NOAA Technical Memorandum NWS WR-206

A COLLECTION OF PAPERS RELATED TO HEAVY PRECIPITATION FORECASTING

Western Region Headquarters
Scientific Services Division
August 1989

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

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Scientific Services Division
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Table of Contents

A COLLECTION OF PAPERS RELATED TO HEAVY PRECIPITATION FORECASTING

Introduction

The second national Heavy Precipitation Workshop, scheduled to be held in Asilomar, California in March 1989, was unfortunately canceled after much of the organization and preparation had been completed. Hopefully, it can be planned for a later date. In the meantime, some of the scheduled speakers agreed to submit their topics to the Western Region Scientific Services Division as papers for publication. This Technical Memorandum is a collection of four of those papers.

The first paper is a general discussion of the complexity of heavy precipitation within Extratropical Cyclone Systems and the theory of "instability bursts". The second paper is a case study which reveals the usefulness of the AFOS Development Analysis Program (ADAP) mesoscale analysis package in identifying heavy precipitation focusing mechanisms. The third is a thorough overview of the Ventura County, California ALERT flood warning system, including its operation, multipurpose uses, concerns of local sponsors, and its impact on users. The fourth paper discusses the use of an orographic precipitation model in part of the Sierra-Nevada mountains as an aid in quantitative precipitation forecasting. These four papers are a good representation of the wide variety of topics that were scheduled for the Heavy Precipitation Workshop.

The problems and possible solutions related to heavy precipitation forecasting need to be addressed and shared among government and private meteorologists, the university community, research organizations, and user groups. We are hopeful that we will be able to work with many of you again in planning a forum for such discussions. Thanks for your help and support.

INSTABILITY BURSTS ASSOCIATED WITH EXTRATROPICAL CYCLONE SYSTEMS (ECSs) AND A 3-12 HOUR HEAVY PRECIPITATION FORECAST INDEX ---
AN EXTENDED ABSTRACT

by

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This note is an extended abstract of a paper to be published as a NOAA/NESDIS Technical Memorandum.

INSTABILITY BURSTS

Today one of the greatest challenges of an operational meteorologist is understanding the evolution and characteristics of precipitation within the Extratropical Cyclone System (ECS). It is known that heavy precipitation in ECSs is convective. Convective bands or areas are a dominant feature of the ECS heavy precipitation areas; this has been documented by Houze et al. (1981), Herzegh and Hobbs (1980) and others. Heavy precipitation areas associated with ECSs develop and end suddenly and usually occur over small areas. Instability Bursts are one of the primary mechanisms for producing heavy precipitation. Instability Bursts are defined as a thrust of maximum atmospheric destabilization into an area. Instability Bursts are best detected by using a combination of satellite imagery with instability analyses derived from surface and upper air data and numerical model data. Figure 1 illustrates a Mesoscale Convective System (MCS) over Missouri. Figure 2 shows a developing ECS that deposited over a foot of snow in Missouri and nearby states. The ECS looks like a MCS (at M) at 1301 GMT. The ECS evolves into an upper level system at (U) and a squall line at (S) at 0031 GMT and finally to a mature comma head (C) and comma tail (T) by December 15, 1200 GMT. Is the ECS at 1301 GMT (at M) really a MCS?

In the satellite imagery, Instability Bursts are identified as subsynoptic scale wave patterns or convective cloud areas or bands embedded within the ECSs. Often these features grow rapidly and the cloud top temperatures become progressively colder in the infrared (IR) imagery; these features appear to "burst" their way into existence like MCSs.

In the surface and upper air data, Instability Bursts are associated with: (1) the maximum advection of unstable air or (2) an upper level disturbance or jet streak passing over an unstable air mass. Instability Bursts can be expected in areas: (1) of positive advection of equivalent potential temperature (θ_e) (especially at 850 mb - see Figures 3a,b and 4a,b*, (2) of maximum 850 mb flow from higher to lower K index values (K = 10-20 for heavy snow; K = 20-30 for heavy rain and $K > 30$ for deep convection (see Figure 5) and (3) where significant upward vertical motion occurs over a moist and rather unstable air mass ($K \geq 0$, 850 mb θ_e advection can vary from slightly < 0 to slightly > 0 and/or Conditional Symmetric Instability (CSI) is present) (see Figure 5).

CSI, which is sometimes called Slantwise Convection, is another cause of the convective bands or areas associated with heavy precipitation in ECSs (Sanders, 1984). As described by Bennetts and Hoskins (1979) and others, CSI is a result of: inertial instability (a horizontal instability; restoring forces are centrifugal), convective instability (a vertical instability; restoring forces are gravitational) and an atmosphere at or near saturation. An approximate criteria for CSI is an atmosphere that is near saturation and possesses a large horizontal temperature gradient and a small Richardson Number.

Moore (1986) and Moore and Blakley (1988) discuss the use of cross sectional analysis for determining the presence of convective instability and CSI. Convective instability is indicated by θ_e decreasing with height, and CSI by θ_e decreasing with height along constant momentum surfaces. An example of these types of instabilities during a heavy snowstorm event follow. The cross sections were derived from upper air stations along a line from Centerville, Alabama to Green Bay, Wisconsin (Figure 6). Satellite imagery, cross sectional analyses and total snowfall accumulations for the storm are displayed in Figures 7, 8 and 9, respectively. The θ_e cross sectional analysis in Figure 8a show the strongest low level positive θ_e advection occurring between Nashville (BNA), Tennessee and Salem (SLO), Illinois (just south of the observed heaviest snow area). Satellite imagery indicated a comma head/cloud band passing over the heavy snow area that was developing as the comma head became more anticyclonic with time. Convective instability areas (θ_e decreasing with height) are indicated by the stippled region above SLO in Figure 8a and CSI (θ_e decreasing with height along a constant momentum surface) is indicated by the dotted lines above SLO in Figure 8b. In this case, both the convective instability area and CSI are collocated. However, there are instances in heavy ECS precipitation events where convective instability is not present BUT CSI is present. Cross sectional analysis routines for determining the presence of convective instability and CSI are available on AFOS.

Instability Bursts are also found by using a combination of the NGM Lifted Index analysis and its 12 hour forecast AND the 850 mb height contour analysis and 12 hour forecast. Instability Bursts are associated with the maximum advection of unstable air. The NGM Lifted Index is a "best" Lifted Index which is a measure of the most unstable air between the Earth's surface and approximately 850 mb. The NGM

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*Experience has shown that the 700 mb θ_e advection analysis is better for analyzing west coast precipitation than 850 mb.

Lifted Index is especially useful in locating unstable air above the Earth's surface (e.g., overrunning situations).

A 3-12 HOUR HEAVY PRECIPITATION FORECAST INDEX

Instability Bursts by themselves are not sufficient to produce heavy precipitation. For heavy precipitation to occur, there must be present (or forecast): an Instability Burst, a slow moving or regenerative ECS (except in rapidly deepening systems) and moisture. Collectively these items form the basis for a 3-12 Hour Heavy Precipitation Forecast Index. This index is presented in the form of a five step decision tree (Figures 10a,b,c). The five steps consist of determining:

(1) the presence (or expectation) of satellite signatures and mechanisms of heavy precipitation;

(2) the presence (or expectation) of moisture;

(3) the type (or expectation) of ECS movement;

(4) the location and estimation (amount) of the heaviest precipitation within the ECS (see Beckman, 1987 and Scofield and Spayd, 1984);

(5) the potential for a rapidly deepening surface low.

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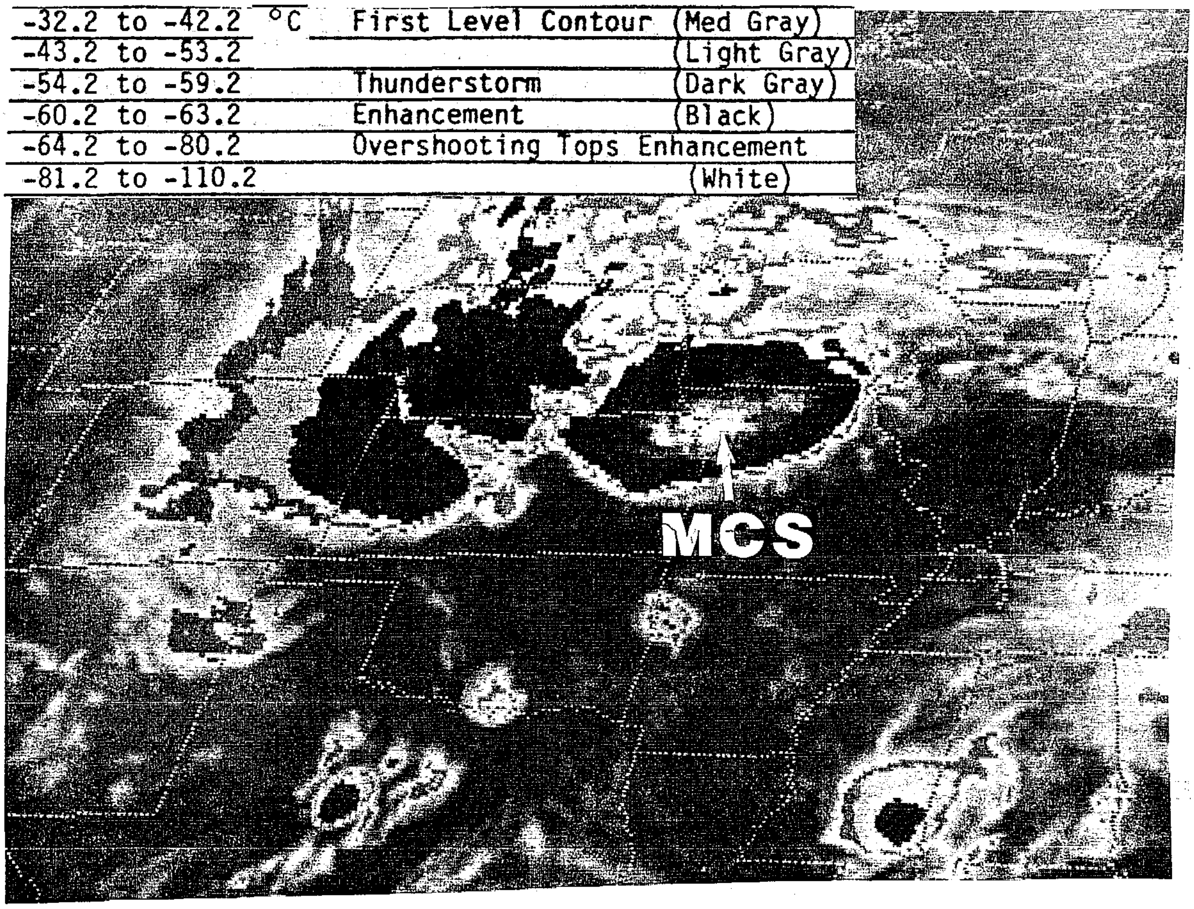


Figure 1. A Mesoscale Convective System (MCS) over Missouri; enhanced IR imagery (Mb Curve).

-36.2 to -41.2 °C	Thunderstorm enhancement
-42.2 to -47.2	" "
-48.2 to -52.2	" " (Light Gray)
-53.2 to -58.2	" " (Dark Gray)
-49.2 to -62.2	" " (Black)
-63.2 to -80.2	Overshooting tops enhancement
-81.2 to -109.0	(White)

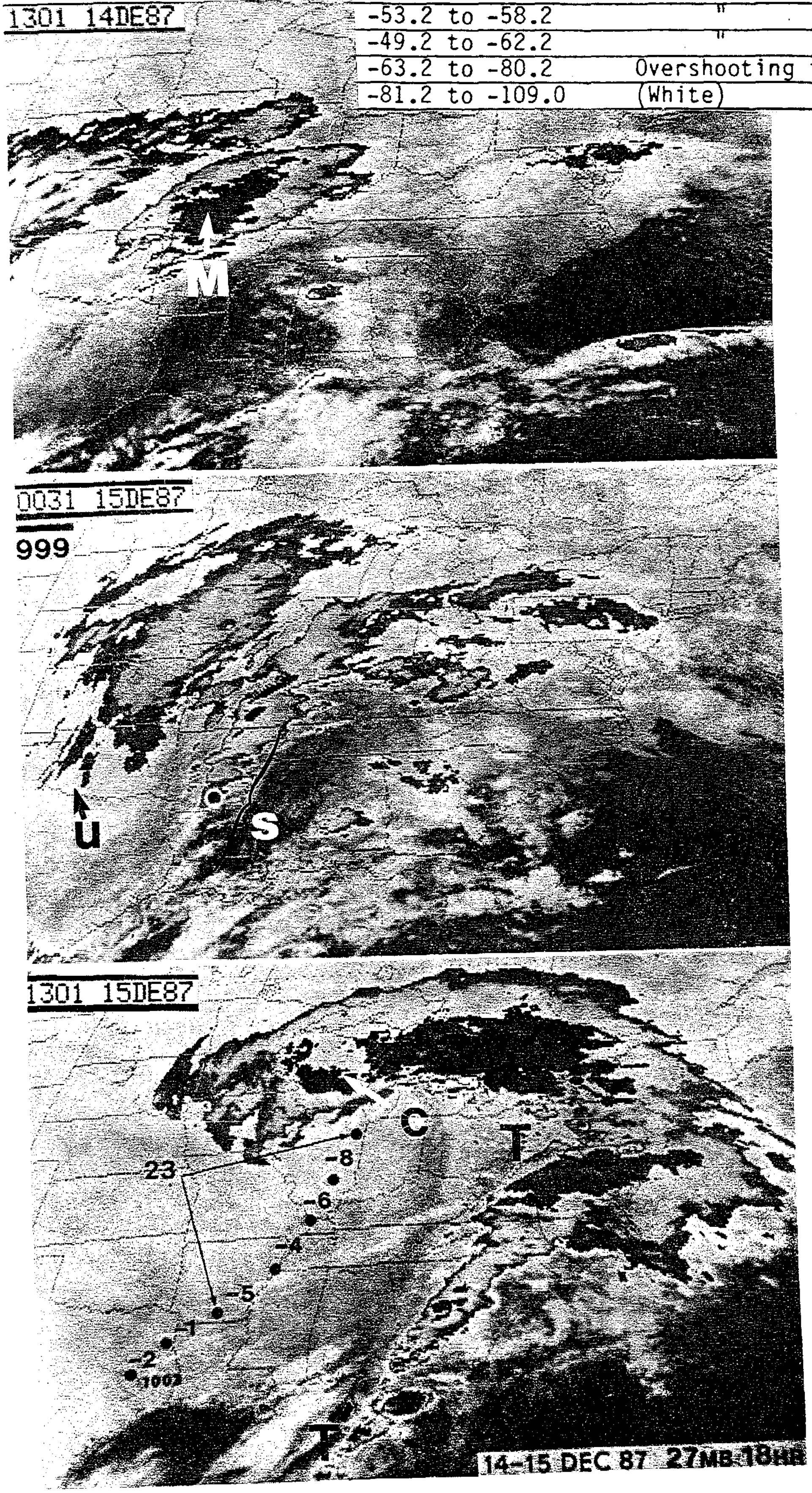


Figure 2. Extratropical Cyclone Systems (ECSs) over the midwest; enhanced IR imagery (CC Curve); dots locate position of surface low and the numbers are in units of millibars.

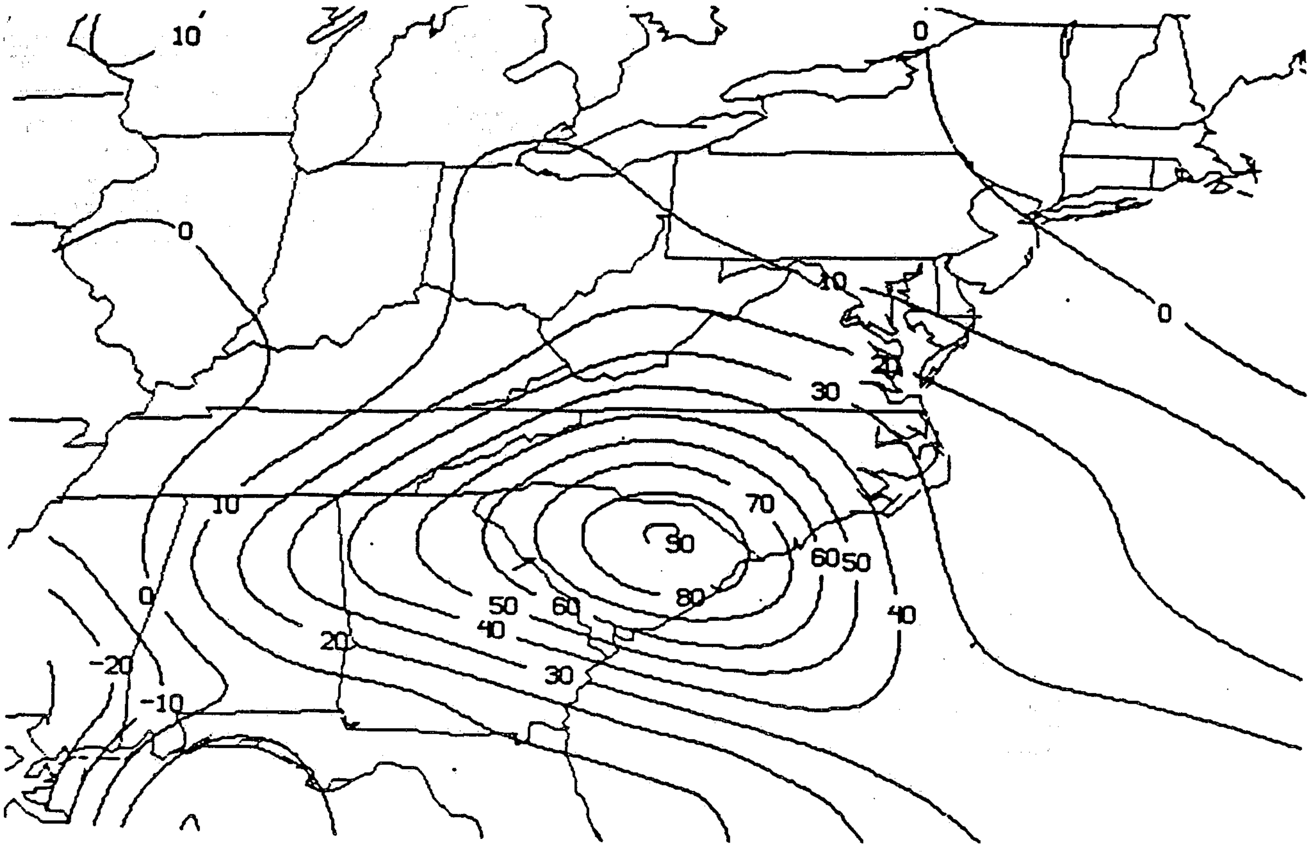


Figure 3a. 850 mb Θ_e advection (° /day), January 8, 1988, 0000 GMT.

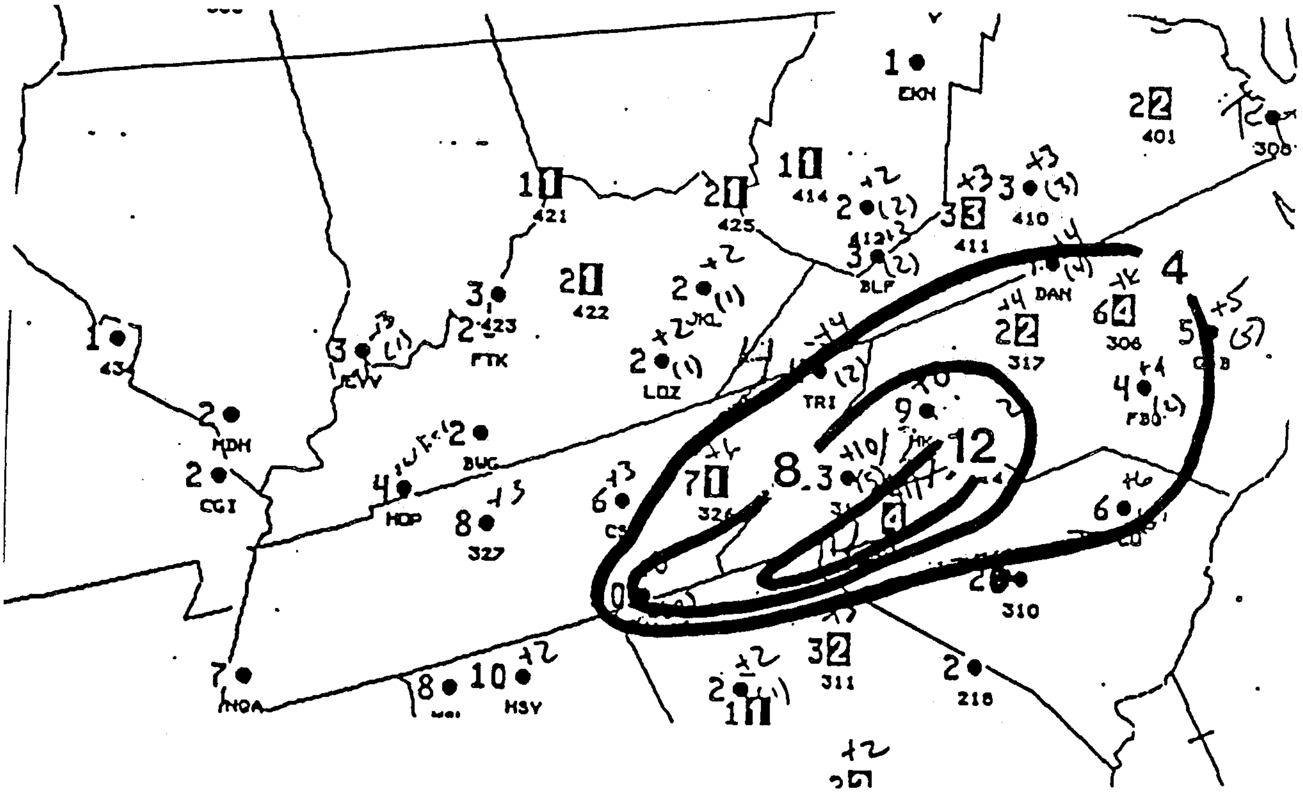


Figure 3b. Twelve hour heavy snowfall (inches) ending at January 8, 1988, 0000 GMT.

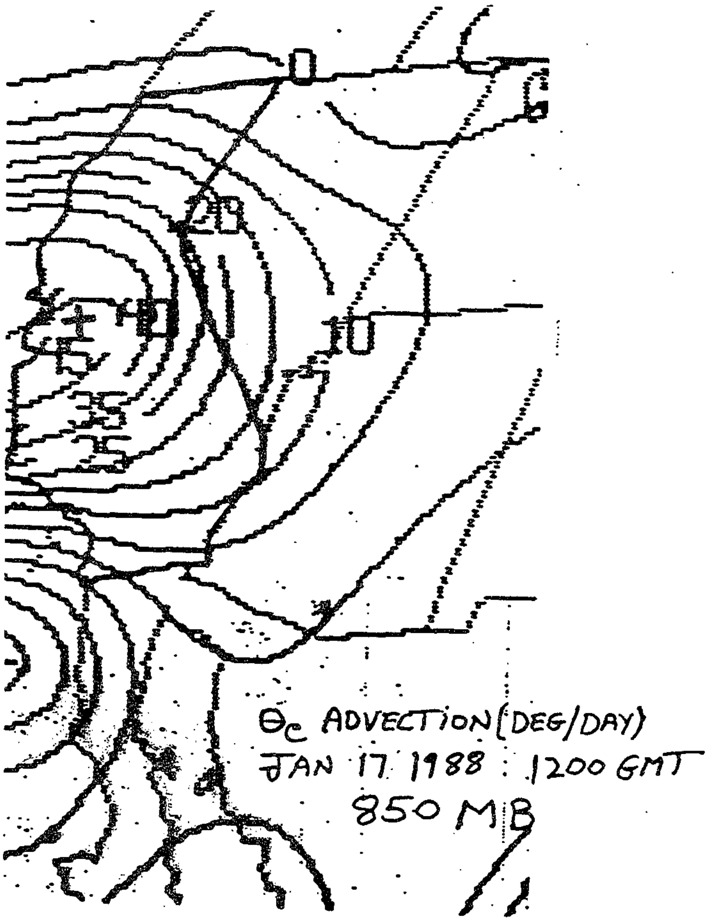


Figure 4a. 850 mb Θ_e advection (° /day), January 17, 1988, 1200 GMT.

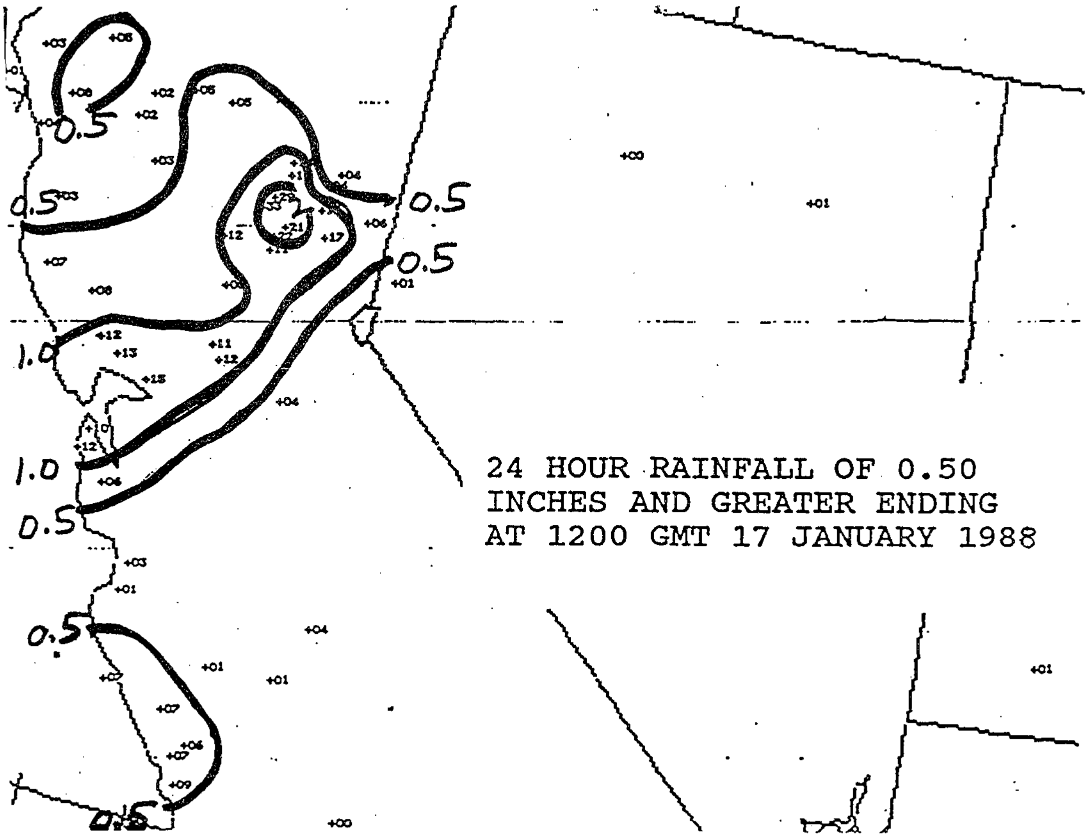


Figure 4b. Twenty-four hour observed rainfall (inches) ending at January 17, 1988, 1200 GMT.

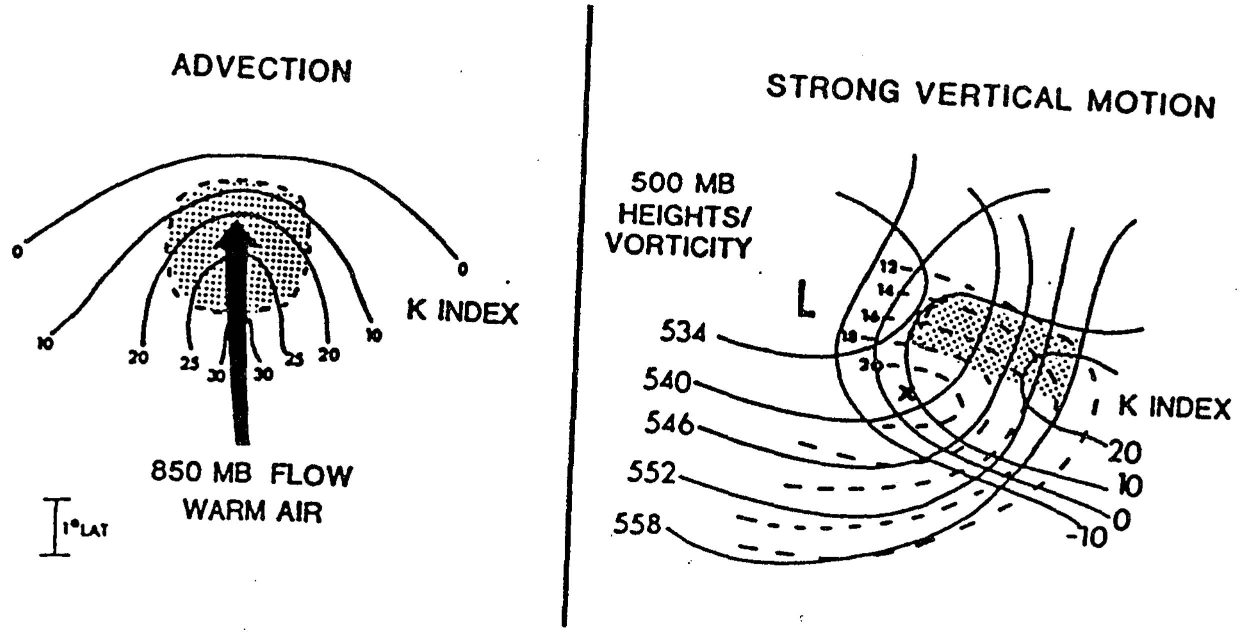


Figure 5. Stability patterns that initiate heavy precipitation in extratropical cyclone systems; stippling represent areas of convective precipitation.

