HEAVY WARM-SECTOR RAINS FROM ILLINOIS TO MIDDLE ATLANTIC COAST, MAY 26–28, 1956

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1. INTRODUCTION

During the weekend of May 26–28, 1956, a large, cold, high pressure system moved slowly off the east coast of the United States followed by a broad current of moist tropical air from the Gulf of Mexico. As this moist current overran the retreating cold air mass, widespread warm-frontal-type rains spread over the northeastern United States. The warm front was poorly defined at the surface, with a broad zone of gradual transition. Aloft the front was somewhat more distinct but still quite broad. To the rear of this frontal zone the warm sector air mass extended uninterruptedly to the Gulf of Mexico. The synoptic situation on May 27 is presented in figure 1A.

It was in the extensive belt of mT air that the rains described in this paper occurred. The rains began in Illinois early Saturday morning of May 26 and spread eastward with the warm front to the coast by Sunday morning. Surprisingly enough, however, they continued throughout a broad strip from central Illinois eastward all day Saturday, Sunday, and part of Monday. The rain over most of this area ceased when a southward-moving cold front brought dry air and subsiding currents to the region.

East of the Appalachian Mountains the warm-sector rains were accompanied by a deepening trough at the surface and aloft. Here the rains began when the flow at the 700-mb. level became cyclonic and ended when the warm-sector flow lost its cyclonic curvature after passage of the 700-mb. trough. The principles relating surface precipitation to cyclonic curvature aloft [1] have long been recognized so the rains occurring in this part of the country were not unusual. Development of heavy rains which fell farther to the west in the warm sector were not so easily explained.

The upward motion in the warm sector must have been quite widespread to produce such a large area of precipitation and therefore should be subject to detection or computation by several of the methods which have been developed for the study of vertical motions. The cause and distribution of these vertical motions will be investigated in this paper by examination of each of the following types of charts: 1. precipitable moisture, 2. Showalter stability index, 3. differential advection, 4. surface isobaric convergence, 5. sea level pressure change (Laplacian of), 6. curvature of flow pattern at 700 mb. and higher, 7. jet stream, 8. tropopause, and 9. JNWP vertical motion computations (900–400 mb.).

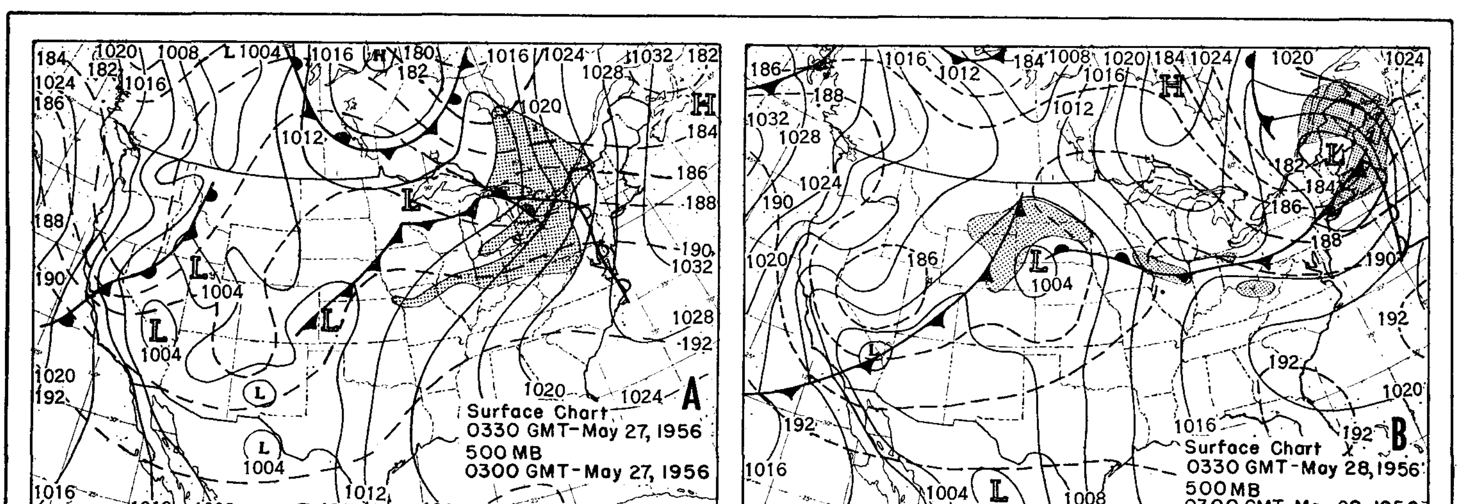

FIGURE 1.—Surface charts for 0330 GMT with 500-mb. contours for 0300 GMT superposed: (A) May 27, (B) May 28, 1956. Solid lines are sea level isobars; dashed lines are 500-mb. contours; shaded area indicates current precipitation.

