SEVERE WEATHER

THE LID STRENGTH INDEX AS AN AID IN PREDICTING SEVERE LOCAL STORMS

Toby N. Carlson (1)
Department of Meteorology
The Pennsylvania State University
University Park, PA 16802

Robert J. Farrell (2)
U.S. Air Force
Barksdale Air Force Base
Bossier City, LA 71110

ABSTRACT

The Carlson and Ludlam conceptual model (4), which describes the development of synoptic-scale circulation patterns favorable to the outbreak of severe storm situations, is applied to the problem of operationally predicting severe local storms. In contrast with schemes which attempt to identify the most favorable convective areas, the present approach first seeks to eliminate areas unfavorable to convection. These unfavorable areas are where a capping inversion (or lid) inhibits convective development. The lid serves to inhibit the convection while allowing the potential for severe convection to increase in surrounding areas; specifically the wet-bulb potential temperature increases in the boundary layer, and the instability is realized along the lateral boundary of the lid where the low-level flow rapidly emerges into a region of large positive area on the sounding and no restraining inversion (i.e., a small or insignificant negative area). This process is called underrunning. While the lid may be removed by the processes of surface heating and evaporation and by low-level moisture advection, the most efficient means for focusing the release of instability promoted by lid formation is through underrunning of the moist air along the lateral boundary of the lid.

In order to quantify the effects of the lid in suppressing convection, a stability index was developed by Carlson, et al., (3) called the Lid Strength Index (LSI), which is sensitive to low and mid-level inversions. The LSI is shown to be effective in locating the areas of true thunderstorm potential by eliminating regions where the Lifted Index (LI) is negative (unstable) but where the stable stratification of the lid is inhibiting convection.

Based on the conceptual model and the results of several case studies, an operational method is discussed which allows the forecaster to diagnose the presence and areal extent of a lid and the location of underrunning.

1. Introduction

Quantitative prediction of severe local storms is aided by use of a multitude of stability indices (e.g., total totals, the lifted index, the SWEAT index), which attempt to quantify the likelihood of intense convective outbreaks. The lid strength index (LSI) also attempts to correlate a measure of convective instability with severe storm occurrence but unlike other indices the LSI includes the effects of lower tropospheric inversions on the convective areas where the lifted index (LI) is negative (unstable) but where the presence of an inversion is preventing the latent instability from being realized. When used in conjunction with conventional forecast methods which utilize existing convective indices, the LSI may prove to be an important conceptual and practical tool for use in the prediction of severe storms.

The occurrence of severe convective storms over the Great Plains during springtime and in other regions during other seasons suggests a direct relationship between the terrain, the large-scale flow patterns, and the outbreak of severe convection. Carlson and Ludlam (4) and Palmen and Newton (5) developed conceptual models relating the synoptic-scale circulation patterns to a unique topographical configuration. The Carlson and Ludlam idea is that the lid is formed not by subsidence but by differential advection of a hot, dry mixed layer from an arid (and sometimes elevated) region over a stream of cooler, more moist air. When the small-scale convection is confined to a relatively shallow layer beneath the lid, the wet-bulb potential temperature (θ_w) in the boundary layer rises without premature release of the convection in a spectrum of small cumulus elements. Deep convection can occur through a combination of processes which remove the lid, effectively by enabling θ_w near the ground to achieve a critical value, above which the lid no longer serves to restrain convection and the rising thermals can break through the inversion. The processes which eliminte the restraining ability of the lid can be vertical motion, surface heating and evaporation and advection. Previously, these processes were thought to be the key elements in removing the inversion. A more efficient means for removing the lid than surface heating or local ascending motion is a process known as underrunning in which the low-level air with high θ_w suddenly emerges into a region where the restraining inversion is absent. It is evident from inspection of Fig. 1 that the boundary layer air with high values of θ_w (21°C) cannot penetrate the inversion at 800 mb, where the saturation wet bulb potential temperature (θ_{sw}) is about 28°C and above which there is a deep mixed layer with a nearly constant potential temperature (θ) of about 45°C. [The lid is considered to be the level at which θ_{sw} reaches its maximum value in the inversion.]

In the United States the source region of the air above the lid, which is a mixed layer, is usually over the arid plateau of Mexico or the United States deserts. Mixing layer lids, however, have been observed by these authors over the upper Mississippi and Ohio Valley into Kentucky and Tennessee. In such cases the origin of the mixed layer above the lid may be the southwestern desert region or even the northern Great Plains. An extensive lid was present over much of the lower Great Plains and southeastern states during the famous 3-4 April 1974 tornado outbreak (6).

Because the source regions of the lid are both arid and usually elevated, air flowing over the dry surface is strongly heated at elevations considerably above that of sea level and, consequently, the potential temperature there is raised significantly throughout a deep mixed layer. When the mixed layer extends to the surface, the potential temperature within the mixed layers will be similar to those at screen level near the time of neutral lapse rate, which occurs an hour or two before 0000 GMT over the Great Plains during summer. The values of the surface-level potential temperature at 0000 GMT are typically in excess of 40°C during May and June over the southwestern and Mexican deserts (4). As the mixed layer over the arid plateau flows away from its source, it moves over moist air and forms a capping inversion called the lid. The base of the elevated mixed layer is anomalously warm for the levels at which it is found and, therefore, it prevents the convection from occurring in the moist air, at least for a time. The potential temperature just above the lid, therefore, corresponds to that at screen level at the source region and the saturation wet-bulb potential temperature (θ_{sw}) at the base of the lid (the maximum value in the layer called $\theta_{sw\ell}$) is a function of potential temperature and the altitude of the lid.

It is important to note that the mechanism of differential advection of mixed layers differs from that suggested by some earlier investigators who viewed the lid's origin as being due to subsidence. Several characteristics distinguish the elevated mixed layer lid from a subsidence inversion: These are the presence of a nearly isentropic layer and slowly varying mixing ratio above a very sharp transition between moist air below and warm, dry air above. Relative humidity tends to increase with height above the lid, unlike that above a subsidence inversion. The extreme variation in moisture and potential temperature with height across the lid, as shown in Fig. 1, is suggestive of two entirely different air streams in close proximity in the vertical. Compared with a typical sounding for the region, a lid sounding will tend to be much warmer and drier just above the lid but cooler and more moist near the top of the elevated mixed layer. In further discussions the lid will be considered to be the result of differential mixed layer advection. However, use of the lid strength index, to be described in the next section, applies generally to lower-tropospheric inversions produced by any mechanism.

