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1964 PROJECT SPRINGFIELD STUDIES

Research Report 2
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INTRODUCTION

Previous studies (Danielsen, Bergman, and Paulson, 1962; Danielsen, 1964) have shown that the extremes of beta radioactivity- are positively correlated with extremes of potential vorticity. Since the stratosphere is a reservoir of long-lived very fine radioactive debris, it was then suggested that air that has large values of potential vorticity as well as beta activity originates from a high-level stratospheric source whereas air in which these values are small is from a tropospheric source.

Aircraft flights were made in the spring of 1964 in what is known as PROJECT SPRINGFIELD, to probe the air in the vicinity of squall lines for radioactivity and to establish whether radioactive material from the stratosphere could enter convective systems at mid-tropospheric level from an extrusion. Showers and thunderstorms often failed to materialize in areas where rainwater was being collected, and there was an additional problem in placing operational aircraft during daylight hours in the required region. Nevertheless, the data assembled in 1964 permitted study of the precision with which the boundaries of stratospheric air must be located to achieve reliable accuracy in the analysis of observational data, and, consequently, to evaluate the stratospheric-tropospheric exchange of radioactivity and the subsequent rainout of this activity at the surface by precipitation systems.

For conclusive proof that radioactive particles from a stratospheric source were Intercepted by a precipitating system and deposited on the surface, the following information Is required:

1. Evidence that high concentrations of radioactivity in rainwater were observed at one or more points along the trajectory of the precipitating system.

2. Evidence that strong gradients of potential vorticlty generally coincided with strong gradients of beta activity.

3. Evidence from potential vorticity analysis and/or air samples that the precipitating clouds penetrated at least several thousand feet into the stratosphere, or that they were engulfed by an extrusion of radioactive stratospheric air. This is required because the level at which this air enters the clouds may influence the distribution of the fallout on the surface (Peteris, Kessler, and Newburg, 1963; Peteris, 1964).

It is necessary to define the boundaries of the stratospheric air within a few miles in the horizontal and one or two thousand feet in the vertical during at least one moment in the life history of the precipitating system. For this purpose, continuous records of the radioactivity during horizontal flight are particularly useful, since a change in the rate of accumulation of activity on the air filter shows when a boundary Is passed. Since the positions of the aircraft were indicated against some of the time marks on the chart of the radioactivity recorder used in the 1964 flights, the location of the boundary could be accurately specified.

During the 1964 study, it was found that the flow patterns at different levels were seriously affected by coding and plotting errors in the radiosonde data which often escape attention in conventional upper air analyses. These data provided illustrations of the effect of such errors on the potential vorticity pattern and on the subsequent location of air mass boundaries. It will be shown in the following sections that trustworthy results can be obtained only by the effort of elaborate three-dimensional analysis, unless very detailed observations of winds and temperatures for the air-sample area are available.

In addition to the evaluation of observational and analytical errors, this report presents a detailed study of one storm and mentions preliminary results from several others.

ACKNOWLEDGMENTS

During this investigation guidance was received from Professor E. Danielsen, Pennsylvania State University, through his short course in isentropic analysis. The help of Mr. Parker T. Jones, who carried out a large part of the analysis work, is also gratefully acknowledged. Mr. Bradley Halter and Mr. Morton Epstein assisted with the coding and plotting of the data. The author is indebted to Mr. P. A. Huff who kindly reviewed the manuscript.

Many thanks are also due to the Defense Atomic Support Agency and the Ninth Weather Reconnaissance Group of the U. S. Air Force for successful completion of the flight missions. The planning

and direction of these flights was accomplished by Glenn E. Stout who was appointed Field Director by the Atomic Energy Commission.

The gross beta radioactivity analyses were made by Isotopes, Inc, Westwood, New Jersey.

CONSERVATIVE AIR MASS PROPERTIES AND ISENTROPIC ANALYSIS

The theory and methods of isentropic analysis have been discussed in detail by Danielsen (Danielsen, 1959* Danielsen, et al., 1962; Danielsen, 1964), and will be reviewed only very briefly here.

The potential temperature (0) and the potential vorticity (P_θ) are important tracers of tropospheric and stratospheric air, because of their conservatism for various atmospheric motions. The potential temperature (entropy) is conservative for all dry-adiabatic vertical motions and for turbulent mixing in the isentropic plane; and it is therefore recommended as an atmospheric tracer by some investigators. However, the potential temperature is altered by radiational heating or cooling, condensation, and evaporation.

Potential vorticity (analogous to angular momentum in rigid mechanics) is conservative for vertical displacements, convergence and divergence, and for associated deformation of air parcels. It is also conservative for uniform heating or cooling, but not for differential heating, condensation, and evaporation. It is destroyed by convection and by turbulence in the boundary layer near the surface. Changes in potential vorticity are also likely as a result of mixing along strong gradients of P_θ, mainly by exchange of momentum with ambient air in regions where there are strong variations of the windshear component in the isentropic plane. Direct estimates of the effects of this mixing are difficult, but experience shows that the potential vorticity is nevertheless an excellent tracer of air of stratospheric origin (Danielsen, 1964; Reiter, 1964).

The expressions for potential temperature (9) and potential vorticity (P_θ) ares

$$\theta = T\,(p_o/p)^k \tag{1}$$

$$P_\theta = -g(\partial\theta/\partial p)(\zeta_\theta + f) \tag{2}$$

where T(°K) and p(mb) are the actual temperature and pressure, and P_o the reference pressure of 1000 mb. The exponent k = .286 is the ratio of the gas constant to the specific heat at constant pressure, and g is the acceleration of gravity; $\partial\theta/\partial p$ is a measure of the hydrostatic stability of a parcel subject to a vertical displacement. ζ_θ is the vorticity of the wind projected on a horizontal surface from an isentropic plane (isentropic vorticity), and f is the vertical component of the earth's vorticity. The isentropic vorticity has two components, namely, shearing vorticity and curvature vorticity.

The shearing vorticity, $\zeta_s = -(\partial V/\partial n)$ is computed from the isotach analysis; n is normal to the direction of flow and directed to the left of the flow. The curvature vorticity is defined as

V/R where R is the radius of curvature of the streamlines. The relationship between wind vectors and streamlines is given by

$$\mathbb{V} = \mathbb{k} \times \nabla_H \psi = \mathbb{k} \times \nabla_H \left(C_p T + g Z \right) \qquad (3)$$

in whieh ψ is the stream function, C_p is the specific heat of air at constant pressure, T is absolute temperature, and Z is the height of the isentropic plane above the surface. Except in areas with saturated ascending air, or where strong radiational heating or cooling exists, there is no detectable velocity component normal to the isentropic planes. Both the shearing vorticity and the curvature vorticity are of the same order of magnitude (either positive or negative), and they are also of the same order of magnitude as the positive coriolis parameter, f.

Analysis of the 1964 data showed that errors in the curvature of the streamlines or misplacement of the isotachs with respect to the streamlines could easily affect the sign of $(\zeta_\theta + f)$ and, thus, that of P_θ. As a result of these errors, air with negative vorticity was sometimes indicated in the polar stratosphere where it obviously was not present. Also, the construction of trajectories is greatly affected by errors or ambiguities in the location of the velocity maxima with respect to the streamlines. The radiosonde stations are too far apart for independent analyses to remove these ambiguities. However, vertical cross-sections help to locate the wind maxima in the proper place, provided that the underlying dynamical principles are satisfied.

Much of the analysis revolves around the thermal wind relationship. With the windshear vector pointing into the cross-section

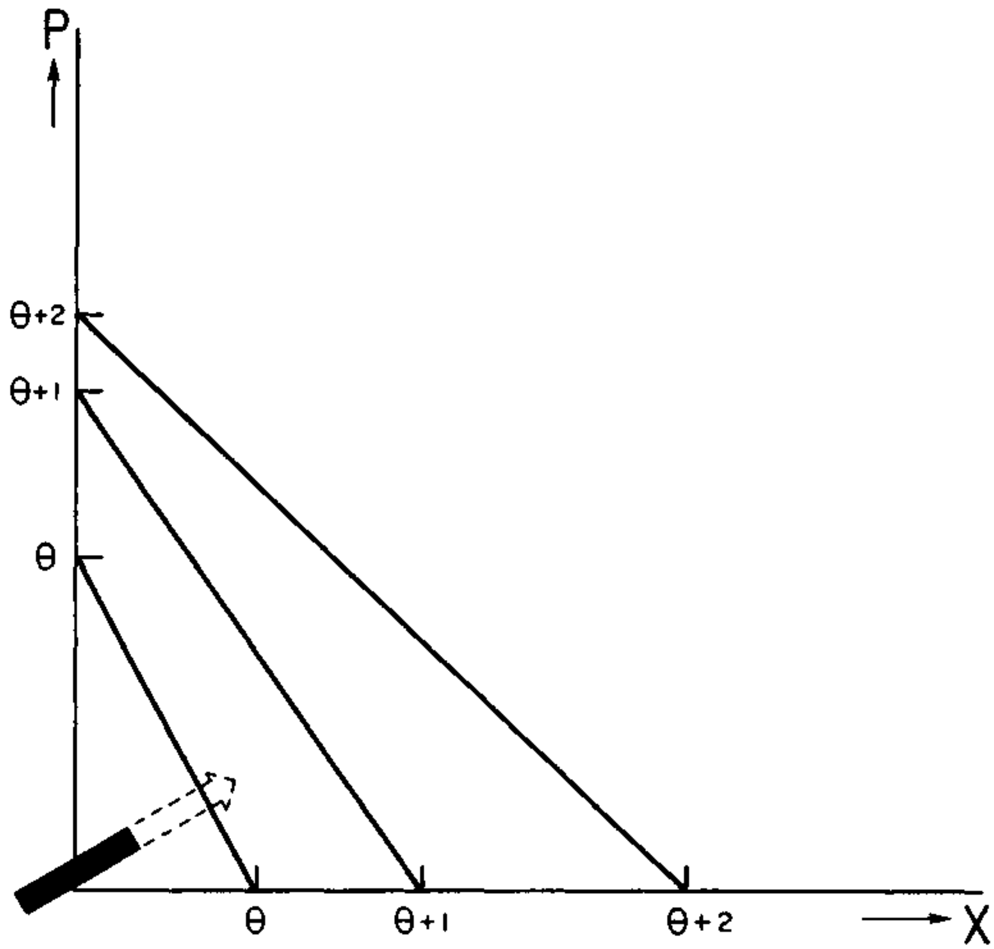


FIGURE 1. RELATIONSHIP BETWEEN THERMAL WIND VECTOR AND SLOPE OF ISENTROPES IN AN X-P DIAGRAM

(figure l), warm air should be found to the right and cold air to the left. Since the potential temperature increases with height, the isentropes should have a negative slope wherever the thermal wind blows into the cross-section (figure l). The steepness of the slope is determined by the magnitude of the thermal wind vector. One can come close to reality only when these requirements are met everywhere on the cross-section and when, in addition, the isotach and streamline analyses on a number of isentropic surfaces through the cross-sections are consistent with the analysis of the cross-section.

