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flood

A METHODOLOGY FOR FORECASTING HEAVY CONVECTIVE PRECIPITATION AND FLASH FLOODING

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Abstract

The importance of accurately forecasting heavy precipitation and flash flooding has been emphasized by substantial increases in the societal impact of these events during the past decade. A forecast methodology is proposed that may help the meteorologist both to identify synoptic scale conditions that favor heavy convective rains and to utilize routinely available products to delineate specific regions where the flash flood threat may be greatest (the flash flood watch area). The scheme primarily emphasizes reanalyses and enhancements of National Meteorological Center (NMC) diagnostic charts and relegates NMC guidance and local station checklists/decision trees to secondary and tertiary roles in the short range (0-12 hour) forecast problem.

1. INTRODUCTION

During the 1970's flash floods have become one of the most significant natural disaster problems within the United States. Concern and interest in improving forecasts and warnings of these events extends from local National Weather Service (NWS) forecast offices through the National Weather Association (NWA) and the American Meteorological Society (AMS) to Congress. In many respects the overall flash flood problem is similar to that of severe thunderstorm and tornado prediction, detection, and warning. The severe storm problem has been effectively handled by a national forecast center at Kansas City whose primary responsibility is the delineation of regions of potential storm development (the watch phase). However, the flash flood system is decentralized with responsibility for both the watch and warning phases residing at the state forecast offices (WSFO's and WSO's).

Recent changes in quantitative precipitation guidance products supplied NWS offices have been designed to improve forecasts of excessive convective precipitation (NOAA, 1978a). Furthermore, the NWS will begin an intensive effort in FY80 to improve the flash flood forecast and warning system (See NOAA, 1978b). One phase of this new program may eventually lead to the establishment of a national center for forecasting heavy precipitation events. Belville et al (1978) recently reported on local procedures being used at the NWS office at Lubbock to apply NMC guidance products to the specific flash flood problems of west Texas. The importance of the problem was emphasized by the NWA position of Weather Services (NWA, 1978) statement that set as a number one priority goal for the next decade:

> "A 50% improvement of forecasts of timing, location and severity of local storms - tornadoes, flash floods, and severe thunderstorms."

Unfortunately a number of factors (work load, manpower, funding, and management policy, etc.) have acted to denigrate the importance of man within man/machine interactive technology. This is ironic, since most significant weather events occur at meso-α (250-2500 km) and meso-β (25-250 km) scales and since these scales are poorly treated within operational numerical models. (For example, the amount of precipitation that falls in convective events that produce flash floods often exceeds Limited Fine Mesh (LFM) quantitative precipitation guidance by more than an order of magnitude!) If the 50% improvement goal stated above is to be attained it is imperative that the advice of Snellman (1978) be heeded:

> "... we in meteorology shall have to learn over again, the lesson that many businesses have learned, that you can automate only so far before getting diminishing return in quality of the final product. Consequently, papers ... should be written to motivate forecasters to using, not just following, MOS products so that the considerable contribution that they can bring to the quality of the final product is realized."

This paper suggests a methodology to be used by the forecaster in dealing with the flash flood problem. Although hydrological considerations are significant, only the meteorological aspects of the event are considered here.

The results presented by Maddox et al (1979) from a study of a large number of flash flood events have been used as a basis for the forecast method. The approach is similar to that developed by Miller (1967) for severe storm forecasting; however, the emphasis is upon identifying the meteorological potential for heavy convective precipitation and upon delineating a flash flood watch area. The procedure requires reanalysis and enhancement of facsimile charts (primarily NMC broadscale diagnostic charts such as the surface map and 500 mb analysis). The method can be adapted to hard copies and local products produced by the eventual Automation of Field Operations and Services (AFOS).

2. CHART REANALYSIS AND ENHANCEMENT

Maddox et al (1979) found certain characteristics and features that were common to almost all flash flood events. These common characteristics were:

1. Heavy rains were produced by convective storms.
2. Surface dewpoint temperatures were very high.
3. Large moisture contents were present through a deep tropospheric layer.
4. Vertical wind shear was weak to moderate through the cloud depth.

The following analysis procedures use routinely available NMC products and are designed to help the forecaster locate regions in which these features exist. Although the analysis routine is for flash flood applications, it should have general value regardless of the type forecast to be made. It should be completed prior to using local check list or decision tree type forecast aids (e.g. the flash flood check list suggested in NOAA, 1978c).

a. Analysis of upper-air data

The NMC standard level charts (850, 700, 500 and 300 mb facsimile maps) should be reanalyzed to locate important mesoscale features such as: the low-level jet stream, moisture and temperature ridges, areas of significant instability, regions of high integrated mositure content and weak vertical wind shear, and middle-level (500 mb) short-wave troughs. Weak short-waves moving slowly around, or through, the long-wave ridge position are potential heavy precipitation producers. A weak cut-off low that has broken into, or underneath, the long-wave ridge is especially dangerous.

Figure 1a shows an NMC 500 mb analysis while Figure 1b shows an enhanced version of the same

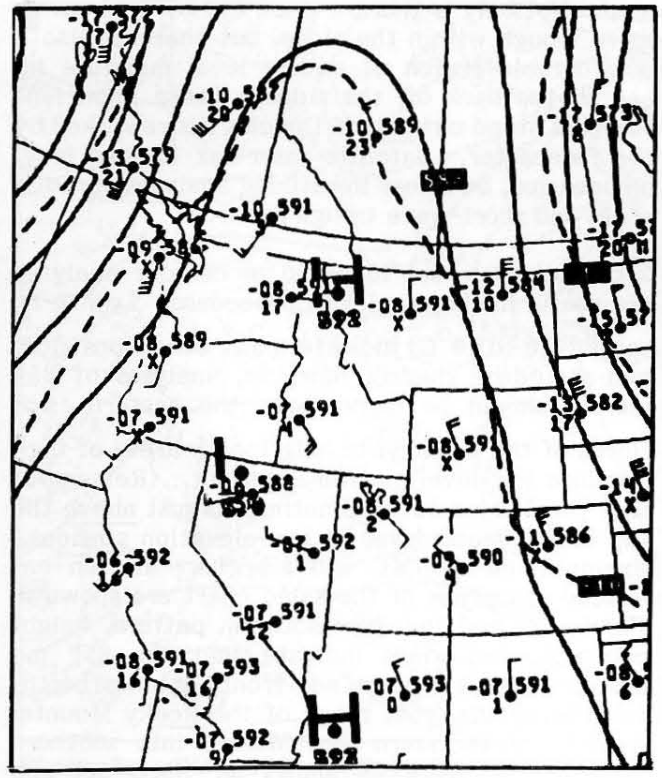

Figure 1a. NMC 500 mb chart for 1200 GMT, 11 July 1975.

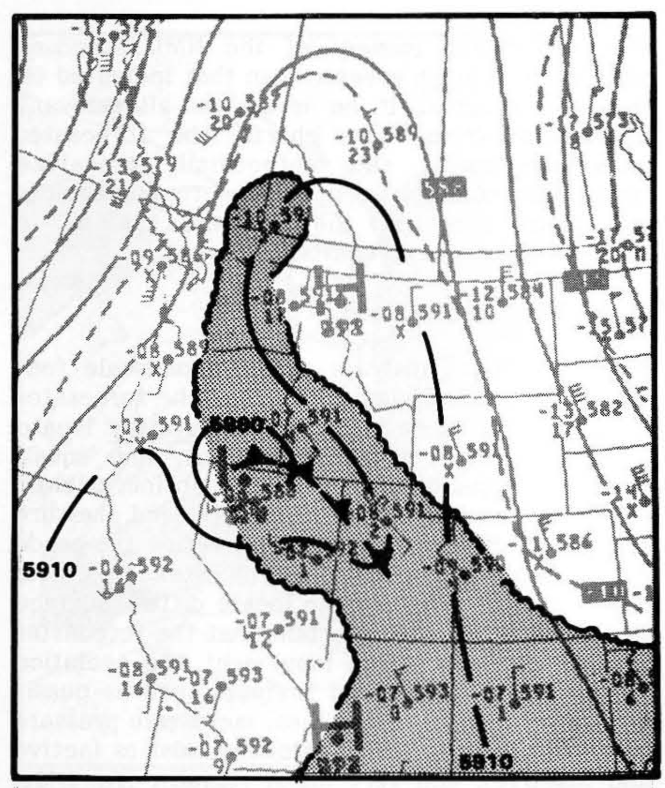

Figure 1b. Enhanced 500 mb chart for 1200 GMT, 11 July 1975. Short-wave trough position is indicated; moist regions are shades; and additional height contours are shown.

map. Not only is there a weak cut-off and short-wave trough within the ridge, but there is also a considerable region of middle level moisture in, and up the back of, the ridge. These important features stand out only if the chart is reworked by the forecaster. Satellite laser-fax images may, on occasion, be of use in refining analyses of moist areas and short-wave trough positions.