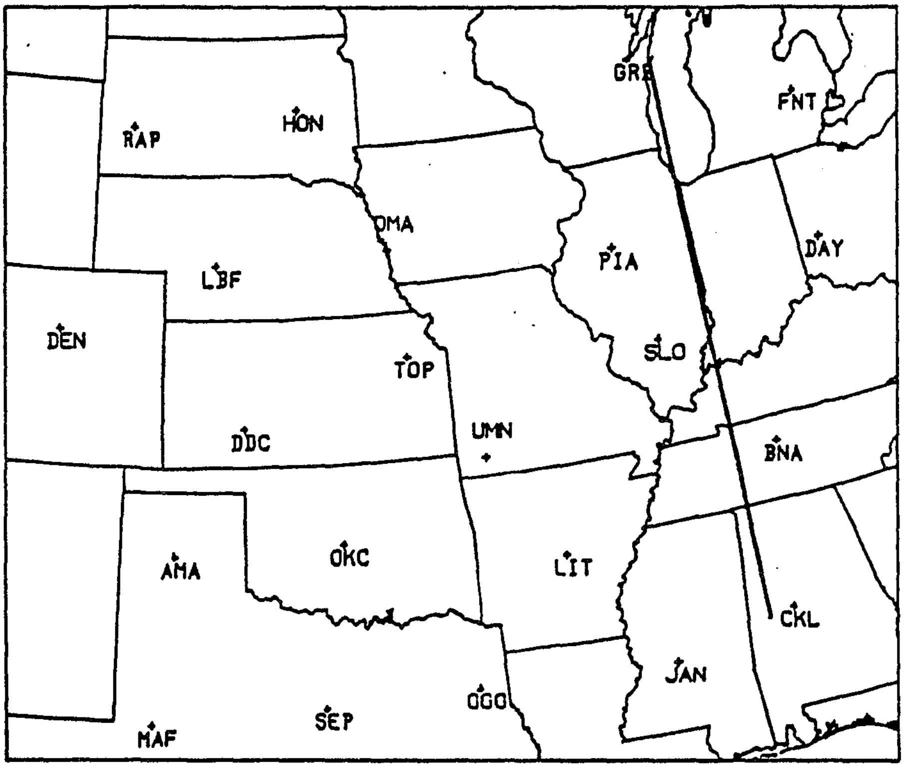


Figure 6. Location of upper air stations used in cross section analysis.

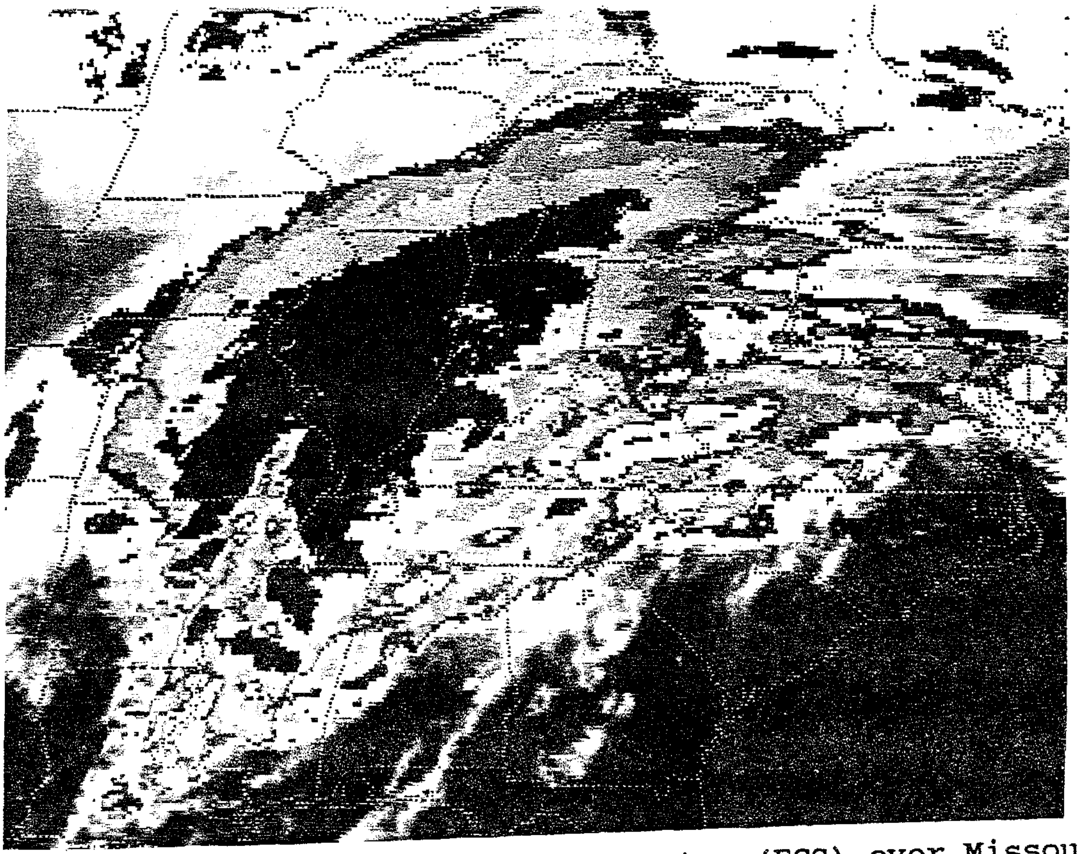


Figure 7. An Extratropical Cyclone System (ECS) over Missouri and Illinois; enhanced IR imagery (CC Curve).

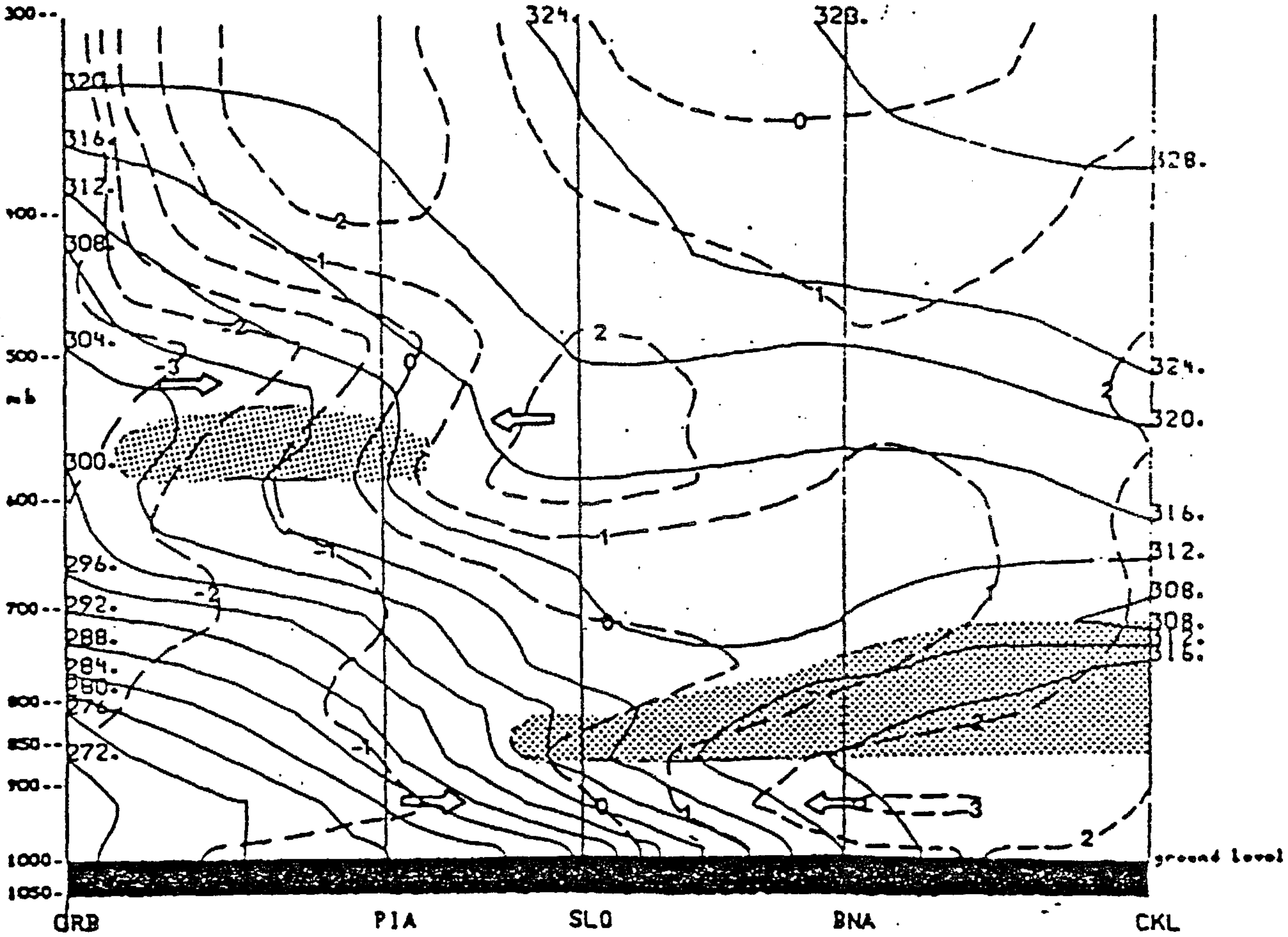


Figure 8a. Cross sectional analysis of Θ_e (solid lines, ° K) and the wind component parallel to the plane of the cross section (dashed lines, m/s) for January 31, 1982, 0000 GMT. Maximum low level winds indicated by an arrow; convective instability areas are stippled (Moore, 1986).

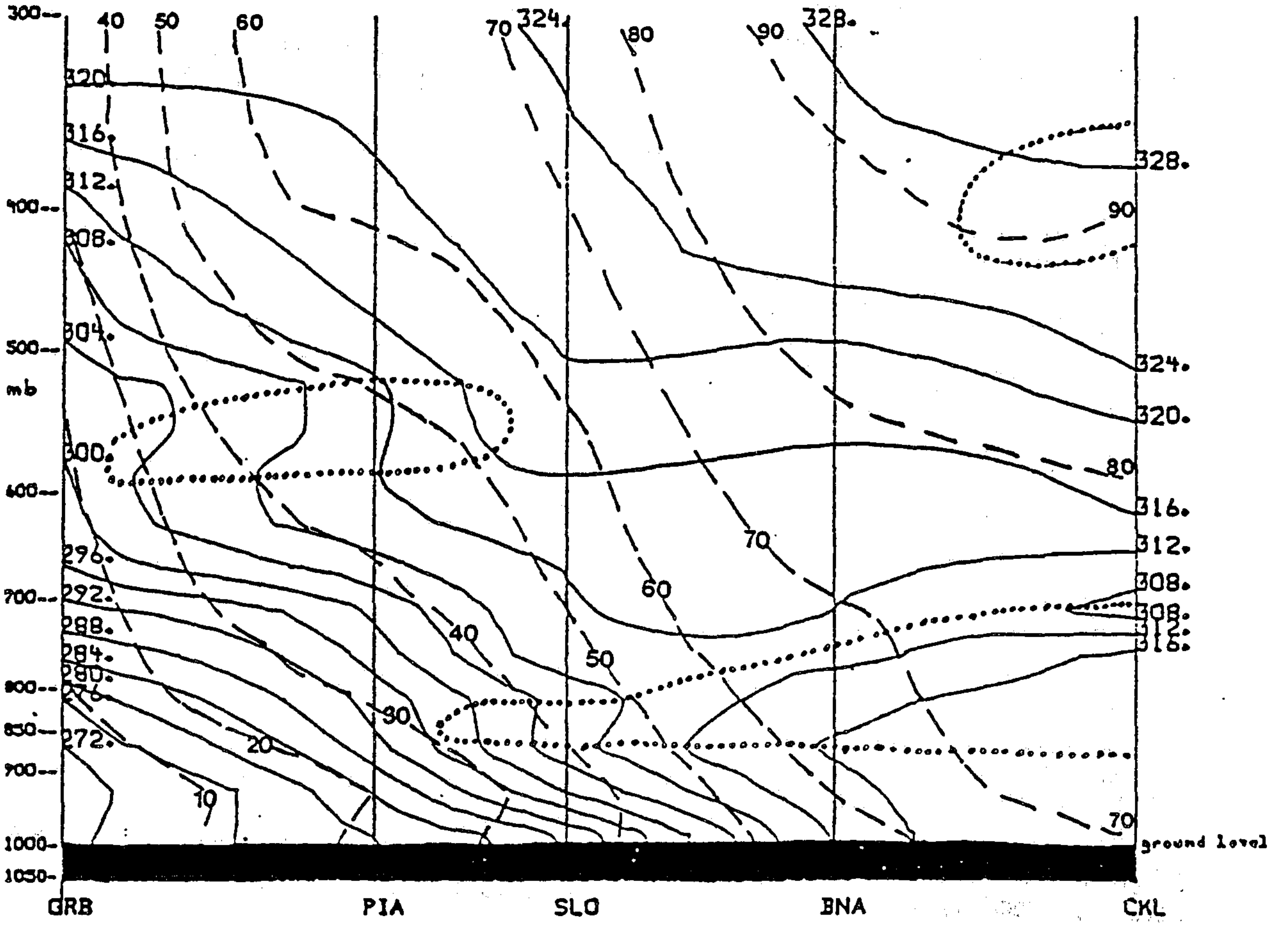


Figure 8b. Cross sectional analysis of Θ_e (solid lines, ° K) and momentum (dashed lines, m/s) for January 31, 1982, 0000 GMT. Conditional symmetric instability areas are indicated by dotted lines (Moore and Blakely, 1988).

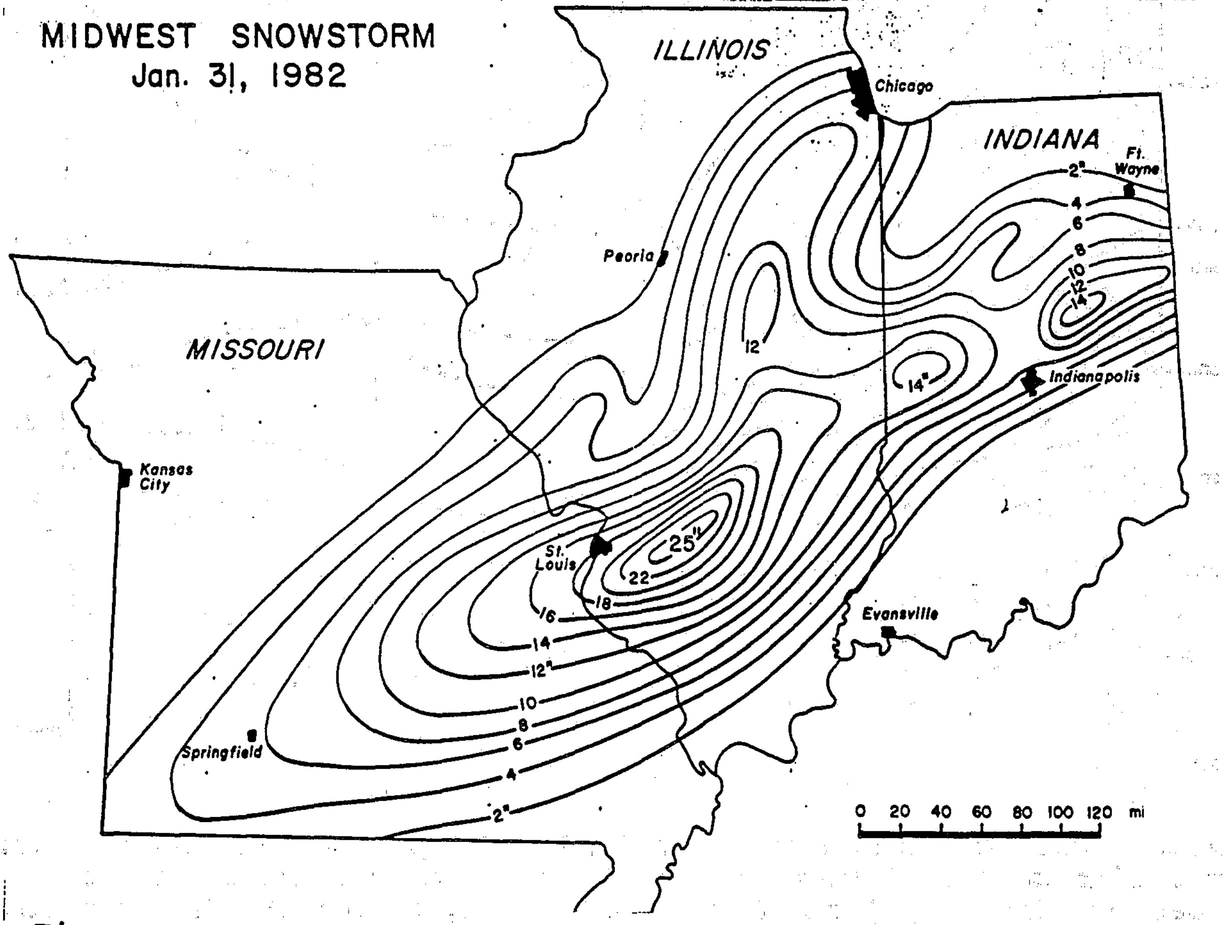
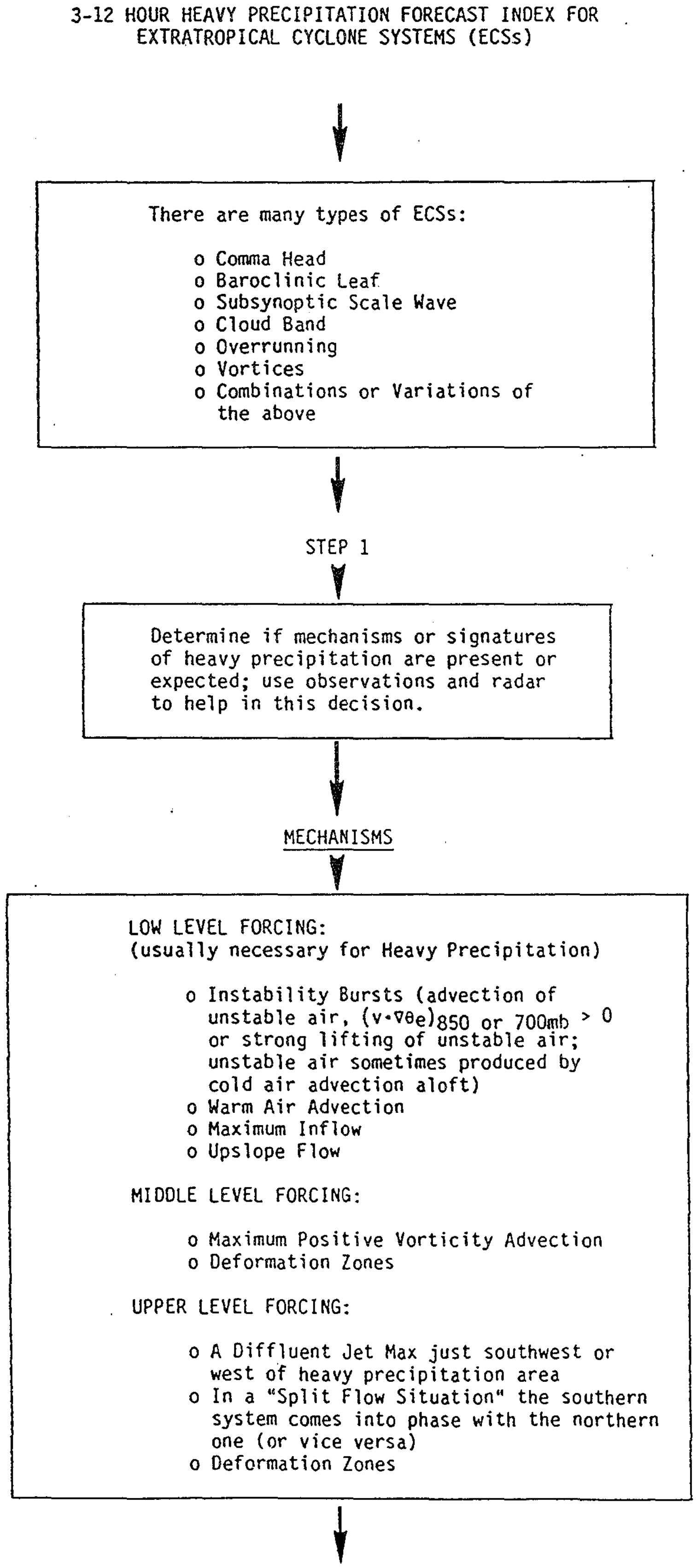


Figure 9. Total snowfall accumulations (in inches) for the ECS over Missouri and Illinois.



3-12 HOUR HEAVY PRECIPITATION FORECAST INDEX FOR EXTRATROPICAL CYCLONE SYSTEMS (ECSs)

There are many types of ECSs:

- o Comma Head
- o Baroclinic Leaf
- o Subsynoptic Scale Wave
- o Cloud Band
- o Overrunning
- o Vortices
- o Combinations or Variations of the above

STEP 1

Determine if mechanisms or signatures of heavy precipitation are present or expected; use observations and radar to help in this decision.

MECHANISMS

LOW LEVEL FORCING:
(usually necessary for Heavy Precipitation)

- o Instability Bursts (advection of unstable air, $(v \cdot \nabla\theta_e)_{850 \text{ or } 700mb} > 0$ or strong lifting of unstable air; unstable air sometimes produced by cold air advection aloft)
- o Warm Air Advection
- o Maximum Inflow
- o Upslope Flow

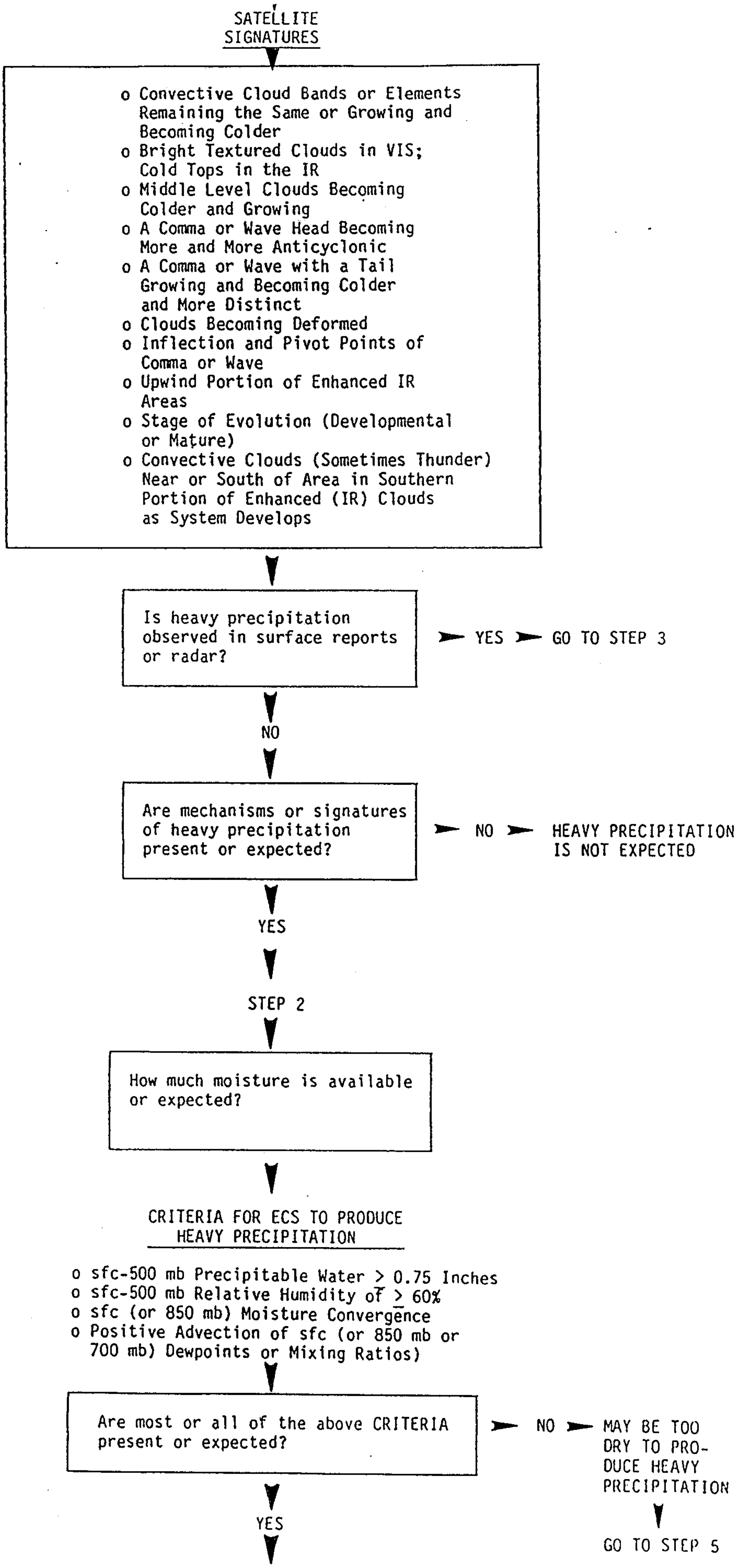
MIDDLE LEVEL FORCING:

- o Maximum Positive Vorticity Advection
- o Deformation Zones

UPPER LEVEL FORCING:

- o A Diffluent Jet Max just southwest or west of heavy precipitation area
- o In a "Split Flow Situation" the southern system comes into phase with the northern one (or vice versa)
- o Deformation Zones

Figure 10a. Three to twelve hour heavy precipitation forecast index decision tree.



SATELLITE SIGNATURES

- o Convective Cloud Bands or Elements Remaining the Same or Growing and Becoming Colder
- o Bright Textured Clouds in VIS; Cold Tops in the IR
- o Middle Level Clouds Becoming Colder and Growing
- o A Comma or Wave Head Becoming More and More Anticyclonic
- o A Comma or Wave with a Tail Growing and Becoming Colder and More Distinct
- o Clouds Becoming Deformed
- o Inflection and Pivot Points of Comma or Wave
- o Upwind Portion of Enhanced IR Areas
- o Stage of Evolution (Developmental or Mature)
- o Convective Clouds (Sometimes Thunder) Near or South of Area in Southern Portion of Enhanced (IR) Clouds as System Develops

Is heavy precipitation observed in surface reports or radar? → YES → GO TO STEP 3

NO

Are mechanisms or signatures of heavy precipitation present or expected? → NO → HEAVY PRECIPITATION IS NOT EXPECTED

YES

STEP 2

How much moisture is available or expected?

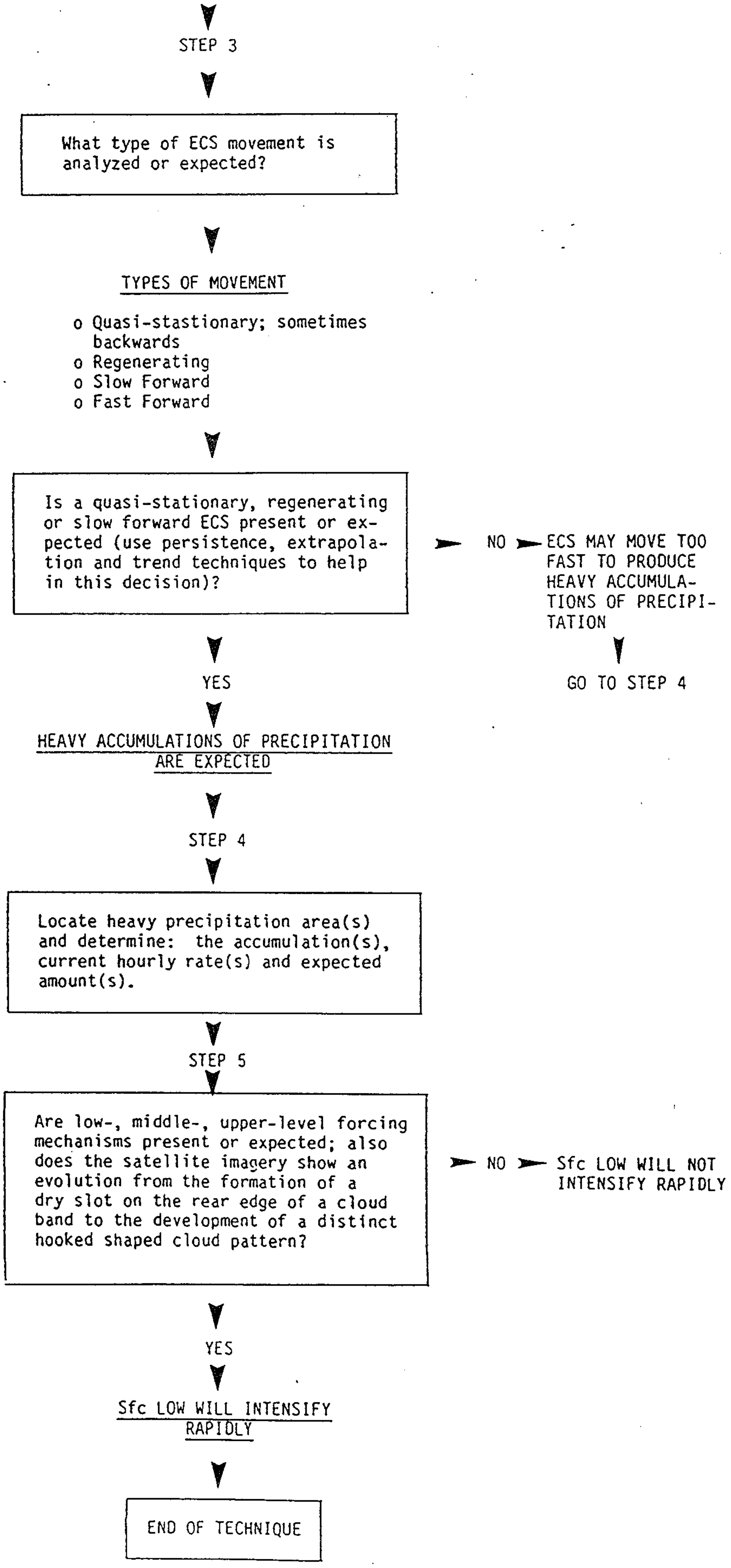
CRITERIA FOR ECS TO PRODUCE HEAVY PRECIPITATION

- o sfc-500 mb Precipitable Water > 0.75 Inches
- o sfc-500 mb Relative Humidity of $\geq$ 60%
- o sfc (or 850 mb) Moisture Convergence
- o Positive Advection of sfc (or 850 mb or 700 mb) Dewpoints or Mixing Ratios)

Are most or all of the above CRITERIA present or expected? → NO → MAY BE TOO DRY TO PRODUCE HEAVY PRECIPITATION → GO TO STEP 5

YES

Figure 10b. Three to twelve hour heavy precipitation forecast index decision tree.



