Temperature and Ozone Variations Near Tropopause Level over Hurricane Isbell October 1964

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ABSTRACT

Temperature and ozone data obtained in hurricane Isbell on 14 October 1964 by an instrumented U-2 aircraft are used in conjunction with several radiosonde observations to reconstruct some features of the structure at tropopause level. The tropopause was inclined upwards toward the eye, with a slope of 1:200, except that the slope reached a plateau at a point over the wall clouds. In addition, it appeared that the horizontal variation of vertical motion was insignificant in the upper troposphere and lower stratosphere regions over the hurricane core. An unusual feature found in Isbell was a deep cloud-filled volume over the eye that extended from about 250 to 100 mb (the tropopause pressure).

1. Introduction

A considerable amount of valuable data has been obtained in hurricanes by research aircraft in recent years. Because of operational limitations of the aircraft, very little information has been obtained from the upper troposphere and lower stratosphere. Clearly, data to high levels are needed for a better understanding of the mechanics of these storms. According to Stear (1965) only three radiosonde observations up to high levels have been obtained in the eye of a hurricane, and only in the case described by Stear did the balloon penetrate into the stratosphere over the eye. A recent source of high level data has been an instrumented U-2 aircraft, and a study of the ozone and temperature observations over hurricane Ginney of October 1963 using such an aircraft has been discussed by Penn (1965). The present paper also deals with U-2 data, obtained this time over hurricane Isbell of October 1964.

A model by Riehl (1954) proposes that the atmosphere above 100 mb remains undisturbed, and that the tropopause is highest over the eye. From a time sequence of three radiosonde observations in hurricane Arlene over Bermuda in August 1963, Stear (1965) indicates that the tropopause height increased until eye passage and then decreased. Unfortunately, a possible secondary tropopause location on two of the soundings introduces some uncertainty about the reliability of the deduced slopes. Stear points out that his analysis of the tropopause profile in Arlene would agree with Riehl's (1954) model. It is interesting to note that the higher tropopause position in the eye of Arlene was near 120 mb, close to that in hurricane Ginny of 1963.

In the case of Ginny [see Penn (1965)], the tropopause was penetrated at points 20 km and 50 km from the rim of the eye. Both penetrations occurred over convective clouds and each time the tropopause was sharply defined at 119 mb (15 km). An estimate of the variation of the tropopause height from the storm's core to the near environment was uncertain because the nearest radiosonde station was some 400 km away and its data was off-time by several hours. Another noteworthy feature about Ginny was that its influence extended only up to the 200-mb level, the top of the wall clouds. The horizontal gradients of temperature and ozone were very weak at 190 mb. Thus, the warm core which was prominent at lower levels appeared to end abruptly at about cloud-top level.

2. Data and analysis of hurricane Isbell

In this paper we are again concerned mainly with an analysis of the tropopause structure, and the nature of the high-level core and the implied field of the vertical motion in a mature hurricane. Our interest is in hurricane Isbell on 14 October 1964. The track, associated weather and other synoptic features of this storm have been described by Dunn (1965). Throughout the 14th, radar indicated marked asymmetry in the precipitation pattern around Isbell, with the rear sector free of significant convective activity. See Fig. 1 for a typical PPI photograph on the 14th. According to Dunn, the asymmetry was verified in the observed weather when no rain of consequence occurred after the center passed Everglade City, Florida, and also when winds were considerably less in the rear portion of the storm.

Our analysis is based upon data from several radiosonde releases and from observations obtained by an instrumented U-2 for about half an hour, centered about 1900 GMT 14 October. At that time, the eye was located about 35 n mi to the north-northwest of Key West and moving towards the northeast at 15–20