2. PRECIPITABLE MOISTURE

In the analysis of the moisture content and distribution within the warm mT air mass, two methods were employed. Charts were prepared showing the total amount of precipitable water available (fig. 2), and values of the temperature minus dew point at the 850- and 700-mb. levels (not shown) were checked. Both methods showed an abundance of precipitable water in the warm air mass whose source region was the Gulf of Mexico. Moreover, the surface had been saturated by widespread rains which fell through most of the central and southern Plains during the 3-day period prior to May 27. Dew points at the surface (fig. 5A) at 0300 GMT on May 27 were in the 60's as far north as the Great Lakes region.

Precipitable water amounts were computed to show the available moisture between the surface and the 400-mb. level using methods developed by Solot [2] and Showalter [3, 4]. These values were computed for all available radiosonde stations in the central and eastern United States for 12-hour intervals between 1500 GMT May 26 and 1500 GMT May 27. Nearly the entire eastern two-thirds of the Nation had precipitable water values in excess of 1 inch (fig. 2). The area of the warm sector rains was overrun by an air mass containing over 1½ inches of precipitable water. The maximum value computed was 2.21 in. at Rantoul, Ill., less than 30 miles from Farmer City, Ill., where 7 to 9 inches of rain fell during the following 9 hours.

3. STABILITY

There is no doubt as to the unstable character of the warm mT airmass in this case since showers and thunderstorms were numerous throughout the rain belt. In order to show more quantitatively the instability of the airmass and the distribution of stability, the Showalter Stability Index Charts [5] as prepared by the National Weather Analysis Center are presented in figure 3. Even a cursory examination of these charts shows the presence of a large unstable area which spread eastward from Missouri and Illinois at 0300 GMT on the 27th to include all of the area from Missouri to eastern Pennsylvania by 1500 GMT of the same day.

4. DIFFERENTIAL ADVECTION

The foregoing analyses of moisture and instability determined the presence of these two basic requirements for heavy precipitation over a much larger area than that in which precipitation actually occurred. In beginning our investigation of the third basic requirement, vertical motion, the principle of differential advection seemed a promising vehicle for the initial attack since it might explain why heavy sustained rains fell over Illinois, Indiana, and Ohio, and only scattered, comparatively light amounts of rainfall were reported from the adjacent States of Kentucky and Tennessee. Gilman's [6] concept of horizontal differential advection as a major cause of vertical motion has been tested with encouraging results in earlier studies of heavy rains by Erickson [7], Appleby [8], and Lott [9].

Prior to, and during the period under consideration, large-scale, warm-air advection was in progress from the Rockies eastward to the Appalachians and from the Gulf of Mexico northward to the Great Lakes. The thermal pattern was illustrated by preparation of thickness charts for the 1000–700-mb. layer (fig. 4). On these charts isotachs for maximum winds from the surface to 7,000 ft. m. s. l. were superimposed and a few representative winds plotted. The combined thickness and isotach