2°C isotherms and 15 or 30 m contour analyses are useful in the reanlaysis procedure. Low $T-T_d$ spreads (6 to 10°C) indicate moist conditions aloft and should be shaded; however, analyses of 850 mb T_d should be made (over the eastern two-thirds of the country) to help locate areas of high absolute low-level moisture content. (Remember that the 850 mb level sometimes is just above the top of the moist layer at low-elevation stations.) Examples of an NMC 850 mb chart and an enhanced reanalysis of the same chart are shown in Figures 2a and 2b. The isotherm pattern, height contours, and winds indicate that the 850 mb front, and thus the surface front, extends northward along the front range of the Rocky Mountai ns from northeastern New Mexico into southern Wyoming. Figure 3a shows an NMC 500 mb analysis while an enhanced version of the same chart is shown in Figure 3b. The height contours, moisture pattern, and 12 hour height changes define the position of the indicated short-wave trough.

The information content of the NMC standard level maps is much greater than that indicated on the base charts. If he is to use all relevant information from these charts, the forecaster must consistently and methodically reanalyze them. The reanalysis procedure actually requires very little time and the potential returns, in terms of improved forecasts, are great.

b. NMC surface map

Since the NMC analyses are of broadscale features it is crucially important that the forecaster reanalyze the surface map to accurately locate fronts, dry-lines, pressure systems, and squall lines. Analyses of pressure for 2 mb increments, temperature, dewpoint temperature, and pressure change fields may be required to refine the crude NMC facsimile product. The standard level charts may be used to help locate diffuse surface features. It is most important that the forecaster locate and monitor the movement and evolution of significant flash flood features such as quasi-stationary fronts, squall-lines, mesoscale pressure systems, thunderstorm outflow boundaries (active and inactive), and very moist regions. An NMC surface analysis and an enhanced version of the same chart are shown in Figures 4a and 4b. The reanalyzed chart shows that the surface front does not trail into New Mexico and vanish; rather, it curves northward along the foothills of the Rocky Mountains. Several pronounced thunderstorm meso-systems are indicatd and the surface winds and dewpoints show a strong influx of moisture along the southwestern portion of the squall-line.

Satellite laser-fax images may be of use both in refining and verifying the reanalyzed surface features. Figure 5 shows the reanalysis of surface features from Figure 4b overlain upon a concurrent, digitized infrared (IR) satellite photograph. It may also help the forecaster if he sketches unstable LI/KI and high precipitable water areas (from the appropriate facsimile chart) onto late morning and afternoon surface analyses. Such an application is shown in Figure 6 along with rainfall amounts that occurred primarily during the following 12 hours. The heaviest rain amounts fell in the region where the most unstable and most moist air was overrunning the surface frontal zone. The narrow band of heavy precipitation amounts is distinctly mesoscale in nature and its orientation indicates the important role of the quasi-stationary surface front in triggering the convective storms.

c. NMC guidance products

The forecaster should use NMC guidance products, in conjunction with supplemental mesoscale analyses, to finalize his evaluation of how various important parameters and features will move, modify, and interact within the next 12 to 24 hours. Remember that the LFM forecasts large scale precipitation along with a convective component derived from a very simple temperature lapse rate adjustment parameterization. Although large scale features play an important role in providing mositure, instability, and favorable motion fields for triggering storms, the convective component of precipitation in flash flood situations may exceed the large scale component by more than an order of magnitude. Figure 7 shows the 12 hour LFM 500 mb vorticity and height forecast valid 12 hours after the time of the surface analysis shown in Figure 6. In this case the NMC guidance product indicates that a weak short-wave trough will be moving eastward along the stationary frontal zone. Thus the guidance would help the forecaster key on a specific portion of the frontal zone and would substantiate his concern that high flash flood potential was developing. Late morning or early afternoon surface, satellite, and radar data can often be used to evaluate how well the 1200 GMT guidance is verifying.

It is important that the forecaster develop a four-dimensional mental picture of the evolving meteorological situation and that he have a good physical understanding of the mechanisms that act to produce heavy precipitation. If the possi-

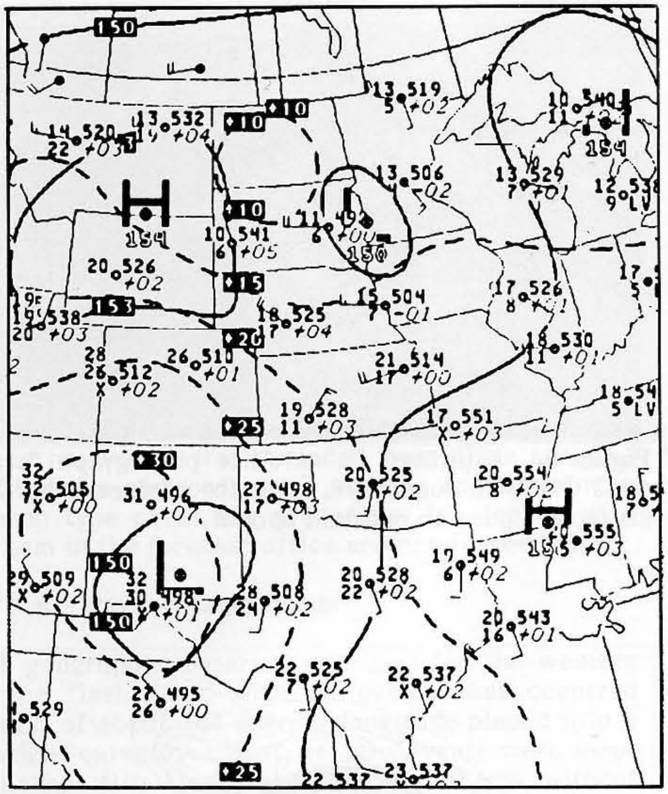

Figure 2a. NMC 850 mb chart for 0000 GMT, 31 May 1977.

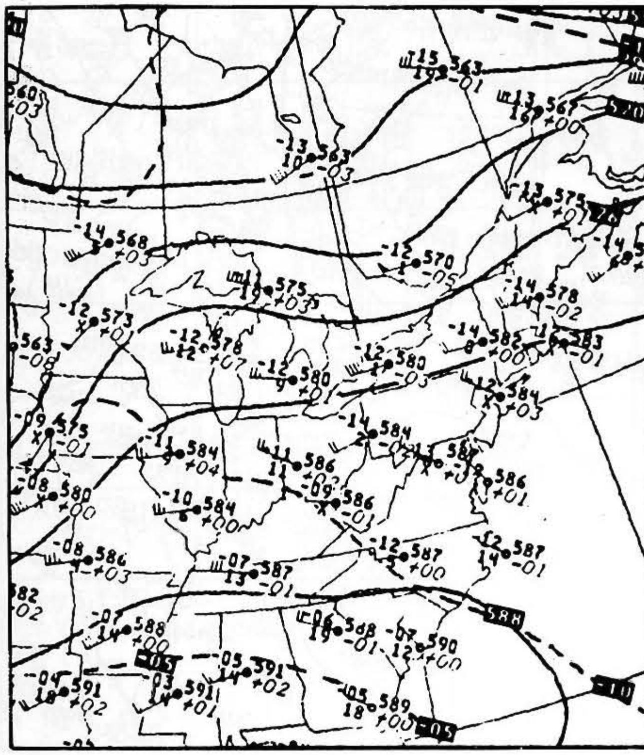

Figure 3a. NMC 500 mb chart for 0000 GMT, 15 June 1976.

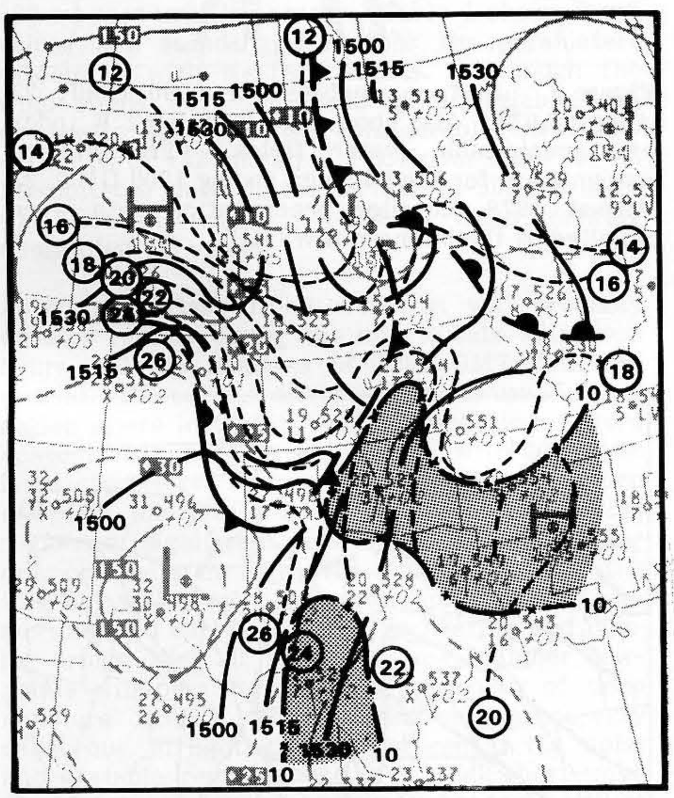

Figure 2b. Enhanced 850 mb chart for 0000 GMT, 31 May 1977. Contours have been redrawn; frontal positions are shown, as are two °C isotherms; and regions with $T_d \geq 10^{\circ}C$ are shaded.

