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AN EXAMINATION OF THE CHARACTERISTICS OF RAIN VERSUS SNOW PREDICTORS AT CHARLESTON, WEST VIRGINIA

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1. INTRODUCTION

One of the most difficult challenges facing operational meteorologists today, continues to be the problem of accurately forecasting rain vs. mixed precipitation vs. snow. Since the 1950s, when the increased availability of upper-air information made such studies possible, research has been conducted to relate the thermodynamic characteristics of the lower and middle troposphere to precipitation type. Wagner (1957) studied the relationship of 1000-500 mb thickness to precipitation type and he noted that the probabilities of rain vs. snow are equal when the thickness is near 5400 m. This critical thickness value was found to be somewhat higher for continental, elevated regions, and lower for locations at low elevations that are influenced by maritime air masses.

Since numerous temperature profiles can be associated with any given value of 1000-500 mb thickness, the critical rain vs. snow thickness value at any given location can vary from event to event. Wagner (1957) suggested that the critical thickness values decrease when the lower troposphere exhibits a steep lapse rate. In such a case warm air near the surface can change snow over to rain, even when the thickness of the entire layer from 1000 to 500 mb is low enough to normally support snow. An example of such an event sometimes occurs along the East Coast of the United States during the winter, when southeast surface winds off of the warm Atlantic Ocean, result in rain instead of snow at thickness values well below 5400 m.

The wide variety of vertical temperature profiles that are possible for any given 1000-500 mb layer thickness value prompted additional studies, which focused on identification of other rain/snow predictors that would be more sensitive to the lowest 100-200 mb of the troposphere. Glahn and Bocchieri (1975) developed a system for forecasting precipitation type based on the Model Output Statistics (MOS) concept using the National Meteorological Center's Primitive Equation (PE) model. This system included 850 mb temperature, boundary layer potential temperature, time of year, and station elevation as predictors, in addition to 1000-500 mb thickness. By the early 1980s, probability of precipitation type (PoPT) forecast equations had been developed for use in the continental United States, based on the MOS statistical approach for a large number of LFM forecast predictors (Bocchieri and Maglaras 1983). A similar method was implemented in December 1992, based on NGM-generated predictors to produce NGM PoPT forecasts (Erickson 1992).

In order to make the best possible forecast of precipitation type, all available information, including numerical model guidance, surface observations, and vertical soundings should be used. As new tools such as the SHARP Workstation (Skew-T Hodograph Analysis and Research Program; Hart and Korotky 1991), PC-GRIDDS, model forecast soundings, and atmospheric profilers become available, forecasters will have a better understanding of the lower tropospheric thermal structure during precipitation events. In order to make effective use of these tools, forecasters should be aware of the critical values of various atmospheric parameters that are used locally to determine precipitation type. In the eastern states, forecasters pay close attention to the 1000-500 and 1000-850 mb thickness values, and 850 mb temperatures.

The purpose of this paper is to examine the rain vs. snow prediction problem in Charleston, WV (CRW). Since previous studies have identified average critical values for thickness and 850 mb temperature at CRW (National Weather Service 1982), this paper will focus on how these critical values can vary. The variation of these values will be related to such factors as stability and precipitation rate. In addition, the use of the NGM FOUS T5, T3, and T1 temperature guidance in forecasting precipitation type will briefly be discussed.

2. EXPERIMENTAL DESIGN

In order to study rain vs. snow predictors at CRW, data from six winter seasons (November 1986 through April 1992) were used. Information was gathered at every 12-h time (1200 or 0000 UTC) for which precipitation was observed at CRW with a surface temperature between 25° and 42°F. These constraints were applied since any precipitation that occurs with a surface temperature above 42°F is almost always rain in CRW, while precipitation that occurs with a surface temperature below 25°F is predominantly snow. In addition, no data were included for any snow event in which the surface visibility did not fall below 5 miles, since such events are typically associated with only very light snow or flurries. However, there were no constraints placed on very light rain, freezing rain, or sleet, since one objective of this project was to examine cases in which very light precipitation rates produced rain or ice at thicknesses that usually support snow. Three precipitation types were defined. Rain was defined at any time during which only rain was observed. Snow was defined at any time during which any combination of snow, mixed snow and rain, sleet, mixed sleet and rain, or snow grains were observed. Finally, ice was defined for any occurrence of freezing rain, or a combination of freezing rain and any other type of precipitation.

