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IMPROVING CONVECTIVE FORECASTS IN WEAKLY FORCED ENVIRONMENTS

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1. INTRODUCTION

The problem of predicting convection, both severe and non-severe continues to be a challenge to forecasters (Doswell 1980; Maddox 1980; and McNulty 1995). It is only within the last few decades that meteorologists have attained some level of skill in predicting small-scale changes in the atmosphere that lead to convection. (Maddox and Doswell, 1982)

In highly baroclinic environments, parameters that favor the development of thunderstorms have been well documented (Johns and Doswell 1992; McNulty 1995). During the summer in middle latitudes, strong baroclinicity is typically absent; meaning that the warm season is often dominated by weak large-scale flow patterns (Gaza and Bosart 1985). These patterns often leave entire regions under nearly homogeneous, warm, moist, and unstable airmasses. The convection that develops in *weakly forced regimes* is difficult to predict. Unless the local forecaster has grown accustomed to diurnal development of convection in weakly forced environments, say from the nearby development of sea breeze convergence or orographically triggered convection, forecasting precipitation remains a difficult task.

Under these weak flow regimes, blandly worded forecasts such as "HAZY HOT AND HUMID ("3H") WITH A CHANCE OF AFTERNOON SHOWERS AND THUNDERSTORMS..." or "PARTLY CLOUDY WITH A 30 PERCENT CHANCE OF AFTERNOON SHOWERS AND THUNDERSTORMS" become a well-established part of the summertime weather lexicon. In reality, the number of outdoor events actually disrupted by showers and thunderstorms are few compared to the number of days that have the potential for precipitation in the forecast.

A preponderance of research has been devoted to inferring the mesoscale processes necessary for the development of convection from synoptic-scale models (Maddox 1980). Improvements have occurred in the understanding of the dynamics of convective storms, in the ability to detect and observe convective storms, as well as in forecaster skill and forecast models. Much of the improvement in forecasting comes from pattern recognition, which is essential to alert the forecaster to the potential for convective development (Johns and Doswell 1992; Mc Nulty 1995). As a result, forecasters have grown fairly adept at recognizing when convection will develop. However specifying the exact location and severity remains an elusive goal.

The objective of this paper will be to provide an approach to forecasting warm season convection, more precisely, the forecasting of convection in **weakly forced** environments (Gaza and Bosart 1985). Recognizing patterns that are **non-conducive** to afternoon convection could allow the elimination of forecast precipitation in what may otherwise still be a warm, humid, and unstable environment. Trying to improve on the standard "3H" low precipitation probability forecast is not an easy task but at least in some circumstances an increase in skill may be attainable.

2. METHODOLOGY

Seventeen days were examined during the summer of 1995 encompassing the period from 20 June to 15 August. For the purpose of this study, only days where convection occurred or was forecast to occur under weak synoptic scale forcing were examined. Convective cases associated with *well-developed* synoptic scale systems that traveled or advected into the region were not examined. The area of study centered on Pennsylvania and adjacent states. An unusually long period of dry weather developed over much of the northeastern United States late in the summer limiting the availability of cases after the middle of August.

Gridded data from the 1200 UTC forecast cycle of several models were examined using PCGRIDDS (Petersen 1992). Choosing which model to examine on a given day was based on model initialization and/or data availability. In an attempt to define parameters which might prove useful in the forecasting (or not forecasting) of afternoon and evening convection (0 through 12 hour forecasts, 1200 through 0000 UTC), several data fields were examined. The fields examined concentrated on evaluating atmospheric stability and areas of favorable or unfavorable large-scale forcing (Barnes 1986; Mc Nulty 1995).

Models used in the study included the Operational "Early" ETA (ETA) model (Rogers et al 1995), the Regional Analysis and Forecast System (RAFS) Nested Grid Model Output (NGM) (Hoke et al 1989; Grumm and Seibers 1989) and the Global Spectral (AVN) Model (Sela 1980). Originally, data for each six-hour period (0, 6, and 12H) were examined to tabulate results. But to achieve some measure of data homogeneity, only initial and 12H (00H and 12H) conditions were used in this study (AVN forecasts valid at 18 UTC were not available at the time).