In accordance with the fact that warm air advection and positive vorticity advection occur east of an upper trough in the westerlies, the establishment of the southerly or southwesterly flow at low- and mid-levels necessary for the formation of a lid over the Great Plains also will be accompanied by large-scale ascent which enables the lid to be removed at some location downstream from the source region of the elevated mixed layer. In situations where there is strong atmospheric lifting, there will be veering winds with height in the relative system moving with the velocity of the upper-level trough. Consequently, the low-level air will tend to move along trajectories to the left of those at middle levels and eventually emerge from beneath the capping inversion, usually along the left edge of the elevated mixed layer. Accordingly, the underrunning process is favored in that part of the pattern where there is also strong ascent. Convection is trapped until the low-level air reaches the lateral boundary of the lid where release is triggered by ascent. Inasmuch as the lateral boundary (7) of the lid will also correspond to a zone of strong horizontal temperature gradient in the 600-850 mb layer, the underrunning moist air will emerge into a region outside the lid where the temperature in the lower-middle troposphere is much cooler than beneath the lid. In effect, there is a sudden change in atmospheric stability above the low-level air parcels at the level of the lid and the release of latent instability is therefore focused outside the lateral boundary of the lid because of the rapid removal of the restraining inversion coinciding with a rapid increase in positive area on the sounding and strong upward motion. Here, it is important to stress that the role of vertical motion is not so much to remove the lid locally but to allow quasi-horizontal slantwise lifting of the lid and the moist air beneath it to occur, leading to the release of convective instability where the lid no longer constitutes an effective restraining mechanism. A quantification of the restraining effect of the lid is presented in the next section.

2. The Lid

Many stability indices which aid in diagnosing areas of potential instability implicitly include the difference between the web-bulb potential temperature in the surface layers and the saturation wet-bulb potential temperature at middle levels of the atmosphere (7, 8, and 9). An example of this type of index is the lifted index (LI), currently in wide use by the U.S. National Weather Service. The LI, however, is not capable of responding to lower-tropospheric inversions such as the lid, since the index accounts for the thermal structure at levels normally below and above those affected by the presence of a lid.

An index capable of responding to the presence of the lid is called the lid strength index (LSI) (3) which is defined as

$$LSI = \underbrace{(\bar{\theta}_{sw} - \bar{\theta}_w)}_{A} + \underbrace{(\theta_{sw\ell} - \bar{\theta}_w)}_{B}$$

where $\theta_{sw\ell}$ is the maximum saturation web-bulb potential temperature at the base of the lid. The lid base is defined as the pressure level of maximum θ_{sw} and can be recognized as being the warmest part on the inversion and at a level close to where the relative humidity (values to left of sounding in Fig. 1) decreases rapidly with height -- typically from about 80% to 30% or less over a few tens of millibars. This rapid variation in temperature and moisture occurs at the vertical interface between the elevated dry plume and the cooler, latently unstable air below (Fig. 1). Here we define $\bar{\theta}_w$ as a representative value of θ_w near the surface; although $\bar{\theta}_w$ was defined by Carlson, et al., (3) as the mean value over the lowest 50 mb above the ground, we will henceforth consider $\bar{\theta}_w$ as being the maximum value over the lowest 100 mb. The reasons for the slight redefinition of $\bar{\theta}_w$ from that of Carlson, et al., (3) is that the vertically averaged value of this quantity over the lowest layer is sensitive to shallow nocturnal or frontal inversions in a manner which produces misleading analyses of the LSI. The term $\bar{\theta}_{sw}$ is the average saturation wet-bulb potential temperature between the base of the lid and 500 mb, although it could be defined as the value at 500 mb, to be more compatible with customary versions of the LI. The level of $\theta_{sw\ell}$ may lie at the ground in regions where the lid is absent, for example, in the degenerate case where a deep dry adiabatic layer extends to the ground, as over the source region of the elevated mixed layer. Such occurrences are excluded from the computation of the LSI.

Term A in the LSI equation (1) represents the buoyancy of a parcel lifted to the level where $\theta_{sw} = \bar{\theta}_{sw}$. This term is very similar to the LI, possessing approximately one-half its numerical value. Term A is negative when a sounding possesses latent instability.

Term B in the LSI equation represents the stabilizing effect of the lid. In the presence of a lid, $\theta_{sw\ell}$ will be greater than $\bar{\theta}_w$ and term B will be positive. In the absence of a lid, term B will tend to be nearly zero or slightly negative and the LSI pattern will conform closely to that of the LI. Thus, the LSI can be either positive or negative, and terms in equation (1) can have differing signs with the sign of the LSI being given by the largest of the terms A or B. In that regard the LSI is similar to stability criteria which involve evaluating both the positive and negative areas on a sounding. A further analysis of the Terms A and B is contained in Fig. 2.

A schematic illustration of LI and LSI analyses is presented in Fig. 3. Due to insensitivity to the lid, the LI exaggerates the area of realizable instability. The LSI exhibits positive values over most of the region, indicating a relatively limited areal extent for convection over almost all the southern plains.

Although the value of the LSI is that it limits the area where one would expect to observe intense thunderstorms, the existence of negative LSI values, such as those shown in Fig. 3, does not necessarily indicate that severe storms will occur over the entire region of negative (unstable) values (11), nor does the presence of slightly positive values preclude the possibility of severe convection. Depending upon the situation, a critical value for intense convection might be taken as high as +2 or +3.

An interpretation of the LSI for forecast purposes must also consider the concept of underrunning, as well as other indicators. To illustrate the LSI application within the context of the overall conceptual model, a sample case will now be presented and the LSI analyses discussed in stepwise fashion for the benefit of the forecaster interested in a rapid operational analysis.

3. Stepwise Analysis of the Lid Strength Convective Potential

The method to be described in this section makes use of the lid strength concept and is presented in a manner suitable for application to operational forecasting. A modern approach to operational weather prediction is one which involves some kind of man-computer interaction in which the meteorologist systematically evaluates a succession of computer-generated products for the purpose of making a prediction, as was described by Cahir, et al. (12). At Penn State, the Department of Meteorology operates an interactive computer facility available for real-time forecasting. Equipment includes a Digital Equipment Corporation PDP 11/34 minicomputer with 112K words of memory, 10 megabytes of disk storage, 2 Tektronic storage-type CRT terminals and various other devices (13 and 12). This minicomputer is connected to the Federal Aviation Administration's 1200 baud 604 data line, which makes available hourly surface reports, radiosonde soundings, manually digitized radar (MDR) summaries and other data.