The thermal wind relationship as well as the geostrophic wind relationship, which determines the distance between the streamlines on the isentropic surface for given wind vectors, are based on the assumption of balance of forces. According to experience, deviation of the winds from geostrophic balance affects the thermal wind relationship to a lesser extent than the relationship between winds and streamlines, since $\partial/\partial z \left(dV/dt \right)$ can be zero while dV/dt is not (Danielsen, 1959, 1965). Furthermore, where the flow accelerates, the wind should blow towards low values of ψ; where it decelerates, it should blow towards high values of ψ; and the analysis should show this relationship. The theory and equations are presented in detail by Danielsen (1959, 1964).

DISCUSSION OF ANALYSIS EXAMPLE

An example of a consistent set of data with respect to vertical cross-section, isotach analysis, and streamline analysis is

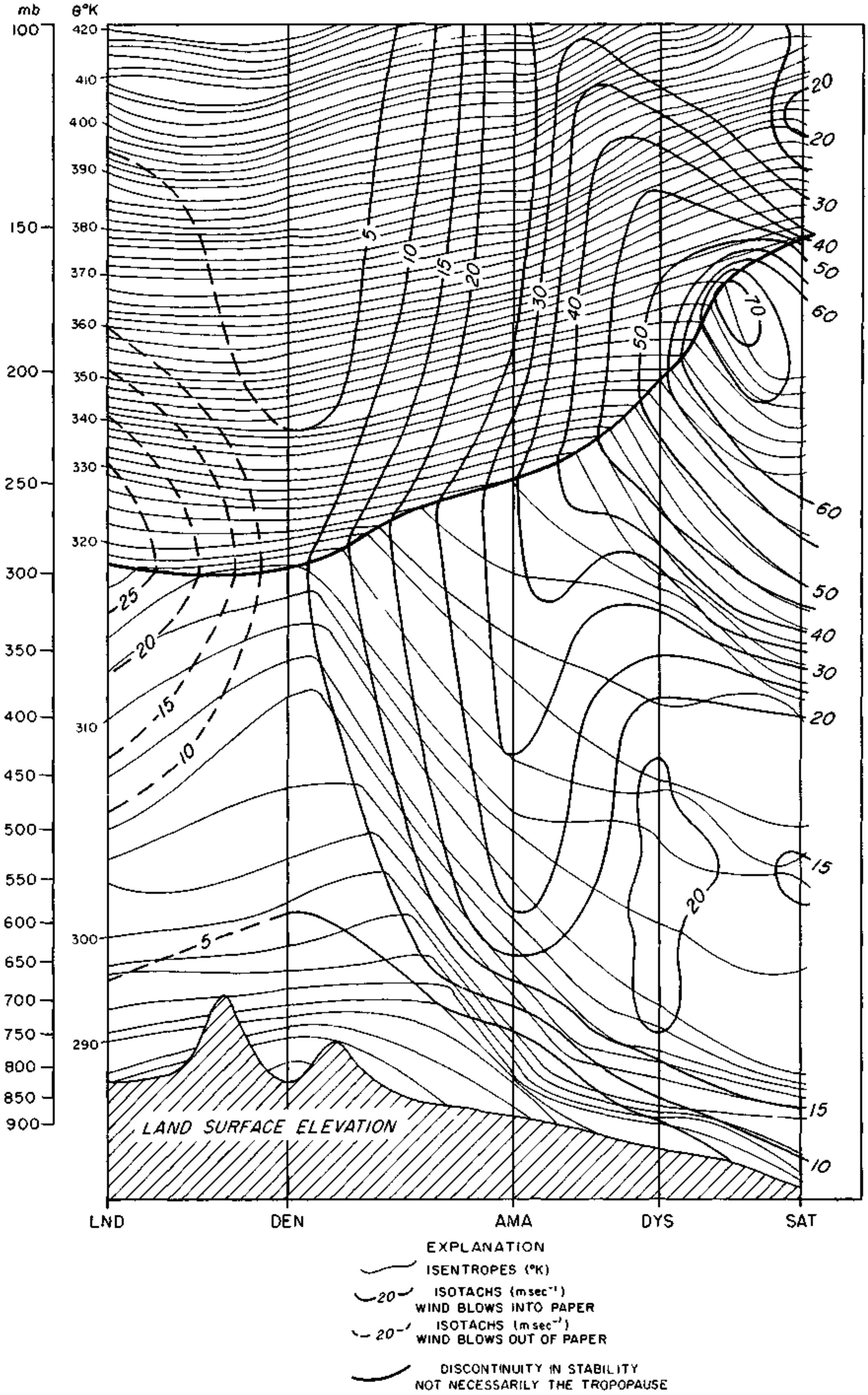


FIGURE 2. ATMOSPHERIC CROSS-SECTION, APRIL 4, 1964, 1200 Z

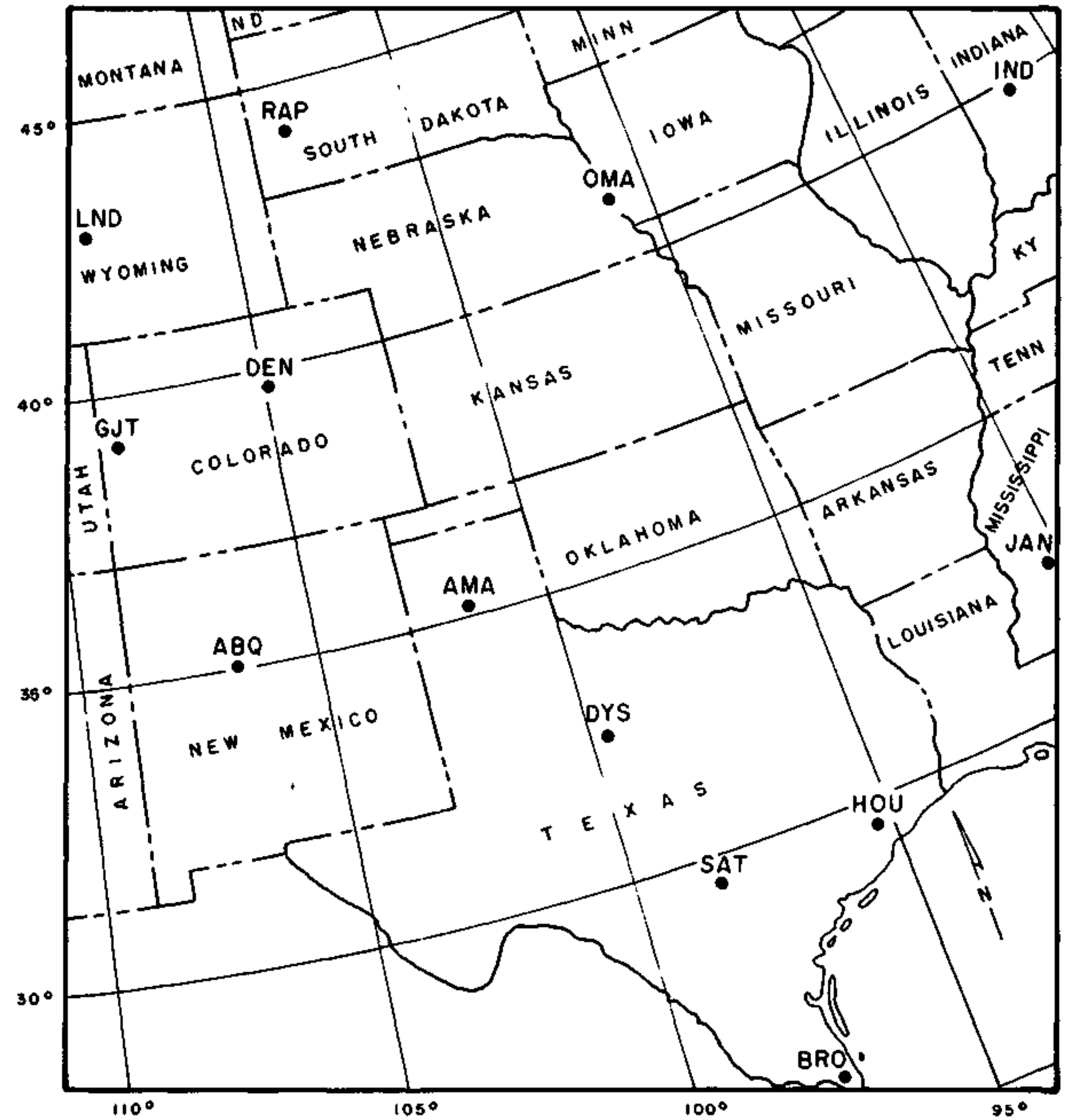


FIGURE 3. AREA OF STUDY

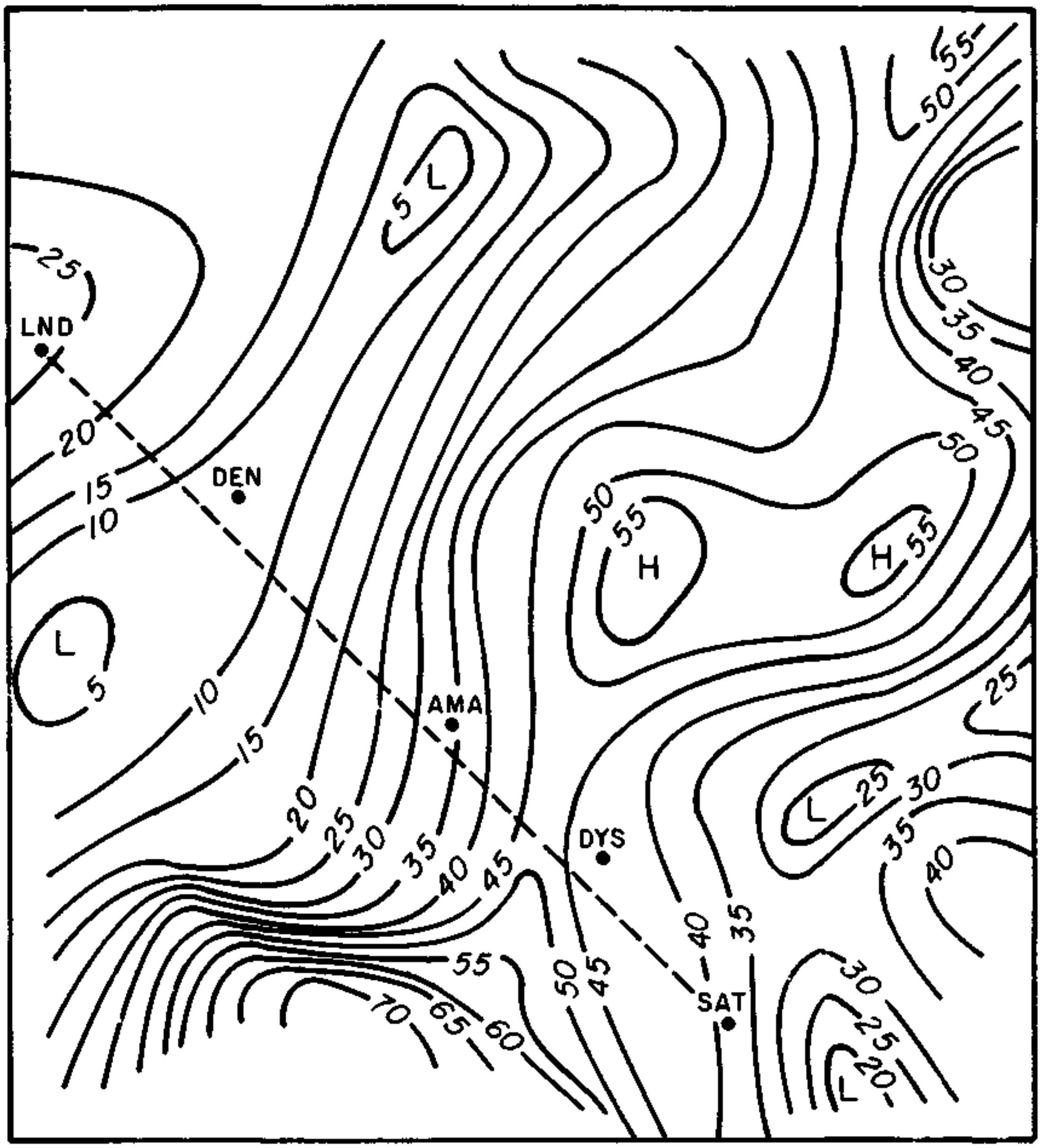
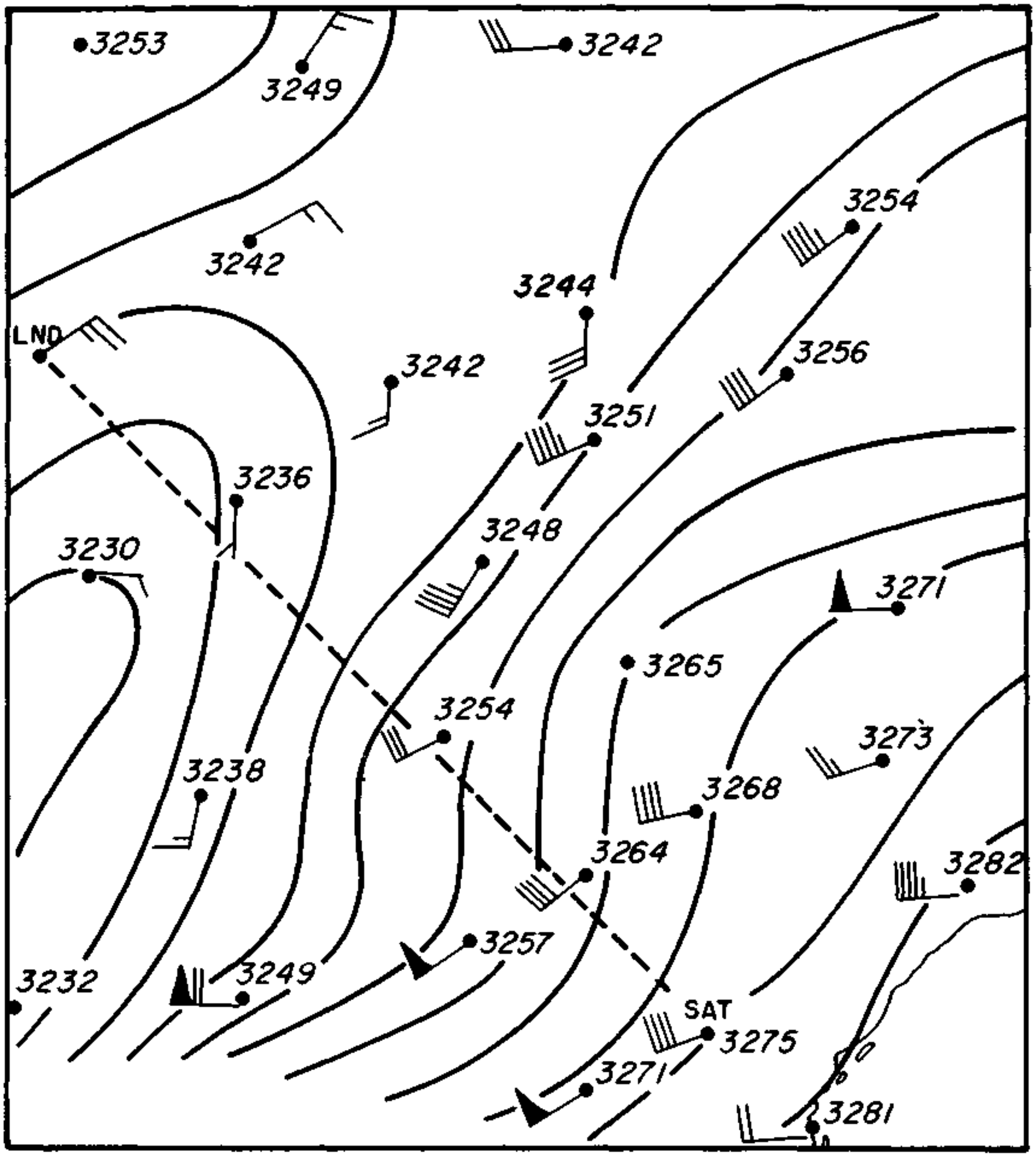


FIGURE 4A. ISOTACH ANALYSIS ($M\ SEC^{-1}$) ON THE ISENTROPIC SURFACE OF 330°K AT 1200 Z ON APRIL 4, 1964



EXPLANATION

WIND AIR AND SPEED (m sec^{-1})

STREAMLINE

3242 STREAM FUNCTIONS, 10 m^2 sec^{-2}

FIGURE 4B. STREAMLINE ANALYSIS ON THE ISENTROPIC SURFACE OF 330°K AT 1200 Z ON APRIL 4, 1964

shown In figures 2, 4a, and 4b. The analyses were made over the Southern Plain states and the eastern part of the Rockies (figure 3). A dashed line Indicates the location of the cross-section with respect to the isentropic maps. The streamlines In figure 4b have been made consistent with the isotach analysis in figure 4a. Similar analyses are made for a number of isentropic surfaces. Then a number of cross-sections are analyzed independently, Note the relationship between the vertical windshear and the isentropes in the cross-section of figure 2. The change of wind direction with height (not shown in the diagram) is also incorporated. Finally, adjustments of the isentropes and isotachs in the cross-section are made concurrently with adjustments of isotachs and streamlines on the horizontal maps until all ambiguities and contradictions have been removed.