Once the data reveals the potential for instability, the forecaster must determine if forcing will be sufficient to initiate convection. The forcing mechanisms that were examined are summarized in Table 1. Various forecast fields were examined over the area where convection either developed or was expected to develop. In an effort to quantify the results, an arbitrary numeric method of evaluation was chosen. If a parameter was found to be **favorable**, that is tending to support or **possibly** act as a trigger for convection, it was assigned a value of one (1). Where forcing was acting to inhibit convection a value of minus one (-1) was assigned. Where forcing was negligible or ambiguous (may have varied over the area of interest), a value of zero (0) was assigned. For example, low-level convergence (divergence) would be assigned a value of 1 (-1) suggesting that this supports (inhibits) convection.

Once stability and potential for forcing was considered, temperature and moisture parameters were examined to determine if convection could actually be supported. The thermodynamic parameters examined are summarized in Table 2. The same method of tabulating parameters as stated above was used. For example, if low-level θ_e advection was positive (negative), a value of 1 (-1) was assigned.

3. RESULTS

a. Stability Indices

Often, the first hint the forecaster gets that the atmosphere may be conducive to convection comes from the examination of stability indices such as the lifted index, K index, total totals, and surface base cross totals (Bluestein 1993; Davies 1988). These indices are easily quantified and tabulated. A summary of the indices used in this study and their meanings are shown in Tables 3 and 4. A comparison of the stability indices (Fig. 1) shows the atmosphere to be unstable on the days examined, but reveals little to aid the forecaster in providing more detail (ability to avoid broad-brushing low POP forecasts) to the forecast regarding potential convective development under weakly forced regimes.

b. Forcing

By the very nature of the term "weakly forced", the implication is that Quasi-Geostrophic (QG) forcing (Barnes 1986; Mc Nulty 1995), would be weak or virtually non-existent (Table 1). Vorticity advections, PIVA (positive isothermal vorticity advection; Trenberth 1978), Laplacian of thermal advection, frontogenetic forcing as well as divergence (convergence) around any discernible jet streaks were examined. In the typically weak flow regimes encountered, the results yielded no consistently useful signals.

Since it is common in the atmosphere to have differential vorticity advection mitigating the effects of temperature advection (Barnes 1985; Hoskins et al 1978; Trenberth 1978), the ability to assess the affects of these separate parameters becomes problematic. Hoskins et al (1978) showed that the differential vorticity advection and the Laplacian of temperature advection could be combined mathematically into an entity known as the Q-vector. Q-vectors also have the advantage of including the effects of deformations which the Trenberth approximation ignored. Where Q-vectors converge in the lower atmosphere, upward vertical motion would be forced. In a strongly unstable environment, weak forcing may be all that is needed to support large-scale upward vertical motions (Doswell 1987). Weak Q-vector convergence and instability may be the first hint that convection is possible, giving the forecaster an opportunity to better focus the prediction of afternoon convection (Barnes 1985).

An examination of Q-vector convergence (divergence) both for individual levels as well as layers (Table 1) revealed a tendency for Q-vectors to show convergence throughout the troposphere (Fig. 2). Because only cases where QG forcing was weak were considered, it was not a surprise that in general Q-vector convergence was also weak and at times difficult to evaluate.

c. Moisture and Temperature

Temperature and moisture variables and their advection were also examined. Low-level warm advection coupled with cold advection in the mid-levels is a well-documented means of decreasing atmospheric stability (differential thermal advection; Mc Nulty 1980). This creates conditions favorable for deep convection. While there was a tendency for the low-levels to experience very weak warm advection, the midlevels tended to show little or no advection.

No consistent pattern of differential thermal advection was found.