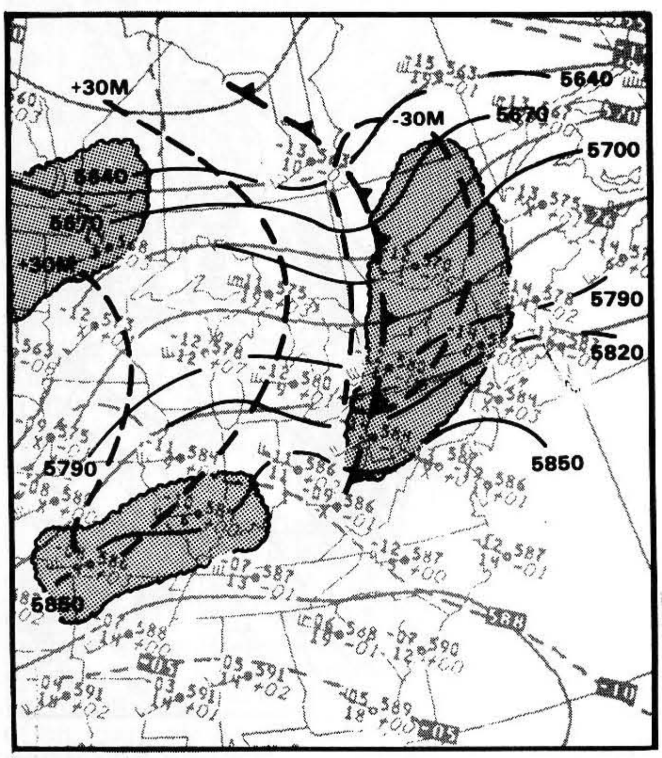

Figure 3b. Enhanced 500 mb chart for 0000 GMT, 15 June 1976. Short-wave trough position is indicated; moist regions are shaded; and additional height contours are shown along with an analysis of the 12 hour height changes.

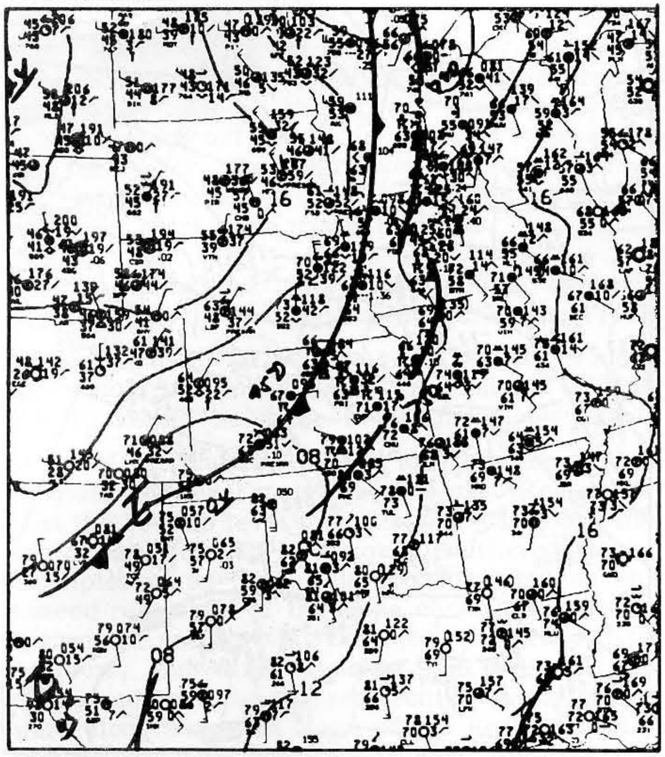

Figure 4a. NMC surface chart for 0600 GMT, 20 June 1978.

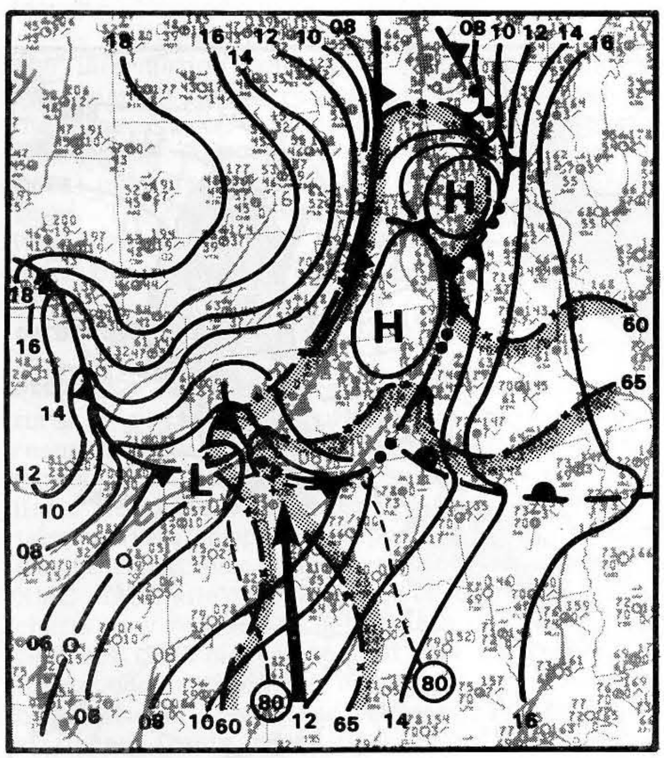

Figure 4b. Enhanced surface chart for 0600 GMT, 20 June 1978. Squall-line positions are indicated with barbs added to denote direction of movement; pressure field reanalyzed at 2 mb increments; 80°F isotherm is shown as are 60 and 65°F dewpoint analyses.

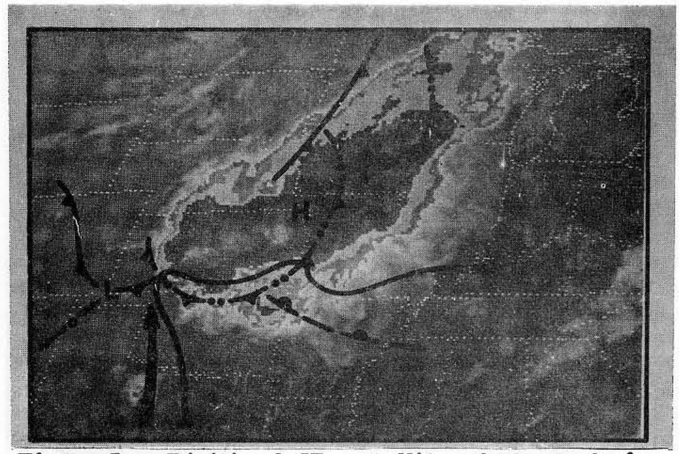

Figure 5. Digitized IR satellite photograph for 0600 GMT, 20 June 1978, with the surface analysis from Figure 4b overlain upon it.

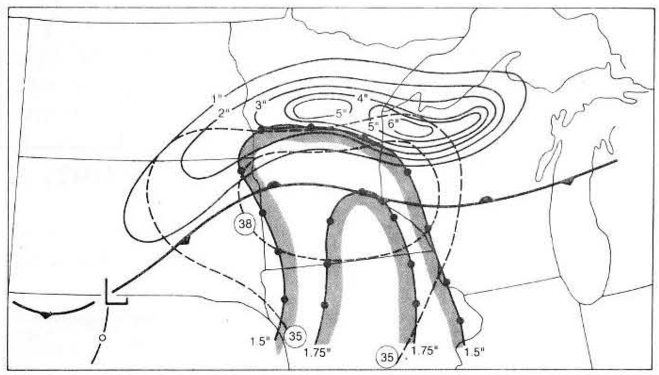

Figure 6. Surface analysis for 0000 GMT, 23 August 1978. Also shown are 0000 GMT K index and precipitable water fields. Precipitation amounts are for the 24 hours ending 1200 GMT, 23 August 1978 (detailed precipitation data were supplied by the Minnesota WSFO).

