TECHNICAL NOTE 10 TDL-1

U.S.DEPARTMENT OF COMMERCE • ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

TECHNICAL NOTE 10- TDL -1

Objective Prediction of Daily Surface Temperature

BASIC KNOWLEDGE
TECHNIQUES DEVELOPMENT LABORATORY
OPERATING PROCEDURES

TECHNIQUES DEVELOPMENT LABORATORY REPORT NO.1

WASHINGTON,D.C.
September 1965

WEATHER BUREAU TECHNICAL NOTES

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Objective Prediction of Daily Surface Temperature

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CONTENTS

OBJECTIVE PREDICTION OF DAILY SURFACE TEMPERATURE

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ABSTRACT

An objective method of forecasting surface temperature at 39 cities in the United States for 1, 2, and 3 days in advance has been developed and tested under operational conditions. This method utilizes daily input to multiple regression equations derived previously for predicting 5-day mean temperature from fields of 700-mb. height and surface temperature. Comparative verification shows that the objective forecasts have skill generally higher than chance, climatology, and persistence. In fact, these exploratory regression equations produce forecasts which approximate the skill of subjective predictions made by experienced meteorologists.

Recent experiments are described which indicate that improved forecasts result when 700-1000-mb. thickness is included as a predictor. Therefore, a new set of equations for maximum and minimum temperatures is being derived for 108 cities from 16 years of daily values of surface temperature, thickness, and 700-mb. height.

The beneficial synoptic climatology which accrues from these studies is also illustrated.

1. INTRODUCTION

Although many objective methods of forecasting surface temperature have been developed during the past 50 years, only a few have been applied on a routine basis. An early description of these methods is contained in a Monthly Weather Review Supplement [17], while later studies are summarized in a comprehensive Weather Bureau Forecasting Guide [4].

Most of the methods which have been developed are empirical in nature and applicable to single stations only. Other methods based on a physical approach involve air trajectories, cloudiness, diabatic heating and cooling, and vertical motion. Estimation of these quantities is difficult, inaccurate, and time-consuming. For this reason there have been few objective methods of temperature prediction applied operationally on a Nationwide basis.

The goal of this project was to develop a method for predicting daily surface temperatures for the entire United States which could be used routinely on an electronic computer. The method selected should have proven itself in application to similar problems and, at the same time, should make optimum use of the constantly improving numerical circulation prognoses. The multiple regression screening technique [13] successfully employed in 5-day mean temperature forecasting during the past seven years [7] meets these criteria. Furthermore, it integrates well with other computer operations at the National Meteorological Center.

In this paper a series of experiments will be described involving preparation and verification of daily mean, maximum, and minimum temperature forecasts for periods from 1 to 5 days in advance. Most of these experiments were performed with multiple regression equations which had been derived from 5-day mean data but were applied unchanged to daily temperature prediction (except for using daily instead of mean data as input). The equations were derived separately for each of the four seasons at each of the cities illustrated in figures 1A, 1B, and 1C by applying the screening program to fields of surface temperature and 700-mb. height [9]. By solving these equations on an electronic computer, an objective forecast of the Nationwide temperature pattern can be obtained in a few seconds.

A typical equation is given below for Indianapolis, Ind., in winter:

$$T_4(\text{Ind.}) = 1.28\ [-0.14 + .067T_0(\text{Ind.}) + .208Z_2(40\text{-}90) - .134Z_2(60\text{-}120) + .269T_0(\text{K.C.})] \quad (1)$$

where T_4(Ind.) is the predicted mean temperature anomaly in degrees Fahrenheit at Indianapolis for a 5-day period centered 4 days in advance, T_0(Ind.) is the 5-day mean temperature anomaly (°F.) at Indianapolis for a period centered on forecast day, Z_2(40-90) is the 5-day mean 700-mb. height anomaly in tens of feet at the intersection of 40°N., 90°W. for a period centered 2 days in advance, Z_2(60-120) is the 5-day mean 700-mb. height anomaly (tens of feet) at 60°N., 120°W. 2 days in advance, and T_0(K.C.) is the 5-day mean temperature anomaly (°F.) at Kansas City on forecast day. The coefficient 1.28 is the reciprocal of the multiple correlation coefficient used to "inflate" the forecasts so that they will have about the same variability as the observed temperatures [10]. This term was included in order to make the forecasts more acceptable to most consumers by predicting more of the extremes than conventional regression forecasts do.

2. DAILY MEAN 72-HOUR TEMPERATURE FORECASTS

Regression equations of the type illustrated in equation (1) have been applied on an operational basis to make objective 72-hr. temperature anomaly forecasts rountinely 4 days a week since September 16, 1961 [8]. The equations are applied by using as height input 36-hr. numerical 700-mb. predictions, made at 1200 GMT on forecast day, and as temperature input predictions of daily mean temperature for the next day prepared for shippers. The latter (hereafter called shippers forecasts) are subjectively prepared for five periods from 12 to 60 hr. in advance by forecasters at Weather Bureau Offices throughout the country and are routinely transmitted over teletype at about 1100 GMT each morning. The objective 72-hr. temperature forecasts are used for guidance by experienced meteorologists of the Extended Forecast Division who subjectively prepare (for transmission over facsimile)

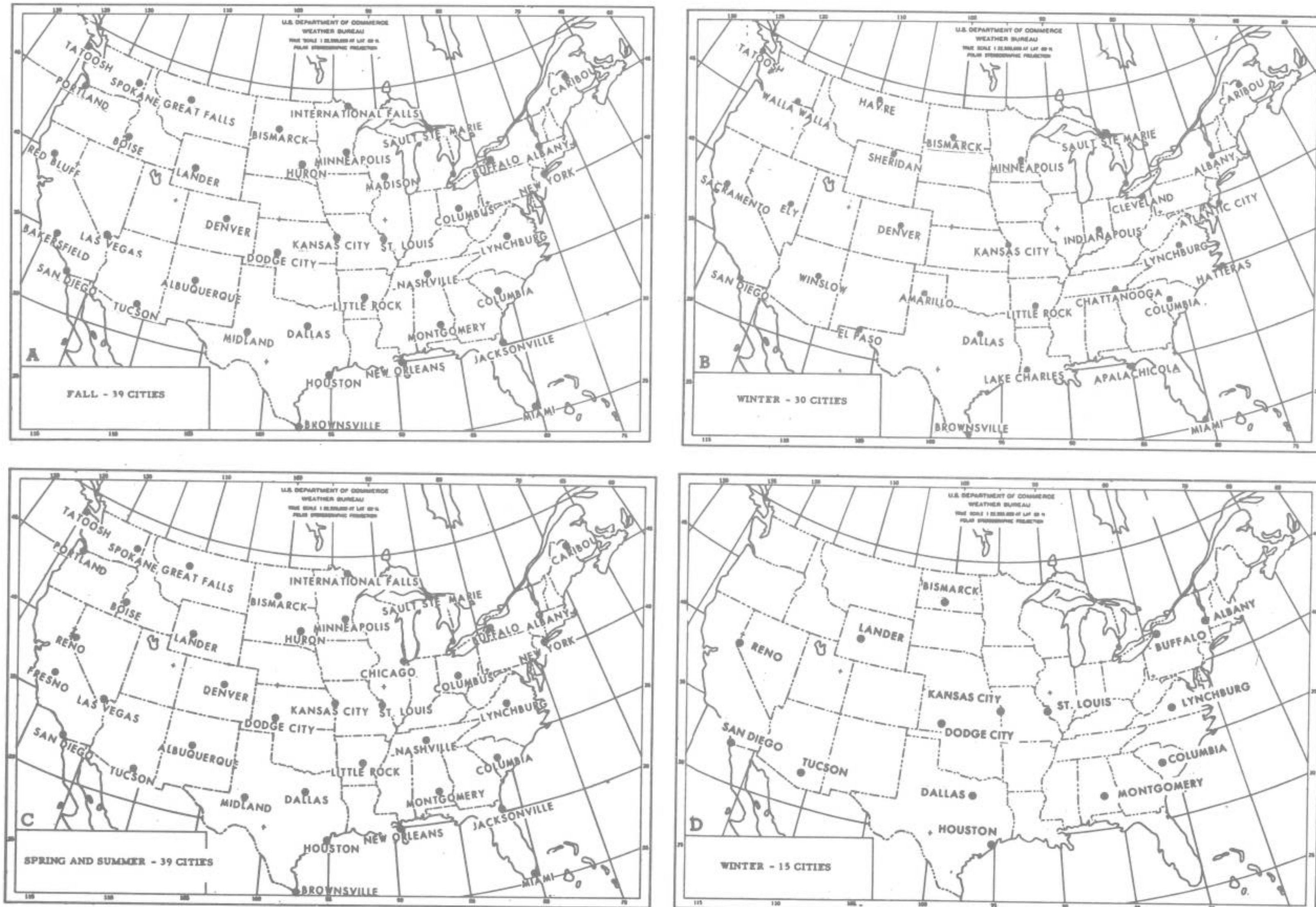

Figure 1. - Location of cities for which objective equations were derived by screening 5-day mean data (A, B, and C) and daily data (D) for the seasons indicated.

maps showing the expected anomalies of mean (daily) temperature for three days in advance over the United States.

Both objective and subjective (official) forecasts have recently been verified during each season of the 3-yr. period from fall 1961 through summer 1964. As a persistence control, shippers forecasts for two days in advance prepared on forecast mornings by conventional methods have been converted to anomalies (by taking the mean of the predicted maximum and minimum and subtracting the normal) and are assumed to persist for another day. It is recognized that this procedure may not be completely fair to the shippers forecasts since they are made for the 2d day but have been verified on the 3d day. Furthermore, they are intended to apply to an area of 50 square miles but have been verified at airport stations. However, no other control forecasts were available for 3 days in advance. Moreover, persistence of either the mean temperature observed on forecast day or the shippers forecasts for the next day would give lower correlations than the control used here.

The comparative verification is presented in table 1 in terms of the average correlation coefficient between forecast and observed temperature anomalies. The verification was performed at 39 cities shown in figures 1A and 1C. In order to equalize the variability between different cities and different months, all temperature anomalies were first standardized; i.e., divided by the appropriate standard deviation. The latter were computed from standard deviations of monthly mean temperature given by Thom [18] and ratios of daily to monthly standard deviation given by Jenkinson [6].

Table 1 shows that during every season except two the official forecasters were able to improve on their objective guidance. However, the amount of improvement was relatively small since the overall correlations for the 3-yr. period (last line) were 0.50 for the official and 0.47 for the objective. By comparison, the control (shippers) forecasts had an overall correlation of only 0.37 and were not superior to either the objective or official forecasts during any season of the 12 tested. The margin of superiority over the control forecasts was considerably greater during the last two years. This improvement can probably be attributed to the replacement of the barotropic and mesh models [5] at the National Meteorological Center by the three-level baroclinic model of Cressman [3] in June 1962, and consequent increased accuracy of the 36-hr. prognostic 700-mb. heights entering into the prediction equations. A parallel improvement in 500-mb. 36-hr. prognostic heights has been documented by Saylor [15] and in 5-day mean temperature forecasts by Klein [7].

Another interesting feature of table 1 is the seasonal variation it reveals. The last five lines show that all forecasts correlate highest in the winter, when large-scale advective effects are most pronounced, and lowest in the summer, when local and small-scale effects are important.

The geographical distribution of the skill of the objective 72-hr. temperature forecasts is portrayed in figure 2 in terms of the correlation coefficient between forecast and observed temperature anomalies. The verification was performed separately at each city during each season and then

TABLE 1. - Verification of 72-hr. mean daily temperature forecasts, averaged at 39 cities in the United States, by seasons and years in terms of the correlation coefficient between standardized values of forecast and observed anomalies.

Season	Year	Objective	Official	Shippers
Fall	1961	.42	.46	.42
Winter	1961-62	.46	.48	.35
Spring	1962	.39	.43	.39
Summer	1962	.32	.35	.27
Year	1961-62	.40	.43	.36
Fall	1962	.52	.55	.41
Winter	1962-63	.52	.57	.37
Spring	1963	.54	.50	.39
Summer	1963	.43	.47	.33
Year	1962-63	.50	.52	.38
Fall	1963	.49	.47	.35
Winter	1963-64	.60	.63	.48
Spring	1964	.50	.55	.34
Summer	1964	.39	.50	.34
Year	1963-64	.50	.54	.38
Fall	1961-63	.48	.49	.39
Winter	1961-64	.53	.56	.40
Spring	1962-64	.48	.49	.37
Summer	1962-64	.38	.44	.31
OVERALL	1961-64	.47	.50	.37

averaged over the three cool seasons of the three years from fall of 1961 to spring of 1964 in order to obtain a more representative sample. Maximum correlations (over 0.6) are found in the Mid-West, and secondary maxima (over 0.5) occur over the southern Plateau States and Montana. Minimum correlations tend to be found along the periphery of the United States. Positive correlations greater than 0.3 occur at every city, and the nation-wide average is 0.5.

On the basis of the results presented in this section, it may be concluded that the objective 72-hr. temperature forecasts exhibit definite skill beyond chance (correlation of 0) or persistence of a good short-range forecast (shippers forecasts), but with some seasonal and geographical variation.

3. DAILY MEAN 48-HOUR TEMPERATURE FORECASTS

It has previously been noted that the objective temperature forecasts tend to verify better at the beginning than at the end of the forecast period [8]. Therefore, the 72-hr. forecasts discussed in the previous section were tested as 48-hr. forecasts, for the same cities and seasons summarized in table 1, by correlating the forecast anomaly with the anomaly of mean temperature observed 2 days (instead of 3 days) in advance. For economy, only one forecast per week was verified, instead of four per week as before.

The results are summarized in part a of table 2, alongside the shippers forecasts for 2 days in advance. The correlations for the objective forecasts exhibit the customary seasonal and annual variation, with summer minimum, winter maximum, and marked improvement of the 2d year over the 1st. Comparison of the scores for each individual season in table 1 and 2 shows that the objective forecasts were more accurate as 48-hr. than as 72-hr. forecasts during seven out of eight seasons tested. Table 2 also shows that the overall correlation for the 2-yr. period was 0.51 for both the objective 48-hr. forecasts and the shippers forecasts used as a control. Thus it appears that objective daily temperature forecasts for 2 days in advance are about as good as 48-hr. forecasts prepared subjectively and better than 72-hr. objective forecasts.

All objective predictions discussed up to this point have been based upon prognostic input (36-hr. forecasts) of both height and temperature. The second part of table 2 presents verifications of 48-hr. objective predictions prepared by using as input to the multiple regression equations the latest observed anomalies of both 700-mb. height (1200 GMT of forecast day) and surface temperature (the day before forecast day). Using similar input, Chidley [2] obtained 48-hr. temperature forecasts for Denver which compared favorably with those prepared by the official forecasters at that station. Objective forecasts based on observed input were therefore prepared each day from January 1, 1962, through March 30, 1963, for the entire network of cities and verified as 48-hr. forecasts. As before, the shippers forecasts for 2 days in advance were used as a control.

The results, averaged over all 39 cities, are shown separately for each of five seasons in part b of table 2. There is little to choose between the objective and shippers forecasts, with an overall correlation of 0.53 for the

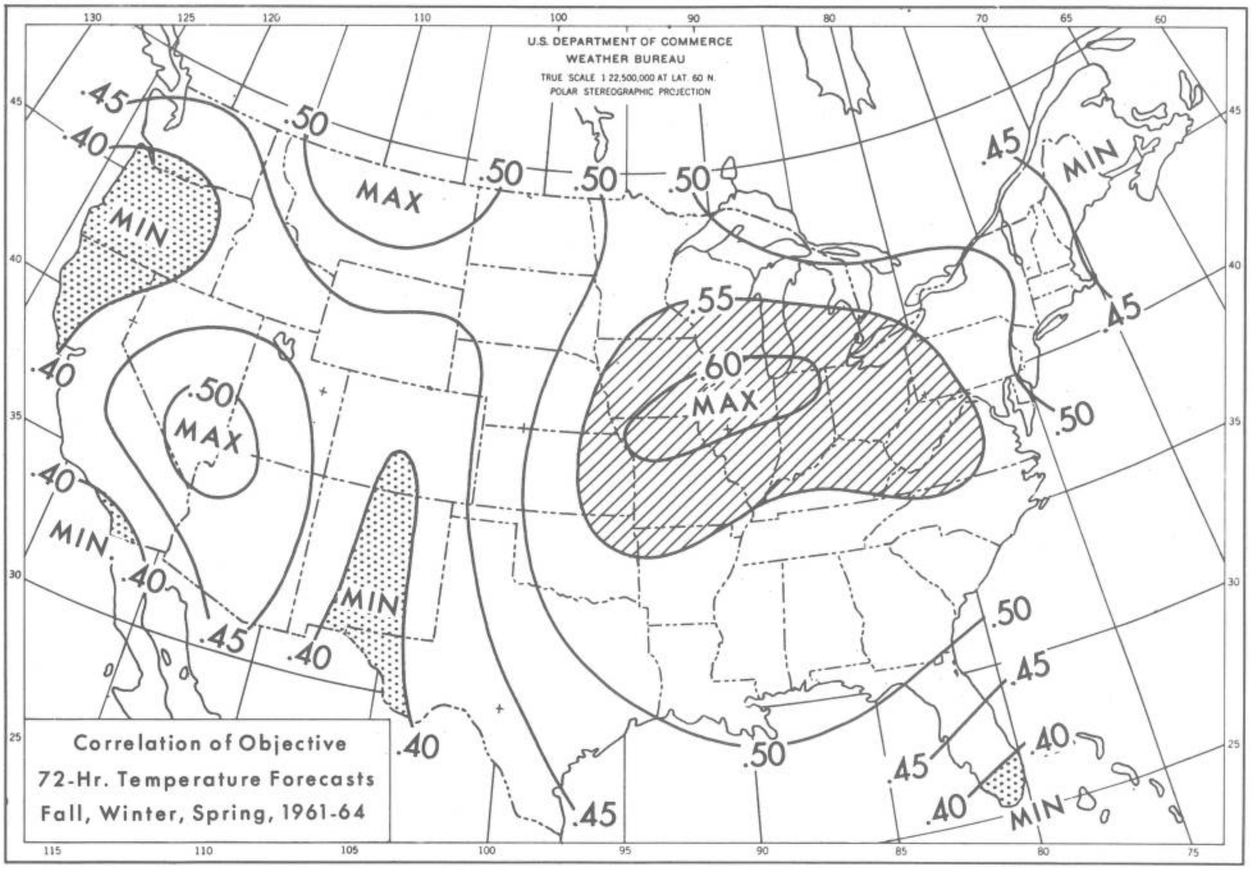

Figure 2. - Simple linear correlation coefficients between standardized anomalies of objective 72-hr. temperature forecasts and verifying temperatures during fall, winter, and spring seasons from 1961 to 1964, with centers labeled as maximum or minimum.

former and 0.51 for the latter. Likewise, there is little to choose between this method of preparing the objective forecasts and the standard method (part a of table 2). The most important conclusion to be drawn from table 2 is that the temperature prediction equations can be used to furnish useful guidance in the 48-hr. forecast range, just as they do for the 72-hr. forecast and the 5-day mean.

4. DAILY MEAN TEMPERATURE FORECASTS FOR OTHER PERIODS

24 Hours - In view of the tendency for the objective temperature forecasts to verify better at the beginning of the forecast period, the 48-hr. forecasts of table 2b, prepared from observed input, were tested as 24-hr. forecasts by correlating the forecast anomaly with the anomaly of mean temperature observed 1 day in advance. The results, given in table 3, show that the objective forecasts were more accurate when verified by the temperature 1 day in advance than 2 days in advance during each of the five seasons tested, with overall correlations of 0.64 for the former, compared to 0.53 for the latter. However, the 24-hr. objective forecasts were not as

TABLE 2. - Verification of 48-hr. mean daily temperature forecasts, averaged at 39 cities in the United States, in terms of the correlation coefficient between standardized values of forecast and observed anomalies.

