A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

NOAA Technical Memorandum NWS NMC-51

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Updating Asynoptic Data for Use in Objective Analyses

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WASHINGTON, D.C.
October 1972

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UPDATING ASYNOPTIC DATA FOR USE IN OBJECTIVE ANALYSES

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WASHINGTON, D. C.
October 1972

UDC 551.509.313:551.501.7

551.5	Meteorology
.501	Methods of observation and computation
.7	Methods of computation of radiosonde data
.509	Synoptic analysis and forecasting
.313	Numerical forecasting methods

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UPDATING ASYNOPTIC DATA FOR USE
IN OBJECTIVE ANALYSES

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ABSTRACT. Case studies are used to evaluate methods for updating asynoptic meteorological observations to a synoptic time for possible use in NMC operational objective analyses. Selected radiosonde height and temperature data from the data-rich area over the United States are updated for 12-hour periods with tendency and advective methods. Persistence of 12-hour old observations is also considered. Overall results for eleven cases indicate that the tendency method exhibits smaller root-mean-square errors for the 12-hour updates than those obtained by advective methods or persistence as verified against NMC operational analyses. The importance of providing good analyses to specify the initial conditions for numerical integrations of the equations of motion is discussed in light of the dependence placed upon the forecast fields to provide first guesses for subsequent analyses. Gravitational oscillations are observed in the primitive equation 500-mb forecast height fields and are discussed as they might relate to improper short-period height updates with the tendency method. The accuracy of any update procedure is solely dependent on the accuracy of the forecasts used to correct the asynoptic reports.

INTRODUCTION

Most objective analysis schemes are designed to provide a best fit of meteorological data from irregularly distributed positions in space for a specified synoptic time. The best fit is then described as an approximation of the true state of the atmosphere for given meteorological parameters. The analyses of parameters such as constant pressure heights, temperatures, and winds, are further used to specify the "approximate" initial conditions of dependent variables in various numerical prediction models.

In the NMC operational environment, analysis-forecast systems are cycled twice daily at 0000 and 1200 GMT. In this system the forecast portion is used to provide appropriate first guesses for subsequent analyses, and accordingly the first guess prevails as the analysis in no data regions.

Although RAWINSONDE observations are generally synoptic, other types of observations may differ from synoptic time by several hours. Over geographical areas where meteorological systems are changing or moving rapidly with time, introduction of off-time observations into the analysis may produce erroneous results. Over tropical areas where changes with time are usually small, introduction of short-period asynoptic data may not seriously affect the analyses, for there the observational errors are probably about the same magnitude as short-period atmospheric oscillations. In the absence of synoptic data in the tropics, data as much as 12 hours off-time are used in the analyses; these may be the only source of information on the state of the atmosphere.

Considering the enormous amount of asynoptic aircraft reports and meteorological satellite soundings available, it is important to utilize these data properly in the operational objective analysis scheme. The ideal method for using asynoptic data would probably involve a sophisticated four-dimensional data assimilation procedure. However, for this study three relatively simple procedures for updating asynoptic reports were investigated: an advective method, a tendency method, and persistence. Radiosonde reports for eleven synoptic cases (table 1) from the data-rich area of the United States (figure 1) were updated for 12-hour periods and then verified against appropriate NMC operational analyses.

2. ADVECTIVE METHOD

The locations of selected radiosonde reports were moved downstream for a 12-hour displacement using the 500-mb space-mean flow obtained from the time-average of initial and 12-hour 500-mb forecast stream function fields. The radiosonde data were not altered, but were merely repositioned by the mean flow. This procedure is similar to the space-mean method used by Fjortoft (1955) and implies that the atmosphere is barotropic and that systems move without change in the space-mean flow. The interval used for space averaging was 600 km; only those radiosonde reports which passed the hydrostatic check were considered for updating. A time-step of 1 hour was used in relocating the radiosonde positions for the 12-hour updates.

Using the operational guess fields and only the 12-hour updated reports from the area shown in figure 1, the analyses were reaccomplished for the case verifying 0000 GMT April 11, 1970, and then were compared to the operational analyses in which all available synoptic data for that time were used. Examples of the 500-mb space-mean 12-hour displacement of selected radiosonde positions are shown in figure 2a. Figure 2b shows the reanalyzed 500-mb heights derived from the 12-hour updates for this case, and the graphical errors between this analysis and the operational 500-mb height analysis (figure 2e). The graphical errors were determined by subtracting the reanalysis from the operational analysis. Over the data-rich area, the largest 12-hour update errors in the reanalyzed 500-mb height field were about 60 meters near Lake Superior and just east of Cape Hatteras; the errors near Vancouver Island and northern Mexico represent those in the first guess (forecast) 500-mb height field, since no updates were available for analysis in those areas. Verifications were also made by comparing radiosonde heights and temperatures at the relocated positions with values extracted by interpolation from the NMC operational analyses. Root-mean-square error (RMSE) and mean error (ME) for the updated heights and temperatures for this case are given in tables 2 and 2a, and average RMSE and ME for all cases are given in tables 3 and 3a.

The first guess fields (McDonell 1967) for the NMC analyses are derived from the 12-hour forecasts of the Cressman (1963) 3-level model, which is run with data analyzed from the FINAL (10+00) data collection. The NMC operational analysis code was allowed to run with no data at the various verification times to recover the guess fields for evaluation. The 12-hour height forecasts from the 3-level model are returned exactly for 500 and 200 mb, while guesses for other levels are obtained by using persistence of mean layer stability, conversion of thickness forecasts to temperatures, and statistical regression equations. The interpolated heights and temperatures from these guess fields were verified against the operational analyses at the relocated radiosonde positions to establish what the errors would have been in the absence of data. As shown in figure 3, the average height errors from the guess fields, GA, are smaller than those obtained by updates from the advective method, UAD, giving some indication of the skill of the forecasts and the validity of the first-guess methods.

In conjunction with this advective method for updating asynoptic data, a different advective flow based on a highly smoothed 500-mb height steering field, described by Hayden (1970), was also evaluated for the same cases. Verifications at the relocated positions against the operational analyses also were made and the results, UAH, are shown in figures 3 and 4 for the height and temperature updates. Although the advective flows were different, the respective errors at 850, 500, and 200 mb are similar.