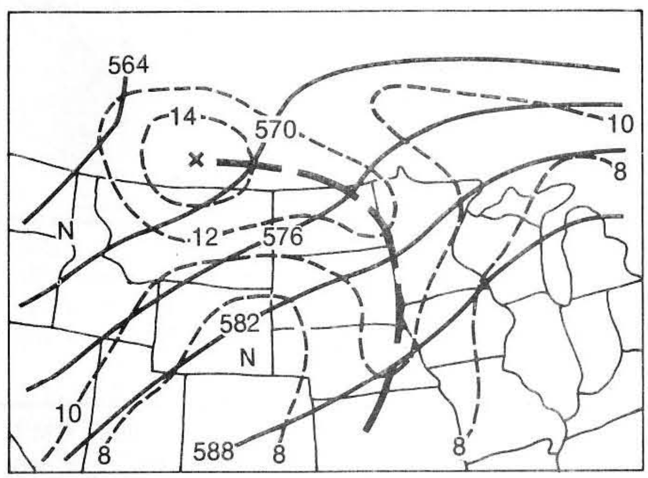

Figure 7. LFM 12 hour forecast of 500 mb heights and vorticity valid at 1200 GMT, 23 August 1978.

bility of flash flood producing storms has been anticipated the entire WSFO or WSO will be in a much better position to repsond correctly and rapidly when heavy rains develop. If it appears that a flash flood potential is present, or may develop, identify the type situation and then consider the following section.

3. METWATCH PROCEDURES FOR SPECIFIC TYPES OF FLASH FLOOD SITUATION

The study by Maddox et al (1979) identified characteristic types of flash flood events that occurred over the conterminous United States. (Note that flash flooding associated with tropical storms and hurricanes was excluded from their sample.) The basic meteorological patterns associated with each type event and procedures for dealing with them in the forecast office are considered below.

a. Western flash floods

A geographic criterion was used for the western type flash flood with all events that occurred west of about 104 degrees longitude placed into a single category. Most western events were associated with weak large scale patterns without well defined surface features. The paucity of surface observations over the West precluded any attempt at detailed classifications and maps of typical surface or upper-air patterns were not developed. An identifiable short-wave trough at 500 mb was usually present. Table 1 shows mean values and standard deviations for parameters associated with Western events. Although the wind fields were light and quite variable, the composite sounding had considerable instability with a KI of +42 and an SI (Showalter Index) of -5. Precipitable water in the surface-to-500 mb layer was 1.02 in. which is 143% of mean monthly climatological values.

A Western flash flood situation will probably develop rapidly during the mid to late afternoon hours and the analyses of 1200 GMT data are crucial. The outlook or threat area is usually that region where instability and tropospheric moisture content maximize in association with a middle level short-wave trough or cutoff low. Surface dewpoint analyses can be of use in identifying regions of significant moisture content. Morning dewpoints may be high over a large region of the Wet but will usually decrease rapidly during late morning and early afternoon as heating and mixing brings drier air to the surface. Higher dewpoints will persist, however, in regions of deep moisture content. Slow-moving storms are very dangerous. If light winds are present in the moist and unstable region ahead of a weak short-wave trough, storm development may be rapid and it might not be possible to go through the watch phase. Satellite laser-fax imagery can be used to monitor storm development and movement in areas of flash flood potential.

Level	T	Td	Wind Direction	Wind Speed
Surface: 1012 mb / 4 (Mean / Std. Dev.)	86 (°F) / 6	56(°F) / 6	120° / 57	9(kt) / 4
700 mb	10(°C) / 2	T-Td: 6 / 4	190 / 73	11 / 7
500 mb	-9 / 2	4 / 3	210 / 79	16 / 11
300 mb	-34 / 3	10 / 7	220 / 62	27 / 19
200 mb	-55 / 2	——	235 / 65	34 / 20

Table 1. Mean conditions associated with Western type flash flood events.

A typical Western flash flood situation is presented in Figures 8, 9, and 10. The reanalyzed morning 500 mb chart (Figure 8) indicated a very weak cutoff low over the Great Basin. There were two short-wave troughs rotating around the cutoff and moisture contents were high in and ahead of the system. The cutoff low was moving slowly southeastward. The enhanced 700 mb chart (Figure 9) also showed the cutoff low over the Great Basin and abundant moisture with the system. The temperature gradient from central Wyoming to northern Utah indicated that a weak frontal boundary was also associated with the system. An afternoon surface chart (Figure 10) indicates that high dewpoints were present in the southwest and along the weak frontal zone from northwestern Colorado to southwestern Idaho. Thunderstorms with locally heavy rains and flash flooding occurred during the evening hours in the mountains of northern Utah where the cutoff low at 500 mb was interacting with a zone of high moisture contents and instability along the old frontal boundary.

b. Synoptic type flash floods

Synoptic type flash flood events develop in association with a relatively intense synoptic scale cyclone or frontal system. A major trough at 500 mb is usually moving slowly eastward or northeastward, and the associated surface front was often quasi-stationary. Convective storms repeatedly develop and move rapidly over the same general area. These events sometimes affect portions of several states and may last as long as 2 to 3 days. Several individual flash floods may occur within the area affected by heavy rains and large areas of general flooding may also occur.

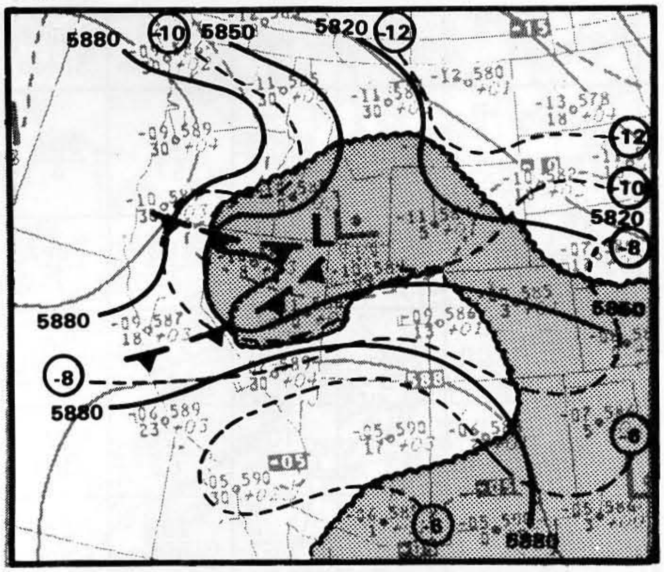

Figure 8. Enhanced 500 mb analysis for 1200 GMT, 14 July 1973. Details as in Figure 1b.

Table 2 lists the mean values of temperature and wind fields at the standard levels and shows the standard deviation for each mean. Variability in the fields is greatest for the winds with fairly small fluctuations in the temperatures at all levels. The orientation of the synoptic scale

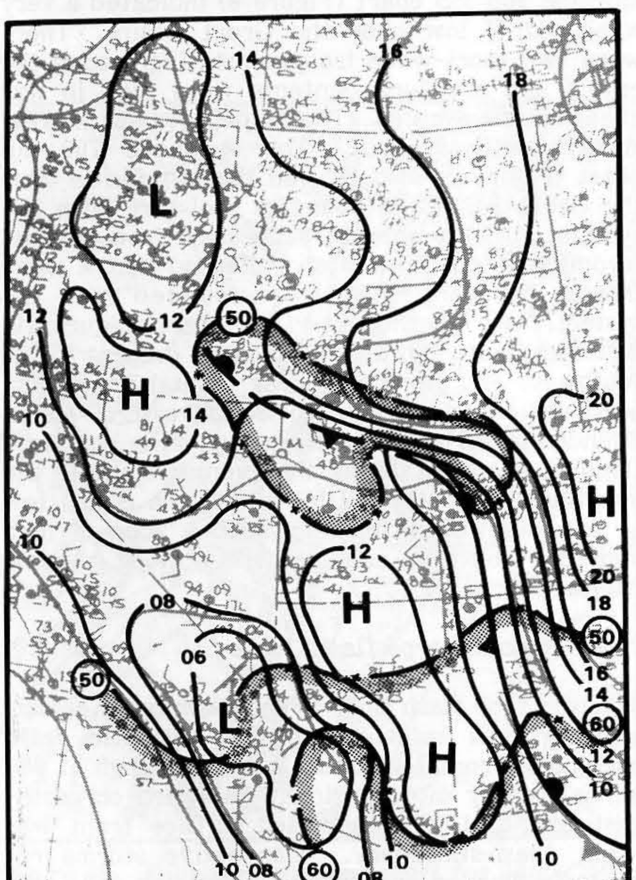

Figure 10. Enhanced surface chart for 0000 GMT, 15 July 1973. Frontal positions and pressure contours have been reanalyzed. Analyses of dewpoints greater than 50 and 60°F are shown.

