A ROCKET PORTRAIT OF A TROPICAL STORM

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ABSTRACT

Photographs taken on October 5, 1954, from an Aerobee rocket fired from White Sands, N. Mex., are presented which show the cloud patterns of a tropical storm near Del Rio, Tex., and a secondary vortex over southwestern New Mexico. The method and purpose of obtaining these photographs are discussed.

Detailed surface-pressure and 300-mb. isotach and streamline analyses reveal features of the circulation missed by the usual contour analysis. This illustrates some possible shortcomings of our routine analysis and the utility of rocket photo-reconnaissance.

1. INTRODUCTION

For almost a decade the Naval Research Laboratory of Washington, D. C., has been actively engaged in the field of high altitude photography from rockets. The principal purpose has been to obtain pictures of the earth so that the rocket aspect (its orientation in space during flight) could be determined. To obtain this aspect information it is desirable that recognizable features of the earth's surface be photographed, an objective best attained when there is a minimum of cloud cover. For that reason and because optical tracking from the ground is also desirable, rockets are seldom fired if the cloudiness exceeds 10 percent. Consequently photographs from rockets have not provided much information relative to large areas of clouds.

A fortunate exception occurred on October 5, 1954. Two rocket-borne movie cameras obtained pictures of towering clouds spiraling into a tropical storm near Del Rio, Tex. The pictures may well launch the era of rocket photo-reconnaissance for meteorology. In the near future more rocket pictures of hurricanes will be made, for plans are already going ahead to fire rockets for that specific purpose. Techniques that will be developed by rocket reconnaissance of hurricanes may find wider application in an expanded program of ultra-high altitude meteorological reconnaissance. Dr. Harry Wexler of the U. S. Weather Bureau has discussed the utility of such ultra-high photography in connection with hypothetical synoptic situations [1].

The purpose of the present paper is to present and discuss the photographs taken from the rocket fired from White Sands, N. Mex., on October 5, 1954, and to illustrate their usefulness in analyzing the meteorological situation.

2. ROCKET PHOTOGRAPHY

As a part of the Naval Research Laboratory's continuing research program, two motion picture cameras were flown in a Navy Aerobee rocket, fired from the White Sands Proving Ground, N. Mex., at 1815 GMT on October 5, 1954. At the time of this flight there was a generous scattering of clouds over the area surrounding the launching site. However, because of a large opening in the cloud cover directly above the site, it was decided to fire as scheduled. The result, in addition to aspect information, was the acquisition of a photographic portrait of a tropical storm and one other associated vortex. These pictures mark the first time such a storm has been photographed from an altitude sufficient to show the detailed structure over a large area. In addition the pictures represent the first time the earth has been successfully photographed in its natural color from rocket altitudes.

The pictures were taken by two 16 mm. motion picture cameras mounted in the nose shell of the rocket in a position so as to take pictures perpendicularly to its axis. In this particular flight the nose shell containing the cameras and other scientific equipment was separated from the body of the rocket on the down leg and parachuted to earth. The films and cameras, armored as usual to protect them from impact damage, were recovered in perfect condition.

One of the cameras was equipped with an extremely wide angle lens (90°) and used Super XX black and white film. The camera took 6 pictures a second with an exposure of 1/1500 sec. at f/4.5. Because of the wide field of view the pictures contain an appreciable amount of distortion. The magnitude of this distortion is, however,

FIGURE 1.—Photograph with 90° lens from altitude of approximately 100 miles over White Sands, N. Mex., showing secondary vortex over southwestern New Mexico.

known. Figure 1 is a frame from this camera showing a vortex which will be discussed later.

The second camera in this rocket was equipped with a semi-telephoto lens and contained Kodachrome film. This camera took 6 pictures a second with an exposure of 1/500 sec. at f/3.5. A Wratten 2B filter was employed to eliminate the blue haze commonly found in color photographs taken from high altitudes.