Similarly, low-level (1000 and 850 mb) equivalent potential temperature (θ_e) patterns and advections were examined. Despite the presence of high θ_e air, on many occasions thunderstorms did not develop. On days when thunderstorms did develop, they formed in high θ_e air but in the absence of significant θ_e advection. Model depictions of low-level convergence and moisture flux convergence were also evaluated. These parameters provided little useful guidance.

The final parameter examined was midlevel capping potential (Carlson 1991). The 700 mb temperature was used to evaluate this parameter. Warm midlevel temperatures have proven to be an effective cap to developing convection. The 14°C isotherm has been cited as a good value to look for when evaluating cap potential (Patrick 1990). Temperatures in this study ranged from as low as 3°C to as warm as 12°C, with the average value around 8°C. The 14°C cap threshold never occurred over Pennsylvania. The 10°C isotherm appeared to be a more reliable convective cap value for Pennsylvania.

4. EXAMPLES

On 26 July 1995 a very weak cold front was approaching the northeast U.S. (not shown). The front was expected to act as a trigger for convection and prompted the inclusion of a 30 % chance of thunderstorms in the forecast for much of the region (30% POPs). The models forecast drier air to advect into the area on weak low-level northwest flow, resulting in expected negative θ_e advection. By mid to late afternoon, negative θ_e advection had established itself (Fig. 3.) inhibiting convective development. Additionally, midlevel (700 mb) temperatures were forecast to average around 7°C (not shown). This is somewhat cooler than the value found to be an effective cap under such weakly forced conditions (10°C).

On 29 July 1995 another weak cold front was forecast to move through the area from the northwest and act as a trigger for thunderstorm activity. As in the previous case, the models forecast θ_e advection to become negative in the low levels during the afternoon. Also, 700 mb temperatures were quite warm, averaging around 10°C which represents the Pennsylvania cap value. A 30 to 40% chance of thunderstorms was included in the forecasts. A few thunderstorms formed over Ohio and moved into extreme western Pennsylvania. The vast majority of the rest of the northeastern U.S. remained rain free.

In both of these cases, moisture and instability were present, along with a traditionally accepted trigger mechanism (cold front). Advection of cooler values of low-level θ_e and or the presence of warm midlevel air effectively inhibited convection.

5. SUMMARY

Forecasts of low-level θ_e fields provided the most significant hint for convective potential in weakly forced regimes (Schofield and Robinson 1992; LaCorte et al. 1994). In the instances where θ_e advection was negative, thunderstorms failed to develop. This may become an even more useful tool as finer-scale models become available to the operational forecaster. Models like the Meso ETA (Black 1994) will hopefully be able to further focus on both areas where forcing and the low-level θ_e fields may be significantly favorable or unfavorable for convection.

Examining midlevel temperature for capping potential also proved quite useful. While 14°C has been cited as a good threshold to look for when evaluating capping potential (Patrick 1990), perhaps this value is more representative under regimes where quasi-geostrophic forcing is significant. In the weakly forced regimes examined over Pennsylvania, 700 mb temperatures of around 10°C seemed to provide an effective cap to local convection. This suggests that "cap" values may vary by region.

In looking for aids to forecasting convection, forecasters will continue to rely on numerical weather prediction models to ascertain the potential for mesoscale forcing (Mc Nulty 1995). Currently available models have the ability to delineate broad areas of favorable and unfavorable large-scale forcing, but are incapable of resolving processes at the mesoscale (Doswell 1982). The current mesoscale Eta model has a horizontal resolution on the order of about 29 km. This means that the model is effective in portraying features on the order of about 175 km in size using the 6Δ (6-delta) rule where a model can resolve a feature approximately 6 times the horizontal grid scale. Since convection typically forms on scales closer to 5-20 km, mesoscale models with resolutions as fine as 0.8-3.0 km may be needed to portray areas where forcing is favorable at the storm scale.

The results of this study suggest that at least on some days, gridded data can provide tools which can be used to make significant improvements in forecasting convection. The ability to diagnose areas of maximum instability, as well as where QG forcing will be at least weakly favorable, may allow a better delineation of which portions of the forecast area will be most likely to experience convective development. While improvements in these models can be expected to continue, the challenge of forecasting convection in weakly forced environments will continue as well.

