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DETAILED SOUNDING ANALYSIS AND COMPUTER FORECASTS OF THE LIFTED INDEX

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ABSTRACT

With the recent availability of numerical means of calculating pseudo-adiabatic lapse rates, it has become possible to perform rather detailed sounding analyses in a routine operational manner. A number of stability and energetic parameters derived from sounding analysis, which are computed at NMC, are described. Also, with the inclusion of various moisture parameters into the six-layer primitive equation (PE) forecast model, it is possible to make forecasts of a somewhat simpler stability parameter, the lifted index. The method of calculation of this quantity and some sample forecasts are presented.

I. STABILITY INDICES

Among the more important quantities derived from atmospheric soundings is some measure of the convective stability, taking moisture into account, of the atmosphere. Such measures are usually presented in terms of stability indices of one sort or another. Probably the most familiar of these is the Showalter Index (Showalter, 1953) which has the considerable advantage of ease of calculation by graphical means. In this calculation, a parcel of air, defined by the observed air temperature and dewpoint at 850 mb, is lifted dry, and, if appropriate, moist adiabatically to 500 mb and the resultant parcel temperature is compared with the 500 mb temperature.

Somewhat more general indices have been proposed and are in use at the National Severe Storms Forecast Center (NSSFC) (Prosser and Foster, 1966) and, for research purposes, elsewhere. These generally involve defining the initial parcels in terms of average temperature and dewpoints through layers of the atmosphere resting on or near the surface of the ground. Such re-definitions of the parcel have the advantages of decreasing the likelihood of unrepresentative values, but this is paid for by the substantial increase of work in preparing them--so much so that these indices are used only in rather specialized areas where the advantages are clear, or rapid preparation is not a consideration.

Even more general stability parameters, involving usually the analysis of a sounding and parcel in terms of their energetics are frequently encountered in text books (e.g., Petterson, 1956), but seldom if ever in routine use, because of the onerous burden of preparation.

Recently, however, a method has been developed (Stackpole, 1967) whereby even the most involved forms of sounding analysis and stability index preparation can be accomplished on a digital computing machine very rapidly and with a minimum of effort. In essence, the method eliminates the necessity for using tabular or graphical means of determining the temperature and pressure along saturation pseudo-adiabats, replacing them with a set of straight-forward numerical calculations. Further in the same paper, Stackpole indicates a numerical means of calculating the lifting condensation level for a parcel given the initial pressure, temperature and dewpoint. These two algorithms along with the existence of the sounding data in a form suitable for machine processing make possible the rapid routine machine preparation of the sorts of stability indices referred to above.

II. DETAILED ANALYSIS OF SOUNDINGS

A number of ways of extracting stability and energetic information from a given sounding have been developed for routine use, principally by the Quantitative Precipitation Forecast (QPF) Section at the National Meteorological Center (NMC), Weather Bureau, ESSA. In general, the calculations involve lifting a suitably defined parcel to the 500 mb level and considering not the simple temperature differences (as in a lifted index calculation) but considering the differences in the pressure-temperature path traced out by the rising parcel and the pressure-temperature path given by the original sounding. The comparisons are made in terms of geopotential thicknesses between pressure levels or the energy equivalent of the area (on an adiabatic chart with suitable coordinates) between the sounding and the parcel lines. Under hydrostatic conditions (the usual assumption), note that these are equivalent quantities differing only by a multiplicative constant. However, for convenience and out of respect for tradition, we shall continue to speak of the two quantities as distinct as the occasion suits us.

The first step in the machine sounding analysis is the determination of an appropriate and representative parcel on or near the ground. At NMC two such parcel definitions are employed in parallel calculations, a Severe Storm Index (SSI) parcel and a Convective Index (CI) parcel. The SSI parcel is determined by calculating the average temperature and moisture content of a series of layers 100 mb thick, the first of which is resting on the ground and the others are successively 20 mb higher until the top of the layer reaches a pressure level 160 mb above the surface. From these parcels, the moistest (as measured by the largest value of the pseudo-equivalent potential temperature when the parcel is lifted to saturation) is selected as having the representative pressure, temperature and dewpoint for subsequent lifting calculations. The CI parcel determination is made in exactly the same manner except that the individual layers investigated are each 160 mb thick and the search for the moistest such parcel-layer continues up to 240 mb above the surface. All of these determinations are, of course, made from the data of the sounding undergoing the analysis.