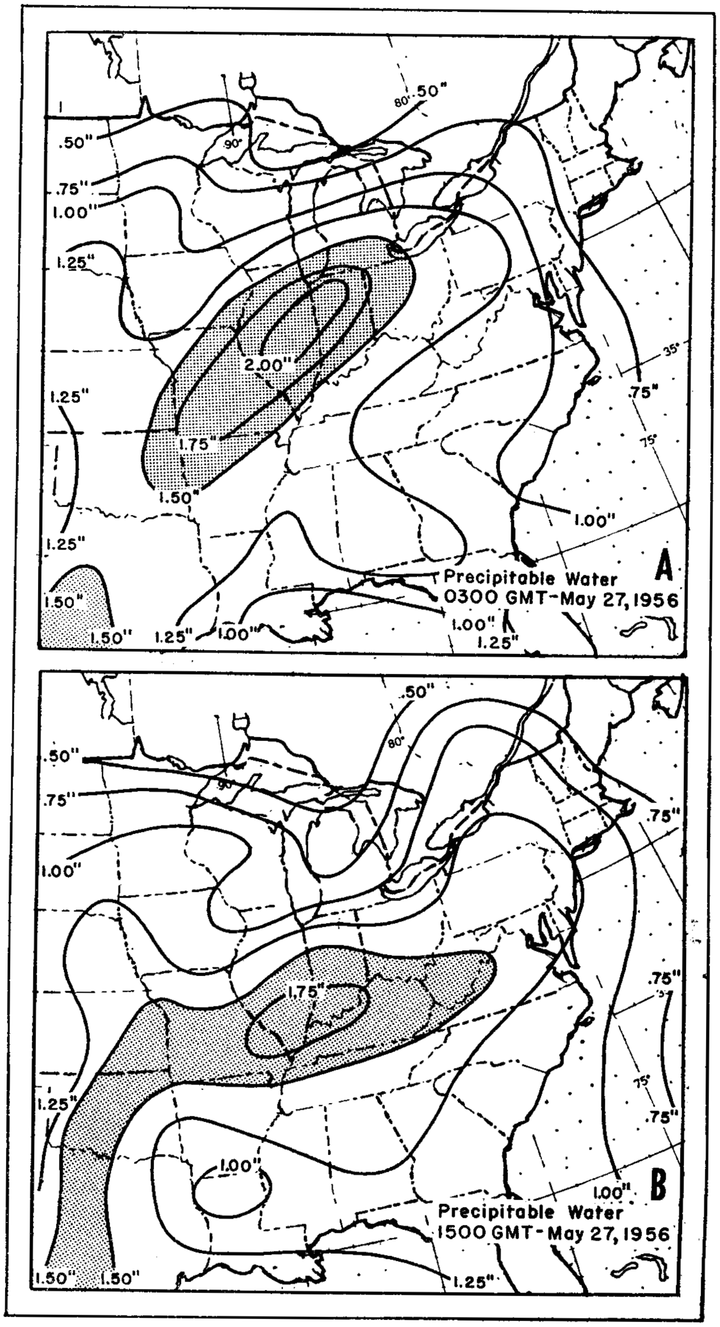

FIGURE 2.—Precipitable water (inches) for layer from surface to 400 mb. for (A) 0300 GMT and (B) 1500 GMT, May 27, 1956.

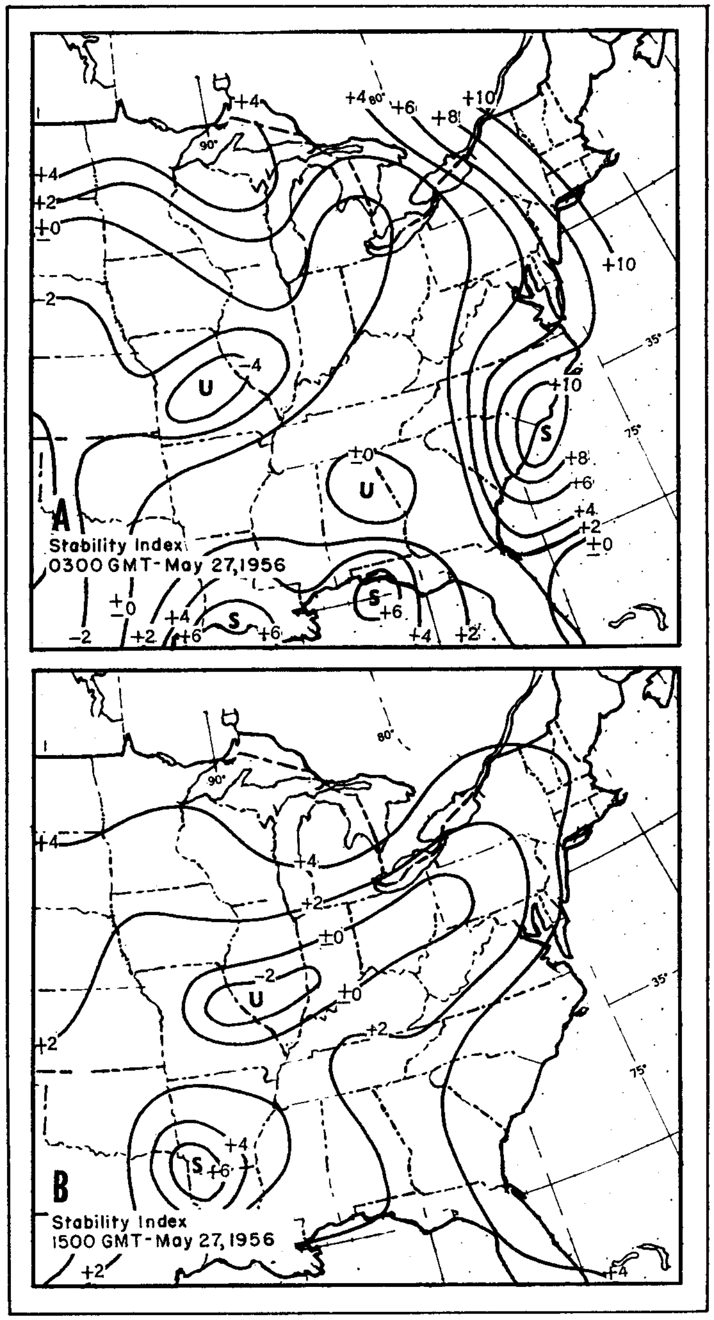

FIGURE 3.—Showalter stability index [5] for (A) 0300 GMT and (B) 1500 GMT, May 27, 1956. U indicates center of instability, S center of stability.