Research to improve how gridded data are used to fine tune convective forecasts under weakly forced regimes should continue. It has been suggested that the 330K θ_e surface along the dynamic tropopause (DT) may create the unstable troposphere needed to release convection (Bosart unpublished paper). We plan to examine the relationship of the DT to low-level θ_e fields during the summer of 1998. Since low-level θ_e fields have shown some operational utility as precursors to convection, it is hoped that short wavelength perturbations near the DT may offer clues to potential convective development.

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Table 1. List of forcing mechanisms evaluated.

Forcing Mechanisms
Upper jet quadrant relative to thunderstorm genesis region
Upper level divergence (250 mb)
Low level convergence
Presence or absence of low level jet
Laplacian of thermal advection at individual levels (850, 700, 500, and 300 mb)
Q-Vector divergence layers (1000-700, 700-400, 500-200 mb)
Frontogenetic forcing at individual levels (850, 700 mb)
PIVA (advection of 500mb vorticity with the 1000-500 mb thermal wind)
Differential vorticity advection (1000 to 500 mb)
Vorticity advection at individual levels (850, 700, 500, and 300 mb)

Table 2. List of moisture and temperature parameters evaluated.

Moisture and Temperature Parameters
Temperature Advection (850 and 500 mb)
Mid Level Moisture Advection
Theta-E advection at 1000 and 850 mb
Moisture Divergence at 1000 and 850 mb
Low Level Theta-E Ridge Placement
Cap Potential (700-mb temperature)

Table 3. List of stability indices evaluated.

Stability Parameters
Lifted Index (up to 500 and 300 mb)
K Index
Total Totals Index
Surface Base Cross Totals

Table 4. A summary of stability indices and their association to the threat of thunderstorm development (after Gaza and Bosart 1985).

	GENERAL THUNDERSTORMS			**SEVERE THUNDERSTORMS**		
	LOW	**MDT**	**HIGH**	**LOW**	**MDT**	**HIGH**
LI	≥ 1	-1 to -2	< -2	> -3	-3 to -4	< -4
KI	> 36	16 to 36	< 16	N/A....................		
TT	< 46	46 to 50	>50	< 50	50 to 55	> 55
SCT	< 26	27 to 30	> 30	≥ 28	≥ 30	

