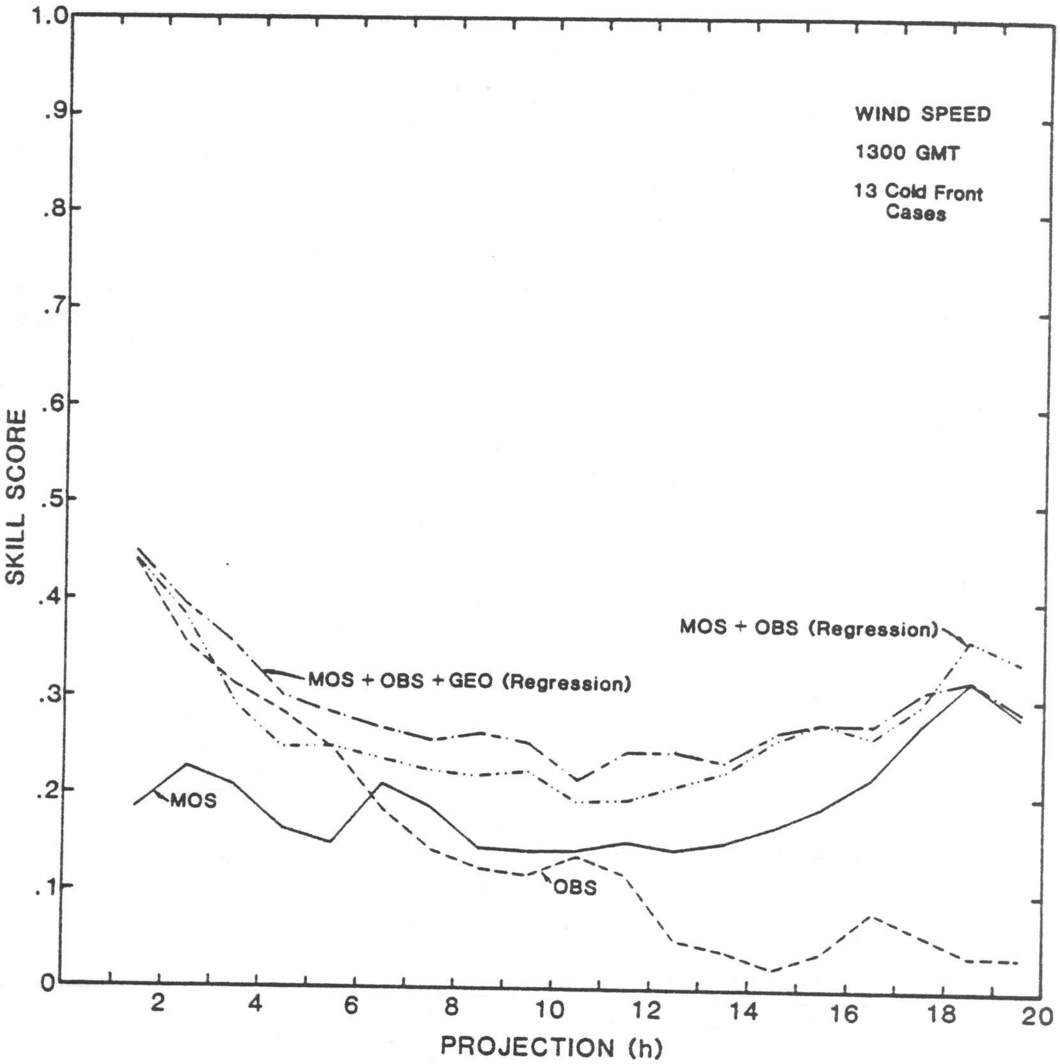

Figure 42. Same as Fig. 41 except for the 1300 GMT start time.