Once the parcel, whether the SSI or CI, has been specified, its lifted condensation level and corresponding pseudo-equivalent potential temperature are calculated (for the numerical methods involved see Stackpole, 1967). With these data in hand, an analysis of the stability of the sounding in terms of the energetics of the two parcels is undertaken. These quantities are calculated:

1. The SSI and CI: The net "area" (equals energy) between the sounding and the parcel line from the mean pressure level of the parcel selected to 500 mb. The area to the right of the sounding (the region of free convection for the parcel) is taken as positive, the area to the left as negative, following the usual convention.

2. The Severe Storm Positive Area (SSPA) and the Convective Index Positive Area (CIPA): Additional detail of the sounding stability is obtained by calculating the area between the parcel and sounding from the level of free convection to 500 mb. (See Stackpole, 1967, for details on the calculation of the latter.) It should be noted that this area is not necessarily always positive -- an inversion above the level of free convection could cause the parcel line to pass back to the left of the sounding. Also, it should be noted that a level of free convection is itself not always found below the 500 mb level. In this circumstance, of course, the SSPA or CIPA are not calculable.

3. The Convective Condensation Level (CCL): This calculation, again described by Stackpole, 1967, makes possible the additional computation of the convective condensation surface temperature for each of the two parcels.

4. The CI Saturation Thickness (SK75): Finally, for the CI parcel alone, the "saturation thickness" of the 700 to 500 mb layer is found, for comparison with the observed thickness. This thickness is defined as the depth the layer in question would have if its temperature profile was just that of the saturation pseudo-adiabat defined by the parcel's pseudo-equivalent potential temperature. The depth is calculated by integration of the hydrostatic equation along the line of constant pseudo-equivalent potential temperature.

An obvious deficiency in all of these indices, even the most general, is that they are purely observational. There is no way to cast them into the future by other than subjective means.

III. PE LIFTED INDEX CALCULATION AND FORECAST

A second application of the sounding analysis algorithms designed to eliminate the deficiency mentioned above is in conjunction with the PE forecasts of the future state of the atmosphere. The PE model (Shuman and Hovermale, 1967) forecasts, with the vertical resolution indicated in Figure 1, the pressure at each of seven levels, the average potential temperature within each layer and the vertical mean precipitable water, within the troposphere, among other things. For the present purposes, it is apparent that a calculation of a lifted index from the initial analysis and forecast data would be most appropriately made by taking the conditions of the boundary layer as defining a parcel which is to be raised to 500 mb and compared with the observed for forecast temperatures there. This would be done for each grid point in the model covering the area of interest.

We need them to specify the mean pressure, temperature, and dewpoint of the boundary layer. These will serve to define the parcel.

First the pressure: This presents no particular problem as the PE model forecasts the pressure at level six, p^*, the surface pressure, and the boundary layer is fixed at a thickness of 100 mb. The initial pressure of the parcel then is given as

$$\bar{p} = p^* - 50. \qquad \text{in mb} \qquad (1)$$

Second, the dewpoint: In that the available moisture parameter, the precipitable water, W, is specified only as a mean value throughout the troposphere, it is necessary to make some assumption about the vertical distribution of moisture within the troposphere. We shall adopt that which is used in the PE model itself and was originally derived by Younkin, LaRue and Sanders, 1965. In their formulation, the vertical variation is expressed as a modeling parameter α such that the specific humidity q could be written

$$q = \alpha \frac{gW}{p^*} \qquad (2)$$

Using the profiles of α in Younkin, et al., an appropriate value for α averaged over the boundary layer is 3.5 (dimensionless).

Given the mean specific humidity of the boundary layer from (2), it is then no problem to estimate the mean vapor pressure $\bar{e}$ of the layer by solving

$$q = 0.622 \frac{\bar{e}}{\bar{p} - 0.378\,\bar{e}} \tag{3}$$

for $\bar{e}$.