STEP 3

What type of ECS movement is analyzed or expected?

TYPES OF MOVEMENT

- o Quasi-stastionary; sometimes backwards
- o Regenerating
- o Slow Forward
- o Fast Forward

Is a quasi-stationary, regenerating or slow forward ECS present or expected (use persistence, extrapolation and trend techniques to help in this decision)?

NO ECS MAY MOVE TOO FAST TO PRODUCE HEAVY ACCUMULATIONS OF PRECIPITATION

GO TO STEP 4

YES

HEAVY ACCUMULATIONS OF PRECIPITATION ARE EXPECTED

STEP 4

Locate heavy precipitation area(s) and determine: the accumulation(s), current hourly rate(s) and expected amount(s).

STEP 5

Are low-, middle-, upper-level forcing mechanisms present or expected; also does the satellite imagery show an evolution from the formation of a dry slot on the rear edge of a cloud band to the development of a distinct hooked shaped cloud pattern?

NO Sfc LOW WILL NOT INTENSIFY RAPIDLY

YES

Sfc LOW WILL INTENSIFY RAPIDLY

END OF TECHNIQUE

Figure 10c. Three to twelve hour heavy precipitation forecast index decision tree.

The Application of ADAP Version 2.0
to a Major Heavy Rain Event in Louisiana

by

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April 14, 1989

1. Introduction.

Portions of southwest, central and northeast Louisiana were deluged by torrential downpours on Nov 16, 1987. Total storm rainfall ranged between 10 and 20 inches with the heaviest rains concentrated in the central portion of Louisiana where about 1,000 people in Alexandria were left homeless by flood waters. The rain came in two separate bursts. The first and heaviest salvo of 4 to 12 inches began around 00Z and tapered off about 12 hours later (Fig. 1). The second 4 to 8 inch downpour occurred during the next 12 to 18 hours and was confined to the central portion of the state. This paper will examine the early aspects of this heavy rain episode.

Previous research by Maddox et al (1979) and Johnson et al (1987) aided forecasters in identifying the heavy rain threat that Louisiana faced. However, these studies rely heavily on 12 hour snap shots of the surface and upper air patterns at standard synoptic times; they only indirectly address the mesoscale or subsynoptic focusing mechanisms which play a dominant role in determining when, where and to what extent a heavy rain episode will occur. The purpose of this paper will be to attempt to identify these focusing mechanisms by using the AFOS Development Analysis Program (ADAP) mesoscale analysis software package (Bothwell, 1988).

2. Synoptic Pattern.

A slow moving cold front extended from just east of the Texas, Oklahoma panhandle region south to the Big Bend at 00Z on Nov 16, 1987 (Fig. 2). A convergent southeast flow of 65 to 70 F dewpoint air was fueling convection along a prefrontal squall line which extended from northeast Texas southwest for several hundred miles. There was strong southerly flow from 850 to 500 mb over Louisiana and east Texas. The 850 mb analysis showed a 40 to 50 knot southerly low level jet advecting 12 to 14 C dewpoint air into east Texas and west Louisiana (Fig. 3). Moisture was deepest at 700 mb (Fig. 4) over Louisiana and Mississippi where dewpoints were in the 2 to 4 C range; in contrast, most dewpoints were below 0 C in Texas. A 500 mb cut off low was located near the Texas, Oklahoma panhandle region with strong southerly flow occurring to the east of a negatively tilted short wave trough which extended from the cut off low southeast through the Rio Grande Valley (Fig. 5). At 200 mb (Fig. 6) the nose of the 130 knot jet was over southern Texas and the extreme northwest Gulf; this placed east Texas and west Louisiana in its left front quadrant where the flow was diffluent.

The infrared satellite movie loop of this episode (Mogil, 1989) showed that the low level inflow had become stronger and the upper level diffluence more pronounced as the negative tilt short wave trough from Texas approached western Louisiana.

The surface and upper air patterns resembled a Maddox et al (1979) synoptic type. In addition, they could be further identified by using the Louisiana heavy rain synoptic climatology developed by Johnson et al (1987) as a 4b upper air and b1 surface patterns.

Additional confirming evidence that Louisiana faced a heavy rain threat can be seen in Table 1 which is the locally developed heavy rainfall checklist used by WSFO Slidell. Most parameters were either moderate or strong by 00Z. Utilizing the Johnson et al (1987) method of adding applicable inflation factors in Table 2 to an initial two inch base, a maximum of eight inches of rainfall was determined for northwest Louisiana.

Table 1. Checklist for heavy rains from middle latitude patterns in Louisiana generally from late October to early June.

	Weak	Moderate	Strong
1. Surface			
a. Baroclinic zone (moving less than 10 knots or stationary) or outflow boundary with temperature difference across the zone Weak: <8 F; Moderate: 8-12 F; Strong: >12 deg F.			XXXX
b. Moist inflow dewpoints. Weak: <60 F; Moderate: 60-68 F; Strong: Strong: > 68 F.			XXXX
c. Moist inflow wind speed. Weak: < 10 knots; Moderate: 10-20 knots; Strong: >20 knots.		XXXX	
2. 850 mb			
a. Temperature advection. Weak: cold advection; Moderate: neutral advection; Strong: warm advection with temperatures >14 C			XXXX
b. Presence of a moisture ridge intersecting surface boundary containing dewpoints: Weak: <10 C; Moderate: 10-13 C; Strong: ≥14 C.			XXXX
c. Wind speed maximum within the moisture ridge. Weak: < 15 knots; Moderate: 15-25 knots; Strong: >25 knots.			XXXX
d. Intersection angle of 850 mb moist ridge with surface baroclinic zone or outflow boundary. Weak: <45 deg; Moderate: 45-60 deg; Strong: >60 deg.	XXXX		
3. 700 mb			
a. Temperature advection. Weak: cold or temperature advection >8 C in strong inversion; Moderate: neutral advection; Strong: warm advection with with advected temperatures 4-8 C.			XXXX
b. Moisture ridge near the surface baroclinic zone or outflow boundary with dew points of: Weak: 0-1 C; Moderate: 2 deg C; Strong: > 2 C.		XXXX	
3. 500 mb			
a. Dynamic forcing of vertical motion. Weak: NVA or cold advection; Moderate: No obvious PVA or temperature advection; Strong: PVA indicated or warm advection.		XXXX	
b. Temperature advection. Weak: >-10 C; Moderate: -10 to -11 C; Strong: <-11 C.			XXXX

4. 200 mb or 300 mb Location in relation to jets. Weak: other than under left front or right rear quadrant: Moderate: under left front or right rear quadrant; Strong: under both left front and right rear quadrants of a system of paired jets.		XXXX	
5. Surface to 500 mb wind shear Weak: >30 knots; Moderate: 15-30 knots; Strong: <15 knots.		XXXX	
6. Average relative humidity Weak: <65 %; Moderate: 65-75%; Strong: >75 %.			XXXX
7. Precipitable water Weak: 1.25"; Moderate: 1.25-1.40"; Strong: >1.40".		XXXX	
8. Stability indices KI - Weak: <28; Moderate: 28-30; Strong: >30. LI - Weak: >1; Moderate: 1 to -1; Strong: <-1.			XXXX
9. Thickness (October to June) and standard deviations: Oct 571 ± 4.0 Jan 550 ± 4.5 Apr 565 ± 3.5 Nov 564 ± 3.0 Feb 560 ± 4.0 May 569 ± 3.5 Dec 561 ± 4.0 Mar 561 ± 3.5 Jun 574 ± 2.5			XXXX

Table 2. Potential inflation factors to determine the final estimate of a quantitative precipitation forecast (QPF) based on conditions existing (denoted by an X) at 00Z Nov 16, 1987. After Johnson et al (1987).

Parameter	Amount (inches)	
Warm advection	1.0	X
Diffluence aloft (200-300 mb)	1.0	X
Meso boundaries	1.0	X
Repeat echoes	0.5	X
Cell movement ≤ 10 knots	0.5	
Right rear or left front quadrant of jet maximum	0.5	X
Mean relative humidity increased ≥ 50% in 12 hours	0.5	X
Precipitable water at least 130% above normal	0.5	X
K index ≥ 34	0.5	X
Mesoscale convective complex	0.5	
Sum of factors	6.0	
QPF = Sum of factors + 2	8.0	

3. Mesoscale Analysis.

When a threat of heavy rain or severe convection exists, WSFO Slidell runs ADAP hourly (Bothwell, 1988). A variety of analysis and 2 hour change charts are produced. This output is easily accessible through an AFOS graphics procedure.

ADAP was not available for WSFO Slidell's use during this episode. So the authors asked Southern Region Headquarters to run the mesoscale analysis programs on the New Orleans grid for the following time periods on Nov 16, 1987: 00, 02, 04 and 06Z. The mesoscale parameters exhibited very distinct patterns during the course of this event. A subset of the 00 and 06Z ADAP output will be presented to illustrate how they influenced the distribution of heavy rain.

At 00Z the atmosphere was very unstable in the layer surface to 500 mb (Fig. 7a) with lifted indices in excess of -6; furthermore, there was a rather strong stability gradient in east Texas which is a favored area for severe thunderstorms according to Bothwell (1988). In addition, there was a complete absence of any middle level capping inversion as indicated in Fig. 7b. A couplet of surface moisture flux convergence and divergence associated with the prefrontal squall line extended from western Arkansas and eastern Oklahoma southwest into eastern Texas (Fig. 8a); the pattern over Louisiana was ill-defined at this time showing only weak surface moisture flux convergence in west central portion of the state. The two hour surface moisture flux convergence change pattern indicated increasing maximum values over northeast Texas and northern Arkansas and extreme northern Louisiana with values decreasing elsewhere (Fig 8b). The surface mixing ratio ridge was just to the east of the area of surface moisture flux convergence (Fig. 9a). Surface mixing ratios were increasing along an axis that extended from northwest Louisiana southwest into eastern Texas ahead of the squall line (Fig. 9b). Further evidence of destabilization is indicated in Figs. 10a,b which show a warm, cold theta advection couplet located near and to the west of the surface mixing ratio ridge. The two hour station change chart (not shown) indicated a small concentrated area of pressure falls in northeast Texas and northwest Louisiana in an area where dewpoints were rising. In addition, the station change chart detected an outflow boundary in the vector wind field in east Texas. Surprisingly, the 2 hour grid pressure change field (not depicted) found the area of greatest pressure falls in central Louisiana. This was somewhat removed from other mesoscale focusing parameters. Thus most focusing mechanisms pointed out east Texas and possibly northwest Louisiana as the main threat area for convection. As indicated earlier (Fig. 1) 4 to 6 inches of rain fell in northwest Louisiana. In addition, an F3 tornado was spawned in east Texas. The tornado moved rapidly northeast into northwest Louisiana where it killed one person and injured 50 people when it struck a trailer park in the rural Desoto parish town of Keatchie. Thus, even though there was strong synoptic and mesoscale forcing for a major heavy rain event in northwest Louisiana, the main threat was from severe convection. This is not an uncommon occurrence according to Maddox _et al_ (1979), who found that approximately half of his synoptic heavy rain patterns were accompanied by severe convection at some point in their life cycle.

Because of boundary problems along the Louisiana coast, ADAP can miss or underestimate mesoscale features in its analysis. ADAP showed a small concentrated area of pressure falls between 00-02Z in southwest Louisiana coastal area (not shown). Satellite pictures indicated numerous heavy thunderstorms were developing over this area and moving rapidly northeast into central and northeast portions of the state. Hourly surface analysis and a 3 hour Manually Digitized Radar (MDR) maximum of 11 units in central Louisiana indicated that a rain-cooled outflow boundary formed there by 04Z. This boundary was to become the primary focus for heavy rain in central Louisiana. The majority of the mesoscale focusing patterns underwent a gradual shift towards central Louisiana as the newly developed boundary effectively blocked further inflow of moisture into the northwest Louisiana squall line.

Mesoscale parameters became more concentrated by 06z. Fig. 11 show~~ed~~s a continued influx of high dew point air into the state especially to the south of the nearly stationary convective boundary in central Louisiana. Strong speed convergence into the outflow boundary is evident. The area of maximum surface moisture flux convergence and change (Figs. 12a,b) had increased almost four times over values observed only 6 hours earlier. The axis of the surface mixing ratio ridge was just to the west of the area of surface moisture flux convergence (Fig. 13a). Further, the mixing ratio change field (Fig. 13b) hinted that this parameter was increasing over portions of southwest and central Louisiana. The area of warm theta advection and change was slightly to the east of the axis of the surface mixing ratio ridge (Figs. 14a,b). The two hour station change chart (not shown) indicated rising temperatures and falling pressures at Fort Polk and Alexandria. It is unfortunate that there was so much missing data from northeast Louisiana and southeast Arkansas on this occasion. These stations could have provided additional evidence that these pressure falls were indeed caused by mesoscale forcing and not by small scale noise from individual thunderstorm cells. The evidence cited above would tend to support the case that the pressure falls were induced as a result of a focusing of mesoscale parameters.

Thus there were many mesoscale clues that a heavy rain episode was in the making. An increasing active outflow boundary in central Louisiana was providing the focus for convection. Mesoscale parameters had much better alignment at 06Z than at 00Z. The axis of heaviest rainfall (Fig. 1) seems to correlate best with the axis of surface moisture flux convergence change at 06z.

4. Conclusions.

Hourly output of ADAP mesoscale analyses and two hour change fields were helpful in delineating the multiple threat of severe convection and heavy rain that Louisiana faced in this episode. This was found to be more true for the interior portions of Louisiana. Near the coast, ADAP had trouble resolving mesoscale parameters due to boundary problems.

Severe convection seems to be more predominant when the surface mixing ratio ridge was located to the east of the warm theta advection ridge; for the heavy rain case the surface mixing ratio ridge was located just to the west of the warm theta one. Another important finding was that the axis of heavy rain was nearly coincident with the surface moisture flux convergence change pattern.

Although synoptic heavy rainfall climatology patterns are useful in alerting the forecaster that a heavy rain event is possible, they are not detailed enough to address the small scale focusing mechanisms which ADAP can resolve in most cases.

5. References.

Bothwell, P.B., 1988: AFOS Data Analysis Programs (ADAP), Version 2.0, National Weather Service Southern Region Technical Memorandum SR-122, Fort Worth, TX.

Johnson, G.A., E.B. Mortimer and H.W. Lau, 1987: Synoptic Climatology of Heavy Rainfall Events in Louisiana, Preprints, 7th Conf. on Hydrometeorology, Amer. Meteor. Soc., Edmenton, Canada.

Maddox, R.A., C.F. Chappel and L.R. Hoxit, 1979: Synoptic and Meso-alpha Scale Aspects of Flash Flood Events, Bull. Amer. Meteor. Soc., 60, 115-123.

Mogil, H.M., 1989: Louisiana Heavy Rains Nov 16, 1989 from 0001Z - 1131Z, VHS Tape, National Environmental Satellite Data and Information Service, Washington, D.C.

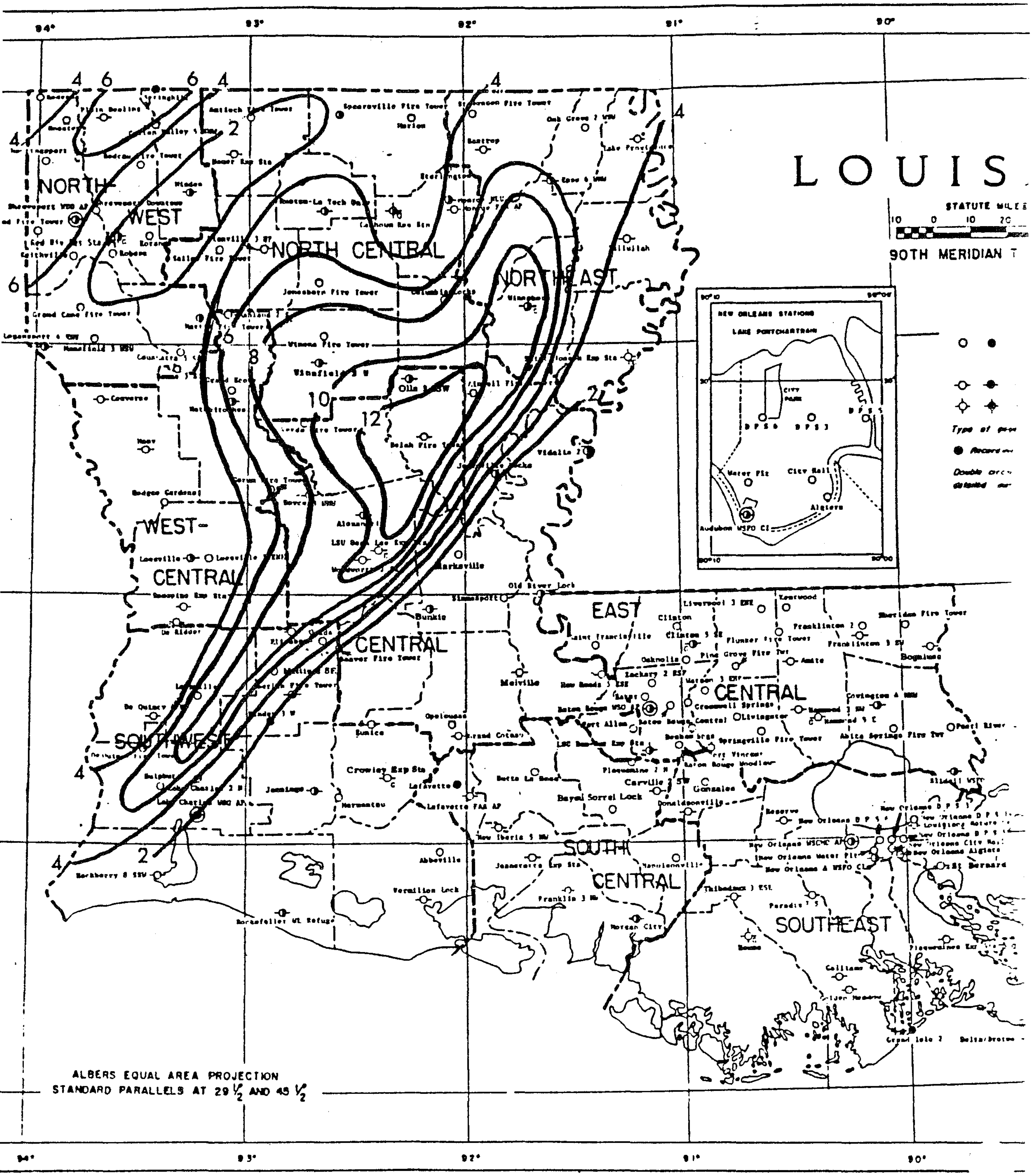


Fig. 1 24 hour rainfall (inches) ending at 12Z November 16, 1987.

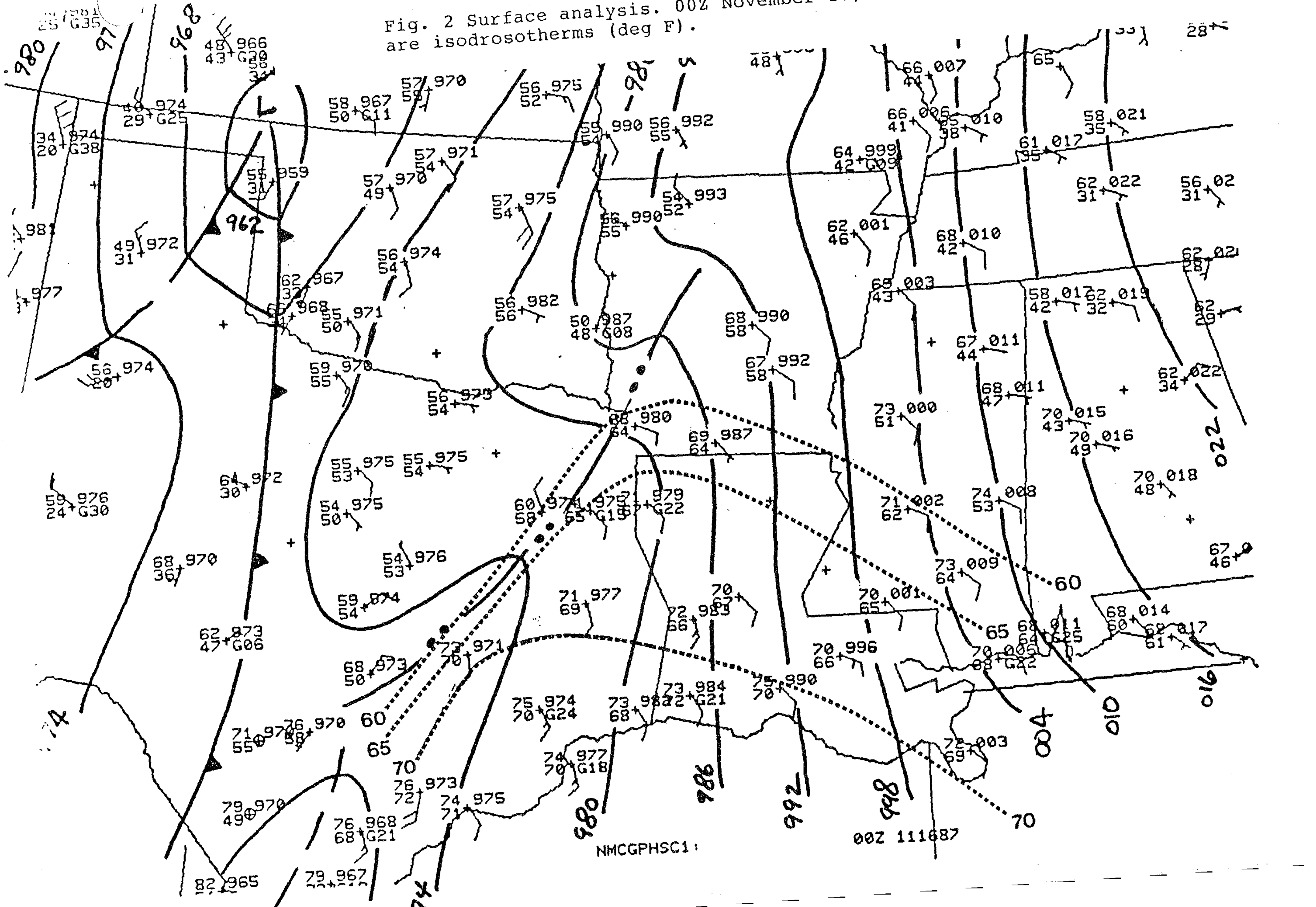


Fig. 2 Surface analysis. 00Z November 16, 1987. Short dashed lines are isodrosotherms (deg F).

Fig. 3. 850 mb analysis. 00Z November 16, 1987. Short dashed lines are isodrosotherms (deg C).

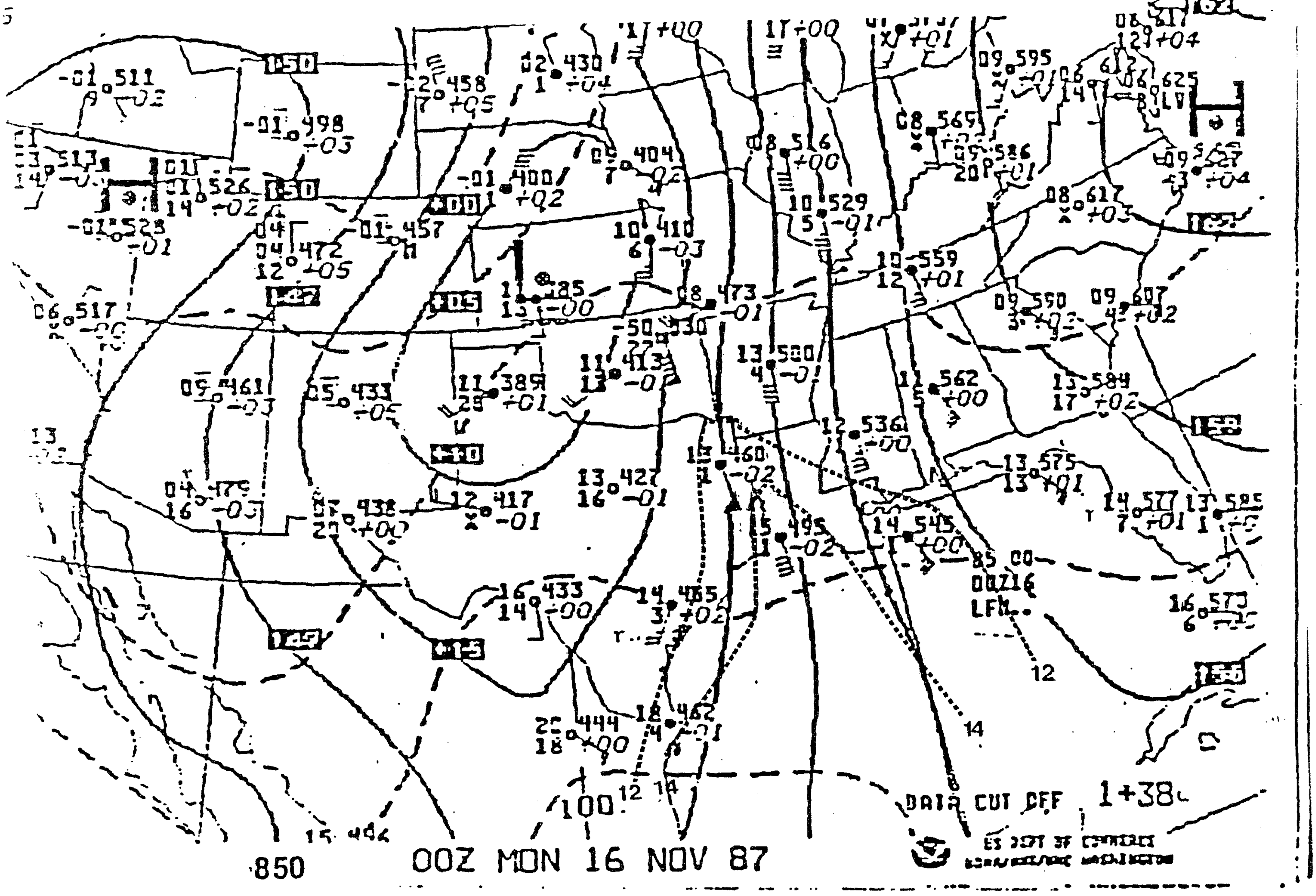


Fig. 4 700 mb analysis. 00Z November 16, 1987. Symbols are same as those used in Fig. 3.

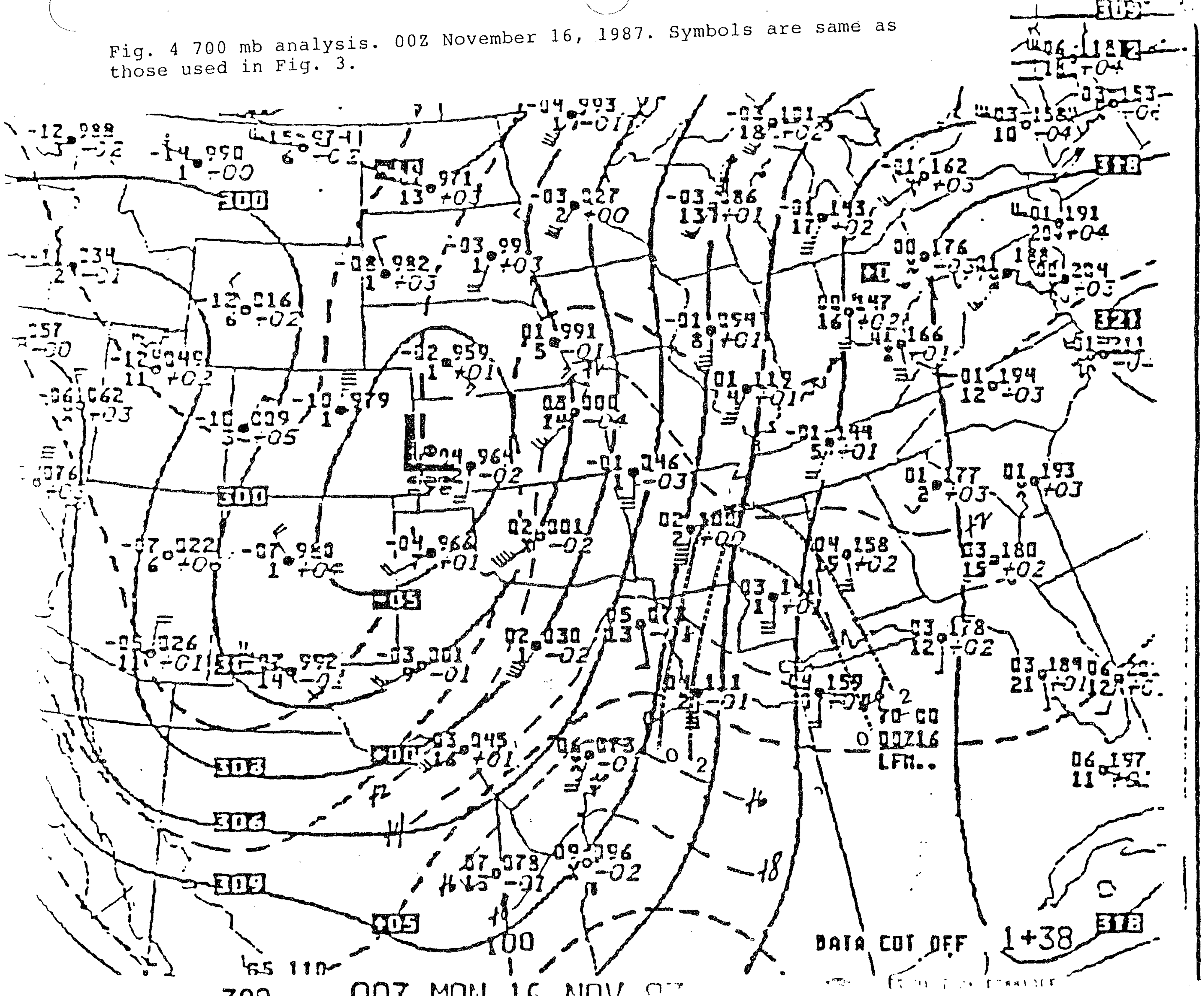


Fig. 5. 500 mb analysis. 00Z November 16, 1987. Symbols same as those used in Fig. 3.