Errors in the wind measurements and local effects, such as funneling of the flow over mountains or circulations through thunderstorms, present analysis problems which are not so readily solved. Here, the forces are likely to be badly out of balance. Gravity waves may be detected, since they give rise to fallacious wind maxima deep inside the stratosphere, but even when the cross-sections look acceptable, there still may remain ambiguities in the horizontal analyses where the winds do not fit the streamlines in a reasonable way.

How the acceptance or rejection of only one observation affects the computed distribution of potential vorticity is indicated in figures 5 and 6. A wind observation is accepted at face value in figure 5a. In figure 6a this wind is discarded and wind direction and speed are computed from the streamline analysis by means of the geostrophic relationship. The minimum in the potential vorticity P_θ on figure 6b is much less extensive than that in figure 5b. Since the values of P_θ in this minimum are representative of tropospheric air, an assessment of the presence or absence of an intrusion of tropospheric air into the stratosphere depends on the judgment of the analyst. This ambiguity is disastrous when one wishes to prove or disprove the entrainment of stratospheric air by precipitating clouds. Hence, a need exists for more detailed temperature and wind measurements in critical areas to overcome the problem brought out above (Danielsen, 1959).

Small coding or plotting errors in the data, though of little importance in routine synoptic analysis, seriously affected the values of the isentropic stream functions in the 1964 cases. This made it necessary to scan through the complete set of soundings, plot the dubious parts, correct the errors, and recompute the stream functions. This procedure improved the analyses considerably. Also, in those cases in which the data above a given level were missing, the last observation showed a wind speed which was often several tens of knots too high. These erroneous observations, suspected to be due to leakage or low elevations of the balloon, resulted in fallacious wind maxima on the cross-sections.