At each 12-h time, data were collected from three sources. Surface data were obtained from the CRW Local Climatic Data Monthly Summaries (LCDs). A CRW atmospheric vertical profile was inferred from the NGM

FOUS data. In addition, the upper air soundings were available for Huntington, WV (HTS), which is located about 50 miles west of CRW at an elevation of 827 ft. Both CRW (1016 ft) and HTS are located in the western foothills of the Appalachian mountains, in terrain that exhibits a general upward slope from northwest to southeast. The highest peaks of the central Appalachian mountains, with elevations over 4000 ft, are located about 50 to 100 miles east and southeast of CRW.

3. RESULTS

Tables 1a-c summarize the distribution of precipitation types that occurred during the study as a function of; a) 1000-500 mb thickness; b) 1000-850 mb thickness; and c) 850 mb temperature. The 1000-500 mb thickness values were taken from the 0000 UTC NGM analysis for CRW, while the 1000-850 mb thickness and 850 mb temperature values were derived from the HTS upper air sounding data. A total of 103 events are represented in Table 1a, while only 99 events are represented in Tables 1b and 1c, due to some missing HTS sounding data.

A comparison of these results with data from a past study (National Weather Service 1982) indicates fairly close agreement. In the aforementioned NWS publication, a 1000-500 mb thickness value of 5378 m is listed as indicating a 50% probability of snow and ice pellets at CRW, given that precipitation is occurring. The data from the cold seasons of 1986-1987 to 1991-1992 appear to indicate a similar 50% value, since a probability of snow near 50% is indicated in the range from 5350 to 5390 m (see Table 1a). Similarly, the data in Table 1b is in agreement with the previously published 50% value of 1299 m for the 1000-850 mb thickness.

Tables 1a reveals the relatively large range of 1000-500 mb thickness values that can support either snow or rain. The lowest 1000-500 mb thickness associated with rain during the 6-year study was 5270 m, while the highest thickness that could support snow was 5460 m (a difference of 190 m). In contrast, Table 1b shows the relatively small range of 1000-850 mb thickness values that could support either rain or snow. The lowest 1000-850 mb thickness value associated with rain was 1292 m, while the highest 1000-850 mb thickness that could support snow was 1304 m (a difference of 12 m).

As was the case with 1000-500 mb thickness, Table 1c shows a large range of 850 mb temperatures that can support snow and/or rain. For the period from 1986-1992, the lowest 850 mb temperature associated with a rain event was -6°C, while the highest 850 mb temperature associated with a snow event was -2°C. One possible explanation for the fact that no snow occurred with an 850 mb temperature of -1°C or 0°C, may be that the data for this predictor was taken from the HTS sounding, which is located about 50 miles to the west of CRW. Since colder air is often moving in from the west through a fairly deep layer during snow or cold rain events in CRW, a slight cold bias may have been introduced by taking data from a point 50 miles to the west.

Table 2a summarizes some of the differences between the weather variables that are typical of high 1000-500 mb thickness snows vs. low 1000-500 mb thickness rains. All of the differences indicated in the table were found to be statistically significant at a 0.15 level of significance based on a multiple comparison technique (Gibbons 1976). The role of stability in determining the type of precipitation that occurs at a given 1000-500 mb thickness is quite evident. High-thickness snows occurred with relatively high 500 mb heights, surface pressures, and 1000-500 and 1000-850 mb lifted indices, which are all indicative of a relatively stable air mass. Conversely, low-thickness rains occurred with low 500 mb heights, low surface pressures, and low lifted index values (relatively unstable).