Wind Direction

Figs. 43 and 44 are similar to Figs. 41 and 42 except they are for wind direction. These results are somewhat surprising in that MOS alone is better than LAMP for some projections. Evidently, for these cases in which wind

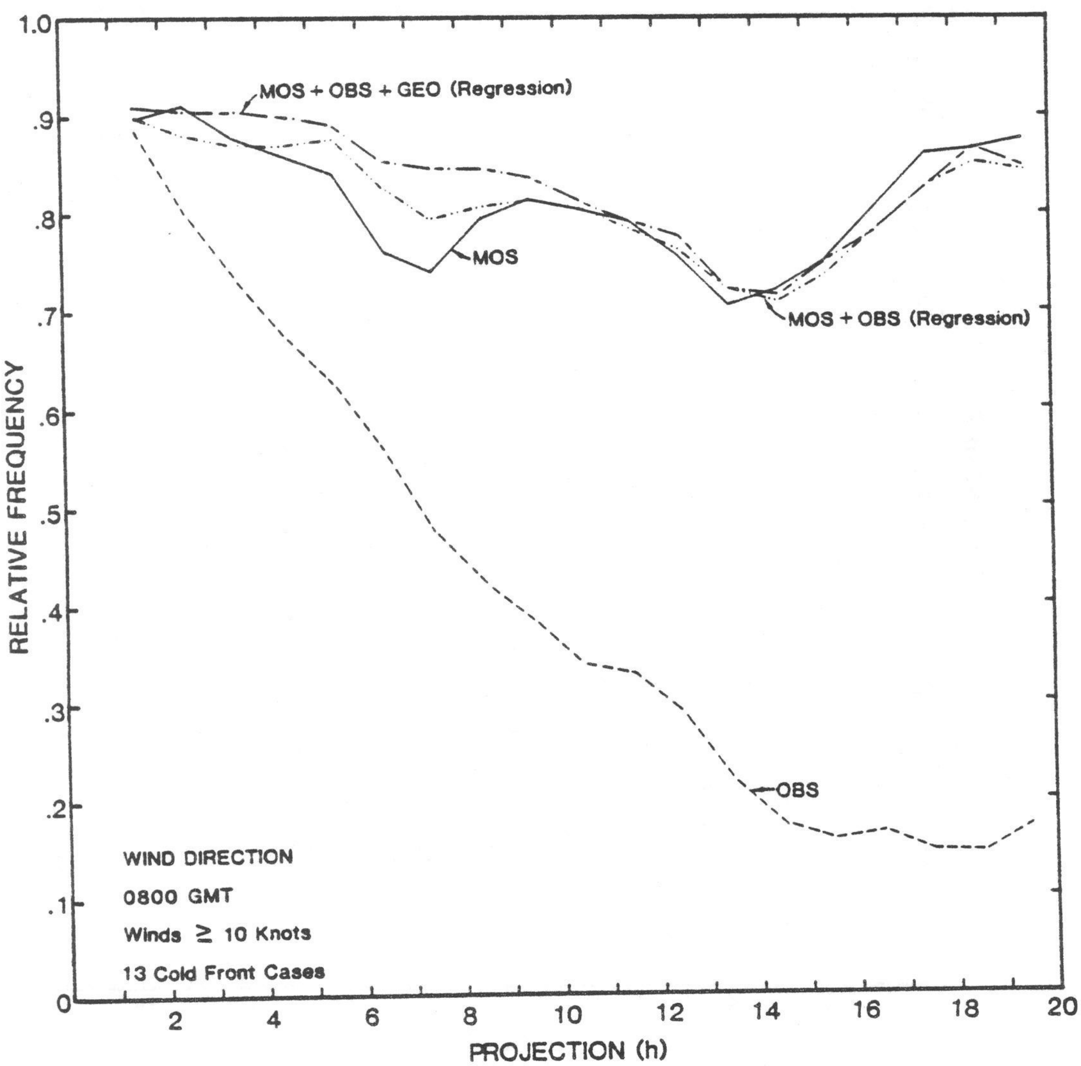

Figure 43. Relative frequency of wind direction for 13 cold front cases correct to within 30° for observed winds ≥10 kt for MOS, persistence, and LAMP regression forecasts for the 0800 GMT start time.

direction may change radically, the use of the recent observation degrades the forecasts for projections after which the wind has shifted. This argues for not using the observation for the longer projections, but rather only MOS and the geostrophic winds in the LAMP equations.