Since the computer program used in the analyses interpolates the wind for levels of constant potential temperatures, one erroneous wind or temperature on the sounding affects several isentropic

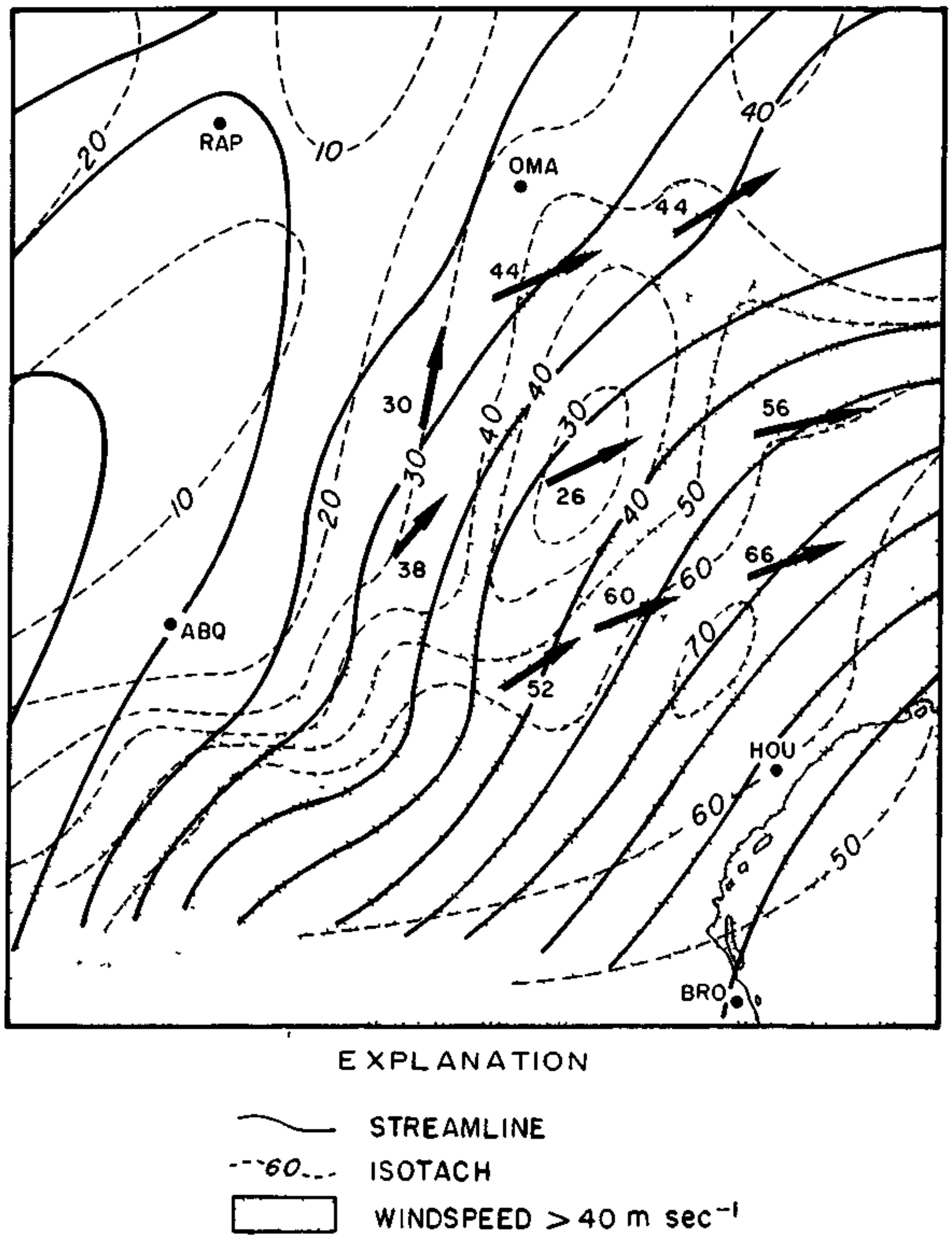
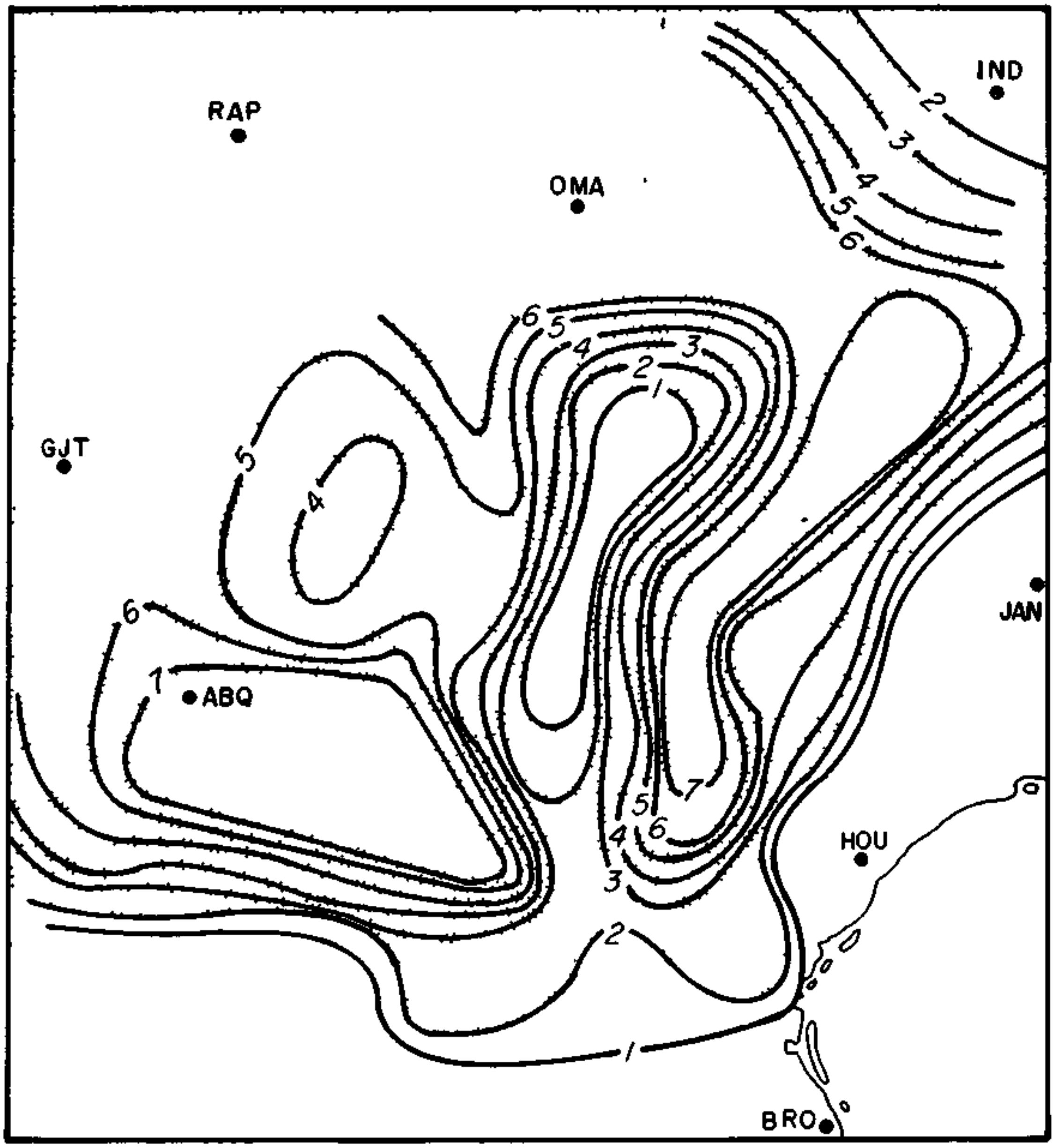


FIGURE 5A. STREAMLINES AND ISOTACHS ON THE ISENTROPIC SURFACE OF 340°K AT 1200 Z ON APRIL 4, 1964, VERSION 1



EXPLANATION

—7— ISOPLETH OF POTENTIAL VORTICITY (10^8 deg. cm. sec. gm^{-1})