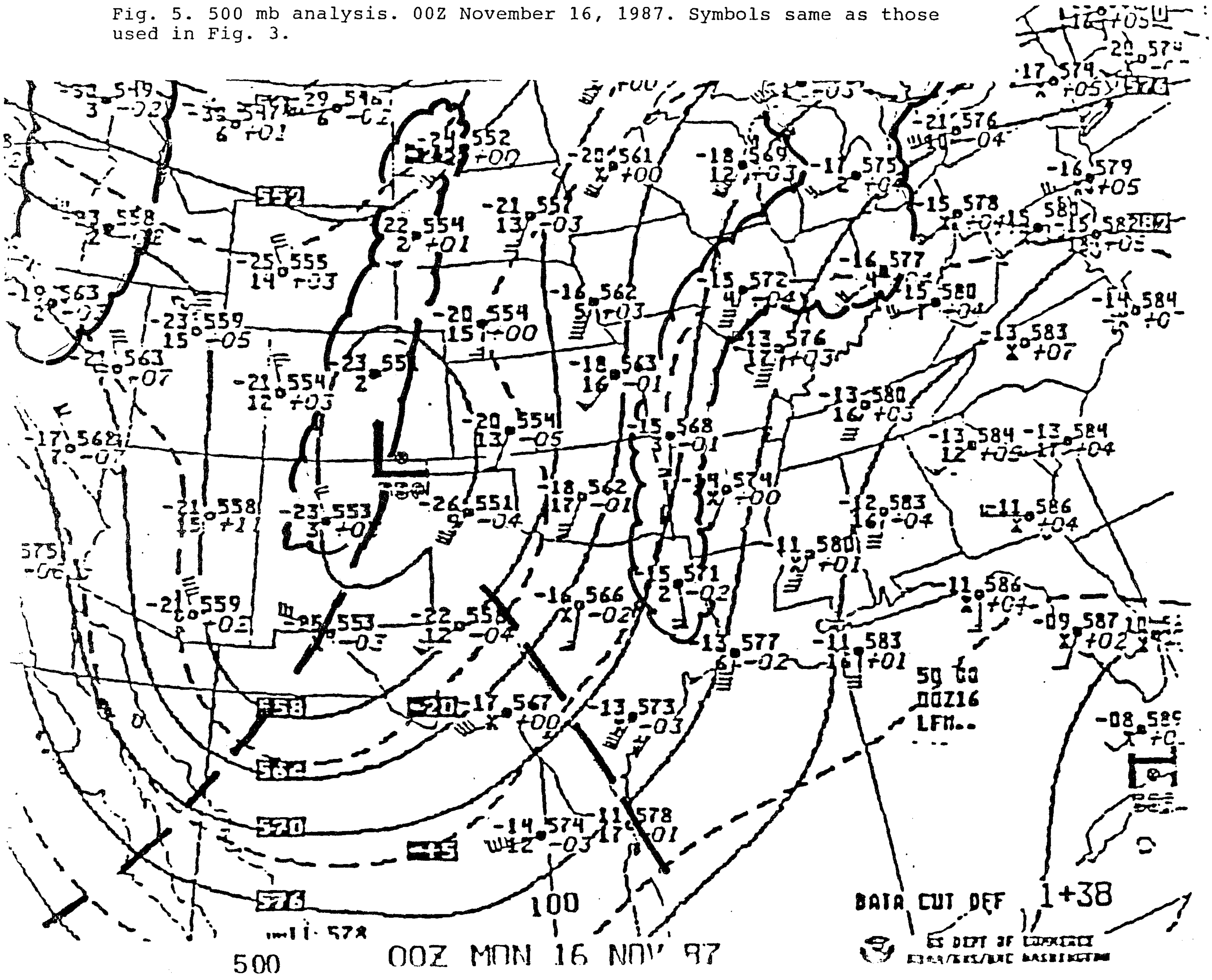
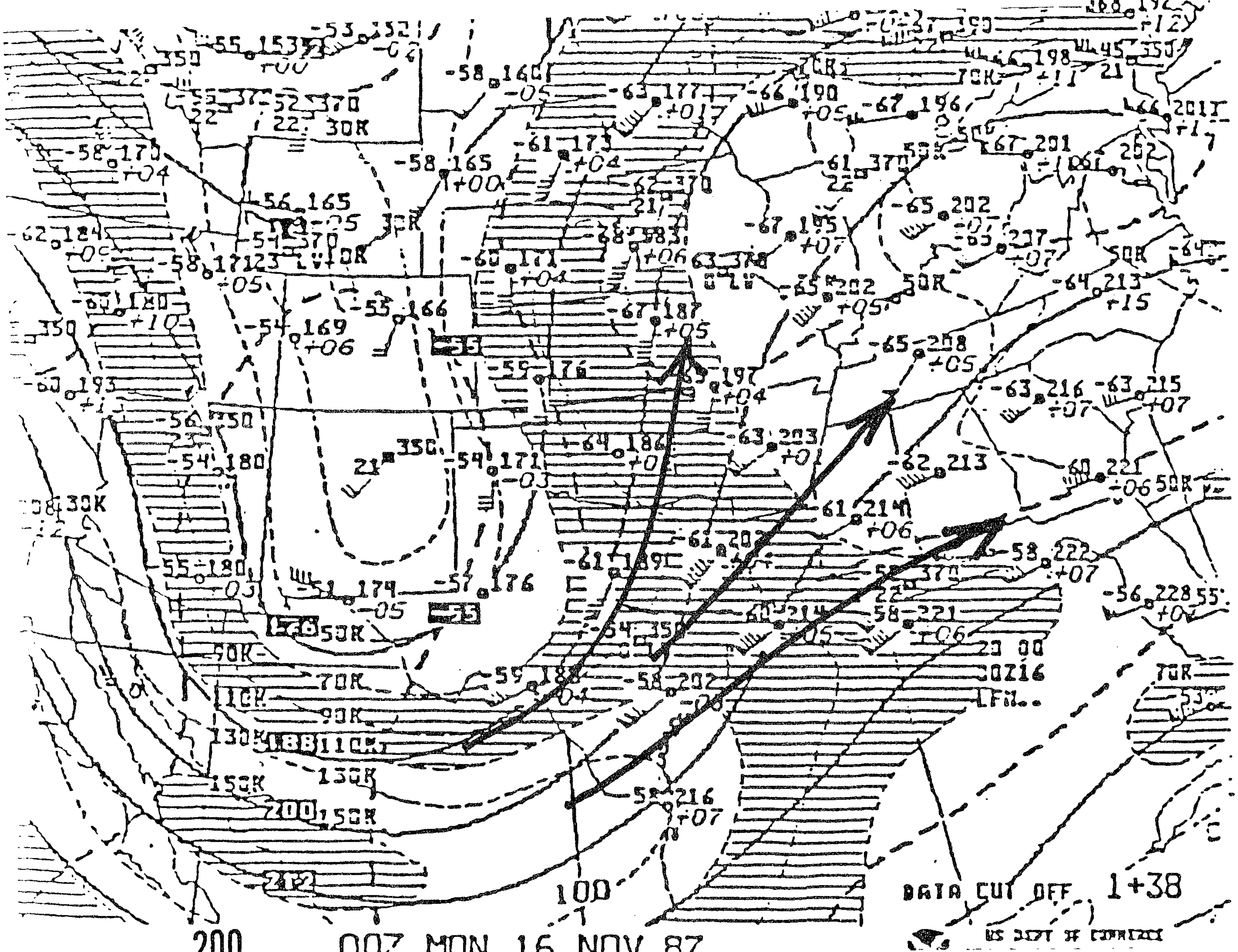


Fig. 6 200 mb analysis. 00Z November 16, 1987.



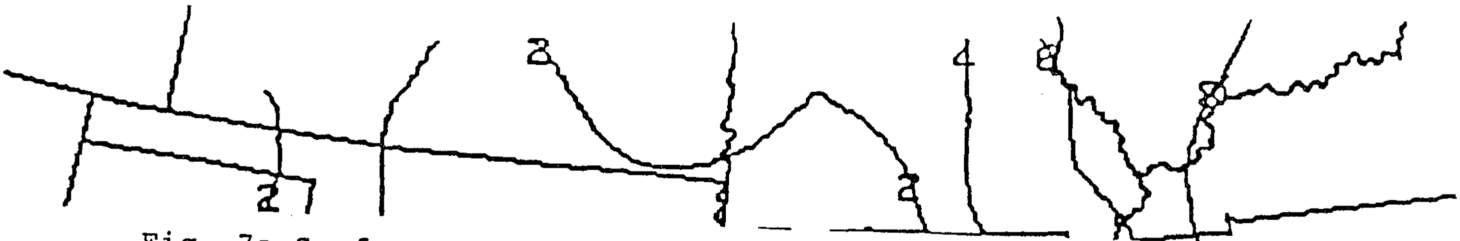


Fig. 7a Surface to 500 mb Lifted Index. 00Z November 16, 1987

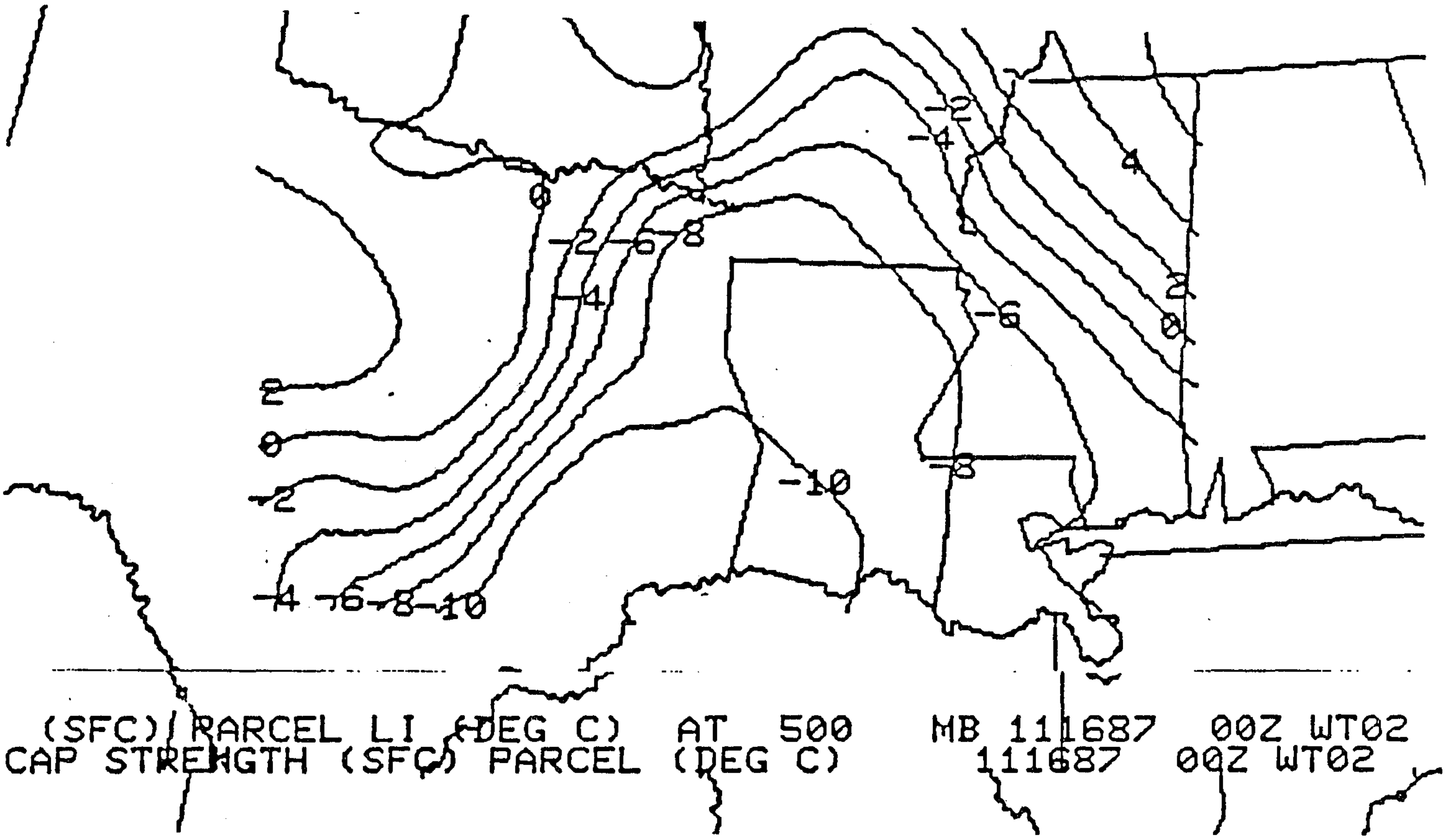


Fig. 7b Cap strenght. 00Z November 16, 1987.

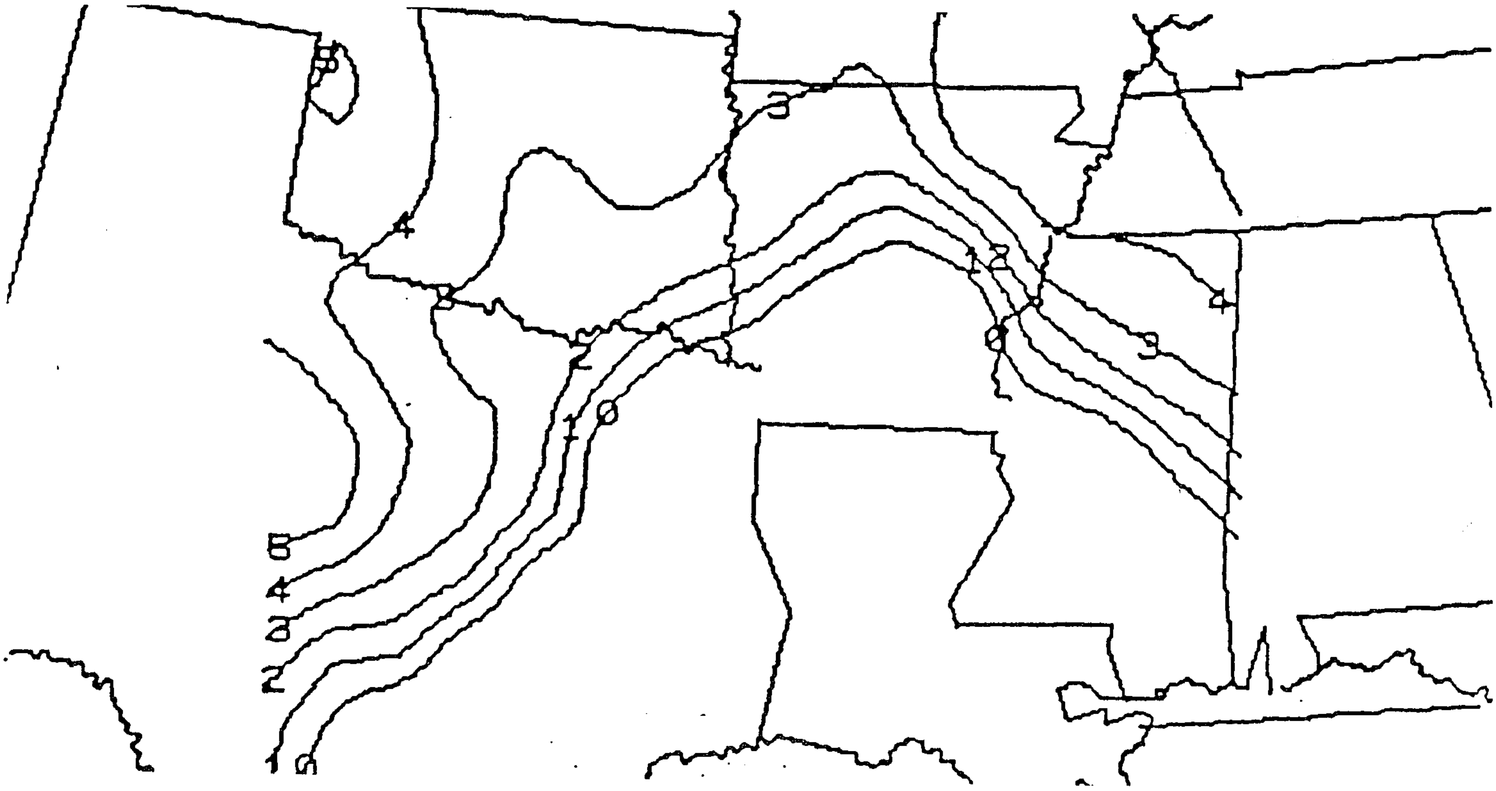


Fig. 8a Surface moisture flux convergence. 00Z November 16, 1987.

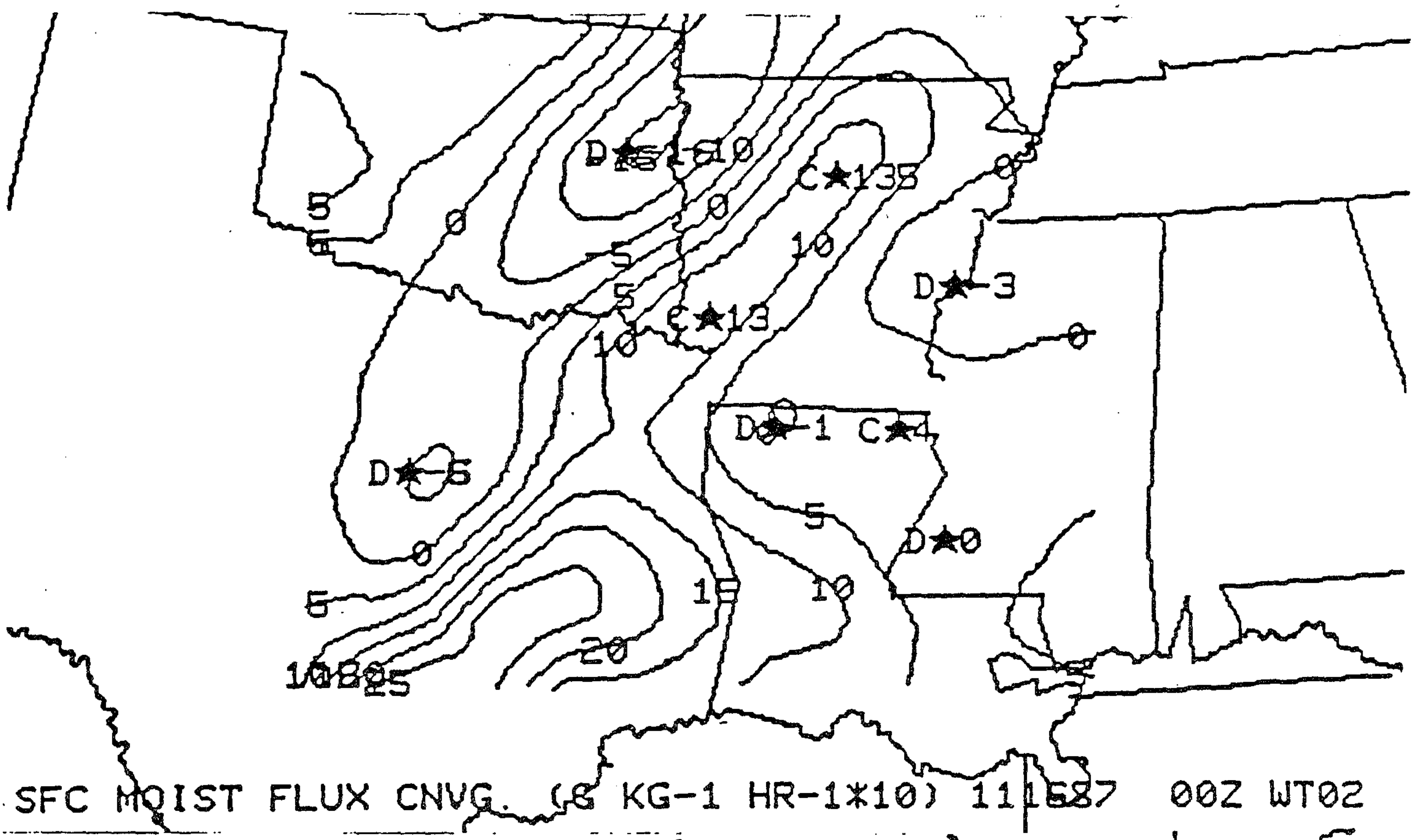
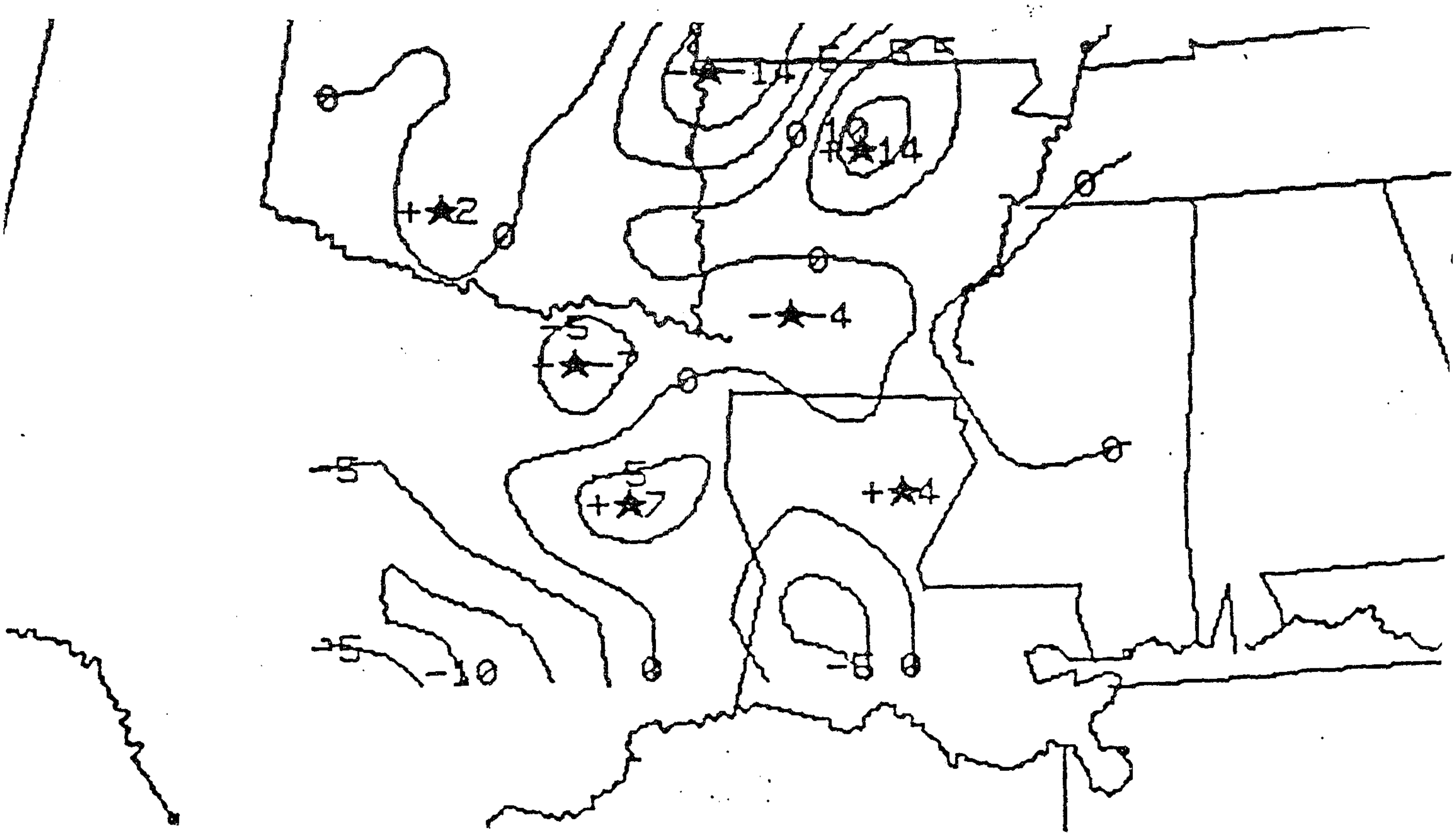


Fig. 8b Surface moisture flux convergence change. 22Z November 15 through 00Z November 16, 1987.



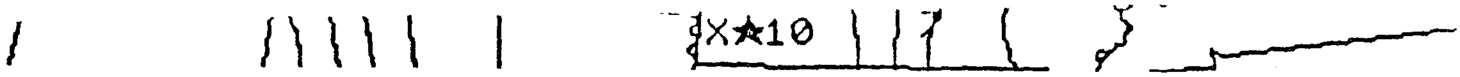


Fig. 9a Surface mixing ratio. 00Z Novmeber 16, 1987.

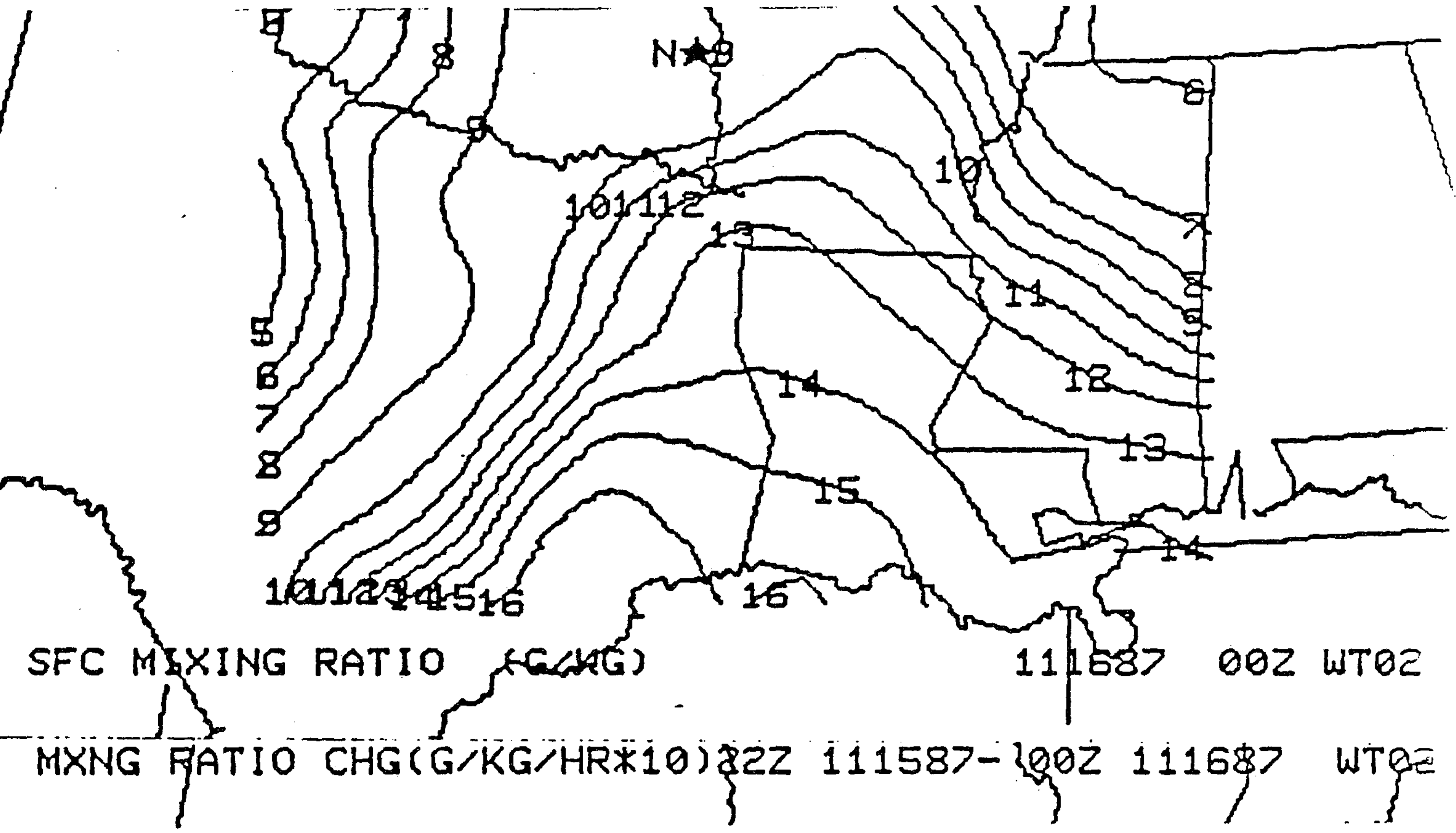


Fig. 9b Surface mixing ratio change. 22Z November 15 through 00Z November 16, 1987.