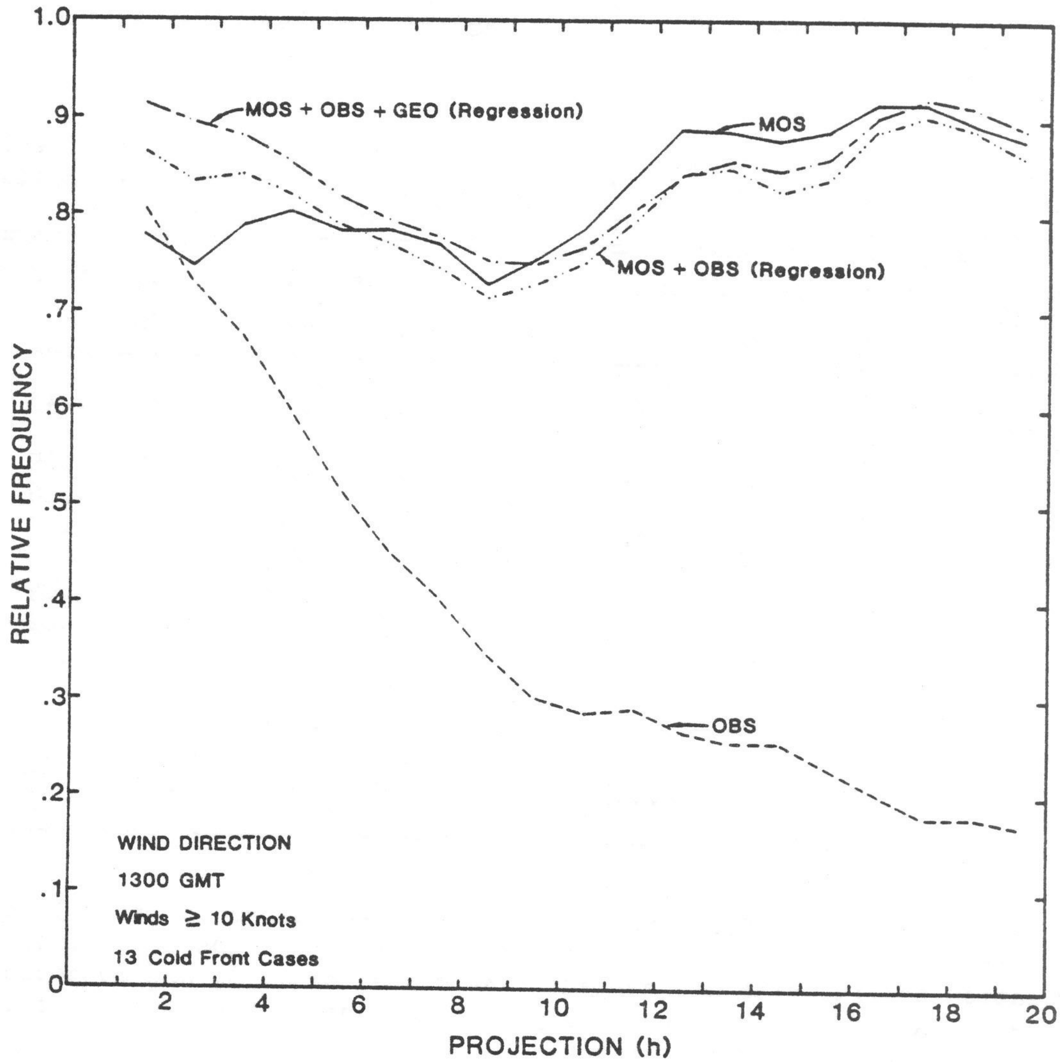

Figure 44. Same as Fig. 43 except for the 1300 GMT start time.

N. Sample Equations

Regression equations for 1-, 6-, and 20-h projections having as predictors the U, V, and S from the initial observation (0800 GMT), the geostrophic winds from the sea level pressure model, and the MOS guidance are shown in Table 3. Although one must be careful in drawing conclusions from individual regression coefficients, the following can be noted:

- For the observation and MOS predictors, the U predictors are generally most important in the U equation, the V predictors in the V equation, and the S predictors in the S equation. This relationship does not hold for the geostrophic wind, partly because of the mean difference in direction between it and the surface wind.