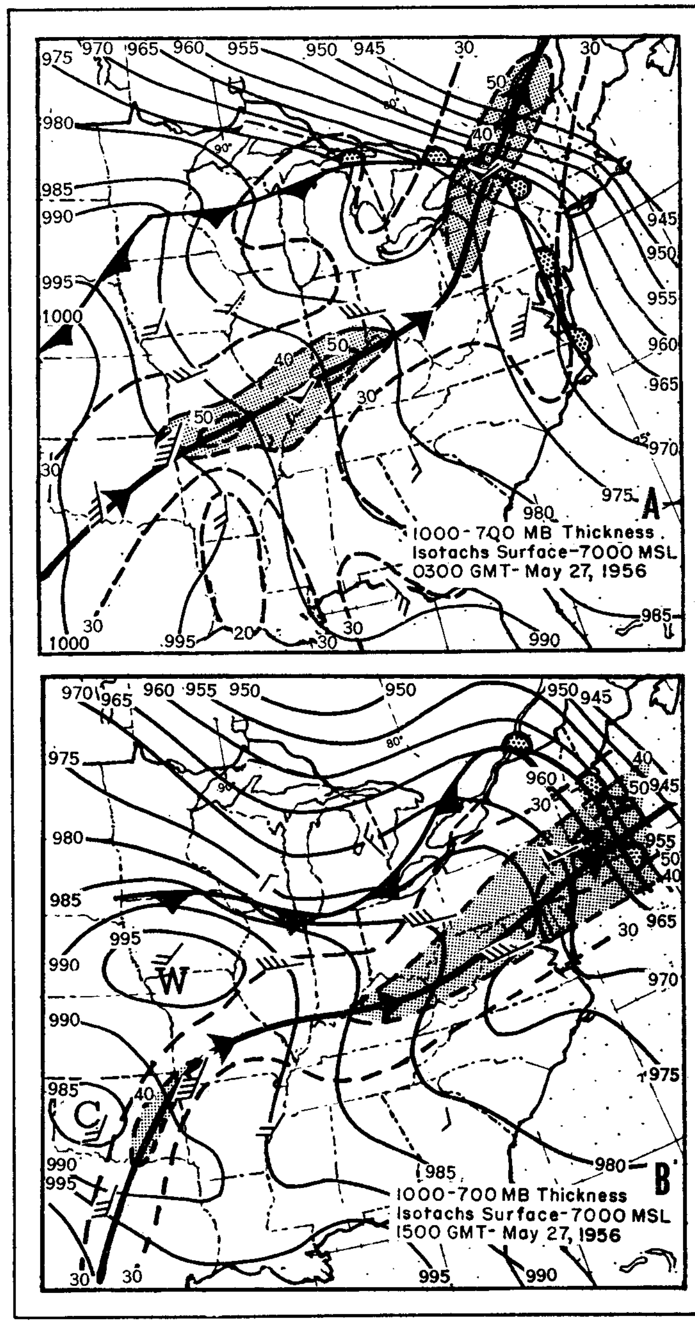

FIGURE 4.—1,000–700-mb. thickness charts with isotachs of maximum wind from surface to 7000 ft. superposed for (A) 0300 GMT and (B) 1500 GMT, May 27, 1956. Solid lines are 1,000–700-mb. thickness (hundreds of feet); dashed lines are isotachs (kt.) of maximum wind.

charts clearly show a general advection of warm air from the South Central States northeastward through the Midwest and into the Central Atlantic States. In the section where the heavy warm sector rains were reported, the wind directions were nearly normal to the isotherms and the speeds were the strongest, ranging from 30 to 50 knots. In the 12-hour period between 0300 GMT and 1500 GMT on the 27th, the thickness lines over the area of heaviest rains moved from 60 to 120 nautical miles at a speed of from 5 to 10 knots. The relatively large difference (25 to 40 knots) between the speed of the advective wind and the speed of movement of the thickness field gives an indication of the large amount of vertical motion which must have occurred in this area. In the adjacent areas the winds were more nearly parallel to the thickness lines and advection was further reduced by the lower speeds of the wind.