A closer examination of low-thickness rain cases, indicated that a theta-e maximum was observed at the surface for 6 out of 7 events for which a theta-e maximum could be calculated (8 low thickness rain events were recorded in total, however incomplete sounding data kept the level of maximum theta-e from being calculated for one event). In contrast, a theta-e maximum was located between 890 and 925 mb in 4 out of 5 high-thickness snow events, which is indicative of the presence of a low-level inversion (HTS sounding data were not available for one of the high-thickness snows). These findings confirm the tendency for low-thickness rains to occur in unstable environments, while high-thickness snows are associated with more stable environments.

None of the high-thickness snows in the study occurred after February. In contrast, 5 out of 8 low-thickness rains occurred in March or April, when strong solar heating of the ground and adjacent boundary layer often produces more unstable conditions than those typically found during early or mid-winter. Maglaras and Goldsmith (1990) also studied the effect of time-of-year on rain vs. snow prediction and found that the LFM MOS tends to overforecast snow during the spring, because of the relation between thickness and boundary layer temperature associated with the high spring-time sun angle.

One surprising finding related to stability, was the weak correlation between the low-level warming associated with downslope surface winds and low thickness rains. Prior to the study, some forecasters in CRW suspected that low thickness rains had a tendency to occur in conjunction with a downslope (100-200 degree) surface wind (which would warm the boundary layer, leading to rain at low thicknesses). However, no such tendency for this phenomenon was observed as 7 of the 8 low-thickness rain events occurred with wind directions of 250-290°. The likely explanation is that southeast (downslope) surface winds often occur during stable overrunning situations, during which any low-level destabilization caused by downslope warming is masked by the large-scale stable environment. In addition, it should be noted that precipitation of any kind is rare with a strong southeast surface wind at CRW, due to the drying and warming effects of the strong downslope flow.

In addition to the effect of stability, Table 2a indicates that another important factor that governs the precipitation type for a given 1000-500 mb thickness value, is the depth of moisture and the resultant rainfall rate. High thickness snows tended to occur with high RH values at mid-levels as indicated by the RH2 values on the NGM FOUS guidance. In contrast, low thickness rains were often accompanied by ample low-level (surface to 965 mb) moisture as indicated by the NGM RH1 values but relatively dry mid-levels, which often results in only light rain or drizzle.

A final conclusion from Table 2a can be derived by comparing the average 850 mb temperatures for low-thickness rains and high thickness snows with the average values of the corresponding 1000-850 mb thickness. In this study, low 1000-500 mb thickness rains were associated with lower 850 mb temperatures than were the high 1000-500 mb thickness snows. Not surprisingly, 4 of the 5 rain events that were associated with an 850 mb temperature below -4°C (see Table 1b) were also associated with a 1000-500 mb thickness below 5350 m. By contrast, the low 1000-500 mb thickness rains were associated with higher 1000-850 mb thicknesses than were the high 1000-500 mb thickness snows (see Table 2a). Again, this indicates the importance of the thermal structure of the layer below 850 mb in the determination of precipitation type.

Table 2b summarizes some of the differences between the weather variables that are typical of high 1000-850 mb thickness snows vs. low 1000-850 mb thickness rains. In contrast to Table 2a, only small differences are indicated. Only the difference in precipitation rate (which indicates a tendency for higher rates to occur with high 1000-850 mb thickness snows) was found to be statistically significant using the same multiple comparison techniques applied to the data in Table 2a.

One method frequently used to predict precipitation type is to examine the T1, T3, and T5 temperatures on the NGM FOUS guidance. For reference, T5 is the NGM mean temperature forecast for 816-755 mb layer, T3 is the forecast for the 922-872 mb layer, and Tl is the forecast for the surface to 965 mb layer. Table 3 summarizes the values for all of the cases in this study.

Several relationships are evident in these data. Snow is extremely rare whenever T5 or T3 values exceed 0°C. By contrast, snow is very likely (given that precipitation will occur) whenever T5, T3 and Tl are all below 0°C. The forecast becomes more difficult when T5 and T3 are below 0°C, while Tl remains above 0°C. However, snow could occur with Tl values as high as +2°C.