On 13 May 1980 an outbreak of intense convection accompanied by hail and tornadic activity occurred over southeastern Kansas along the Oklahoma-Kansas border and northwestern Arkansas. The National Weather Service radar chart for 0735 GMT May 13 shows the intense (level 3) activity (Fig. 4a) to be confined to a narrow region oriented approximately west to east along the Kansas Oklahoma border. These echoes remained in this region throughout May 13 but shifted southeastward on the 14th (labelled My 14 in Fig. 4b). One curious aspect of this convective outbreak, which may be explainable by the presence of the lid, is the sharply defined border to the echo pattern, a feature noted on many other occasions by the authors.

Let us suppose that a forecaster desires to assess the severe storm potential using the lid concept. The following steps illustrate the method for analyzing the influence of the lid using computer-generated products.

Step 1: Convective Potential Analysis

a) Examination of the Surface Chart

On the surface weather chart for 0000 GMT on 13 May 1981 (Fig. 5), there can be seen a moist flow from the Gulf of Mexico across Texas, Oklahoma, Kansas and neighboring states to the east.

b) LI and LSI Analysis

A narrow tongue of unstable LI values extended from Texas to Iowa (Fig. 6a) but the LSI shows only a small region of negative values over Kansas, Nebraska, and Iowa (Fig. 6b). It is significant to note that the LI tongue follows the direction of the low-level flow (Fig. 5), which extends across a strong gradient of the LSI over Oklahoma and Kansas. We conclude from these analyses (Figs. 6a,b) that a lid may be present south of Kansas and that the moist air flowed from high to low values of LSI south of Kansas.

c) 700 mb Temperature and Wind Chart

The presence of a lid is often reflected by a broad tongue of rather high temperatures at 700 mb, indicative of the intense heating over arid regions. The lateral boundaries of the lid can be identified most easily in the 600-800 mb layer, depending on the height of the lid. In general, the strongest horizontal temperature gradient between the elevated warm plume and its surroundings lies close to 700 mb. In Fig. 7 a strong horizontal temperature gradient, oriented north to south, can be seen just north of the Texas border from Arkansas to Colorado. The location and orientation of the edge of the temperature gradient signifies the presence of a lateral lid boundary. Temperatures of 8-10°C prevalent over the southwestern states in Fig. 7 correspond to potential temperatures of about 40°C, approximately that in the mixing layer over the southwestern part of the United States. This $\theta \sim 40°C$ air extended eastward at upper levels across Texas and Oklahoma.

The winds clearly show warm advection taking place along the strong temperature gradient. One can conclude that the vertical motion in that region is upward, by assuming that the overall temperature pattern was moving much more slowly than the wind velocity, which was generally about 25-50 kt over the southern plains. Consequently, the flow of air toward colder temperatures (warm advection) is analogous to ascent up sloping isentropic surfaces (14). Accordingly, one can infer, at least tentatively, from an examination of Fig. 7 that:

- A lid appears likely to have been present over the southern Great Plains. This fact remains to be substantiated by further analysis.
- The elevated mixed layer above the lid possessed potential temperature of about 40°C.
- A lateral boundary of the lid existed along an east-west line across Oklahoma and Kansas where there was a strong horizontal temperature gradient bordering a rather uniformly warm region to the south.
- Ascending motion was occurring along the region of strong horizontal temperature gradient.

The source region for the elevated mixed layer above the lid can be investigated in greater detail by examining an analysis of 0000 GMT surface potential temperature for the previous day. This product is not presented here, but there was a wide region of 40°C surface potential temperatures over the southwestern United States.

Step 2) Lid Analyses and Underrunning

a) Lid Area Analysis

The region occupied by the lid is determined automatically from a program which inspects every sounding, identifies the θ_{SW} maximum (θ_{SW*}), and applies an arbitrary set of criteria designed to distinguish lid-type features. Lid soundings are indicated by a zero and non-lid soundings by a ten in Fig. 8a. The boundary between the lid and non-lid is indicated by the single isopleth in the figure. A subjective verification of the lid region presented in Fig. 8b corresponds very closely with the computer and analyzed lid area of Fig. 8a. The pressure level of the lid base (not presented), ascended toward the north and east from below 850 mb over south Texas to about 750 mb along the northern border of the lid, a further indication that the air near the base of the lid was ascending as it moved northeastward.

b) Upper Air Soundings

Examination of upper air soundings can be made as a useful check on the lid analyses. First, a station can be selected from within the lid region diagnosed in part (a) of this step. For example, in the Oklahoma City sounding (Fig. 9; location 0 in Fig. 7), there is a strong lid at 795 mb, above which the lapse rate is nearly dry adiabatic with a mean isentropic value of about θ = 40°C. Similarly, a lid is present at Topeka (not shown; location T in Fig. 7), but it is less imposing than at Oklahoma City even though $\overline{\theta}_w$ is less than that at Oklahoma City. A station such as Amarillo, west of the surface dryline (not shown; location A in Fig. 7), exhibits a deep dry adiabatic layer of θ = 40°C air between the surface and 520 mb. It is clear, therefore, that the air above the lid within the region diagnosed in Fig. 8a is the advected air from the desert mixing layer, typified by the sounding at Amarillo which is representative of that west of the dryline. The blackened circles in Fig. 8b, which denote a lid sounding, refer to soundings similar to those in Fig. 9.

c) Underrunning

The process by which low-level moist flow moves out from beneath the lid to an area where the lid is absent is called underrunning. Underrunning must occur along the lateral boundary of the lid, in this case over Oklahoma and Kansas. Mathematically, maximum underrunning can be estimated objectively by forming the product of the low-level wind component normal to the lid edge times the gradient of LSI. The underrunning potential is defined as $-V_{850}\cdot\nabla$ (LSI), where the 850 mb winds are chosen because because they appear to yield the best results. Where $-V\cdot\nabla$ (LSI) is large and positive within the latently unstable air, as for example can be seen by the large positive values over northeastern Oklahoma in Fig. 10, there is a strong likelihood of severe storms. The region of maximum underrunning potential along the lid edge in the region of negative LI draws attention to the forecaster to the region favorable for severe convection (arrow in Fig. 10).

Step 3. An Assessment of Severity

Convection severity is known to be directly related to large-scale vertical wind shear, as well as to latent instability (13). If the vertical wind shear is sufficiently strong, the updrafts and downdrafts are able to tilt from the vertical and achieve a maximum efficiency of operation. In such circumstances the convection may be accompanied by incidents of large hail and tornadoes. On the other hand, weak wind shears in the presence of large latent instabilities may lead to flooding rains. Further discussion of methods for prediction of flash floods or tornadoes lies outside the scope of this paper. On May 13, rather strong wind speeds of approximately 30-50 kt were observed over Oklahoma, signifying the likelihood of tornadic and hail events accompanying the storms.