Season	Year	Objective	Shippers
a. Standard Objectives (Prog. Input) 1 Day a Week			
Fall	1961	.46	.53
Winter	1961-62	.56	.53
Spring	1962	.45	.53
Summer	1962	.46	.39
Year	1961-62	.48	.50
Fall	1962	.54	.55
Winter	1962-63	.60	.59
Spring	1963	.52	.52
Summer	1963	.49	.44
Year	1962-63	.54	.53
OVERALL	1961-63	.51	.51
b. Objectives Using Observed Input 7 Days a Week			
Winter	1962	.65	.54
Spring	1962	.53	.51
Summer	1962	.36	.42
Fall	1962	.55	.50
Winter	1962-63	.56	.58
OVERALL	1962-63	.53	.51

accurate as the shippers forecasts for 1 day in advance, which were available for comparison during only two seasons of the five tested (table 3).

96 and 120 Hours - The feasibility of preparing objective temperature forecasts for 4 or 5 days in advance was also investigated, but with a very small sample. For this purpose use was made of six cases during May and June 1963 (a week apart) in which the three-level baroclinic model had been extended out to 72 hr. at 0000 GMT. For each of these cases two sets of 96-hr. daily objective temperature forecasts were made from the standard prediction equations, using as input the shippers temperature forecasts for the next day and the baroclinic heights for 48 and 72 hr. in advance. In addition, prognostic heights for 48, 72, and 96 hr. from both the barotropic and mesh models [5] were tried as input in the prediction equations.

The resulting objective forecasts were correlated with temperatures observed four days later. The correlation coefficients, averaged over 39 cities and six cases, varied between 0.4 and 0.5 for the different models, with the highest (0.50) yielded by the 72-hr. baroclinic. The same objective forecasts were verified against daily temperatures observed 5 days in advance. The resulting correlation coefficients, for the six cases and 39 cities, were only slightly lower than for the 4-day forecasts, with the highest (0.47) yielded by the 96-hr. barotropic.

It thus appears feasible to use the objective method to prepare a series of mean daily temperature forecasts for 1 to 5 days in advance. Furthermore, the prediction equations seem to work best with a 1-day lag between height and temperature (although derived with a 2-day lag); so that 72-hr. temperature forecasts can be made from 48-hr. height predictions, 96-hr. temperature forecasts from 72-hr. height forecasts, and 120-hr. temperature forecasts from 96-hr. height forecasts.

5. 48-HR. MAXIMUM AND MINIMUM TEMPERATURE FORECASTS

Because of the consumer requirement for daily maximum and minimum temperatures, experiments were carried out to uncover a satisfactory method for producing forecasts of the daily temperature extremes. As an interim measure, maximum temperatures were obtained by using the equations already available for mean temperature (like equation (1)) and simply adding the predicted anomaly to the normal maximum. A similar procedure was followed for the minimum.

Maximum Temperature - Maximum temperature forecasts for 48 hr. in advance were made at the 30 cities of figure 1B during the months of January and February 1964. Several combinations of 700-mb. height and surface temperature anomalies were tried as input to the multiple regression equations, with results summarized in table 4. In every case the 24-hr. baroclinic 700-mb. prognostic heights gave better objective forecasts than the last observed 700-mb. height (1200 GMT) in terms of both correlation coefficient and mean absolute error. This again indicates that the regression equations work best with a 1-day lag between temperature output and height input. However, there was little difference between the forecasts produced by using different temperature input (observed or shippers

TABLE 3. - Verification of 24-hr. mean temperature forecasts, averaged at 39 cities in the United States, in terms of the correlation coefficient between standardized values of forecast and observed anomalies.

Season	Year	Objective	Shippers
Winter	1962	.70	---
Spring	1962	.65	---
Summer	1962	.51	---
Fall	1962	.63	.69
Winter	1962-63	.69	.78
OVERALL	1962-63	.64	---

TABLE 4. - Verification of objective 48-hr. maximum temperature forecasts, averaged at 30 cities in the United States, in terms of the correlation coefficient between forecasts and observed anomalies and the mean absolute error (°F.). Forecasts were prepared 5 days per week from January 9, 1964, to February 28, 1964, from 1200 GMT data.

Height Input	Temperature Input	R	MAE
Obs. (1200 GMT)	Obs. max. yesterday	.45	7.5
Obs. (1200 GMT)	Prog. max. fcst. day	.44	7.8
24-hr. prog.	2100 GMT fcst. day	.52	7.1
24-hr. prog.	Prog. mean tomorrow	.50	6.9
24-hr. prog.	Prog. max. fcst. day	.51	6.8

forecasts). All objective forecasts were superior to persistence of the maximum temperature observed on forecast day, which produced a correlation of 0.33 and a mean absolute error of 7.8°F.

In view of the preceding results, an experiment was conducted in conjunction with the Analysis and Forecast Division of the National Meteorological Center. Objective forecasts of the maximum temperature 48 hr. in advance were prepared at 2200 GMT five days per week, from January 9 to March 31, 1964, for the 30 cities of figure 1B. As input to the regression equations, use was made of 24-hr. baroclinic prognostic heights (made at 1200 GMT) and temperatures observed at 2100 GMT on forecast day (in lieu of the actual maximum which was not available at forecast time). These objective forecasts were then supplied as guidance to experienced forecasters, who attempted to improve them by conventional methods.

The comparative verification is presented in part a of table 5. The objective and subjective forecasts were equal in accuracy in terms of the correlation between forecast and observed temperature anomalies. However, the subjective forecasts had a slightly lower mean absolute error, largely because of their smaller standard deviation (last column). It is noteworthy that the variability of the objective forecasts (standard deviation, 8.6) was almost equal to the variability of the observed temperatures (standard deviation, 8.7), thereby indicating that the inflation procedure (section 1) had accomplished its purpose [10].

The objective forecasts were also compared to two controls: (1) the shippers forecasts for maximum temperature 2 days in advance, and (2) persistence of the maximum temperature observed on forecast day. The objective forecasts were better than either control in terms of the correlation coefficient, but they had a larger mean absolute error than the shippers forecasts. This may be attributed to the small standard deviation of the latter forecasts (7.0), indicative of a tendency to "underforecast."

<u>Minimum Temperature</u> - The second part of table 5 verifies minimum temperature forecasts for 48 hr. in advance for the same cities and cases verified for the maximum. The objective minimum forecasts were prepared from the same 24-hr. baroclinic prognoses for height input and from temperatures observed at 1200 GMT on forecast day as temperature input (in lieu of the minimum on forecast day). Unfortunately no minimum temperature forecasts were made by meteorologists of the Analysis and Forecast Division during this period. However, comparison was possible with shippers forecasts of the minimum for 2 days in advance and with persistence of the minimum observed on forecast day. Table 5b shows that the shippers forecasts were considerably better than persistence, were not as good as the objectives in terms of the correlation coefficient, and had a slightly lower average error than the objectives because of a tendency to "underforecast" (standard deviations were 8.4 for objective, 6.8 for shippers, and 8.3 for observed temperature).

The results of this section indicate that the regression equations can be used to forecast daily mean, maximum, and minimum temperatures with about equal skill. The objective 48-hr. forecasts are more accurate than persistence and about equal in accuracy to subjective forecasts.

TABLE 5. - Verification of 48-hr. maximum and minimum temperature forecasts, averaged at 30 cities in the United States, in terms of the correlation coefficient between forecast and observed anomalies and the mean absolute error (°F.). Forecasts were prepared 5 days per week from January 9 to March 31, 1964, from 1200 GMT data.

Method	R	MAE	S.D
a. Maximum Temperature			
Objective	.51	7.2	8.6
Subjective	.51	6.9	8.2
Shippers	.43	6.8	7.0
Persistence	.34	8.2	8.7
b. Minimum Temperature			
Objective	.53	6.5	8.4
Shippers	.50	6.4	6.8
Persistence	.26	8.2	8.3

TABLE 6. - Input for preparation of operational maximum and minimum objective temperature forecasts for 1 to 3 days in advance.

Forecast	Temperature Input	700-Mb. Height Input
24-hr. min.	Mins. obs. yesterday	Obs. 0000 GMT today
24-hr. max.	Max. obs. yesterday	Obs. 1200 GMT today
48-hr. min.	Prog. min. for today	24-hr. prog. made 0000 GMT
48-hr. max.	Prog. max. for today	24-hr. prog. made 1200 GMT
72-hr. min.	Prog. min. for tomorrow	36-hr. prog. made 0000 GMT
72-hr. max.	Prog. max. for tomorrow	36-hr. prog. made 1200 GMT

6. ROUTINE MAXIMUM AND MINIMUM TEMPERATURE FORECASTS

Operational Aspects - The results of the experiments described above were considered sufficiently encouraging to warrant preparation of Nation-wide maximum and minimum temperature forecasts on an operational basis. Accordingly, on July 1, 1964, the National Meteorological Center began routine transmission of predicted isotherms of maximum and minimum temperature for the 48 States from 1 to 3 days in advance. The maximum temperatures are transmitted at 2344 GMT over FAX No. 117; the minimum temperatures at 1210 GMT over FAX No. 62.

All forecasts are prepared with the aid of objective guidance from the electronic computer. Multiple regression equations of the type illustrated in equation (1) are applied by allowing the 700-mb. height and surface temperature input to consist of appropriate observed or prognostic daily heights and maximum or minimum temperatures. Although the same equations are used for each forecast, the input varies in accordance with the scheme illustrated in table 6. This system is based on approximately a 2-day lag in temperature and a 1-day lag in height, with prognostic heights obtained from the three-level baroclinic model and prognostic temperatures from the shippers forecasts. The anomaly forecasts are converted to absolute temperatures using the 1931-60 climatological normals at each station [19].

Since the regression equations incorporate only the upper-air circulation pattern and initial thermal distribution, the objective predictions are modified before transmission by experienced forecasters of the National Meteorological Center on the basis of such additional factors as prognostic thickness, cloudiness, sea level pressure distribution, and frontal structure. In order to capture large-scale topographic and coastal effects, the objective forecasts are extended to an additional 37 stations (from the original 39) by assuming that the variation of anomaly between neighboring cities is negligible compared to the difference of normal temperatures. Figure 3 locates the supplementary cities and shows (by arrows) the primary stations used to make each supplemental forecast. A typical forecast map transmitted over facsimile to illustrated in figure 4. Caution should be used in interpolating on these generalized maps since sharp changes of temperature may occur in short distances because of mountains, bodies of water, air drainage, urban heat effects, snow cover, sea breezes, etc.

Verification - The maximum temperature forecasts for 1, 2, and 3 days in advance have been verified regularly each month since September 1964 at the 39 cities of figure 1A and 1C in terms of the correlation coefficient and the mean absolute error. The results are averaged for the 11-month period from September 1964 through July 1965 in table 7 and for the 3-month period from September through November 1964 in figures 5 and 6. During both periods the experienced forecasters of the National Meteorological Center were able to improve upon their objective guidance in terms of both verification statistics, but their margin of superiority decreased as the length of the forecast period increased from 1 to 3 days. The objective forecasts were better than climatology (normal) during all time periods tested, and better than both persistence and the shippers forecasts (FM) for 2 (and presumably 3) days in advance. However, they were not as accurate as

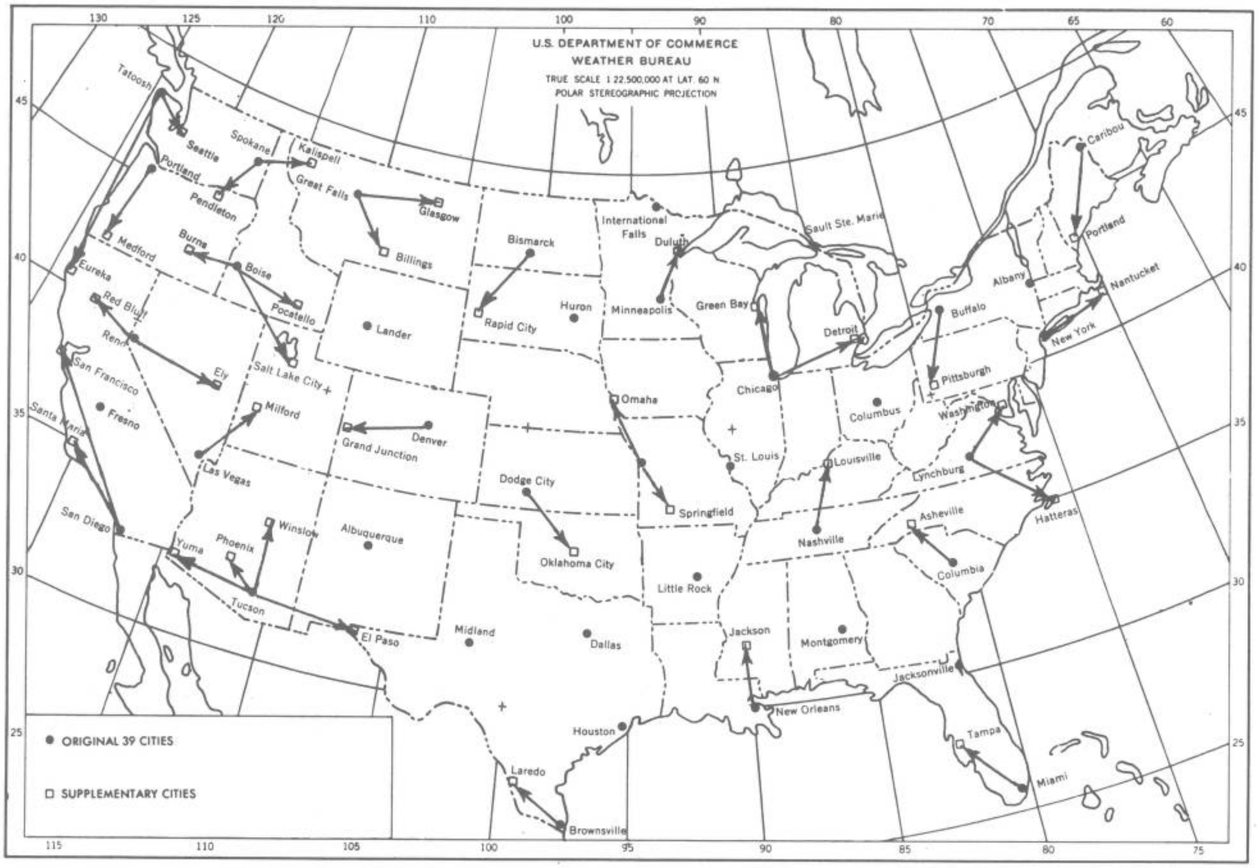

Figure 3. - Location of cities for which operational forecasts of maximum and minimum temperature have been prepared since July 1, 1964. The arrows indicate which original equation is assumed to apply at the supplementary city.

Figure 4. - A sample 48-hr. maximum temperature forecast transmitted over facsimile by the National Meteorological Center on February 2, 1965. Isotherms are labeled in °F.

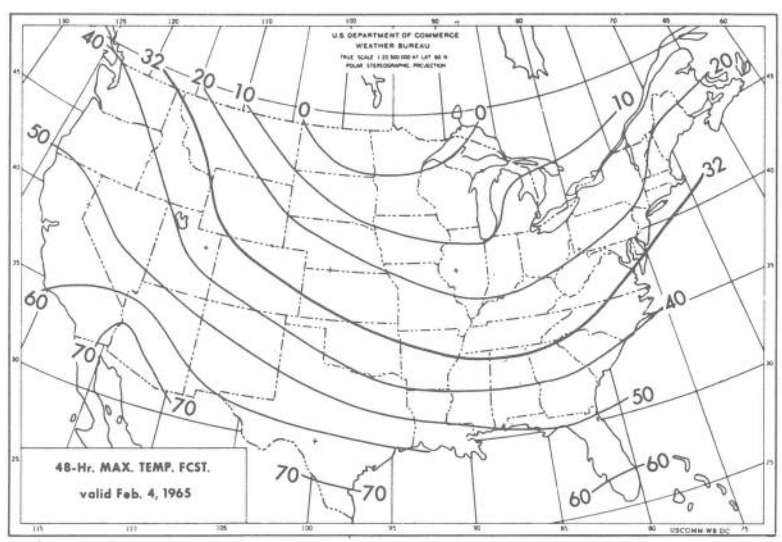

TABLE 7. - Verification of operational maximum temperature forecasts for 1 to 3 days in advance in terms of correlation coefficient and mean absolute error (°F.), averaged over 39 cities in the United States, from September 1964 through July 1965.

Forecast	24 Hours		48 Hours		72 Hours	
	R	MAE	R	MAE	R	MAE
Objective	.48	6.3	.43	6.5	.33	7.0
Subjective (NMC)	.62	5.1	.46	6.1	.36	6.9
Shippers	.55	5.5	.35	6.7	---	---
Persistence	.51	6.0	.19	8.2	---	---
Normal	---	7.1	---	7.1	---	7.1

VERIFICATION OF MAXIMUM TEMPERATURE FORECASTS
FOR FALL OF 1964

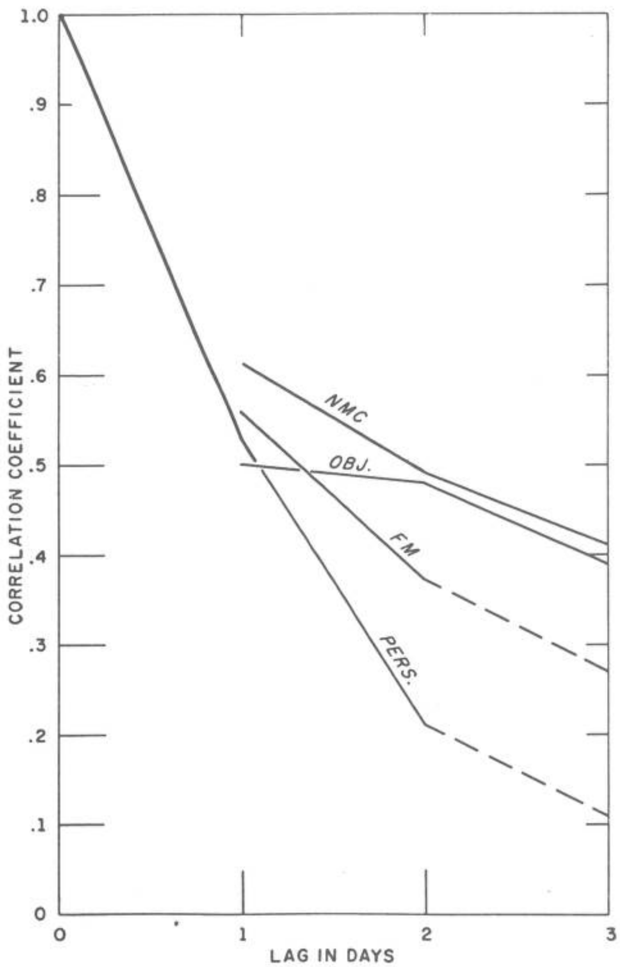

Figure 5. - Correlation coefficients between predicted and observed maximum temperatures for 1, 2, and 3 days in advance, averaged over 39 cities. The forecasts were prepared each day during September, October, and November 1964 by forecasters of the National Meteorological Center (NMC), by the objective method (Obj.), for shippers (FM), and by persistence of the maximum on forecast day (Pers.). Dashed portions of curves are extrapolated.