4. FORECAST PROCEDURE

Based on the results outlined in Section 3, a simplified flow chart (Fig. 1) was developed to provide a quick-look guidance tool to enable forecasters to determine the likely precipitation type based on variables in the NMC model guidance. It should be noted that these rules were derived specifically for use at CRW, and some modification will be required before they can be used at other locations. Also, it should be understood that when one is making a short-term (< 6-hr) forecast, it is always best to examine a complete local sounding as opposed to examining only a collection of sounding variables.

5. CASE STUDY

Figures 2a,b,c show the sea level pressure analysis and the 1000-500 mb thickness pattern, 850, and 500 mb analyses, respectively at 0000 UTC on December 2, 1987. Light rain, drizzle, and fog, with precipitation falling at the rate of 0.01 inch every 2 hours, was observed at CRW. Light rain was also falling at HTS. Both the 1000-500 mb thickness of 5270 m and the 850 mb temperature of -6°C would usually support snow. In addition, the 1000-850 mb thickness at HTS was 1291 m; also within the range where snow is favored over rain. However, the possibility of a low-thickness rain event was indicated by a combination of low surface pressures, and low 500 mb heights over West Virginia. These variables produced a relatively unstable 1000-500 mb lifted index value of +6 at HTS. The most compelling evidence for a rain event was found by examining the NGM FOUS data, which indicated T5, T3, and Tl temperatures values of -11°C, -3°C, and +3°C, respectively. Although cold air was present in the layers from 922 mb to 755 mb, temperatures in the lowest 50 mb of the atmosphere were predicted to be too warm to support snow.

6. SUMMARY AND CONCLUSION

Data from the six cold seasons (November-April) from 1986 to 1992 were examined to determine significant precipitation type predictors at CRW. Although this study produced critical values for 1000-500 and 1000-850 mb thicknesses, and 850 mb temperatures that were in close agreement with previous research, several additional meteorological variables were identified that appear to modify the mean critical values of the rain vs. snow predictors. There was strong evidence supporting that the 1000-850 mb thickness values are more reliable than the 1000-500 mb thickness values as precipitation type predictors. Greater stability and a deep moist layer raised the critical values of the predictors, especially in the case of 1000-500 mb thickness and 850 mb temperature. However, greater instability and relatively dry air in the mid- levels of the atmosphere appeared to have the opposite effect. Finally, the NGM FOUS T5, T3 and Tl temperature output can aid the forecaster in predicting difficult rain vs. snow situations. Generally, snow can be forecast with a high degree of confidence whenever T5, T3 and Tl are all below 0°C, while rain could be expected whenever T3 or T5 are above 0°C. When T5 and T3 are below 0°C, and Tl is above 0°C, the results were less clear. However, it seemed that a Tl critical value of about +2°C was indicated for those cases. From these results, a procedure for forecasting precipitation type at CRW based on thickness, 850 mb temperature, and NGM temperature profile data was outlined, and an example was reviewed.

While the mean critical values for rain vs. snow predictors vary from place to place, the effects of stability and moisture depth on the critical values of these predictors is somewhat universal. In addition, the relationship of the NGM FOUS T1, T3, and T5 values to precipitation type, probably can be used at places other than West Virginia. Therefore, the author hopes that the findings illustrated in this study will be of use to forecasters at other nearby locations where the prediction of rain vs. snow is also a challenge.

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APPENDIX

In order to calculate 1000-850 mb thickness from the HTS sounding data stored by the SHARP program, an estimate of the 1000 mb geopotential height had to be obtained, since SHARP did not store 1000 mb heights for any time during which uncorrected surface pressure was below 1000 mb. In order to produce the estimate, first the uncorrected surface pressure was corrected to sea-level pressure. An equation typically used for such a calculation is given by:

$$P=P_0(1+r)$$

where P is the sea-level pressure, P_0 is the uncorrected pressure, and r is the local "r value" which is a function of station elevation and the average temperature at the station for the 12-hour period ending at the time of observation. An estimate of 32°F was used for this 12-hour average temperature for each event in the study. It was determined that an error of 10°F for this temperature estimate would produce an error of approximately 0.5 mb in the sea-level pressure calculation. Since the data stored in the SHARP data-base were rounded to the nearest mb, it was decided that the error in making this estimate was not significant. After a sea-level pressure was determined, the 1000 mb geopotential height was found using the approximate relationship:

$$HT=7.9(P-1000)$$

where HT is the estimated 1000 mb height in m, and P is the estimated sea level pressure in mb. This 1000 mb height is then used to calculate the 1000-850 mb thickness.