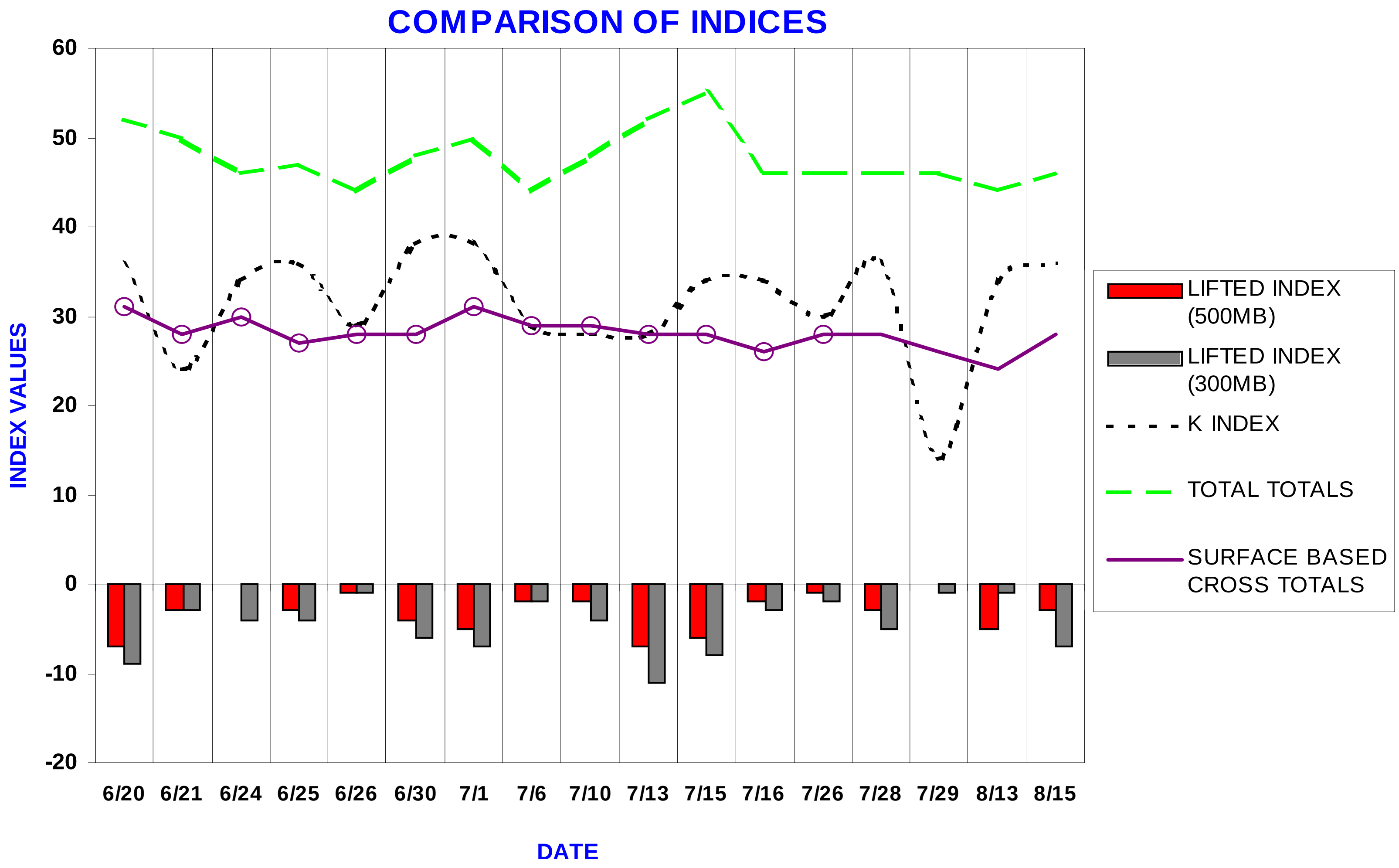

Figure 1. A comparison of the stability indices evaluated. Data show the various stability indices forecast by the model on the dates convection developed in the study area.