Finally, the mean dewpoint of the layer $\bar{t}_D$ is obtained through the use of an empirical formula due to Tetens, 1930:

$$e_s = 6.11 \times 10^C, \qquad C = \frac{7.5\,t}{t + 237.3} \tag{4}$$

which relates the saturation vapor pressure e_s to temperature. Thus, if we substitute the vapor pressure $\bar{e}$ obtained from (3) into (4) and solve for t, we have obtained the temperature at which the observed vapor pressure would be the saturation vapor pressure; i.e., the temperature at which the air is saturated. This is just the dewpoint temperature that we started out to find.

Thirdly, the temperature: Here it is necessary to introduce further manipulation of the data in an attempt to approximate the effects of diurnal heating not currently included in the PE model. The inclusion of these effects should be accomplished shortly. The particular modifications of the data here described were suggested and developed by Dr. Wayne Sangster of the Weather Bureau Central Region Headquarters during a stay at NMC. The nature of the modifications depend upon the time of observation of the initial data. At the 00Z observation time, the solar heating is already incorporated into the observational data and nothing special is done to neither the initial nor forecast calculations. The analyzed or forecast potential temperature of the layer between levels five and six, $\theta_{5.6}$, is simply converted to Celcius temperature via the definition of potential temperature.

$$t = \left(\frac{\bar{p}}{1000}\right)^{0.2857} \times \theta - 273.16 \qquad (5)$$

where $\bar{p}$ from equation (11) is used in equation (5) to obtain the mean temperature of the layer.

If the initial data are observed at 12Z, the effect of subsequent diurnal heating is introduced by the following process. This procedure is done for both the initial and all forecast calculations. The mean temperature of the layer between levels four and five is obtained by conversion from the forecast potential temperature of the layer and the average pressure altitude, is extrapolated down to level five, the top of the boundary layer, at a lapse rate of 7°C per 100 mbs. This resulting temperature is then extrapolated down to the center of the boundary layer (to $\bar{p}$) dry adiabatically, implicitly assuming the boundary to be thoroughly mixed. This temperature at the center of the boundary level is increased by 2°C and we have (finally) obtained the desired temperature of the parcel to be lifted. This procedure parallels that of Prosser and Foster, 1966.

Once these data are obtained for the parcel then there are only the steps of calculating the lifting condensation level for the parcel, finding the pseudo-equivalent potential temperature at the LCL and the parcel temperature at 500 mb given by the intersection of the pseudo-adiabat (the line of constant pseudo-equivalent potential temperature) and the 500 mb pressure surface. These tasks are all accomplished using methods developed by Stackpole, 1967.

The field of lifted index then is defined as the analyzed or forecast 500 mb temperature minus the 500 mb parcel temperature, thus negative numbers are indicative of instability.

Figure 2 shows one lifted index forecast package: initial analysis, 12-hour, 24-hour, and 36-hour forecasts, and Figure 3 shows the subsequent analyses which serve as verifications for the forecasts. For comparison, Figures 4 and 5 show the observed values of Showalter Stability Index and SELS Lifted Index (Prosser and Foster, 1966) for the same times. The initial time selected, 12Z April 20, 1967, precedes by about thirty hours a severe outbreak of tornadoes in the northern Illinois-Chicago area, and southwestward through northern Missouri.

The salient features of the NMC lifted index observations (the upper-left panel of Figure 2 and all of Figure 3) show an instability region initially over Texas and extending northward to eastern South Dakota, the northern portion of which moves to Ohio and Kentucky while the southern portion remains more or less fixed in southern or southeastern Texas. The SELS and Showalter indices show essentially similar patterns -- differences in detail can be rationally ascribed to the various means of calculation of the numbers.

What is heartening, of course, is that the forecast lifted index also shows a similar pattern. Indeed, considering the forecast verifying at 12Z April 21, 1967, one might say that from the point of view of the severe weather areas, the forecast is better than the verification, but this is rather speculative.

The purpose of presenting this set of maps, of course, is not to imply that the availability of a lifted index forecast will solve the severe weather forecast problem, but to point out, by example, that we can forecast with fairly good success the future patterns of certain meteorological quantities of which the observed patterns have proven useful as forecast tools. The hope is, of course, that having the forecast values available will be a further aid in preparing and improving weather forecasts. Some preliminary work seems to indicate that this hope will be born out.