3. TENDENCY METHOD

Integrations of the equations of motion cannot produce accurate forecasts if the initial conditions are not correctly specified. Numerical weather prediction methods utilize synoptic analyses as information relating to an "approximate" specification to desired initial conditions. Over data-rich areas, these "approximate" initial conditions are usually sufficient to capture most large-scale features of meteorological systems, and most short-range numerical forecasts derived from these initial conditions exhibit considerable skill in forecasting the large-scale motions. However, over areas where no meteorological reports are available for processing in analysis schemes, specification of initial conditions is heavily dependent on appropriate guesses from recent forecasts, climatological data, or a combination thereof. Ideal conditions, of course, would consist of an observing network over the entire earth sufficiently dense to enable analyses to capture scale features considered necessary for initial condition specification. Realistically, numerical forecasts will continue to be made from initial conditions derived from fullest consideration of timely meteorological observations

If numerical forecast models were capable of specifying correct changes of a meteorological parameter with time, this forecast information could be used to correct, or update, short-period asynoptic data to a desired nominal time by adding the forecast change for the indicated time difference to the observed data. Figure 5 schematically shows a perfect 12-hour forecast, F_{12}, of some meteorological parameter at a fixed point in space whose initial condition is specified by A_o. An off-time observation, 0_6, agrees exactly with the forecast value, F_6, and is to be considered for updating for possible use in the subsequent analysis cycle. Given only the 12-hour forecast, F_{12}, and the initial condition, A_o, the apparent forecast change could be considered linear, and the observation 0_6 could be updated by using the implied linear change. In this case, however, the linear correction would be insufficient for the 6-hour update, but nevertheless in the right direction. On the other hand, if F_6 is available, the forecast change $(F_{12} - F_6)$ could be applied to 0_6 for the 6-hour update, U_6. In such a system, perfect forecasts would permit perfect updates, but if all forecasts were perfect there would be no need to update any asynoptic data. The use of persistence, that is, no change of 0_6 during the subsequent 6-hour period, would produce a large discrepancy. The success of updating an asynoptic observation is dependent on the accuracy of the forecast change, which in turn is dependent on the analyses that provide the initial forecast conditions. It seems reasonable that, as the initial conditions are more closely specified for each forecast cycle, the subsequent forecasts should also improve.

Consider a case (figure 6) which has 12-hour forecasts derived from doubtful initial conditions. As indicated earlier, in the absence of meteorological observations, a guess, G, is usually provided as the initial condition in a no-data area. A numerical forecast model might indicate the 12-hour forecast changes of some meteorological parameter at a fixed position in space, as shown by curve FCST1 in figure 6. An update correction for an off-time observation, 0_t, could be handled as described above. However, for this case let us assume that the guess, G, was definitely poor and that the initial condition should have been A_o; the forecast made from A_o is given by curve FCST2. Although the forecast values of the given meteorological parameter are different for each case, the characteristic changes are somewhat similar. A reliable observation, 0_t, shows that the forecast, F_t, contains an error and indicates that probably insufficient data were available to properly describe the initial conditions in space around the observation A_o. The update correction to be applied to 0_t for time=12 would be based on the forecast change $(F_{a12} - F_t)$ shown by curve FCST2, and the updated value would be U_t. The update of 0_t by the forecast changes given by FCST1 would be U_g. Although U_t and U_g differ, each one provides information that could be useful in the subsequent analysis cycle if additional data are not available.

In an attempt to evaluate the practicality of this update method, forecast height and temperature changes were applied to radiosonde data to provide 12-hour updates for the same cases that were used for the advective method. Again, only those reports which passed the hydrostatic check were updated. The forecast height changes from both the primitive equation (PE) model (Shuman and Hovermale 1968) and Cressman's 3-level model were used for updating height data; forecast temperature changes from the PE model were used for temperature data updates. Twelve-hour tendency updates of radiosonde data from the area shown in figure 1, for the case verifying 0000 GMT April 11, 1970, were introduced as the only source of data in the analysis code to provide a comparison with the operational analyses based on numerous synoptic observations. The resulting 500-mb height analysis together with graphical difference errors are shown in figure 2c. The 500-mb height errors for the tendency updates for this case are generally smaller than those derived from the advective method reanalysis (figure 2b). Verifications of all cases were made at the radiosonde positions by comparing the tendency method update values with values interpolated from the NMC operational analyses. The average RMSE at 850, 500, and 200 mb for 12-hour height and temperature updates for all cases are shown in figures 3 and 4; average RMSE and ME for other pressure levels are given in tables 3 and 3a.

It should be noted in figure 3 that the 12-hour height updates which used the Cressman 3-level filtered model forecast height changes (UT3FA) were uniformly better than those derived from the forecast height changes from the operational PE model (UTPFA and UTPF1). Bengtsson (1972) and others have argued in the literature that four-dimensional assimilation ought to be done with filtered models.

4. PERSISTENCE

Instead of modifying asynoptic data by an advective or tendency method, off-time data could be treated as on-time for the purpose of analysis. For very short periods and for some geographical areas, persistence may be quite acceptable, but for periods of 12-hours the RMSEs for persistence of 12-hour old observed data, PO, verified against the next observation 12 hours later, are very large at most levels considered. An example of 12-hour persistence of the operational 500-mb height analysis for the case verifying 0000 GMT April 11, 1970, and the errors when compared to the operational analysis are shown in figure 2d. Verifications of 12-hour persistence of observations were made against the subsequent observations. Average RMSEs for all cases are shown in figures 3 and 4. For the April 11 case, the 500-mb height errors for persistence were larger than both the tendency and the advective method update reanalyses. Similar results were obtained for 12-hour persistence verifications of the PE initialized, PI, and NMC operational analyzed, PA, 500-mb height and temperature fields. Except at 850 mb, use of 12-hour persistence would result in rather large errors in subsequent analyses; at 850 mb, persistence of temperatures shows smaller RMSE than temperatures updated by the advective methods considered.

5. DATA FIT IN OPERATIONAL ANALYSES

Since the operational analyses were used as the "truth" for verifications, an evaluation of how well the analyses fit the data was made. The NMC operational analysis procedure (Cressman 1959, and McDonell 1967) is based upon successive corrections to a first-guess field, with observed data supplied from RAWINSONDE, PIBAL, SIRS, and aircraft reports to produce gridpoint values to approximate the state of the atmosphere. Data checking is done in the analysis system, and most erroneous data are rejected. Verifications were made on the data fit of the observed data with the operational analyses (indicated by OA in figures 3 and 4). All data which passed the hydrostatic check were used in the data-fit determinations, even though some data could have been rejected and not used in the final make-up of the operational analyses. Results indicate that reasonable fits are attained at all levels.

6. FORECAST 3-HOURLY HEIGHT CHANGE CHARACTERISTICS

A study of the characteristics of the 3-hourly forecast height changes at 500 mb from the PE model during the first 12-hour period indicates that considerable gravitational oscillations are present, as shown in figure 7. The curves in figure 7 show the 3-hourly height changes which were determined at all gridpoints along J-row 15 (see figure 1). The characteristics of the 3-hourly height changes at 500 mb from the 3-level model for the same case indicate that the changes are somewhat more regular with time and that gravitational oscillations are not apparent. The oscillations in the PE model become important if the forecast height tendencies are to be used to update short-period asynoptic height reports. Referring to figure 3 again, note that the errors for the 12-hour PE height forecasts at 500 mb, FP, and from the 3-level model, F3, verified against the NMC operational analyses, are nearly the same. For 12-hour height updates, the gravitational oscillations in the PE almost cancel out,but for a 3-hour update, say from hour 9 to hour 12 at point I=32 in figure 7, the PE correction would be about -8 meters, when in fact the correction should probably be about +24 meters, as indicated by the more uniform changes from the 3-level model for the last 3-hour period. Therefore, it becomes necessary to apply some sort of filter on the PE forecast height changes to remove the gravitational modes if the height forecasts are to be used for updating purposes. Glahn (1970) has also studied the gravitational oscillations in the PE forecast height fields and has suggested methods of filtering the forecast data by least-square fitting of a third or fourth degree polynomial.