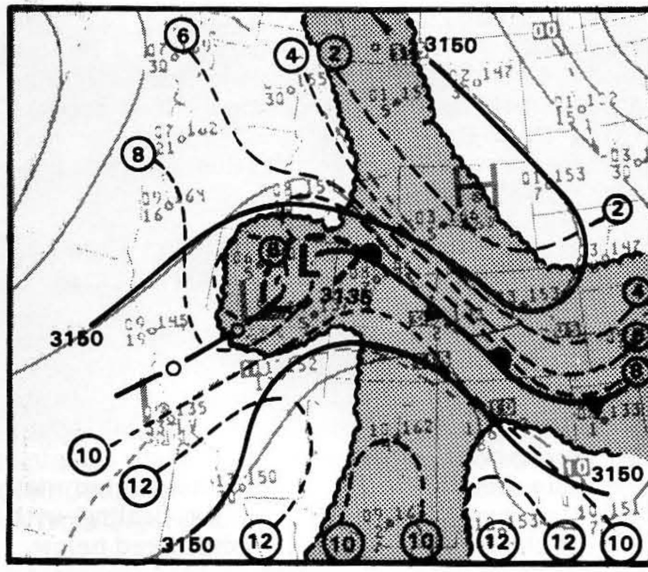

Figure 9. Enhanced 700 mb analysis for 1200 GMT, 14 July 1973. Frontal position is indicated as are two °C isotherms and moist regions (shaded). Height contours have been reanalyzed.

systems affects the variance of the winds, and although most fronts attending these events tend to be oriented SSW to NNE, a few systems were oriented essentially W to E. Regardless of the orientation, winds aloft tend to parallel the front. The composite sounding was unstable with a KI of +36 and an SI of -2. Precipitable water in the surface-to-500 mb layer was 1.48 in. which was 181% of the mean monthly climatological value.

Surface features, 850 mb, and 500 mb flow patterns are shown in Figure 11 for a typical Synoptic type event. Possible watch areas for heavy rains and flash flooding are indicated by the shaded rectangles. The eastward extension is shown since a warm frontal boundary often limits the northward spread of heavy rains while helping trigger new developments further eastward.

Of the four flash flood types a synoptic situation is probably the easiest to identify and deal with. Watches may be required over portions of several states and mesoanalysis (reanalysis) procedures should be used to identify specific regions in which rainfall might be greatest. The seriousness of the specific situation is determined by the speed of movement of the large scale frontal system, the absolute moisture content of the warm sector air, and the degree of convective instability present. One should monitor radar and satellite data to determine regions subject to persistent cell genesis or passage. The development of important focusing features may be detected in the reanalysis of the facsimile surface charts. If an E-W warm frontal boundary or pressure trough develops, the heaviest rains are likely along and to the north of it. The same is true if a mesohigh and E-W thunderstorm outflow

Level	T	Td	Wind Direction	Wind Speed
Surface 1009 mb / 6 (Mean / Std. Dev.)	74(°F) / 7	67(°F) / 4	165° / 33	13 (kt) / 3
850 mb	15(°C) / 3	T-Td 2(°C) / 1	195 / 28	32 / 11
700 mb	5 / 2	3 / 3	215 / 29	36 / 11
500 mb	-11 / 3	8 / 9	220 / 29	47 / 14
300 mb	-38 / 3	10 / 7	230 / 30	57 / 21
200 mb	-57 / 3	—	235 / 32	66 / 21

Table 2. Mean conditions associated with Synoptic type flash flood events.

boundary develops. Such boundaries, once formed, may be very slow to move since continued precipitation cooling helps to enforce and maintain them. Figure 12 shows a surface map depicting the development of such an E-W frontal boundary during a Synoptic flash flood situation. The region that experienced heavy rains and local areas of flash flooding during the subsequent 36

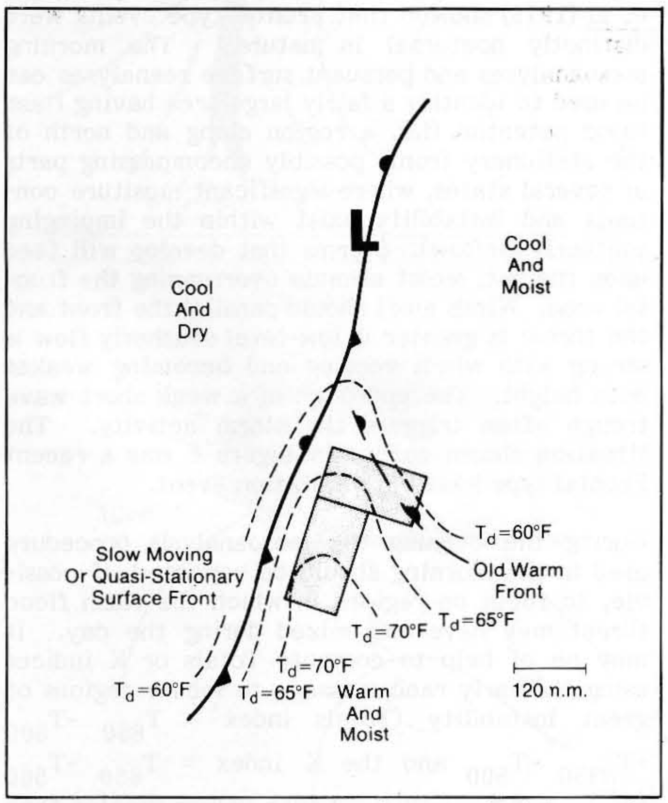

Figure 11a. Surface pattern for a typical Synoptic type flash flood event. Possible flash flood watch areas are shown as shaded rectangles.

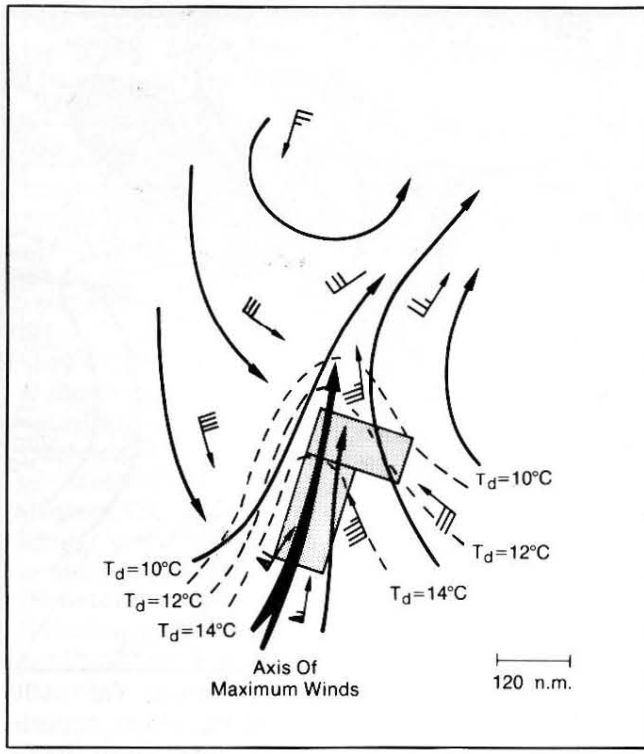

Figure 11b. The corresponding 850 mb flow pattern for a typical Synoptic type flash flood event. Winds are in knots with full barb = 10 kt and flag = 50 kt; the relative location of the flash flood rectangles is the same as in Figure 11a.

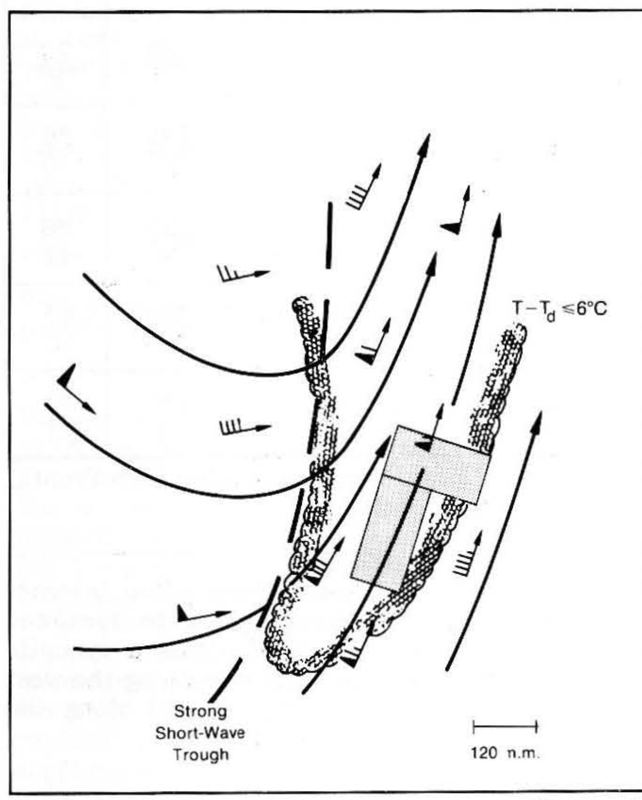

Figure 11c. The corresponding 500 mb flow pattern for a typical Synoptic type flash flood event.