The flight pattern of the rocket near its summit made it possible to assemble a mosaic from the individual frames of the color film. As the rocket approached its summit 100 miles above the earth it was slowly rolling on its axis and gradually tipping over toward the southeast. As a result, on each roll the camera was scanning successive strips of the earth, each swath overlapping and appearing northwest of the previous one. Figure 2 is a black and white reproduction of the resulting mosaic composed of about 90 enlarged prints from the color film.

Because a semi-telephoto lens was used on the camera, individual enlargements from the color film contain no appreciable distortion. There is however, a small amount of distortion in the composite picture (fig. 2). The distortion resulted from the individual enlargements being mounted on a sphere of too large a radius. This was purposely done so that a single photograph of the mosaic could be taken. It is necessary to mount the individual enlargements on a sphere because the focal surface of the rotating camera is a sphere. For purposes of measurement and location of specific points on the earth's surface, the enlargements were also mounted on a sphere of the correct radius. Figure 3 is a sketch of the area covered by the composite, showing the principal cities and the point from which the pictures were taken.

The mosaic (fig. 2) exhibits an area of one and a quarter million square miles and a horizon length of 2,800 miles. This is the largest area of the earth ever contained in a single picture from effectively one point. The outstanding feature is, of course, the full-area portrait of the tropical storm centered near Del Rio, Tex., in the upper left portion of the picture. A more critical analysis of the