4. Additional Considerations:

It is possible to form a picture of the lid strength potential by examining a relatively few products obtained using the Penn State interactive computer system, the 700 mb temperature and wind chart, the LSI, LI, lid area analysis, underrunning potential and a couple of soundings. A more detailed analysis of the lid source region could involve a wider examination of the soundings, one or more vertical cross sections, an isentropic analysis (16), and surface potential temperature charts. A greater consideration could be paid by the forecaster to predicting the movement of the lid using continuity charts and the 700 mb wind field. It is also important to evaluate the changes in surface θ_w during the day, as the result of low-level heating, evaporation and advection because such changes can lead to convective penetration of the lid.

Analysis of the relative wind isentropic chart for a surface just below that of the lid (θ = 30°; Fig. 11) shows that winds were blowing across the lid area (as shown in Fig. 8) from the southwestern part of the United States. The maximum surface potential temperature over the source region west of the dry line on 12 May was close to 40°C, and this same air can be found aloft east of the dry line on 13 May. Thus, air originating over the desert was present aloft above the moist layer over east Texas.

Finally, isentropic cross sections can be examined to provide greater insight into the lid structure. For example, it can be seen in Fig. 12 that a nearly isentropic layer (θ = 312-315K) was present south of Topeka, Kansas (456) on the 1200 GMT cross section, but the depth of the layer decreased rapidly with distance north of Oklahoma City (353), along with the strength of the inversion. Within the quasi-isentropic layer the airflow was generally from west to east (toward the reader) with a slight southerly component. At low levels, however, the airflow was from the south and, therefore, ascending motion is indicated along sloping isentropic surfaces which coincide with the northern edge of the lid. The important point to be made is that the lid was not being removed locally by vertical motion, although ascent plays a vital role in triggering the convection, but that differential advection was responsible for removing the restraining inversion over the moist air and that this removal occurred at the point where the low-level moist air moved out from beneath the lid. It should be pointed out also that the edge of the lid may be poorly defined in places where the lid has been lifted by a large amount.

5. Conclusions

A stability index (LSI) designed to allow the forecaster to diagnose the existence and stabilizing influence of low to mid-tropospheric inversions has been found to be very effective in narrowing down the region of true convective instability. Typically, values greater than about +2 or +3 are considered stable although the increase in low-level θ_w as the result of insolation exerts a strong diurnal change in the LSI. Values of +5 or +6, which are normally considered very stable, may change locally to +2 or +1 later in the day, as the result of surface heating and evaporation. Therefore it is advisable to consider the overall pattern of LSI and the presence of underrunning and also to forecast the changes in LSI that will occur as the result of insolation and moist air advection near the surface.

Acknowledgements

We would like to thank the following who generously gave their time and expertise in reading through the manuscript and offering suggestions and criticisms: Dr. Gregory S. Forbes, Mr. Stanley G. Benjamin, Dr. Richard P. McNulty and Mr. Paul S. Dreyer. This research has been supported by the United States Air Force, Grant #AFOSR-79-0125.

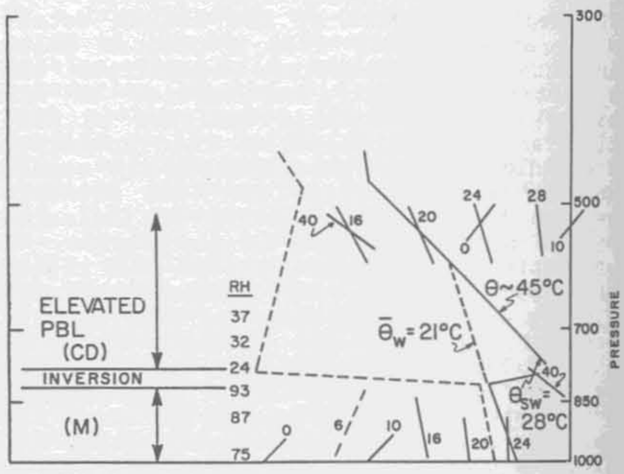


Fig. 1. Schematic lid sounding on a Skew T sounding. The values listed near the dewpoint curve are the relative humidities in percent at these levels. The potential temperature (θ), saturation wet-bulb potential temperature (θ_{SW}), and wet-bulb potential temperature ($\bar{\theta}_W$ is moist adiabat for the low-level air) are indicated at their appropriate locations. The low-level moist layer (M) and elevated mixed layer (PBL) are labeled.

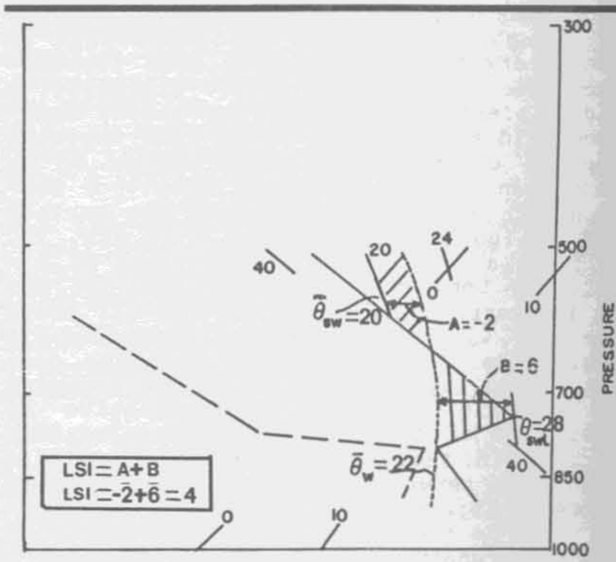


Fig. 2 Schematic sounding similar to that in Fig. 1, showing components A and B in the LSI calculation (equation 1). A sample calculation of the LSI is presented.