- the control by the observation at 1 hour and by MOS at 20 hours can be clearly seen. Although the coefficients are not large, the contribution of the geostrophic wind is larger at 6 hours than at 1 hour or 20 hours.

Table 3. Nine-term regression equations from the 0800 GMT start time for 1-, 6-, and 20-h projections. Predictors are U, V, and S from the initial observation (OB), the geostrophic wind (GEO), and MOS guidance.

Constant/ Predictors		U- Wind Equation			V- Wind Equation			Speed Equation		
		1-h	6-h	20-h	1-h	6-h	20-h	1-h	6-h	20-h
Constant		.42	-.56	.35	-.26	-1.01	.13	.69	3.43	2.32
OB	U	.56	.25	.01	-.12	-.07	.03	.02	.05	.05
	V	.02	.02	-.02	.70	.22	.01	.02	.06	.07
	S	.06	-.07	.01	.03	.05	-.08	.70	.12	.05
GEO	U	.08	.10	-.01	.24	.32	.13	-.06	-.09	-.05
	V	-.12	-.11	-.05	.00	.10	.02	.02	-.02	-.01
	S	-.03	.05	.02	.06	-.15	-.01	.09	.16	.06
MOS	U	.15	.54	.93	-.12	-.12	-.18	.08	.17	.03
	V	.02	-.02	.07	.04	.54	.93	-.02	-.10	.05
	S	-.02	.02	-.00	-.11	.19	.07	.07	.27	.61

The constants and coefficients for the speed equations in Table 3 produce uninflated forecasts. To inflate the forecasts, the means and multiple correlation coefficients are needed. The means for 1, 6, and 20 hours are 8.13, 9.16, and 8.31 kt, respectively; the relevant correlation coefficients are .86, .73, and .66, respectively.

O. Sample Predictions

Fig. 45 shows MOS and LAMP forecasts for each of the 20 projections and the initial and verifying observations for Washington, D.C. for the 0800 GMT start time on December 8, 1981. The wind shifted from light southerly to stronger northwesterly between hours five and six. MOS direction was considerably in error until about hour six, the LAMP winds being somewhat better in that regard. Both LAMP and MOS forecasts were good after hour seven or eight. The gradual shift in direction of LAMP forecasts is the best that can be expected, rather than a rapid shift, because of the 95-km grid spacing used with the sea level pressure model. A smaller grid length and little or no smoothing would allow a more rapid shift, although the skill and accuracy of the forecasts in terms of the scores computed in this paper might actually decrease slightly.