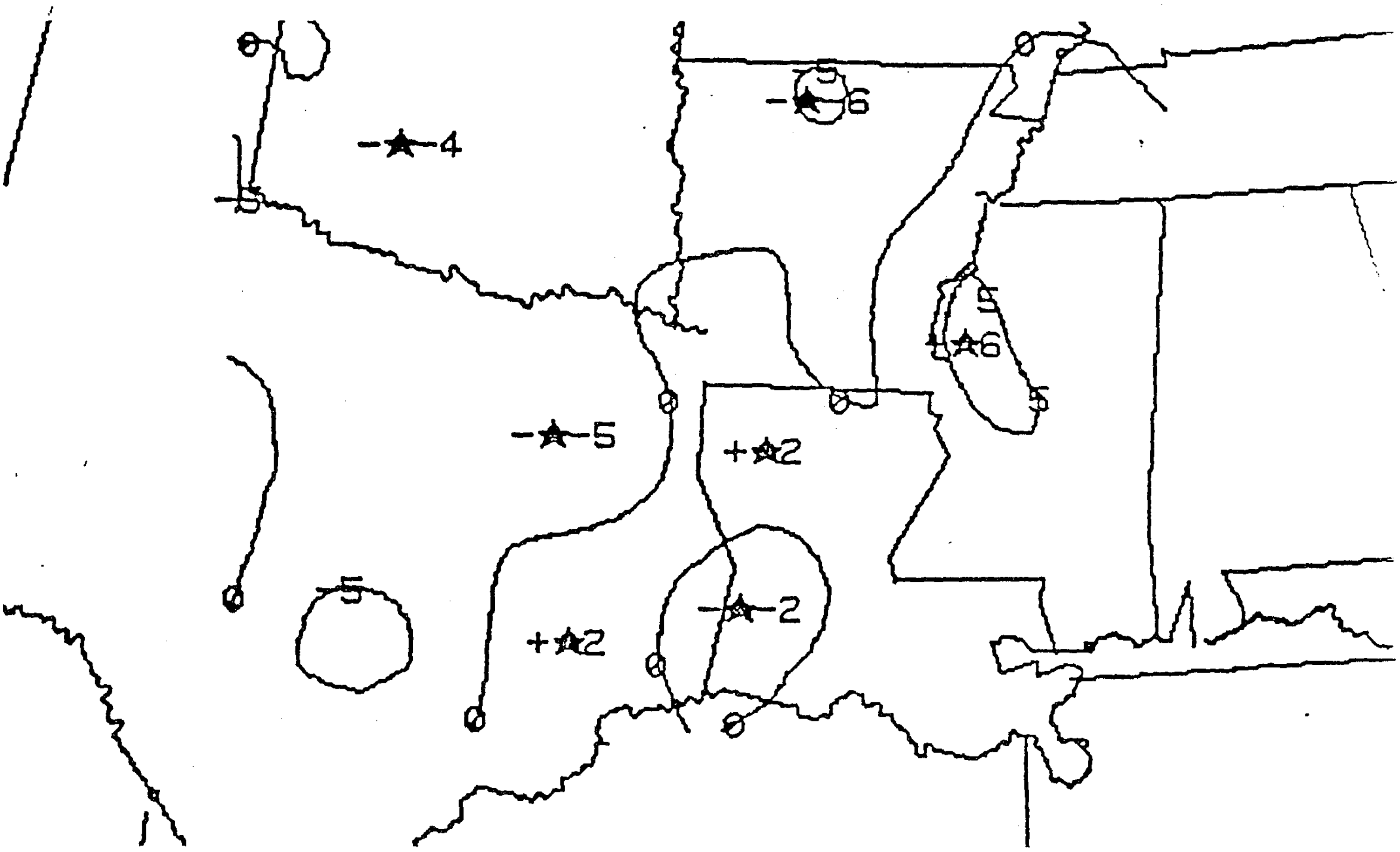
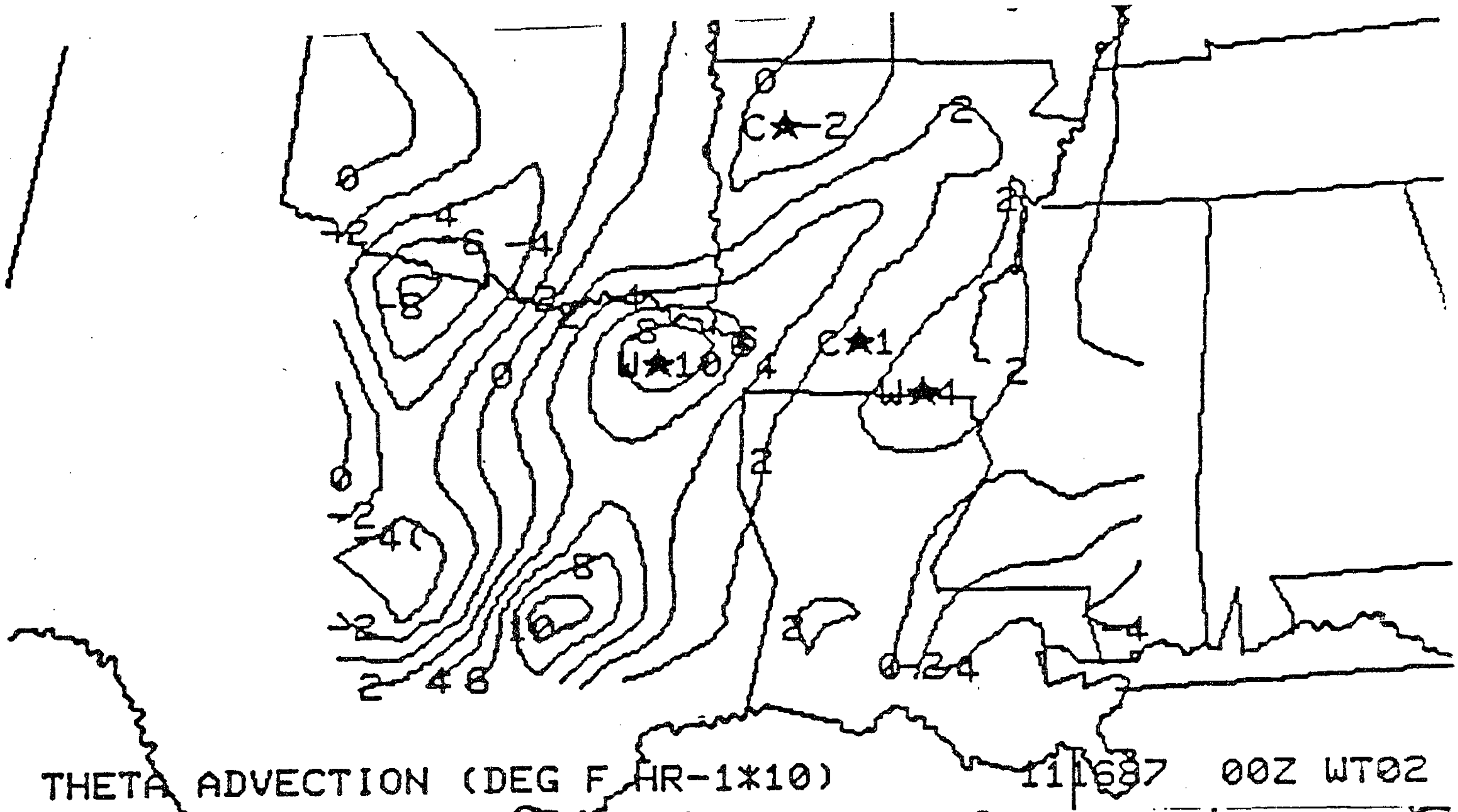


Fig. 10a Theta advection. 00Z November 16, 1987.



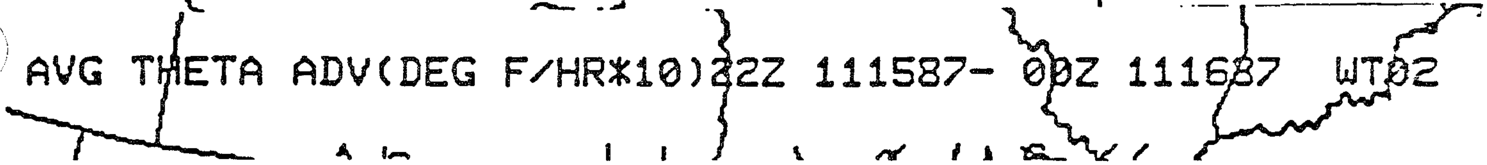


Fig. 10b Theta advection change. 22Z November 15 through 00Z November 16, 1987.

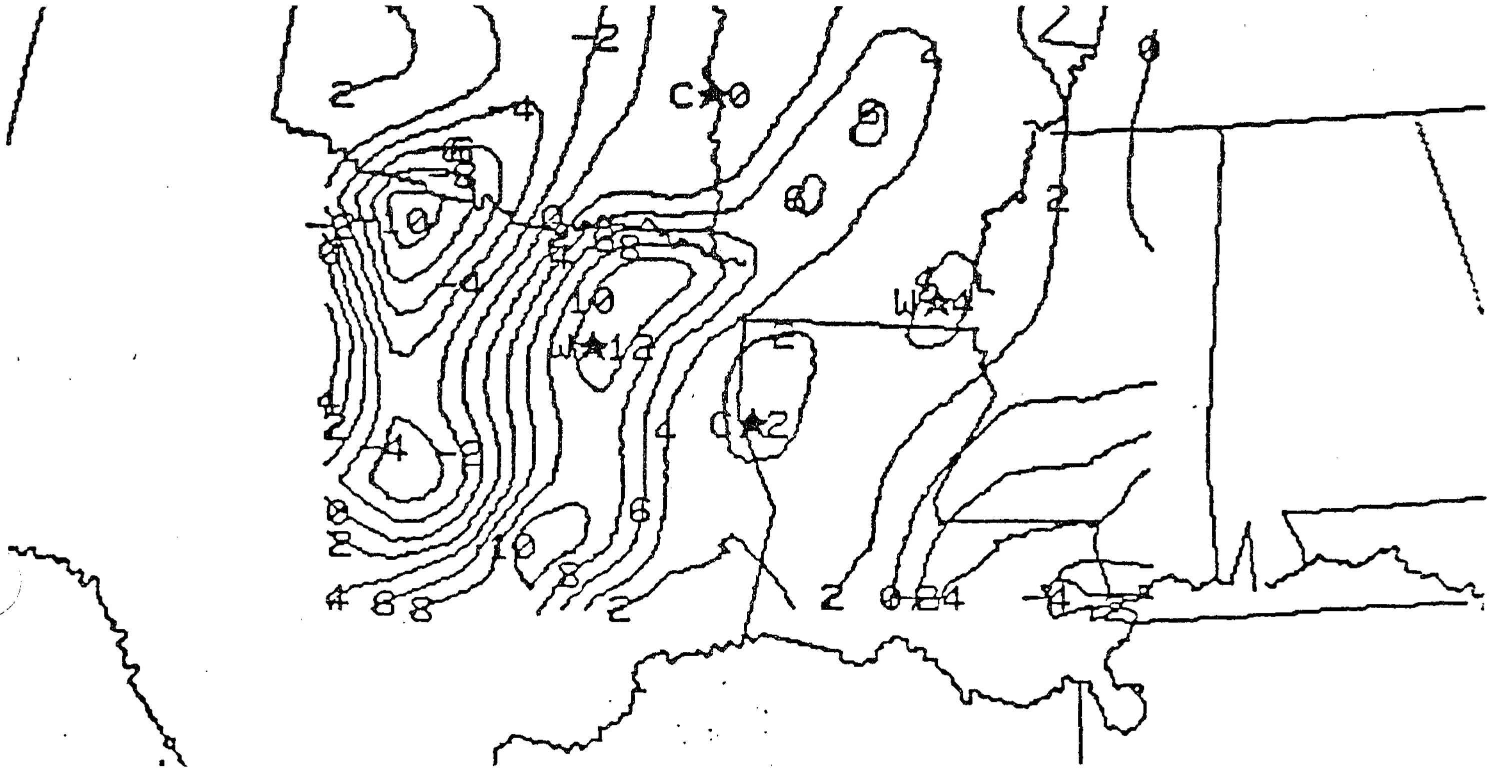


Fig. 11 Surface analysis. 06Z November 16, 1987.

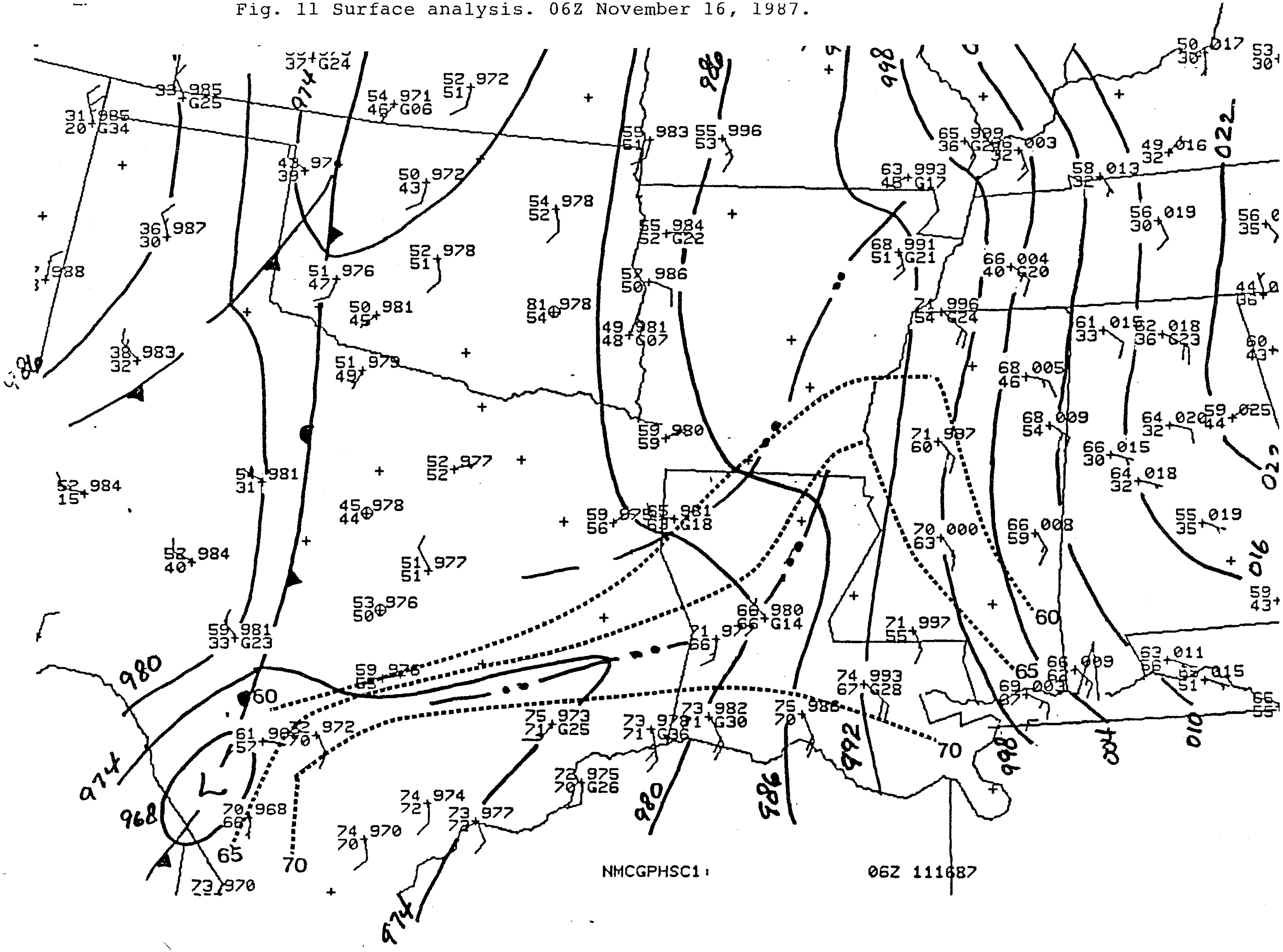


Fig. 12a Surface moisture flux convergence. 06Z November 16, 1987.

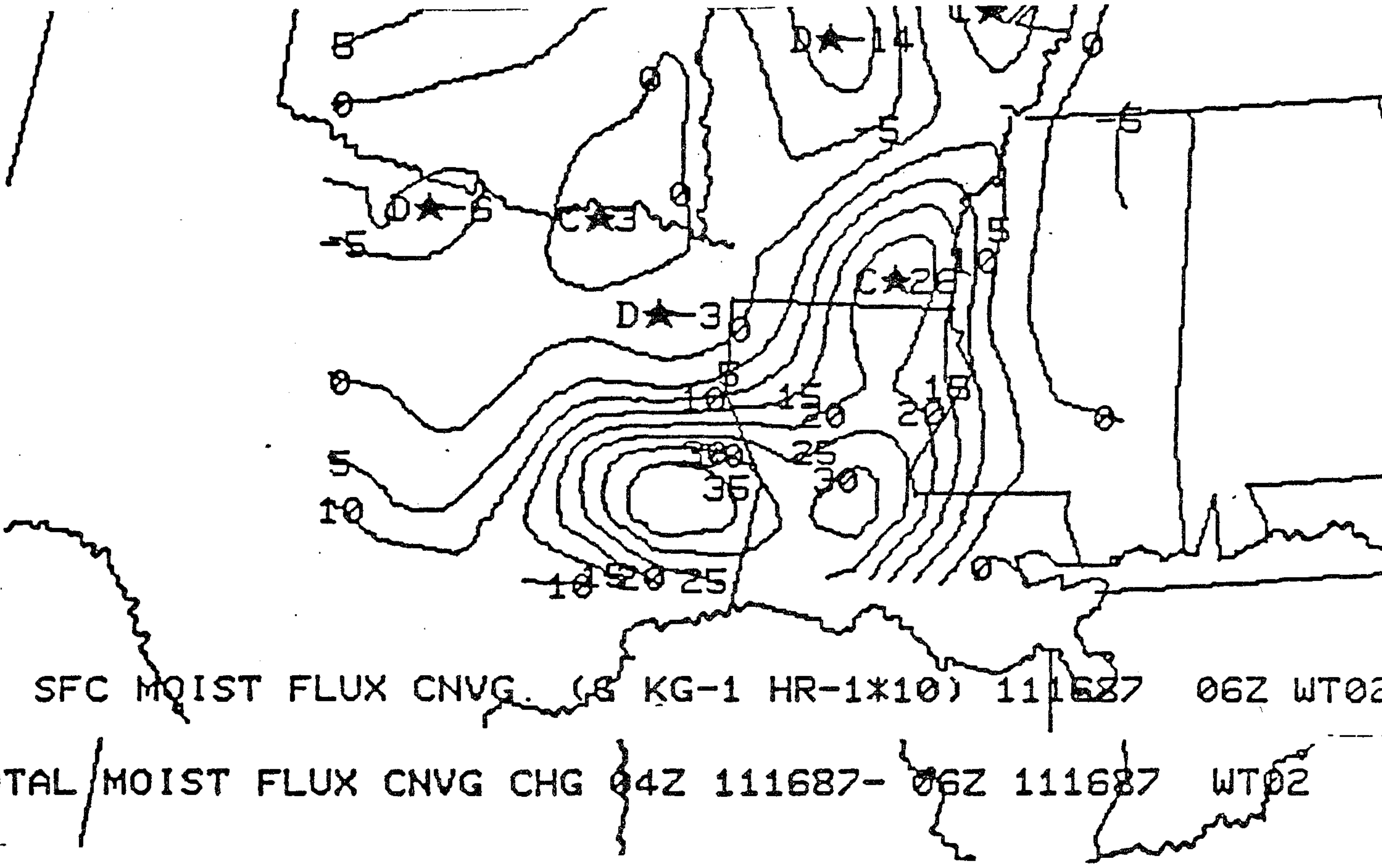


Fig. 12b Surface moisture flux convergence change. 04Z through 06Z November 16, 1987.

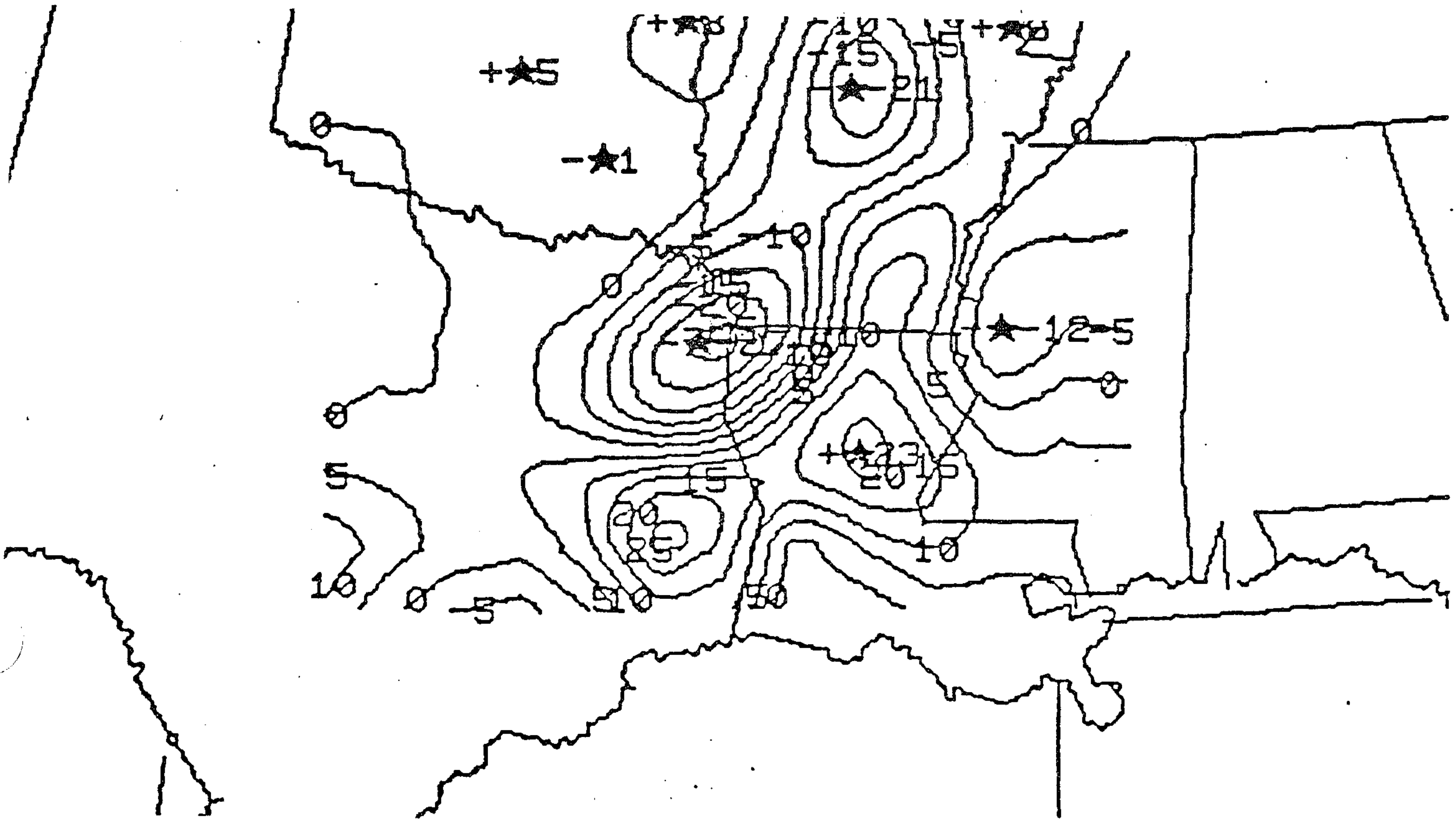
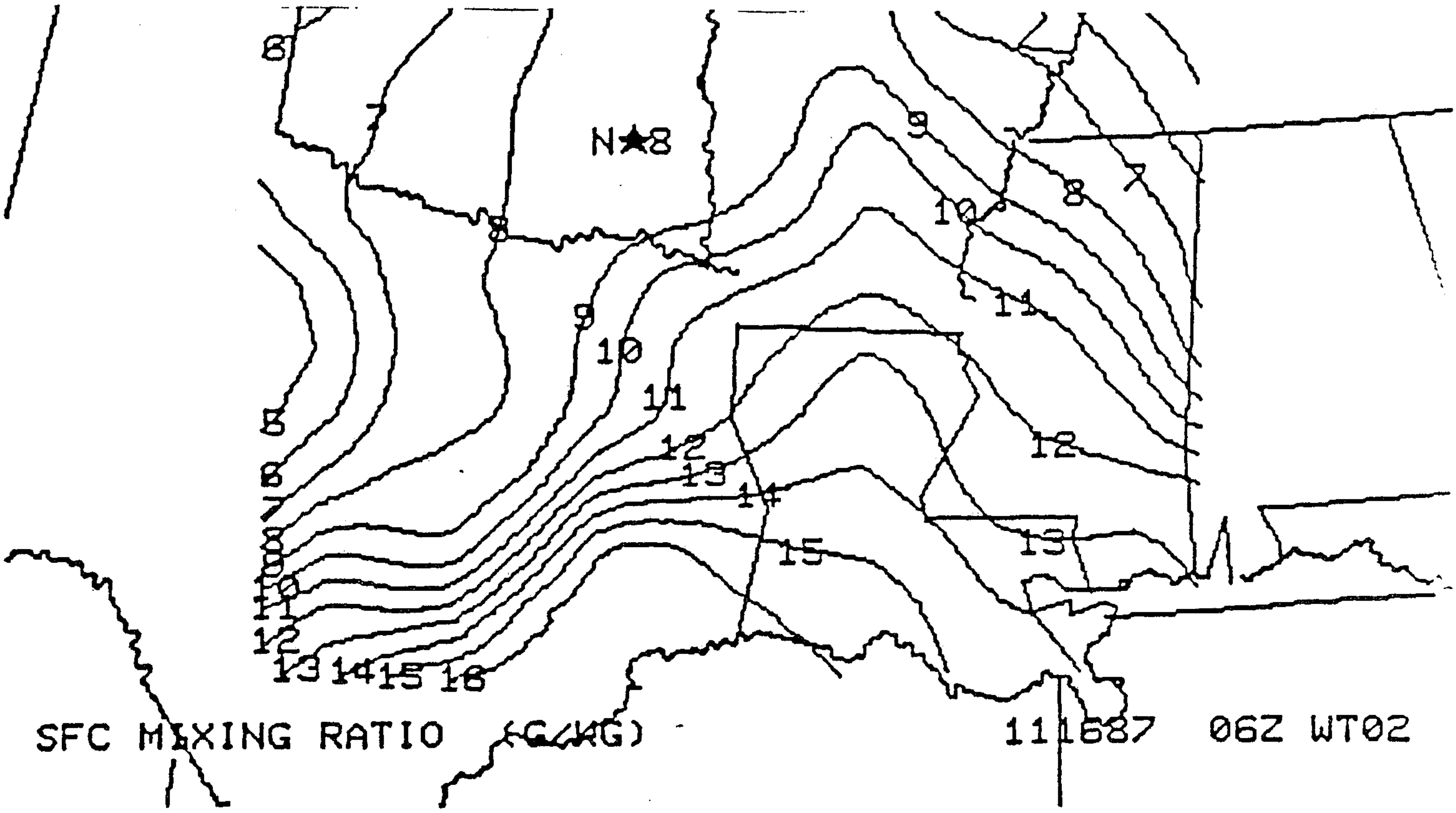
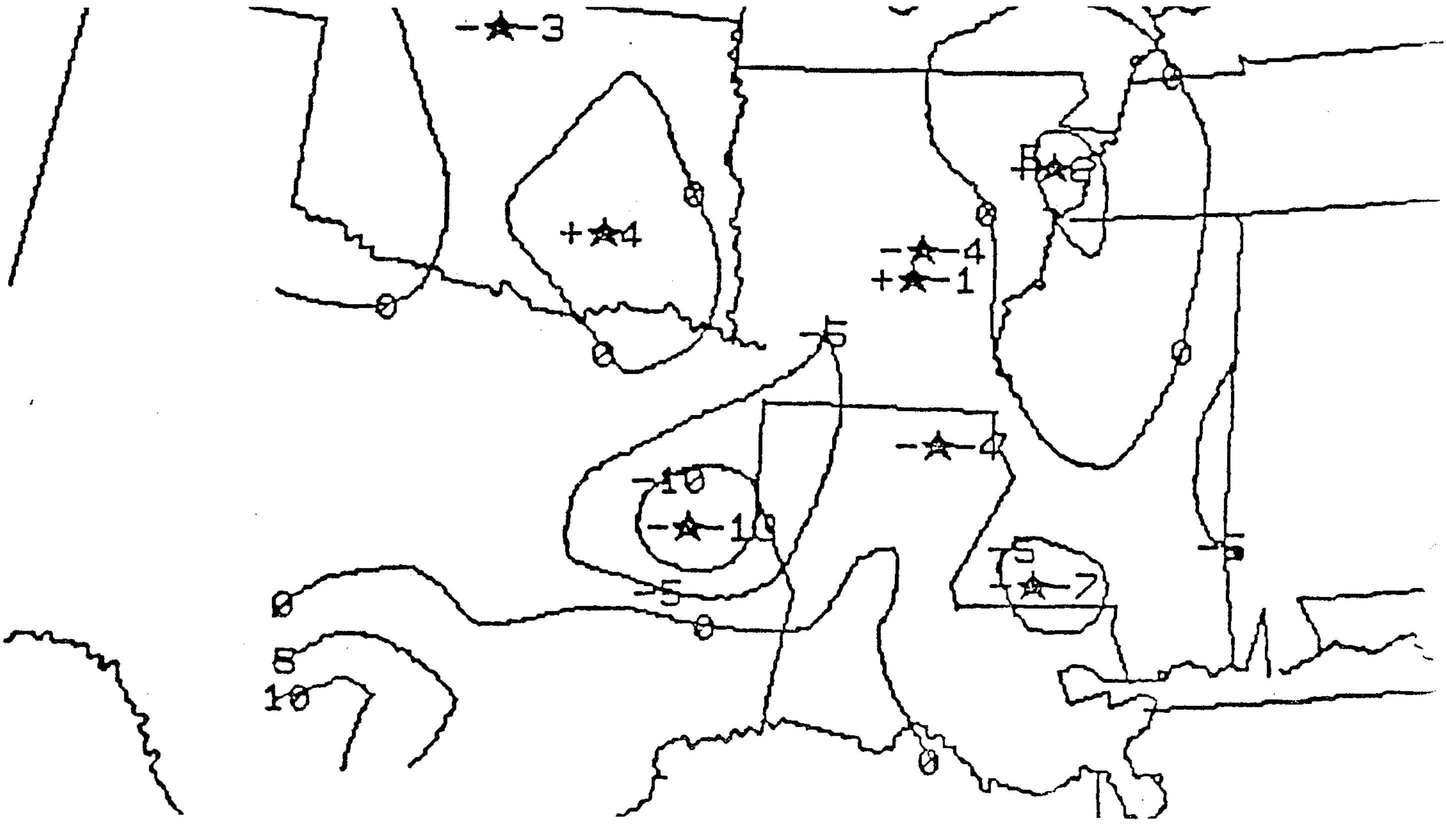


Fig. 13a Surface mixing ratio. 06Z November 16, 1987.



MXNG RATIO CHG(G/KG/HR*10)04Z 111687- 06Z 111687 WT

Fig. 13b Surface mixing ratio change. 04Z through 06Z November 16, 1987.