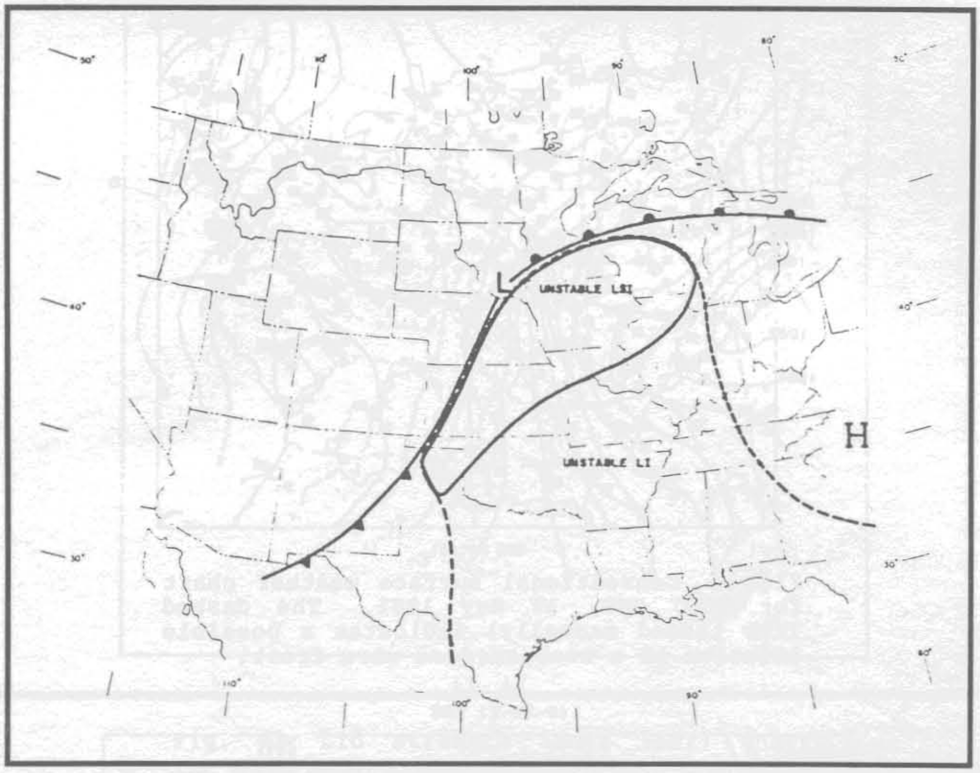


Fig. 3 Typical distribution of LI and LSI values for an idealized situation. The area of relative instability as diagnosed by the LSI, is enclosed within the solid line, and as diagnosed by the LI is enclosed within the dashed line. Note that the area of relatively unstable LSI values is smaller than, and is encompassed by, the area of relatively unstable LI values.

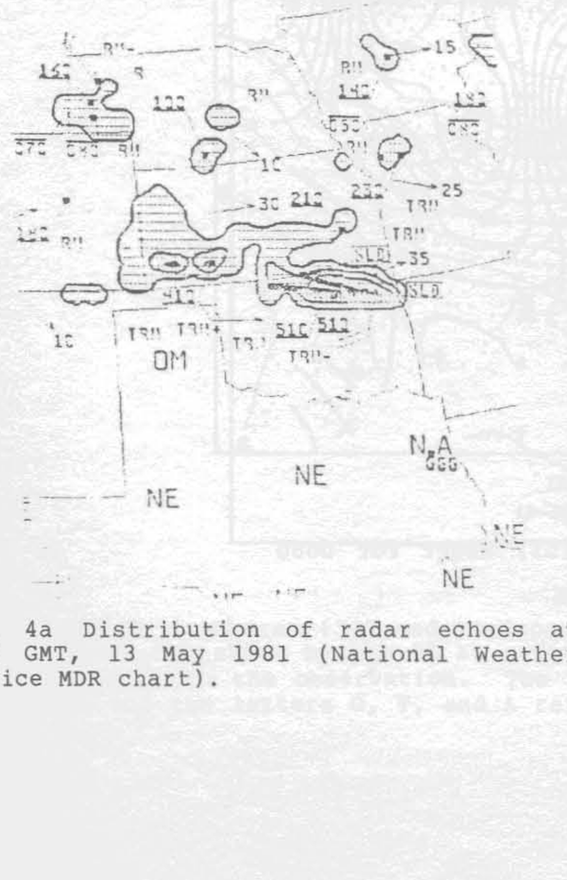


Fig. 4a Distribution of radar echoes at 0735 GMT, 13 May 1981 (National Weather Service MDR chart).

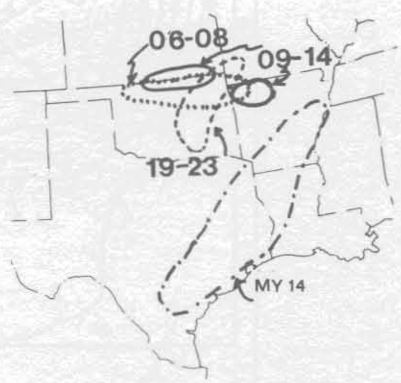
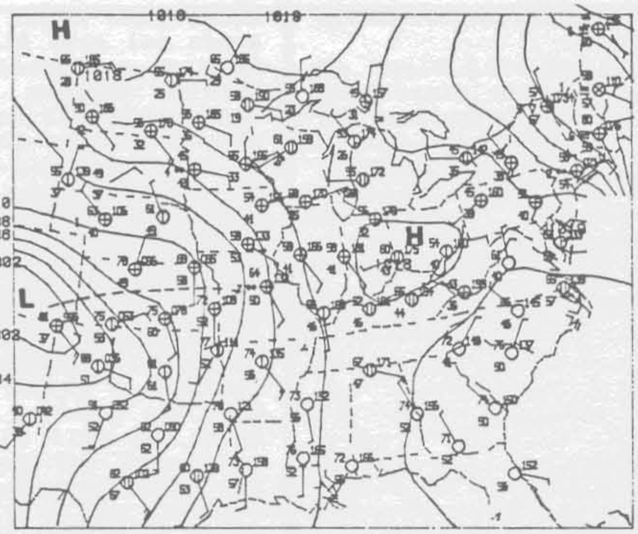
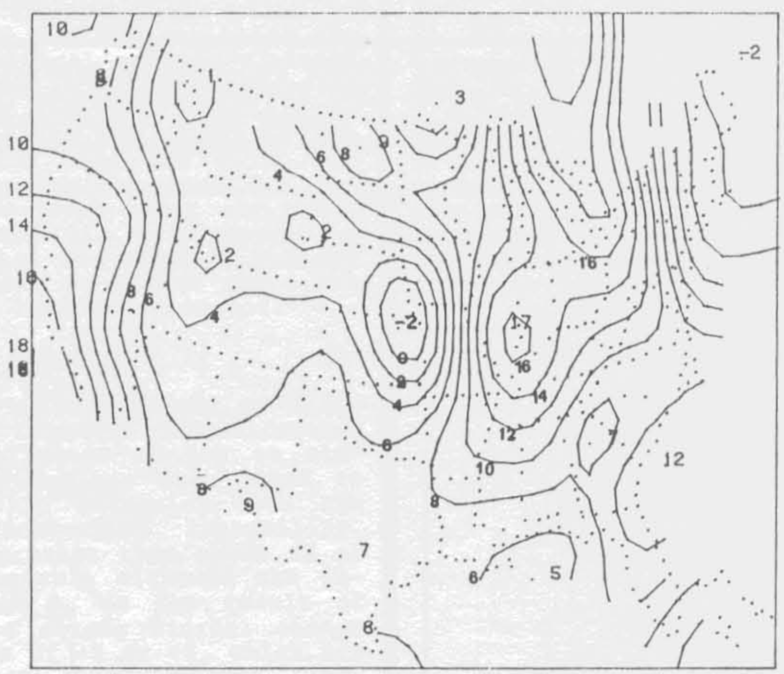


Fig. 4b Regions of severe weather and times (GMT), 13-14 May 1981. The contours are the outlines of the main level 3 (precipitation 1.1 - 2.2 inches per hour) radar echo regions. The dot-dashed contour labelled (My 14) refers to the distribution of radar echoes early on May 14.