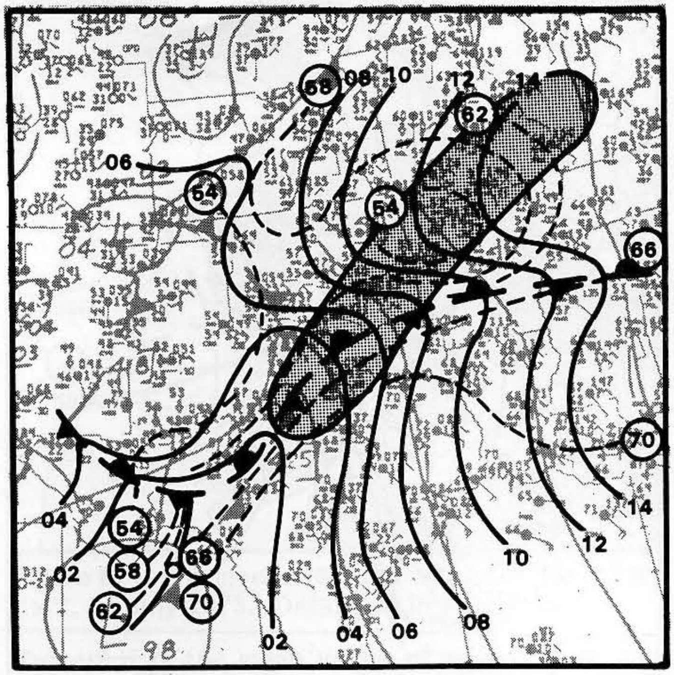

Figure 12. Enhanced surface analysis for 0600 GMT, 27 March 1977. The region which experienced general heavy rains and several flash floods during the subsequent 36 hours is shaded.

Level	T	Td	Wind Direction	Wind Speed
Surface (1013 mb / 4; Mean / Std. Dev.)	70(°F) / 6	65(°F) / 5	100° / 36	9 (kt) / 2
850 mb	17(°C) / 3	T-Td 4(°C) / 2	200 / 26	20 / 8
700 mb	7 / 2	3 / 3	235 / 30	20 / 10
500 mb	-10 / 3	6 / 7	250 / 34	28 / 12
300 mb	-36 / 3	15 / 11	260 / 29	40 / 16
200 mb	-56 / 3	———	270 / 22	47 / 21

Table 3. Mean conditions associated with Frontal type flash flood events.

hours is shaded. Terrain features often interact with the low-level flow to generate localized regions of very heavy rainfall within a synoptic type event. This is especially true along the west coast west of the Sierra Ranges and along the east coast in the Appalachian Ranges.

c. Frontal flash flood events

A stationary or very slow moving synoptic scale frontal boundary (usually oriented E-W) that acts to trigger and focus heavy rain storms is the distinguishing characteristic of the Frontal type event. The heavy rains occur on the cool side of the surface front as warm unstable air flows over the frontal zone. Thi situation is distinctly different than the synoptic event where the storms predominantly develop in and move over the same region. The 500 mb analyses indicated that a detectable meso-α scale shortwave trough was usually associated (85% of the time) with these events.

Table 3 lists mean values of wind and temperature that were associated with these events. Wind speeds increase little from 850 through 300 mb, although significant veering occurs. This veering favors movement of the storms roughly parallel to the forcing boundary, while inflow of unstable air continues undisrupted on their right flanks. The composite sounding has a KI of +38 and an unstable SI of -4. Precipitable water in the surface-to-500 mb layer was 1.60 in. or 158% of the mean monthly climatological value.

Surface features, 850 mb, and 500 mb flow patterns are shown in Figure 13 for a typical Frontal event. In some cases a weak mesolow moves eastward along the frontal boundary increasing small scale convergence and inflow to the storm area. During a Frontal situation the events of the afternoon and evening will set the stage for the nighttime scenario. (The earlier paper by Maddox et al (1979) showed that Frontal type events were distinctly nocturnal in nature.) The morning mesoanalyses and persuant surface reanalyses can be used to identify a fairly large area having flash flood potential (i.e. a region along and north of the stationary front, possibly encompassing parts of several states, where significant mositure contents and instability exist within the impinging southerly airflow). Storms that develop will feed upon the hot, moist airmass overrunning the frontal zone. Winds aloft should parallel the front and the threat is greater if low-level southerly flow is strong with winds veering and becoming weaker with height. The approach of a weak short-wave trough often triggers the storm activity. The situation shown earlier in Figure 6 was a recent Frontal type heavy precipitation event.

During the evening the mesoanalysis procedure used in the morning should be repeated, if possible, to focus on regions in which the flash flood threat may have maximized during the day. It may be of help to compute Totals or K indices using the early raob message to locate regions of great instability (Totals index = $T_{850} - T_{500} + T_{d850} - T_{500}$ and the K index = $T_{850} - T_{500} + T_{d850} - (T_{700} - T_{d700})$ with values greater than 44 and 30, respectively, indicating increasing probabilities of thunderstorms.)

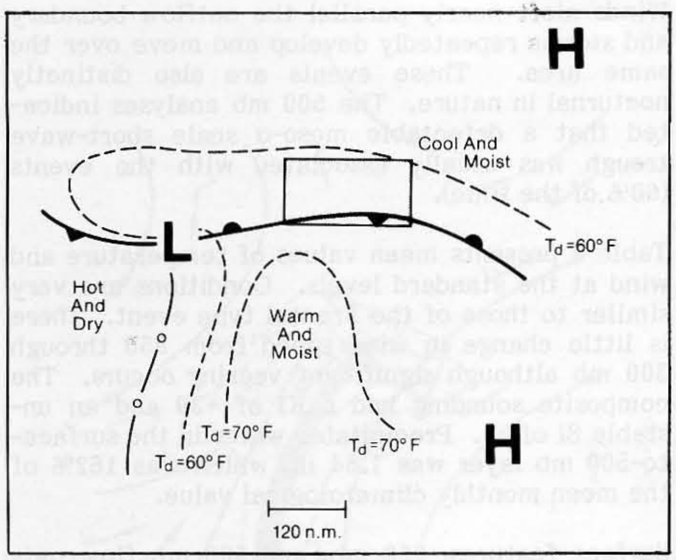

Figure 13a. Surface pattern for a typical Frontal type flash flood event with details as in Figure 11a.

Satellite and radar data should be used to monitor the threat area and they can provide vital information needed to define the flash flood watch area. Radar tops are usually quite high; however, if low-level forcing is strong and convective instability marginal the storms may present deceptively weak radar signatures. If coalescence is very effective in the lower part (warm portion) of a cloud system radar may indicate high tops but relatively weak reflectivities at medium to long ranges. Watch for changes in the radar depiction of storm orientation. A line of storms that evolves from a classic N-S to an E-W orientation along an outflow boundary or frontal zone is acquiring greater flash flood potential. Digitized IR satellite images are of great value and bright (interior gray and white shades) areas along and north of the frontal zone indicate high falsh flood threat.

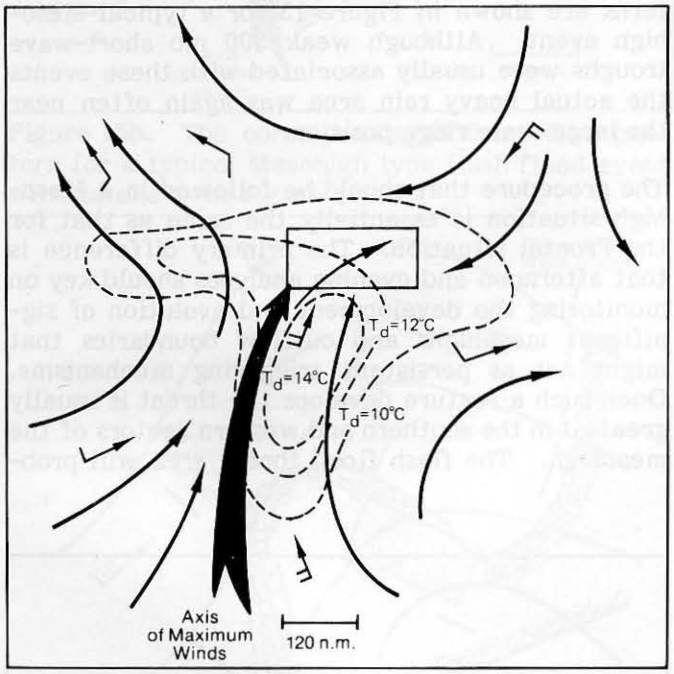

Figure 13b. The corresponding 850 mb flow pattern for a typical Frontal type flash flood event with details as in Figure 11b.