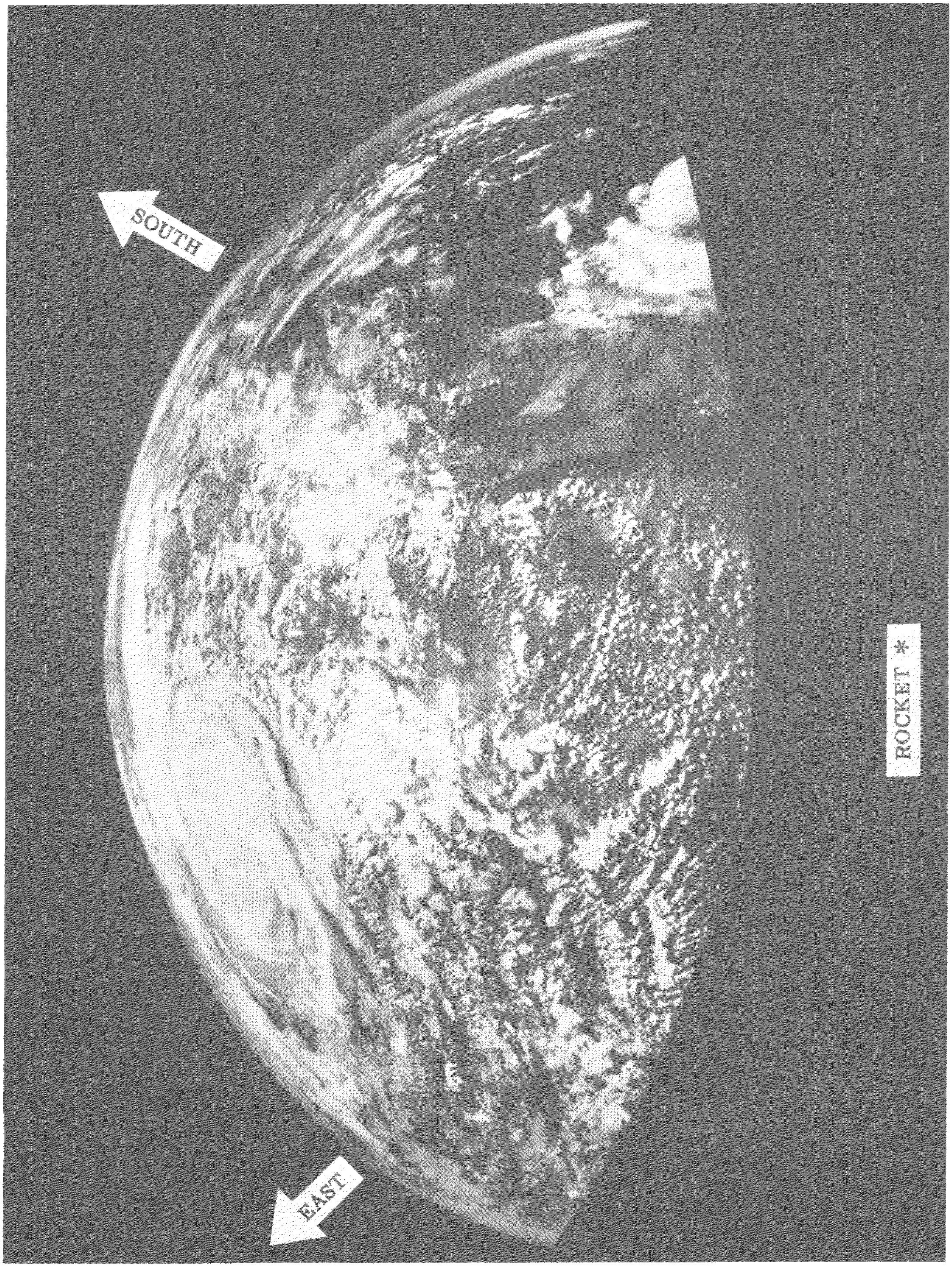

FIGURE 2.—Mosaic composed of approximately 90 frames taken by telephoto lens from altitude of approximately 100 miles over White Sands, N. Mex. The tropical storm is slightly left of upper center and the secondary vortex (shown also in fig. 1) is in lower right. The distortion in this composite is made apparent by comparison with figure 3.

FIGURE 3.—The area pictured by mosaic of figure 2 is outlined by the dashed lines. The apparent discrepancies between mosaic and this diagram are due to the distortion discussed in text. (Note, for example, that the tropical storm in the left upper center of figure 2 is centered near Del Rio, Tex.)

storm and associated clouds can be made from this mosaic as it appears in full color in *Life* magazine of September 5, 1955.

3. METEOROLOGICAL SITUATION

A tropical storm moved westward from western Cuba on October 2 with a central pressure of about 1007 mb. and winds up to 30 knots, and continued across the Gulf of Mexico with little change—it never did develop into a hurricane. On October 4 the center entered the Texas coast some 40 miles north of Brownsville but no surface winds above 18 knots were reported. During passage of this system Brownsville recorded 3.09 inches of rain in 45 minutes and over 6 inches in 3 hours. During the following day the rainfall pattern moving with the storm decreased in intensity, then increased again when the storm moved over the Big Bend region of Texas and the southwestern corner of New Mexico and caused floods in the Roswell, N. Mex., area. At about the time of the New Mexico rains, all traces of a vortex disappeared as an advancing polar air mass invaded the region.

Some provocative characteristics of the circulation are revealed by a detailed analysis of this situation. The words "detailed analysis" are used advisedly, for the smoothing inherent in the routine surface and upper air analysis of the regular data completely obliterates these features. The primary system shown in the upper left portion of figure 2 was one of a family of three vortices over southwestern United States at that time. Figure 5, a streamline analysis of the 300-mb. surface, shows the three systems. To the east, and out of the camera range, is a center near Corpus Christi, Tex. The primary system just northwest of Del Rio is the one shown in the upper part of figure 2, while the westernmost system can be seen at the lower right edge. The radiosonde observation for Del Rio suggests the clouds in the primary system extended to 35,000 to 40,000 feet. Figure 1, the print of a frame from the wide-angle camera, shows more of the western vortex. A certain part of this cloud system is due, no doubt, to the terrain. The vortex is not as well organized and the circular cloud arrangement less spectacular than in the primary system.

The primary system produced the abnormal rain, but areas of increased precipitation associated with the other two vortices can also be detected. Systems of this scale are very common in the upper troposphere at low latitudes, but this particular family of three extended all the way to the surface, providing a mechanism for abnormally rapid transport of moisture into the upper troposphere. It is significant that these vortices were embedded in an upper flow that curved anticyclonically toward the north then easterly over Illinois and that on October 10 Chicago had record floods [2].