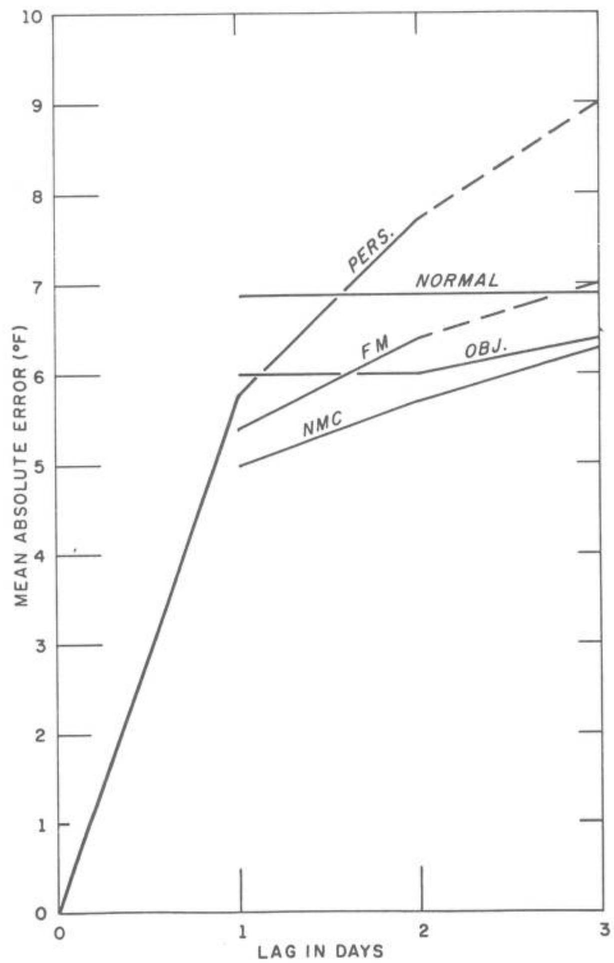

Figure 6. - Mean absolute errors of the same forecasts verified in figure 5. The average error obtained by predicting the climatological normal is also indicated.

either of the latter two controls for 1 day in advance. A similar result was noted in Section 4. This suggests a need for additional research to improve the 24-hr. objective forecasts, and the results of a pilot project along this line are presented in the next three sections.

7. SCREENING OF DAILY DATA

In the search for improved prediction equations for daily temperature, some experiments were conducted using daily data only [7]. The anomaly of daily mean temperature on forecast day (hereafter called M-0) was screened against simultaneous and preceding anomalies of 700-mb. height, sea level pressure, 700-1000-mb. thickness, and surface temperature. All temperatures were taken at the 15 winter cities of figure 1D, and all circulation parameters at the 70 grid points used in previous studies [9]. In all cases 140 winter days from 1949 to 1959 were used. The results are presented in figures 7-10 in the form of graphs showing the percent of temperature variance (EV or square of the multiple correlation coefficient), averaged at all 15 cities, explained by from 1 to 10 variables in the multiple regression equations.

Figure 7 reveals that there is no appreciable lag between temperature and thickness (lower diagram), which shows a steady decrease of EV with increasing lag from a maximum for the simultaneous (M-0) value to a minimum 5 days earlier (M-5). On the other hand, both 700-mb. height and sea level pressure do exhibit appreciable lag, with higher EV for 1 day earlier (M-1) than for M-0 day after the first or second variable. This result is in accord with the findings of Malone and Miller [11] who obtained better forecasts of daily mean temperature at Bismarck from the sea level pressure pattern for the preceding day than for the current day. It may be attributed to the time required for advection of air masses which are steered by the circulation pattern [10].

Figure 7 also reveals that for concurrent (M-0) values, thickness explains about 20-30 percent more of the daily temperature variance than does either height or pressure. Because of varying lag effects, thickness is only 5-10 percent better than height or pressure for M-1 values; and for M-2 values (2 days earlier), the difference is reversed; i.e., thickness is about 5 percent worse than height or pressure.

The preceding results can be improved considerably by including surface temperature as a predictor. This is demonstrated in figure 8, which shows the results of screening M-0 temperature as a function of M-0 height (above) or M-1 height (below), each taken in conjunction with M-1, M-2, and M-3 temperature. As expected, in each case the explained variance diminishes with increasing lag of surface temperature from a maximum on M-1 to a minimum on M-3 day. An important aspect of figure 8 is the high explained variance yielded by the curves for M-1 temperature in conjunction with 700-mb. height for either M-0 or M-1 day. Comparison with the appropriate curve in figure 7 reveals that addition of M-1 temperature increases the EV by about 30 percent over that explained by heights alone. Thus the initial field of surface temperature, by incorporating numerous local, persistence, and low-level effects, make a significant and independent contribution to prediction of daily temperature.

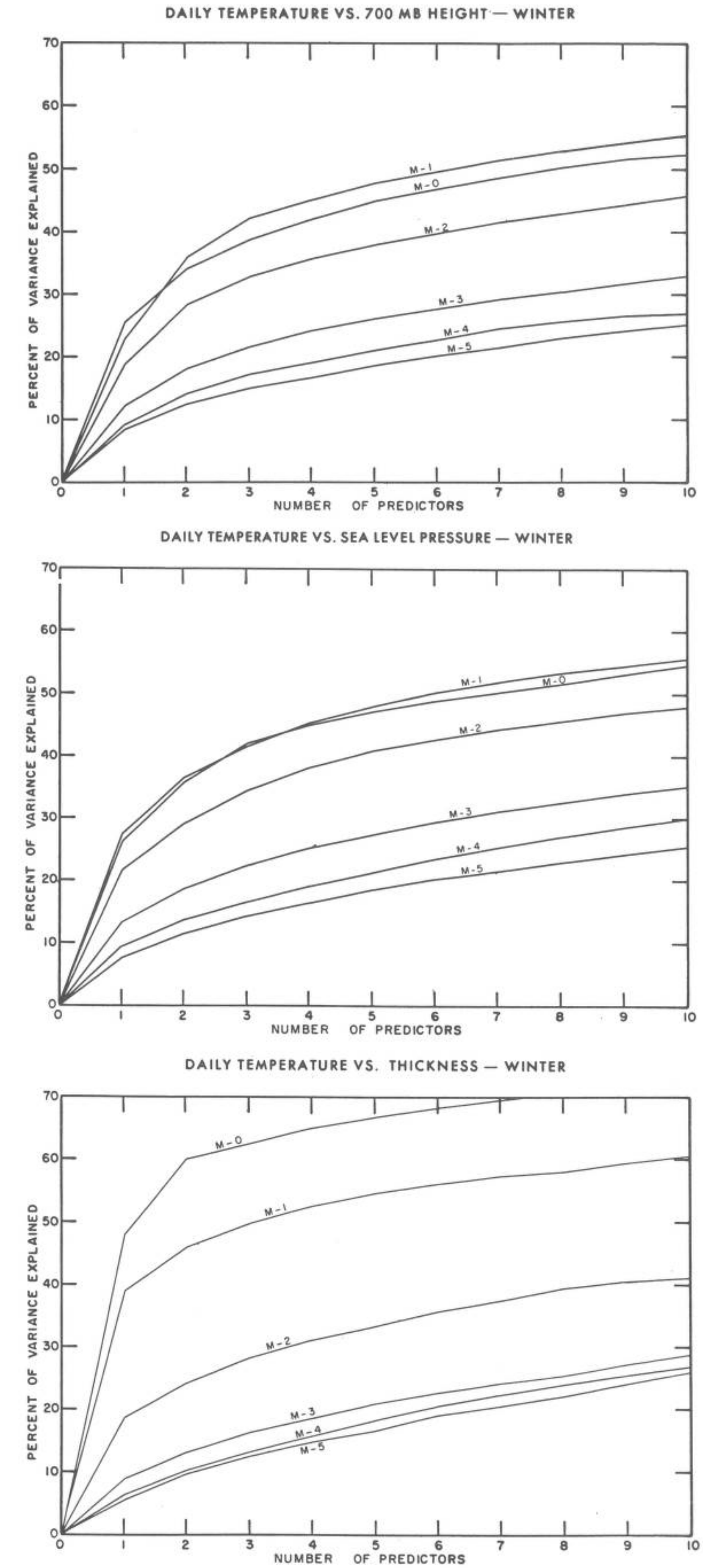

Figure 7. - Percent of variance of daily temperature anomaly in winter on M-0 day explained by the number of variables taken along the abscissa. The results are averaged over 15 cities and are shown separately for anomalies of 700-mb. height (above), sea level pressure (middle), and 700-1000-mb. thickness (below) on each of the 6 days from M-0 to M-5.

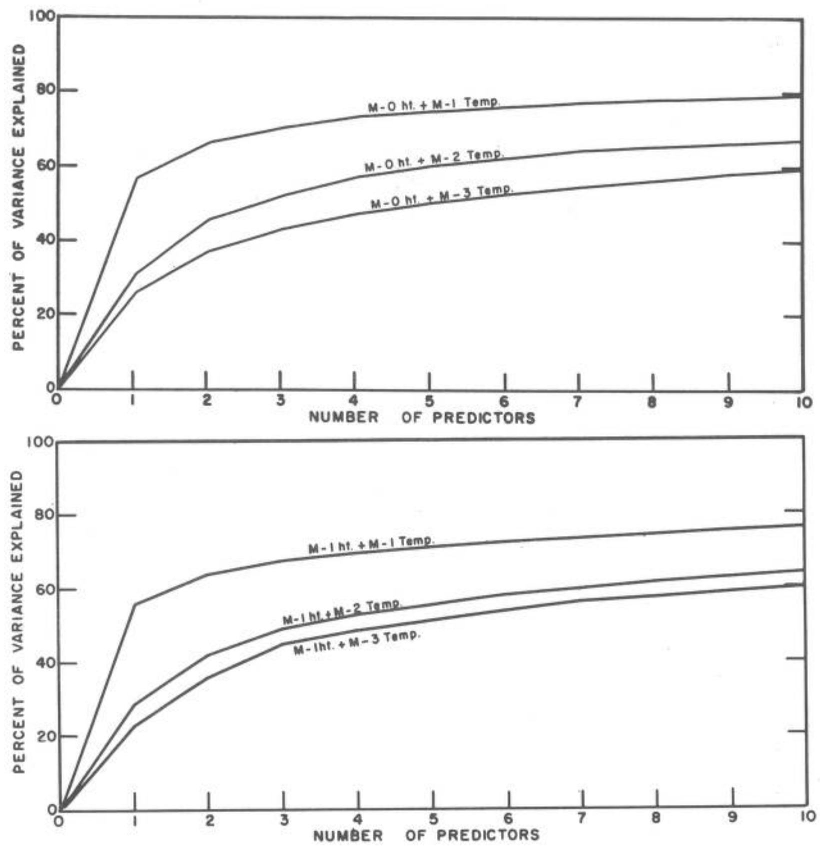

Figure 8. - Percent of variance of daily temperature anomaly in winter on M-0 day explained by the number of 700-mb. height and surface temperature predictors given along the abscissa. The results are averaged over 15 cities and are shown separately for anomalies of M-1, M-2, and M-3 temperature in conjunction with M-0 heights (above) and M-1 heights (below).

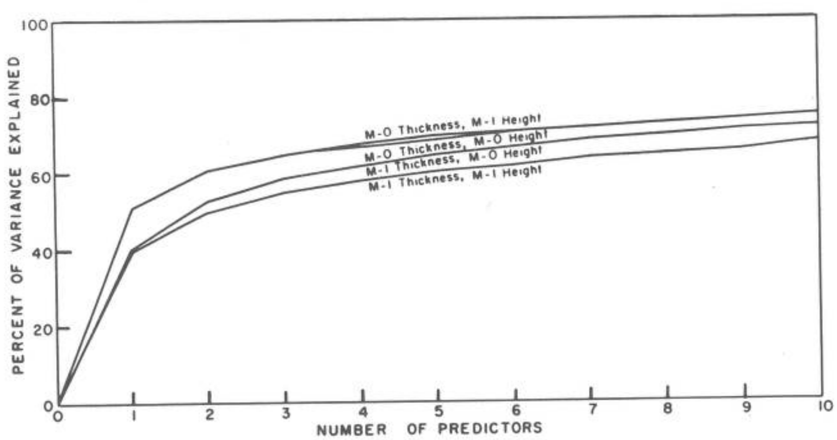

Figure 9. - Percent of variance of daily temperature anomaly in winter on M-0 day explained by the number of 700-mb. height and 700-1000-mb. thickness predictors given along the abscissa. The results are averaged over 15 cities and are shown separately for anomalies of M-0 and M-1 thickness in conjection with M-0 and M-1 height anomalies.

Figure 9 represents an attempt to substitute thickness for surface temperature in the above relationship. The M-0 temperature was screened against the four possible combinations of thickness and height for M-0 and M-1 days. Although the curves for M-0 thickness explain more of the temperature variance than those for M-1 thickness, none of the combinations in figure 9 explains as much of the variance as do the curves using M-1 temperature (fig. 8), and they give only a few percent improvement over thickness alone (fig. 7C). It therefore does not appear to be advantageous to use an objective method for temperature based upon only thickness and height, probably because they are so highly interrelated.

Figure 10 shows the results of screening the M-0 temperature against three parameters in conjunction: M-0 height, M-0 pressure, and either M-1 or M-2 temperature. As expected, the later temperature (M-1) gives better results than the earlier one (M-2). The combination of M-0 height and pressure with M-1 temperature yields higher EV than anything tested thus far, with 80 percent of the temperature variance explained by five variables.

In order to reduce the danger of statistical instability and to provide greater operational feasibility, the number of parameters in the forecast scheme was decreased from three to two by using thickness in place of height and pressure. The M-0 temperature was then screened as a function of M-0 thickness in conjunction with M-1 temperature. The results have not been reproduced because they are almost identical to those obtained from M-0 height, M-0 pressure, and M-1 temperature and plotted in figure 10. For three variables in the regression equation, the combination of M-0 thickness and M-1 temperature explained about 12 percent more of the temperature variance than M-0 thickness alone (fig. 7C) and about 5 percent more than M-0 height in conjunction with M-1 temperature (fig. 8). Therefore the thickness and temperature parameters appear to be the most promising ones to use in deriving new equations.

8. SYNOPTIC CLIMATOLOGY

The screening program, through the correlation coefficients that it furnishes, reveals useful spatial relationships between the dependent and the independent variables. In this project, correlation fields, showing the mean daily temperature anomaly as a function of the anomalies of concurrent 700-mb. height, concurrent 700-1000-mb. thickness, and mean daily temperature 1 day earlier, were plotted and analyzed for the 140 winter cases. These maps are illustrated in figure 11 for Dallas, Tex. Similar correlation fields were prepared for each of the 15 cities of figure 1D, and they are presented in the Appendix. The results are summarized in figures 12, 13, and 14, which give the location and magnitude of the centers of maximum positive correlation in the vicinity of each reference station, and are discussed below.

<u>700-Mb. Height</u> - In most of the United States surface temperatures are best related to 700-mb. heights located about 100-400 miles to the east of the station in question (fig. 12). This indicates that cold weather tends to occur in northerly flow just west of a trough and warm weather in southerly flow just west of a ridge. However, over the middle and northern Plains temperatures correlate most highly with heights about 400-600 miles to the

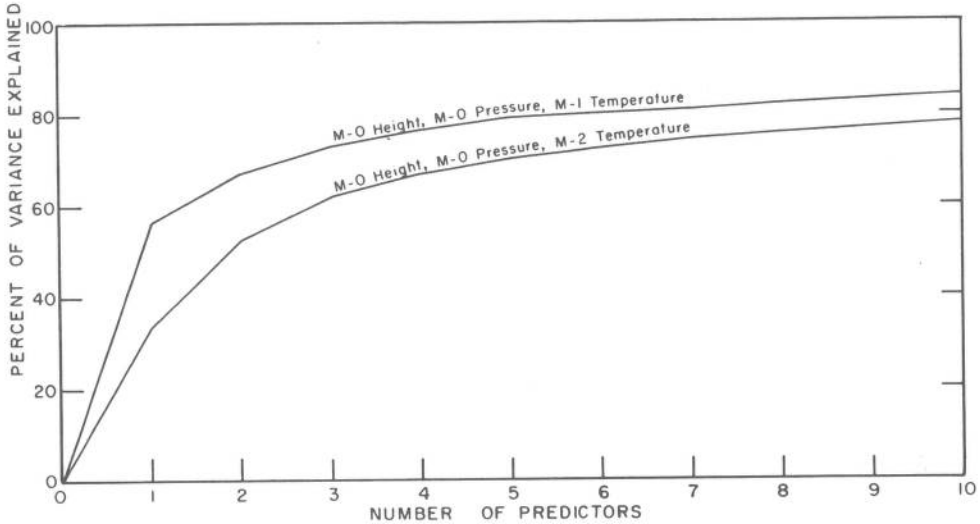

Figure 10. - Percent of variance of daily temperature anomaly in winter on M-0 day explained by the number of 700-mb. height, sea level pressure, and surface temperature predictors given along the abscissa. The results are averaged over 15 cities and are shown separately for anomalies of M-0 height and pressure in conjunction with anomalies of M-1 temperature (above) and M-2 temperature (below).

southwest. This was also noted for 5-day mean data [7] and is probably related to orographic effects.

In the southern and central Plains the magnitude of the positive correlation in the vicinity of the station is quite small. However, another correlation center, negative in sign, but larger in absolute magnitude, is usually located about 1500 miles to the northwest, as illustrated in figure 11A for Dallas. This implies that 700-mb. heights in the western portions of Canada and the United States exercise more control over winter temperatures in Texas, Oklahoma, and Kansas than do local heights. A similar finding was noted earlier for 5-day mean data by Martin and Hawkins [12] and by Klein et al. [10].

700-1000-Mb. Thickness - At all of the 15 cities studied, surface temperature is more closely related to 700-1000-mb. thickness (fig. 13) than to 700-mb. height (fig. 12). Differences are small in the mountainous west but are very large in the Great Plains. Here the correlations between temperature and thickness are high, but the correlations between temperature and 700-mb. height are low. As a single predictor of temperature over the Plains, thickness obviously would give better results than height.

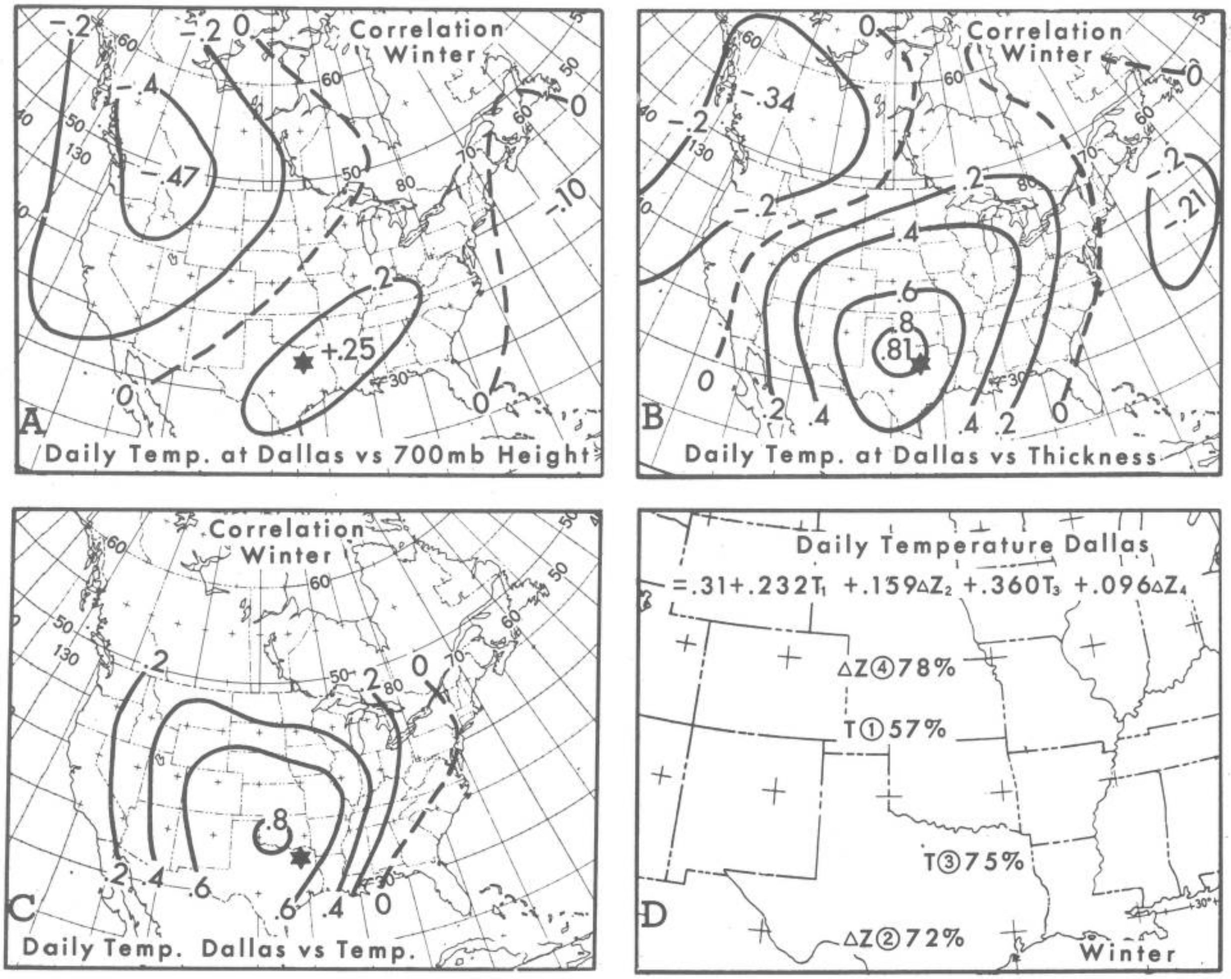

Figure 11. - Correlation fields between anomalies of mean daily temperature at Dallas, Tex. (located by the star) for 140 winter cases and (A) 700-mb. height on the same day; (B) 700-1000-mb. thickness on the same day; (C) mean daily temperature on the previous day. Part D illustrates the multiple regression equation derived by screening. T is the temperature anomaly in °F, ΔZ is the thickness anomaly in tens of feet, and the explained variance after inclusion of each variable is given in percent.