NOTE ADDED IN PROOF

As of July 5, 1967, diurnal (solar) heating was added to the PE mode and the boundary layer thickness was reduced to 50 mb. As a consequence, equation (1) should now be corrected to be

$$\bar{p} = p^* - 25 \; ,$$

and the boundary layer temperatures are given by equation (5) for all observation times. There is no longer any need for the diurnal heating approximations described on pages 5 and 6.

REFERENCES

Petterssen, S., 1956: Weather Analysis and Forecasting, Second Edition, Volume II, New York, McGraw-Hill Book Co., 133-195.

Prosser, N. E., and D. S. Foster, 1966: Upper Air Sounding Analysis by Use of an Electronic Computer, J. Appl. Meteor., 5, 296-300.

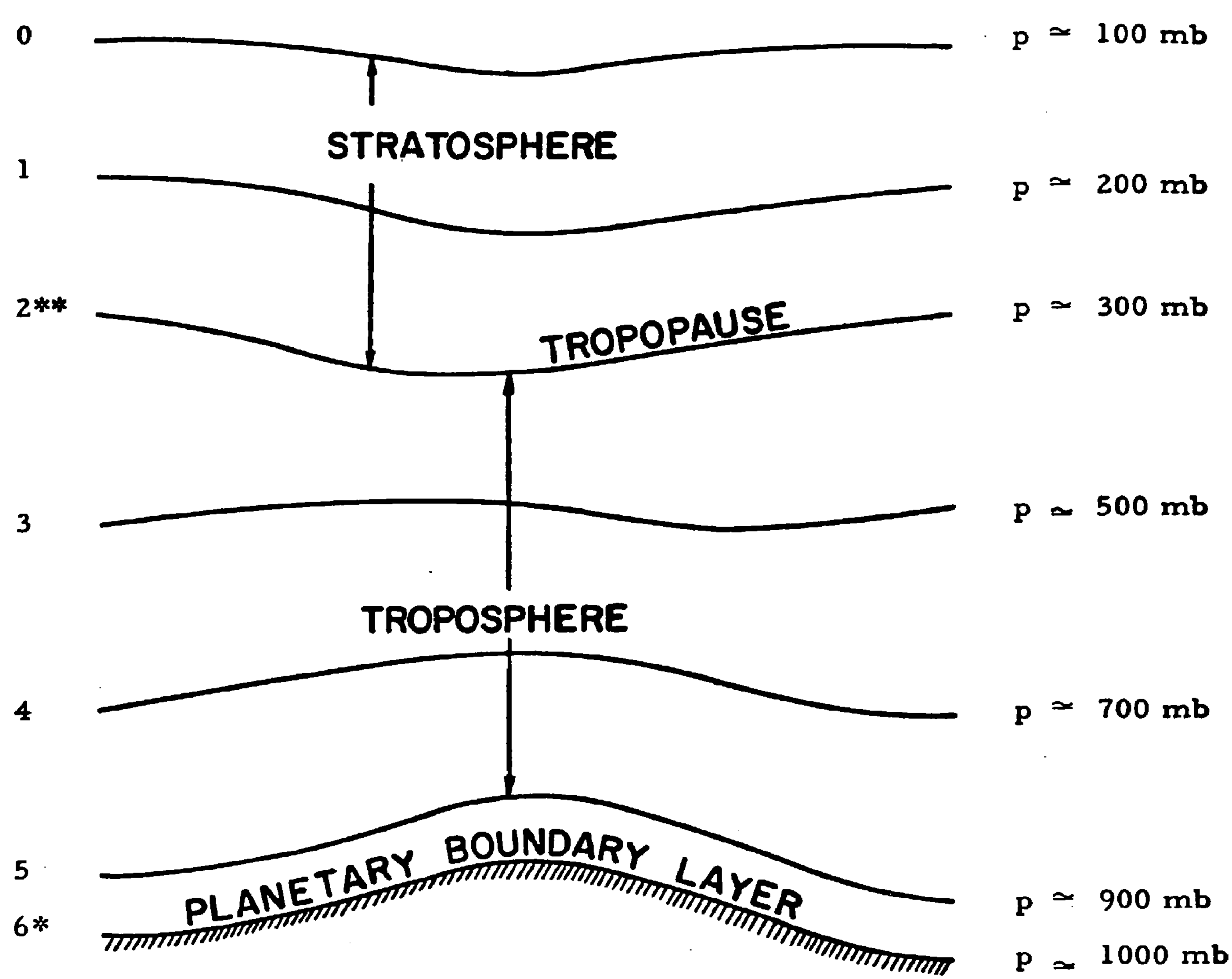
Showalter, A. K., 1953: A Stability Index for Thunderstorm Forecasting, Bull. Amer. Meteor. Soc., 34, 250-252.