00Z MY1381

Fig. 5 Conventional surface weather chart for 0000 GMT, 13 May 1981. The dashed line (added manually) indicates a possible location of a weak surface warm front.



LSI LSI
00Z 13-05-81

Fig. 6a Lifted index (LI) chart for 0000 GMT, 13 May 1981.

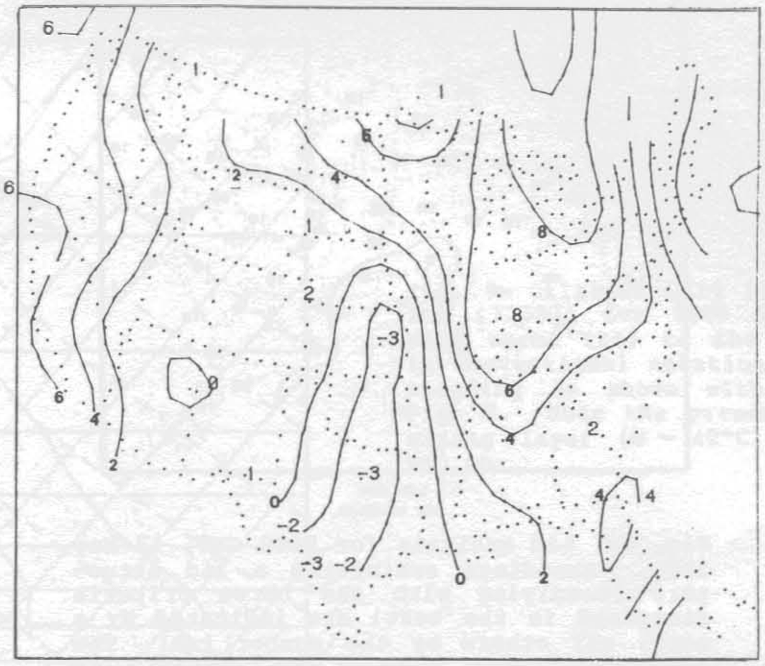


Fig. 6b Lid strength index (LSI) chart for 0000 GMT, 13 May 1981.

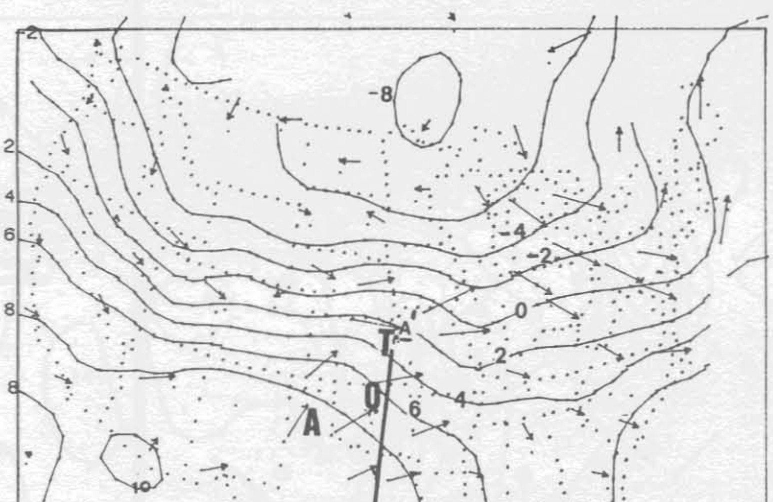


Fig. 7 700 mb isotherms (°C) and windspeeds. The length of the barb is proportional to the windspeed, as shown by the 25 kt reference mark at the bottom. The head of the arrow corresponds to the observation. The line A-A' is the location of the cross-section in Fig. 12 and the letters O, T, and A refer to locations of soundings discussed in the text.

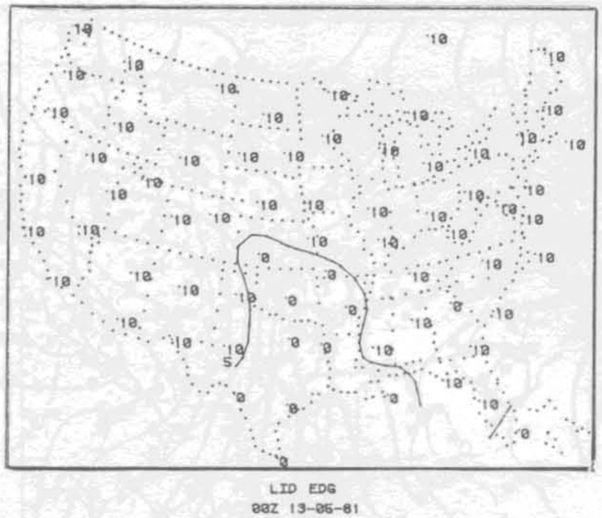


Fig. 8a Lid analysis for 0000 GMT, 13 May 1981. Soundings exhibiting a lid structure (complying with the three criteria discussed in the text) are indicated by a zero; all others by the number ten. The single isopleth denotes the lateral lid boundary.