In the eastern half of the United States temperatures are best related to thicknesses located about 50-250 miles to the west (fig. 13), rather than to the east as was noted for 700-mb. heights (fig. 12). This difference agrees with the well known fact that on the average thickness waves lag 700-mb. height waves by about 400 miles [14, 20]. In the intermountain region of the West temperatures are best correlated with the thickness located about 500 miles to the south, probably because of topographic effects. This indicates the advantage of considering the entire field of thickness in predicting temperature, rather than just local values (at the same point) as were used by Showalter [16] and by Allen and Ellis [1].

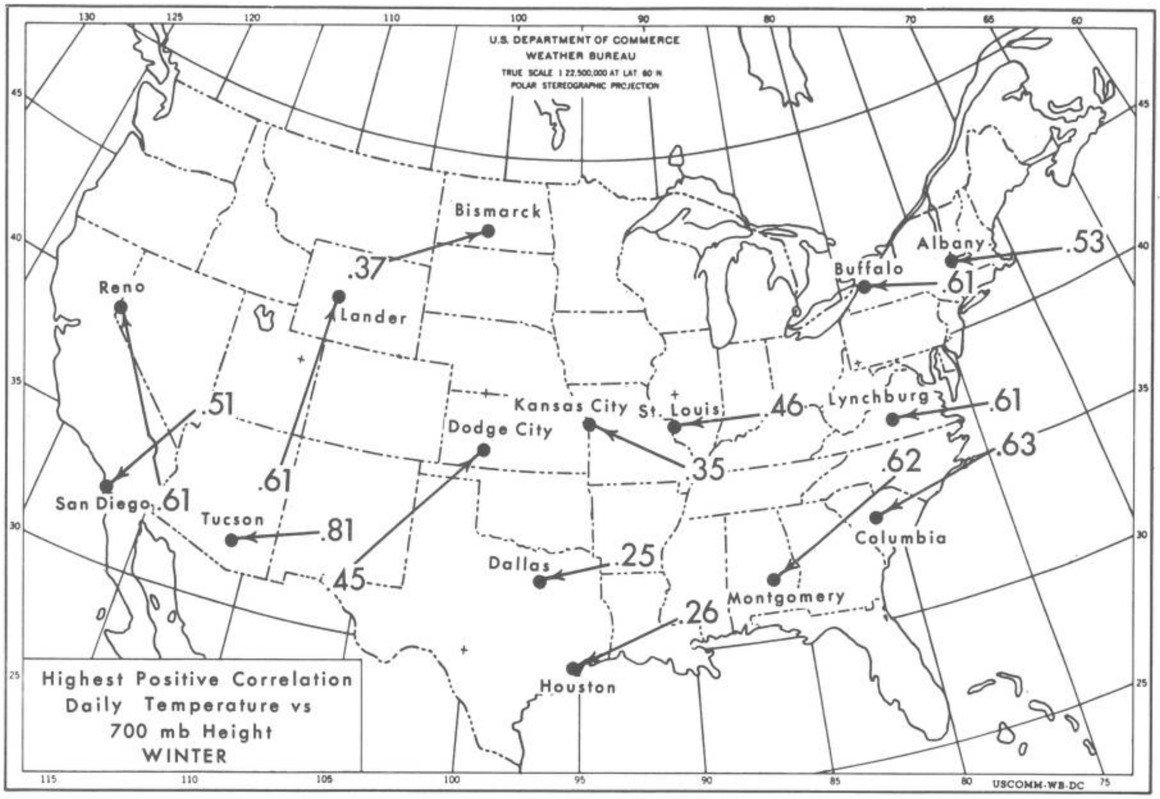

Figure 12. - Center and magnitude of maximum positive correlation between anomalies of mean daily temperature at the cities indicated and 700-mb. height on the same day for 140 winter cases.

Temperature - The correlation coefficients between surface temperature and temperature 1 day earlier (fig. 14) are generally as high (or higher) than those between temperature and concurrent thickness (fig. 13), as illustrated in figure 11 for Dallas. The magnitudes of the maximum correlations are quite uniform (around 0.8), indicating no significant geographical variation.

In the eastern United States, the Midwest, and the central Rocky Mountain region, temperatures are most highly related to temperatures 1 day earlier located about 150-350 miles to the west or westnorthwest (fig. 14). In Texas the location of the highest correlation is more to the north than in other areas, probably reflecting the prevalence of strong cold outbreaks directly from the north in this region in the wintertime.

At Tucson persistence of local temperature is dominant. Little can be said about the western and northern peripheral areas because no temperatures were used outside of the United States. In general these results are similar to those noted earlier for 5-day mean temperatures by Klein et al. [9].

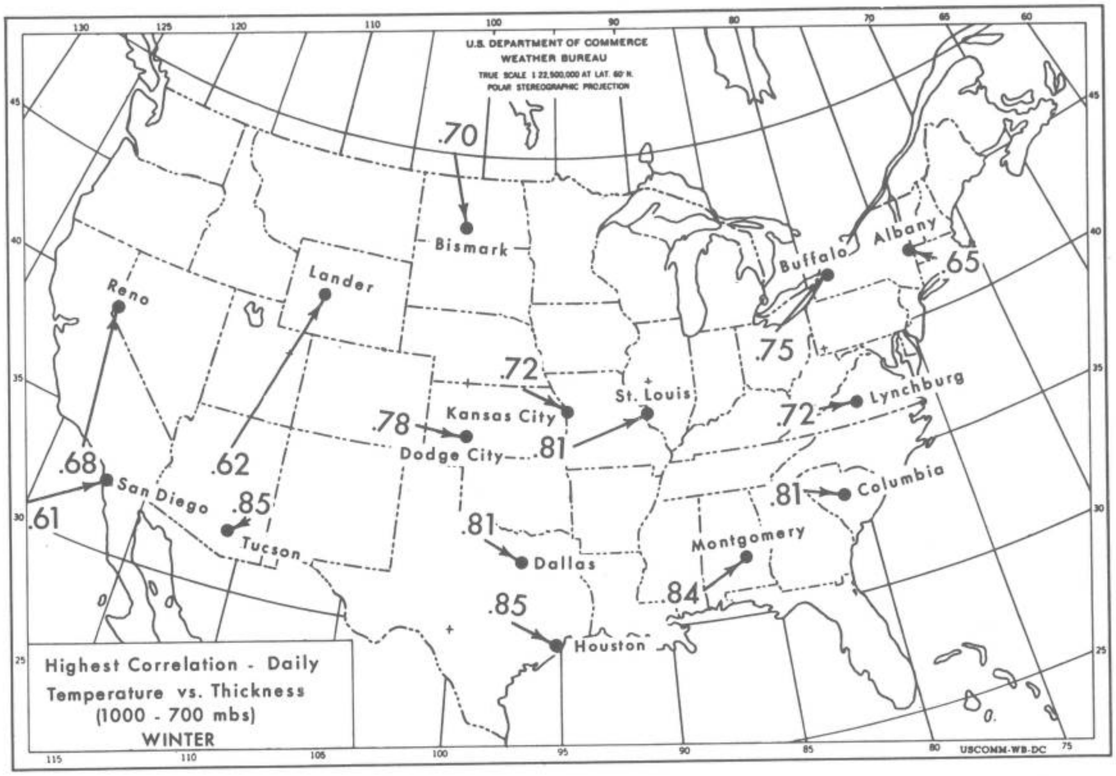

Figure 13. - Center and magnitude of maximum correlation between anomalies of mean daily temperature at the cities indicated and 700-1000-mb. thickness on the same day for 140 winter cases.

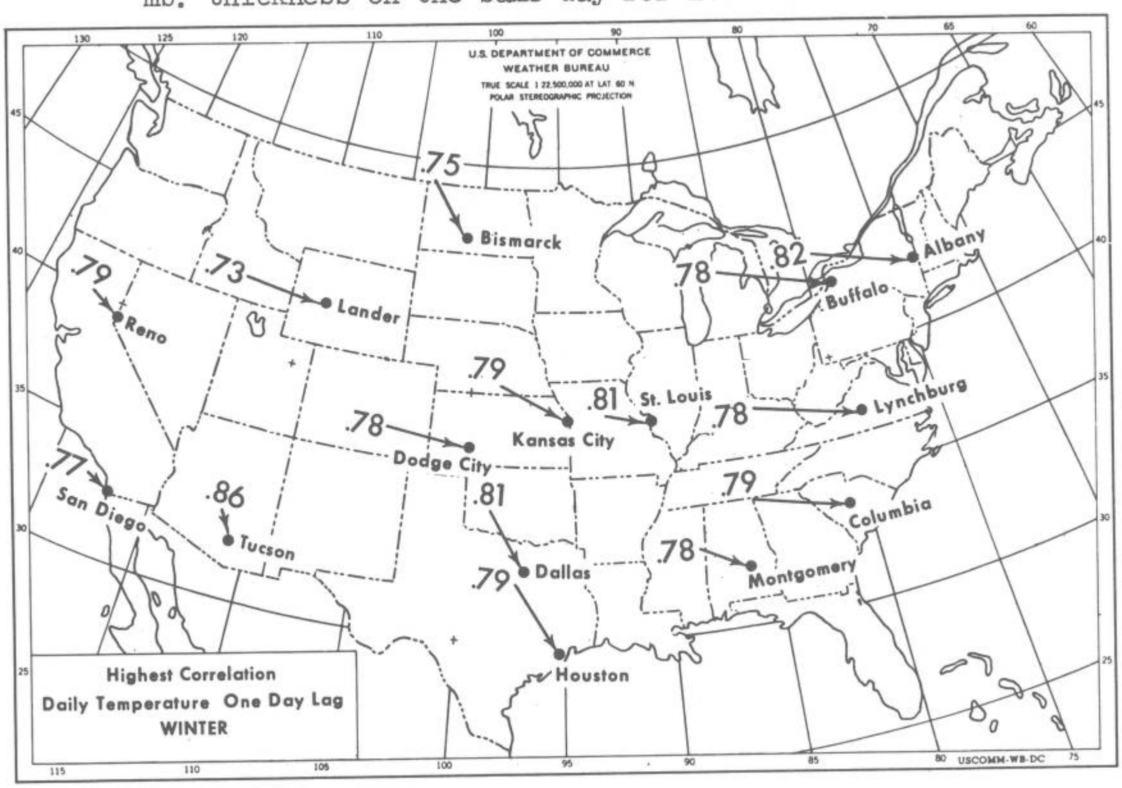

Figure 14. - Center and magnitude of maximum correlation between anomalies of mean daily temperature at the cities indicated and mean daily temperature on the previous day for 140 winter cases.

9. NEW PREDICTION EQUATIONS

Development - In view of the results of Sections 7 and 8, a set of multiple regression equations was selected which gives the anomaly of daily mean temperature as a function of anomalies of the fields of concurrent daily 700-1000-mb. thickness and the preceding day's temperature. An example is illustrated in figure 11D, where the first predictor selected is the initial temperature anomaly at Dodge City, Kans., which explains 57 percent of the next day's temperature variance at Dallas, Tex. The second predictor selected is the thickness anomaly of the same day in southern Texas, which raises the explained variance to 72 percent. The third variable is the initial temperature anomaly at Dallas, resulting in 75 percent EV, and the fourth is the concurrent thickness anomaly in northwestern Kansas, raising the EV to 78 percent. The screening process was stopped at this point with the multiple regression equation given at the top of figure 11D, where units are °F. and tens of feet.

Similar equations were derived at each of the stations of figure 1D. For all 15 cities combined, these equations explain 77 percent of the variance by means of three predictors, of which half are thickness and half temperature. At all but three cities the equations incorporate persistence of local temperature; at all but five cities initial temperature at a station west or north of the reference point is also used as a predictor.

At all 15 cities at least one thickness is selected. These thickness predictors are generally located in the vicinity of the reference city, as would be expected on physical grounds. As a result, although thickness was screened at 70 grid points, it is needed at only 15 points, all located in the continental United States between 30°N. and 50°N. and 80°W. and 120°W. Thus these equations make good synoptic sense and contain a relatively small number of terms. They can therefore be expected to prove quite stable in tests on independent observed data.

Verification - The equations described above were tested under operating conditions each day during the period from January 9 to March 31, 1964, the same period verified in table 5. They were applied to predict the maximum temperature approximately 24 hr. in advance by using as input the maximum temperature expected on forecast day (obtained from the shippers forecasts) and the National Meteorological Center's 24-hr. prognostic thickness based on 1200 GMT data (obtained by combining the numerically-predicted 700-mb. height with the subjectively-predicted sea level pressure). The resulting "new objective" forecasts are verified in line 1 of table 8 for all 15 cities combined in terms of the correlation coefficient between forecast and observed anomalies and the mean absolute error.

The following six control forecasts were verified for comparison:

1) Objective forecasts based on new equations, similar to those illustrated in figure 11D, but derived from 700-mb. heights instead of thickness, and made using the latest heights, observed at 1200 GMT on forecast day, as input.

2) The "old objective" forecasts based on the 5-day mean equations (like equation (1) and the method described in Section 6.

3) Persistence of the maximum temperature observed on forecast day (which was not known when the forecasts were made).

4) Persistence of the maximum temperature observed the day before forecast day.

5) Persistence of the shippers forecasts for the maximum expected on forecast day.

6) The shippers forecasts for the next day's maximum.

Table 8 shows that the new objectives were superior to the first five control forecasts in terms of both statistics verified. However, there was little to choose between the new objective and the last control. One reason is the conservatism of the shippers forecasts noted previously (Section 5). This shows up in their small forecast standard deviation, given in the last column of table 8 (6.8), compared to the standard deviation of the new objective forecasts (9.7) or the observed temperatures (9.6). If the shippers forecasts had had the observed variability, their mean absolute error would probably have exceeded that of the new objectives. In any case, the new objective 24-hr. forecasts appear to be at least as good as subjective forecasts prepared by experienced meteorologists.

TABLE 8. - Verification of 24-hr. maximum temperature forecasts, averaged at 15 cities in the United States, in terms of correlation between forecast and observed anomalies, mean absolute error (°F.), and forecast standard deviation (°F.), for period January 9 - March 31, 1964.

Forecast	R	MAE	S.D
New Objective (prognostic thickness)	.65	6.4	9.7
New Objective (observed height)	.62	6.5	9.4
Old Objective	.60	6.7	8.7
Persistence (today)	.58	6.9	9.6
Persistence (yesterday)	.34	8.5	9.5
Shippers (today)	.52	7.2	9.6
Shippers (tomorrow)	.64	6.2	6.8

10. CONCLUSION

The results presented in this paper show that it is feasible to prepare objective temperature predictions on a daily basis for 1, 2, 3, 4, and 5 days in advance. This can be done by means of an iterative scheme somewhat as follows: For 24-hr. prediction, apply specification equations derived from M-0 thickness and M-1 temperature to a 24-hr. thickness prognosis and to temperatures observed on forecast day. For 48-hr. prediction, apply the same specification equations to a 48-hr. thickness prognosis and to temperatures for the day after forecast day predicted by the objective 24-hr. prediction. For 72-hr. prediction, apply prediction equations derived from M-1 heights and M-1 temperatures to 48-hr. forecasts of height made numerically and of temperature prepared objectively. For 96-hr. prediction, apply the same prediction equations to 72-hr. forecasts of height prepared numerically and temperature prepared objectively. For 120-hr. prediction, apply the same prediction equations to 96-hr. forecasts of numerical height and objective temperature. In order to prevent a steady decrease in the variability of the daily objective predictions with time, they can be inflated to the observed variability [10] before being used as input to predict the next day's temperature. A 5-day mean forecast can then be obtained by simply taking the mean of the five daily objective temperature predictions.

In order to implement the above scheme and obtain improved objective forecasts, daily data for 16 years, from 1948 to 1963, of temperature, height, and thickness taken at a finer grid than used previously are now being assembled. During the second half of 1965 new prediction equations will be derived from these data for 108 cities in the United States, for maximum and minimum temperatures taken separately, and for each two months of the year. These equations will be incorporated into the computer operations of the National Meteorological Center so that improved temperature predictions will be available on a routine and Nationwide basis.

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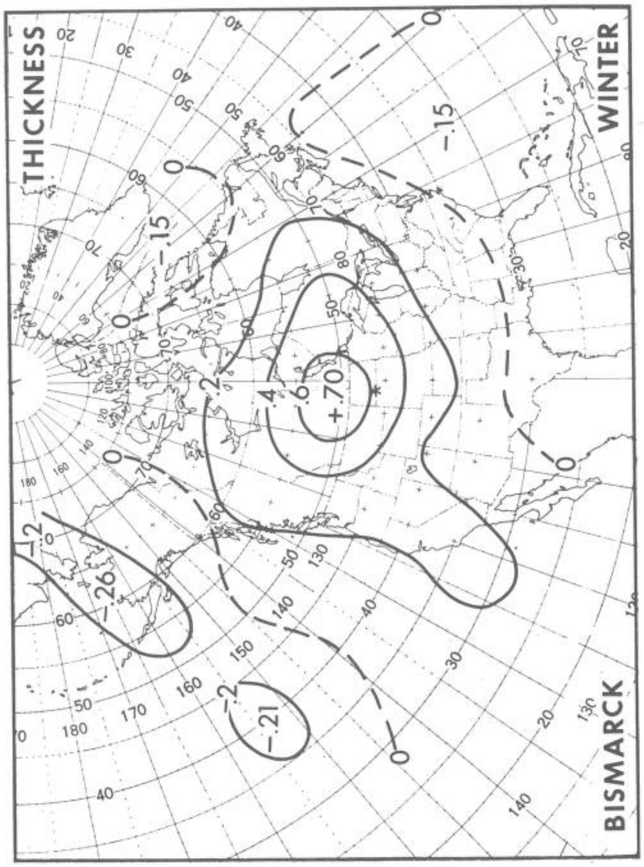
APPENDIX

The appendix presents correlation fields like those of figure 11 between anomalies of mean daily temperature at the 15 cities of figure 10 (arranged alphabetically) and (A) 700-mb. height on the same day; (B) 700-1000-mb. thickness on the same day; and (C) mean daily temperature on the previous day.