☐ $P_\theta > 2 \times 10^8$ deg. cm. sec. gm^{-1}

FIGURE 5B. DISTRIBUTION OF POTENTIAL VORTICITY, P_Θ COMPUTED FROM FIGURE 5A

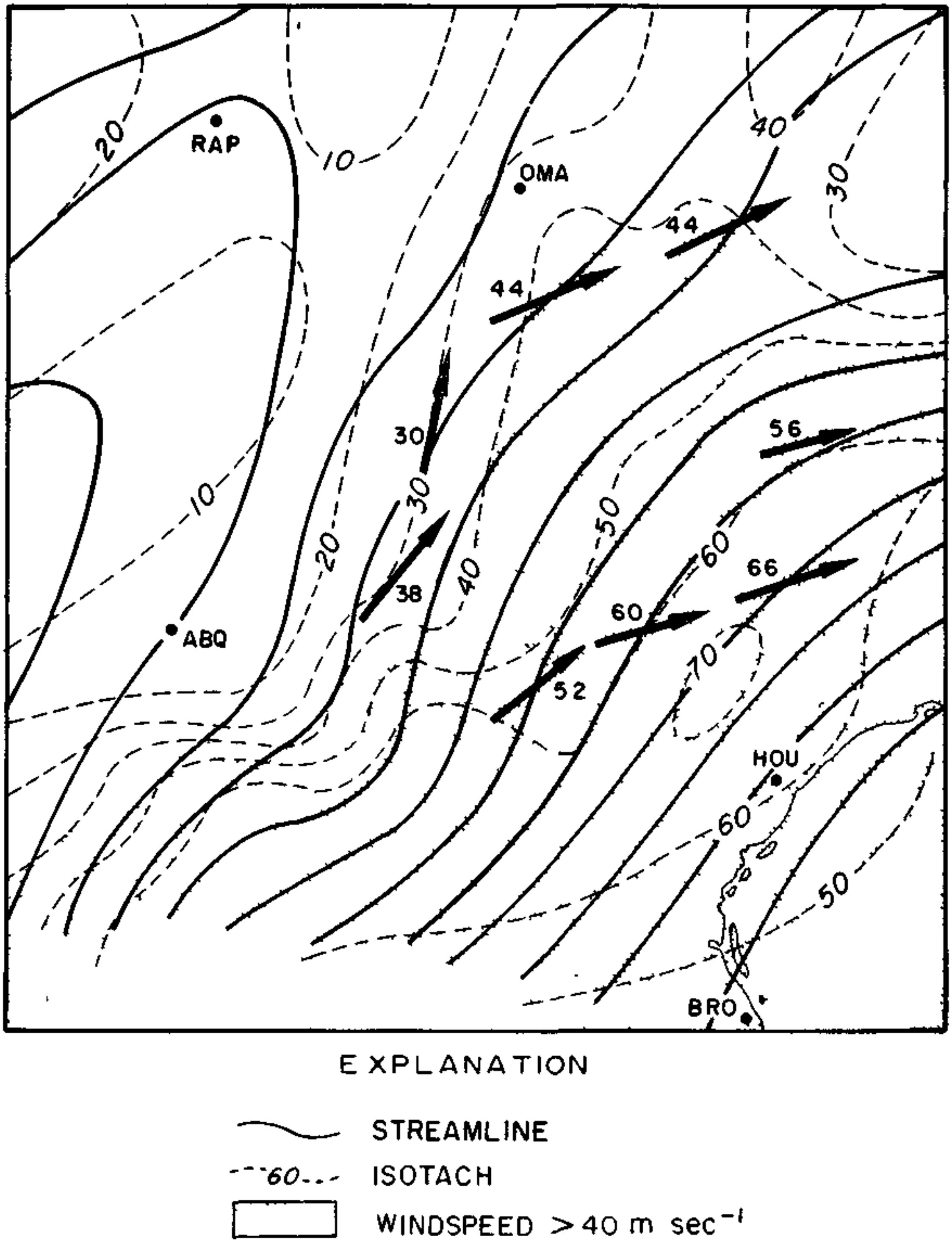
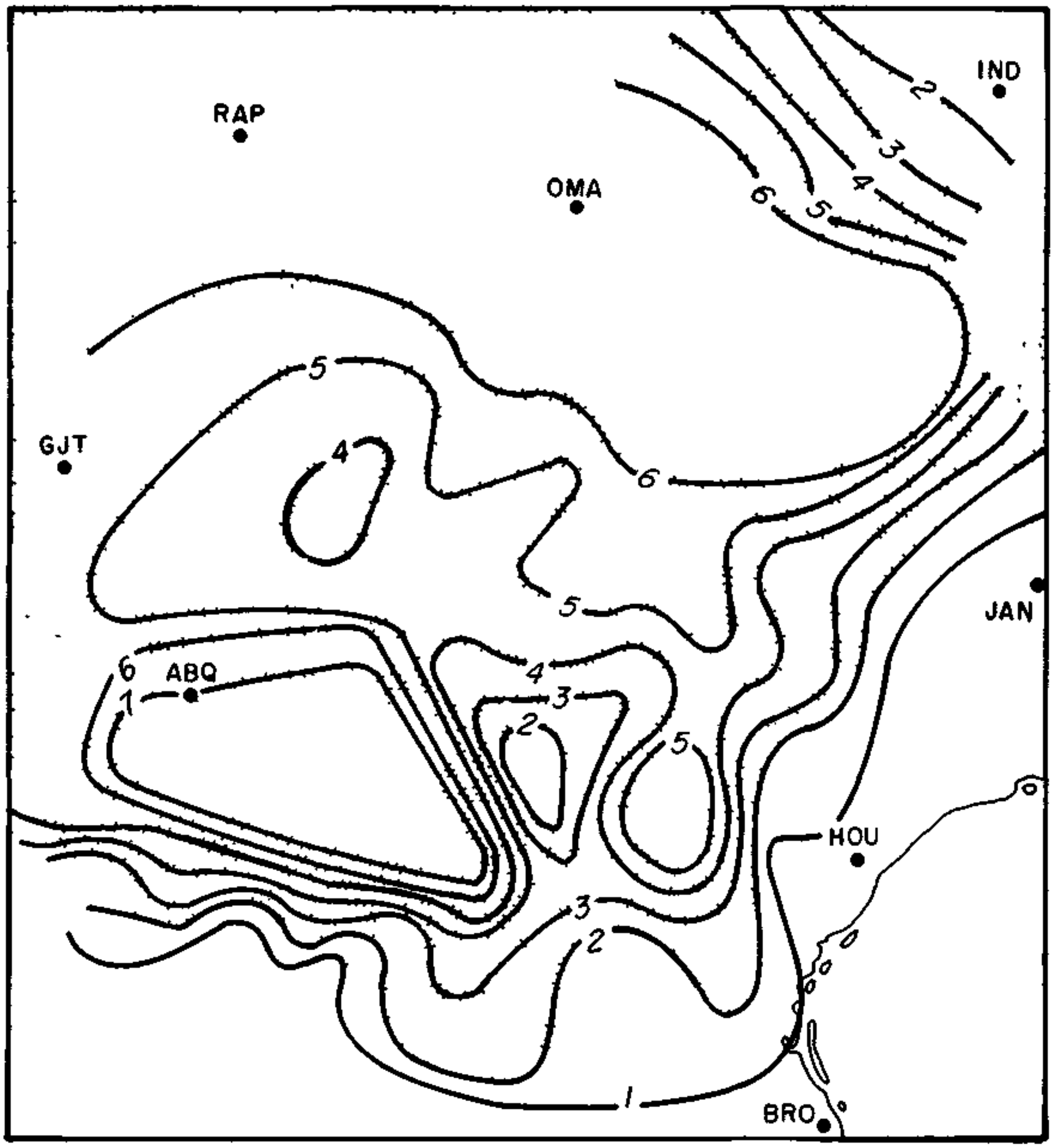


FIGURE 6A. STPEAMLIIES AND ISOTACHS ON THE ISENTROPIC SURFACE OF 340°K AT 1200 Z ON APRIL 4, 1964, VERSION 2



EXPLANATION

—7— ISOPLETH OF POTENTIAL VORTICITY (10^8 deg. cm. sec. gm^{-1})

☐ $P_\theta > 2 \times 10^8$ deg. cm. sec. gm^{-1}

FIGURE 6B. DISTRIBUTION OF POTENTIAL VORTICITY COMPUTED FROM FIGURE 6A surface analyses. This makes the completion of a consistent set of horizontal and vertical isentropic analyses a time-consuming job which is not feasible for operational use, although the application of the underlying principles is recommended for many kinds of meteorological analyses.

In most cases air samples were made in between the time of scheduled standard balloon flights. The location of the sampled air parcels at map time had to be determined by means of trajectory analysis. Since two consecutive maps are needed for this analysis, the errors in the trajectories will contain errors in both maps. The data did not permit unambiguous map and trajectory analysis, and since it was difficult to assess the nature of the likely errors, the emphasis was shifted towards the presentation of synchronous (or nearly snychronous) distributions of radioactivity, potential temperature, and horizontal and vertical motions. These distributions indicated a fairly good correlation between radioactivity and potential vorticity. Also, they suggested how radioactive air could have entered thunderstorms and squall lines and the approximate location of the entry.

STORM OF APRIL 4, 1964

Radioactivity in Relation to the Tropopause

The cross-section in figure 7 shows the distribution of radioactivity with respect to the boundary between tropospheric and stratospheric air. This boundary was made to coincide with the potential vorticity isopleth of 2×10^{8} cm sec deg gm^{-1}, since in

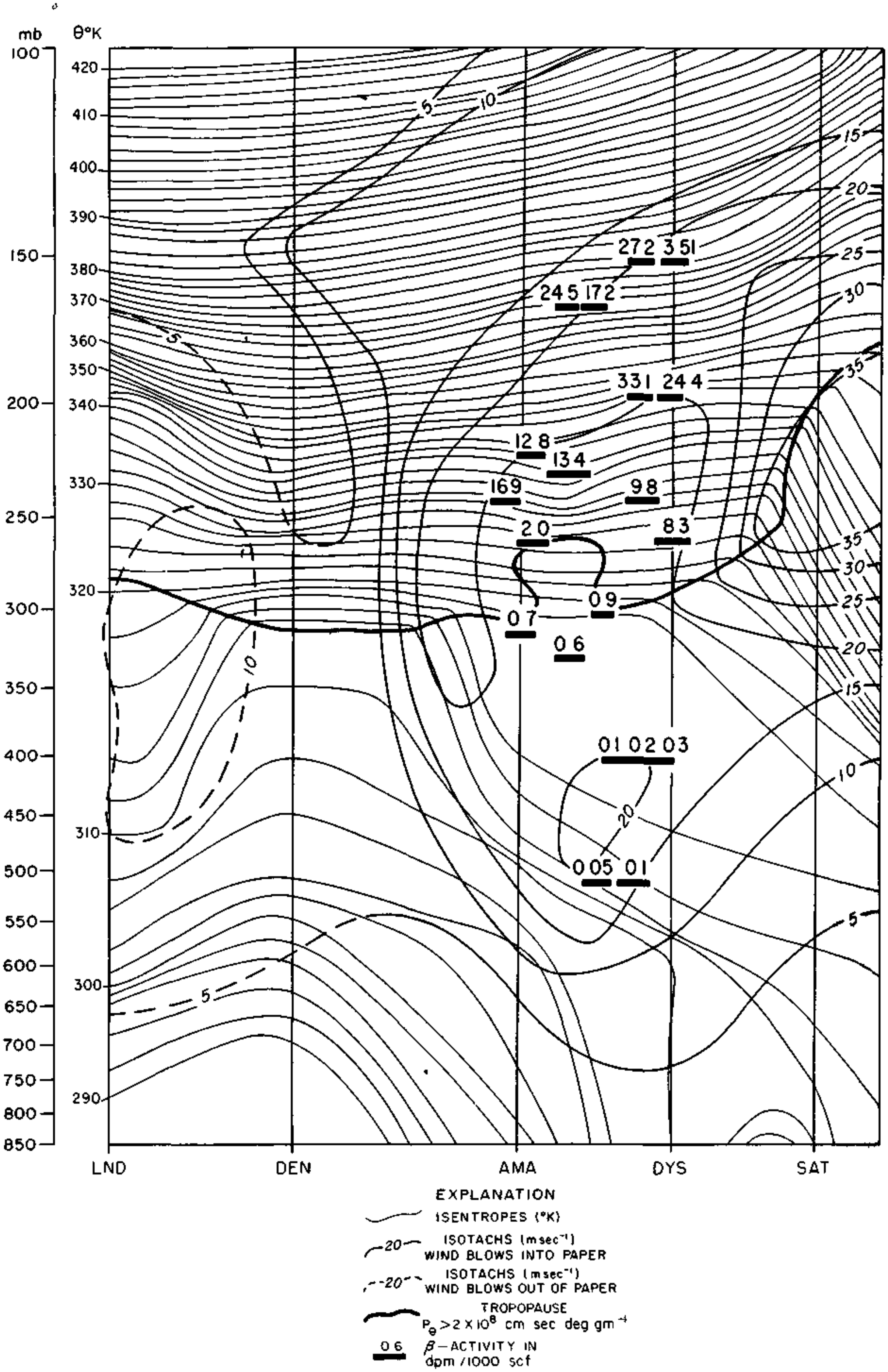


FIGURE 7. CROSS-SECTION ON APRIL 4, 1964, 0000 Z

many places this isopleth marks the discontinuity in stability which corresponds to the definition commonly employed in operational forecasting.