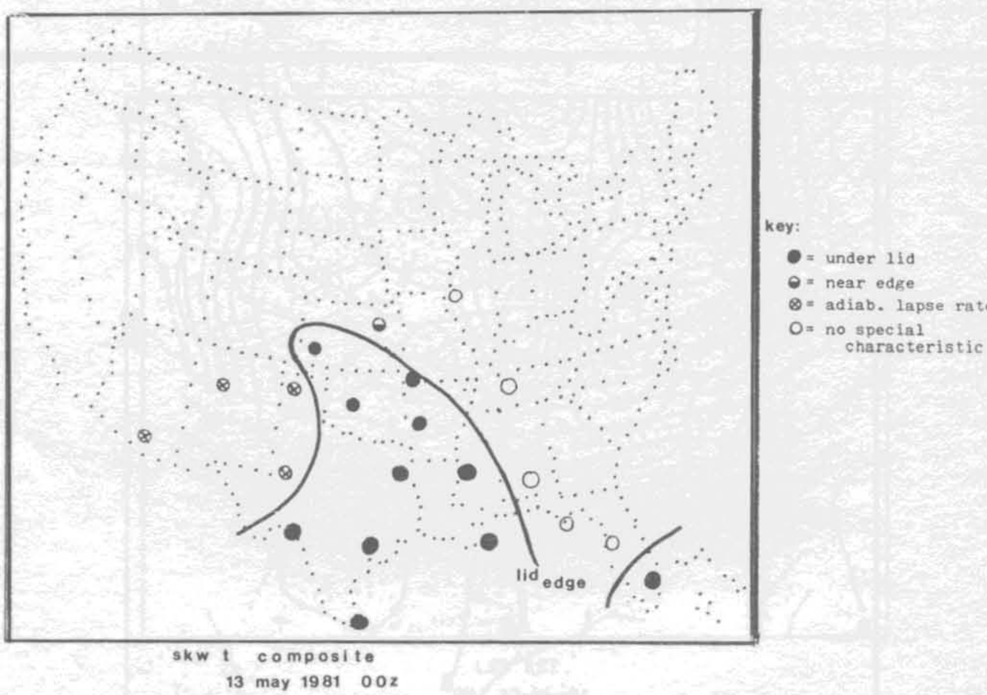


Fig. 8b Lid analysis determined subjectively by visual inspection of soundings (see key). Note comparison with Fig. 8a determined by computer.

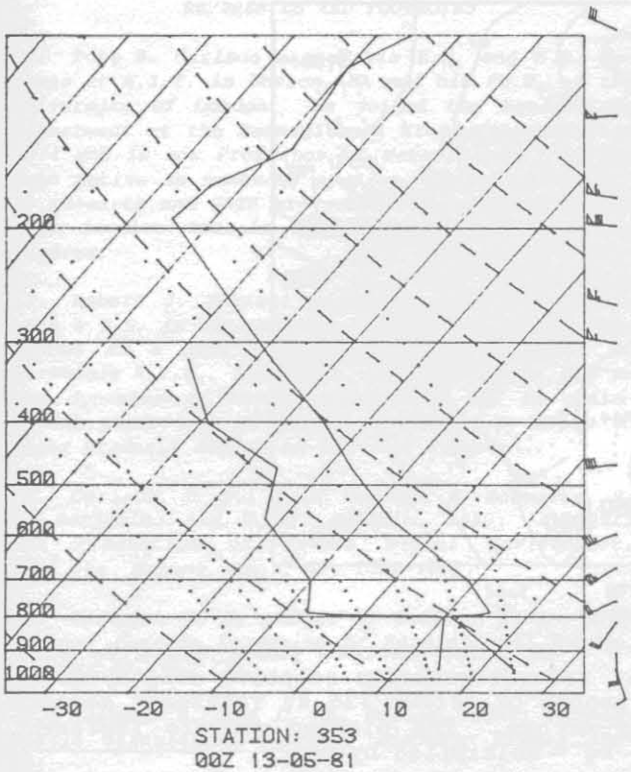


Fig. 9 Oklahoma City Skew T-log P sounding (72353) for 0000 GMT, 13 May 1981. Wind barbs (kt) to the right are plotted in conventional notation. The location of sounding is shown with the letter O in Fig. 7. Note the presence of an elevated mixing layer ($\theta \sim 40°C$), between 795 and 560 mb.

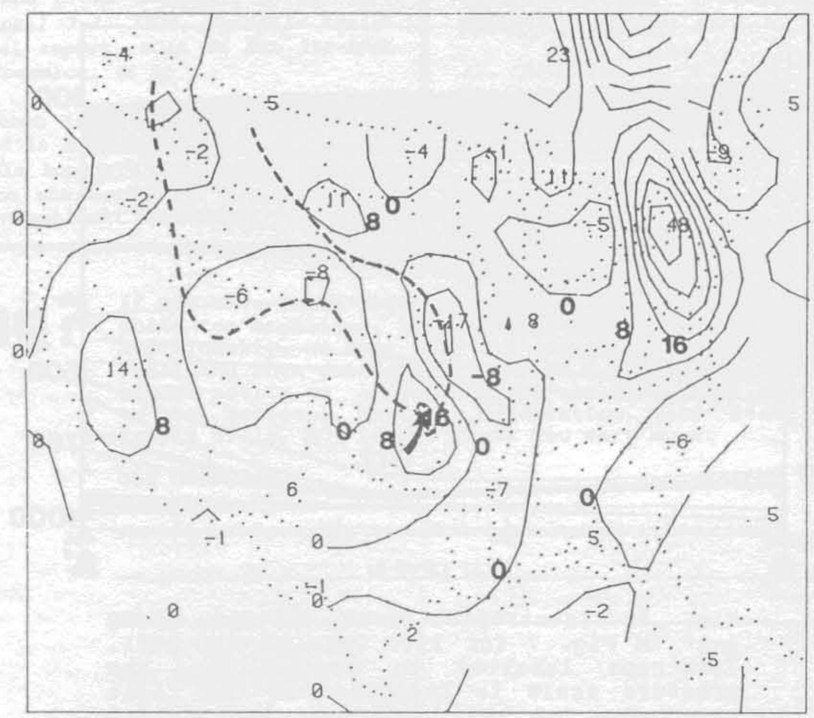


Fig. 10 Lid strength index advection ($- V_{850} \cdot \nabla$ (LSI)) for 0000 GMT, 13 May 1981 in units of °C s^{-1} times 10^5. The maximum underrunning of latently unstable air is occurring in the vicinity of the strong positive values over eastern Oklahoma and Kansas (see arrow). The heavy dashed line denotes the +3 LSI contour from Fig. 6a.

