Ozone and Temperature Structure in a Hurricane

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ABSTRACT

For the first time detailed ozone measurements were obtained in a hurricane. An instrumented U-2 airplane was flown into hurricane Ginny on 22 October 1963 off the South Carolina coast. The hurricane core was over-flown at several altitudes and observations of ozone and the standard meteorological variables were obtained from 50 mb (67,000 ft) to 300 mb (30,000 ft). Supplemental temperature data were available below 700 mb from two dropsondes. From the above observations and by including some information about the mean thermal structure in a hurricane similar to Ginny, an "eye" sounding was constructed from sea level up to 50-mb level. Some nearby environmental data above 200 mb were available, and more distant observations were obtained from the coastal radiosondes and an ozonesonde released at Tallahassee.

Analysis of the data suggested that the warm core extended only up to 200 mb, cloud top height. Between 190 and 119 mb (tropopause height), horizontal gradients of ozone and temperature were poorly defined. Above the tropopause and up to 105 mb the region over the eye was warmer and considerably richer in ozone. In the layer from 100 to 50 mb, the horizontal gradients again became very weak.

1. Introduction

Since the mixing ratio of ozone is a conservative property below 25 km or so, this gas has found important application as a natural tracer in studies of circulation mechanics. In a typical case the ozone mixing ratio is small in the troposphere and increases rapidly from the tropopause up to 65–85 thousand ft. The Cambridge Research Laboratories ozone program (see Hering, 1963) is supported with an instrumented U-2 airplane containing a Regener chemiluminescent ozonometer. The high resolution capabilities of this instrument and that of the temperature sensor provide tools suitable for probing the smaller scale features of the atmosphere. Similar data from our U-2 phase of the program were used in a case study of tropopause wave motions by Penn (1964). In that paper it was pointed out that absolute errors to the 95 per cent confidence limits are 0.4C for temperature, and 0.85 mb for atmospheric pressure. We are usually concerned with point-to-point or relative values, and the relative errors appear to be less than the errors given above. In regard to the accuracy of the ozone measurements, it is estimated that the errors are less than 10 per cent of the indicated values.

Detailed measurements of the standard meteorological parameters in hurricane cores have been made by the National Hurricane Research Project (for example see Jordan, Hurt and Lowrey, 1960); however, this is the first time that ozone measurements have been obtained in a hurricane. In addition, these are the first observations of the thermal structure through the tropopause and of the horizontal gradients at high elevations above the storm. A considerable amount of data was obtained in the eye, above the eye, and above the wall clouds. Additional temperature observations were obtained across the eye at 700 mb by weather reconnaissance, and in the eye below 700 mb by dropsondes. Our attention will be directed largely to comparing observations in or over the eye with those of the environment. We shall define the upper boundary of the eye by the top of the wall clouds, which in this case was around 200 mb (40,000 ft).

2. Hurricane Ginny

On 22 October 1964 Ginny was located about 250 miles east-southeast of Charleston, S. C., and south of Cape Hatteras, N. C., and moving to the southwest. The storm's history has been described by Dunn and Staff (1964), and some pertinent points from the paper will be reiterated here. First the storm developed from a cold core, and it was not until the 22nd that reconnaissance aircraft found a thermal structure (warm core) that resembled a hurricane. The manner in which the thermal structure changed was not clear. Ginny produced relatively light rain; hence, the release of latent heat was not unusual. As will be shown later, our observations in Ginny about 1700 GMT October 22 confirmed the warm-core nature of the storm.

3. Observations

Hurricane Ginny's eye was overflown at about 50 mb (67,000 ft), 115 mb (50,000 ft), and 200 mb (40,000 ft); in addition, a descent was made in the eye to 300 mb

(30,000 ft). The eye was somewhat elliptical in shape with longest axis about 45 miles long and oriented nearly north-south. The traverses were in a general northwest-southeast direction except that exit from the eye was through the north wall. The airplane's tracks with a schematic view of the core are shown in Fig. 1.