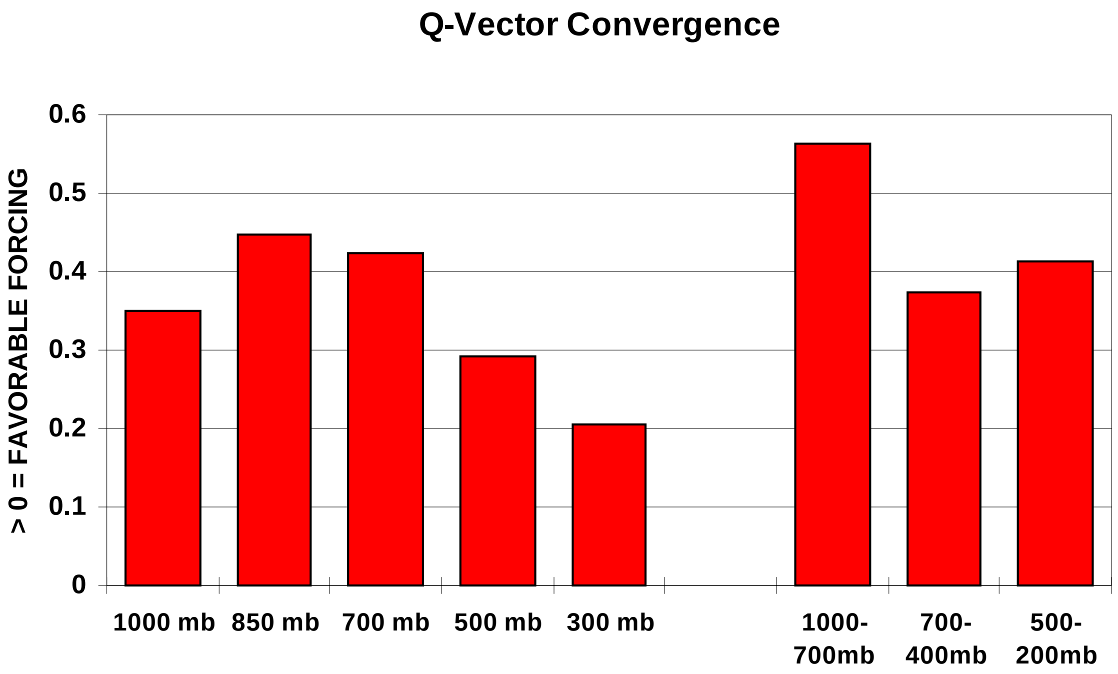

Figure 2. Data summarizes Q-vector convergence averaged for various atmospheric levels and layers on the days that convection developed in the study area. Favorable forcing (Q-vector convergence) was arbitrarily assigned a value of one (1), unfavorable forcing (Q-vector divergence) negative one (-1), and neutral forcing (Q-vector pattern too weak to evaluate) zero (0). Favorable forcing is implied with average values of greater than zero (0).