It is important to use radar and satellite information in conjunction with the reanalyzed surface maps (see Figure 5). Anvil outflow may, in some cases, extend out over the storm-triggering frontal zone and obscure the precise threat area. Usually the flash flooding will be associated with a large complex of thunderstorms and the brightest tops will occur along the southern periphery of the system where the most unstable air is feeding storm development (see also Scofield and Oliver, 1977).

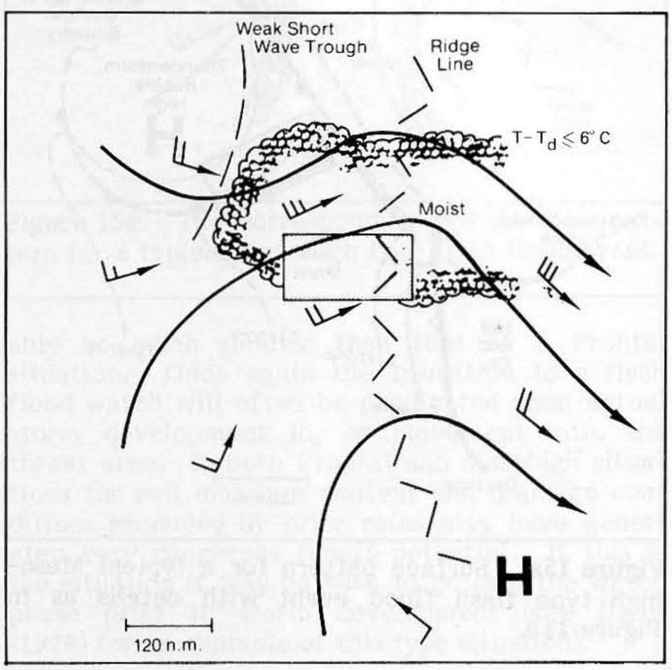

Figure 13c. The corresponding 500 mb flow pattern for a typical Frontal type flash flood event.

Various situations will require different amounts of frontal lift to trigger convective development. This factor will determine how far to the north of the surface front the watch area should be located. Radar data is of great use in determining the positioning of the watch relative to the triggering boundary. The transition from a met-watch phase to an actual flash flood watch should, in many cases, be predicated upon actual storm development in or west of the threat area. On occasion the threat may be great but not be realized because large scale subsidence totally suppresses storm development. This emphasizes once again the importance of identifying and maintaining continuity for weak 500 mb shortwave troughs.

d. Mesohigh flash flood events

Maddox et al (1979) found that Mesohigh type flash floods were predominant comprising 34% of the events studied. These flash floods were associated with a nearly stationary thunderstorm outflow boundary that had been generated by earlier convective activity. The heaviest rains occurred on the cool side of the boundary usually to the south or southwest of the mesohigh pressure center. About half of the events occurred to the east of a slow moving large scale frontal system, while the other events were far removed from any notable surface fronts. Figure 14 illustrates a slow-moving outflow boundary and mesohigh that were associated with flash flooding that occurred within a very benign surface pattern.

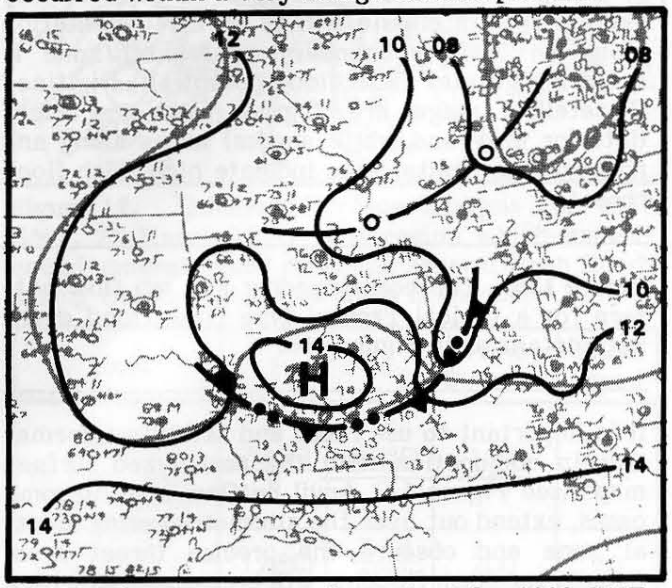

Figure 14. Enhanced surface chart for 0600 GMT, 8 July 1975.

Level	T	Td	Wind Direction	Wind Speed
Surface 1014 mb / 4 (Mean / Std. Dev.)	71(°F) / 4	66(°F) / 4	090° / 41	9 (kt) / 3
850 mb	18(°C) / 3	T-Td 3(°C) / 2	205 / 33	22 / 8
700 mb	7 / 2	4 / 3	230 / 32	21 / 10
500 mb	-10 / 3	6 / 6	240 / 27	27 / 11
300 mb	-36 / 4	10 / 8	255 / 32	37 / 16
200 mb	-57 / 3		260 / 40	41 / 20

Table 4. Mean conditions associated with Mesohigh type flash flood events.

Winds aloft nearly parallel the outflow boundary and storms repeatedly develop and move over the same area. These events are also distinctly nocturnal in nature. The 500 mb analyses indicated that a detectable meso-α scale short-wave trough was usually associated with the events (60% of the time).

Table 4 presents mean values of temperature and wind at the standard levels. Conditions are very similar to those of the Frontal type event. There is little change in wind speed from 850 through 300 mb although significant veering occurs. The composite sounding had a KI of +39 and an unstable SI of -5. Precipitable water in the surface-to-500 mb layer was 1.64 in. which was 162% of the mean monthly climatological value.

Surface features, 850 mb, and 500 mb flow patterns are shown in Figure 15 for a typical Mesohigh event. Although weak 500 mb short-wave troughs were usually associated with these events the actual heavy rain area was again often near the large scale ridge position.

The procedure that should be followed in a Mesohigh situation is essentially the same as that for the Frontal situation. The primary difference is that afternoon and evening analyses should key on monitoring the development and evolution of significant mesohighs and outflow boundaries that might act as persistent triggering mechanisms. Once such a feature develops the threat is usually greatest in the southern and western sectors of the mesohigh. The flash flood threat area will prob-

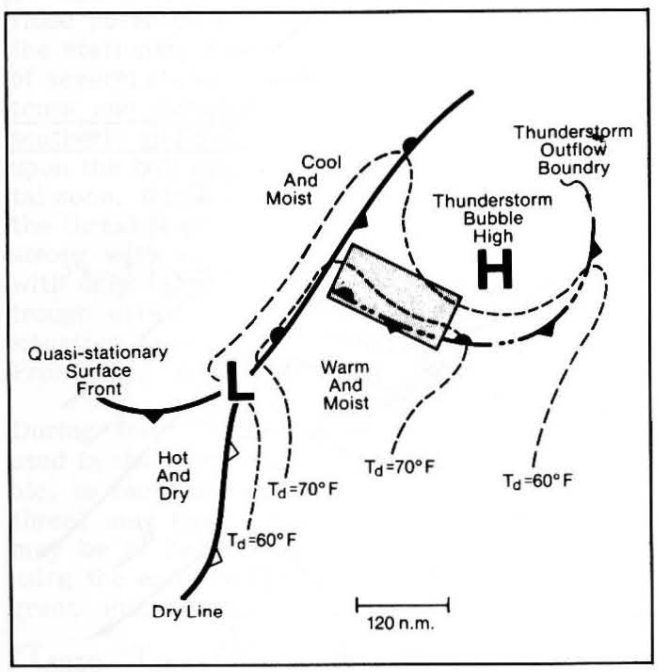

Figure 15a. Surface pattern for a typical Mesohigh type flash flood event with details as in Figure 11a.

