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THE CONVECTIVE SNOW BURST OF 3 FEBRUARY 1994 IN WESTERN PENNSYLVANIA

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1. INTRODUCTION

On 3 February 1994, a band of convective snow showers developed over eastern Ohio and intensified as they moved east into western Pennsylvania. Snowfall rates of 3 to 6 in/hr were observed. This band of snow was accompanied by thunder and wind gusts exceeding 35 kt. Near blizzard conditions existed for a brief time, as visibilities lowered to near zero in heavy and blowing snow. Consequently, numerous traffic accidents were reported resulting in several injuries (National Weather Service 1994).

An analysis of the Nested Grid (NGM), Eta (ETA), and Aviation (AVN), models from the National Meteorological Center (NMC) suggested that a cold frontal passage would occur. The official forecast issued by the National Weather Service Forecast Office in Pittsburgh, PA (NWSFO PBZ), called for scattered snow showers with accumulations of around an inch. However, the precipitation scenario that developed was more typical of a spring or summertime squall line. Snowfall amounts of 2 to 4 inches occurred in less than one hour.

Studies conducted by Scofield and Robinson (1990) have shown that convective snowfall events can be detected by using a combination of satellite imagery, and the analysis of surface, upper-air, and numerical forecast model data. They categorized these events as instability bursts; defined as a thrust of maximum atmospheric destabilization into one area.

The purpose of this paper is to discuss both the synoptic and mesoscale conditions that led to the development of the convective snow showers, including the role of jet streak dynamics as a forcing mechanism. A detailed look at the NGM, and ETA models based on the PC GRidded Interactive Display and Diagnostic System (PCGRIDDS) will be presented. GOES-7 Satellite imagery and data from the Weather Surveillance Radar - 1988 Doppler (WSR-88D) radar at NWSFO PBZ will also be examined.

2. INITIAL CONDITIONS

2.1 Surface Analysis

On the morning of 3 February 1994, an arctic airmass covered much of the northern United States. Subzero surface temperatures (°F) extended across the Northern Plains and Great Lakes. Surface temperature readings averaging in the teens were observed across the Ohio Valley. The 1200 UTC surface analysis depicted a cold front extending from western New York State, to western Pennsylvania, and south along the Ohio River (Fig. 1). This baroclinic zone separated a very dry arctic airmass, from a relatively warmer and modified arctic airmass along the East Coast.

An isodrosotherm analysis of the 1200 UTC surface observations depicted an area of dewpoint temperatures greater than 20°F, extending from southern Ohio into West Virginia and southwest Pennsylvania. Surface aviation weather observations (SAOs) across western Pennsylvania indicated that the higher dewpoint temperatures were being advected into the region by southerly winds of 10 to 20 kt. Just upstream of the cold front, dewpoint temperatures were in the single digits illustrating a large dewpoint discontinuity.

Along the surface cold front, west winds with gusts of 35 kt were observed, supported by strong pressure rises on the order of +8 hundredths of an inch altimeter change between 1000 and 1200 UTC (Fig. 2). Heavy snow (3 to 6 in/hr) was also observed along the leading edge of the front.

2.2 Upper-Air Analysis

One of the most important features that influenced the development of the convective snow event of 3 February 1990 was the presence of a 140 kt jet streak at 300 mb (Fig. 3). The position of this jet streak put western Pennsylvania under the left exit region of the jet, where the magnitude of the divergence is usually at a maximum (Beebe and Bates 1955). Studies by Newton (1967), and Uccellini and Johnson (1979), have shown that this is a favorable area for convective development, especially when the low-level flow is juxtaposed to the upper-levels. The 1200 UTC NGM 850 mb analysis (not shown) confirmed that the low-level flow was directed into the area of maximum 300 mb divergence, with a 50 kt wind maxima present over the Ohio Valley.

The 1200 UTC NGM 500 mb analysis (not shown) for the same time period revealed a negatively tilted short wave trough with its axis extending from near Toronto, Canada, to Columbus, OH. Height falls of 110 and 130 meters were measured at Buffalo, NY and Detroit, MI, respectively, while 90 and 70 meter height falls occurred at Pittsburgh, PA, and Dayton, OH, respectively. The cooling generated from the height falls substantially contributed to the destabilization of the atmosphere.

2.3 Local Sounding Analysis

Through the use of the Skew T Hodograph Analysis Research Program (SHARP; Hart and Korotky 1991), a modified sounding was constructed from the 1200 UTC 3 February 1994 NWSFO PBZ sounding in an attempt to represent the local conditions that would be present over western Pennsylvania at 1000 UTC (Fig. 4). Slight modifications were made to the surface layer by adjusting the temperature and dewpoint to reflect preconvective conditions.

The modified sounding showed a deep moist environment. Dewpoint temperature depressions were less than 5°C from the boundary layer to 500 mb. Weak conditional instability was present within the lowest 200 mb of the sounding. A modest positive buoyant area (B+) of 168 J/kg was calculated. The corresponding Lifted, K, and Total Totals indices were +3, +15, and 55, respectively.

These thermodynamic parameters along with abundant moisture conformed to thresholds established by Scofield (1990), for cold season convection. Scofield revealed that a K-Index of between 10 and 20, and a surface to 500 mb mean relative humidity of greater than 50% are conducive to heavy convective snow.