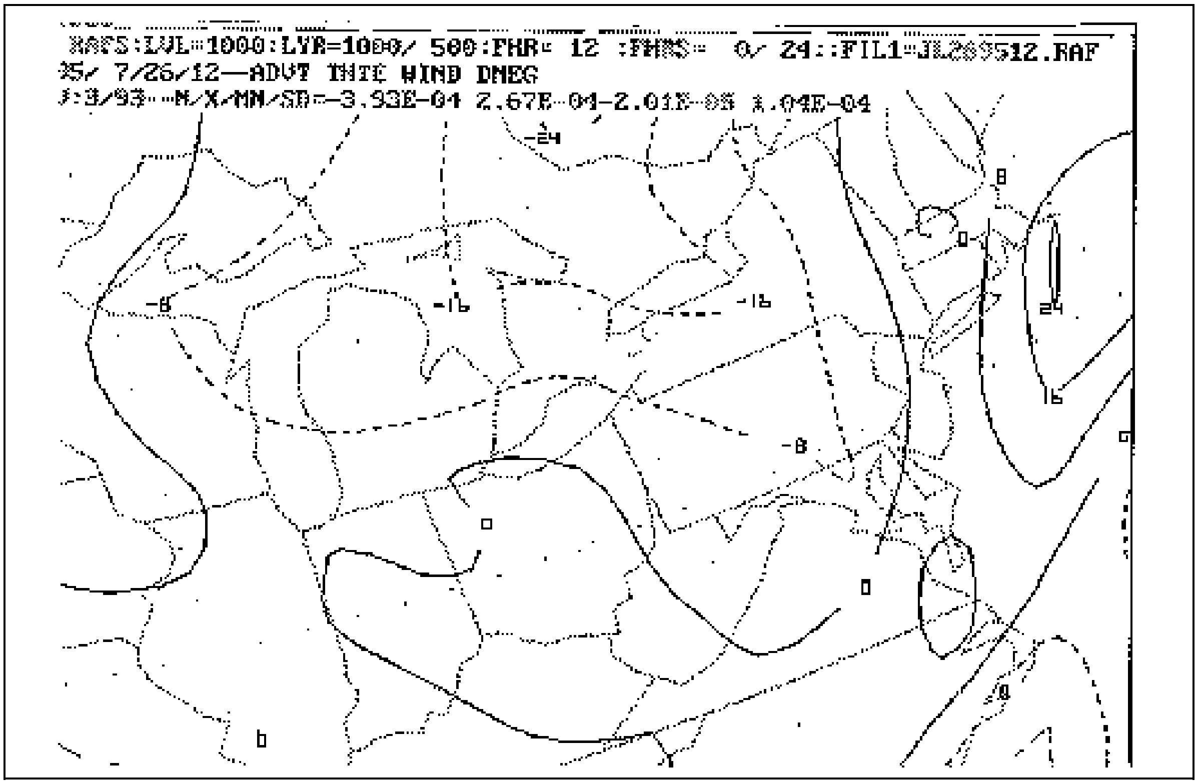

Figure 3. 1000 mb θ_e advection (°C/12 hr) valid 0000 UTC 27 July 1995. Dashed values represent negative θ_e advection.

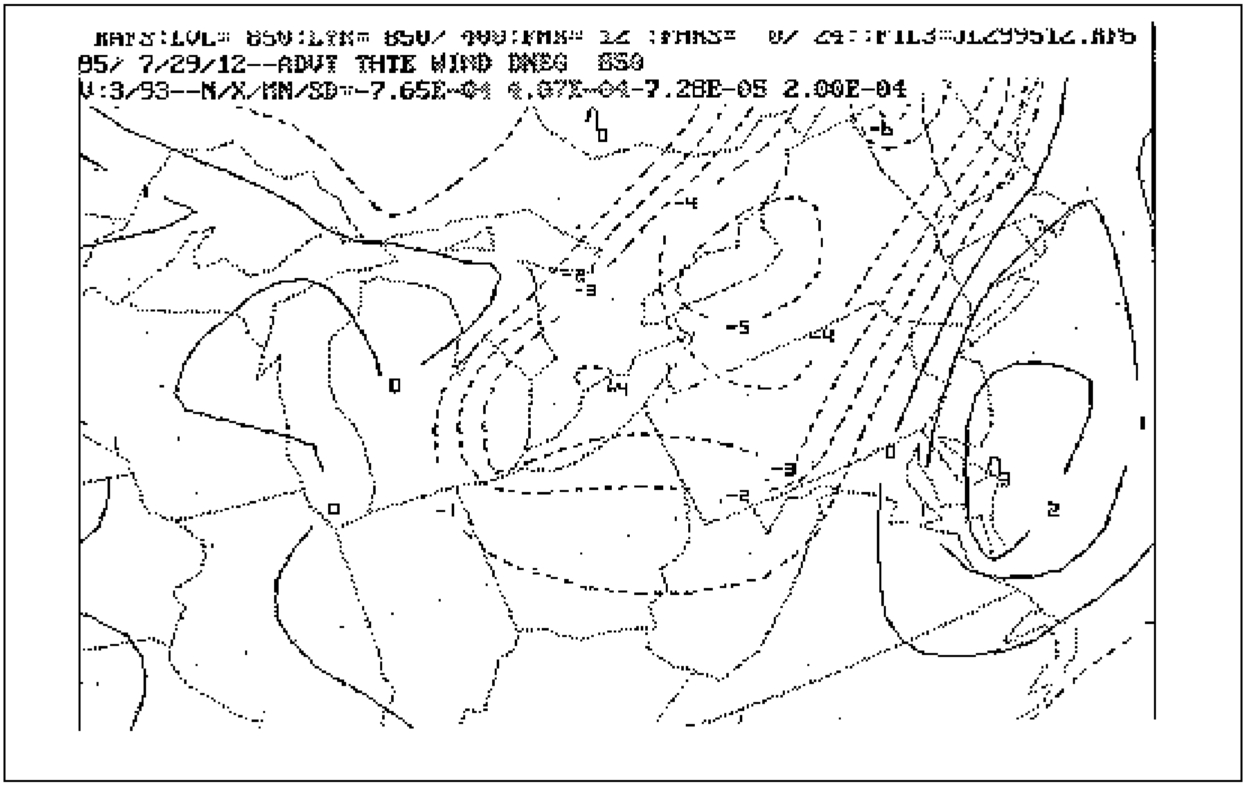

Figure 4. As in Fig. 1 except for 0000 UTC 30 July 1995.