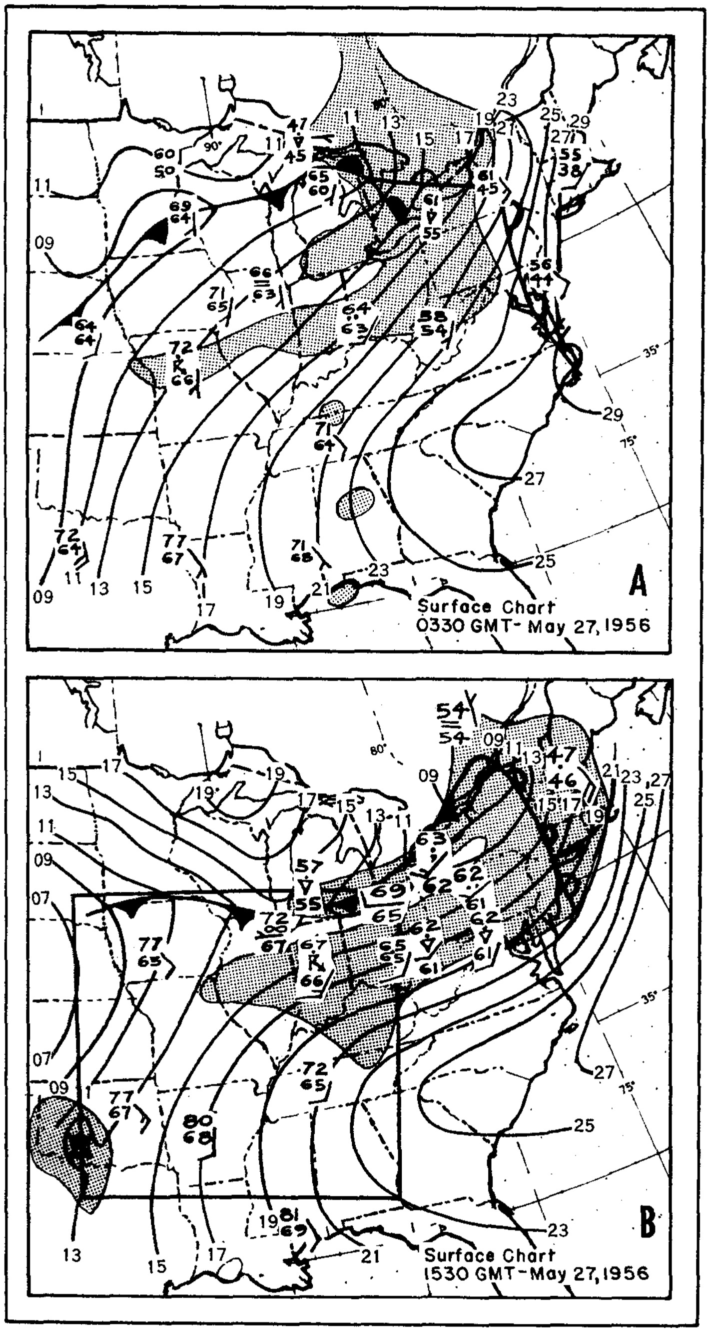

FIGURE 5.—Surface charts for (A) 0330 GMT and (B) 1530 GMT, May 27, 1956. Shaded area indicates current precipitation; representative reports are plotted. See figure 6 for enlargement of isobaric pattern of area outlined in (B).

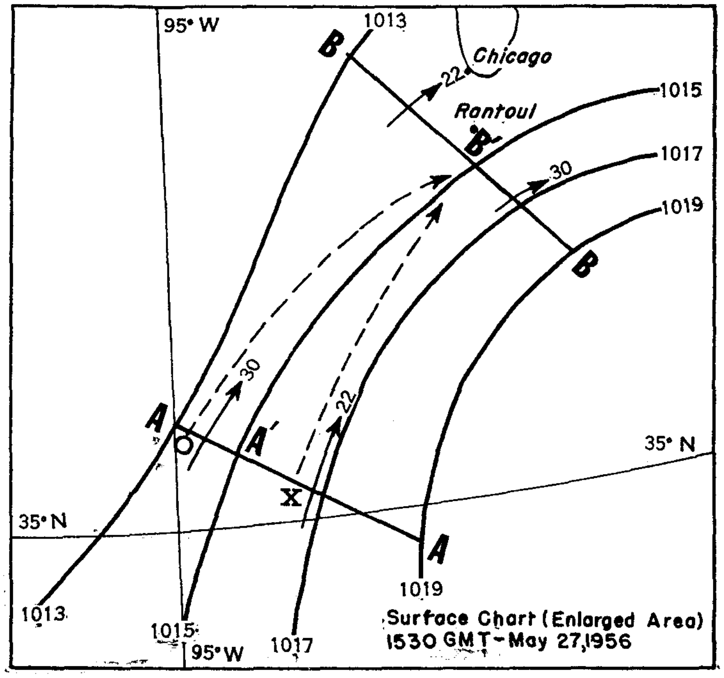

FIGURE 6.—Enlargement of pertinent isobaric pattern of area outlined in figure 5B. Solid lines are isobars; dashed lines are approximate trajectories of air parcels in area of convergence. Solid arrows are geostrophic wind vectors with speeds in knots.

5. SURFACE ISOBARIC CONVERGENCE

The sea-level isobaric pattern for 1530 GMT on May 27 (fig. 5) in the vicinity of Missouri and Illinois is a good example of Bjerknes' classical convergence pattern [10]. Figure 6 is an enlargement of the pertinent isobars within the box outlined in figure 5B. If we consider this isobaric pattern as stationary relative to the winds we see that a parcel of air located at point O on line A–A′ would be moving into an area of weaker pressure gradient as it approached line B–B′. In this area the pressure gradient force to the left of the wind direction would not be strong enough to balance the Coriolis force acting to the right. Therefore the parcel would be turned to the right along a path similar to line O–B′. On the other hand, a parcel starting at point X on line A–A′ would be moving into a region of stronger pressure gradient as it approached line B–B′. It would, therefore, be deflected to the left of the direction of geostrophic flow, similar to line X–B′. These oppositely directed ageostrophic components would meet along line A′–B′. In this manner low-level convergence is indicated along line A′–B′ by the sea level pressure pattern.