3. CONVECTIVE EVOLUTION

3.1 WSR-88D Presentation

The Composite Reflectivity returns from the NWSFO PBZ WSR-88D provided an early indication that the snow showers were intense. The structure of the snow showers depicted a linear squall line configuration. At 1100 UTC, the line of convective snow (Fig. 5) extended from Bradford, PA, to just west of NWSFO PBZ. The most intense convective cells contained core reflectivity returns greater than 40 dBZ. Isolated cells approached 46 dBZ and were producing snow fall rates of 6 in/hr. One core produced 4 inches of snow over Indiana County, PA, in about 40 minutes.

The forward speed and direction of the squall line was to the east at 35 kt, thus traversing the entire NWSFO PBZ forecast area in about 6 hours. The maximum tops of the convective cells ranged between 12,000 and 18,000 ft.

The Velocity Azimuth Display (VAD) Wind Profile (VWP) from the NWSFO PBZ WSR-88D (Fig. 6), as well as the 1000 UTC SHARP hodograph (Fig. 7), supported a continued evolution of the squall line. Warm air advection was occurring through the first 7,000 ft of the atmosphere. The persistence of this feature created the instability needed to fuel the convection. Strong speed shear, noted in the 1000 UTC SHARP hodograph, enhanced the surface outflow of each convective cell, aiding in the squall line evolution (Klemp and Weisman 1983).

3.2 Satellite Imagery

GOES-7 infrared satellite imagery valid at 0800 UTC, indicated a band of cold cloud tops (less than -50°C) extending from northeast Ohio to southeast Indiana. This cloud band moved east into western Pennsylvania by 1100 UTC, with the coldest cloud tops coinciding with the most intense radar returns (Figs. 8a-b). At no time during the evolution of the cloud band, were there signs of surface cyclogenesis. The cloud feature remained confined to the mesoalpha scale, with an areal coverage no larger than the exit region of the jet streak.

4. NMC NUMERICAL MODELS

The 0000 UTC 3 February 1994 NGM, AVN and ETA models, indicated this event would be a fast clipper type storm. An arctic front was forecast to move rapidly across the NWSFO PBZ forecast area, producing very little precipitation, and reinforce the arctic airmass that was already entrenched over the Ohio Valley. Analysis of the NWSFO PBZ NGM model sounding data indicated that the duration of the precipitation event would be brief, with a total Quantitative Precipitation Forecast (QPF) of two hundredths of an inch (0.02). However, surface weather observations indicated a greater amount of precipitation, with water equivalent measurements around 0.08 of an inch.

Through the use of PCGRIDDS (Figs. 9-12), a detailed post-analysis of the numerical model data was conducted in order to determine the synoptic and mesoscale variables that produced the convective snow showers. Analysis of the gridded data from the NGM, ETA, and AVN models indicated the possibility of a brief heavy precipitation event. Forecast wind profiles (not shown) from all three models suggested that there would be warm air advection within the boundary layer, with cold air advection aloft across western Pennsylvania prior to 1200 UTC 3 February 1994. The combination of these two processes steepened the lapse rate, thus increasing the atmospheric convective instability.

Of more importance, upward vertical motion over western Pennsylvania reached a maximum at 1200 UTC. At 500 mb, Q-vector convergence, which is indicative of large scale upward vertical motion was indicated by all three models. The ETA model also forecast Q-vector convergence at 700 mb (Fig. 9). As discussed by Barnes (1985), Hoskins et al. (1978), and Dunn (1991), Q-vectors provide an approximation to the total large scale atmospheric vertical motion. Recall that the two terms involved in the Omega equation are the vertical variation of vorticity advection, and the laplacian of thickness advection. The Q-vector equation Hoskins et al. (1978), may be used to combine the two terms in the Omega equation, where the vector Q is equal to the rate of change of the horizontal temperature gradient that is advected by the quasi-geostrophic wind, and the vertical variation of the positive vorticity advection in the area ahead of the approaching short wave trough. Where the Q-vectors converge, large scale upward vertical motion is present.

All three numerical models showed a 120 to 130 kt jet streak at 300 mb, with the left quadrant of the exit region over the upper Ohio Valley. One would expect to find divergence in the wind field at this level in the vicinity of western Pennsylvania. All three models forecasted this, but the ETA model was the most pronounced with this feature (Fig. 10). Figure 10 depicts two 300 mb mass divergence/convergence couplets. The first, located in the exit region of the jet streak with the divergence maxima over northwest Pennsylvania (left front quadrant), and the convergence maxima (right front quadrant) over eastern Virginia. The second mass divergence/convergence couplet was located in the entrance region of the jet streak with a divergence maxima over northwest Arkansas (right rear quadrant) and a convergence maxima over eastern Iowa (left rear quadrant). Both couplets were indicative of the ageostrophic circulations induced by the jet streak. A cross section of the exit region of the jet (heavy solid line in Fig. 3) confirmed the existence of the transverse circulation (Fig. 11), with the region of maximum upward vertical motion in the vicinity of western Pennsylvania (Fig. 12).

5. CONCLUSION

The presence of a 140 kt upper-tropospheric jet streak was one of the key features that resulted in the development of the western Pennsylvania convective snow event of 3 February 1994. Upper-level divergence associated with the left front exit region of the 300 mb jet streak, coupled with warm air advection in the lower troposphere (i.e., 850 mb) helped to induce strong upward vertical motion. This resulted in a band of convective snow showers developing along the surface front. A brief, but intense burst of snow was observed.