7. CONCLUDING REMARKS

Of the three methods investigated for this study, the tendency method provides the best means for updating 12-hour old data. The accuracy or suitability of any of the methods for making 6-hour updates was not determined because of the lack of both observations and verifying analyses at 0600 and 1800 GMT.

Depending on the numerical model used, direct applications of the forecast height changes to update short-period asynoptic height reports could lead to erroneous adjustments if, as in the case of the NMC PE model, gravitational oscillations are present and are ignored. For such cases, arrangements should be made to filter the unwanted gravitational modes before applying the tendency correction to height observations.

The overall view is that asynoptic data should be introduced in operational analyses, especially where synoptic data are not available or where data are sparse, by updating the data to synoptic time with the use of forecast changes. However, once the data have been introduced in the analysis-forecast cycle, they should not be reused for any additional updating because the subsequent forecast or guess portion of the cycle will contain the updated information. As these updated observations improve the synoptic analyses and the initial conditions for the forecast model, the forecast changes for the next cycle also should improve. The real value of the feedback between the analysis and forecast systems would best be judged by assessing the skill of the resulting forecasts.

An advective method has been used since May 1970 to introduce available SIRS data into the NMC analyses. The method is similar to the one described for this study but uses the space-mean flow from the operational 500-mb stream function field and restricts updates to a maximum of 6 hours. More SIRS data are expected to become available in the near future and they should continue to be incorporated in NMC analyses by appropriate updating and monitoring.

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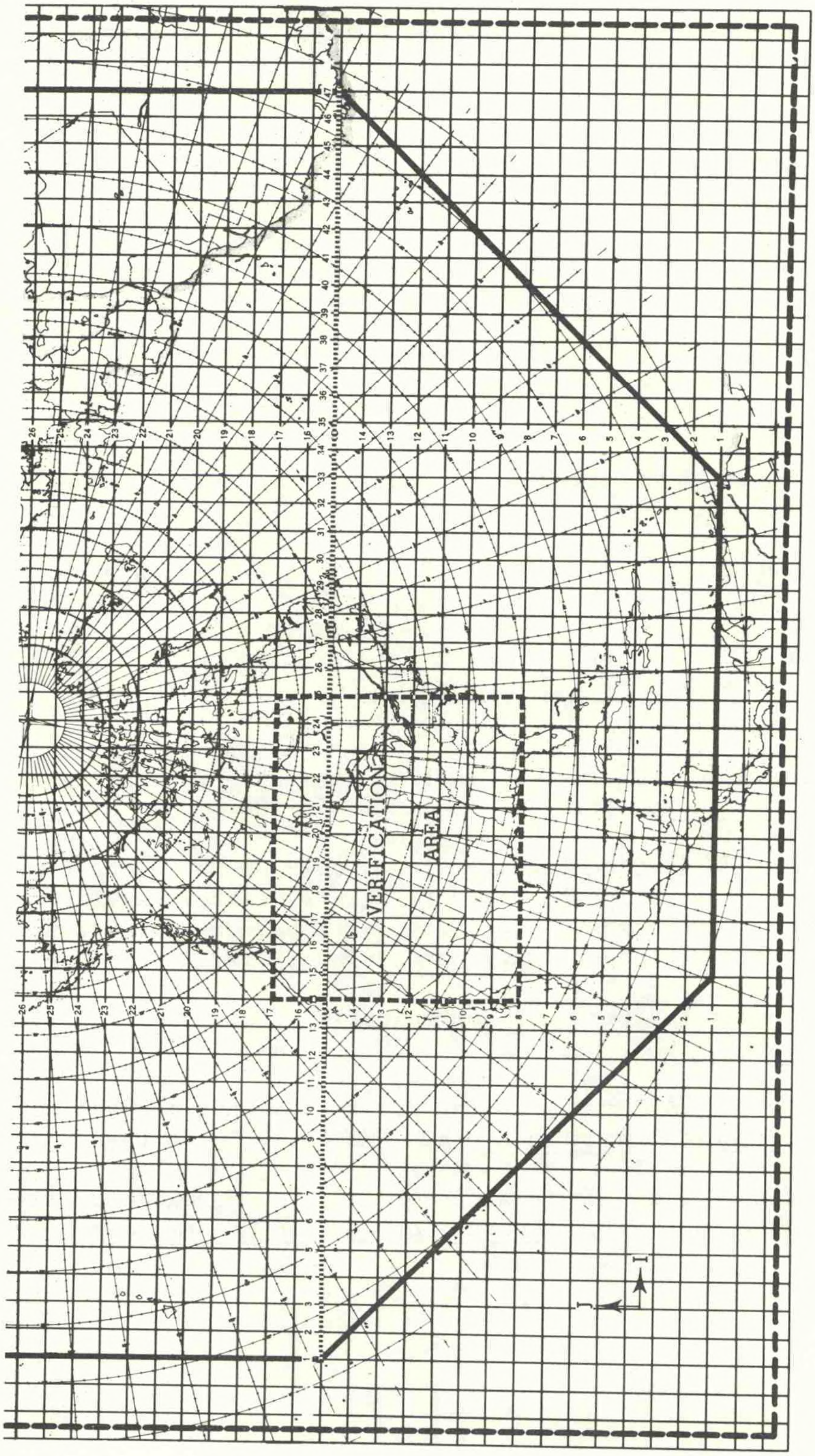

Figure 1.--Verification area.

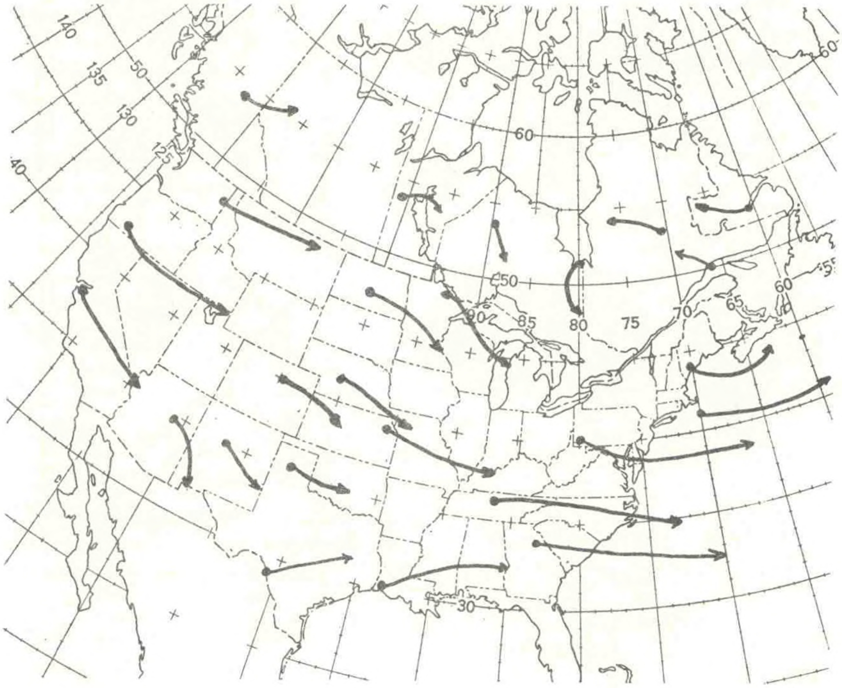

Figure 2a.--Examples of 500-mb space-mean relocation of radiosonde reports for 12 hours from 1200 GMT April 10, 1970.