Table 1a. The distribution of precipitation type at Charleston over the range of 1000-500 mb thicknesses observed during the study.

1000-500 mb THICKNESS VALUES (dm)

Type	T<530	530-534	535-539	540-544	545-549	T≥550	sum
snow	18	11	6	5	1	0	41
rain	2	6	8	13	13	18	60
ice	0	0	0	2	0	0	2
sum	20	17	14	20	14	18	103

Table 1b. The distribution of precipitation type at Charleston over the range of 1000-850 mb thicknesses observed during the study. Note: for details on the calculation of thickness from SHARP data, see Appendix 1.

1000-850 mb THICKNESS VALUES (m)

Type	T<1290	1290-1293	1294-1297	1298-1301	T≥1302	sum
snow	26	4	5	4	1	40
rain	0	6	5	9	37	57
ice	0	2	0	0	0	2
sum	26	12	10	13	38	99

Table 1c. The distribution of precipitation type at Charleston over the range of 850 mb temperatures observed during the study.

850 MB TEMPERATURES (°C)

Type	T<-6	-6≤T<-4	-4≤T<-2	-2≤T<0	T≥0	sum
snow	20	8	7	5	0	40
rain	0	5	13	7	32	57
ice	0	0	0	0	2	2
sum	20	13	20	12	34	99

Table 2a. The average of several variables for the 8 rain events that occurred at thicknesses less than 5350 m (R(T<535)) vs. the averages of the same parameters for the 6 snow events that occurred at thicknesses greater than or equal to 5400 m (S(T≥540)). The variables are: 1000-500 mb lifted index, 1000-850 mb lifted index (defined here as the difference between the wet bulb temperatures at 850 and 1000 mb), 500 mb geopotential heights, surface pressure, 965-473 mb mean relative humidity (R2) on the NGM, the height of the maximum theta-e value measured within the lowest 150 mb of the troposphere, 2 hour precipitation total centered around the data gathering time, 850 mb temperature and 1000-850 mb thickness. Variables followed by an asterisk were calculated by SHARP for HTS sounding data.

PP TYPE	1000-500 LI*	1000-850 LI*	HT500* (m)	P SFC (mb)	PHEX1* (mb)
R(T<535)	7.5	-7.8	5410	1012.5	976
S(T≥540)	24.4	-1.7	5600	1020.0	923

PP TYPE	RH2	2HRPPP (INCHES)	T850* (°C)	THK850* (m)
R(T<535)	59.5%	0.01	-4.8	1299
S(T≥540)	82.5%	0.05	-3.0	1287

Table 2b. The averages of 1000-850 mb lifted index, surface pressure, and 2 hour rainfall rates for the 6 rain events that occurred with 1000-850 mb thickness below 1294 m (R(T<1294)) vs. the 5 snow events that occurred with 1000-850 mb thickness at or above 1298 m (S(T≥1298)).

PP TYPE	1000-850 LI*	P SFC (MB)	2HRPPP (INCHES)
R(T<1294)	-5.9	1009.0	0.02
S(T≥1298)	-4.7	1014.0	0.05

Table 3. Characteristics of the 00-hour NGM T5, T3, and T1 temperatures and the associated distribution of rain and snow events.