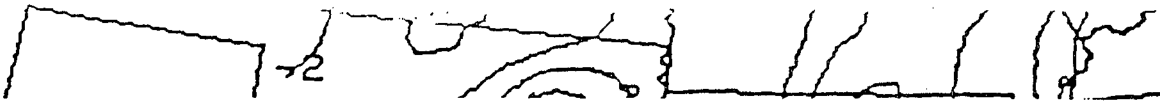
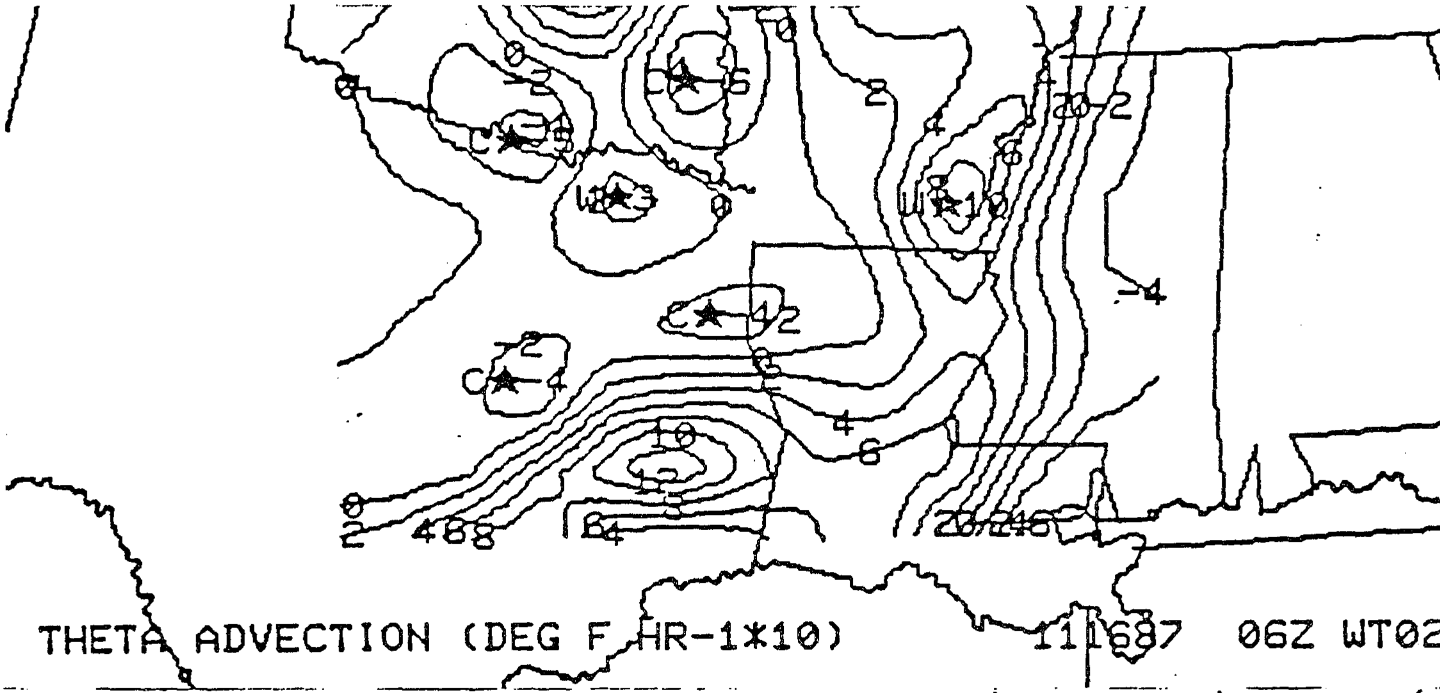


Fig. 14a Theta advection. 06Z November 16, 1987.



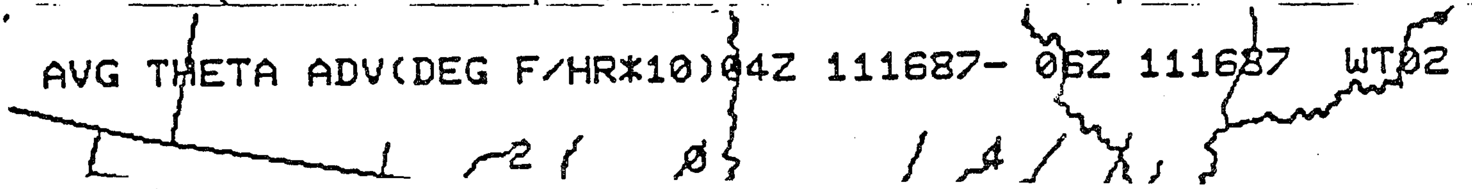
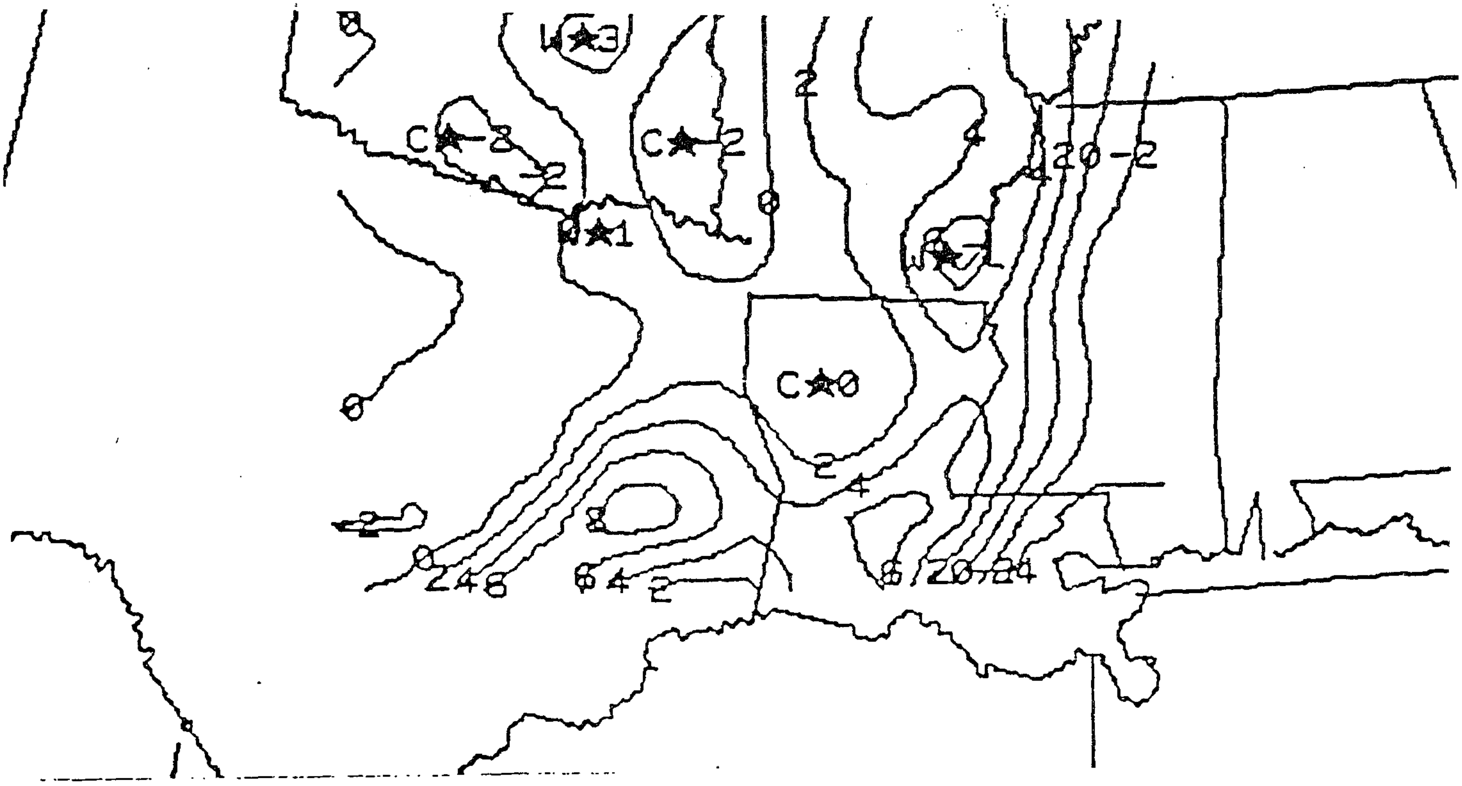


Fig. 14b Theta advection change. 04Z through 06Z November 16, 1987.



NWS AND NSSL

1989 SECOND NATIONAL HEAVY PRECIPITATION WORKSHOP

VENTURA COUNTY ALERT SYSTEM

A Case Study

March 20 - 23, 1989

ASILOMAR CONFERENCE CENTER

Prepared by

Dolores B. Taylor and John G. Weikel

VENTURA COUNTY PUBLIC WORKS AGENCY
FLOOD CONTROL AND WATER RESOURCES DEPARTMENT
VENTURA, CALIFORNIA

Table of Contents

Page No.

Concerns of Local Sponsors in Operating and Maintaining a Flood Warning System

VENTURA COUNTY FLOOD WARNING SYSTEM

A Case Study

Figures

THE HYDROLOGIC ENGINEERING CENTER
TRAINING COURSE

"FLOOD WARNING PREPAREDNESS PROGRAMS"

23 - 27 January 1989
Davis, California

INTRODUCTION

After ten winters' experience with the ALERT System, Ventura County Flood Control District has come to truly appreciate the value of real-time information on both rainfall and runoff plus the predictive peak flow models provided by the National Weather Service River Forecast Center in Sacramento. From a single application in the Sespe Creek in 1979, the Ventura County Flood Warning System has expanded to include twelve regular users of the real-time data in addition to operations at the Public Works Agency for the Road and Flood Control Departments.

Each of the users has different applications of the data from the System. Present users include: City of Fillmore, City of Santa Paula, the United States Navy, the National Weather Service, Pacific Weather Analysis (private forecaster), Casitas Municipal Water District, United Water Conservation District, the USGS in Bakersfield, the Ventura County Fire Department, and the Corps of Engineers--Los Angeles District.

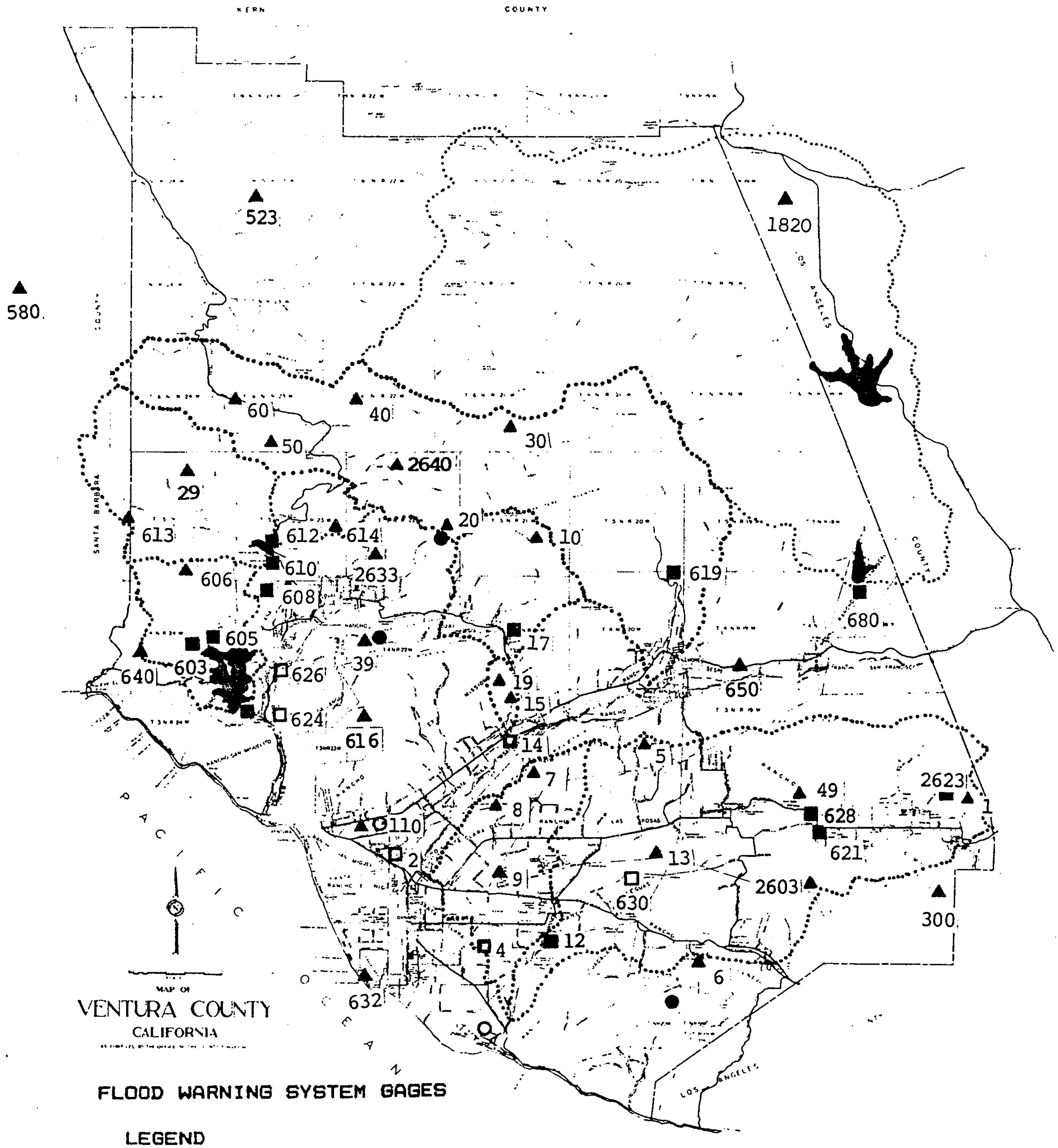
ELEMENTS AND OPERATION

Basically, the Flood Warning Operation application consists of five elements:

1. Self-reporting rain and stream gages at strategic points in the watershed. These gages collect the rainfall data and water-level data and transmit signals via radio waves whose frequencies have been reserved for this special function. (Figure 1)

2. Local Flood Warning Center equipped with a receiver to receive signals from the gages and two computers which convert the signals into inches of rain, stage levels in streams to flow rates, and store the data relative to the time of occurrence. Models of 17 watersheds generate local flood condition reports every 12 minutes for flood warnings or assurance of no danger to users. The two computers are networked together to share tasks under normal circumstances. If one computer should fail, the other will take over all the necessary functions. (Figure 2)

3. The California-Nevada River Forecast Center in Sacramento, a branch of the National Weather Service, which, by use of its hydrologic models and rainfall data from the local center, forecasts peak discharges to be expected for various amounts of additional rain. The redundant analysis serves as a quality assurance tool. (Figure 3)



FLOOD WARNING SYSTEM GAGES

LEGEND

▲ SELF REPORTING RAIN GAGE

■ SELF REPORTING STREAM & RAIN GAGE

□ SELF REPORTING STREAM GAGE

● REPEATER STATION

○ RECEIVER STATION

Figure 1

V.C.F.C.D. - ALERT ID NO'S.

K	PRECIP. GROUPS								
GROUP NO.	GROUP NAME	PRECIP. STATION ID. NO.							
1	CALLEGUAS CREEK	1	621	49	2603	13	5	6	2623
2	REVOLON, FAGAN, S. PLA.	7	8	9	10	15	19	18	20
3	SESPE, MATILIJA	30	40	50	60	29	615	614	619
4	LAKE CASITAS, VEN. R.	601	603	605	606	608	610	612	613
5	VENTURA CO. NEW	110	640	650	628	630	39	632	616
6	CHANNEL ISLANDS	150	170	180	190	543	103		
7	SANTA BARBARA CO.	570	77	72	73	74	75	76	580
8	" " "	590	503	527	529	531	543	545	547
9	" " "	513	515	517	519	521	523	99	999
10	LOS ANGELES CO.	0	300	301	302				
11	FOREST SERVICE W.S.	570	580	590					
12	MONTEREY CO.	16	44						
13	VENTURA CO. NEWEST	12	680						
14									

T	SENSGROUP & STATREPORT								
GROUP NO.	GROUP NAME	SENSOR I.D. NO.							
1	ZONE I STREAMS	600	602	604	607	609	611	624	626
2	ZONE II STREAMS	2	14	17	618	631	678		
3	ZONE III STREAMS	4	11	620	2622	627	629	70	630
4	WEATHER STA TEMP.	112	652	642	2605	2625	2635	582	1822
5	" " REL. HUM.	111	651	641	2604	2624	2634	581	1821
6	" " WIND	107	647	637	2600	2620	2630	577	1817
7	FILLMORE F.H. WTHR.	647	650	651	652	654			
8	VEN. CO. CTR. WTHR.	107	110	111	112	114			
9	LA GRANADA WTHR.	637	640	641	642	644			
10	HUNGRY VLY. WTHR.	1817	1820	1821	1822	1824			
11	S. BAR. POTR. WTHR.	577	580	581	582	584			
12	W. BIG. PINE WTHR.	567	570	571	572	574			
13	LAS LLAJAS WTHR.	2620	2623	2624	2625				
14	LANG RANCH WTHR.	2600	2603	2604	2605				
15	SENIOR-GRIDLEY WTHR.	2630	2633	2634	2635				
16	ORTEGA HILL WTHR	2647	2650	2651	2652				

HELPFCST RIVER FCST	SESPE CR.	S.PLA. CR.	CALLEG. CR.-CSH	REVOLON SL.	COYOTE CR.	SANTA ANA CR.	ARROYO SIMI	CONEJO CR.	MATIL. CR.	NORTH FORK	SAN ANTONIO	LAKE CASITAS	MATILIJA INFLOW	MATILIJA OUTFLOW	CASITAS INFLOW	CASITAS OUTFLOW	VEN. R. LOCAL
SIMUL. POINT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

PMAP	VEN. CO. PCP.	S.B. CO. PCP.	L.A. CO. PCP.	CALLEG. PCP.	SESPE PCP.	VEN. R. PCP.	CH. IS. PCP.	VEN. CO. TEMP.	VEN. CO. R.H.	VEN. CO. WIND	CH. IS. WIND			
MAP NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14

(4-27-88)

Figure 2

VENTURA COUNTY FLOOD ADVISORY

PROVIDED BY
THE CALIFORNIA-NEVADA RIVER FORECAST CENTER OF THE NATIONAL WEATHER SERVICE

****

FORECAST PEAK FLOWS IN THOUSAND CFS RESULTING FROM 3 HOUR PRECIPITATION

	3 HOUR PRECIPITATION (IN INCHES)				
	1	2	3	4	5
SESPE CREEK NEAR FILLMORE	.45	2.70	10.89	19.39	27.98
SANTA PAULA CR	.12	1.59	5.35	9.04	12.72
CALLEGUAS CREEK AT CAMARILLO	.23	2.16	8.88	29.19	50.90
REV. SLOUGH (CAL CK PARM)	.27	.85	4.02	8.36	12.82
FAGAN CANYON	.02	.09	.36	.54	.71
SANTA ANA CREEK	.00	.06	.13	3.98	6.81
COYOTE CREEK	.01	.10	1.37	5.70	9.47
MATILIJA CR 100% BURNED	.18	.48	6.11	14.50	22.52
MATILIJA CR IF UNBURNED	.05	.11	.27	2.39	11.09
ARROYO SIMI NR SIMI	.26	.63	9.95	35.18	55.67

****

Feb 29 88 14:12:49

Figure 3

4. A weather consultant charged with forecasting the amount of rain that can be expected over the next 24 hours along with the maximum 6-hour amounts for different watersheds. In the event that the rainfall amount expected would generate a peak discharge that would exceed the capacity of the stream channel, it is the local center's responsibility to notify the proper authorities in the threatened areas to initiate whatever precautions and evacuation warnings are judged to be appropriate. (Figure 4)

5. A technician assigned to keep the system equipment regularly maintained and calibrated to assure reliability. The value of regular maintenance on the gages cannot be underestimated: battery replacement; tipping bucket cleansing; stream gage base-setting and ratings; weather station calibration and accuracy are all critical to the credibility of the System.

   Ventura County uses a skilled hydrographer full time to keep the system in good working order. With 123 sensors to maintain, it is indeed fortunate that most of the gages operate with only an annual visit to clean tipping buckets and change out the battery. The new weather stations are much more complex to install, operate, calibrate, and maintain than rain and stream gages. There is a need for the manufacturers to provide improved manuals for the weather station maintenance.

MAJOR OBSTACLES TO DESIGN AND IMPLEMENTATION

There are two major obstacles encountered in designing and implementing a floodwarning System to minimize the chance of failure.

1. Lack of understanding of the potential problem.

   In Southern California, as in the rest of the United States, we have FIRM maps or C.O.E. FPI of the possible flood plains from a 100-year storm. The flood plain managers who utilize these maps understand the code used in determining the depth of inundation resulting from a 10-year storm as compared with a 100-year storm. It is quite common along our coastal streams for velocities of 10, 15 or 20 feet per second to severely scour the bottom on the rising limb of the flood and deposit this material downstream. Capacities in streams can change drastically.

   Such a case occurred in the Sespe Creek in 1978 when localized scour increased the capacity for the creek to pass 72,000 cfs. Damage due to meanderers was evident from the canyon mouth to the confluence with the Santa Clara River. Less than a month later, a second storm blew in from the Pacific Ocean with four hours of intense rain on ground that was somewhat saturated and produced

Ventura County Flood Control District

SURFACE-WATER SECTION

WEATHER FORECAST

Date: 2/14/86 24-Hour ☐ 5-Day ☐ Weekend ☐ Update ☒

Time: 4:30 p.m.

Front now moving rapidly southeastward thru Central California and should reach the Ventura area between 1800 and 2000 with shorter duration.

Rainfall amounts will be revised downward - moderate to heavy rain this evening, turning to showers tonight.

NEXT FORECAST: This Afternoon ☐ Tomorrow ☐ Monday ☐

Ventura County Flood Control District

SURFACE-WATER SECTION

WEATHER FORECAST

Date: 24-Hour ☐ 5-Day ☐ Weekend ☐ Update ☐

Time:

Date: Time:	2/14/ 1600-2200	2/14/ & 2/15 2200-0400		
Ventura	1.5	.5		
Mountains	4	1.0		
Calleguas	2.2	.8		
Fagan Cyn.	3.0	1.0		

3B-36

NEXT FORECAST: This Afternoon ☐ Tomorrow ☐ Monday ☐

Figure 4

54,000 cfs at the gage on Sespe Creek above Fillmore. Deposits of rocks and gravel left by the previous storm had reduced the capacity, and the flow exceeded its banks and deposited five feet of silt and water in a large area of Fillmore. The resulting 6 million dollars in damages and the anger of the victims because of the lack of forewarning provided the impetus for a pilot project of $50,000 for an ALERT Flood Warning System for this flashy creek.

2. Lack of staff capability and experience.

In 1978, we knew nothing of radio-operated gages, and the only computers we used were IBM and HP mainframes for HEC-2 and hydrologic modeling. It was "batch" work and not interactive as today. Without the tremendous cooperation and support of the National Weather Service CA-NEV River Forecast Center in Sacramento, we could not have started. Their hydrologists helped us select the six sites and have been helpful with many of the additional 118 sensors that are now part of the System. They produced calibrations of the Sacramento model and provided forecasts through a modem early each morning. "Hand-holding" continued during the initial installations with cooperation from the State of California Department of Water Resources. Hydrologist to hydrologist, hydrographer to hydrographer, the knowledge was passed for site selection, installation and computer operation. FCC licensing, site use permits, cooperative agreements, and response plans were challenges to be met with determination.

CONCERNS OF THE LOCAL SPONSORS IN OPERATING AND MAINTAINING A FLOODWARNING SYSTEM

1. Dependency on National Weather Service

From the beginning, we were concerned about our total dependency on the National Weather Service. In addition, for two winters we operated with one computer, no UPS System to assure power, and a temperamental telemark on our critical stream gage--Sespe Creek near Fillmore. We did not have the predictive model running "in-house," nor were we experienced enough to question the calibrations. In 1980, high water in Sespe Creek again posed a threat to the City of Fillmore. Implementation of the newly installed Flood Warning System made it possible to warn homeowners of possible breakout and bring in equipment to shore up the danger spots. This incident proved that the system really worked and was particularly impressive to those who suffered damage in the 1978 flood.

2. Alternate Application of ALERT Technology

Now that we have triple redundancy, a fine UPS system on all critical computer-related equipment, emergency power to the receiver on the roof of the County Government Center, and networked computers, our concern is to continue to find other uses for the equipment that enhances its value year round without "overloading" the System to the point that during major storms it cannot function as designed. Many weather stations have been introduced into our network that produce voluminous amounts of wind data that is magnified during frontal passage of big Pacific storms. The weather stations are used daily for many applications including fire weather, irrigation demand (evapotranspiration data), forest monitoring of ecosystems, and power demand by utility companies. However, with the addition of weather stations, the maintenance requirements increase by an order of magnitude. Increased cost for labor to keep them operating and furnish more data is another result.

3. Quantitative Precipitation Forecasts

As dependency by multiple agencies grows larger and larger on the ALERT System, the desire for meso-scale quantative precipitation forecasts (QPF) becomes a concern of staff. Advance warning is tied to predicted rain on top of the current level of saturation of each watershed. A difference of 1 inch of rain can make a significant difference in peak flows. (Figure 3)

A program called "Upset" will display the various basin parameters used in the streamflow simulation models. Comparison of contents and capacity of the different soil moisture storage indicates the degree of saturation. With sufficient rainfall to fill up the soil storage, additional rainfall will result in runoff. (Figure 5)

IMPACT OF CA-NEV ALERT USERS GROUP

Without hesitation, I feel the most important interest level generator and stimulation comes from the ALERT Users Group. Since 1982, we have met annually, and for recent years, quarterly, to share concerns, innovations and hear of new developments by vendors, both hardware and software. The Western Region of the National Weather Service has contributed greatly by facilitating those meetings which allow weather forecasters, hydrologists, technicians, manufacturers, and river forecast center personnel to participate and share problems, ideas, and experiences. At Asilomar, most participants stay on the cloistered grounds to eat together, meet formally together for presentations or workshops and share informally at breaks. The group has been effective in modifying standards, encouraging design improvements, and monitoring the use of the real-time technology throughout California.

I H S PROGRAM "UPSET"

VENTURA RIVER SYSTEM MODELS

```
Strike (RETURN) to continue, (ESC) to stop
                                                         Feb 29 88 13:10:09

For basin # 9 (Matilija Cr Unburned)
Valid date/time of contents is  2/29/1988   1300
Simulation time step is 1 hour(s)
Drainage area =   50.7 square miles
                Mean Daily Potential Evapotranspiration
  Jan   Feb   Mar   Apr   May  June  July   Aug  Sept   Oct   Nov   Dec
 0.060 0.060 0.110 0.190 0.260 0.310 0.330 0.300 0.230 0.120 0.060 0.060
           UZTW  UZFW  LZTW  LZFWS LZFWP
Capacity   4.50  1.50  8.00  5.00  7.00   ADIMP=  0.020      PFREE=  0.300
Contents   4.50  1.26  1.50  0.14  0.43   ADIMC=   7.86
   UZK   LZSK   LZPK    ZPERC  REXP  SIDE  SSOUT  PCTIM  SARVA  RSERV  PBASE
  0.200  0.050  0.0050   13.0  1.00  0.00   0.00   0.01   0.01   0.15  0.285

Parameters for Layered Routing are not defined
```

```
Strike (RETURN) to continue, (ESC) to stop
                                                         Feb 29 88 13:10:49

For basin # 10 (North Fork Matilija)
Valid date/time of contents is  2/29/1988   1300
Simulation time step is 12 minutes
Drainage area =   15.0 square miles
                Mean Daily Potential Evapotranspiration
  Jan   Feb   Mar   Apr   May  June  July   Aug  Sept   Oct   Nov   Dec
 0.020 0.020 0.030 0.030 0.030 0.030 0.030 0.030 0.030 0.030 0.020 0.020
           UZTW  UZFW  LZTW  LZFWS LZFWP
Capacity   1.80  1.50 10.70  5.00  7.00   ADIMP=  0.020      PFREE=  0.300
Contents   1.80  1.50 10.70  0.87  2.51   ADIMC=  11.86
   UZK   LZSK   LZPK    ZPERC  REXP  SIDE  SSOUT  PCTIM  SARVA  RSERV  PBASE
  0.200  0.050  0.0050   13.0  1.00  0.00   0.00   0.01   0.01   0.15  0.285

Parameters for Layered Routing are not defined
```

```
Strike (RETURN) to continue, (ESC) to stop
                                                         Feb 29 88 13:11:02

For basin # 11 (San Antonio Ck.)
Valid date/time of contents is  2/29/1988   1300
Simulation time step is 12 minutes
Drainage area =   51.2 square miles
                Mean Daily Potential Evapotranspiration
  Jan   Feb   Mar   Apr   May  June  July   Aug  Sept   Oct   Nov   Dec
 0.065 0.050 0.100 0.130 0.180 0.230 0.300 0.280 0.240 0.180 0.120 0.090
           UZTW  UZFW  LZTW  LZFWS LZFWP
Capacity   5.00  2.00 10.50  3.30 18.00   ADIMP=  0.100      PFREE=  0.200
Contents   5.00  1.01  1.16  0.00  0.31   ADIMC=   7.51
   UZK   LZSK   LZPK    ZPERC  REXP  SIDE  SSOUT  PCTIM  SARVA  RSERV  PBASE
  0.200  0.090  0.0055   11.0  1.70  0.50   0.00   0.01   0.00   0.30  0.396

Parameters for Layered Routing are not defined
```

Figure ~~6~~ 5

IMPACT OF SUCCESSFUL APPLICATIONS

While the former stimulates the actual Flood Warning System operators, local officials who approve budgets that contain funds for new equipment or improved software need to see successful applications. For example, the very close agreement between the model prediction and the actual flow in the 1980 flood in Sespe Creek, and the ensuing successful implementation of the response plan, gave us the confidence to present the ALERT concept to the Navy officials at Point Mugu. This same storm caused flooding of personnel housing at the base resulting in 15 million dollars in damages plus closing of the base for three days at a cost of $300,000 per day. In six months, the 11-gage System was designed, implemented, and functioning with a duplicate computer at the Navy base which is connected to the County by direct phone line to exchange data received, flood forecasts, and weather reports.

During the winters of 1981 and 1982, enough streamflow occurred on Calleguas Creek and Revolon Slough to allow the National Weather Service RFC to recalibrate the urbanizing stream model both for peak flow and time to peak on the two streams impacting the Navy base. The River Forecast Center also provided the models to be running in-house as our local officials funded the expansion of our computer memory.

On March 1, 1983, we were watching rainfall gages and stream levels for cities of Fillmore and Santa Paula, the U. S. Navy at Point Mugu, and our own Flood Operations Department. Not only were National Weather Service personnel watching this large Pacific storm, but our private forecaster for meso-scale quantitative precipitation forecast was very concerned. At that time, models used six-hour QPF, and engineering judgment caused "sweaty palms" among us as we looked at the models. Armed with a 24-hour forecast, local OES officials assisted in bringing together response people from sheriff, fire, cities, public works, the Red Cross, and radio reporters.