Despite the importance of these vortices they were sufficiently small to be overlooked in the routine contour analysis. This suggests that subtropical regions may have flood-producing rains from systems that are so small that they are filtered out by the coarse grid of the standard numerical weather prediction methods. It is interesting to notice that the primary and the eastern vortices were discernable from a *detailed analysis* of time-altitude cross sections (along with all the routine analysis aids)—the type of analysis used in every careful tropical analysis where the data are frequently more sparse than in the United States. The vortex west of El Paso, however, was suspected but not inserted in the analysis until its existence was confirmed by the photograph. It is also significant that the vortex was not recognized on the photograph until after it was suggested by the meteorological analysis. This situation then, presents systems which bracket the detection threshold of our data network: the two eastern vortices that were detected by a subjective streamline analysis and the western vortex which could not be analyzed with any confidence. Notice this is referred to as a threshold of *data* capability because it requires subjective streamline analysis. All three vortices are below the detection threshold of contour analysis.

Another interesting feature is that these vortices were cold-core systems and had a decided slope with altitude. Since the primary system was in the vicinity of Brownsville at 1500 GMT October 4 and near Del Rio a day later, there is sufficient evidence to deduce the fact that

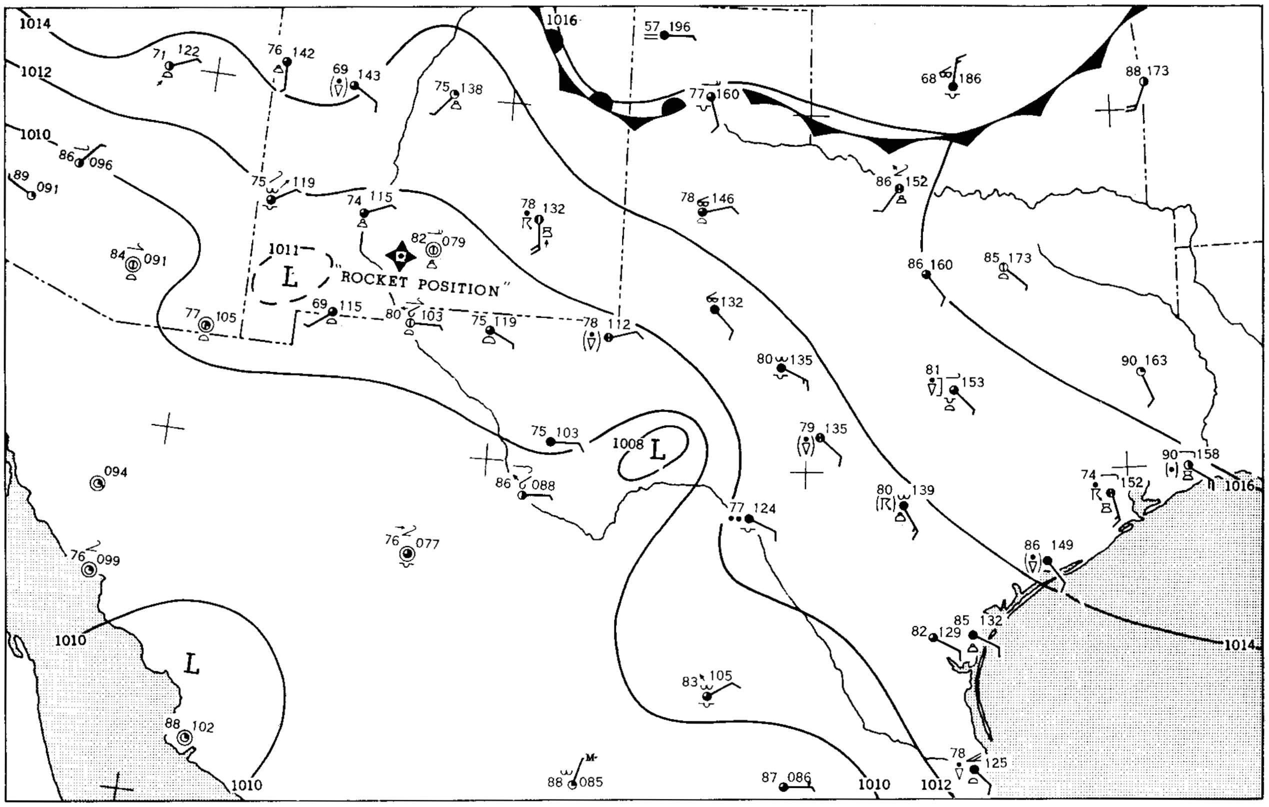

FIGURE 4.—Surface pressure analysis for 1830 GMT, October 5, 1954.

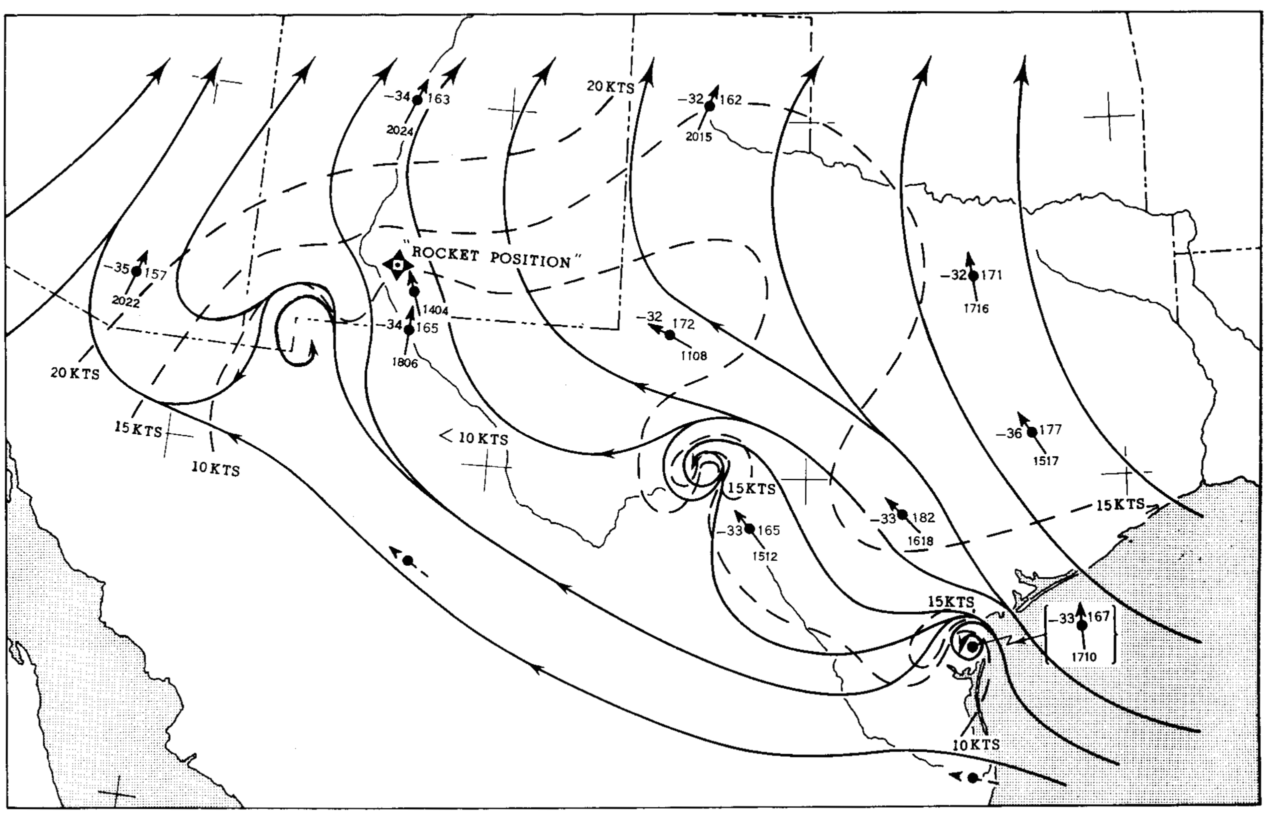

FIGURE 5.—Streamlines (solid lines) and isotachs (broken lines) of the 300-mb. surface for 1815 GMT October 5. 1954. The wind data have been interpolated for time of rocket flight and plotted at end of wind arrow in form "ddff". Height and temperature of the 300-mb. surface for 1500 GMT are plotted in conventional manner.