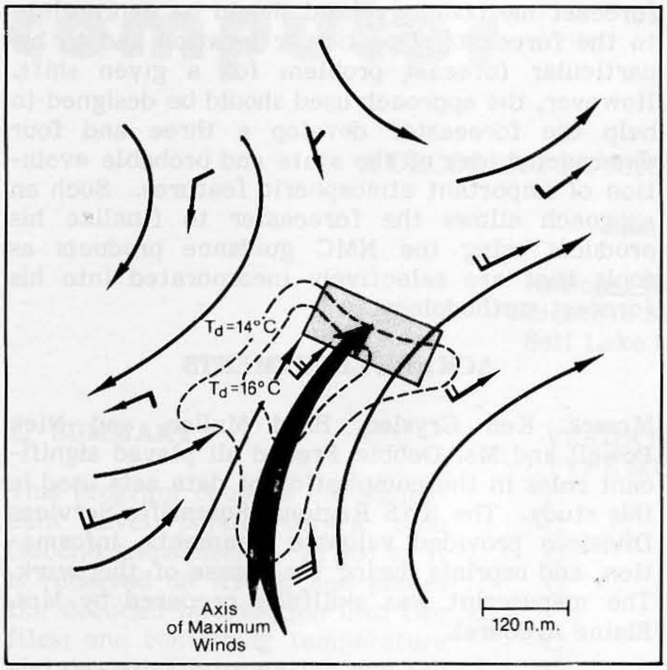

Figure 15b. The corresponding 850 mb flow pattern for a typical Mesohigh type flash flood event with details as in Figure 11b.

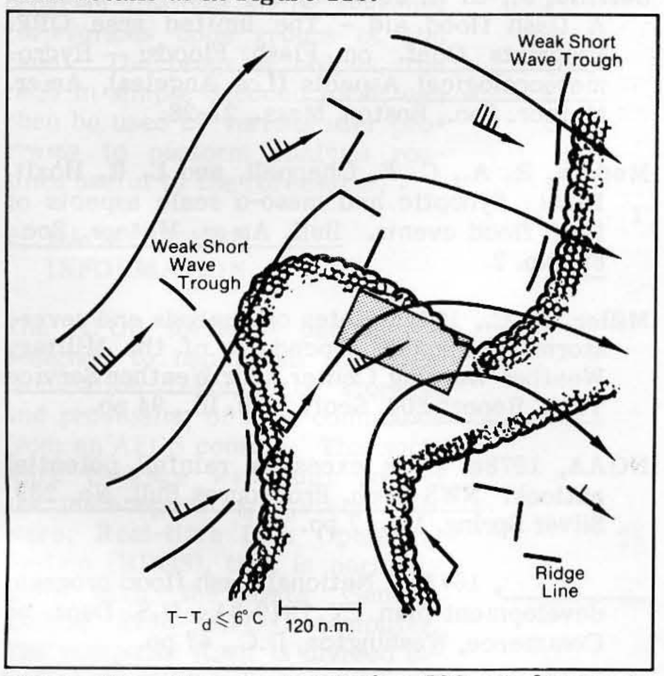

Figure 15c. The corresponding 500 mb flow pattern for a typical Mesohigh type flash flood event.

ably be much smaller than that of a Frontal situation. Once again the transition to a flash flood watch will often be predicated upon actual storm development in, or movement into, the threat area. In both Frontal and Mesohigh situations the soil moisture content and drainage conditions produced by prior rains may have generated very dangerous runoff potential. If this is the situation it may be wise to go into the watch phase prior to storm development (see Hales (1978) for an example of this type situation).

4. COMPOSITE CHART

It may be of great help (whether one is forecasting flash flood potential, precipitation probability, cloud cover, maximum temperature, etc.) to construct a three-dimensional composite chart. The composite map is developed by overlaying important features and parameters from the significant level analyses onto an appropriate base chart. Data from the various levels may be identified by color coding (e.g. 500 mb features in blue, 700 mb features in brown, 850 mb features in red, low-level moisture analyses in green, stability analyses in orange, and surface analyses in black).

A composite chart for use in identifying flash flood potential might logically be built upon the reanalyzed surface chart (1200 or 1800 GMT/0000 or 0600 GMT). Parameters and features depicted should fit the particular type situation and the locale involved and might include some of the following:

500 mb streamlines, isotachs, short-wave trough positions, and moist regions.

700 mb short-wave trough positions, moist regions, +10°C isotherm (at low elevation stations middle level temperature warmer than 10°C usually act to suppress convective development).

850 mb Frontal positions, streamlines, isotachs, +10°C dewpoint isoline.

Moisture Precipitable water analysis for amounts ≥ 1", surface dewpoints greater than 50 or 60°F (depending upon locale).

Stability K index analysis for values ≥ 30.

It may also be useful to indicate forecast positions of some of the more important features.

Figure 16 illustrates a simple composite chart done in black and white (color keyed composites are much simpler to interpret and use). The chart indicates that a moderately strong southerly flow of very moist air at 850 mb is overrunning the southwestern sector of the meso-high pressure system, that a weak 500 mb short-wave trough is approaching from the southwest, and that the troposphere is very moist up through at least 500 mb ahead of the short-wave. The composite analysis indicates that a number of favorable flash flood features are about to interact over southeast Oklahoma, northeast Texas, northwest Louisiana, and southwest Arkansas. The NMC short range (0-12 hours) guidance products should be used at this point in time by the forecaster as he makes his final evaluations of the developing flash flood threat.

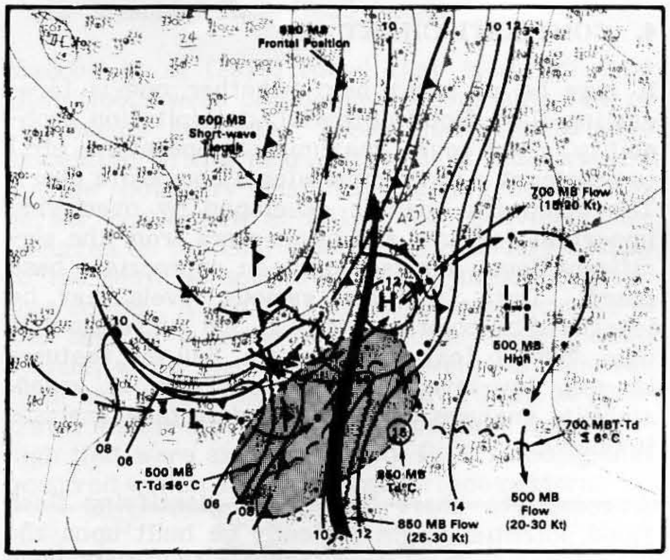

Figure 16. Black and white composite chart for a Mesohigh type flash flood situation. Upper-air features are from reanalyzed 0000 GMT, 18 June 1976, standard level charts. The enhanced surface chart used as a base map is for 0900 GMT, 18 June 1976.

5. SUMMARY

A forecast methodology has been developed that is designed to help the Forecaster identify and monitor meteorological conditions favorable for the occurrence of heavy convective rain. A number of meteorological processes interact on several scales of motion to eventually define the region of excessive rain. As in severe thunderstorm situations, marginal values of one important parameter may be compensated by more intense values of another parameter. This large natural variability makes the definition of necessary conditions for flash flooding most difficult.

The forecast and warning problem is also complicated by the nocturnal nature of many flash flood events. Unlike severe thunderstorms, many flash floods occur near the large scale ridge position and within normally benign surface pressure systems and patterns. This elusive characteristic further complicates the forecast problem and emphasizes the importance of the role of the professional meteorologist in the flash flood warning system.

The suggestions presented in this paper should be considered as general guidelines. The actual forecast methodology used should be appropriate to the forecasters' particular location and to his particular forecast problem for a given shift. However, the approach used should be designed to help the forecaster develop a three and four dimensional idea of the state and probable evolution of important atmospheric features. Such an approach allows the forecaster to finalize his products using the NMC guidance products as tools that are selectively incorporated into his forecast methodology.

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REFERENCES

Belville, J., G. A. Johnson, and J. D. Ward, 1978: A flash flood aid - The limited area QPF. Preprints Conf. on Flash Floods: Hydrometeorological Aspects (Los Angeles), Amer. Meteor. Soc., Boston, Mass., 21-28.

Maddox, R. A., C. F. Chappell, and L. R. Hoxit, 1979: Synoptic and meso-α scale aspects of flash flood events. Bull. Amer. Meteor. Soc., 60, No. 2.

Miller, R. C., 1967: Notes on analysis and severe storm forecasting procedures of the Military Weather Warning Center. Air Weather Service Tech. Report 200, Scott AFB, Ill., 94 pp.

NOAA, 1978a: The excessive rainfall potential outlook. NWS Tech. Procedures Bull. No. 239, Silver Spring, Md., 7 pp.

________, 1978b: National flash flood program development plan FY 1979-84. U.S. Dept. of Commerce, Washington, D.C., 47 pp.

________, 1978c: How to not issue a flash flood watch. NWS Eastern Region Tech. Attach. No. 78-10, Garden City, N.Y. 4 pp.

NWA, 1978: NWA position on weather services. NWA Newsletter, No. 78-2, Clinton, Md., 1.

Scofield, R. A. and V. J. Oliver, 1977: A scheme for estimating convective rainfall from satellite imagery. NOAA-NESS Tech. Memo. 86, Washington, D.C., 47 pp.

Snellman, L. W., 1978: Go Western Region, young man. NWA Digest, 3, 4.