Although the NMC numerical models usually cannot accurately pinpoint areas of focused convection (particularly in the wintertime), they often can reveal regions that may become favorable for convective development. The standard graphics, in this case issued via the Automation of Field Operations and Services (AFOS), did not clearly depict the potential for a convective snow event. Through diagnostics of Q-vector convergent fields at 500 and 700 mb, and upper-level divergent patterns at 300 mb obtained through PCGRIDDS analyses of the NGM, ETA, and AVN gridded data, indications pointed to the development of an of organized wintertime convection event.

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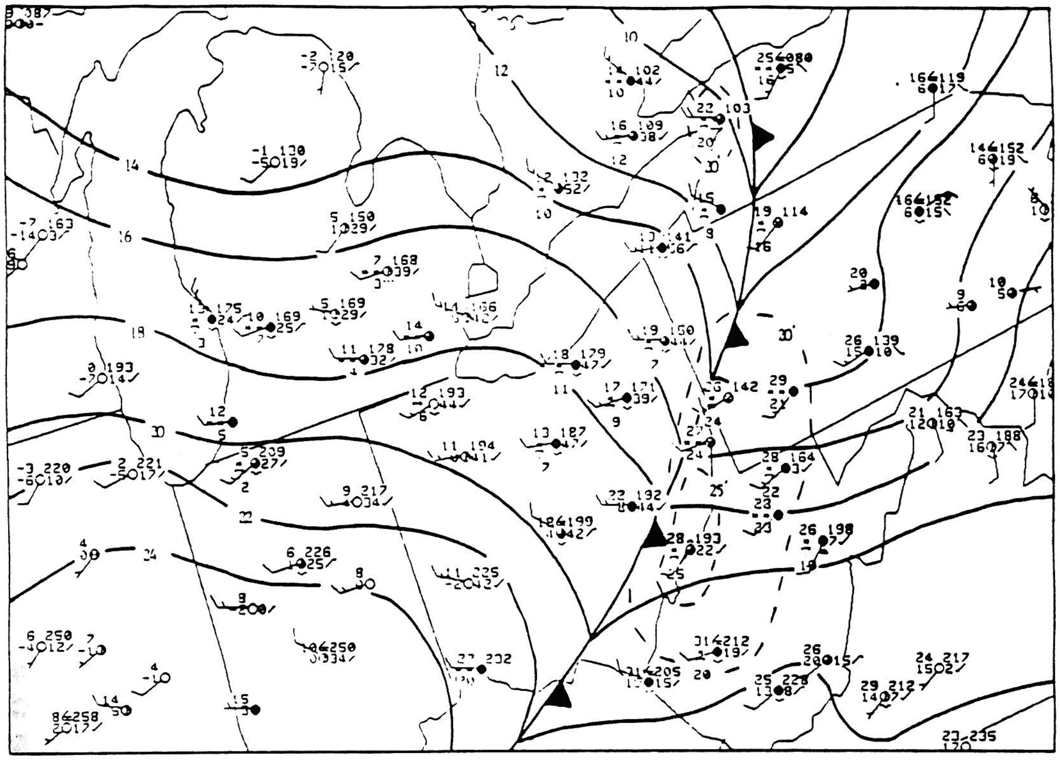


Figure 1. 1200 UTC 3 February 1994 surface analysis. Isobars (solid lines) are contoured every 2 mb. Isodrosotherms (dashed lines) are contoured every 5°F.

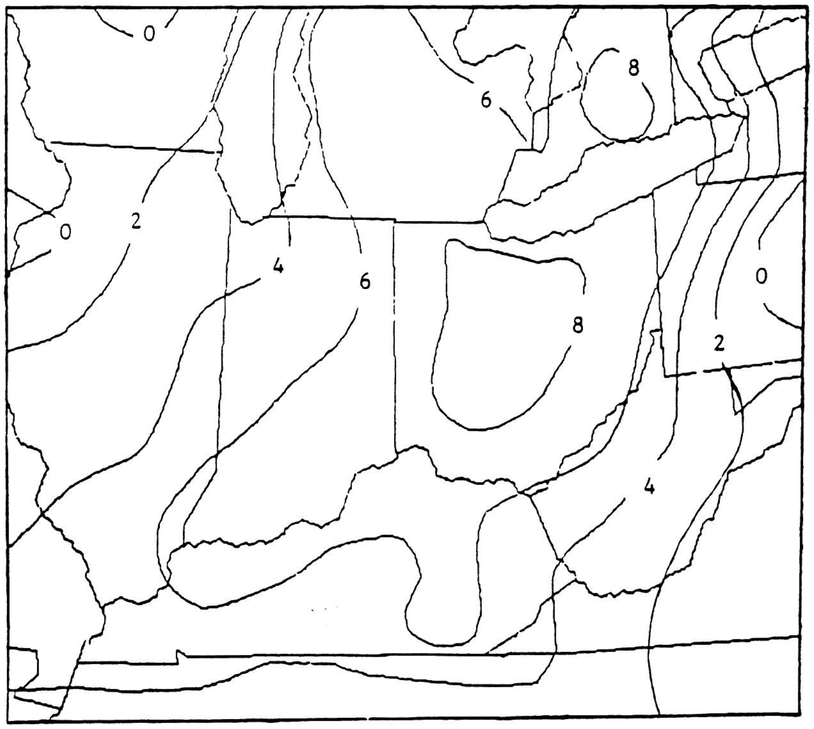


Figure 2. Total altimeter change (hundredths of an inch) between 1000 and 1200 UTC on 3 February 1994. From ADAP (AFOS Data Analysis Program; Blothwell 1988).