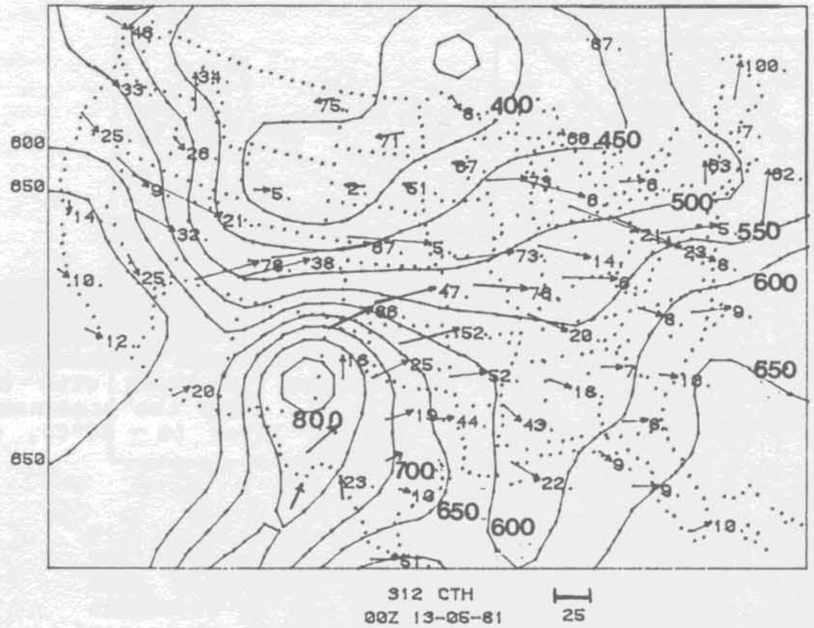


Fig. 11 Relative wind isentropic analyses at Θ = 39°C for eastern phase speed C_x of 0 kts. Solid lines are isobars (labelled in mb). Arrow represents relative wind speed on isentropic surface with speed proportional to length of arrow; (25 kt reference segment shown below). Stations correspond to heads of arrows. The plotted numbers represent the mixing ratio on the isentropic surface (g • kg^{-1} multiplied by 10).

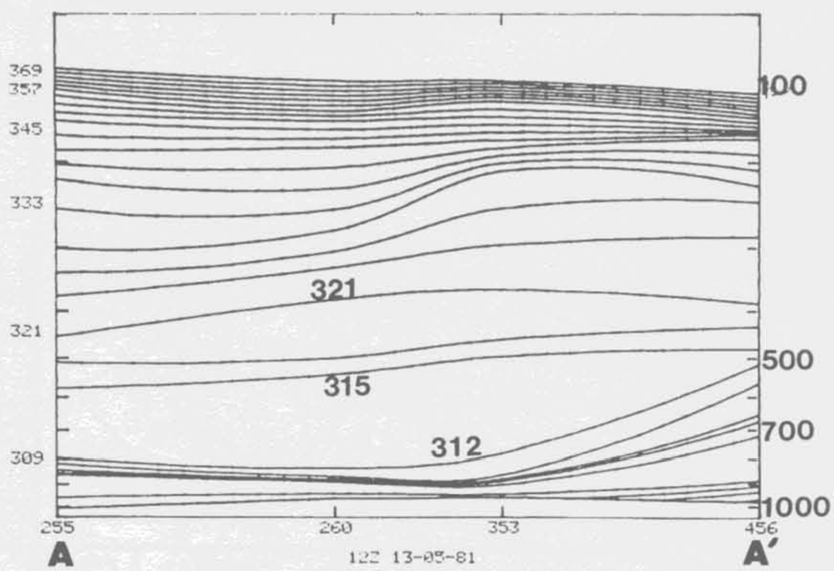


Fig. 12 Isentropic cross section along A-A' in Fig. 7 for 1200 GMT, 13 May 1981. Isentrops labelled in degrees K. The pressure scale is indicated at the right and values of the isentropes are plotted to the left. Note the presence of a nearly isentropic layer (Θ ~ 312-315K) south of Topeka (456) between approximately 850 and 500 mb.

REFERENCES AND FOOTNOTES

1. Toby N. Carlson earned his B.S. and M.S. degrees at M.I.T. in Boston, MA and his Ph.D. at the University of London. He joined the Meteorology Department at the Pennsylvania State University in 1974 and is now Professor of Meteorology. He has been active in numerous studies, including tropical research and GATE projects. His current interests involve terrain modeling and soil moisture studies.

2. Robert J. Farrell graduated from Penn State with a B.S. in meteorology in 1982 and is now stationed as a duty forecaster in the U.S.A.F. at Barksdale A.F.B., Louisiana. His interests are in the dynamics of severe convection and in operational prediction of severe weather. He hopes to enter graduate school in the near future.

3. Carlson, T. N., R. A. Anthes, M. Schwartz, S. G. Benjamin, and D. G. Baldwin, 1980: Analysis and Prediction of Severe Storms Environment. Bull. Am. Meteor. Soc., 61, 1018-1032.

4. Carlson, T. N. and F. H. Ludlam, 1968: Conditions for the Formation of Severe Local Storms. Tellus, 20, 203-226.

5. Palmen, E. and C. W. Newton, 1969: Atmospheric Circulation Systems, Academic Press, 394-401.

6. Hoxit, L. R. and C. F. Chappell, 1975: Tornado Outbreak of April 3-4, 1974, Synoptic Analysis. NOAA Technical report, NOAA TR ERL 338-APCL 37, U.S. Dept. of Commerce, 48 pp.

7. In analyses shown in this paper, the lateral boundary of the lid is drawn as a discrete boundary. In effect this boundary represents only the approximate location where the lid can no longer be identified on conventional soundings.

8. Galway, J. G., 1956: The Lifted Index as a Predictor of Latent Instability. Bull Am. Meteor. Soc., 37, 528-529.

9. Darkow, G., 1968: The Total Energy Environment of Severe Storms. J. Appl. Meteor., 7, 199-205.

10. Morgan, G. M. and R. G. Beebe, 1981: Analysis of Space-Time Behavior of the Field of Equivalent Potential Temperature During a Severe Weather Situation. Preprints, Seventh Conference on Severe Local Storms, Kansas City, MO, AMS, 54-59.

11. To achieve compatibility with the LI, the LSI has been defined with the opposite sign from that in Carlson, et al. (3).

12. Cahir, J. J., J. M. Norman, D. A. Lowry, 1981: Use of a Real Time Computer Graphics System in Analysis and Forecasting. Mon. Wea. Rev., 109, 485-500.

13. Cahir, J. J. and W. D. Lottes, 1980: Experiments in Forecasting Summer Showers Using a Weather Station Computer Graphics System. Preprints, Eighth Conference on Weather Forecasting and Analysis, Denver, CO, 10-13 June 1980, AMS, 447-452.

14. Uccellini, L., 1978: Operational Diagnostic Applications of Isentropic Analysis. National Weather Digest, 1, 4-12.

15. Browning, K. A., 1964: Airflow and Precipitation Trajectories within Severe Local Storms Which Travel to the Right of the Winds. J. Atmos. Sci., 21, 634-639.

16. For a discussion of relative-wind isentropic analysis, see Carlson, et al. (3).

Moving?

If you have moved and not notified us, or offered to pay forwarding costs for magazines, the NATIONAL WEATHER DIGEST will not reach you. Additionally, we must pay the cost for returned Digests as well as remailing them out again. To save a lot of work and inconvenience, please notify us immediately of any change of address, and send it to the National Weather Association, 4400 Stamp Road, Room 404, Temple Hills, MD 20748. Thank you very much.

OLD ADDRESS:

____

____

____

NEW ADDRESS:

____

____

____