Cloud photographs at 16 sec intervals were taken with a panoramic camera having an angular coverage of 42°×180° and displayed on 70 mm film. The 180° view is perpendicular to the direction of flight. Composite photographs of the core were constructed for each pass over the storm, and the one for the 50-mb traverse is shown in Fig. 2. The flight track is along the middle of the picture and goes through points identified by letters A and B. Radiometer readings in the atmospheric window (8–12 μ region, 15 sec intervals) were used to help locate the boundary between the eye and the wall cloud, and the letters A and B in Fig. 2. identify two boundary points. In regard to the clouds, the pilot reported cloud tops at the wall to be 40–42,000 ft from west to north, and 38–40,000 ft from east to southeast. The eye as viewed in Fig. 2 appears to contain two circulations with lower clouds in the eastern portion of the eye, and mostly clear in the western portion. The photograph from 115 mb (12 minutes after the 50-mb pass) looked very similar to Fig. 2. On the 200-mb traverse (17 minutes after second pass) the west side of eye seemed to be filling up with thin cirrus.

Unfortunately uncertainties in the wind observations over the storm limited the extent of our analysis of the eye circulation. The wind measurements were felt to be reliable only in a relative sense along a given heading for the plane. It was found that winds at 50 and 115 mb remained essentially unchanged across the storm. At 200 mb shifting winds gave some support to the suggestion of a double circulation; however, light wind speeds (less than 10 knots) made even the relative winds questionable.

It is informative to examine, first of all, vertical profiles of temperature and ozone constructed from the descent and ascent data in the storm, and to compare these with other soundings. These data are displayed on a ozonogram in Fig. 3. The agreement between the soundings in the storm is very good, and agreement between the storm data and coastal profiles looks very reasonable. Certain differences exist and these will be discussed later. Meanwhile we see that the ozone and temperature data are consistent in delineating the tropopause, which appears to be near 119 mb over the storm and about 110 mb near the coast. A striking feature is the similarity in the configurations of the three ozone profiles in the lower stratosphere.

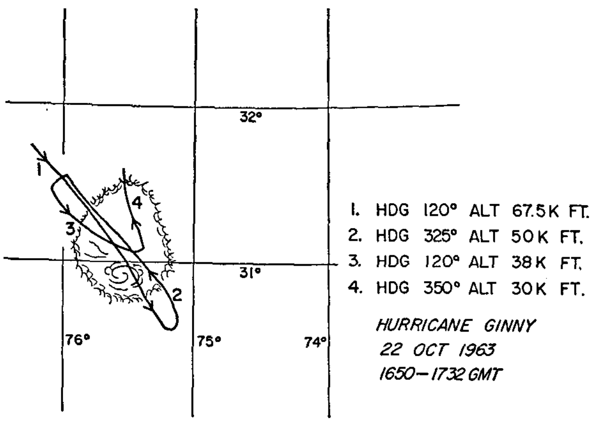

FIG. 1. Schematic view of hurricane eye and the airplane's tracks.