The changes in the radioactivity counts near this boundary indicate a change in the gradient of the concentration of radioactive debris, rather than a "zero order" discontinuity. This suggests some diffusion of radioactive material along the isentropic surfaces. A similar change in the potential vorticity gradient can be anticipated, but its sharpness is difficult to assess from conventional synoptic data. The precision with which the boundary of the stratospheric air could be located in cross-sections such as figure 7 seems to be of the order of 300 meters in the vertical. The aircraft samples of β activity narrow the limits of uncertainty to a considerable extent.

Radioactivity in Relation to a Stratospheric Extrusion

For conclusive proof of whether or not radioactive debris from the stratosphere entered precipitating clouds and at what levels, the boundaries need to be located within a few miles from the cloud edge. Such locating is difficult, especially where stratospheric air descends in extrusions. An extrusion which looks like a bag or funnel-shaped extension on a cross-section is in reality a very thin filament of stratospheric air, which may be less than one hundred miles wide and less than a mile deep. The uncertainty in determining its horizontal extent has already been indicated in figures 5 and 6.

A search was made through the recordings of radioactivity-counts on the flight track of a B-47 aircraft for points of abruptly increased radioactivity. These discontinuities were found, however, only during the climb or descent of the B-47. Since the traces also show the increase of background radiation with height, the moment of transition of the boundary is, again, ambiguous. This was also the case on the only occasion on which an instantaneous picture at map time could be obtained,, The matching of the potential vorticity distribution with the other observations required trajectory analysis, which added more uncertainties.

It was felt that in spite of the extreme care taken to obtain a consistent three-dimensional synoptic scale analysis of the distribution of potential temperature, wind, and potential vorticity, conclusive proof of entrainment by a precipitating system of stratospheric air from long, thin extrusions will be extremely difficult to obtain from conventional meteorological data. As has been mentioned earlier, recordings of beta activity during flights can be used to locate the boundaries of extrusions with more precision. It is then assumed that a strong correlation between beta activity and potential vorticity exists. Unless experiments are carefully planned, even the recordings of beta activity counts can remove only a small part of the ambiguities in the analysis of ordinary radiosonde data.

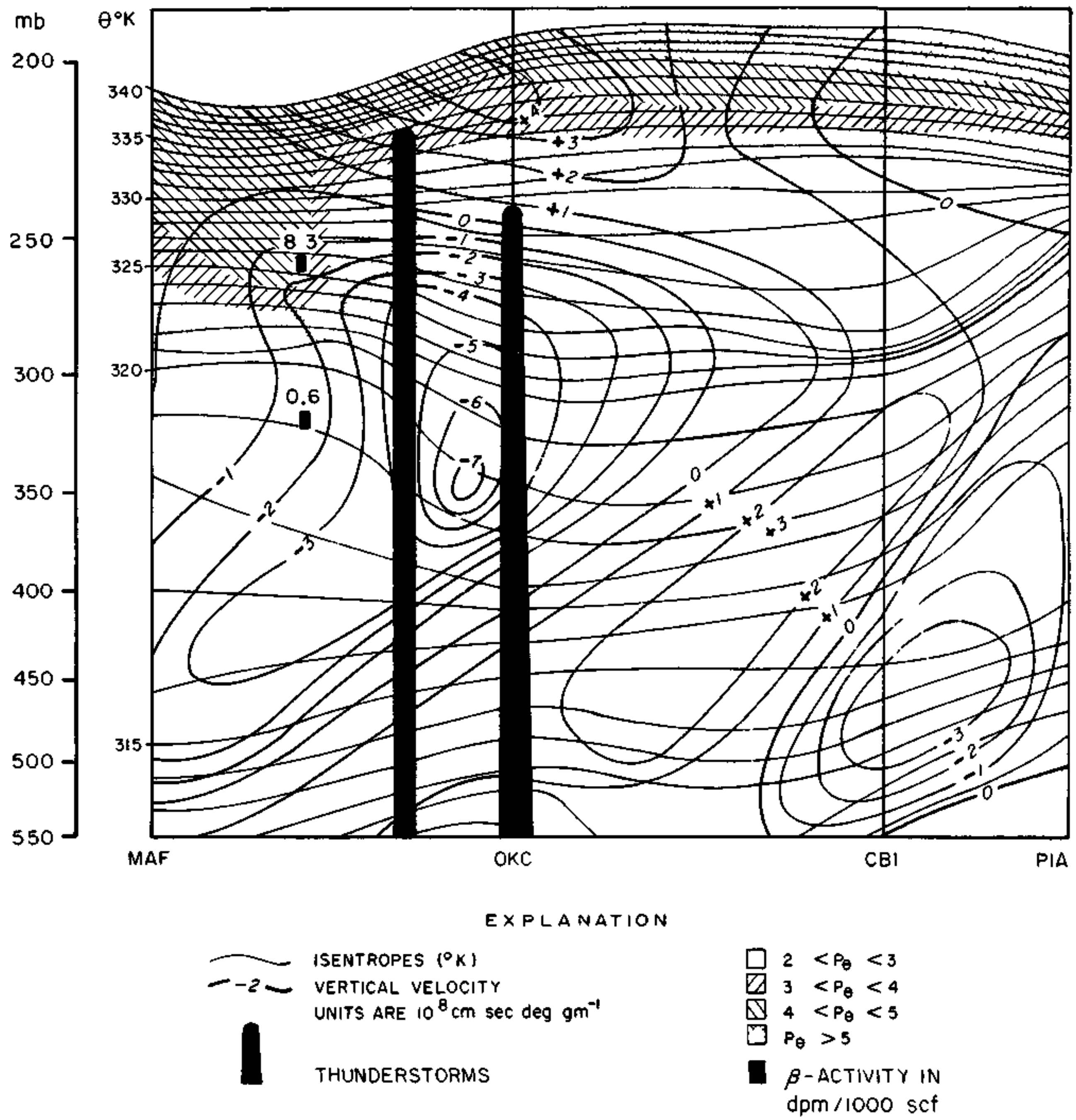


FIGURE 8. CROSS-SECTION THROUGH A REGION OF THUNDERSTORMS AT 0000 Z ON APRIL 4, 1964

Location of the Boundary of Stratospheric Air In Relation to Tall Convective Clouds

In the vertical, uncertainties are much less than in the horizontal plane,, Where tall convective clouds penetrate into the stratosphere, radar and aircraft measurements of cloud tops, combined with synoptic-scale potential vorticity analysis, will usually permit a determination of the extent of the penetration within less than 1000 meters. The result of such an analysis is presented in figure 8.

Additional information about the distribution of vertical motions in the upper troposphere and lower stratosphere was provided by a combined isobaric-isentropic analysis, the technique of which has been described elsewhere, for instance, by Reiter (1963a). The vertical velocity field thus obtained forms a consistent pattern with the distribution of large-scale convection and also indicates the sense in which the folding of the tropopause was progressing at the time of the observations.

The cross-section in figure 8 runs parallel to the main component of the wind, which blows generally from left to right. It intersects a region with thunderstorms, which were located by the radar of the National Severe Storms Laboratory in Norman, Oklahoma, at 0000 Z on April 4. The upper parts of the storms penetrated a region with cold advection and fairly strong descending motions in the upper troposphere. The descending motions extended into the stratosphere, where the potential vorticity distribution indicated the beginning of the formation of an extrusion. The cold advection aloft and the warm advection in the middle troposphere suggest a destabilization sufficient to trigger large storms. The descending motions aloft could have brought down air with high potential vorticity and high concentrations of radioactive material. There was no collection of rainwater at this time in the Oklahoma area to substantiate the upper air analyses of the data.

It goes beyond doubt that instantaneous pictures of the thermal structure of the atmosphere and the vertical velocity field in relation to weather systems and sources of radioactivity can be very valuable for the study of entrainment of radioactive air in precipitation. It is therefore important to show to what extent they can be relied upon.

Vertical Motion Patterns in the Isentropic Plane

Although the isentropic analysis gives a good qualitative estimate of the vertical velocity pattern, Reiter (1963a) questions the accuracy of quantitative results in regions of wind maxima, where the angle between isobars and isentropes is small and, hence, small changes of these angles may seriously affect vertical velocity computations. To investigate the ambiguities in this type of analysis, the vertical velocity pattern was first computed from the actual wind at each radiosonde station on April 4, 1964. These winds contain geostrophic departures (inertia, curvature) as well as errors. It was soon found that missing data introduced uncertainties in the location of the boundaries of rising and sinking motions as well as in the maxima. In regions with acceptable data coverage, only moderate vertical velocities were encountered. In figure 9, a vertical velocity pattern is