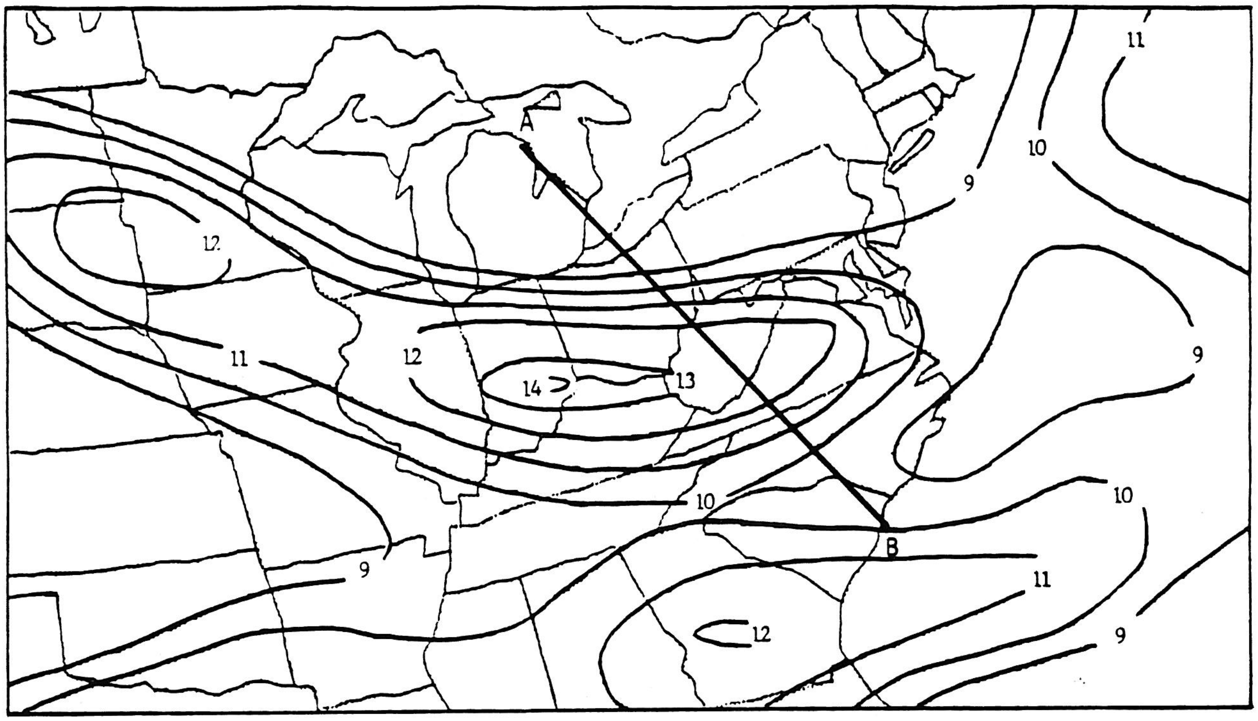
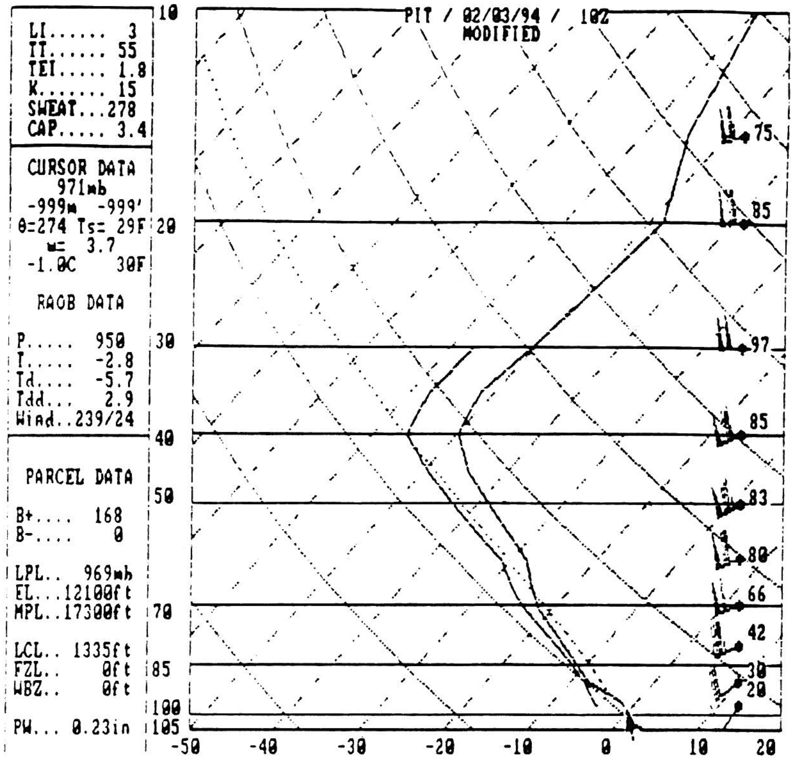