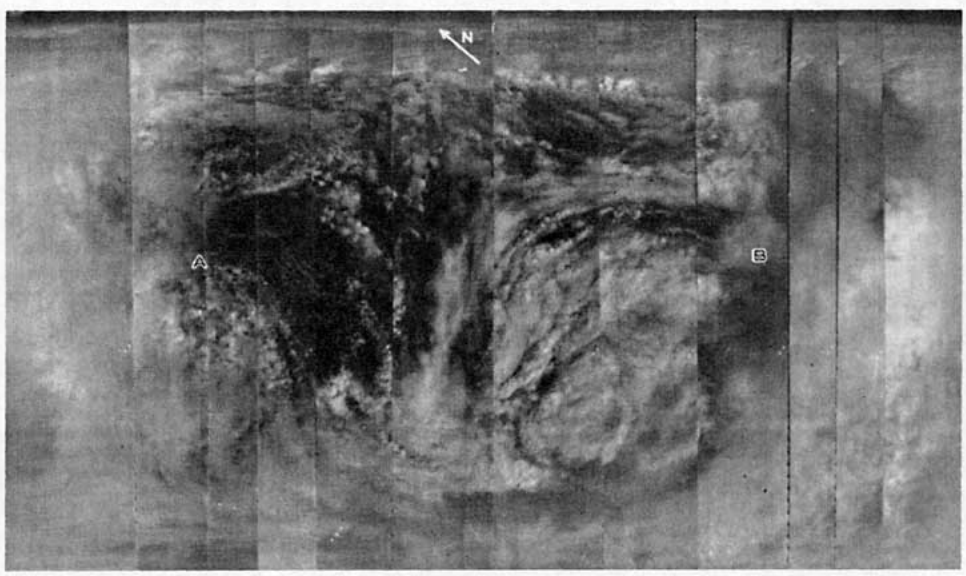

FIG. 2. Composite photograph of storm from 50-mb level. Points A and B are 40 miles and five minutes apart and indicate inner sides of wall clouds.

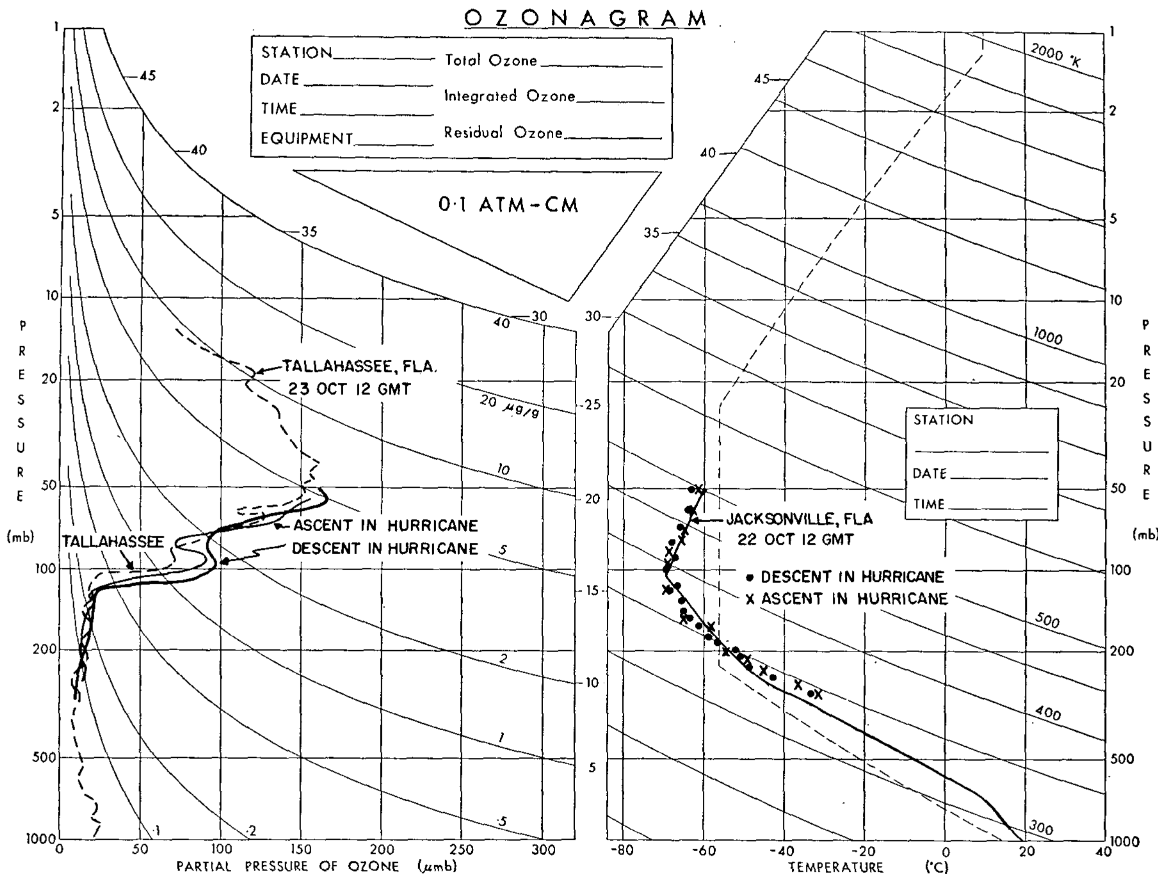

FIG. 3. Comparison of descent and ascent data in hurricane with temperatures sounding at Jacksonville, and with ozone sounding made the next morning at Tallahassee, Florida.