The isopleths of equal correlation are labeled, and the central value denotes the maximum (interpolated) correlation coefficient.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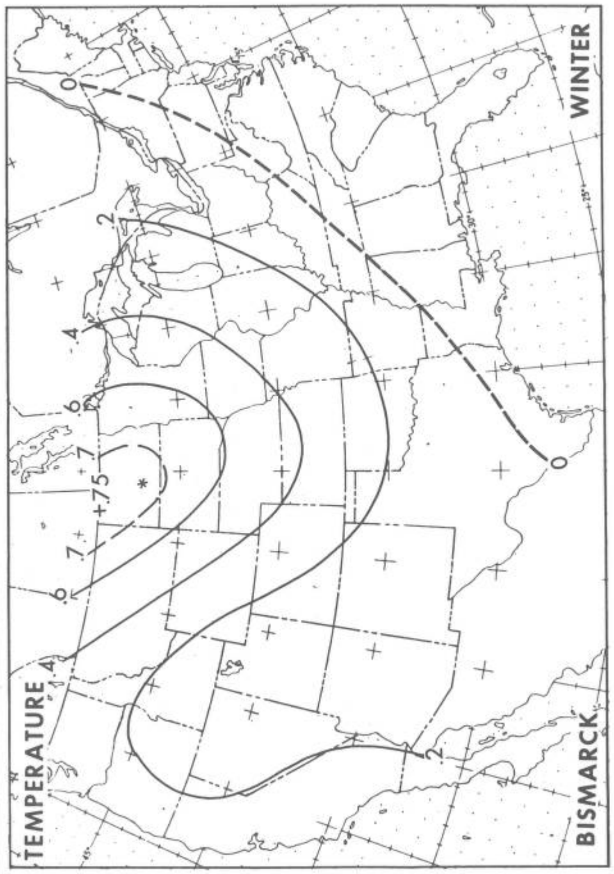
BISMARCK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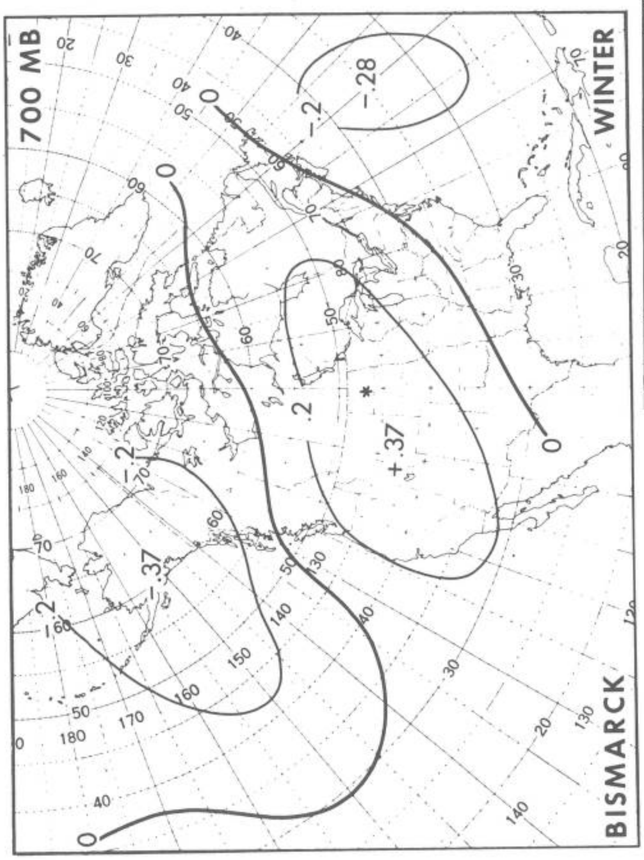
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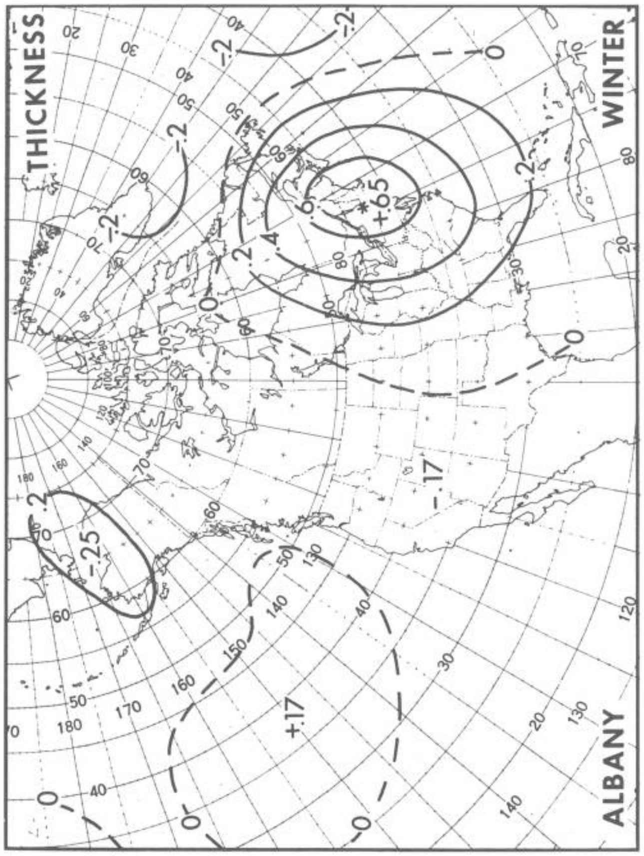
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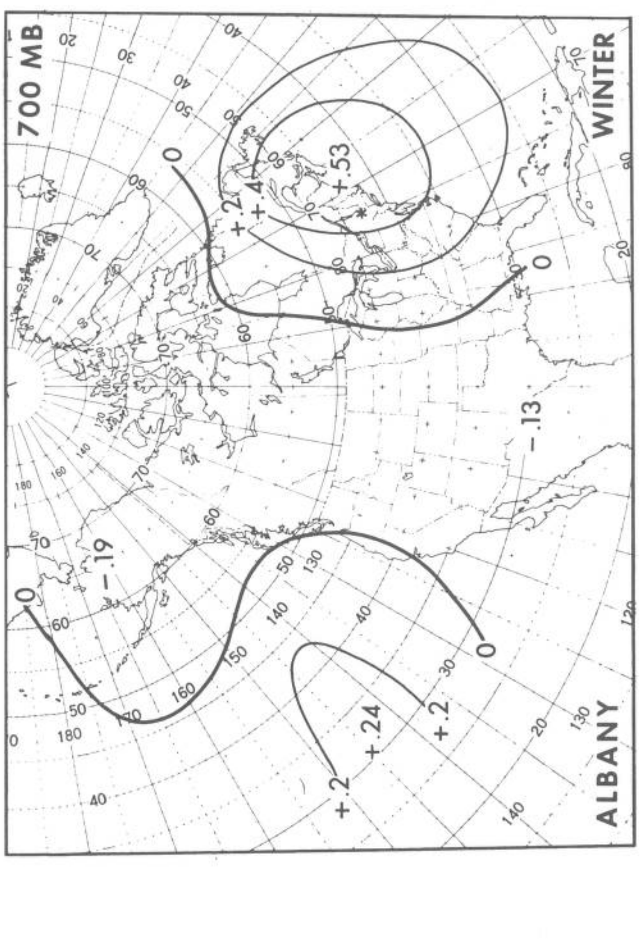
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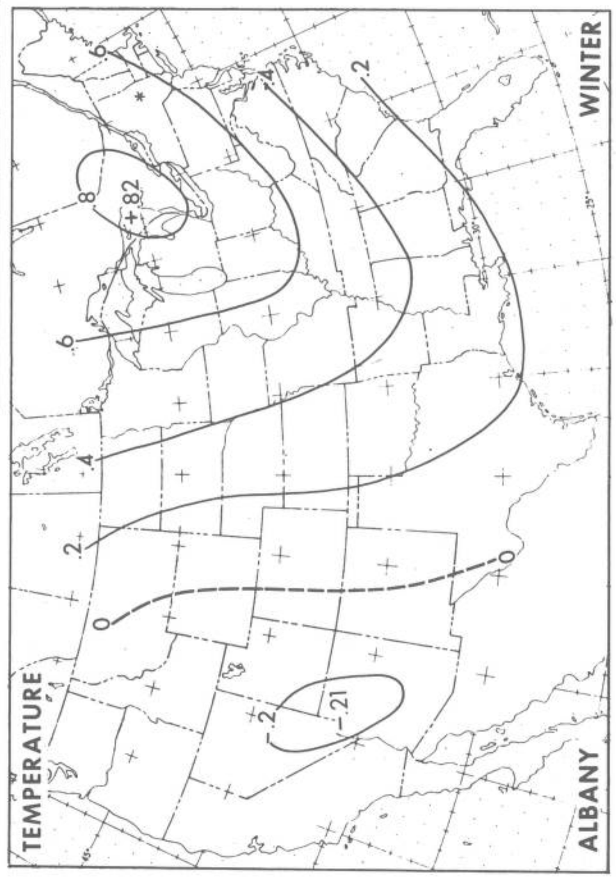
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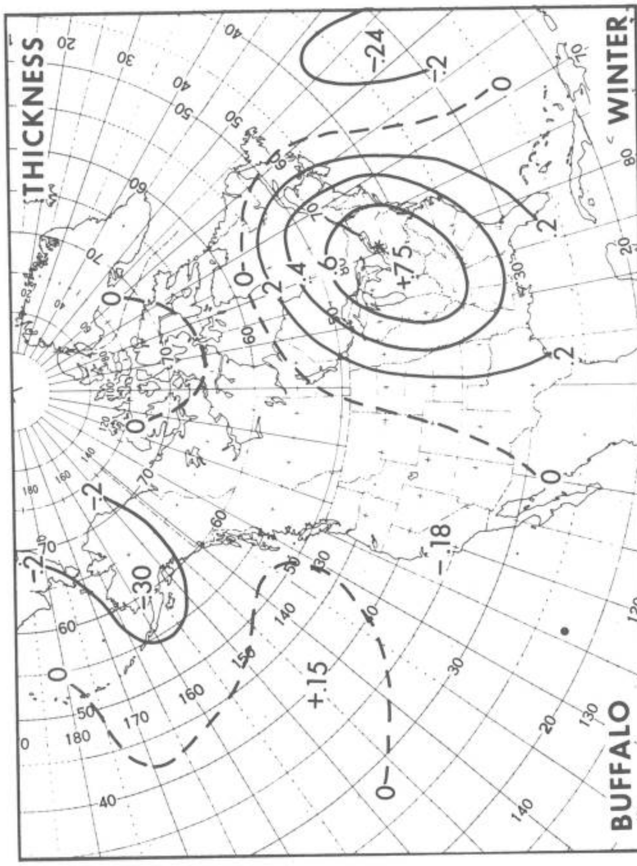
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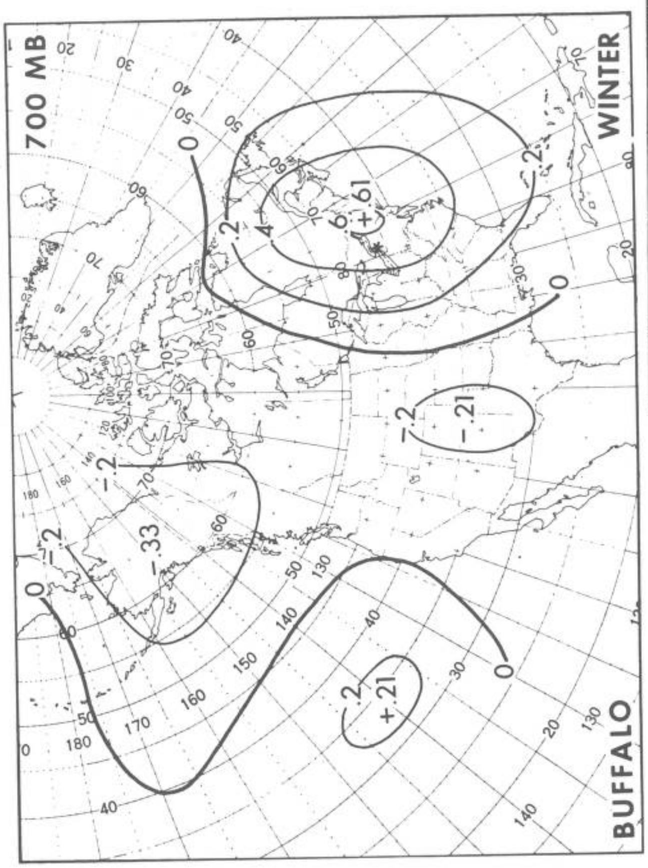
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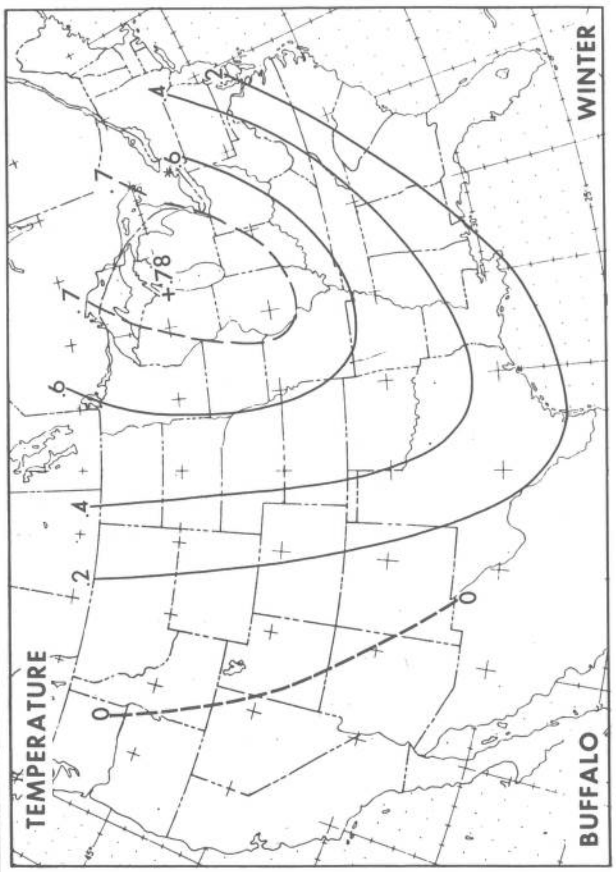
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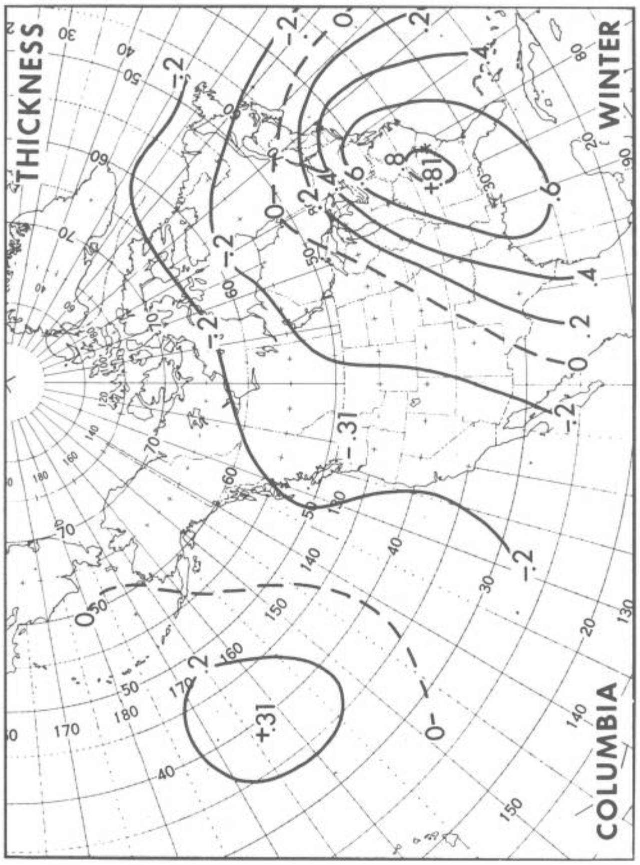
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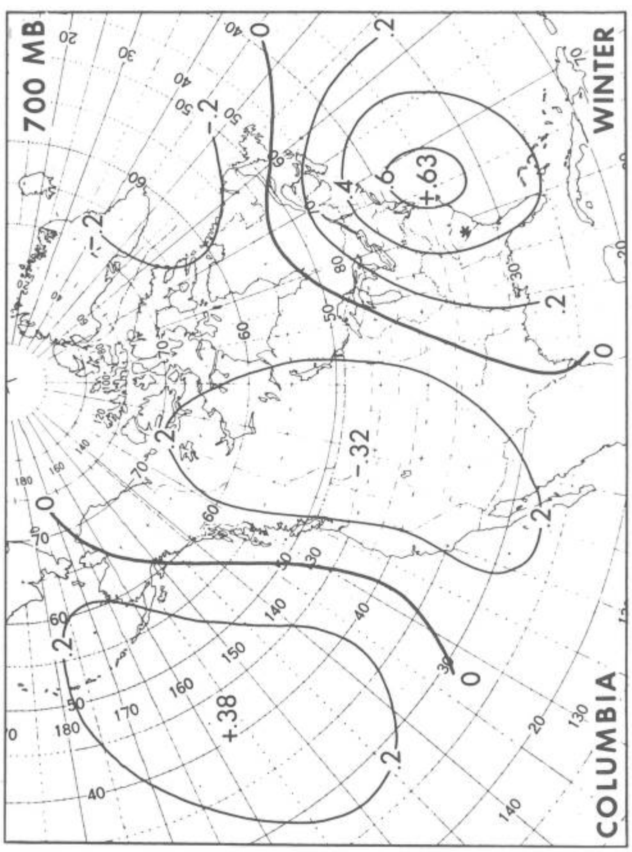
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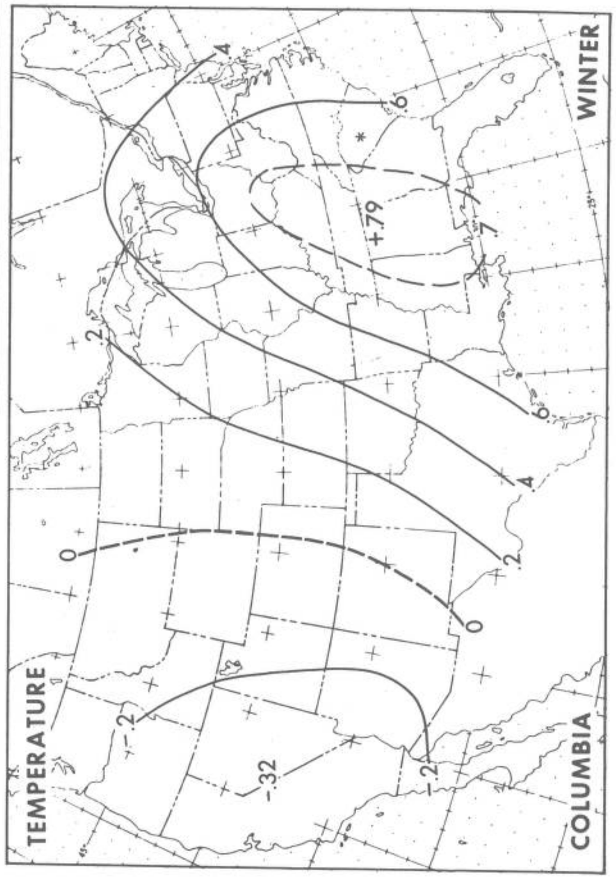
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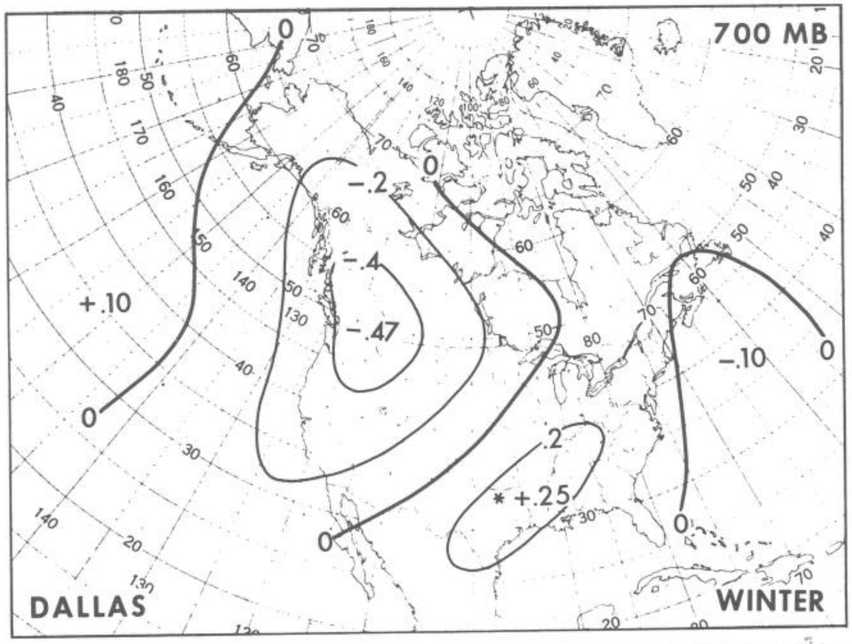
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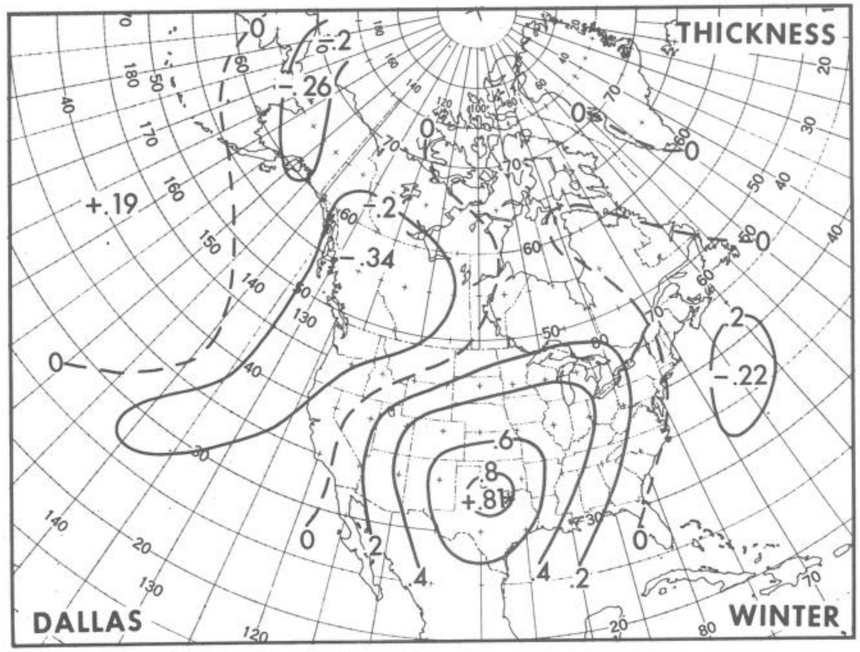
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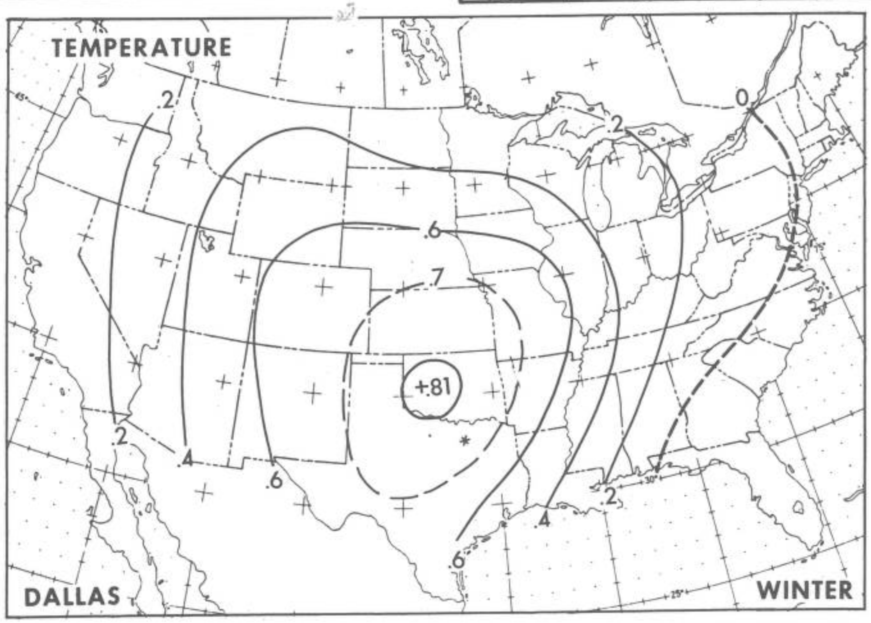
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DALLAS
WINTER
+.81
.7
.6
.4
.2
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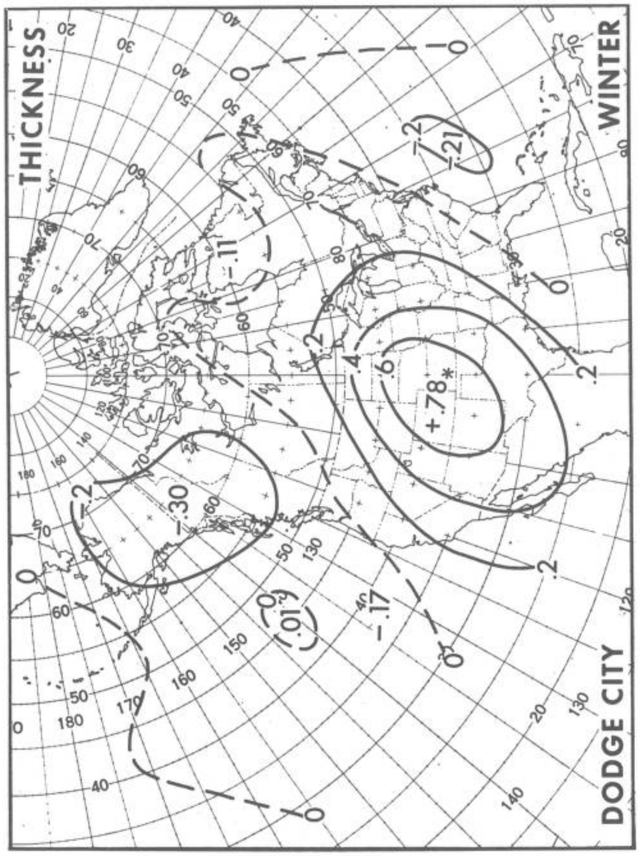
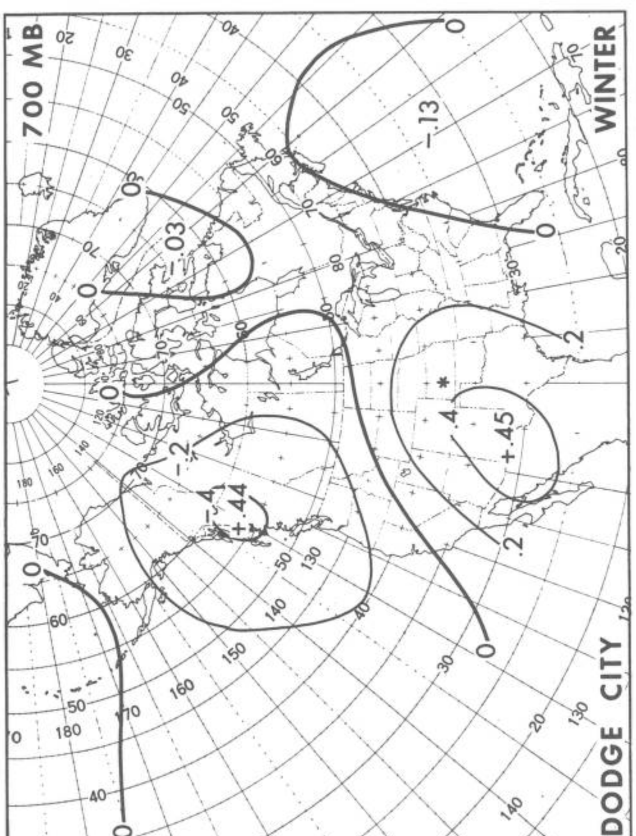