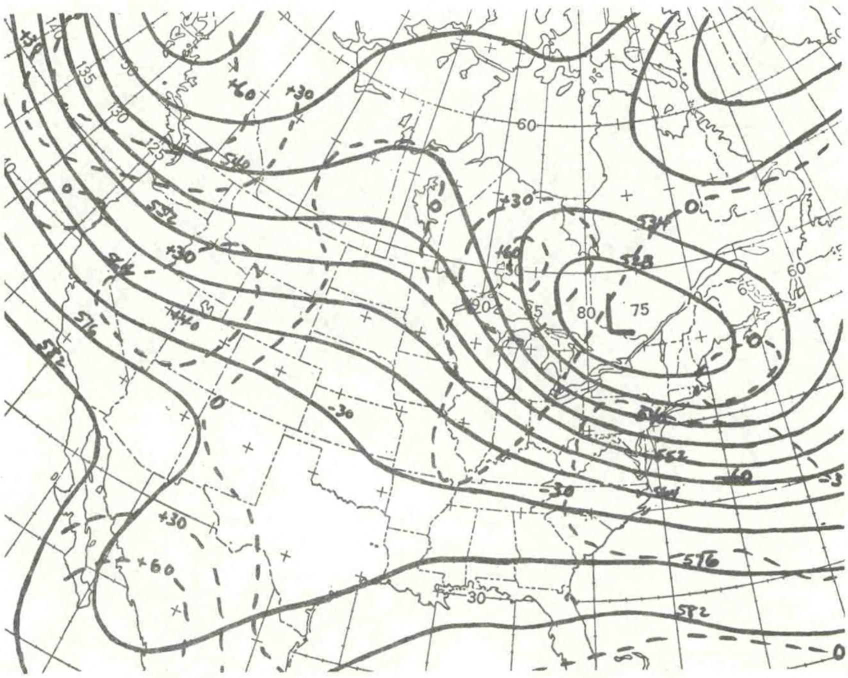

Figure 2b.--500-mb height analysis of relocated reports, and errors(meters), valid 0000 GMT April 11, 1970.

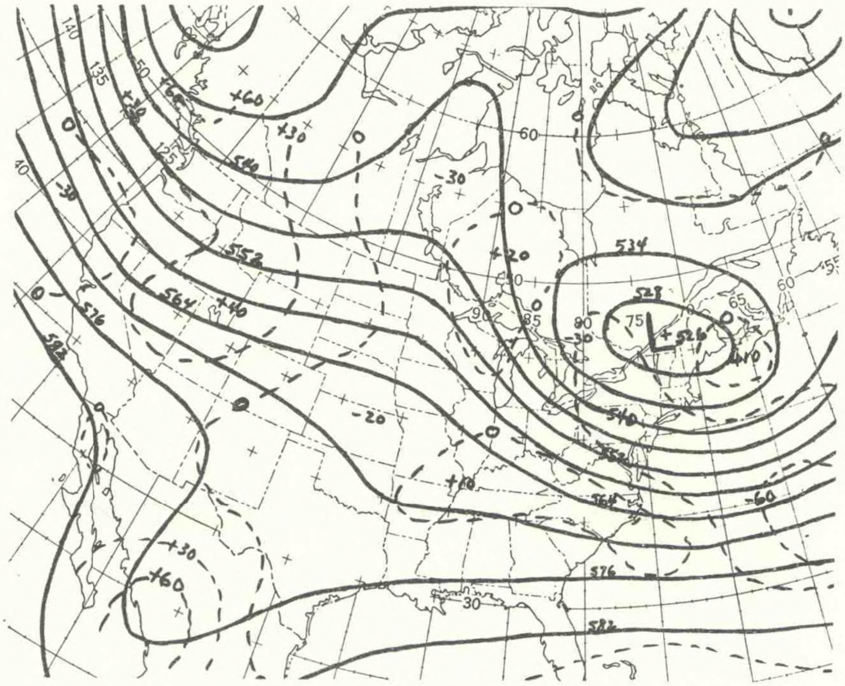

Figure 2c.--500-mb height analysis of 12-hour old data updated with tendency method, and errors(meters), valid 0000 GMT April 11, 1970.

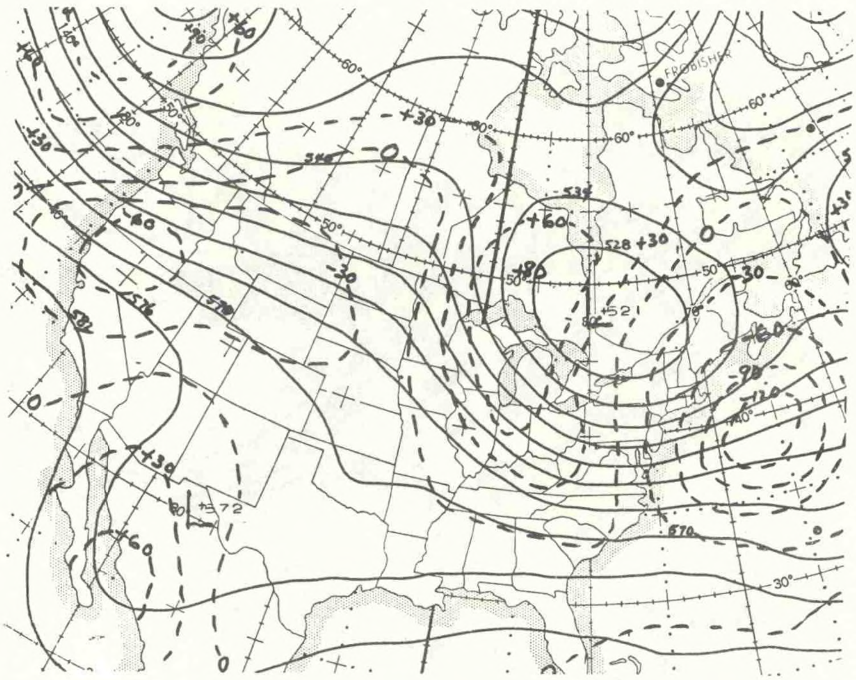

Figure 2d.--500-mb height analysis with 12-hour persistence, and errors (meters), valid 0000 GMT April 11, 1970.