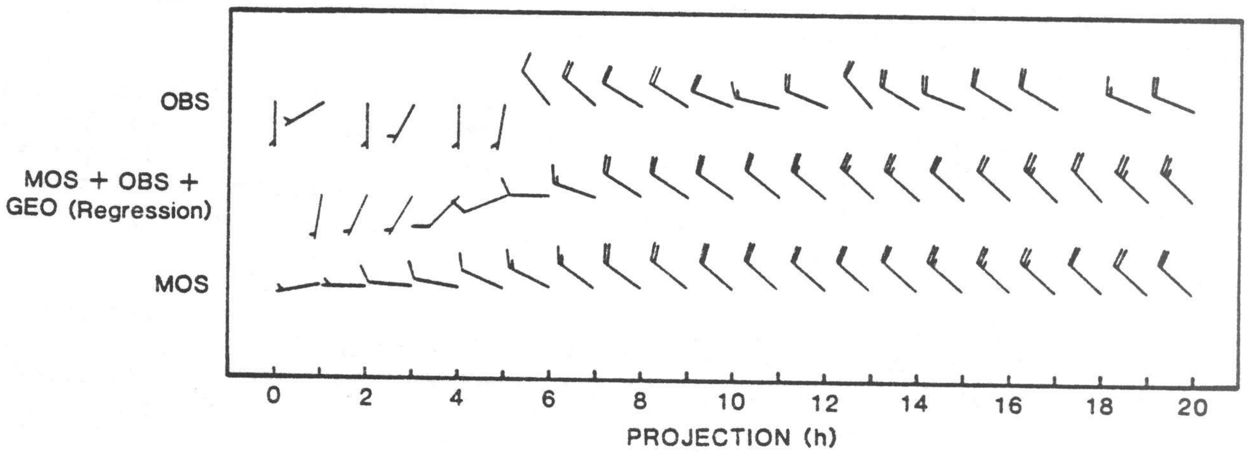

Figure 45. MOS forecasts; LAMP forecasts based on MOS, initial observations, and geostrophic winds; and initial and verifying observations for Washington, D.C. for start time of 0800 GMT on December 8, 1981. Conventional plotting model is used; full wind barb is 10 kt.

6. SUMMARY AND CONCLUSIONS

Guidance forecasts are needed at the local forecast offices on an on-call basis 24 hours a day, not just twice a day as currently available. Also, local forecasts must be made for two or three times the number of locations for which MOS guidance is provided. A system such as LAMP could provide forecasts at any hour for most locations for which forecasts are needed for projections of 1 to about 20 hours.

This report presents results of testing an experimental wind forecasting system for 32 stations in the Washington, D.C. WSFO area. The major conclusions are:

- o Persistence and regression estimates based on the initial wind observation give better forecasts than MOS guidance for projections up to 6 hours from 0800 and up to 3 hours from 1300 GMT for speed and for 1 or 2 hours for direction; thereafter, MOS is equal to or better than these simple controls.

- o LAMP forecasts with initial observations, MOS, and geostrophic winds as predictors are better than persistence at all hours, although the improvement is not great at 1 hour. For speed, they are better than MOS at all projections and better than regression based on MOS alone out to 9 hours from 0800 GMT and out to 16 hours from 1300 GMT. For direction, they are better than MOS and regression based on MOS alone out to 16 hours from 0800 GMT and to 11 hours from 1300 GMT. Much of the improvement in speed afforded by regression with MOS predictors (with or without other predictors) is due to non-MOS stations; the improvement of LAMP over MOS is not as great at MOS stations as at non-MOS stations, and, hence, for the 32 stations combined. However, the LAMP speed forecasts based on 9-term equations are better than MOS at MOS stations out to at least 16 hours from both start times (graphs not shown).

- o LAMP forecasts with initial observations, MOS, and geostrophic winds as predictors provide speed skill scores ranging from .60 to .35 from 0800 GMT for projections of 1 to 20 hours, respectively. The percent of the directions being within 30° (10°) of the observed direction range from 97 (80) to 83 (50) from 0800 GMT and from 96 (73) to 83 (50) from 1300 GMT.

- o LAMP forecasts from 1300 GMT are generally better at specific verifying times than forecasts from 0800 GMT, although by 2100 GMT (a 13-h forecast from 0800 GMT and an 8-h forecast from 1300 GMT) the direction accuracy from the later start time is no better than that from the early start time.

- o A backup system using analyzed winds as input rather than the initial observations, along with geostrophic winds and MOS, is quite good. Some loss of skill is noted for the early projections from 0800 GMT.

- o For cold front cases, LAMP improves on observations and MOS by greater amounts than for all cases together for wind speed. However, MOS alone is actually better than LAMP for later projections (after the front has passed), indicating use of the recent observation is detrimental in these specific cases.

- o LAMP wind direction forecasts will probably not change rapidly (within 1 hour) with a cold frontal passage, but rather require 3 to 5 hours. Computation of geostrophic winds from a model with a smaller grid spacing than the 95 km used in LAMP would be required for a more rapid forecast shift.

ACKNOWLEDGEMENTS

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APPENDIX I

Stations Used in the Study

Forty-six stations in TDL's hourly data archive in and around the WBC WSFO area of responsibility, the 32 that had sufficient observations at each hour of the day to furnish meaningful results, and of those 32 the ones that have MOS guidance are shown in Table 4. Fig. 46 shows locations of MOS and non-MOS stations.