Shuman, F. G., and J. B. Hovermale, 1967: An Operational Six-Layer Primitive Equation Model, (to be published in J. of Appl. Meteor., later this year).

Stackpole, J. D., 1967: Numerical Analysis of Atmospheric Soundings, J. Appl. Meteor., 6, In Press.

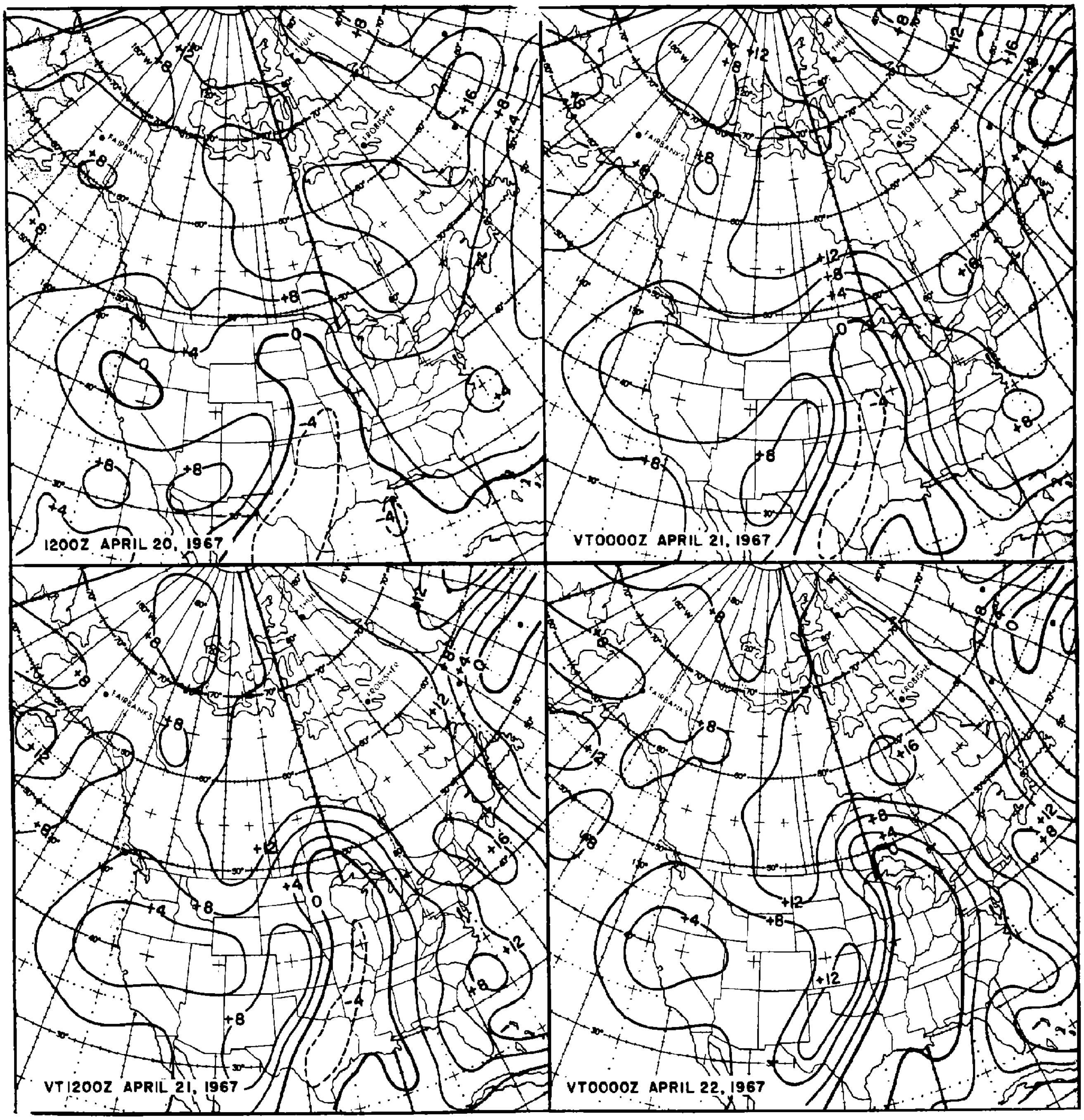
Tetens, O., 1930: Ober einigen meterologische vergriffe, Z. Geophys., 6, 297-309.