Figure 3. 1200 UTC 3 February 1994 NGM 300 mb isotach (10^1 kt) initialization.



```
LI......  3
TT...... 55
TEI..... 1.8
K....... 15
SWEAT...278
CAP..... 3.4

CURSOR DATA
  971mb
-999m  -999'
θ=274 Ts= 29F
  w=  3.7
-1.0C     30F

RAOB DATA

P.....   950
T.....   -2.8
Td....   -5.7
Tdd...    2.9
Wind..239/24

PARCEL DATA

B+....   168
B-....     0

LPL..  969mb
EL...12100ft
MPL..17300ft

LCL..  1335ft
FZL..     0ft
WBZ..     0ft

PW... 0.23in
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Figure 4. 1000 UTC 3 February 1994 NWSFO PBZ modified sounding. The sounding represents the environmental conditions present at the onset of the convective snow. From the SHARP workstation (Hart and Korotky 1991).

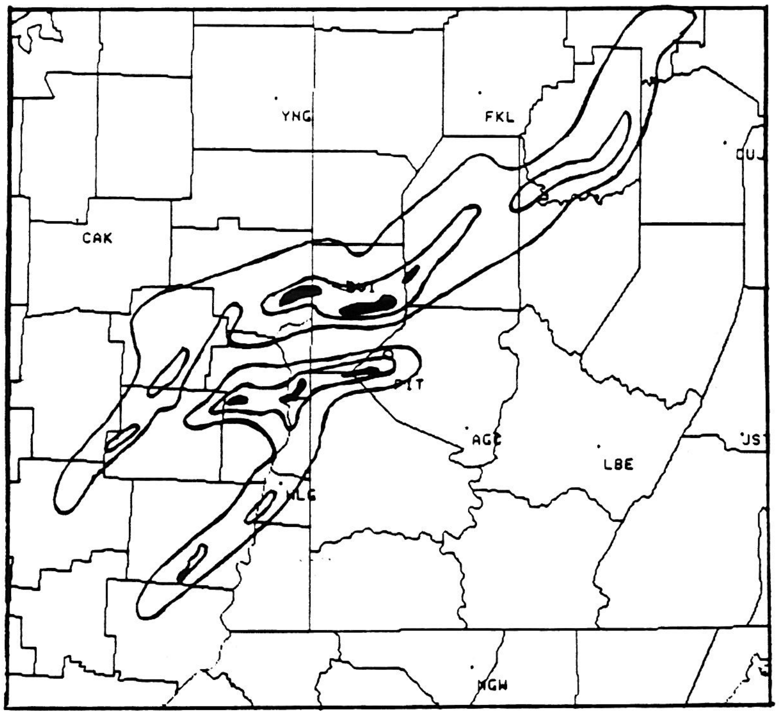


Figure 5. 1049 UTC 3 February 1994 contoured NWSFO PBZ WSR-88D composite reflectivities. Dark shaded areas indicate returns greater than 41 DBZ.

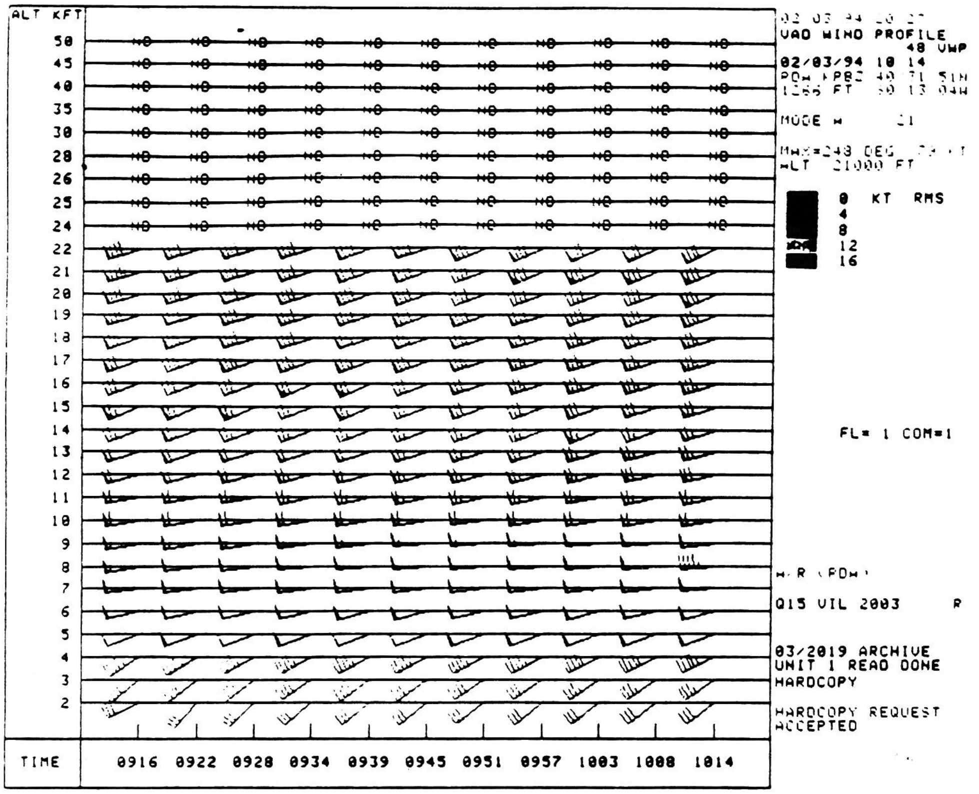
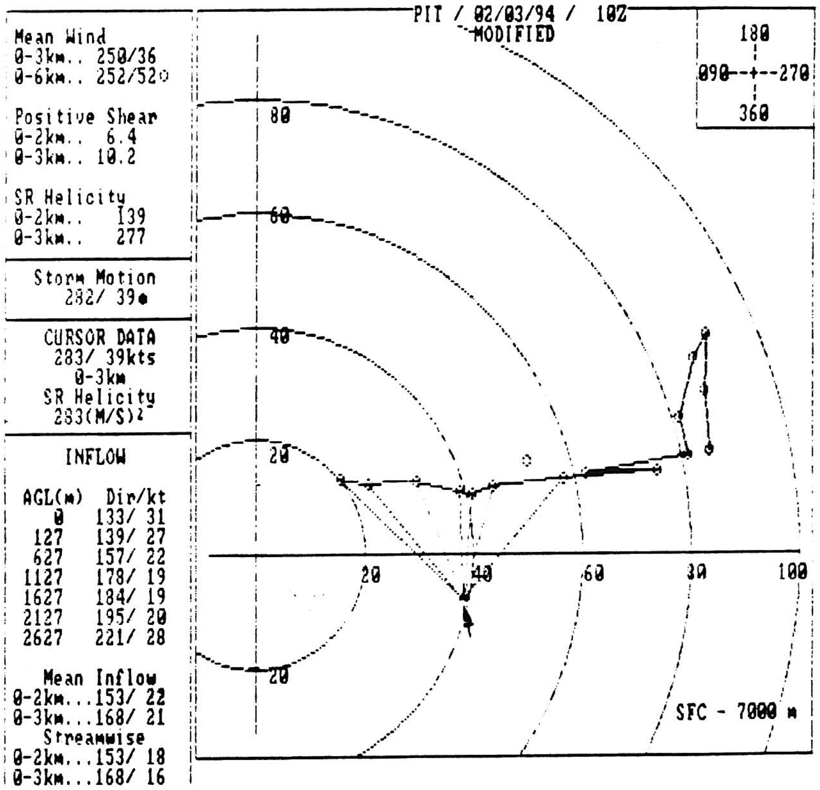


Figure 6. 0916 to 1014 UTC 3 February 1994 VWP from the NWSFO PBZ WSR-88D.



Mean Wind
0-3km.. 250/36
0-6km.. 252/52

Positive Shear
0-2km.. 6.4
0-3km.. 10.2

SR Helicity
0-2km.. 139
0-3km.. 277

Storm Motion
282/ 39

CURSOR DATA
283/ 39kts
0-3km
SR Helicity
283(M/S)²

INFLOW

AGL(m)	Dir/kt
0	133/ 31
127	139/ 27
627	157/ 22
1127	178/ 19