This type of convergence has also been described by Rossby [11] using the vorticity equation with the same isobaric model. The vorticity equation (see for example [12]) is

$$\frac{d\eta}{dt}=\eta(-\text{div } \mathbf{V}),$$

where η is the vertical component of absolute vorticity, t is time, and div $\mathbf{V}$ is the horizontal divergence of the wind vector $\mathbf{V}$. This equation states that the time rate of change in vorticity of an individual parcel is proportional to the negative divergence, i. e., convergence. Applying this principle to figure 6, consider a parcel of air at point A′ on the line A–A′. The geostrophic winds to the west of point A′ are stronger than those to the east of point A′. The resultant shear indicates that anticyclonic relative vorticity exists at point A′. As the parcel moves from point A′ to point B′, the shear along its path changes from anticyclonic to cyclonic. This change from anticyclonic to cyclonic relative vorticity indicates an increase in absolute vorticity of the parcel and therefore convergence along the path from A′ to B′.

The convergence-producing pattern of the sea level isobars through Missouri and Illinois remained relatively unchanged for over 24 hours. During this period rain fell with fluctuating intensity, but rather continuously, through Illinois, Indiana, and eastward to the coast. Near Rantoul, Ill., the rains were heaviest, with a report of 13 inches in 24 hours at Farmer City, Ill., and 8 inches at Fisher, Ill.

In connection with the study of synoptic conditions at the surface level, an isallobaric chart showing pressure changes for the 12-hour period between 0300 GMT and 1500 GMT on the 27th was prepared (fig. 7). Since the convergence of the isallobaric wind is known to be highly correlated with rainfall and since this convergence is greatest where the Laplacian of the isallobaric field is greatest, we computed this Laplacian from figure 7. The axis of greater values is shaded and agrees well with the area of persistent warm-sector rainfall.

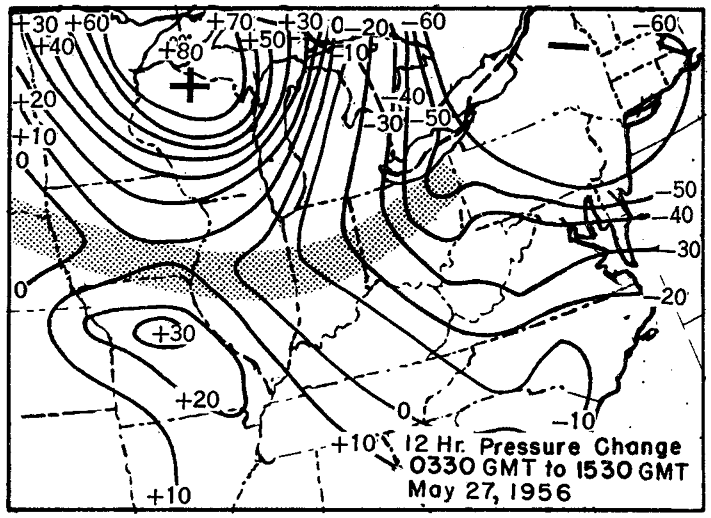

FIGURE 7.—12-hr. sea level pressure changes (tenths of mb.) 0330 to 1500 GMT, May 27, 1956. Shaded area is zone of maximum Laplacian of pressure change field.

6. JET STREAM ANALYSIS

Low-level convergence in an unstable airmass is usually associated with high-level divergence when large upward velocities are observed; Riehl [13] has described how the jet stream is associated with rainfall and just where high-level divergence would be found relative to the axis of the jet stream and the wind maxima along the jet. In this case, however, examination of the 300-, 200-, and 150-mb. isotach charts eliminated the upper-level jet as a contributing factor in the warm-sector precipitation.

On May 26 at 0300 GMT, the jet stream flowed southeastward from north of Lake Winnipeg to northern New Jersey. During the next 48 hours the jet moved slowly northward to a path from just west of Hudson Bay to northern New England. On the 28th a shorter secondary jet appeared at 200 mb. extending eastward from eastern Lake Superior to Delaware Bay. During the entire period under consideration the closest proximity of the upper jet stream to the area of heavy precipitation in the Midwest was several hundred miles. The precipitation area was under a region of light, variable, high-level winds. Thus it was apparent that the relationship of precipitation to jet stream position would not, in this case, be pertinent.

After abandoning the search for upper jets, attention was turned toward low-level jets. Here more gratifying results were obtained. All available wind reports were checked for maximum speeds between the surface and 7,000 ft. m. s. l. Isotachs prepared from these data revealed the presence of a well-defined, low-level jet running from Oklahoma northeastward into the Middle Atlantic States (fig. 4). This strong current persisted just south of the area of heaviest precipitation from the evening of the 26th to the afternoon of the 27th.

The location of the heaviest rains relative to the position of the low-level jet maximum is consistent with the convergence-divergence distribution about jet streams. Inspection of figure 4A shows a strong jet stream through the area of precipitation. Several small centers of maximum wind speed appeared along this jet, each moving eastward. Small zones of convergence and divergence probably accompanied these isotach maxima eastward along the jet axis. By 1500 GMT (fig. 4B) the pattern was better developed with a cyclonically curved jet maximum definitely downstream from the Illinois area.

According to the horizontal convergence-divergence patterns prepared by Riehl, convergence would be indicated to the left (north) of the main jet axis and behind the zone of strongest wind velocity in the area where the curvature changes from anticyclonic to cyclonic.