the vortex axis extended about 55 miles horizontally and 7 miles vertically, i. e., a slope of about 1:8. There is some evidence that the center near Corpus Christi had about the same slope. The vortex west of El Paso is so poorly documented however, that no slope estimate can be made.

An equation relating slope to temperature gradient (Panofsky [3]) shows that slope is a function of the temperature gradient in the layers of atmosphere bearing the vortex and the curvature of the pressure profile of the vortex:

$$\frac{dz}{dx}=-\frac{RT^2}{mgp}\frac{\frac{\partial^2 p}{\partial x^2}}{\frac{\partial T}{\partial x}}$$

Unfortunately data are not sufficient to make a reliable computation of the curvature, nevertheless it is interesting to make such a computation to determine whether or not the slope, deduced from meteorological analysis, is reasonable in view of the expected temperature gradient. The contour analyses of the 850-mb. and the 500-mb. surfaces were used to determine $\frac{\partial^2 p}{\partial x^2}$. With that value, the temperature gradient necessary to produce a slope of 1:8 was computed from Panofsky's equation. The result of 0.25° C. per 60 nautical miles agrees surprisingly well with the independent result obtained from a simple advection calculation. For the latter it was assumed that the isotherm pattern 100 miles upstream from the vortex was advected with the speed of the vortex (about 11 knots) and that the temperature increase at 700 mb. at Del Rio after the center passed was due solely to that advective effect. The result from this computation was approximately 0.2° C. per 60 nautical miles. The close agreement must be largely fortuitous since the data and analysis are not sufficiently accurate to justify such precision. The significant fact is that the slope deduced from meteorological analysis is consistent with a reasonable temperature gradient.

The axis slope of the primary vortex was toward the southwest with height on October 4 when it passed Brownsville and toward the southeast when it passed Del Rio one day later. From this, one infers that the isotherms of mean virtual temperature were oriented NW–SE over the Gulf of Mexico and NE–SW over Del Rio. Such a pattern is suggested by the isotherm analysis, but the pattern is not a simple one.

The facts that the systems were cold-core and that the primary system did not quite develop into a hurricane are intimately connected. Hurricanes are invariably warm-core and there is little doubt that the hurricane winds and the tremendous convergence into a hurricane at low levels depend upon the core becoming warm so that the energy of latent heat can be converted *directly* into circulation acceleration. Stated in another way, we might say that the only manner in which condensation of water vapor can accelerate the circulation directly is by causing a pressure fall near the center and this in turn obtains only when condensation produces a warm-core system. When the level of non-divergence is situated in the middle or upper troposphere (as it is with most tropical disturbances) the organized zones of convection remain cold-core [4].

Apparently there was convergence into the primary vortex throughout a deep layer (level of non-divergence perhaps above 300 mb.) so that the entire ascending column was maintained cooler than its environment and the released latent heat was not utilized in direct circulation acceleration. (See fig. 1 of [4].)

4. CONCLUSIONS

The possibilities suggested by this accidental rocket reconnaissance of a tropical storm are tremendous. One obvious use is already being planned—rocket photography of hurricanes. There are many unsolved problems in meteorology that may be vulnerable to this approach however. Vast regions of the earth are still meteorologically unexplored territory. For example the important meteorological zone across equatorial Africa and South America has been described in only the crudest detail. The fact that huge amounts of rain are precipitated along this zone makes it quite important to several problems. Rocket photography has the advantage of providing truly simultaneous data, albeit of a specialized nature. Rocket and aircraft reconnaissance then, may well supplement each other in a highly successful manner.

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