1627	184/ 19
2127	195/ 20
2627	221/ 28

Mean Inflow
0-2km...153/ 22
0-3km...168/ 21
Streamwise
0-2km...153/ 18
0-3km...168/ 16

Figure 7. 1000 UTC 3 February 1994 modified NWSFO PBZ hodograph. From the SHARP workstation (Hart and Korotky, 1991).

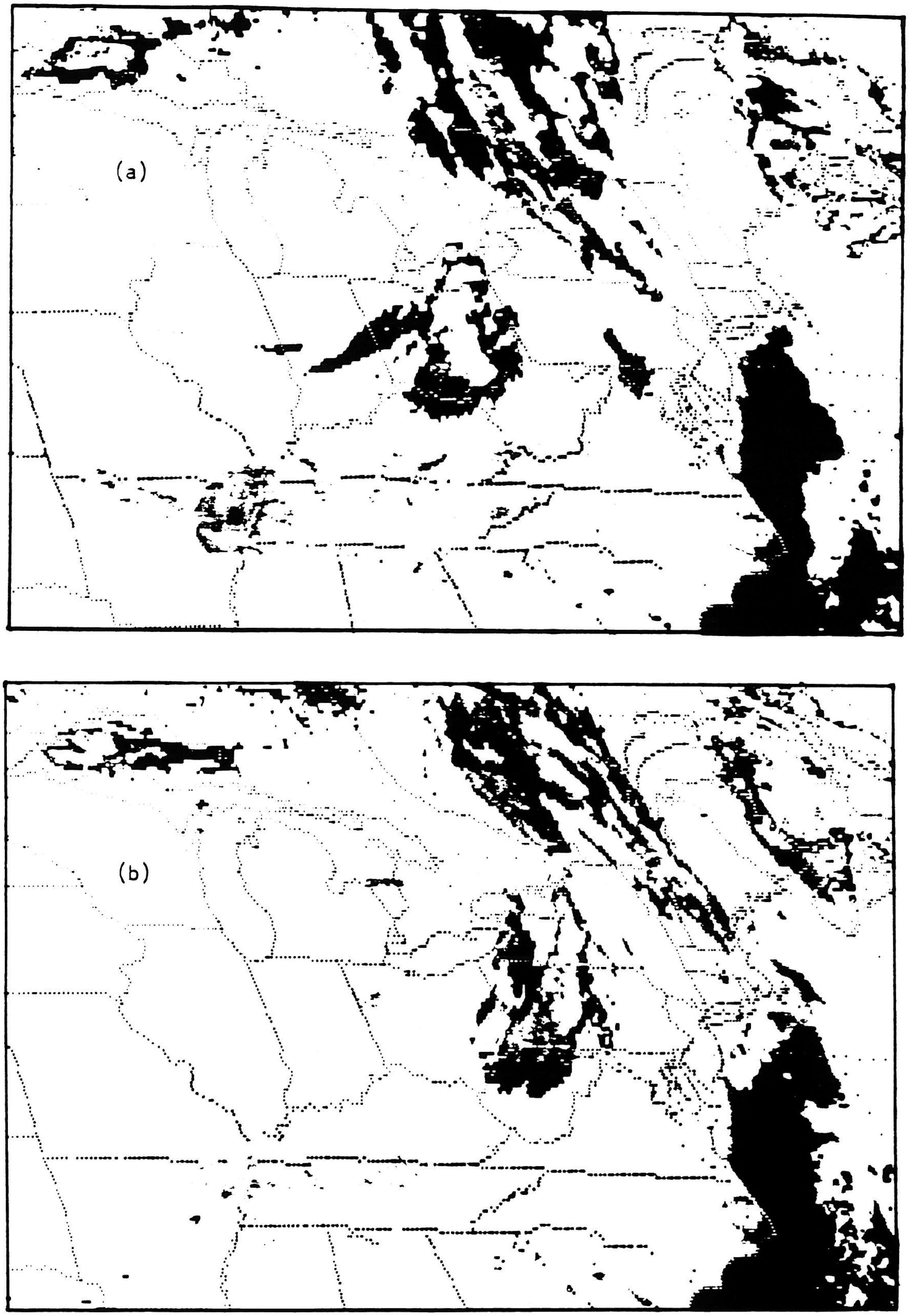


Figure 8. GOES-7 enhanced IR satellite imagery for a) 0800 UTC, and b) 1100 UTC 3 February 1994.

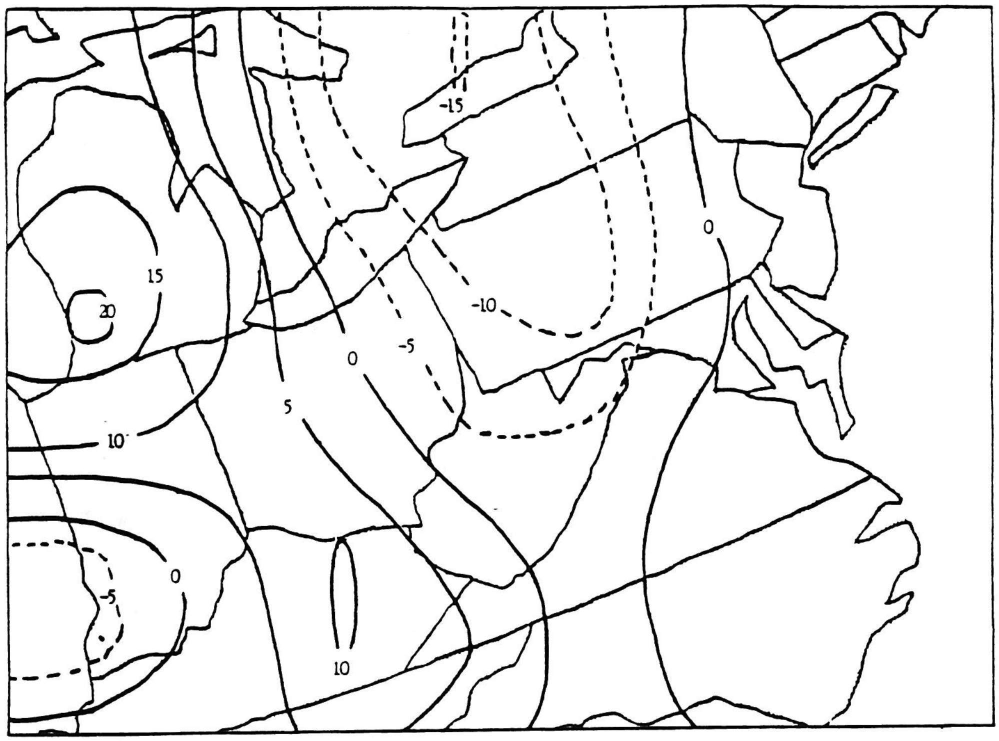


Figure 9. 0000 UTC 3 February 1994 ETA model 12-h forecast valid at 1200 UTC of 700 mb divergence of Q. Negative (positive) values imply upward (downward) motion. From PCGRIDDS.

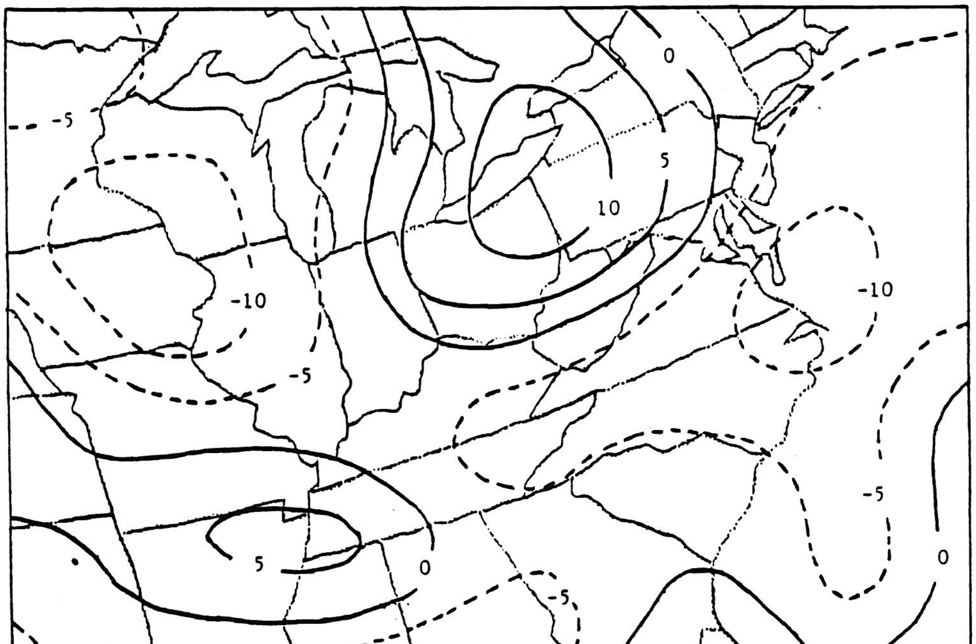