It may be noted that in addition to its role in supplying convergence in this situation the low-level jet also contributed to the convective instability of the air mass by advection of moisture to the lower levels. This contribution, it must be admitted, was probably of lesser value due to the presence of both instability and abundant moisture in the air mass prior to May 27.

Incidental to inspection of the high-level isotach charts the tropopause chart was examined to determine if there were any possible correlation between the tropopause "breaklines" and the precipitation areas. This investigation was stimulated by a recent study by Culkowski [14] of the tropopause analysis as related to surface forecasting. Culkowski's paper described the southern or eastern edges of a breakline as the optimum location for heavy precipitation but also pointed out the diminished value of tropopause breaks as indicators of precipitation areas during the summer months. In this case no apparent correlation existed between the tropopause and the surface precipitation.

7. VERTICAL MOTION

After the various methods by which pronounced vertical motion might have been indicated in the warm-sector airmass had been investigated, vertical motion charts for the 900- to 400-mb. layer were prepared from data furnished by the Joint Numerical Weather Prediction Unit (JNWP). During the period, JNWP prepared daily vertical motion analyses for 800 mb. and 550 mb. which represent, respectively, the layers from 900 to 700 mb. and from 700 to 400 mb. From the initial analysis and a forecast for 30 minutes later made with the 3-layer baroclinic model, vertical velocities were computed using the adiabatic method. Both the 30-minute forecast and the vertical velocity computations were produced by machine. By simple addition of the values computed for the two layers (centered at 800 mb. and 550 mb.), vertical motion values for the combined layer (900 mb. to 400 mb.) were derived. These values are roughly proportional to the integrated vertical velocities through the combined layer and are here employed to illustrate the instantaneous vertical motion through the entire layer.

Superimposition of isohyets for 24-hour precipitation on the vertical motion charts (fig. 8) shows relation of rainfall to areas of greatest positive, i. e., upward, vertical motion.

8. CONCLUSIONS

The heavy and widespread warm-sector rains discussed in this paper were the result of a combination and an unusual concentration of several of the usual precipitation factors. The configuration of the rain area was apparently determined more by the extent to which these factors interacted than to their presence or absence. Precipitable water charts prepared for this period show an abundance of available moisture even in areas where no rain fell, and the area of instability as shown by the stability index charts was considerably larger than the precipitation area. A large share of the warm-sector air mass was very moist and convectively unstable just prior to the precipitation.

With two of the basic elements, i. e., moisture and instability, determined to be present in sufficient quantities, the third element, vertical motion, was investigated. Factors which are favorable for vertical motion—differential advection, low-level convergence, Laplacian of sea level pressure change, and the effects of the low-level jet—interacted in such a manner that the greatest concentration of vertical motion assumed a long narrow east-west orientation which coincided rather well with the observed pattern of heavy precipitation. Upper-air features such as position of the high-level jet, tropopause breaks, and cyclonic curvature aloft were notably absent during the period.

In summary, it is apparent that the heavy rains in the warm sector resulted from a strong sustained vertical motion through a very moist and convectively unstable