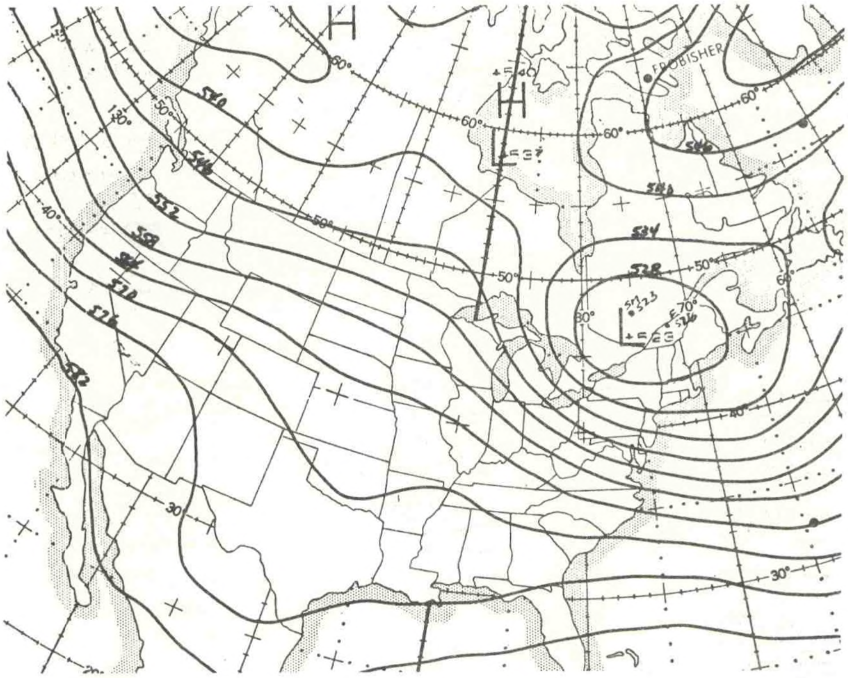

Figure 2e.--NMC 500-mb operational height analysis valid 0000 GMT April 11, 1970.

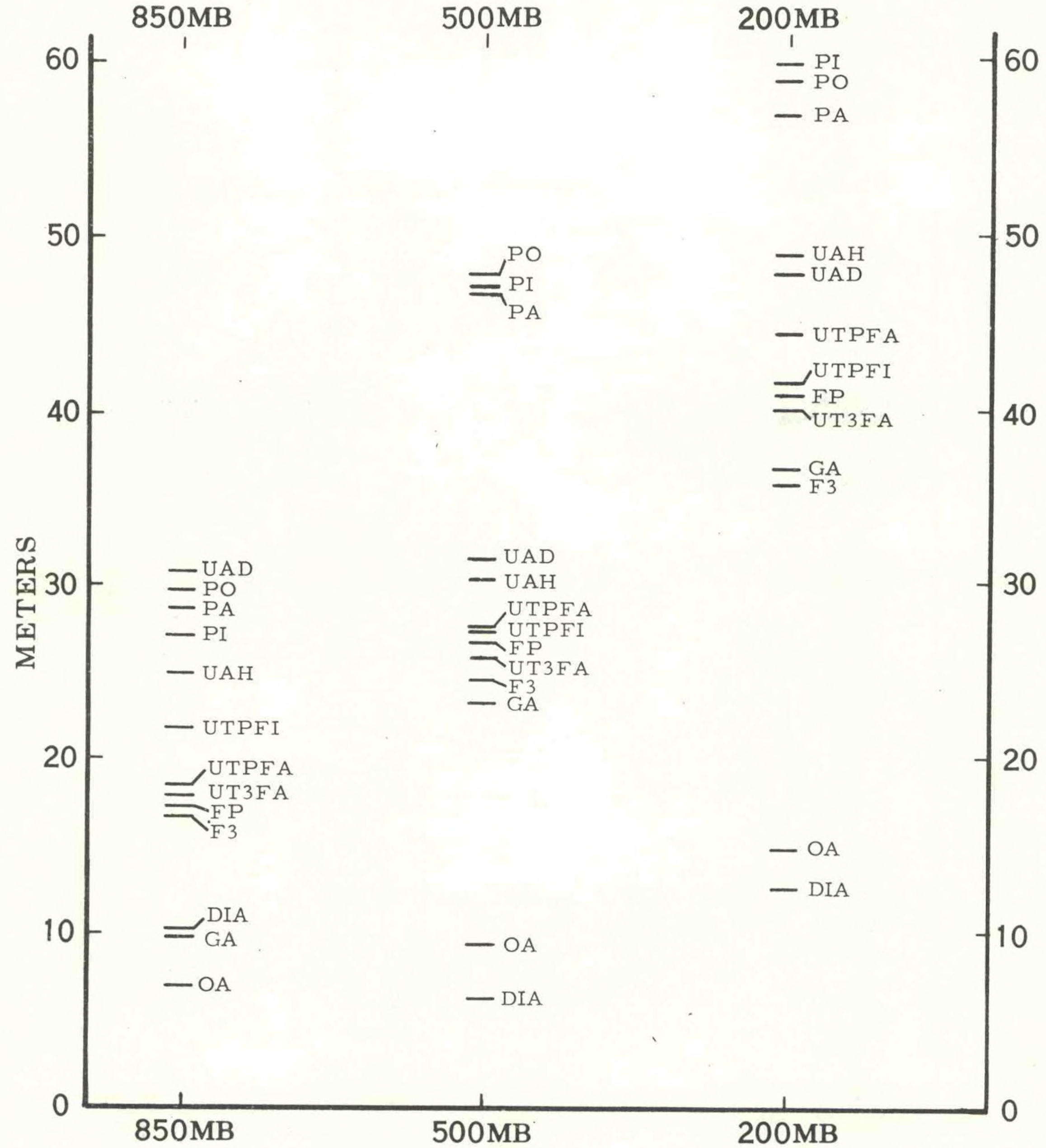

Figure 3.--Average root-mean-square height errors for all cases. See table 4 for definitions.