T5,T3,T1 Characteristics	**Rain/Snow Distribution**
T5>0	#snow=0 #rain=17
T5=0	#snow=1 #rain=11
T3>0	#snow=0 #rain=31
T3=0	#snow=3 #rain=19
T5,T3,T1<0	#snow=19 #rain=0
T5,T3<0 ; T1>0	#snow=4 (Avg T1=1.8) #rain=7 (Avg T1=2.9)

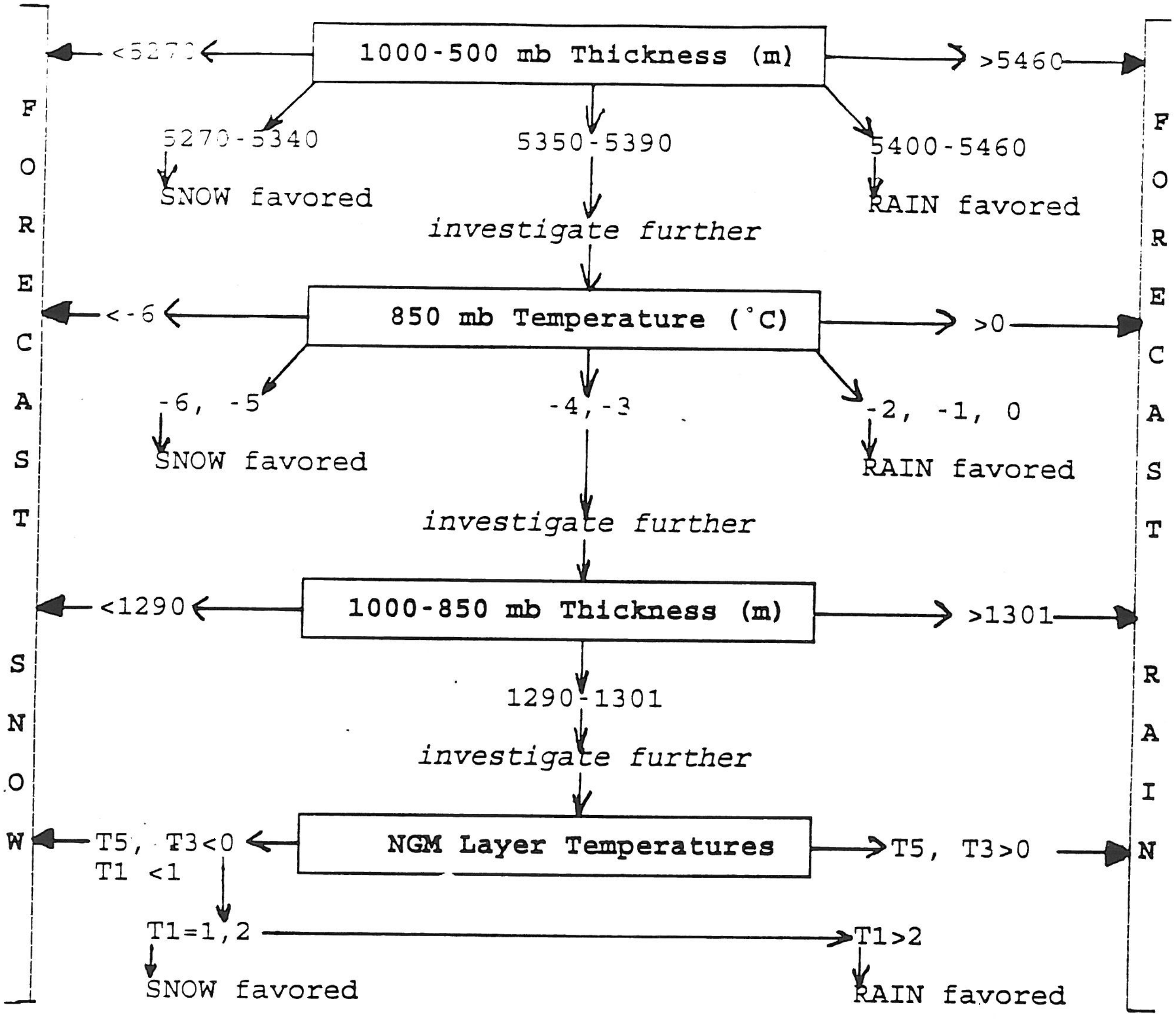


Figure 1. Forecasting precipitation type at Charleston, WV based on NGM model forecast parameters.