Severe flooding to agricultural areas and flood damage occurred due to the runoff from Calleguas Creek along its route, but the U. S. Navy was able to close its tide gates and flood gates several hours before breakout. In Fillmore, local police and firemen notified occupants of the potential for a flood, and equipment to remove debris was rolled into place in Santa Paula at a critical culvert. Satisfaction was the general acclaimer.

IMPACT OF PUBLIC INVOLVEMENT

The third event that has acquainted not only local officials but also the public to the use of our Flood Warning System was the Wheeler and Ferndale fires of 1985. Over 17 percent of the County of Ventura was burned, including brush that had stood for over 50 years. The Wheeler fire was started on July 2, 1985, by an arsonist.

By July 11, the fire rehab team from the U. S. Forest Service had identified that nearly 70 percent of the fire area was in a hydrophobic condition. Recognition of the fireflood cycle was addressed before the fire was contained. Twenty-six agencies of local, state and federal officials worked together to prepare a response plan. During public meetings, the ALERT System expansion to cover the fire area was explained to public groups and taped by television stations to be shown over and over during the fall months. ALERT gages purchased as spares, and others furnished by the State Department of Water Resources, were sited and installed among the charred chaparral skeletons. The National Weather Service RFC completed additional calibrations for selected canyons, as well as the main Ventura River, impacting towns along its banks. In Santa Paula, a breakout of Santa Paula Creek would inundate 60 percent of the urban area. Concern that the Ferndale fire that burned 70 percent of Santa Paula Creek would mirror expected flooding predicted for Ojai from the Wheeler fire.

Many service clubs who had heard about ALERT following the 1980 flood and 1983 flood invited Flood Control officials to return and explain what could happen. Slides of the denuded areas, debris control structures and potential flood plain maps were shown and explained. Service clubs in Ojai and Santa Paula manned sandbag and sand distribution centers for several weekends.

Early rains served as training exercises for the response team, now well versed in "buzz" words like hydrophobic soils, flood plain, debris production and saturation.

By February 10, 1986, the 5-day forecast from both the National Weather Service QPF forecaster in Los Angeles and our private forecaster was for a major event with several severe bands of rain over a period of four days. Adrenalin ran high, as did the "media-hype" from all over Southern California. Predictions by our hydrologists of a 10-year storm producing the 100-year flood plain due to debris loading had reached everyone. Maps were hung in libraries, schools, fire stations, and city halls. Hour after hour it rained, but never did any gage detect more than 0.5 inch per hour intensity. Fortunately, the rain stopped before the soil reached its water saturation limit.

Occupants of a small settlement at the mouth of the Matilija Canyon were notified that their access would probably be cut off because of landslides soon, but many elected to stay. (Several of these were rescued by helicopter the following day!)

FLOOD THREAT RECOGNITION AND RESPONSE

The major task involved in flood forecasting is recognition of the circumstances which can cause flooding. The ALERT system is a remarkable tool for providing rapid access to a large amount of hydrologic data. Real-time data from a large area can be monitored effectively. The following steps to a flood warning are involved:

1. In order to more effectively use this large number of sensors in the Ventura County ALERT system, it is most helpful to have a good location map (Figure 1) and a concise summary table for the user (Figure 2). The summary table is a matrix showing station I.D. numbers in groups, simulation point numbers and map numbers. A large-scale copy of the location map and summary table are mounted on the wall behind the computer terminal to assist the person who monitors data during a storm.

   The storm of February 27-29, 1988, will be used to illustrate various ALERT data output options using Sierra Misco International Hydrologic Services (IHS) software.

2. The character precipitation map shows the distribution in space of rainfall for any time increment. Figure 6 is the map for Ventura County precipitation for 48 hours ending February 29, 1988, at 12:00. Interrogation of the precipitation map is the first step in using the ALERT system to monitor a storm.

3. A graphical plot of 4 raingages for the same time period shows the hourly time distribution of the rainfall, or this hourly rainfall can also be shown in a numerical tabulation. In areas without streamgages, recognition of high-intensity rainfall is the only indication of potential flood problems. (Figure 7)

4. The Statistical Report showing the maximum stage at a group of stream gages enables a person to get a quick look at runoff activity during a storm. (Figure 8)

5. The National Weather Service Advisory gives forecasts of peak flows from 1-inch increments of 3-hour precipitation, all on a single convenient table. (Figure 3)

6. Using the quantitative precipitation forecast in combination with the discharge forecast, specific predictions can be made. Without a point of reference, a numerical discharge forecast may have little or no value to many people. A summary table for the major streams in Ventura County was developed. Included on the table are drainage areas, 10-year and 100-year discharges used in flood insurance studies, and the peak flows of recent historical floods. Copies of this table can be used to post flood forecasts. (Figure 9) The river forecasts are simulated for 3-hour precipitation with 1-inch increments ranging from 1 inch to 5 inches. However, Ventura County has a wide range of rainfall zones which range 3.5 inches to 8.0 inches for the 100-year, 6-hour precipitation. The 1-inch to 5-inch range is not ideally suited to all of our Ventura County forecast models.

I H S - A L E R T N E T CHARACTER SENSOR MAP DISPLAY

VENTURA COUNTY PRECIPITATION MAP

Totals for 48 Hours ending Feb. 29, 1988 at 1200

```
  .    Hopper Cyn.                                   Hungry Valley
  .                                                           ..
  .               VENTURA COUNTY PRECIPITATION                 ..
  .                                                             ..
  .                                                              ..
  .       3.94 in    6.06 in                                      ..
  .          4.06 in                 2.72 in                       ..
  .   2.52 in                                                       ..
5.75 in             6.61 in  5.67 in                                 ..
  Matilija  3.82 in   NA in          1.73 in                          ..
  . 4.49 in   3.03 in                            3.62 in          NA in
  .      3.39 in   Ojai                                                 ..
  .   2.93 in          3.46 in    1.63 in    Fillmore 2.44 in            ..
 2.72 in  1.34 in                  1.50 in                                ..
 .  L. Casitas       3.11 in      1.50 in                                  ..
 . .           Ventura        Santa Paula      1.18 in                      ..
     ..                                1.69 in   Moorpark  1.97 in     0.67 in
        ..            0.47 in    1.26 in                          Simi  0.00 in
            ..  County Center                 0.98 in      2.17 in  1.26 in
              ..                  0.79 in                  2.76 in  .....
                ..                     0.98 in   Thousand Oaks       .
                  .. 0.33 in         Camarillo    1.30 in            .
                   ...    Pt. Hueneme                        ............
Values for Map # 1: 48 hours  2/29/88 12:00:00               .
```

Figure 6

IHS - ALERTNET STATISTICAL SUMMARY PROGRAM

Hourly Values for Precipitation Group 3
Storm Dates Feb.27, 28, 29, 1988

```
                                   Ventura County Flood Control District
                                                  Date      Time
                                                6/22/88   1156
Sensor #         30          40          50          60          614          615
StatType        dif         dif         dif         dif          dif          dif
DataType     precip      precip      precip      precip       precip       precip
Units            in          in          in          in           in           in
 2/29/88
1200           0.04        0.47        0.28        0.39         0.71         0.08
1100           0.12        0.28        0.24        0.31         0.20         0.24
1000           0.00        0.28        0.16        0.35         0.31         0.04
0900           0.04        0.55        0.24        0.16         0.31         0.20
0800           0.04        0.31        0.31        0.59         0.28         0.24
0700           0.16        0.16        0.16        0.20         0.43         0.28
0600           0.00        0.43        0.12        0.31         0.51         0.20
0500           0.08        0.35        0.31        0.59         0.35         0.20
0400           0.08        0.43        0.16        0.20         0.28         0.12
0300           0.04        0.24        0.16        0.24         0.43         0.08
0200           0.00        0.04        0.00        0.12         0.16         0.00
0100           0.00        0.00        0.04        0.00         0.00         0.00
 2/28/88
2400           0.00        0.08        0.04        0.04         0.00         0.00
2300           0.00        0.00        0.00        0.00         0.00         0.00
2200           0.00        0.00        0.00        0.00         0.00         0.00
2100           0.00        0.00        0.00        0.00         0.00         0.00
2000           0.00        0.00        0.00        0.00         0.00         0.00
1900           0.00        0.00        0.00        0.00         0.00         0.00
1800           0.00        0.00        0.00        0.04         0.00         0.00
1700           0.00        0.00        0.04        0.12         0.04         0.00
1600           0.00        0.04        0.08        0.08         0.08         0.00
1500           0.00        0.04        0.00        0.04         0.00         0.00
1400           0.00        0.00        0.00        0.00         0.00         0.00
1300           0.00        0.00        0.00        0.00         0.00         0.00
1200           0.00        0.00        0.04        0.00         0.00         0.00
1100           0.00        0.00        0.00        0.00         0.00         0.00
1000           0.00        0.00        0.00        0.00         0.00         0.00
0900           0.00        0.00        0.00        0.00         0.00         0.00
0800           0.00        0.00        0.00        0.00         0.00         0.00
0700           0.00        0.00        0.00        0.00         0.00         0.04
0600           0.04        0.00        0.00        0.00         0.04         0.00
0500           0.00        0.04        0.00        0.04         0.04         0.00
0400           0.00        0.08        0.04        0.04         0.08         0.00
0300           0.04        0.16        0.04        0.04         0.08         0.00
0200           0.00        0.16        0.08        0.08         0.39         0.00
0100           0.24        0.24        0.16        0.04         0.31         0.00
 2/27/88
2400           0.12        0.08        0.08        0.31         0.04         0.00
2300           0.16        0.20        0.12        0.16         0.12         0.00
2200           0.04        0.31        0.12        0.28         0.12         0.00
2100           0.79        0.55        0.47        0.55         0.67         0.20
2000           0.16        0.31        0.28        0.24         0.39         0.39
1900           0.24        0.08        0.12        0.16         0.12         0.08
1800           0.20        0.12        0.16        0.16         0.12         0.08
1700           0.04        0.00        0.00        0.04         0.00         0.08
1600           0.00        0.00        0.00        0.00         0.00         0.00
1500           0.00        0.00        0.00        0.00         0.00         0.00
1400           0.00        0.00        0.04        0.00         0.00         0.00
1300           0.08        0.04        0.00        0.04         0.00         0.00

TOTALS:        2.72        6.06        4.06        5.94         6.61         2.52
```

Figure 7

IHS - ALERTNET STATISTICAL SUMMARY PROGRAM
Hourly Values for Streamgages Group 1
Storm dates Feb. 27, 28, 29, 1988

Ventura County Flood Control District
Group Name Date Time
Zone I Streams 6/22/88 1150

Sensor #	600	602	607	609	611	624	626
StatType	max	max	max	max	max	max	max
DataType	river	river	river	river	river	river	river
Units	ft	ft	ft	ft	ft	ft	ft
2/29/88							
1200	------	3.42	3.67	------	3.52	3.80	6.60
1100	------	3.42	3.68	------	3.42	3.65	6.70
1000	550.80	------	2.84	------	3.57	3.70	6.35
0900	550.71	3.42	------	------	3.32	------	6.55
0800	550.74	------	------	------	3.02	3.40	6.30
0700	------	3.34	------	------	2.82	------	5.65
0600	------	------	------	------	2.42	------	------
0500	550.66	2.14	------	------	2.02	------	4.50
0400	------	------	2.82	------	1.67	3.25	------
0300	550.58	------	2.83	------	------	3.15	------
0200	------	------	------	------	------	------	------
0100	550.55	------	------	------	------	------	------
2/28/88							
2400	550.50	------	------	------	1.62	------	------
2300	------	------	------	------	------	------	------
2200	------	------	------	------	------	3.15	------
2100	------	------	------	------	------	------	------
2000	------	------	------	------	------	------	------
1900	------	------	------	------	------	------	4.45
1800	------	------	2.82	------	------	------	------
1700	------	------	------	------	------	------	4.45
1600	------	------	------	------	------	------	------
1500	------	------	2.88	------	------	3.20	------
1400	------	2.14	3.23	------	1.67	------	------
1300	------	------	------	------	------	------	------
1200	------	------	------	------	------	------	------
1100	------	------	------	------	------	------	------
1000	------	2.22	------	------	1.77	------	4.65
0900	------	------	------	------	1.82	------	4.75
0800	------	------	------	------	1.87	------	4.80
0700	------	2.30	2.98	------	1.92	------	5.05
0600	------	------	------	------	1.97	3.25	5.20
0500	------	------	------	------	2.02	------	5.25
0400	------	2.38	------	------	1.82	3.30	4.80
0300	------	2.46	------	------	------	3.35	4.95
0200	------	------	2.96	------	1.77	3.45	5.10
0100	------	2.54	------	------	1.82	3.73	5.55
2/27/88							
2400	------	2.38	------	------	1.67	4.00	6.20
2300	------	------	2.35	------	1.77	3.90	6.25
2200	------	------	2.94	------	------	------	5.00
2100	550.35	2.08	------	------	1.67	3.35	4.95
2000	550.39	1.98	2.91	------	------	------	------
1900	550.36	------	------	------	------	------	4.20
1800	------	------	------	------	------	------	------
1700	------	------	------	------	------	------	------
1600	------	------	------	------	------	------	------
1500	------	------	------	------	------	2.85	------
1400	550.36	------	------	------	------	------	------
1300	550.36	------	------	------	------	------	------

Figure 8

MAJOR STREAMS IN VENTURA COUNTY
Flood Insurance Flow Values & Historical Peaks

					HISTORICAL PEAKS				DATE: TIME:	DATE: TIME:
SIMUL. PT.NO.	STREAM NAME	DRAINAGE AREA (SQ.MI)	Q-10 (cfs)	Q-100 (cfs)	'69 (cfs)	'78 (cfs)	'80 (cfs)	'83 (cfs)	PRECIP. FCST. (INCHES)	DISCH. FCST (CFS)
1	FILLMORE Sespe Crk.	251	33,000	92,000	60,000	73,000	40,700	56,000		
2	Santa Paula Crk. at Steckel Park	40	6,800	26,000	21,000	16,000	11,800	4,750		
N	Fagan Canyon Below Harvard	3.3	1,100	3,000	2,300	1,240	2,500	580		
	Santa Clara River at Montalvo	1,612	41,000	161,000	165,000	102,200	81,400	100,000		
7	SIMI Arroyo Simi at Madera Rd.	71	4,400	17,000	6,330	7,730	9,310	10,700		
3	Calleguas Crk. at Camarillo State Hospital	248	5,900	25,000	16,300	18,700	25,300	25,900		
4	Revolon Slough at Laguna Rd.	46	2,500	8,700	-	-	5,470	5,700		
10	N. Fork Matilija Crk. at Matilija Hot Springs	16	3,900	12,600	9,440	5,780	3,720	2,660		
9	Matilija Crk. above Matilija Dam	55	12,000	27,500	20,000	16,500	10,600	12,200		
5	Coyote Creek Near Oak View	13	5,400	20,800	8,000	6,130	5,100	2,110		
6	Santa Ana Crk. Oak View	9	3,200	11,300	4,730	5,330	3,830	2,120		
11	San Antonio Crk. Near Casitas Springs	51	7,000	19,900	16,200	13,900	7,380	8,730		
17	VENTURA Ventura River	187	30,000	68,000	58,000	63,600	37,900	27,000		
8	Conejo Crk. Above Hwy. 101	64	4,400	20,000	-	9,830	11,800	13,300		

Figure 9

7. This is illustrated by Figure 10 which has a table of recurrence intervals for 3-hour precipitation. Note that in the Calleguas Creek watershed, five inches has a recurrence interval of 1200 years, and in Matilija Creek, five inches has a 25-year interval. This suggests that other values of the 3-hour precipitation may be more appropriate. (Figure 10)

8. A possible alternative to the 1-inch precipitation increments would be to choose increments corresponding to the 5-year, 10-year, 25-year, 50-year, and 100-year 3-hour precipitation. These values have been calculated for the respective basins in Ventura County and are shown in tabular form. (Figure 11) These calculated precipitation values can be input as user specified rainfall in the discharge forecast models using IHS software. As a quality-control measure, we frequently make comparisons with our in-house model simulations and the National Weather Service Advisory. If we use a different set of precipitation values, we lose the ability to make this comparison.

GOALS FOR ALERT USER

As ALERT users for Ventura County, we feel our primary responsibility is to be able to use the system with a maximum degree of efficiency. We need to keep up to date with each new change or addition to the system. Our goal is to constantly improve our ability to recognize hydrologic conditions that may develop into flood situations. (Figure 12)

ACQUIRING ADEQUATE FUNDING LEVELS

1. Since our ALERT System has proven its value for three major events in ten years, funding to upgrade and add to the System has not been difficult to justify. By encouraging alternative uses of the equipment, such as real-time monitoring of reservoir inflows and fire-weather monitoring, other public agencies cooperate by funding equipment and assisting with the installation. Also, with routine annual maintenance, rain gages installed in 1979 are still working fine.

2. As the number of remote sensors in the Ventura County ALERT System exceeds 100, maintenance efficiency and agreements with agencies served gain importance. In-house technical skill of a specialized hydrographer is augmented by regular service on an as-needed basis by our County Communications Department. Vendors of ALERT equipment with hundreds of units in California alone are recognizing the need for systematic maintenance for quality assurance. Weather stations are far more complex than the original tipping bucket rain gages. Helicopter access to mountain sites and related high cost have stimulated the creative use of small, efficient solar panels to increase gel-sel battery life.

RECURRENCE INTERVAL VERSUS
THREE-HOUR PRECIPITATION
for
VARIOUS WATERSHEDS IN VENTURA COUNTY

	3-HOUR PRECIP. : INCHES				
	RECURRENCE INTERVAL - YEARS				
	5	10	25	50	100
CALLEGUAS CR. REVOLON SL.	1.5	2.0	2.5	3.0	3.5
SESPE CR. S. PAULA CR. SAN ANTONIO CR.	2.0	2.5	3.0	3.5	4.0
COYOTE CR. SANTA ANA CR.	2.5	3.0	3.5	4.0	4.5
MATILIJA CR.	3.5	4.0	5.0	5.5	6.0

Figure 10

VENTURA COUNTY PUBLIC WORKS AGENCY

SHEET ______ OF ______

PROJECT ALERT SYSTEM

ITEM RIVER FORECASTS
PRECIPITATION CASES

			CASE				
			1	2	3	4	5
SIMUL. PT. NO.	DESCRIPTION	RECORDING RAINGAGE NO.	3-HOUR PRECIP. (INCHES)				
			5-YR.	10-YR.	25-YR.	50-YR.	100-YR.
3	CALLEGUAS CREEK	196	1.5	2.0	2.5	3.0	3.5
4	REVOLON SLOUGH	189	↓	↓	↓	↓	↓
7	ARROYO SIMI	196	↓	↓	↓	↓	↓
8	CONEJO CREEK	188	↓	↓	↓	↓	↓
1	SESPE CREEK	152	2.0	2.5	3.0	3.5	4.0
2	SANTA PAULA CR.	173	↓	↓	↓	↓	↓
11	SAN ANTONIO CREEK	165	↓	↓	↓	↓	↓
5	COYOTE CREEK	44	2.5	3.0	3.5	4.0	4.5
6	SANTA ANA CREEK	44	↓	↓	↓	↓	↓
9	MATILIJA CANYON	207	3.5	4.0	5.0	5.5	6.0
10	N. FORK MATILIJA CR.	207	↓	↓	↓	↓	↓

Figure 11

FLOOD WARNING - FLOW CHART

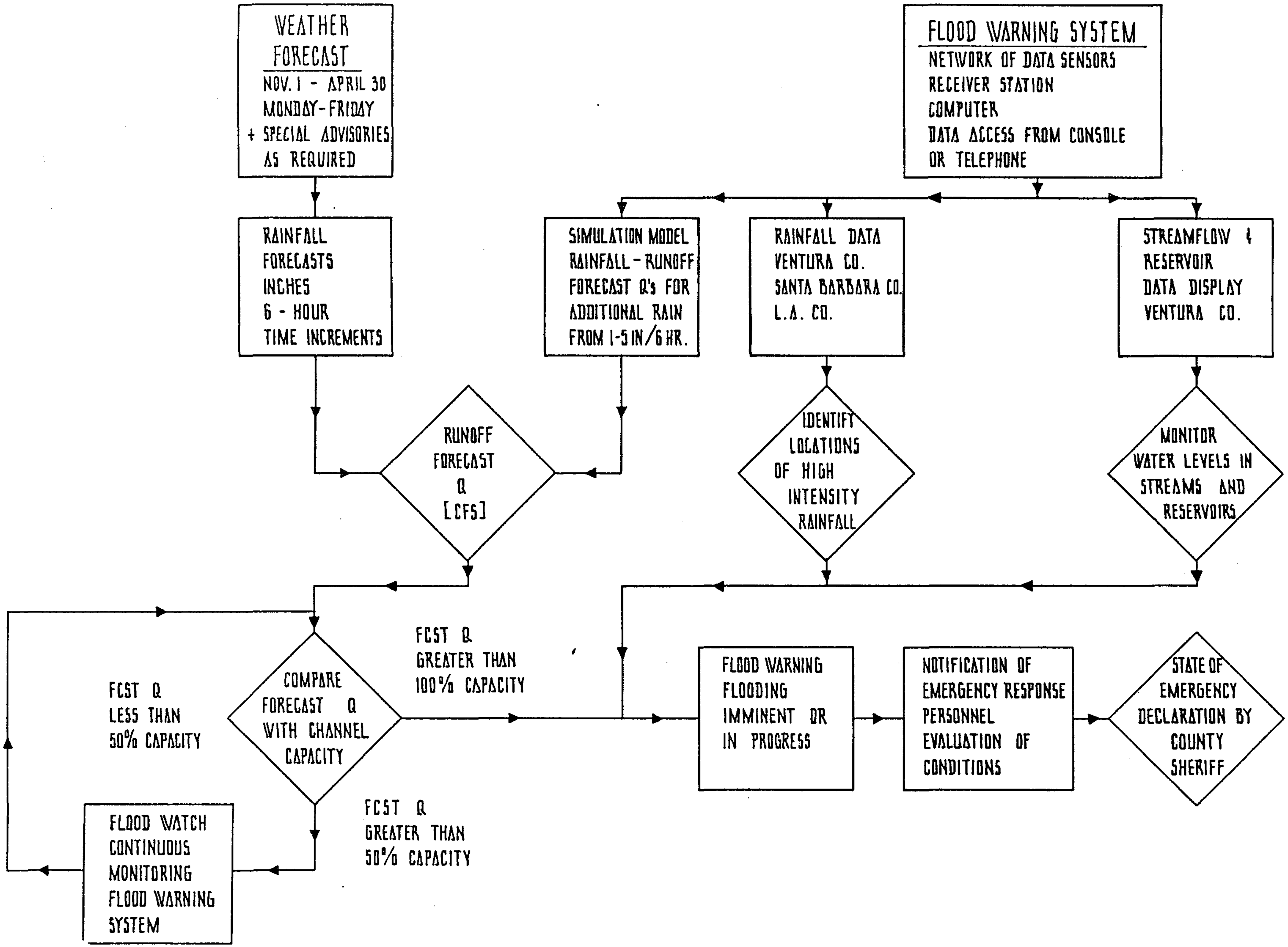


Figure 12

MAINTENANCE OF PUBLIC SUPPORT

A willingness by County hydrologists and administration to present slide shows at service clubs, career day programs at high schools and community colleges, as well as regular contact with radio, TV and newspapers, assures ongoing awareness.

MULTIPURPOSE FUNCTIONS OF THE ALERT SYSTEM

Ventura County has long served as the "cheerleader" for ALERT technology. Alternative applications seem a natural outgrowth to apply to any disaster requiring real-time, alarming capable systems. For instance:

1. Dam inundation

   Remote water-level sensors could give indication of a dam breach if a sudden drawdown were to occur which exceeds the rate the outlet gates could achieve.

   There are five major dams with sizeable reservoirs on tributaries outside the boundaries of Ventura County that all drain into the Santa Clara River. The river traverses Ventura County and ends on the Oxnard Plain, where nearly a quarter of a million people work and live. The confirmation of a dam breach could provide several hours' notice to move folks or property to higher ground. Experts on earthquakes expound that the critical period for a major quake in California is here, and the seriousness should not be underrated. The Sylmar quake in 1972 caused a strong concern for monitoring Castaic Dam, as getting an inspector to the dam required several hours, due to freeway damage and resulting traffic jams.

2. Fire-weather monitoring

   Fire station personnel at selected stations are required to make periodic readings during the day to provide the data for calculating the "Burn Index." This value determines the response level to a fire; i.e., two engines, a helicopter, and handcrews. With real-time monitoring at key locations throughout the county, fire officials can deploy their forces more effectively, thus saving many dollars.

   Also, when station personnel are on a fire or other incident, the required readings cannot be made, which leaves a gap in the data base. Some of the most pertinent data reflecting conditions during a fire are not available unless an automated system is implemented.

Ventura County Flood Control has cooperated with the fire department in a joint effort to install retrofitted raingage transmitters as full weather stations. The fire department budget furnished capital for hardware and a fund to cover the cost of installation and maintenance.

Maps of current temperature, humidity, and wind (both speed and direction) are accessible by phone modem, while the base station contains preset alarm levels on sensors for humidity, temperature, and wind.

3. Water supply and inflow modeling

With a second dry year drawing to a close and water use aggravated by the steady inflow of new immigrants to California, a safe and adequate water supply continues to gain importance. Not only reservoir level monitoring, but also modeling of inflows in real-time, assist the operator to understand his watersheds and better manage diversions, allocations, and water rights.

4. Irrigation Demand

As overdrafts of valuable aquifers exceed normal rates by 200 percent, the need to irrigate more scientifically becomes more critical. With the addition of sensors to the existing ALERT Weather Stations, any evapotranspiration index can be calculated in real time to supplement the sparse CIMIS network in Ventura County. Irrigation requirements is then computed for the specific crop.

CONCLUSION

The evaluation of the ALERT technology in the past ten years has proven that local government can effectively cooperate with the federal government in such a way that each entity performs the jobs that it does best. The National Weather Service conceived the idea of stand-alone data collection sensors and guided the manufacturers in the original prototype designs of real-time equipment. They further provided watershed model calibrations when the local agency compiled the required data. Acting as FCC contact, the National Weather Service assigned sensor members by counties and applied for licenses for the radios. Statewide coordination of a huge system has resulted.

The local government sponsor maintains not only the hardware in the field to assure quality but also monitors forecasted flows versus real-time flows to best assess where local problems may occur. Utilizing the best precipitation forecast available, local officials notify other agencies of potential problems many hours before the storm maximizes. Response plans are activated by the officials who continue to receive updates during the actual event. Determination that no problems are expected from a certain storm event can result in considerable savings to local agencies.

Living on the growing edge of the ALERT technology is stimulating! Applications to other public safety programs, such as fire-weather and dam inundation, are being supplemented in recent years with many other real-time uses from power demand forecasting to agricultural monitoring to better irrigate crops. New uses stimulate software development that benefits all users. A well-organized ALERT Users Group continues to lobby for higher standards while policing itself to assure an excellent data base for the State of California.

The California inter-cooperative ALERT program serves as a model for other states and will continue to lead as long as the National Weather Service continues lending the invaluable support.

DT/JGW/fm
3-K/1(10)
12/1/88

ADAPTING AN OROGRAPHIC PRECIPITATION MODEL AS A QPF AID FOR A PART OF THE SIERRA NEVADA

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1.0 INTRODUCTION

Principles from Rhea's orographic model, (Rhea, 1978), were adapted for QPF use by the California Department of Water Resources, CDWR, (Rhea, 1986) for a part of the Sierra Nevada, using the February 12-20, 1986 period of excessive precipitation as one of several test cases.

The model was originally developed for the western half of Colorado for both climatological purposes and as a QPF aid. It has been used by both the U. S. Forest Service (the funding agency for the research) and the National Weather Service in Colorado as a QPF aid. The approach was also used for QPF purposes from 1979 through 1986 in the Sierra Cooperative Pilot Project (SCPP), a U.S. Bureau of Reclamation weather modification research project.

2.0 MODEL DESCRIPTION AND SOME PRIOR USAGE

Fast running time and usage of routinely available upper air data as input were key considerations in constructing this operationally-oriented computational method. Therefore, no mesoscale modeling of the flow field over complex terrain was attempted. Rather, it is assumed that the air flows along grid lines with the elevation grid x-axis aligned with the 700mb wind (or 850mb, if preferred for areas of lower mountains) and with the "x-component" winds for each layer computed accordingly. Thus a topographic grid of different orientation may be needed for each run.

The method keeps track of the condensate or evaporation due to vertical displacements as the air flows over the underlying topography. At a given grid point, part of the condensate precipitates. The rest moves downstream to the next grid point where a fraction of it and the condensate generated by additional orographic lift precipitates. For sinking motion, part or all of the parcel cloud water evaporates. Precipitation falling into a layer from above partially (or totally) evaporates when encountering subsaturated conditions. Eventually, precipitation generated in the highest layers reaches the ground provided it does not totally evaporate.

With the foregoing stipulations and the further assumptions of steady state, two-dimensional flow, U, precipitation efficiency, E, and a coordinate framework moving with the parcel, model precipitation, $\bar{r}_{I,I+1}$, along grid interval, Δx, over time, Δt, for a layer with initial pressure thickness, ΔP, and initial x-component wind, U, can be written

$$\bar{r}_{I,I+1} = \frac{EU\Delta P}{\rho_w g \Delta X}(Q_I + \Delta C_{I,I+1})\Delta t \qquad (1)$$

where Q_I is total cloud water content at grid point I, $\Delta C_{I,I+1}$ is additional condensation (or evaporation) due to vertical displacement between points I and I+1 (for evaporation, if $\Delta C_{I,I+1} > Q_I$, numerically, $\bar{r}_{I,I+1} = 0$), ρ_w is density of water and g is gravity. Layer vertical displacement is assumed to decrease from the terrain elevation change value at the surface to a stability-dependent fraction of this value at cloud top. All computations are made by following the parcel along a moist adiabat (at the pressure mid-point of the layer) by re-initialization of location indices (i.e., by setting I = I+1 and I+1 = I+2).