Younkin, R. J., and J. A. LaRue, and F. Sanders, 1965: The Objective Prediction of Clouds and Precipitation Using Vertically Integrated Moisture and Adiabatic Vertical Motions, J. Appl. Meteor., 4, 3-17.



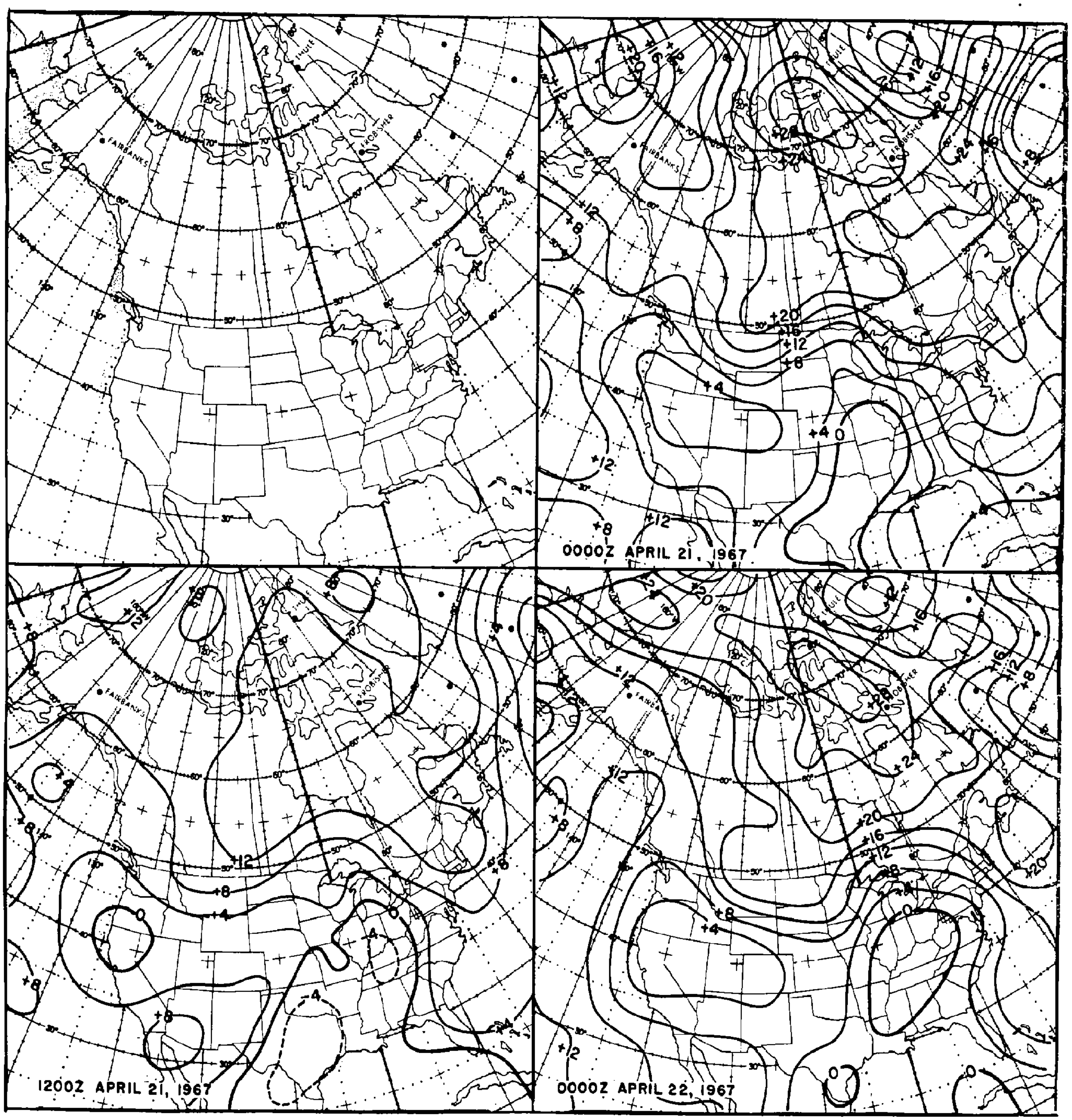
VERTICAL RESOLUTION IN P.E. MODEL

FIG. 1



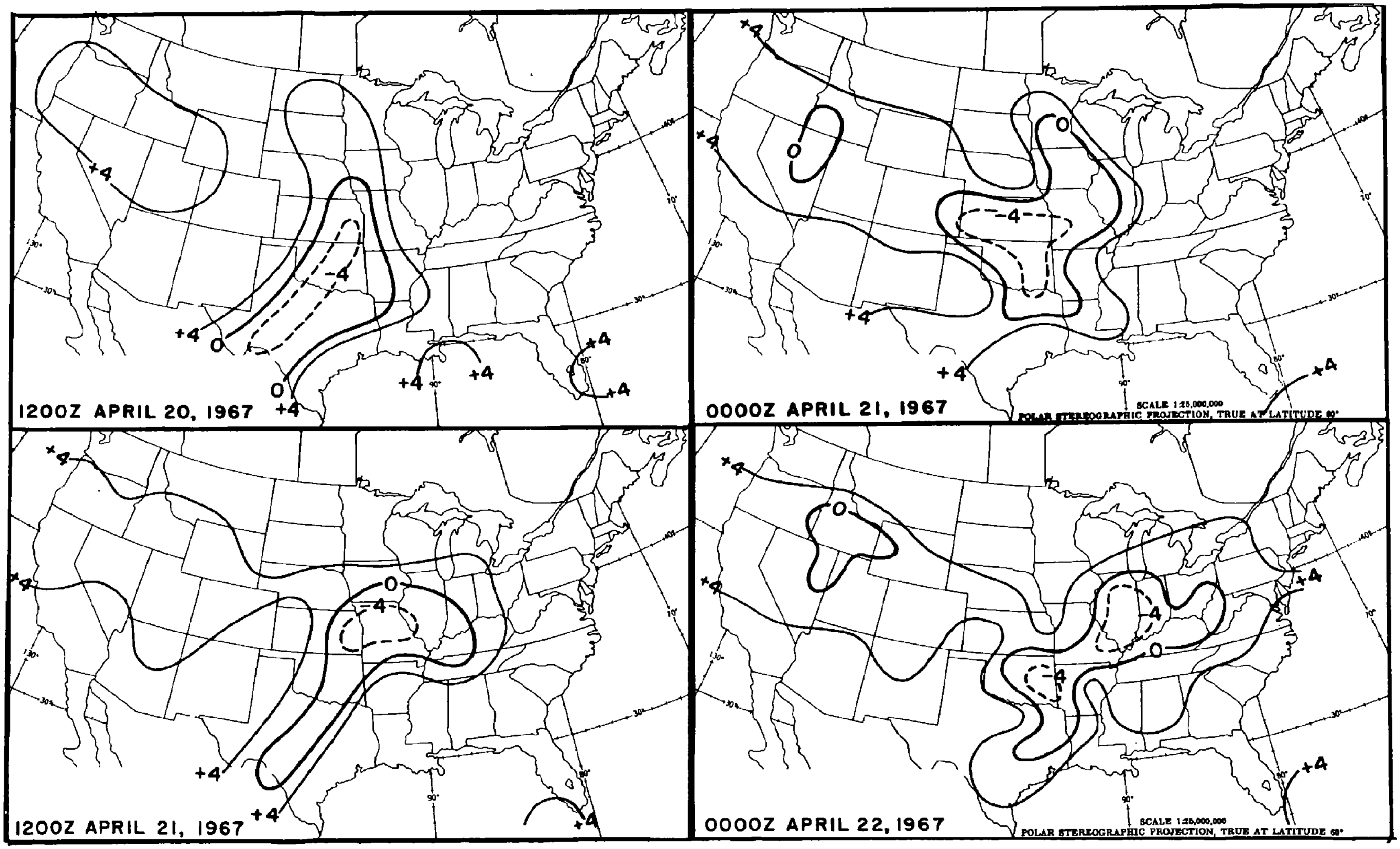
INITIAL & FORECAST NMC LIFTED INDEX