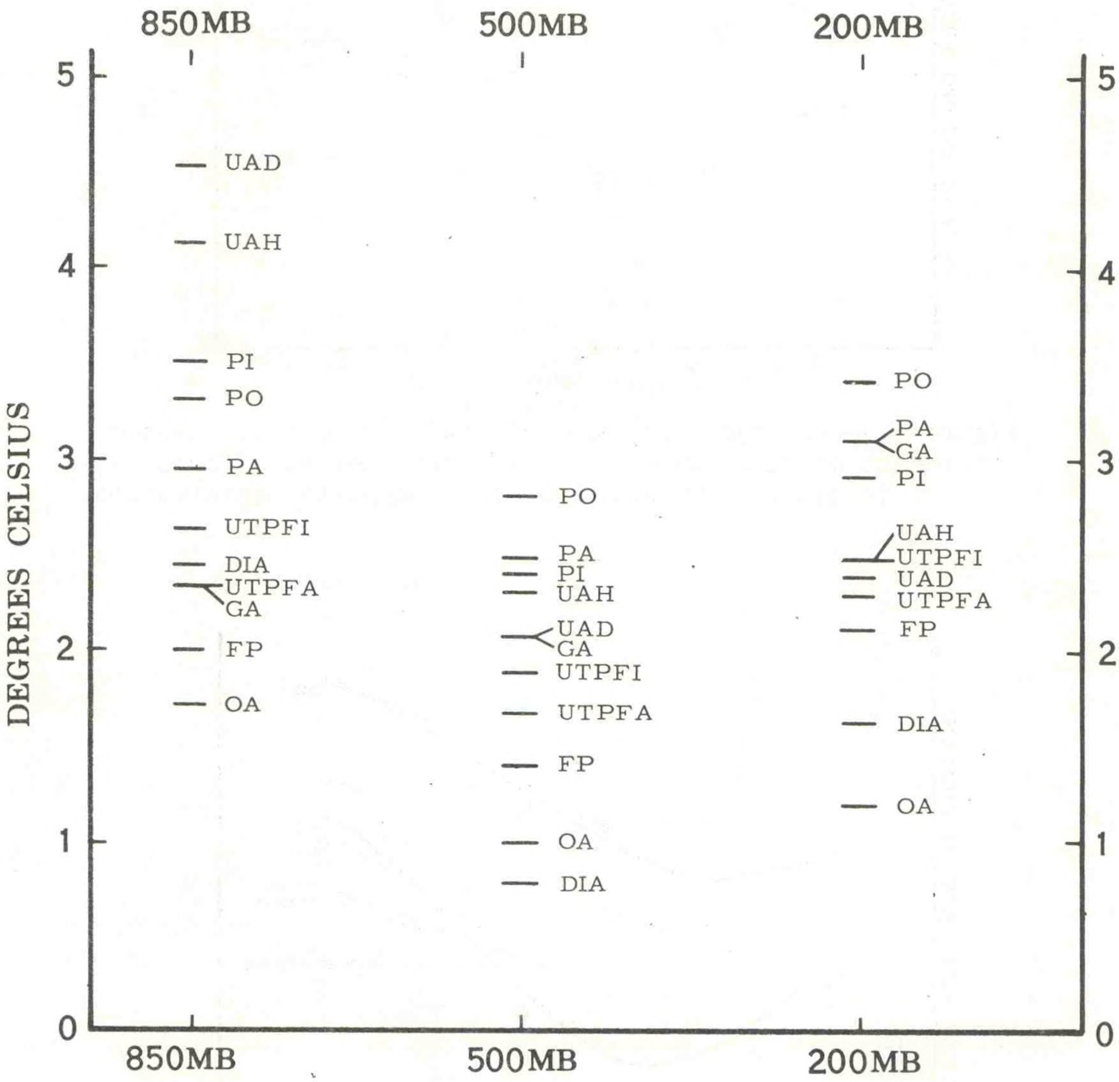

Figure 4.--Average root-mean-square temperature errors for all cases. See table 4 for definitions.

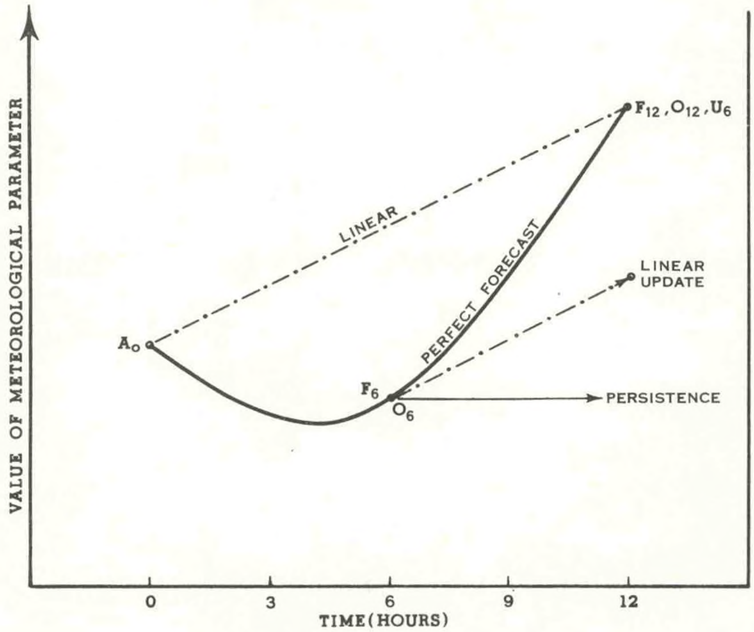

Figure 5.--Schematic diagram indicating a perfect 12-hour forecast of some meteorological parameter at a fixed point in space, and updating of an asynoptic observation.

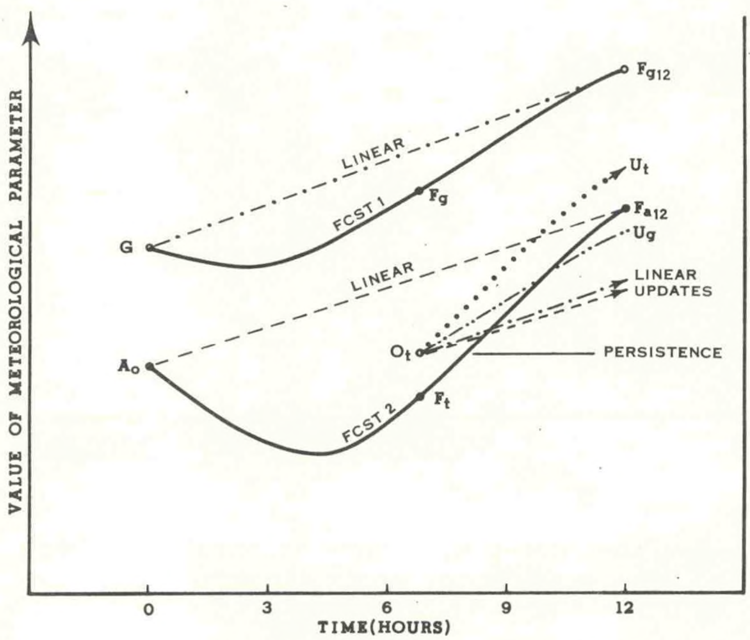

Figure 6.--Schematic diagram indicating a 12-hour forecast of some meteorological parameter at a fixed point in space with doubtful initial conditions, and various asynoptic updates.