Computations are made at the pressure mid-point of several 50mb thick layers (up to as high as the 450mb level, depending on where the top of the moisture is found) using the required inflow border sounding. Over a given grid interval I,I+1, computations are made for the highest layer first and proceed downward. When computations are completed for all layers over that grid interval, a step forward along the line is made by incrementing location indices as described above. Thusly, computations proceed one line at a time. Printout of precipitation for each grid point gives the resulting map of amounts. Specific measurement site amounts can also be calculated, as well as area averages for desired watersheds.

The orographic model "moisture top" is defined as the highest level with at least 65% relative humidity which is not undercut by any lower layer(s) of less than 50% relative humidity.

Some model features such as precipitation efficiency can be varied if desirable when adapting it for use in an area.

A key feature of the model is its simulation of upstream barrier shadowing effects . This was by design due to the known strong precipitation pattern variation by 700mb wind direction over the complex terrain of Colorado.

Input requirements are (1) an actual or predicted profile of temperature, humidity, and winds aloft, (2) a set of topographic grids with grid interval of 10km or less, and (3) the "period of representativeness" of the input sounding, (usually set as the time interval between input soundings, observed or predicted).

Model programs are compatible with mainframes, minis, and microcomputers. Terrain data from the NGDC for the western U. S. at 1 minute lat./long. resolution has recently been converted to microcomputer compatibility, thus increasing the ease of application of the method to other desired areas.

The climatological portion of the original Colorado study used elevation data with a 10km grid interval and 13 winter seasons of twice daily sounding data as input. When summed seasonally over a large part of the main runoff-contributing areas of Colorado, the correlation to observed spring and summer runoff was 0.91. Use of seasonal <u>model</u> precipitation amounts for selected snowcourse locations to predict spring and summer runoff showed a correlation coefficient of 0.90 compared to 0.95 when using <u>actual</u> snowcourse readings to make the predictions. Also, a 13-season <u>average</u> model precipitation map compared quite well over the mountains to the NOAA <u>average</u> isohyetal map for Colorado by Peck and Brown (1962).

3.0 STUDY AREA AND TOPOGRAPHY

The study area extended primarily from the American River Basin (ARB) northward through the Feather River Basin, but excluding the portion of the Feather above Lake Almanor. Figure 1 shows the location of this area in relation to the upper air measurement site (Oakland) and LFM prediction model grid points.

For this study, elevation information was extracted from 1:250,000 scale topographic maps on a 2.5km grid interval and then averaged to generate smoothed gridded elevation data with a 5 km grid interval for model use. Figure 2 gives a contoured map of the resulting data with a contour interval of 500 feet (labeled in hundreds of feet).

4.0 DATA AND METHODS

Table 1 shows the storm periods selected for study. Due to various data limitations, days marked with an asterisk were later eliminated. Also, the period in February, 1982, had rather limited precipitation data with a number of stations missing. The extremely heavy, extended storm period in February, 1986, of course was of major interest.

The CDWR provided hourly precipitation data for eighteen stations they selected for the study for comparing to model output. Table 2 shows the list of stations. Their locations are indicated on the contoured map in figure 2.

Observed as well as predicted profiles of wind, temperature, and moisture were used as model input. Predicted 850mb, 700mb, and 500mb values of wind, temperature, and moisture (for grid points 1 and 2 of fig. 1) from the 12-hour and 24-hour predictions of the LFM model were employed for the 1985 and 1986 study periods along with rawinsonde observations from Oakland for all the periods.

The model program is structured to expect sounding information to be available at each of the "inflow border points" indicated along the border of Figure 1, with the number of border points used in each case ranging from 2 to 5 depending on the wind direction. In practice, if only one sounding is available, e. g., from Oakland, all border points are filled with that value. In the case of the LFM data, interpolation based on distance of the two LFM grid points from the orographic model border points is done.

5.0 EXAMPLES OF PATTERN DEPENDENCE ON WIND DIRECTION

To illustrate the dependence of model precipitation patterns on wind direction a set of model reference runs were made, with a run for each 10 degree wind direction class, using a hypothetical "maximized" sounding and varying only the wind direction from one run to the next. The hypothetical sounding was characterized by (1) approximate moist adiabatic lapse rate and 0C 700mb temperature, (2) 50 kt. wind at 700mb and with the component speed (aligned with the 700mb direction) at any other given level being:

50kts x (avg. component for the level)/(avg. 700mb speed)

where the averages are based on the entire sample of Oakland sounds used in this study, (3) deep moisture to 450mb, and (4) an assumed duration of 12 hours. This resulted in such "pattern maps" as figures 3 and 4.

Interesting direction-dependent pattern variations from these runs can be seen. For instance, the heaviest precipitation area for 180 degree flow is in the Feather River drainage both in the vicinity of Buck's Lake and Four Trees and also north of the Feather River Canyon. For 240 degrees many areas have large amounts and the maxima in the areas just described above are not so noticeable by comparison.

6.0 MODEL RUNS WITH ACTUAL RAWINSONDE DATA AND PREDICTED CONDITIONS

Full model runs were made using actual rawinsonde information from Oakland as well as predicted conditions from gridded field information from the LFM model. The assumed periods of representativeness for Oakland and the LFM were 0000-1200pst and 1200-0000pst for the 1200z and 0000z data (or prediction valid times), respectively. Summation of model output for calendar days was then done and used to compare to 24 hour totals of precipitation at selected stations or groups of stations. Summation over storm periods was also made and compared to storm totals at the stations.

In addition to computing model values at the selected stations, area averages were computed over several selected watersheds. Output was studied in relation to observed precipitation and 700mb wind direction. Classification of cases for study by 700mb wind direction was already known to be important as the inter-station correlation of precipitation over the ARB was observed to be poorer for south to southsouthwest flow than for more westerly regimes (Rhea, et al, 1980). As expected, sample size was too limited to derive other than preliminary corrections at this stage.

Model runs were first made using the Oakland sounding as input and some parameter modifications were made to produce a better fit to observed precipitation data. Then, LFM model <u>predicted</u> upper air conditions were used as input to the version of the orographic model resulting from the Oakland study.

7.0 RESULTS USING OAKLAND RAWINSONDES

Figure 5 shows computed and observed storm totals for the February, 1986 storm period for each station. Station numbers (from Table 2) are indicated beside each point on the graph. In general reasonably good agreement can be seen. A notable exception is Sierraville (No. 8) for which model computations were essentially meaningless. This is because Sierraville is situated a little too low over on the downwind side of the main Sierra crest for its precipitation to be reasonably simulated by the present version of the model. In particular the model does not explicitly consider precipitation particle trajectories, and thus "spillover precipitation" is not reliably quantified in some leeside locations. A known characteristic of the model is the underprediction of broad valley precipitation.

The generally good agreement exemplified by Figure 5 (with a correlation coefficient of 0.87 when Sierraville is omitted) was obtained after several runs of the model in which precipitation efficiency, an important but generally difficult factor to quantify, was varied from one run to the next. The general form of the efficiency function finally used is layer-dependent with decreasing efficiency in higher layers, and also a decrease in the lowest 3 layers of the model when the underlying terrain is above the approximate average snow level. This type of formulation was invoked partly to compensate for the lack of precipitation particle trajectory considerations by the model. One other model modification arose because initial runs indicated that the 5km grid interval was localizing the precipitation too severely very near high terrain. Thus, some "smoothing" was invoked whereby a gradual lift was permitted to begin to occur (for all but the lowest 3 layers) up to 20 km upwind of a given locally high area, thus distributing the precipitation more smoothly on the upwind side of the peaks or ridges. This version of the model was then used in all subsequent calculations in this work.

Results for the March, 1986, storm (not shown) were generally good (r=0.85) except for two seriously over-predicted station totals on high ridges further downstream, but some precipitation data was missing from the observed totals at these sites.

On the other hand simulation of the storm period for Feb. 27-March 2, 1983 yielded serious over-predictions by the model in general with the over-prediction being worse the further south in the study area one goes. This is probably largely because this was a storm period with generally 190-200 degree 700mb flow. The model, by using an elevation grid with its "x-axis" aligned with the 700mb wind compensates for the more nearly barrier-parallel flow by decreasing the slope. However, in its simplicity, it does not consider the realistic possibility that if the flow becomes too nearly parallel to the ridge line the air may just flow parallel to it rather than climbing the barrier. This probably happens. Also, the Sierra Nevada orientation is more nearly N-S in the American River Basin than in the Feather which is located further north . While this is only one storm, it does yield a clue to invoking direction-dependent correction factors for QPF use.

From all storms studied, results were encouraging, especially if direction-dependent corrections can be made for the events with more nearly southerly flow.

However, it is more important to know how the model compares on a daily basis. For Buck's Lake and Blue Canyon the correlation coefficients between model and observed daily values were 0.73 and 0.76, respectively, and an encouraging feature was the trend of the points to fall not too far from the 1:1 line. Particularly encouraging was the computation of about 10 inches of precipitation at Buck's Lake for 17 February, 1986, when 13 inches was observed. A very close estimate for this day was computed for Blue Canyon.

8.0 RESULTS USING LFM PREDICTED SOUNDING INPUT

Since the model requires data at 50mb increments, it was necessary to extrapolate downward to 1000mb and upward to 300mb and to interpolate to 50mb intervals between 850mb and 500mb. Moisture is considered only to 450mb in model water budget computations, so the extrapolation to 450mb from 500mb is probably not too critical. The scheme used permitted the model to "find" a "cloud top" at 450mb provided the 500mb level was very moist. Otherwise, the "cloud top" would be found at a lower layer. A more serious problem arises in generating information by extrapolation all the way to 1000mb from the 850mb and 700mb data. For moisture, the 1000mb level was assumed to have the same dew point depression as the 850mb level. To obtain the wind speed component at interpolated or extrapolated points, the components in the direction of the 700mb wind were first computed at 850 and 500mb, consistent with the way the model makes its computations. Interpolation and/or extrapolation then proceeded using these winds.

A first set of runs of the orographic model using the resulting generated input sounding data as just described indicated seriously low values of computed precipitation due to serious underestimates of the low level wind components aligned with the 700mb direction. A comparison of the observed 850mb and 1000mb winds at Oakland was then made for the available sample of 77 Oakland soundings and the average relation found from that exercise was employed to obtain a 1000mb wind component using the LFM predicted 850mb wind. Interpolation to 950 and 900mb was then done. Results for the February, 1986, storm from the set of model runs using this scheme still showed underestimates of precipitation.

Further study of the observed Oakland wind profile indicated the LFM was doing quite well in predicting the winds at 700mb, but was seriously under-predicting the 850mb level component wind along the 700mb direction compared to the observed relationship on the Oakland sounding. Thus the low level winds used as input to the orographic model were still too weak.

Since the overall orientation of this work was toward developing a QPF tool, the next logical step was to use the 700mb LFM-predicted winds and then generate the winds at levels below this using the observed average ratios at the other levels in relation to the 700mb wind (where, as discussed earlier, the ratios were the average derived from the 77 Oakland soundings in the available sample). This is also reasonable when considering that 850mb level LFM predictions may not be operationally available when employing any resulting QPF technique. When this was done, resulting model calculations of the February storm totals were almost identical to those produced using the Oakland sounding

Summing over the March, 1986, storm period, amounts were generally over-predicted, with particularly large percentage overestimates at stations on high, downstream ridges, but as mentioned in discussing results using Oakland input data, these sites were missing some precipitation data from their totals.

Results from summing the 12 and 24hour predictions (using LFM prediction data as input) over 24hour periods showed a correlation coefficient of 0.70 between computed and observed amounts for Blue Canyon. Computed amounts summed over the Feb., 1986, storm showed about 35" for Blue Canyon and 42" for Bucks Lake (Feather River area), compared to 34" and 48" observed, respectively. A primary outlier is February 17, 1986. The orographic model, using LFM input data, predicted over 7 inches and 6 inches at Buck's Lake and Blue Canyon, respectively, but observed amounts were 13.12 and 8.57 in. Still, considering the fact that these are objective predictions using the 12 and 24 hour LFM predicted sounding information, results look quite promising for QPF assistance.

The fact that reasonable amounts were produced without considering non-orographic influences clearly means that the model is over-emphasizing the orographic precipitation. However, the incorporation of LFM predicted values of non-orographic vertical motion as an additional lifting mechanism for precipitation production (not shown) did nothing to improve the correlation between predicted and observed amounts. Thus, since the objective was to develop a QPF aid, the version of the orographic model used to produce the results here was retained for use in developing this QPF aid.

It is of practical importance to know how well the model simulated each stations' precipitation. Table 3 shows the ratios of observed to orographic model computed station totals using the LFM prediction data as model input. Kettle Rock and Quincy had too many days with missing observations to compute a meaningful ratio. Also, none is computed for Sierraville since model performance for that site is of little use. These ratios can be employed as correction factors if desired in developing a QPF aid in the next section.

It was noted in Section 7.0 that the southerly storm of February 27- March 2, 1983 was over-predicted by the orographic model with the over-predictions becoming more severe the further south in the study area a given station was located. Table 4 shows the station-by-station ratios of observed to predicted amounts for this storm period. These numbers offer some guidelines for a wind direction-dependent correction factor set, but it should be regarded as tentative, as the sample size is very small. Similar numbers were obtained, though, from the few events with 700mb winds of <210 degrees from the LFM runs in the 1986 data.

Finally, a note of caution should be stated here in regard to using these results operationally. Most of the sample days used here came from major, long duration storm periods. When dealing with more typical day-to-day events greater departures between LFM-predicted and observed conditions are likely, especially regarding humidity when the area is near the edge of the precipitation pattern.

9.0 USE OF RESULTS AS A QPF AID

A preliminary methodology and guidelines for using model principles as a QPF aid for the area studied is provided below. The usefulness of the method, like any objective forecasting device, will be extremely dependent on the accuracy of prognostic information from the larger scale prediction models. Also, further "calibration testing" is recommended, especially for more cases of southerly storms to check the consistency of the indications of model over-prediction in such conditions.

Inspection of equation (1) in Section 2.0 and in Rhea (1978) suggested the possibility of developing a QPF aid based on model principles without the necessity of making full model runs each time (and lacking adequate prognostic input data for such, anyway, especially beyond 24 hours). First, model computations can be made using a known "maximized" input sounding varying only the wind direction between runs as shown by example in section 5.0, and the output stored by grid point, selected areas, or station location for future use. Then, by comparing (1) "expected"to "maximized" sounding features and (2) "expected" to "maximized" duration of conditions, "adjustment" or "correction" of the stored output from the model (for station locations and/or watersheds) can be made to arrive at a forecast amount of precipitation for the appropriate wind direction.

From the form of the model equation, this "adjustment" of the "maximized sounding" amounts can be done by multiplying the reference maximized amount, R_m, by the product of the values of the several "correction factors" in Table 5. These correction factors were derived by (a) assuming approximate moist adiabatic lapse rate on both the expected and maximized sounding, (b) letting the wind speed correction factor be based only on the 700mb wind speed, and (c) knowing that the reference "maximized" sounding key features were as described in Section 5.0. Prediction of cloud depth is difficult, and in practice, either 1, 0.75, or 0.5 is recommended for use for deep, medium, and shallow clouds, respectively.

With the reference "maximized" model-computed precipitation amounts already computed and stored, the QPF task then becomes one of first selecting the appropriate values from the table (based on the expected 700mb wind direction) and then, based on expected conditions as described above, making the adjustments to the station and watershed values for the given forecast period. To make use of the procedure, the user needs a predicted value of: (1) 700mb wind direction, (2) 700mb wind speed, (3) 700mb temperature, (4) cloud depth class, and (5) duration of conditions (1) through (4).

As an example, suppose we expect: 700mb wind direction of 240 degrees with speed of 30kts, 700mb temperature of -8C, deep clouds (DEPCOR=1.0), and a duration of these conditions of 6 hours. Then, from the stored table (not shown) the reference "maximized" value for Buck's Lake is 4.1 inches, as can be approximately verified by looking at Buck's Lake, (i. e., station #2), in Figure 4. The total correction factor is:

$$\text{TOTCOR}=(\text{DFRAC})(\text{TCOR})(\text{DEPCOR})(\text{VCOR})$$

or

$$\text{TOTCOR} = (6/12)(1+.035(-8))(1.0)(30/50) = .216$$

The adjusted (or forecast) amount at Buck's Lake then is:

$$\text{TOTCOR} \times \text{REFERENCE "MAXIMIZED" AMT.} = .216 \times 4.1 = .89 \text{ in.}$$

Expected duration is not necessarily synonomous with length of the QPF forecast period. That is, the forecast above may have been for a 12 hour or 24 hour period, but with dry conditions expected for all but 6 hours of that period.

A FORTRAN program to perform the "adjustment" calculations for all stations and watershed areas was written as a part this work. Program documentation describes the input required by the user for these calculations to be made. Output is in the form of a table of forecast amounts for the stations and watersheds used in this study. Amounts for sub-periods as well as summations by user-specified days are printed out.

Such calculations may be made by the user for any number of desired periods for as far into the future as useful predictions of expected upper air conditions exist. LFM (or other large scale prediction model) accuracy decreases with time, and so, likely will the QPF accuracy using this or any other technique. As can be seen, an important item needed for good QPF's with this technique is a reliable estimate of moisture depth, and this is frequently one of the more poorly predicted variables. Thus, highly accurate QPFs by whatever method must await improvements in predictions of moisture fields, particularly. However, this method has already proven a convenient and useful QPF aid in Colorado and for Blue Canyon (since 1979 for QPF assistance for the SCPP). While relatively few heavy precipitation episodes have occurred over the area since delivery to the CDWR, indications are it is proving helpful to their operations.

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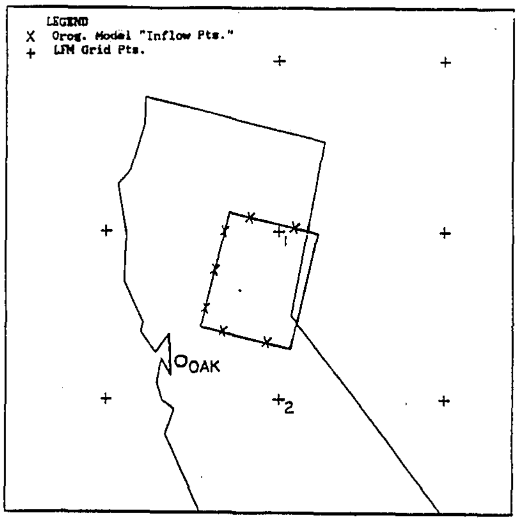
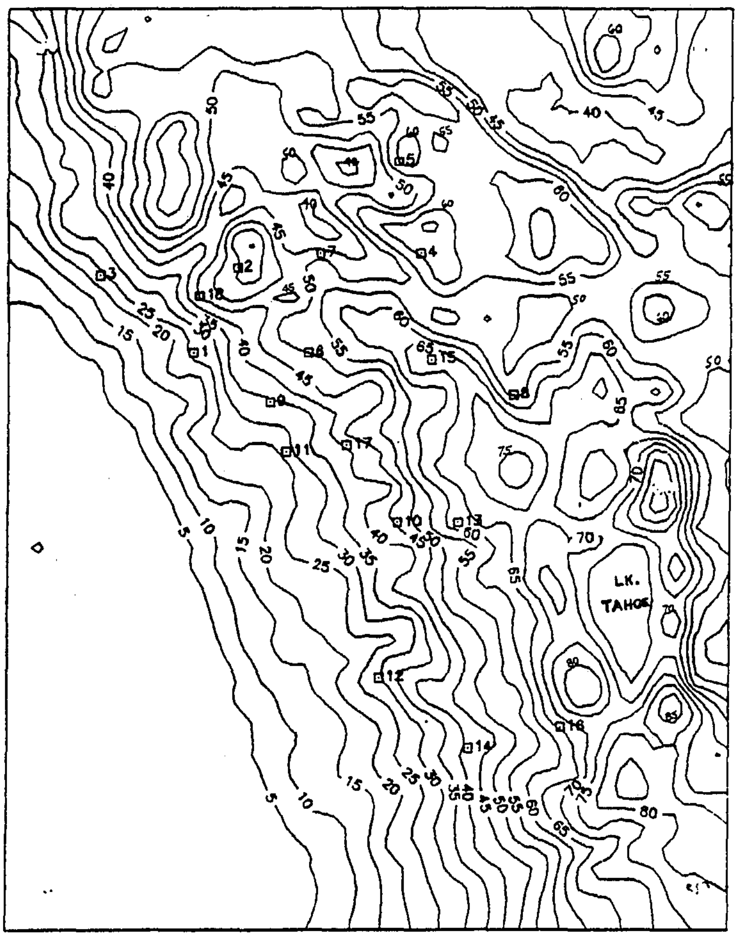


Figure 1. Location of study area in relation to upper air measurement site (Oakland) and NMC LFM prediction model grid points (crosses). Orographic model inflow border points are shown as X's.



STUDY AREA TOPOGRAPHY

Figure 2. Contoured elevation map of the study area using 5km grid interval data. Contour interval is 500 feet (labeled 5, 10, etc., in hundreds of feet).

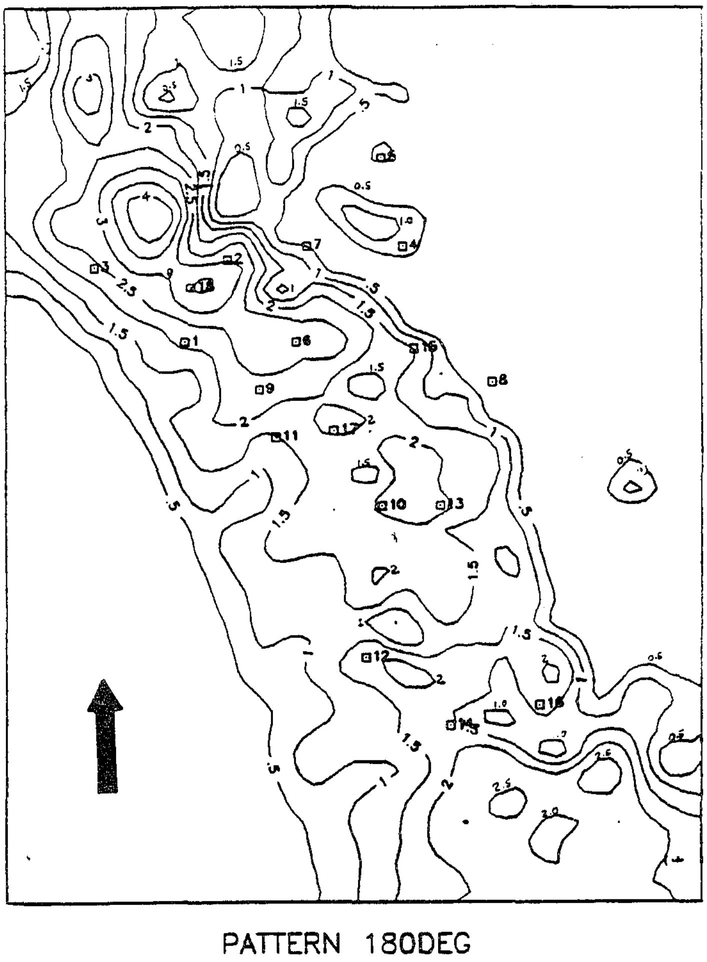


Figure 3. Model "pattern map" for 180 degree 700mb wind direction, using the hypothetical "maximized" sounding as described in the text as input. Minimum isohyet drawn is 0.5 inch (per 12 hours).

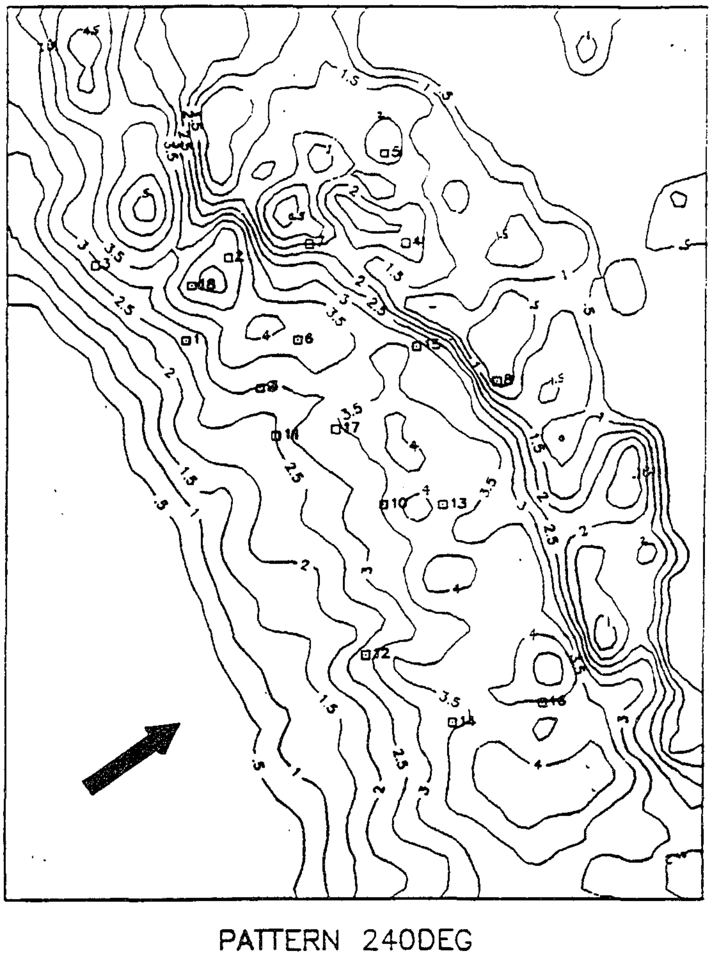


Figure 4. Model "pattern map" for 240 degree 700mb wind direction, using the hypothetical "maximized" sounding as described in the text as input. Minimum isohyet drawn is 0.5 inch (per 12 hours).

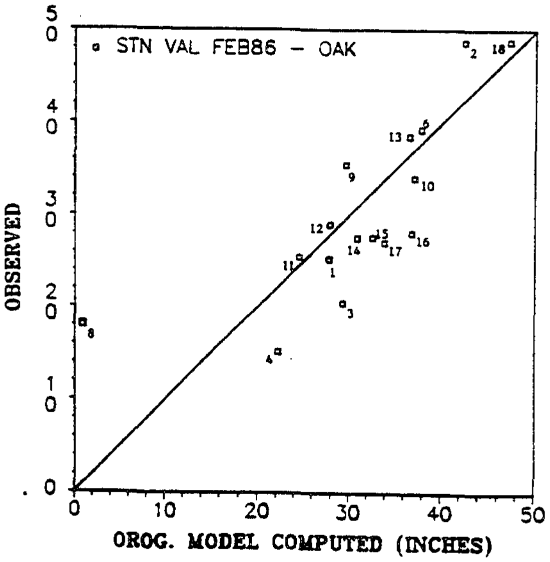


Figure 5. Scatter plot of computed and observed storm totals for the February, 1986, storm period for each station. Station numbers (from Table 2) are indicated beside each point. Oakland soundings were used as orographic model input.

Table 1
Periods Selected for Study

1. February 13, 14, 15, 16, 17, 1982
2. Feb. 27, 28, and Mar. 1, 2, 1983
3. Feb. 7, 8, 1985
4. January 15, 16, 1986
5. January 29*, 30, 31*, 1986
6. February 11*, 12, 13, 14, 15, 16, 17, 18, 19, 20, 1986
7. March 6*, 7, 8, 9, 10, 11, 1986

Table 2
List of Precipitation Stations for Which Model Calculations Were Made

1. Brush Creek Ranger Station
2. Bucks Lake
3. De Sabla
4. Grizzly Ridge
5. Kettle Rock
6. La Porte
7. Quincy
8. Sierraville
9. Strawberry Valley
10. Blue Canyon
11. Camptonville
12. Georgetown
13. Huysink
14. Pacific House
15. Gold Lake
16. Forni Ridge
17. Alleghany
18. Four Trees

Table 3
Table of Ratios of Observed to Model Predicted Station Totals Using LFM Data as Model Input.

1. Brush Creek RS	.974	10. Blue Canyon	.888
2. Bucks Lake	1.058	11. Camptonville	.971
3. De Sabla	.656	12. Georgetown	1.039
4. Grizzly Ridge	.574	13. Huysink	.924
5. Kettle Rock	M	14. Pacific House	.791
6. La Porte	.936	15. Gold Lake	.768
7. Quincy	M	16. Forni Ridge	.686
8. Sierraville	No Meaning	17. Alleghany	.760
9. Strawberry	1.116	18. Four Trees	1.056

Table 4
Table of Ratios of Observed to Model Predicted Station Totals for the Feb. 27 - March 2, 1983 Storm Period Using Oakland Sounding Data as Model Input.

1. Brush Creek RS	.627	10. Blue Canyon	.422
2. Bucks Lake	.795	11. Camptonville	.469
3. De Sabla	.913	12. Georgetown	.408
4. Grizzly Ridge	M	13. Huysink	M
5. Kettle Rock	M	14. Pacific House	.400
6. La Porte	.780	15. Gold Lake	.479
7. Quincy	M	16. Forni Ridge	.295
8. Sierraville	No Meaning	17. Alleghany	.435
9. Strawberry	.802	18. Four Trees	.677

Table 5
Form of Correction Factors for Adjusting Model "Maximized" Values to Obtain a Predicted Amount.

Subscript e means "expected", while m denotes "maximized" conditions.

1. DURATION FACTOR

DFRAC = t_e / t_m = (expected duration in hrs.)/12

2. TEMPERATURE FACTOR (Variation in condensation per unit lift)

TCOR = 1 + .035xT_e (where T_e = expected 700mb Temperature)

This amounts to a 3.5 percent decrease per degree C below 0C, and can be verified to be a reasonable fit by making a series of runs varying only the temperature profile.

3. CLOUD DEPTH FACTOR

DEPCOR = 1.0, 0.75, or 0.5 for deep, medium, and shallow cloud tops, respectively.

"Deep" means tops to at least 450mb.
"Medium" means tops of 550-600mb.
"Shallow" indicates very shallow moisture, topping at 700-750mb.

A series of model runs was made, varying both cloud top and wind speeds to verify that DEPCOR is usable as a "correction multiplying factor".

4. WIND SPEED FACTOR

VCOR = V_e / V_m = (expected 700mb wind speed in kts.)/50

5. TOTAL CORRECTION FACTOR

TOTCOR = DFRAC x TCOR x DEPCOR x VCOR

6. THE FORECAST AMOUNT, R_j (for point, area, or isohyet j)

R_j = R_m x TOTCOR

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