FIG. 2



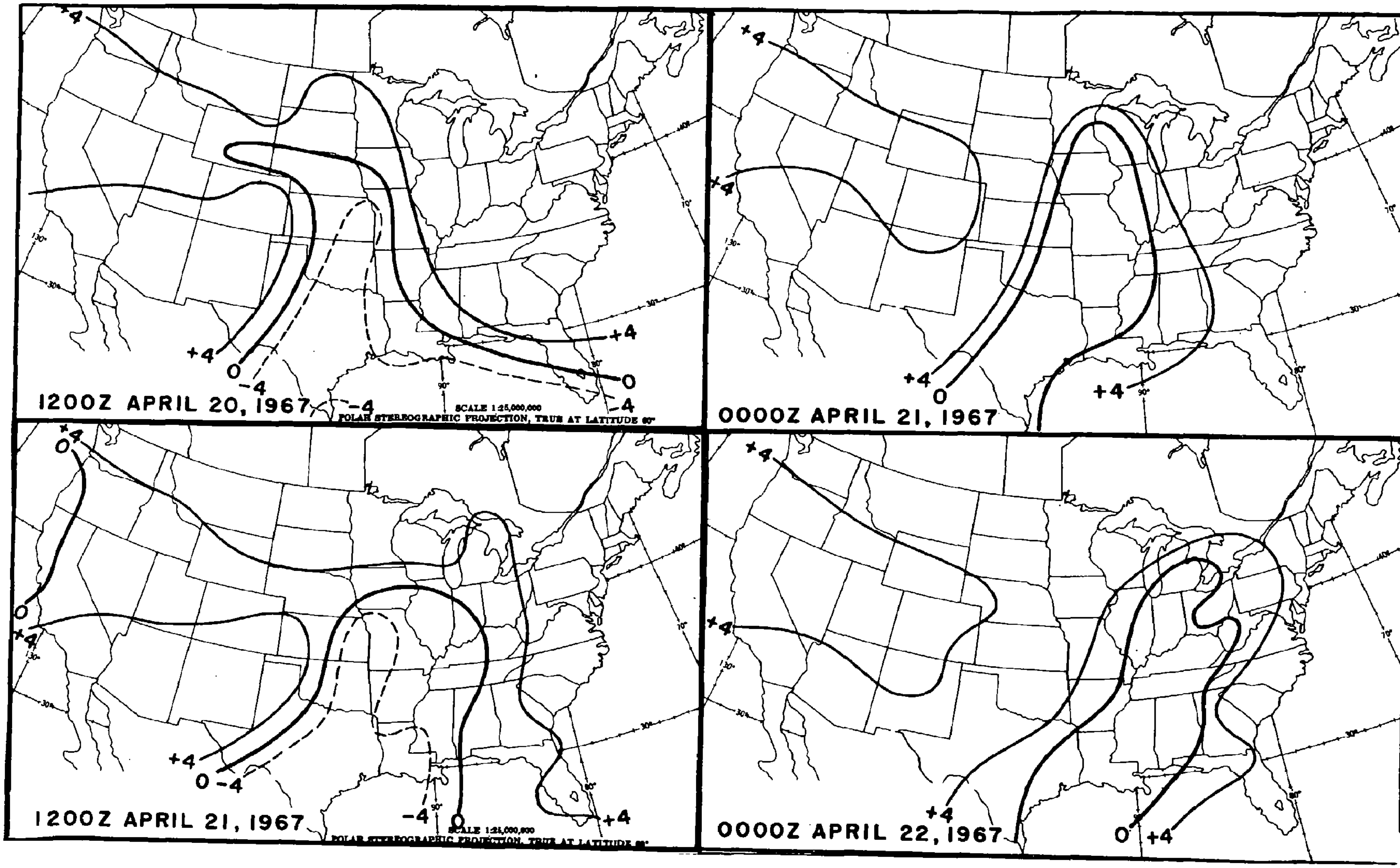
OBSERVED NMC LIFTED INDEX

FIG. 3



OBSERVED SHOWALTER INDEX

FIG. 4



OBSERVED SELS LIFTED INDEX

FIG. 5