Table 4. Forty-six stations in and around the WBC WSFO area. The 32 stations used in this study, and of that subset the 15 stations having MOS guidance, are indicated.

Call Letters	WBAN No.	Station Name	Used in This Study	MOS Station
ACY	93730	Atlantic City, N.J.	X	X
ADW	13705	Andrews AFB, Md.	X	
AOO	14736	Altoona, Pa.	X	
BWI	93721	Baltimore, Md.	X	X
BKW	3872	Beckley, W. Va.	X	X
BLF	3859	Bluefield, W. Va.	X	
CHO	93736	Charlottesville, Va.	X	
CKB	3802	Clarksburg, W. Va.	X	
CRW	13866	Charleston, W. Va.	X	X
CXY	14751	Harrisburg, Pa.	X	X
DAA	93728	Fort Belvoir, Va.	X	
DAN	13728	Danville, Va.		
DCA	13743	Washington, D.C.	X	X
DOV	13707	Dover AFB, Del.	X	
EKN	13729	Elkins, W. Va.		
FAF	93735	Fort Eustis, Va.		
FME	93733	Fort Meade, Md.		
GSO	13723	Greensboro, N.C.	X	X
HGR	93706	Hagerstown, Md.		
HSP	93757	Hot Springs, Va.		
IAD	93738	Dulles Airport, Va.	X	X
ILG	13781	Wilmington, Del.	X	X
JST	4726	Johnstown, Pa.		
LBE	54735	Latrobe, Pa.		
LFI	13702	Langley AFB, Va.	X	
LWB	53801	Lewisburg, W. Va.		
LYH	13733	Lynchburg, Va.		
MDT	14711	Middletown, Pa.	X	
MGW	13736	Morgantown, W. Va.	X	
MIV	13735	Millville, N.J.	X	
MRB	13734	Martinsburg, W. Va.	X	
MTN	93744	Martin Airport, Md.		
NGU	13750	Norfolk NAS, Va.	X	
NHK	13721	Patuxent River NAS, Md.	X	
NTU	13769	Oceana NAS, Va.	X	
NYG	13773	Quantico MCAS, Va.		
ORF	13737	Norfolk, Va.	X	X
PHF	93741	Newport News, Va.	X	
PHL	13739	Philadelphia, Pa.	X	X
RDU	13722	Raleigh-Durham, N.C.	X	X
RIC	13740	Richmond, Va.	X	X
ROA	13741	Roanoke, Va.	X	X
SBY	93720	Salisbury, Md.	X	
SHD	93760	Staunton, Va.		
TRI	13877	Bristol, Tenn.	X	X
WAL	93739	Wallops Island, Va.		