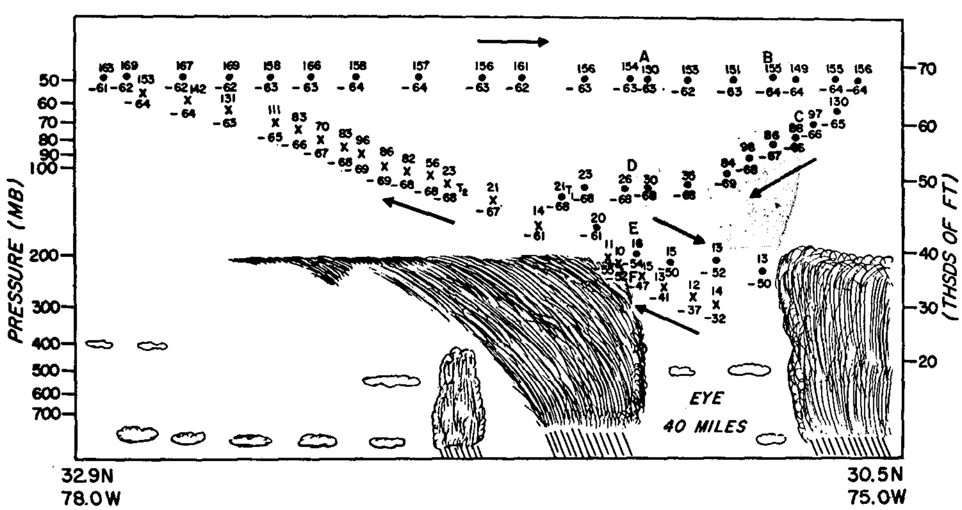

FIG. 4. Cross section of ozone and temperature observations. Upper figure is partial pressure of ozone (μmb), lower figure is temperature (deg C). Clouds interpreted from photography and radiometer data. Stippling shows regions above eye. Arrows indicate path of plane, (X) designates points on departing leg.

Selected observations of ozone and temperature are presented in quasi-cross-sectional form in Fig. 4. The abscissa represents data along a northwest-southeast line except on the final exit from the eye where the track was to the north. Letters in the figure indicate where the observations identifying the eye-wall boundaries were taken. Letters A, D, and E are over the northwest boundary, B and C over the southeast one, and F at the north boundary. The fact that the boundary locations data agree so well suggest that the navigational fixes may not be as uncertain as we are assuming. However, whether or not the terminals of the northwest-southeast axes agree is not vital to our discussion. The tropopause was encountered twice over the wall clouds and these locations are identified in the cross section by T_1 (on descent) at 119 mb, and T_2 (on ascent) also at 119 mb (50,000 ft). Points T_1 and T_2 are 13 and 35 miles, respectively, from the eye wall. At the nearest coastal stations located some 250 miles from the eye, the tropopause at 12 GMT was found to be about 10 mb lower (about 2500 ft higher), for example, Cape Hatteras 112 mb, Charleston 107 mb, and Jacksonville 108 mb. Thus the tropopause showed a small downward slope from the coast to vicinity of the hurricane, and about zero slope over the region outside of the eye. There was no direct information available regarding the slope into the eye.

In order further to examine variations into the eye, an "eye" sounding was constructed from the U-2 observations, hurricane reconnaissance data, and mean eye temperatures from 900–500 mb as given by Jordan (1957). The collective observations are shown on an adiabatic chart in Fig. 5. The eye sounding is composed of U-2 observations from 50–119 mb and 165–295 mb. Hurricane reconnaissance, Gull Ginny One, provided 700-mb temperatures in the eye and its environment, and observations to sea level pressure were derived from two dropsondes released in the eye one and a half hours before and after the time of the U-2 data. On the basis of its sea level pressure, Ginny rated as a weak storm according to a classification by Jordan (1957), and the (X's) in Fig. 5 represent the temperature profile, 900–500 mb, which Jordan found to be characteristic of a weak hurricane. It is noteworthy that the dropsonde data, available only to 700 mb, agree very closely with the mean values. In view of this agreement, it was felt that the dropsonde temperatures could be extended with some confidence to 500 mb by following the mean case. Between 500 mb and the U-2 data at 300 mb, the only resort was to use simple interpolation.