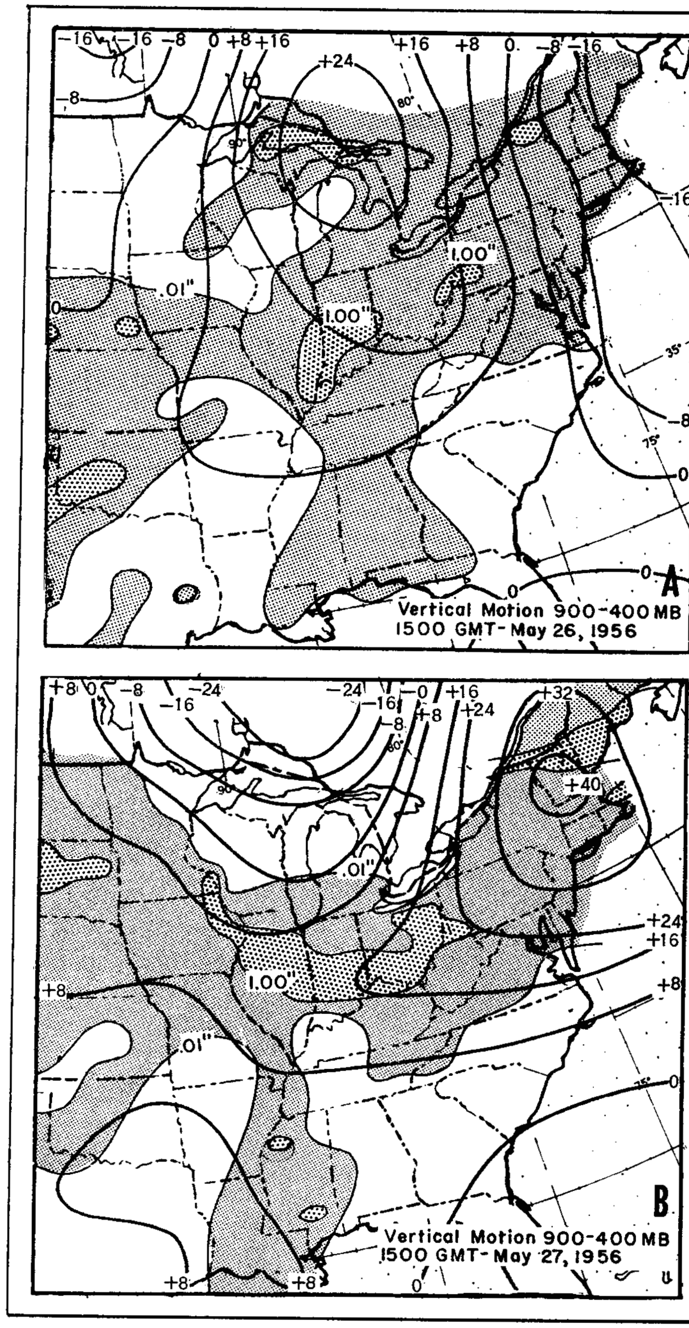

FIGURE 8.—Vertical motions (solid lines, mm.sec.$^{-1}$) for layer 900–400 mb. for 1500 GMT, (A) May 26 and (B) May 27, 1956. Fine-stippled area represents 24-hr. precipitation of 0.01 to 1.00 inch and coarse-stippled area 1.00 inch or more ending at 1230 GMT, (A) May 27 and (B) May 28, 1956.

air mass. The greatest rainfall amounts were reported from areas which coincided very well with zones of maximum effective low-level convergence and cyclonic vorticity.

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Weather Notes

SEVERE THUNDERSTORM, CLEVELAND, OHIO, MAY 12, 1956

A very severe thunderstorm struck the center of Rocky River, Lakewood, and the western portions of Cleveland at 8:45 p. m. EST on May 12, 1956. The storm moved in off Lake Erie from the west-northwest over Rocky River and Lakewood until the center of the storm was about 2½ miles inland from the lake, and then moved generally eastward across western portions of Cleveland to the Cuyahoga River Valley. (See fig. 1.) East of the Cuyahoga River, the storm moved in a more northeasterly direction but very little wind damage occurred.

In the path of the storm damage very little rain occurred, but the eastern portions of the city received a torrential downpour and hail up to 1 inch in diameter. Downtown Cleveland reported ½-inch hail. The heavy rainfall, particularly in Shaker Heights and Cleveland Heights, caused serious flooding of underpasses and low spots, and hundreds of basements. The Weather Bureau recording rain gage located at East 140th Street and the lakefront, recorded about 2 inches of precipitation in 30 minutes. Evidence indicates heavier amounts about 3 miles southeast of the Weather Bureau gage.

At the airport, 2¼ miles southwest of the southern edge of the path of damage, the maximum wind was 45 m. p. h. from the northwest, the fastest mile 57 m. p. h. from the northwest, and on the direct-reading indicators gusts to 71 m. p. h. were observed. On a privately owned anemometer located on Beach Road ("G" in fig. 1), gusts to 100 m. p. h. were observed on the indicator before the mast of the anemometer bent over, and the instrument ceased to function.

A pressure jump occurred at the airport at 8:45 p. m., EST amounting to 0.16 inch Hg in 3 minutes. The pressure fall in the 45 minutes preceding 8:45 p. m. amounted to 0.18 inch. On a privately owned Friez 4-day barograph located at 230 Buckingham Road, Rocky River, Ohio (just north of "C" in fig. 1), a fall of 0.32 inch Hg was recorded in the 45 minutes prior to the low point, and then a pressure jump of 0.22 inch Hg.

Seven people were killed and about 70 injured during the storm. Three of the deaths occurred when a tavern collapsed (point "M," fig. 1); one was killed by a tree toppling across an automobile, and two were electrocuted by fallen wires. One person died 8 days later from injuries received during the storm.

The damage throughout the path of the storm, while extensive, was not major as far as structural wind damage was concerned. A large share of the structural damage was caused by large trees falling on buildings and houses. About 3,000 trees were uprooted or broken off, bringing down power and telephone lines generally throughout the area. Toppling of huge trees, tall and with wide-spreading top branches, was aided by the supersaturated soil. Precipitation in thunderstorms late on May 11 and in the early hours of May 12, amounted to 1.76 inches at the airport. This heavy rainfall on ground already wet from an excess of precipitation this spring, produced a condition favorable for uprooting of trees. The City Forester stated, "At least 50 percent less trees would have toppled if the soil had not been so saturated. The trees that toppled had survived heavier winds in past storms."

A ground survey on May 13 and an aerial survey on May 14 indicated little or no scattering of debris. All of the trees were alined roughly parallel to each other and fell toward the southeast along the first 2 to 2½ miles of the path, and then generally easterly along the last 6 miles.

The damage varied considerably within the storm path. Figure 1 shows the path of damage and particular locations where damage was unusually severe. Damage estimates made by the three cities of Rocky River, Lakewood, and Cleveland, total approximately $8 million.—*H. N. Burke, MIC, WBAS, Cleveland, Ohio.*