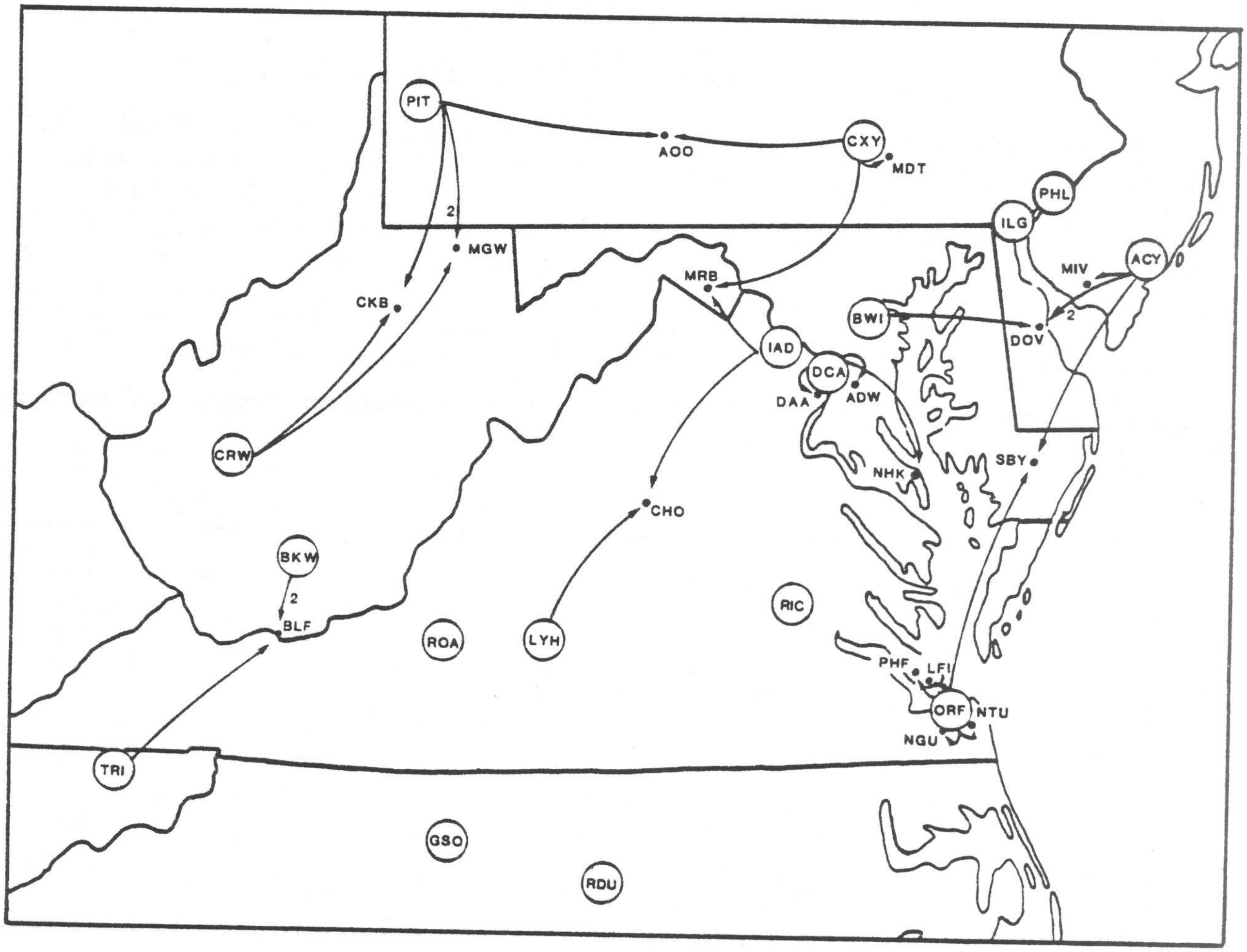

Figure 46. Seventeen MOS stations (call letters in circles) and 17 non-MOS stations (see Table 4 for call letter definitions). All 34 stations shown were used in this study except the MOS stations Pittsburgh (PIT) and Lynchburg (LYH). Each non-MOS station has one or two arrows pointing to it. If there is a single arrow, MOS forecasts at that station were obtained by using the MOS forecasts from the station as indicated by the arrow. If there are two arrows, an average (weighted average if a number appears beside the arrow) MOS forecast was obtained as indicated. The averages were taken for the U- and V-components and for speed.

APPENDIX II

Sample Forecast-Observed Contingency Table

The forecast-observed contingency table for forecasts from the final LAMP equations (those based on MOS, initial observations, and geostrophic winds) from the 1300 GMT start time for the 6-h projection is shown in Table 5. Biases by category are also shown. The skill score associated with this table is .35.

Table 5. Forecast-observed contingency table for 6-h forecasts from the final LAMP equations for the 1300 GMT start time. Biases by category are also shown.

Observed Category	Forecast Category (kt)							Total
	≤7	8-12	13-17	18-22	23-27	28-32	≥33	
≤7	1267	506	38	1	0	0	0	1812
8-12	595	1052	321	36	2	0	0	2006
13-17	34	283	355	109	9	0	0	790
18-22	0	7	85	69	18	2	0	181
23-27	0	0	4	7	4	2	0	17
28-32	1	0	0	0	1	0	0	2
≥33	0	0	0	0	0	0	0	0
Total	1897	1848	803	222	34	4	0	4808
Bias by Category	1.05	.92	1.02	1.23	2.00	2.00	--	

(Continued from inside front cover)

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