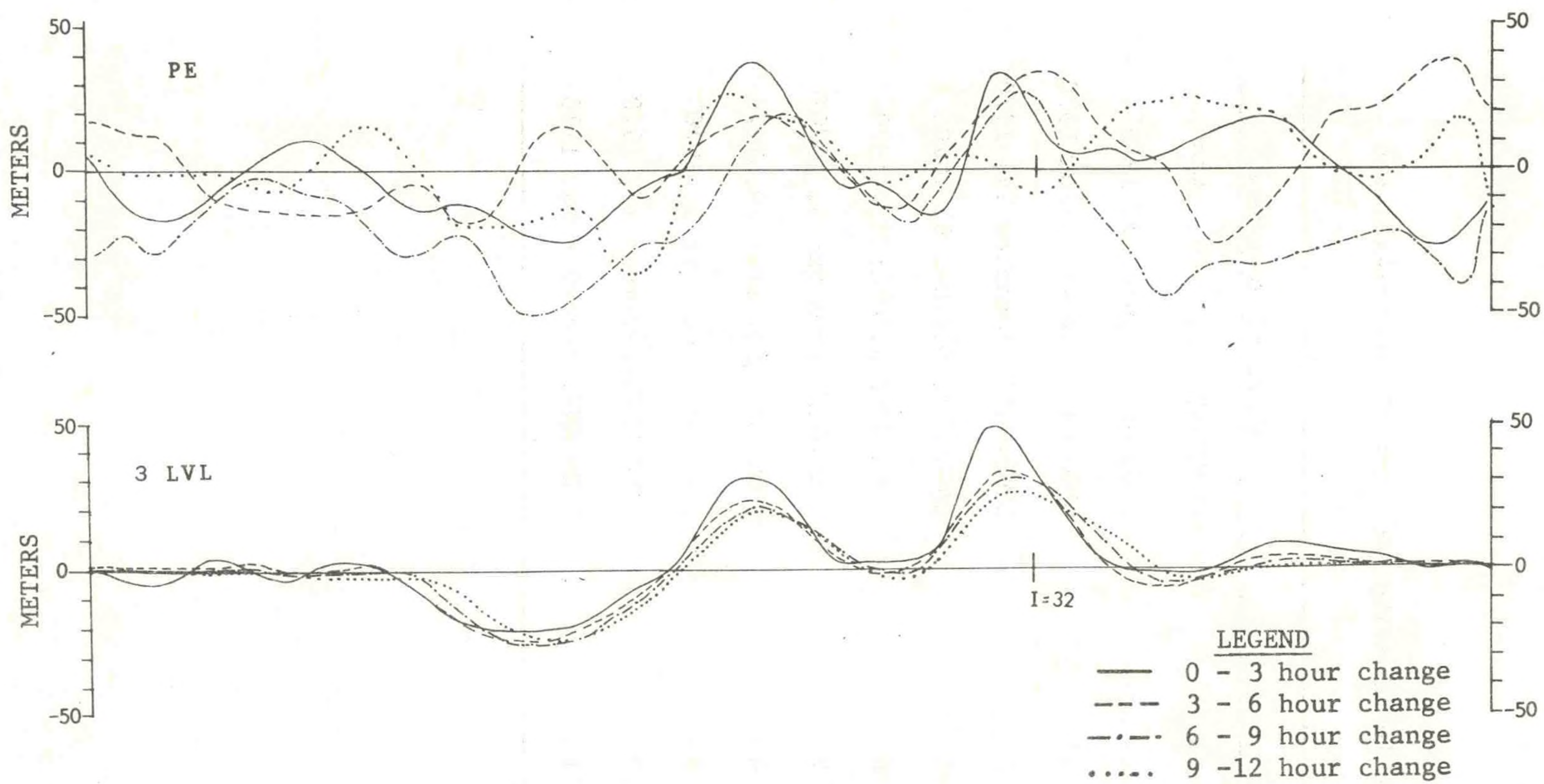

Figure 7.--500-mb 3-hourly primitive equation (PE) and 3-level forecast height changes from 1200 GMT April 10, 1970. Height changes were determined at all gridpoints from I=1 thru I=47 along J-row=15 as shown in figure 1.

Table 1.--Date and time of test cases used

Case no.	Verification time
1	0000 GMT, April 11, 1970
2	0000 GMT, August 27, 1970
3	0000 GMT, September 10, 1970
4	0000 GMT, September 24, 1970
5	0000 GMT, October 8, 1970
6	0000 GMT, October 22, 1970
7	0000 GMT, November 5, 1970
8	0000 GMT, November 19, 1970
9	0000 GMT, December 3, 1970
10	0000 GMT, December 17, 1970
11	0000 GMT, December 24, 1970

Table 2.--Height statistics (meters), case 1, April 11, 1970

Symbol[1]		Pressure level, mb								
		850	700	500	400	300	250	200	150	100
UAD	RMSE	36.3	25.9	28.3	31.9	34.3	36.5	42.2	50.2	44.1
	ME	19.8	13.4	2.2	-1.1	-9.4	-15.8	-21.3	-33.7	-22.8
UAH	RMSE	20.1	14.9	23.4	30.2	41.2	49.9	52.8	59.1	51.2
	ME	9.6	-2.5	-14.5	-19.1	-26.1	-34.6	-39.0	-49.6	-37.4
UTPFA	RMSE	17.5		27.5				49.8		
	ME	-3.1		3.9				3.9		
UT3FA	RMSE	16.0		20.3				43.1		
	ME	4.1		-1.9				-18.6		
UTPFI	RMSE	**		**				**		
	ME									
FP	RMSE	15.9		26.1				42.8		
	ME	-4.1		3.6				10.5		
F3	RMSE	14.9		18.9				36.8		
	ME	3.1		-2.1				-16.5		
PA	RMSE	25.2		34.1				46.3		
	ME	-10.0		.6				7.0		
PI	RMSE	**		**				**		
	ME									
PO	RMSE	25.6		34.2				46.2		
	ME	-9.0		.9				4.9		
GA	RMSE	9.2*	13.4	17.8	20.3	24.5	27.7	31.4	33.4	41.4
	ME	-5.9	-6.9	1.2	4.8	.3	1.7	9.4	17.7	33.3
OA	RMSE	6.1	6.5	10.5	13.8	17.0	18.9	17.7	21.2	31.2
	ME	.1	-.2	.6	.3	1.6	.7	1.7	2.8	-7.6
DIA	RMSE	**	**	**	**	**	**	**	**	**
	ME									

Table 2a.--Temperature statistics (deg C), case 1, April 11, 1970

Symbol[1]		Pressure level, mb								
		850	700	500	400	300	250	200	150	100
UAD	RMSE	5.7	3.1	2.4	1.7	1.9	2.7	2.9	2.7	2.8
	ME	-2.1	-1.2	-1.6	-1.0	-1.3	-1.8	-1.9	-.9	0.0
UAH	RMSE	4.6	2.5	2.6	2.2	2.1	2.5	2.9	2.6	2.8
	ME	-2.6	-1.6	-1.6	-1.1	-1.4	-1.7	-2.0	-1.4	.5
UTPFA	RMSE	**	**	**	**	**	**	**	**	**
	ME									
UT3FA	RMSE				Not applicable					
	ME									
UTPFI	RMSE	**	**	**	**	**	**	**	**	**
	ME									
FP	RMSE	**	**	**	**	**	**	**	**	**
	ME									
F3	RMSE				Not applicable					
	ME									
PA	RMSE	**	**	**	**	**	**	**	**	**
	ME									
PI	RMSE	**	**	**	**	**	**	**	**	**
	ME									
PO	RMSE	**	**	**	**	**	**	**	**	**
	ME									
GA	RMSE	2.3	1.7	1.9	1.3	2.0	1.9	2.9	1.6	1.5
	ME	-.6	.7	1.3	.2	-.7	-.3	1.8	.2	1.0
OA	RMSE	1.8	1.0	1.0	.8	1.0	1.0	1.0	1.0	1.5
	ME	-.4	0.0	.5	.5	.5	.4	.5	.6	0.0
DIA	RMSE	**	**	**	**	**	**	**	**	**
	ME									