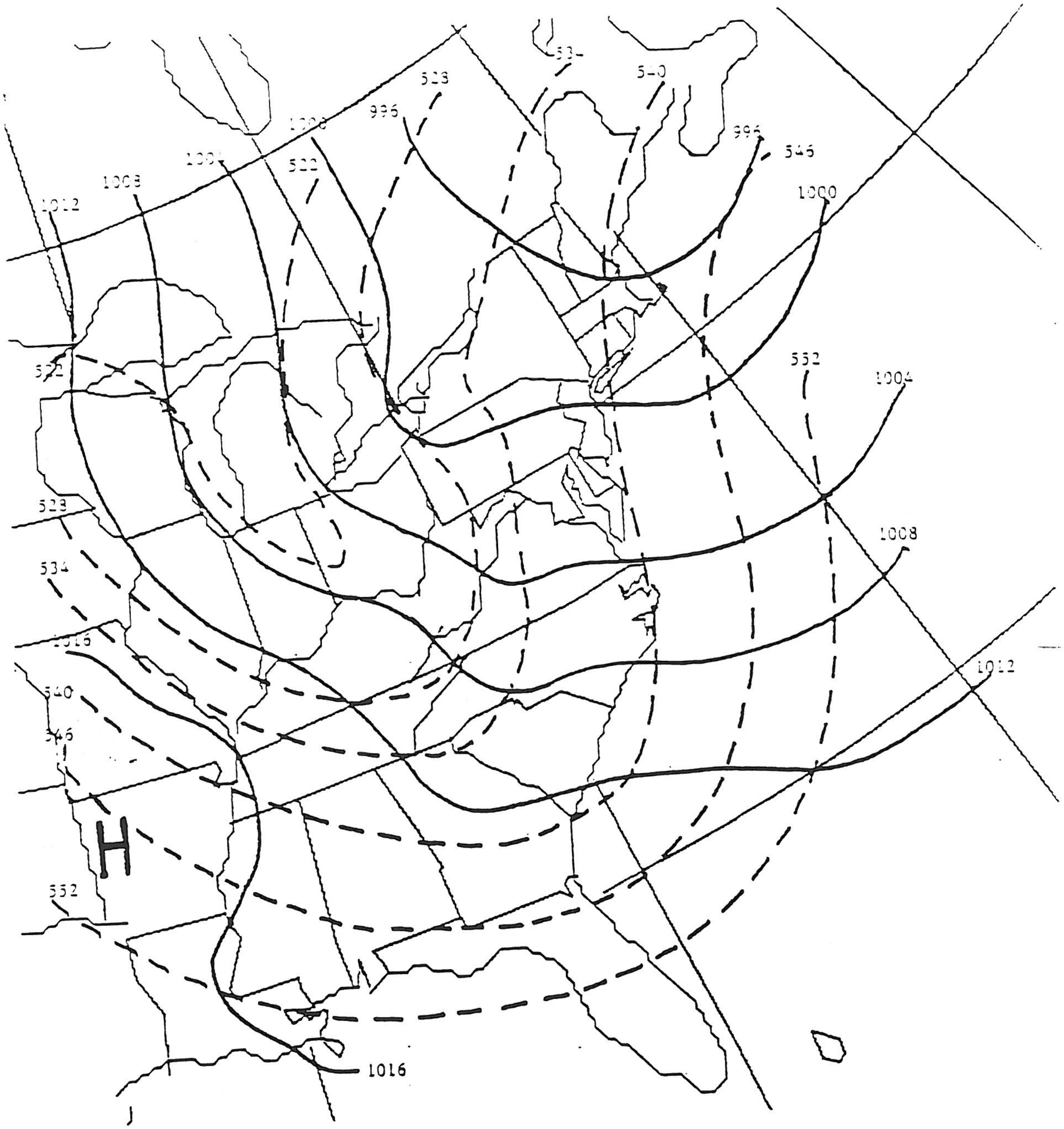
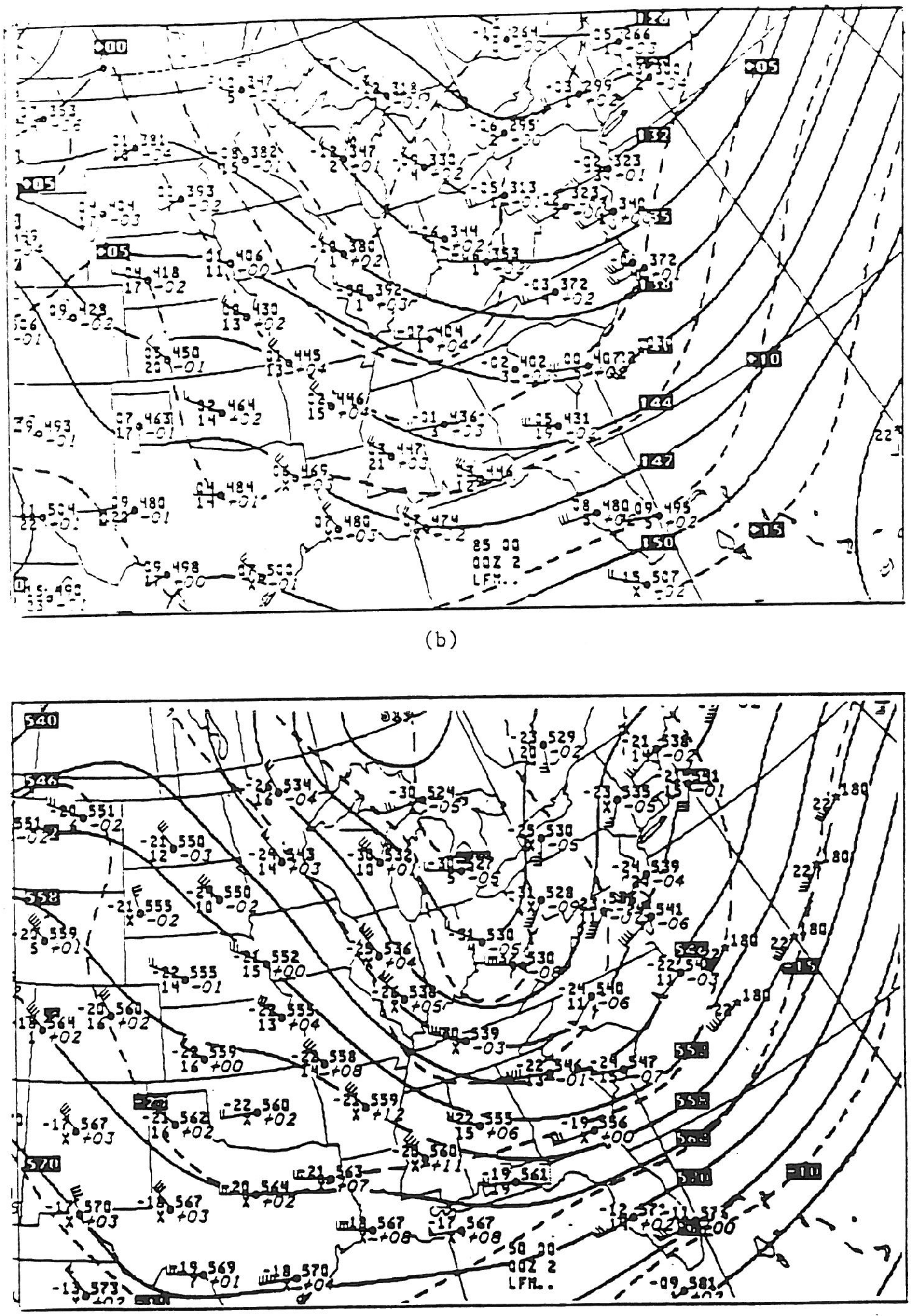


Figure 2a. The surface pressure analysis (mb, solid lines) and 1000-500 mb thickness analysis (dm, dashed lines) at 0000 UTC 2 December 1987.



(b)

(c)

Figure 2b-c. The 0000 UTC 2 December 1987 (b) 850 mb and (c) 500 mb analyses.