THICKNESS
WINTER
DODGE CITY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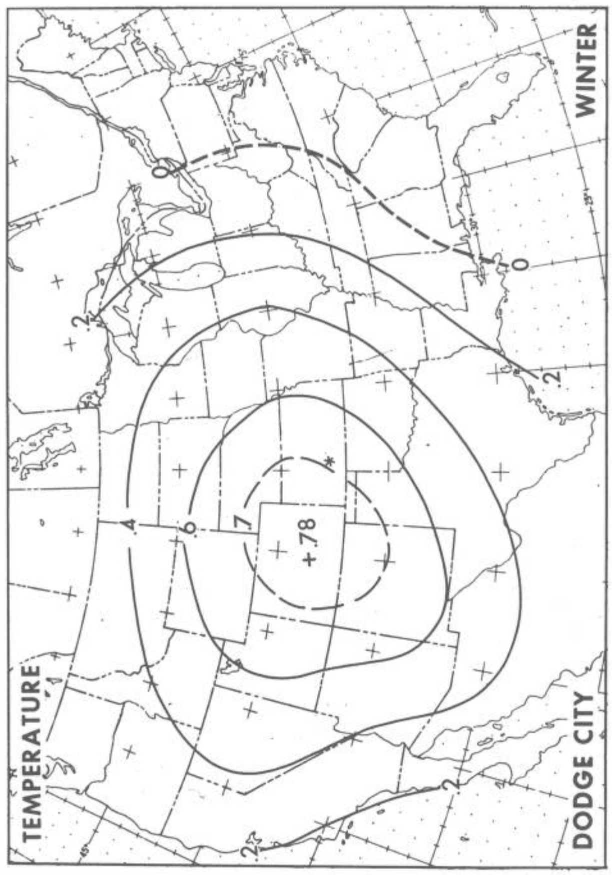
DODGE CITY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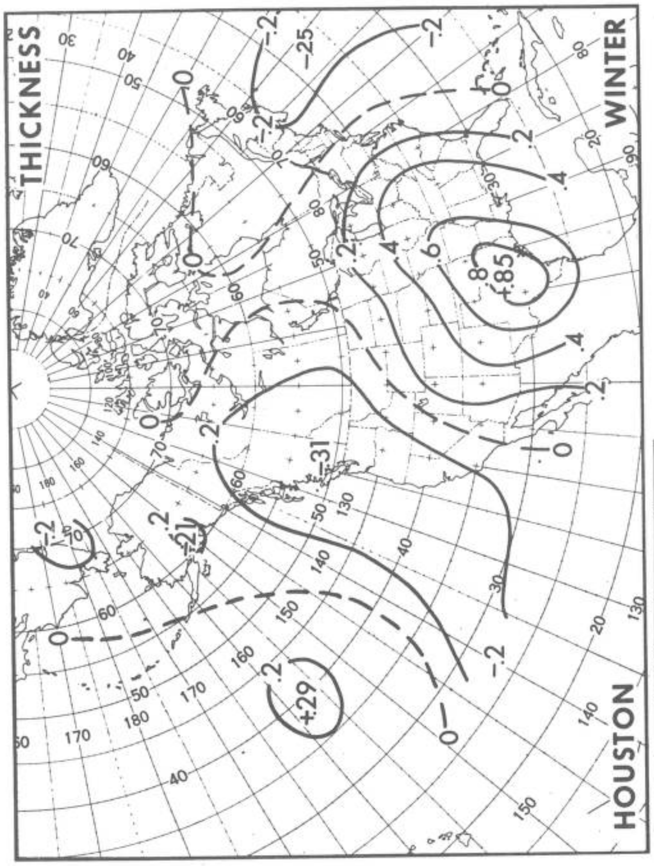
DODGE CITY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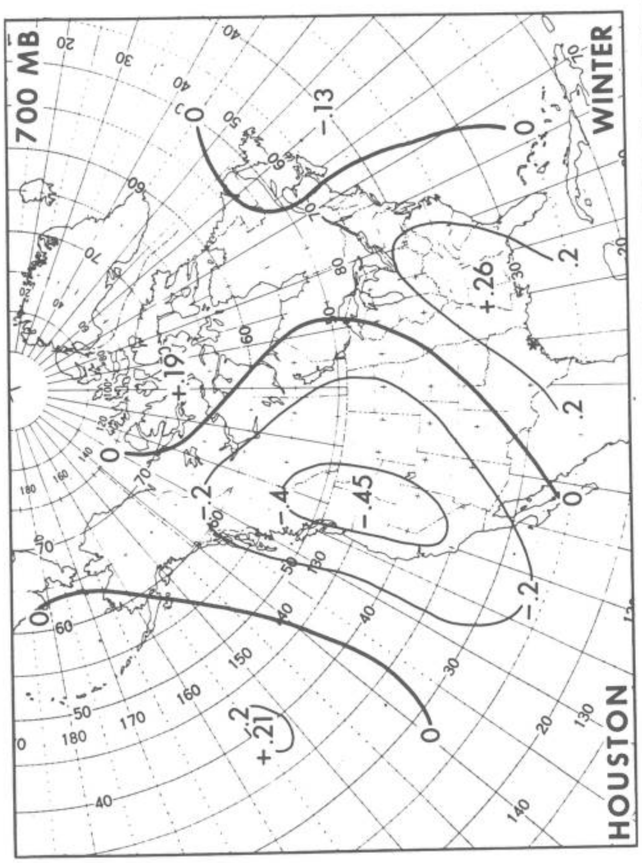
WINTER
HOUSTON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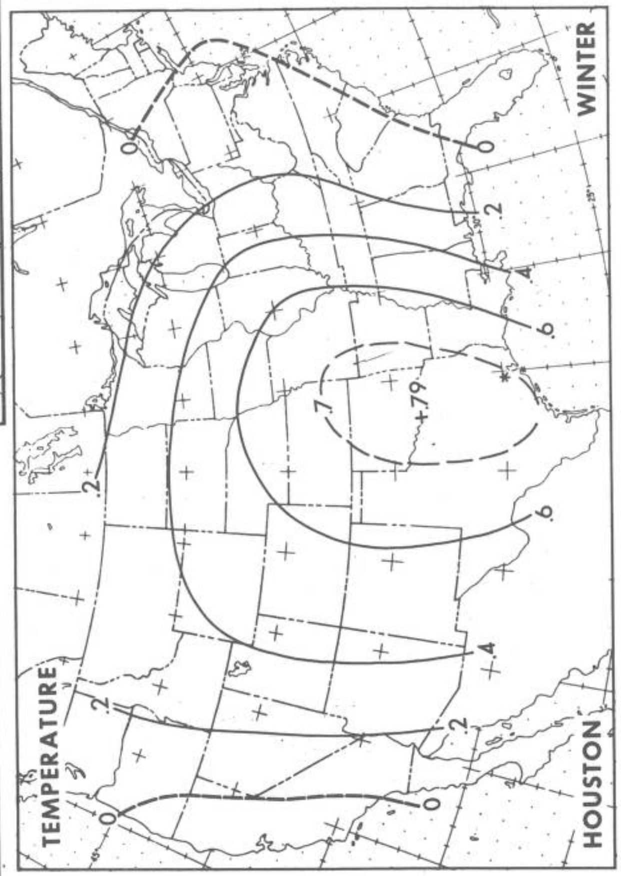
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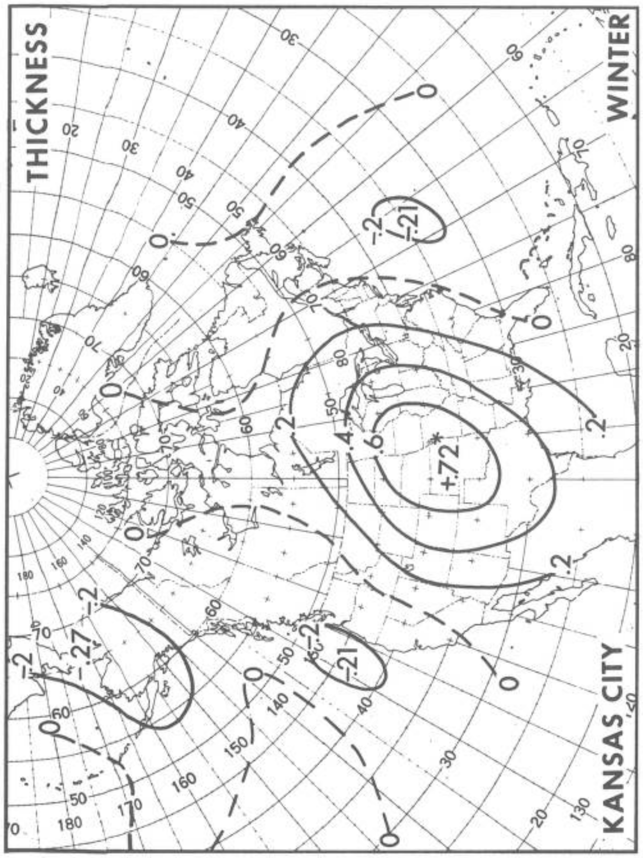
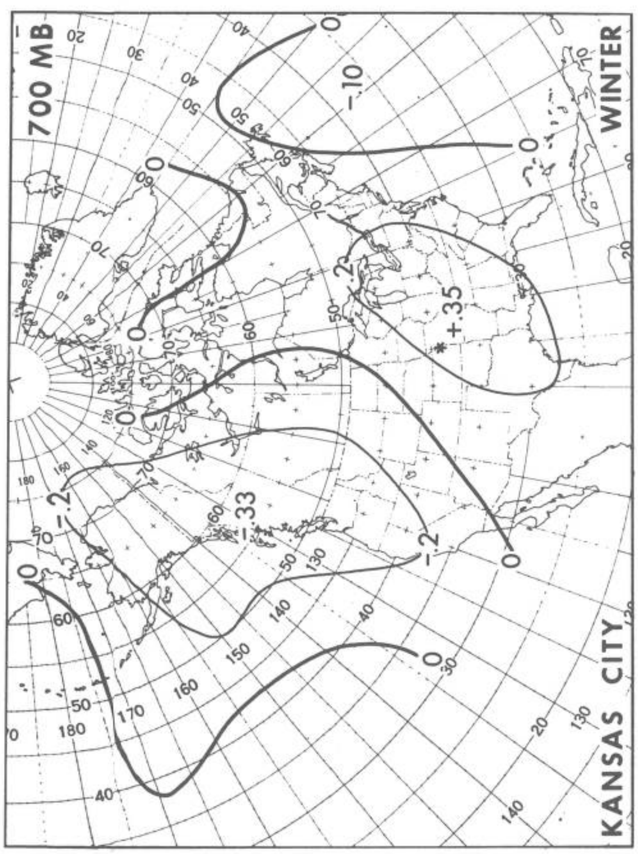
WINTER
HOUSTON