[1] See table 4 for definitions

* See table 4 for definition

** See table 4 for definition

Table 3.--Height statistics (meters), averages, all cases

Symbol[1]		Pressure level, mb								
		850	700	500	400	300	250	200	150	100
UAD	RMSE	30.6	26.6	31.1	35.9	40.4	43.4	47.3	49.4	44.4
	ME	5.7	3.0	-3.0	-4.8	-8.2	-9.6	-14.8	-18.7	-17.3
UAH	RMSE	24.7	21.9	29.9	37.6	44.3	46.3	48.6	47.7	42.8
	ME	7.2	2.4	-3.7	-5.7	-9.1	-11.4	-15.7	-18.8	-16.7
UTPFA	RMSE	18.2		27.2				44.0		
	ME	-3.3		-.8				13.9		
UT3FA	RMSE	17.7		25.5				39.8		
	ME	-1.1		-2.9				-1.5		
UTPFI	RMSE	21.6		27.1				41.2		
	ME	-8.6		-2.5				10.0		
FP	RMSE	17.1		26.5				40.6		
	ME	-3.9		-.4				14.5		
F3	RMSE	16.7		24.3				35.5		
	ME	-1.7		-2.5				-1.4		
PA	RMSE	28.4		46.3				56.5		
	ME	-4.3		3.0				12.7		
PI	RMSE	26.8		46.8				59.4		
	ME	1.5		8.3				18.3		
PO	RMSE	29.4		47.3				58.4		
	ME	-3.7		2.6				12.6		
GA	RMSE	9.7*	15.1	23.0	31.2	36.8	39.1	36.3	34.8	36.9
	ME	-2.1	-1.1	3.2	6.3	1.8	1.4	4.4	5.0	22.8
OA	RMSE	7.0	6.5	9.2	10.5	13.4	14.2	14.7	15.5	26.5
	ME	.3	.3	-.1	-1.1	-.9	-1.2	-.4	.1	-3.2
DIA	RMSE	10.1	5.7	6.4	8.5	13.9	14.4	12.6	8.0	13.6
	ME	-3.9	-2.2	-1.3	-2.8	-7.0	-6.0	-4.8	-3.5	-10.5

Table 3a.--Temperature statistics (degC), averages, all cases

Symbol[1]		Pressure level, mb								
		850	700	500	400	300	250	200	150	100
UAD	RMSE	4.5	2.7	2.1	2.0	2.0	2.3	2.4	2.0	2.2
	ME	-.8	-.6	-1.1	-.9	-.8	-1.2	-.8	-.7	-.5
UAH	RMSE	4.1	2.6	2.3	2.2	2.0	2.2	2.5	2.1	2.2
	ME	-1.1	-.8	-1.1	-.9	-.8	-1.1	-.8	-.7	-.4
UTPFA	RMSE	2.3	1.7	1.7	1.7	1.8	2.0	2.3	1.9	3.0
	ME	-.1	0.0	.3	.2	-.2	-.4	.1	.4	2.4
UT3FA	RMSE				Not applicable					
	ME									
UTPFI	RMSE	2.6	1.9	1.9	1.9	1.7	2.4	2.5	1.9	1.9
	ME	-.6	.2	.2	.1	.2	.6	.6	.5	.5
FP	RMSE	2.0	1.3	1.4	1.5	1.6	1.8	2.1	1.6	2.9
	ME	-.2	-.1	.3	.3	-.2	-.4	.1	.5	2.5
F3	RMSE				Not applicable					
	ME									
PA	RMSE	2.9	2.5	2.5	2.4	1.9	2.6	3.1	2.3	1.5
	ME	.7	.5	.4	.2	0.0	.6	.5	.2	.2
PI	RMSE	3.5	2.5	2.4	2.3	1.9	2.2	2.9	2.3	2.6
	ME	1.2	.3	.4	.4	-.2	-.4	0.0	.2	2.1
PO	RMSE	3.3	2.9	2.8	2.6	2.0	2.9	3.4	2.6	2.0
	ME	.7	.6	.4	.1	.2	.6	.5	.2	.1
GA	RMSE	2.3	1.6	2.1	2.0	2.2	1.9	3.1	1.9	1.7
	ME	.4	.3	.9	0.0	-1.1	-.2	1.1	.2	.9
OA	RMSE	1.7	1.3	1.0	.9	1.0	1.0	1.2	1.0	1.2
	ME	-.3	0.0	.5	.5	.5	.5	.5	.5	.3
DIA	RMSE	2.4	1.1	.8	1.1	1.5	1.8	1.6	1.3	2.3
	ME	-.6	-.1	-.1	-.2	.5	1.1	.5	.1	-1.9

1 See table 4 for definitions

* See table 4 for definition

** See table 4 for definition

Table 4.--Table of definitions

Symbol	Meaning
UAD	Radiosonde report updated using an advective flow (Desmarais) to relocate the radiosonde position, and verified against NMC operational analysis
UAH	Radiosonde report updated using an advective flow (Hayden) to relocate the radiosonde position, and verified against NMC operational analysis
UTPFA	Radiosonde report updated using the PE forecast tendency (forecast minus initial analysis), and verified against NMC operational analysis
UTPFI	Radiosonde report updated using the PE forecast tendency (forecast minus initialized), and verified against NMC operational analysis
UT3FA	Radiosonde report updated using the NMC 3-level forecast tendency (forecast minus initial analysis), and verified against NMC operational analysis
FP	PE forecast verified against NMC operational analysis
GA	First guess verified against NMC operational analysis
F3	3-level forecast verified against NMC operational analysis
PI	Persistence of PE initialized data
PA	Persistence of analyzed data
PO	Persistence of observed data
OA	Observed data verified against operational analysis
DIA	Difference between analyzed and initialized data
RMSE	Root-mean-square error
ME	Mean error
*	Includes some benefit from 1000-mb analysis
**	Unable to compute because data tape was purged

(Continued from inside front cover)

NOAA Technical Memoranda

NWS NMC 49 A Study of Non-Linear Computational Instability for a Two-Dimensional Model. Paul D. Polger, February 1971. (COM-71 00246)

NWS NMC 50 Recent Research in Numerical Methods at the National Meteorological Center. Ronald D. McPherson, April 1971.