In the immediate environment of the eye, U-2 observations were available from 50 to 205 mb at various distances from the eye wall, for example, five miles at 200 mb, 15 at 165 mb, and 45 at 110 mb. Also shown in Fig. 5 is the Charleston sounding for 12 GMT; the Cape Hatteras and Jacksonville soundings were very similar to the one at Charleston.

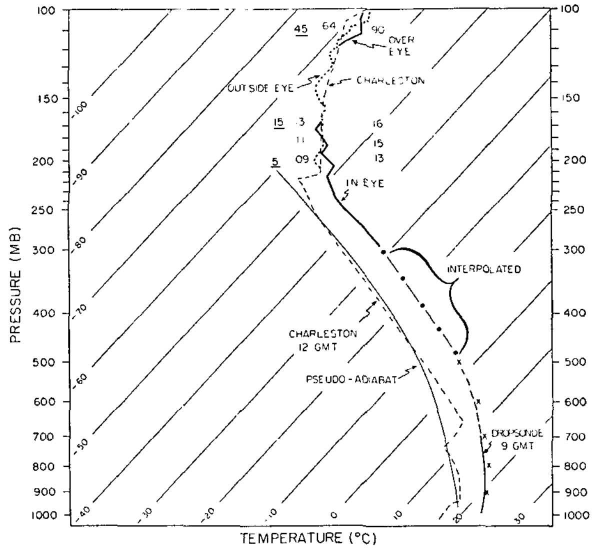

FIG. 5. Comparison of data in eye of Ginny with data in the immediate environment and with the coastal environment. The (X's) from 900 to 500 mb represent mean temperatures in eye of weak hurricane. Mixing ratios of ozone ($\mu g/g$) are shown, those to right of soundings are concentrations in eye, those to the left are concentrations in environment. Distance of environmental points shown in miles by underlined numbers.

From Fig. 5 it appears that the eye region below about 220 mb was 5–6C warmer than the distant environment at the coast. Meanwhile the reconnaissance observations at 700 mb found that the eye temperature was about 6–8C higher than the temperature at a point 50 miles from the eye. The fact that much of the temperature gradient was in the immediate vicinity beyond the eye wall verifies an often observed feature in hurricanes. At cloud top height, in the vicinity of 200 mb U-2 observations indicate that the eye was about 3C warmer than a point some five miles from the eye wall. We also see that ozone concentrations were somewhat larger within the eye. In view of temperature gradient noted above it is reasonable to assume that a temperature difference of several degrees existed over a distance of 40–50 miles from the eye wall. Just above the cloud tops, at 190 mb or 40,000 ft, the temperature difference was essentially zero although the environmental observation point was about nine miles from the eye wall. The flat horizontal temperature field and a weak ozone gradient extended at least up to 165 mb where the environmental measurement was 15 miles from the eye wall. It is interesting to see that the upper troposphere over the storm appeared to be colder than over the coastal environment. In the vicinity of 110 mb the hurricane region was warmer than the coastal environment, and the over-eye area was about two degrees warmer and contained about 50 per cent more ozone than the region about 40 miles from the eye wall. From 105–50 mb the horizontal gradients appeared to be poorly defined.

4. Summary and conclusions

From this study it appears that Ginny's circulation did not extend into the uppermost region of the troposphere. The warm core of the eye extended up to about 200 mb—the top of the wall clouds. The warmness of the core appeared to be roughly uniform with height; however, the limited extent of the data introduces a certain degree of uncertainty into this suggestion.

A noteworthy feature was that the horizontal gradients of temperature and ozone became very weak just above cloud tops, at 190 mb. The flat gradients continued up to the tropopause level at 119 mb. The tropopause showed a slight downward slope from the coast to the storm, and in vicinity of 110 mb the eye was warmer and contained more ozone than a point about 45 miles from the eye wall. From 105–50 mb the horizontal gradients again appeared to be poorly defined.

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