THICKNESS
WINTER
KANSAS CITY
+.72
-.21
-.27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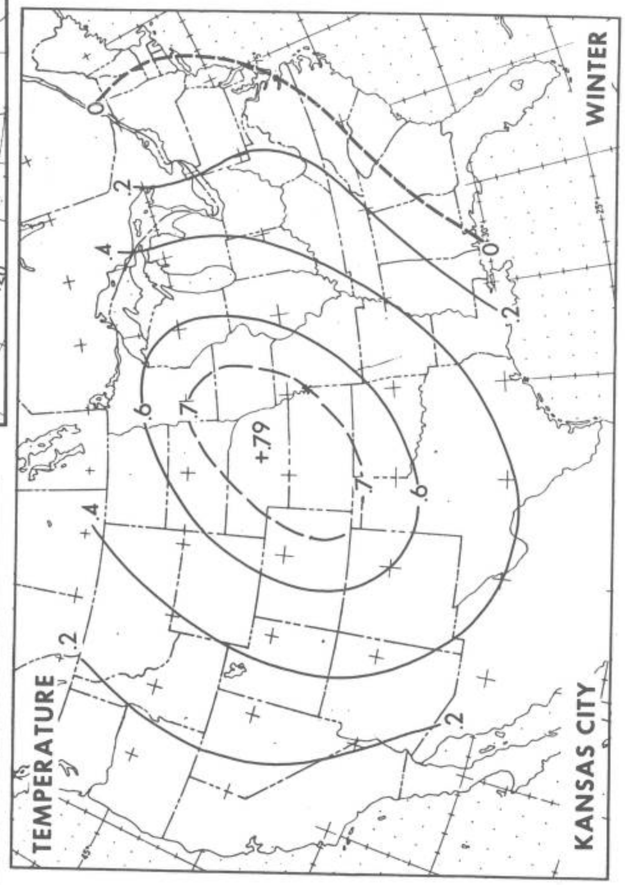
WINTER
KANSAS CITY
+.35
-.33
-.10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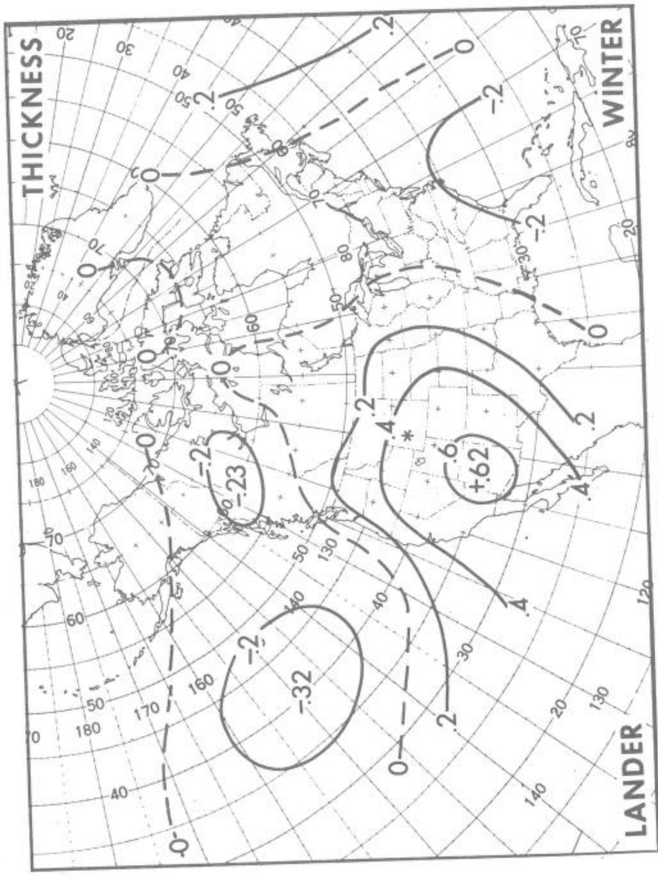
WINTER
KANSAS CITY
+.79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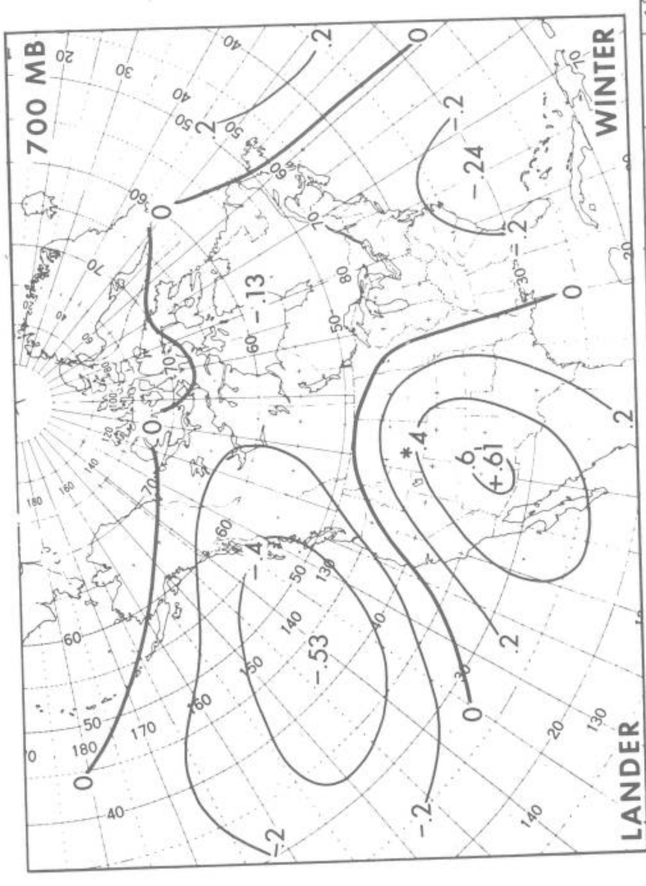
WINTER
LANDER
+.62
-.23
-.32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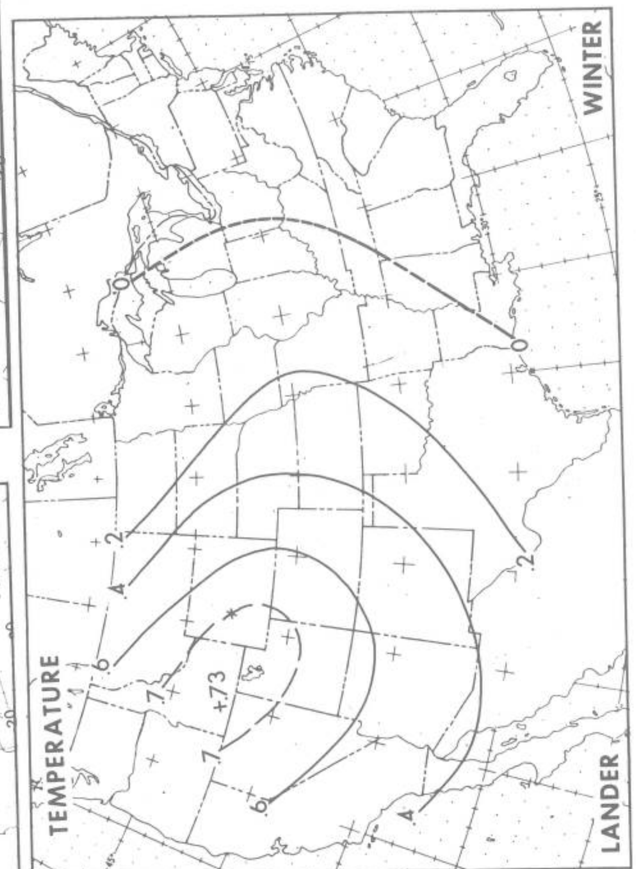
LANDER
+.61
-.53
-.24
-.13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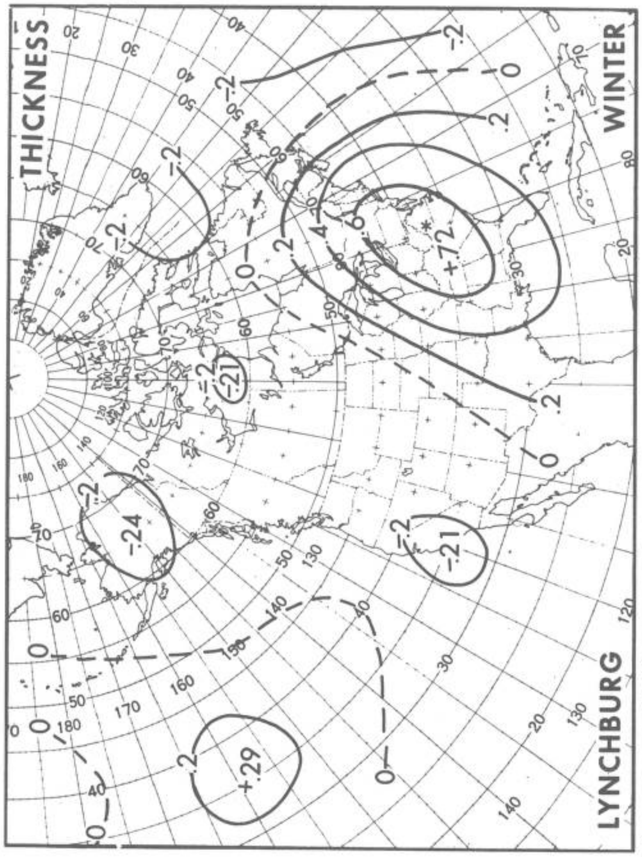
WINTER
LANDER
+.73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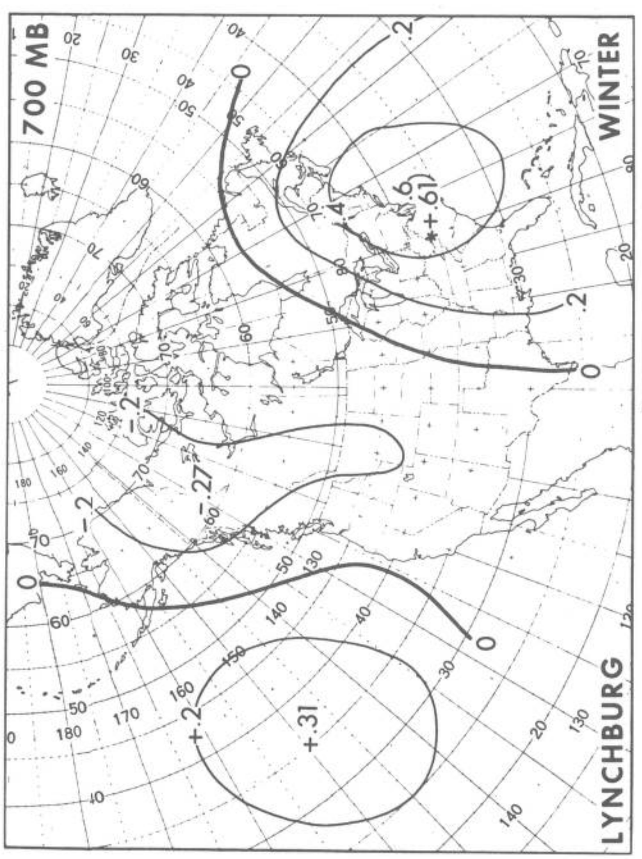
WINTER
LYNCHBURG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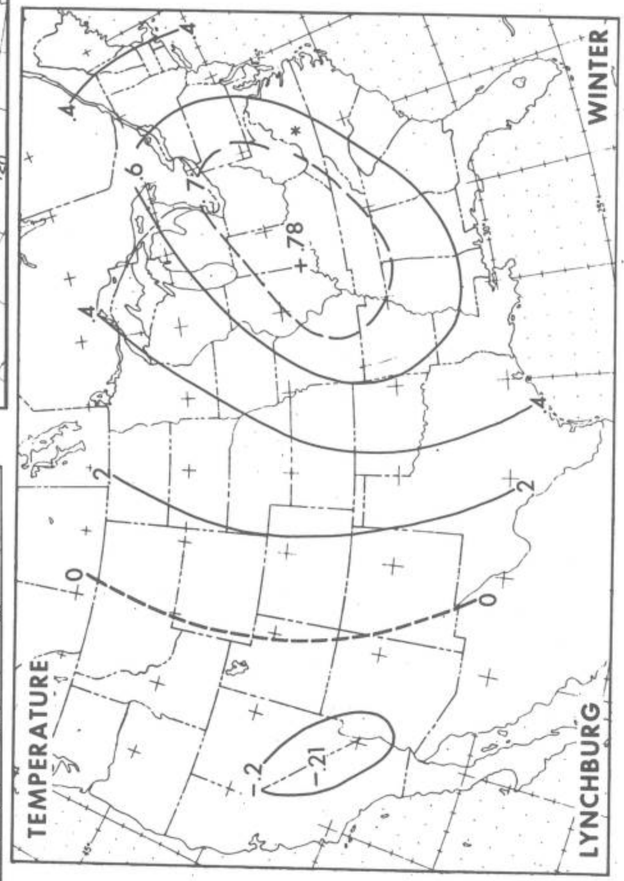
LYNCHBURG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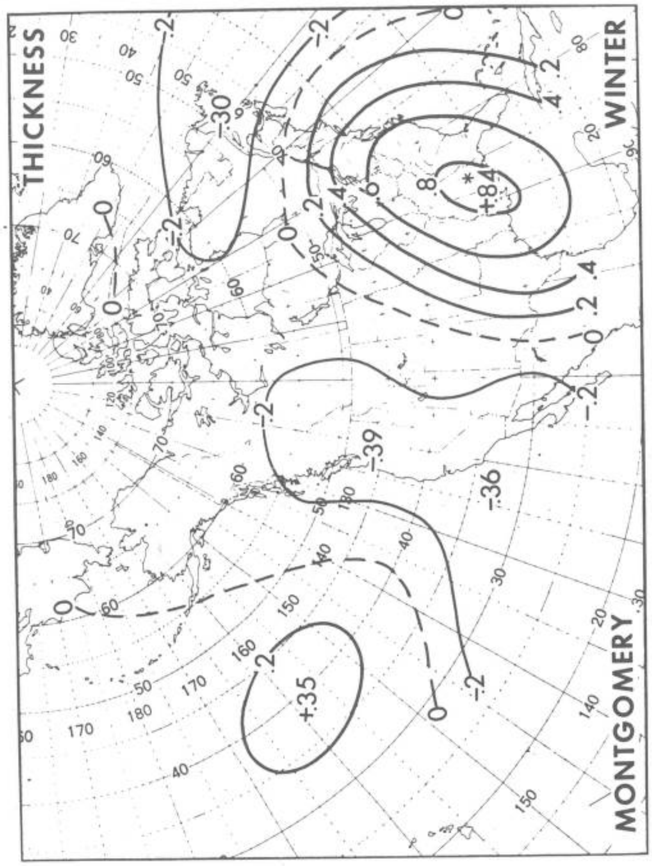
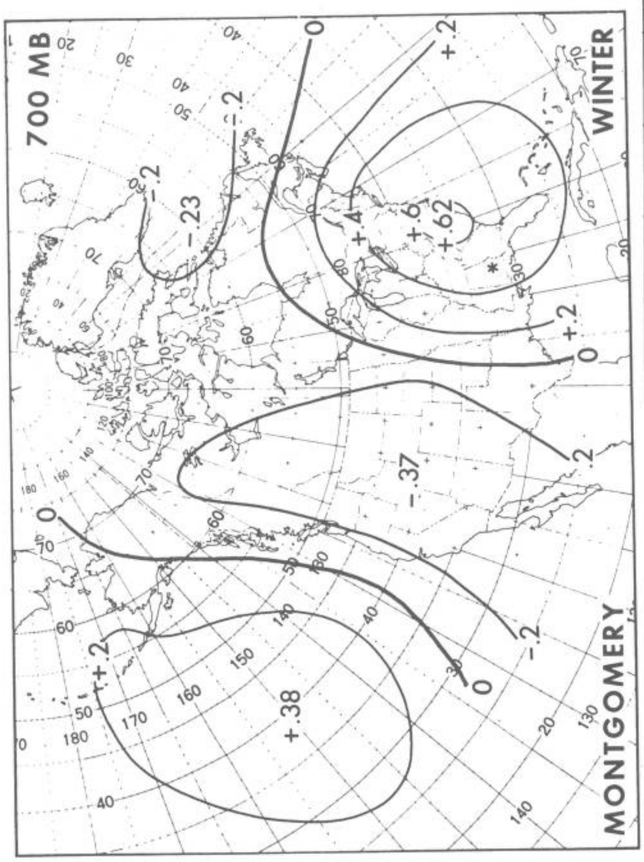
LYNCHBURG