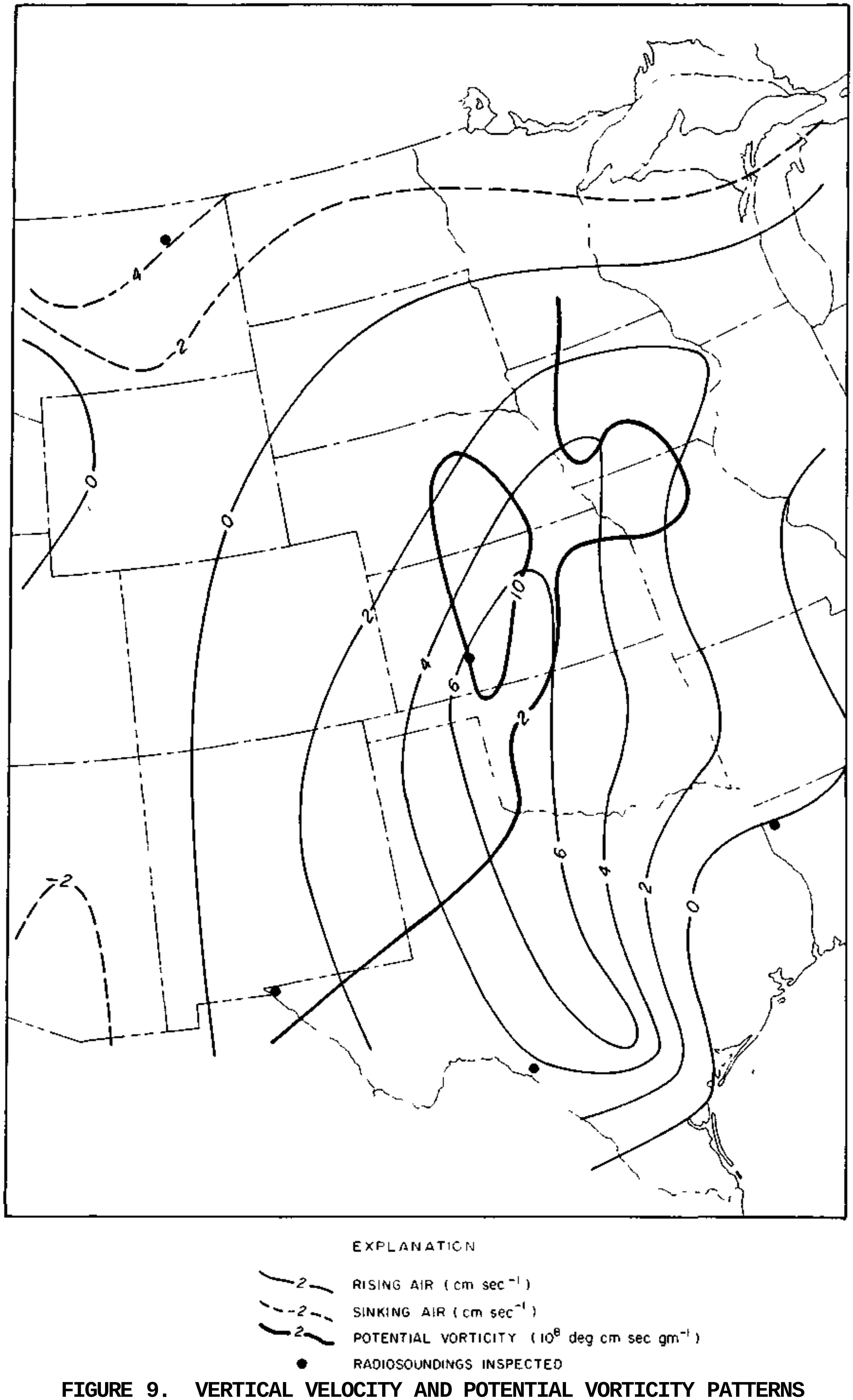


FIGURE 9. VERTICAL VELOCITY AND POTENTIAL VORTICITY PATTERNS COMPUTED FROM ACTUAL WINDS AND ISOBARIC FIELD ON THE ISENTROPIC SURFACE OF 335°K AT 0000 Z ON APRIL 5, 1964

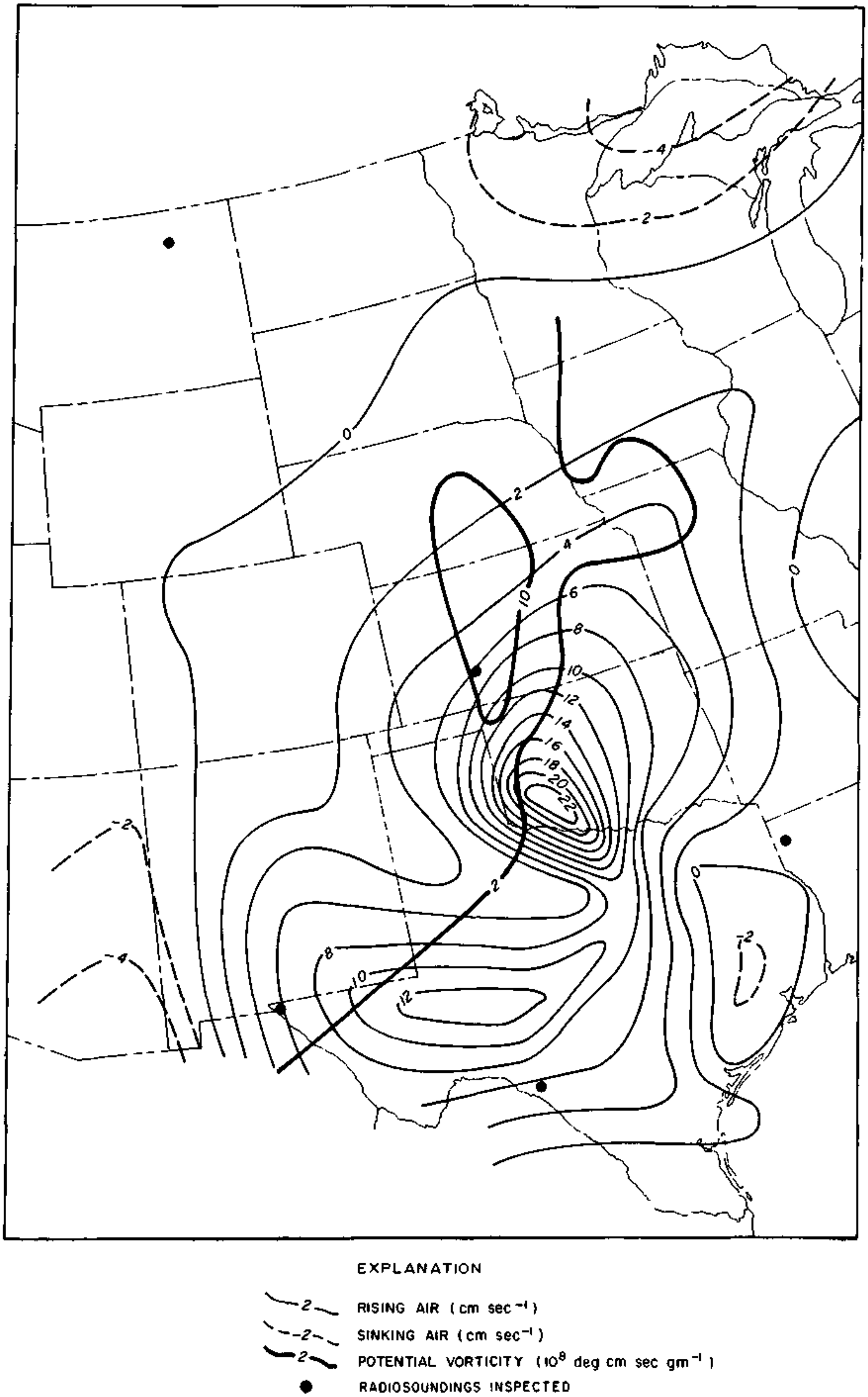


FIGURE 10. VERTICAL VELOCITY AND POTENTIAL VORTICITY PATTERNS COMPUTED FROM STREAMLINES, ISOTACHS AND ISOBARS ON THE ISENTROPIC SURFACE OF 335°K AT 0000 Z ON APRIL 5, 1964

superimposed on the corresponding potential vortlcity pattern, The analysis shows air rising at 7 cm sec^{-1} in the troposphere as well as in the stratosphere.

Next, the vertical velocities were computed from the direction of the streamlines and the isotach pattern. The latter may contain components of geostrophic departures in the direction of the streamlines, but since the isotachs in this particular case were consistent with the distance between the streamlines as well as with the vertical cross-sections, it was assumed that the flow pattern was almost geostrophic. The vertical velocity pattern in figure 10 is in much better agreement with the location of the stratosphere, where the stability of the air inhibits large vertical displacements. However, the pattern is much less smooth and indicates several maxima and minima. It is difficult to" say offhand whether omission of geostrophic departures of the winds introduced errors in the wind direction large enough to account for the high vertical velocities displayed in figure 10.

A comparison with the soundings from the stations marked in figures 9 and 10 gave fairly weak relationships between relative humidity and vertical motions, although the two were positively correlated. Since this evidence was rather inconclusive, vertical velocities computed for a number of isentropic surfaces were transferred onto the cross-section in figure 11. It can be seen that the sense of the horizontal air velocity component in the plane of the cross-section is determined by the sign of the vertical motion. On the 335 K surface, areas of diffluence and confluence are found,