Figure 10. 0000 UTC 3 February 1994 12-h forecast valid at 1200 UTC of 300 mb divergence (s^{-1}). Positive (negative) values represent divergence (convergence). From PCGRIDDS.

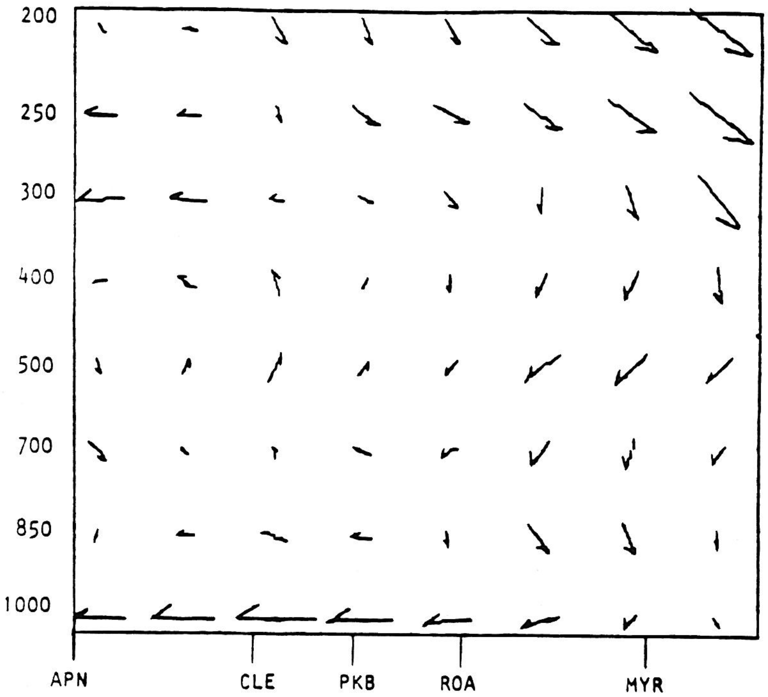


Figure 11. 0000 UTC 3 February 1994 ETA model 12-h forecast cross section (solid line in Fig. 3) valid at 1200 UTC of the tangential circulation of ageostrophic winds. From PCGRIDDS.

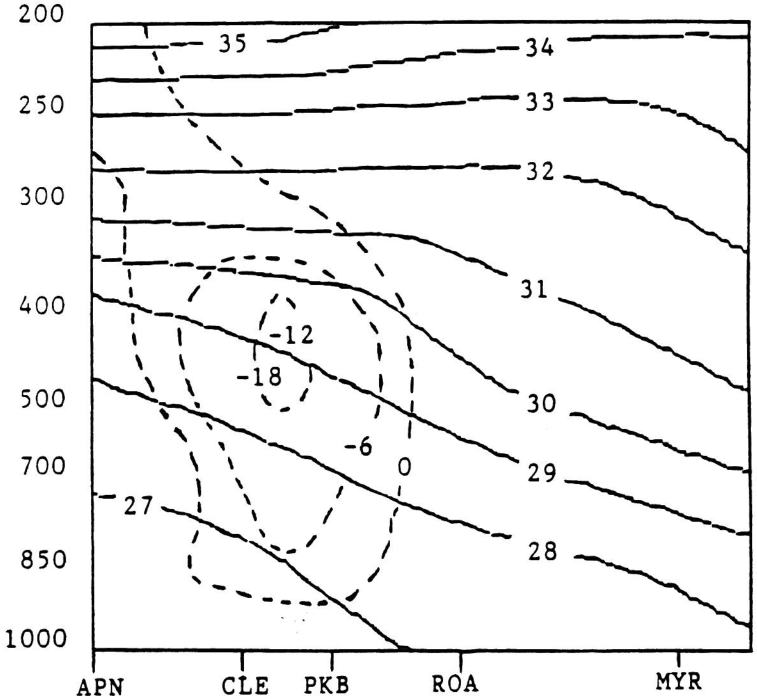


Figure 12. 0000 UTC 3 February 1994 ETA model 12-h forecast cross section (solid line in Fig. 3) valid at 1200 UTC of potential temperature (solid lines) (10^1 K) and vertical velocities (dashed lines) (ub s^{-1}). From PCGRIDDS.