THICKNESS
WINTER
MONTGOMERY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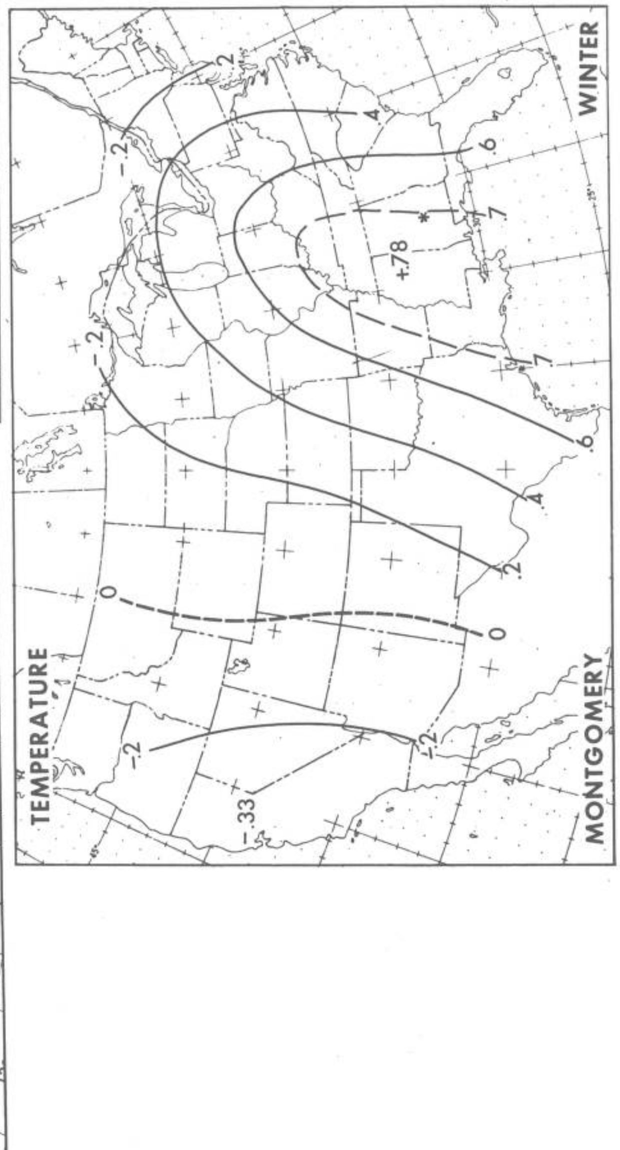
MONTGOMERY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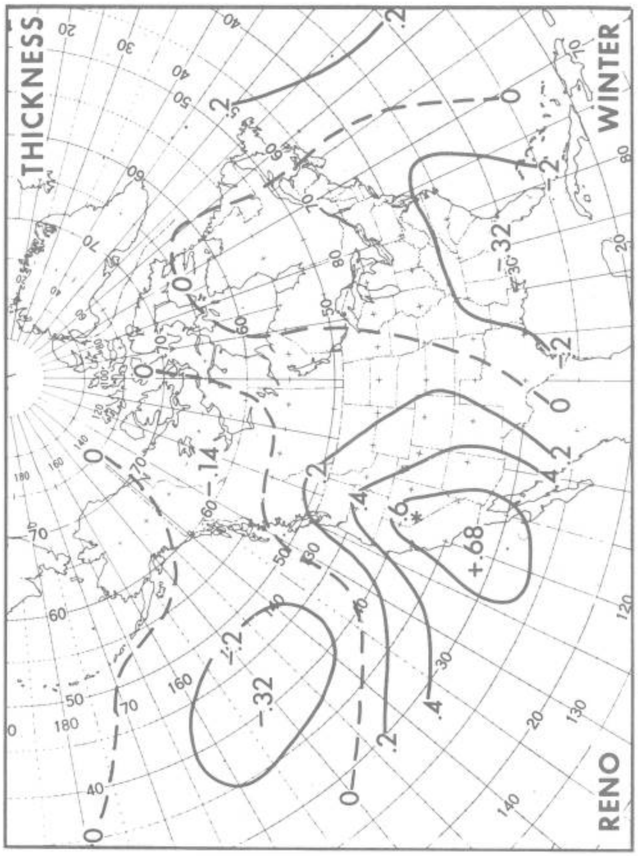
WINTER
MONTGOMERY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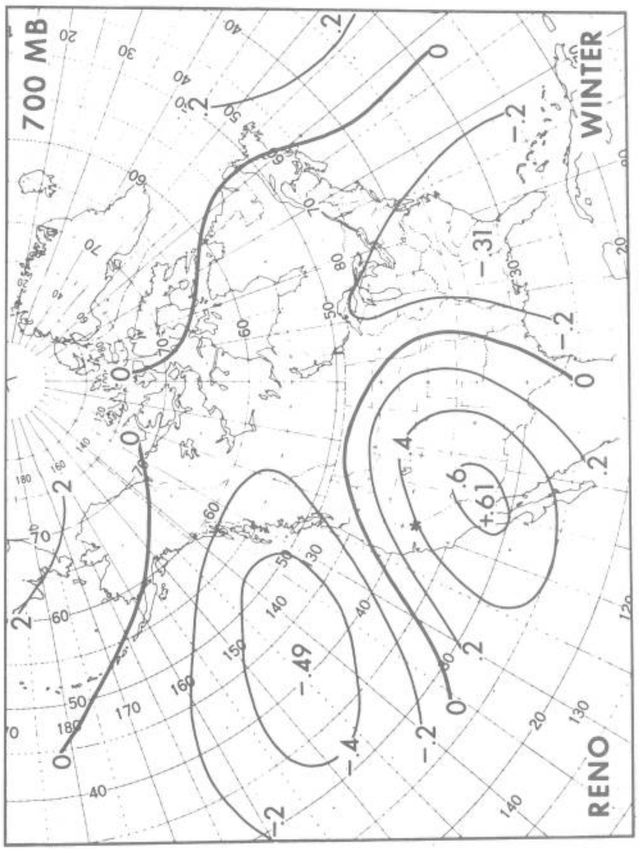
WINTER
RENO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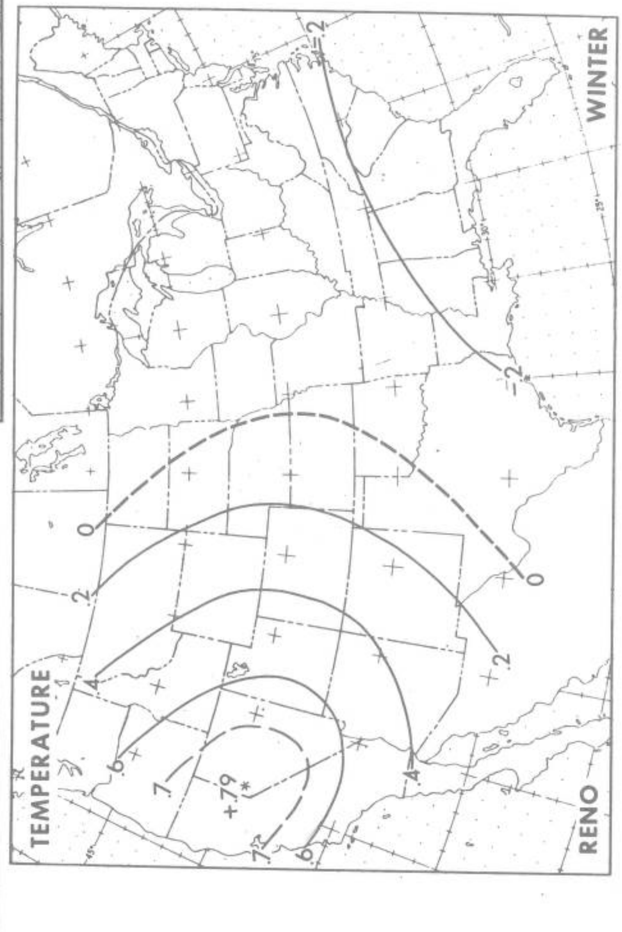
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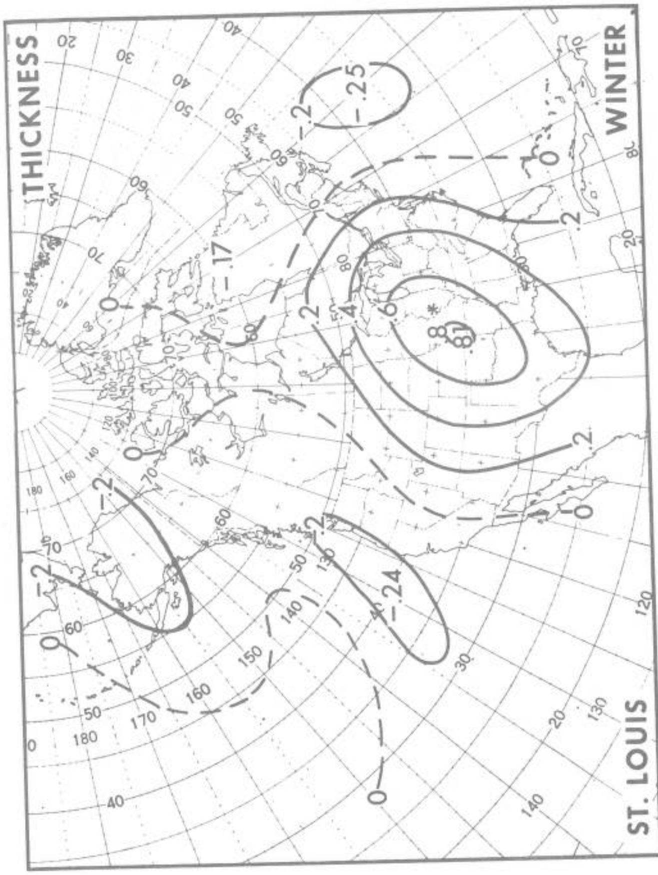
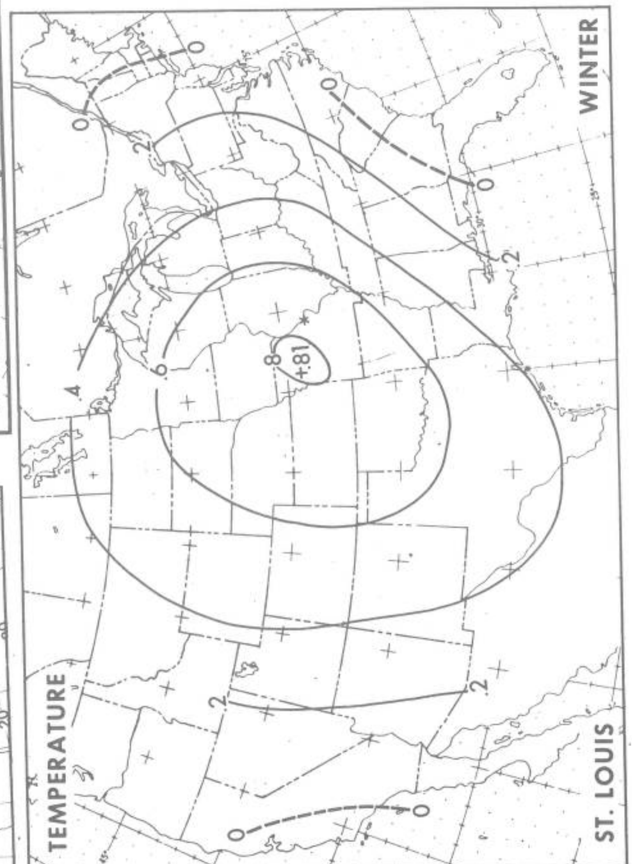

THICKNESS
WINTER
ST. LOUIS
-.25
-.17
-.24
+.81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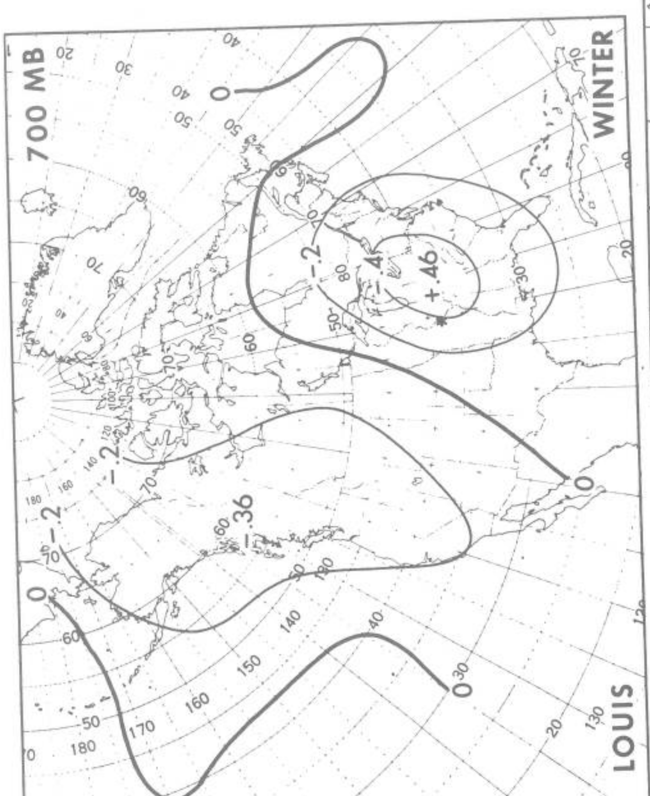
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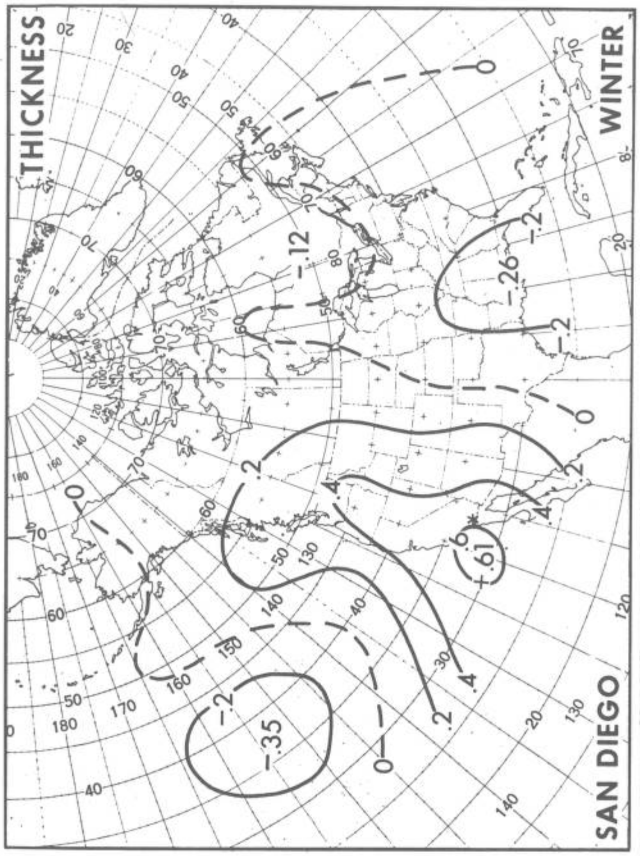
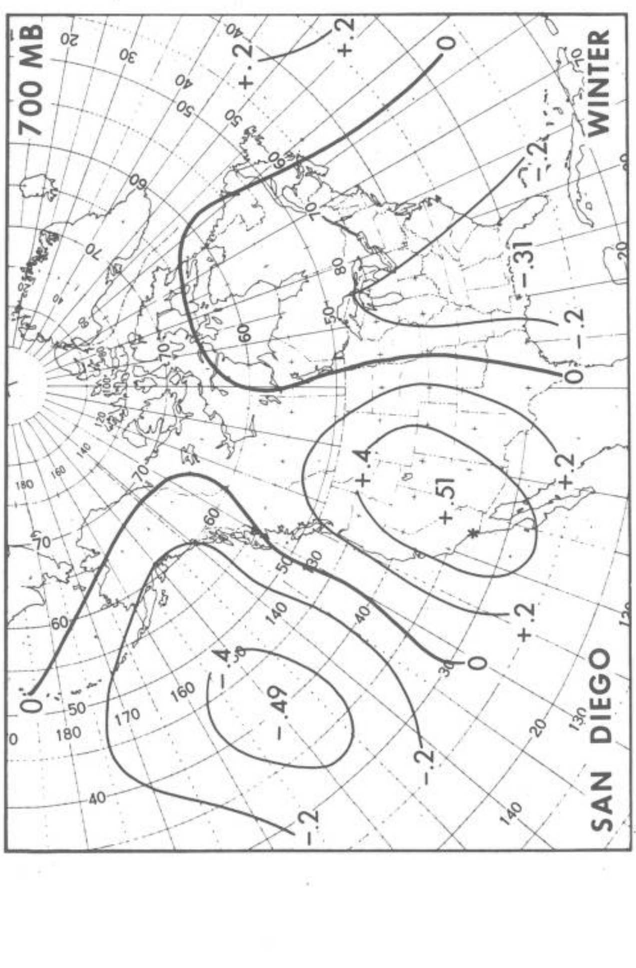
ST. LOUIS
+.46
-.36


THICKNESS
WINTER
SAN DIEGO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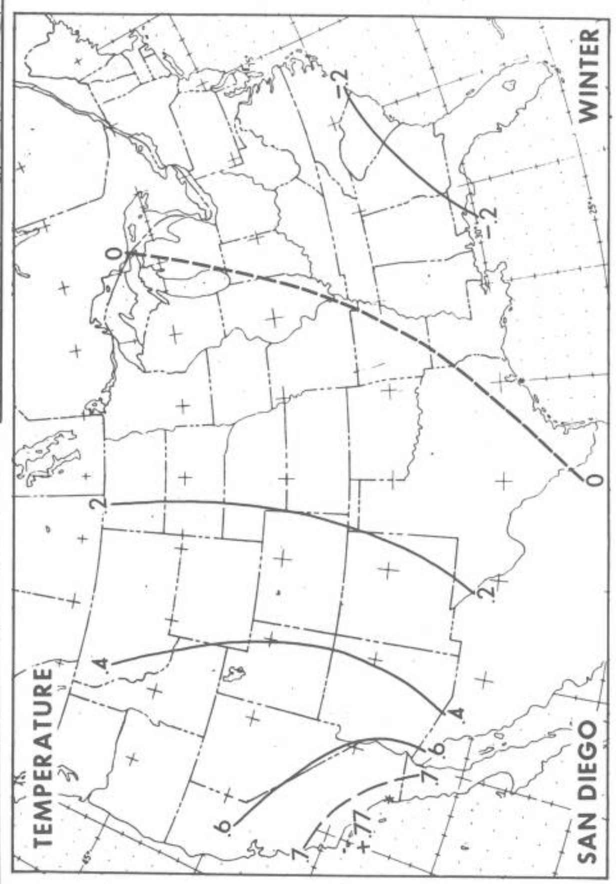
SAN DIEGO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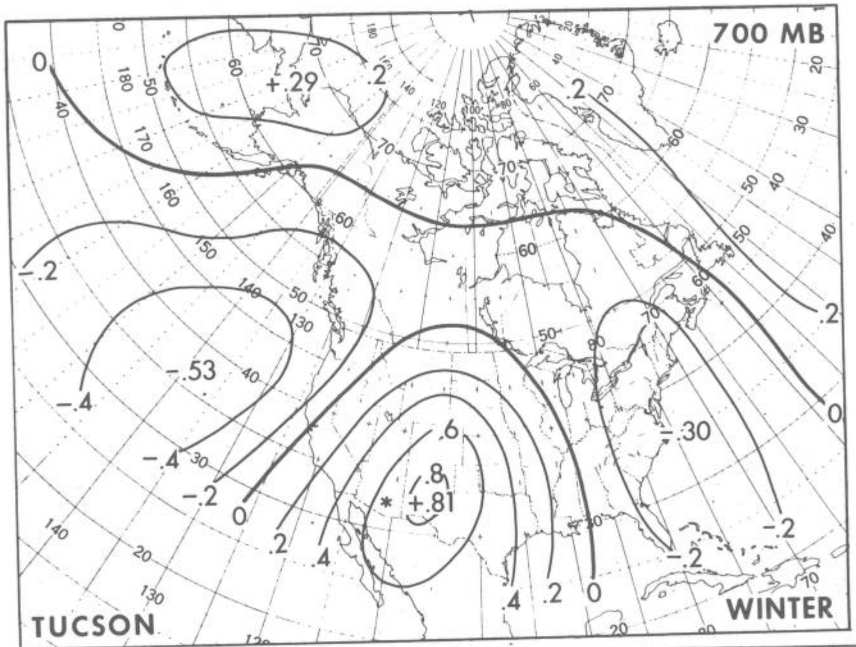
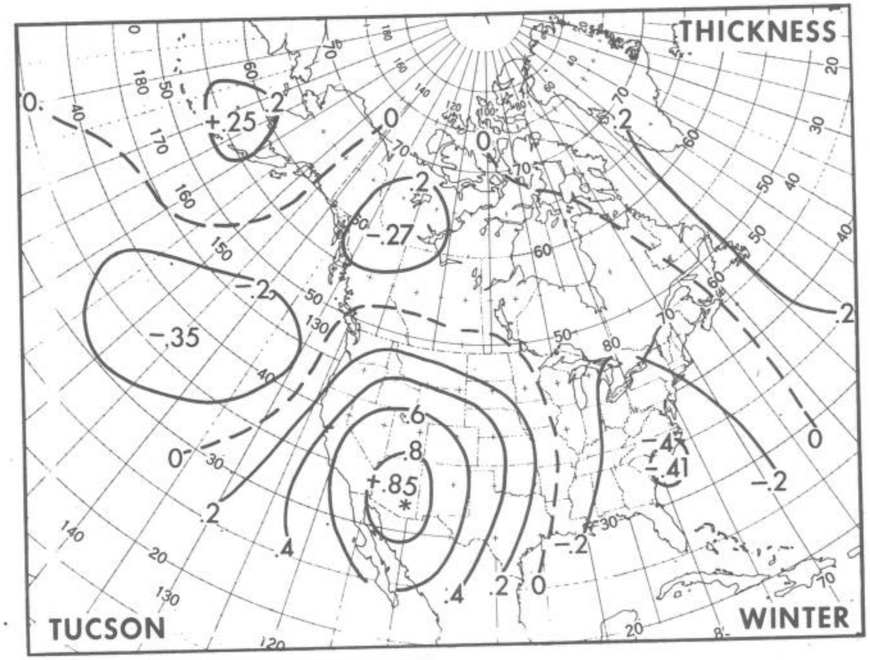
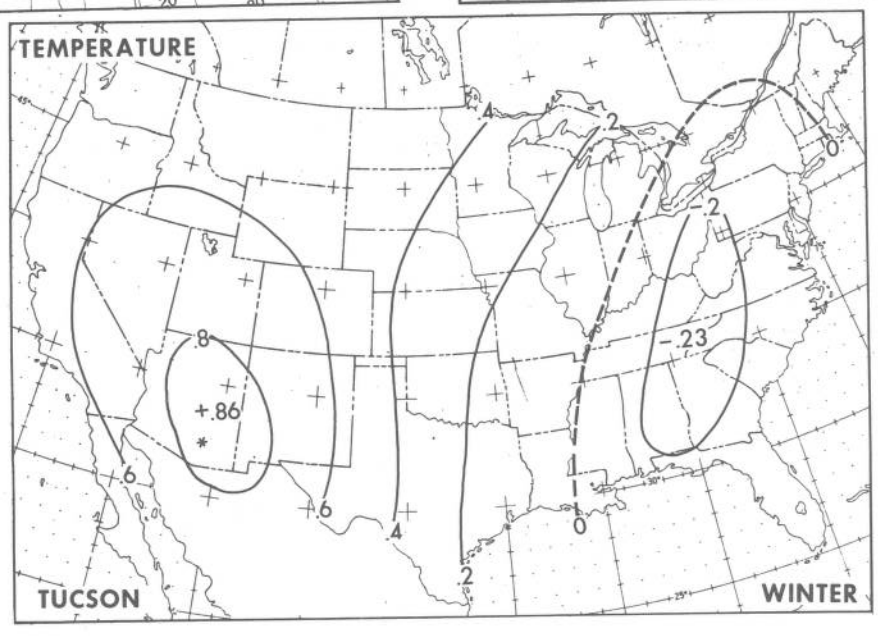
SAN DIEGO


700 MB
TUCSON
WINTER


THICKNESS
TUCSON
WINTER


TEMPERATURE
TUCSON
WINTER