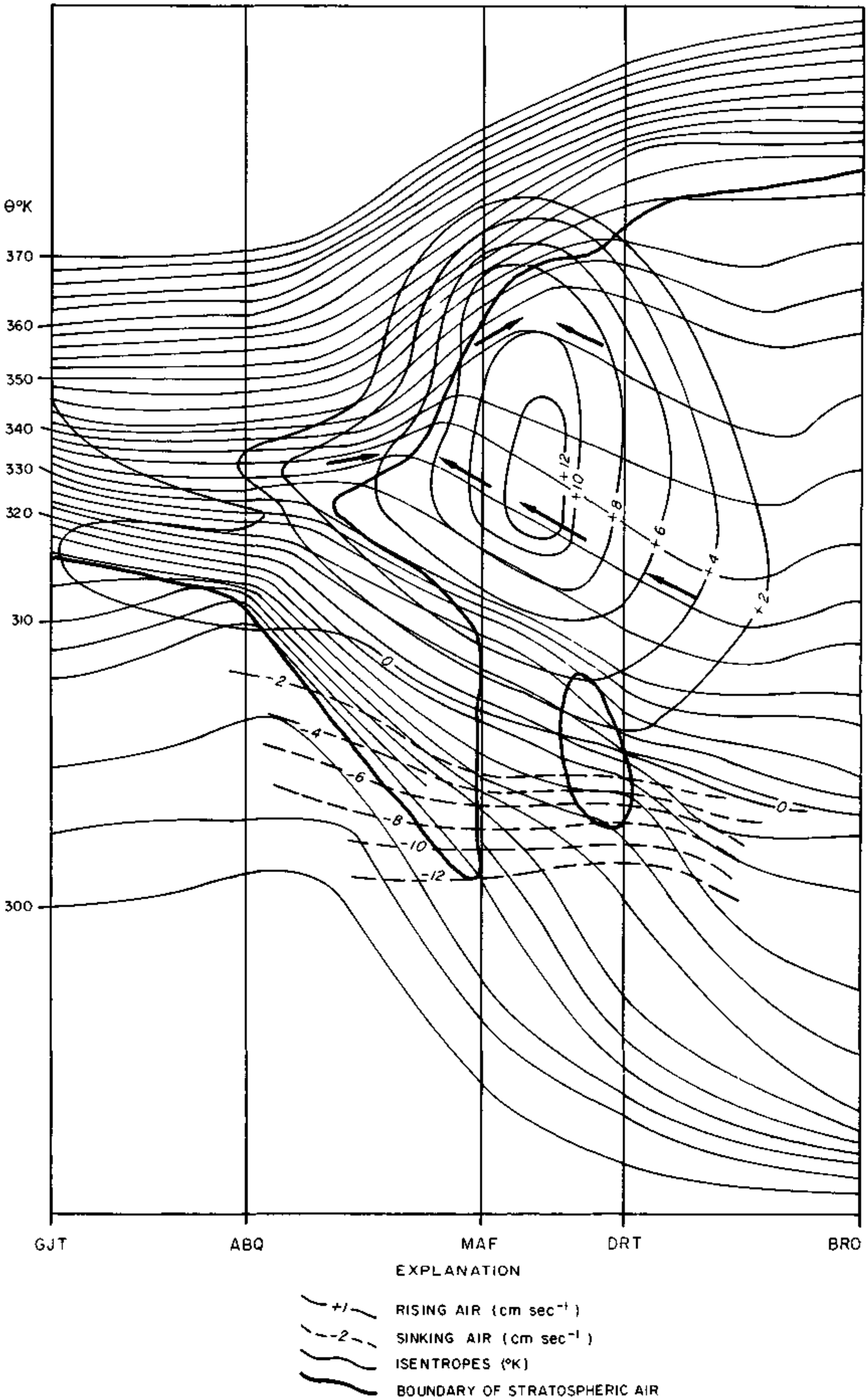


FIGURE 11. CROSS-SECTION AT 0000 Z ON APRIL 5, 1964

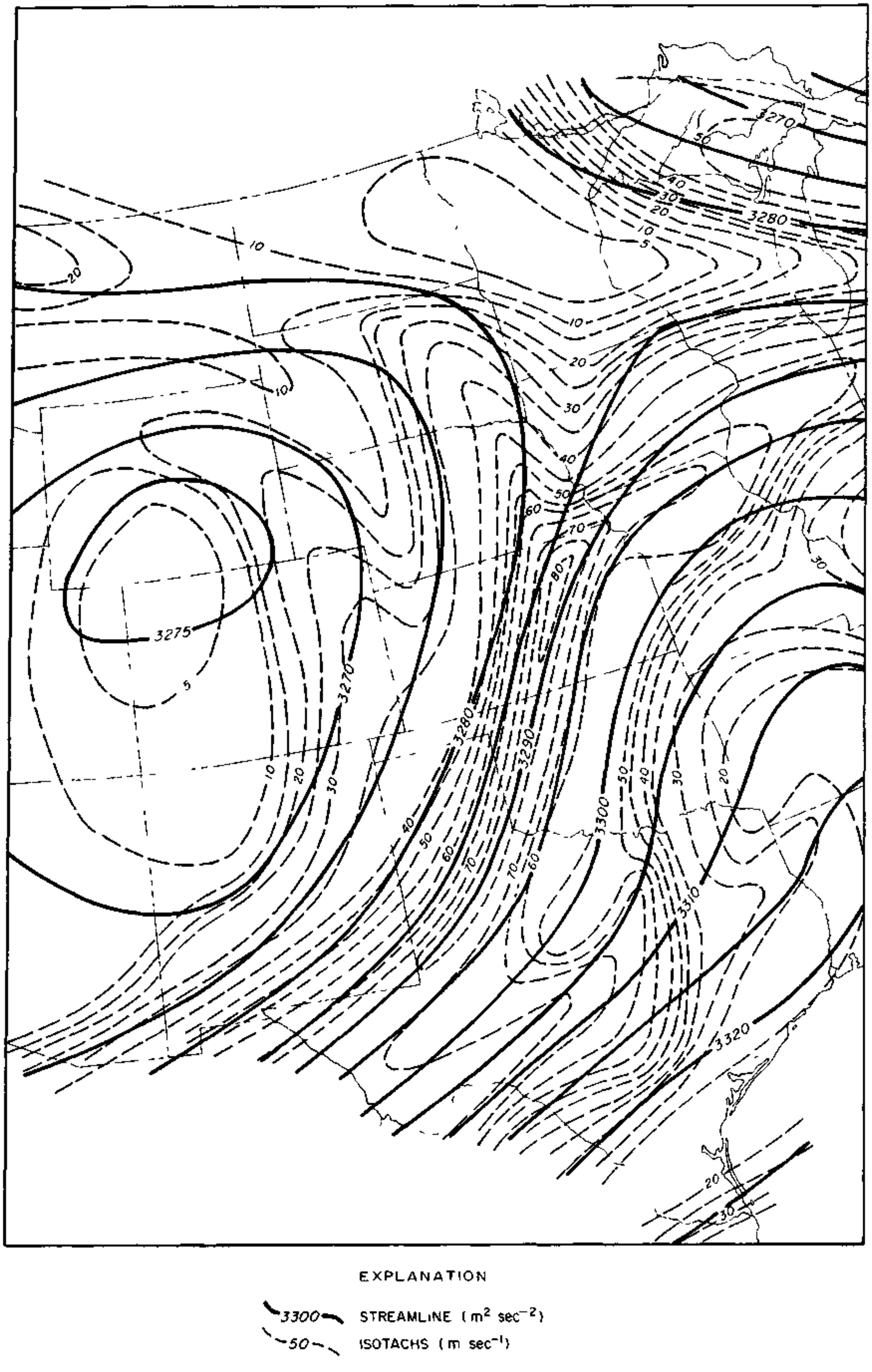


FIGURE 12. STREAMLINE-ISOTACH PATTERN ON THE ISENTROPIC SURFACE OF 335°K AT 0000 Z ON APRIL 5, 1964

i.e., $\partial u/\partial x$ on the isentropic plane is not zero. X is In the plane of the cross-section and points to the right. Since the component of the air motion perpendicular to the isentropic plane is zero by definition for sinking motions and close to zero in moist ascending air at the levels considered, $\partial u/\partial x + \partial v/\partial y$ must be very close to zero. Thus, $\partial v/\partial y$ must be equal and opposite to $\partial u/\partial x$ (V and Y point Into the paper). The cross-section in figure 11 and the streamline-isotach pattern in figure 12 show that this relationship Is qualitatively correct; it is incorrect for the vertical velocity pattern computed from the actual winds (figure 9).

The vertical velocity pattern in figure 10, the cross-section of figure 11, and the streamline-isotach pattern of figure 12 form a consistent set of analyses, whereas the pattern of figure 9 is inconsistent with the other analyses. Therefore, it must be concluded that the vertical velocity pattern computed from the set of streamlines, isotachs, and isobars on an isentropic surface is superior to that computed from actual winds, which contain errors in wind direction larger than the neglected geostrophic departures (Reiter, 1963a, chapter 2; 1963b). Also, the following conclusions can be safely drawn from the cross-section of figure 11:

1. An intrusion was formed by rising tropospheric air between stations at Midland Air Force Base (MAP) and Del Rio, Texas (DRT).

2. The extrusion near Midland Air Force Base was shrinking in the vertical and stretching in the horizontal.

The Interpretation of the flight data on April 4 requires additional analysis of the 1800 Z meteorological information. Since winds were available, but only a few radiosondes, a different analysis technique must be used. Since this technique Is presently being tested, a discussion of the flight data is deferred to the next report,

CONCLUSIONS

The analysis of the data for April 4, 1964, has shown that in spite of all efforts to obtain a dynamically and internally consistent three-dimensional analysis of conventional wind, pressure, and temperature data, there remain ambiguities of 50 to 100 miles in the horizontal location of the boundaries of the stratospheric air. These ambiguities may be a few thousand feet in the vertical. Missing wind data and temperature errors, though not disastrous In routine meteorological analysis, can seriously affect the potential vorticity computations for several isentropic surfaces. Trajectory analyses introduce additional errors.

Aircraft measurements of beta activity, when carefully planned and made at map time, can improve the precision to 1000 feet in the vertical, and to a few miles in the horizontal. This precision Is necessary for conclusive proof of the capture of radioactive particles from the stratosphere by precipitating clouds. However, for large-scale global studies of fallout transport, errors of 50 to 100 miles in the location of air parcels with certain potential vorticities may be quite tolerable, and on this scale, isentropic analysis has proven to be a very useful tool (Reiter 1963b),

In view of the large amount of labor involved in isentropic analysis of conventional upper air data, it is recommended that simultaneous measurements of beta activity, wind, and temperatures be made by aircraft at close intervals during horizontal flight at a number of levels near the axis of the jet stream or close to precipitating systems. When the same aircraft is used, these measurements form an internally consistent set of data, even if they deviate from contemporaneous radiosonde measurements. Since this procedure was more closely followed in 1965, a more detailed picture of wind and temperature patterns emerged from preliminary analysis of a few cross-sections flown by the B-47. It is hoped to describe these in the next report.

In the case of April 4, 1964, an instantaneous cross-section through a region with thunderstorms showed an internally consistent distribution of stability, differential advection, and vertical motions. It indicated the beginning of the downward development of a stratospheric extrusion and suggested entrainment of radioactive particles from that extrusion into the rear part of a thunderstorm system. However, proof that the radioactive air was indeed captured and that the radioactive material was deposited on the surface by precipitation is lacking, due to no rainwater being collected in the area.

Vertical velocities in the upper troposphere and lower stratosphere seem to be more reliable when computed from streamline and isotach patterns than from actual winds. There are two reasons for the greater reliability of the computed patterns. First, this analysis is much more consistent with the three-dimensional analysis of the structure of the atmosphere. Second, the analysis does not depend on a few widely scattered observation points, but on rather continuous fields of wind and pressure in which errors in wind measurements (which outweigh the neglected ageostrophic wind components) are smoothed out. However, before these computations are undertaken all contradictions and ambiguities in the pressure, streamline, and isotach analyses must have been removed, and these analyses must be consistent with the vertical cross-sections.

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