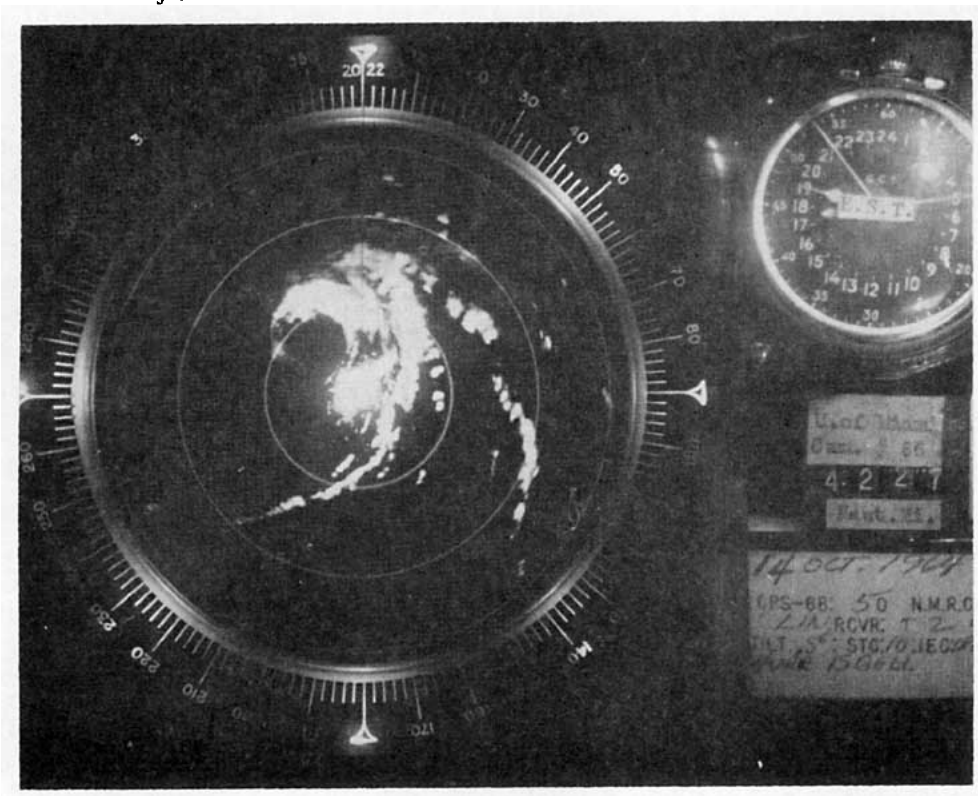

FIG. 1. PPI photograph taken at 2353 GMT 14 October 1964 on 10-cm wavelength radar showing eye centered approximately 50 n mi northwest of radar site at Coral Gables. Scale is 50 n mi between circles. (Photograph courtesy of Institute of Marine Science, University of Miami.)

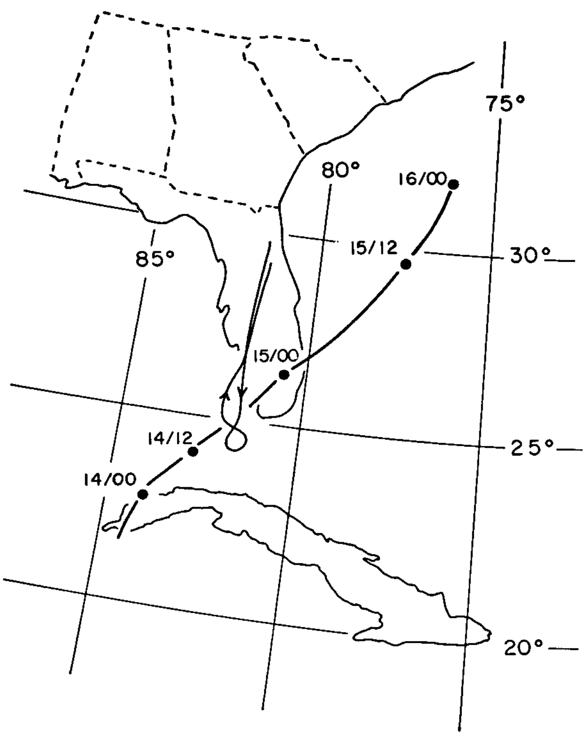

FIG. 2. Tracks of Isbell and of U-2. The U-2 was over the eye from 1842-1915 GMT 14 October.

kt. The tracks of the hurricane and the U-2 are shown in Fig. 2. The plane was given radar vectors into the eye by the Federal Aviation Agency air traffic controllers; however, because the upper portion of the eye was cloud-filled, there was no visual verification of the eye by the pilot. The pilot reported clouds to the 68-mb level at the north side of the storm. The plane came in over the convective clouds, and an (X) pattern was made over the eye, mainly in the 90–95 mb height range. The southward leg was about 100 km long. On the return leg, a penetration was made into the eye down to 116 mb (15.7 km), and the plane's position at 116 mb is located where the U-2's tracks cross in Fig. 2. The vertical probe was terminated at the indicated pressure height because of increasing turbulence. The tropopause was found to be at 101–102 mb (16.4 km).

A thick layer of cirrus-type clouds covered the eye and the pilot noted that he entered the clouds near 100 mb and that the clouds were still very dense at the bottom of the descent at 116 mb. Radiometric measurements, from instrumentation on the U-2, suggest that a cloud depth of several kilometers was below the 116-mb level. A research aircraft from the National Hurricane Research Laboratory taking measurements near 12 km reported flying in thick clouds (not the wall clouds) in the eye at the time. Thus, it appears that

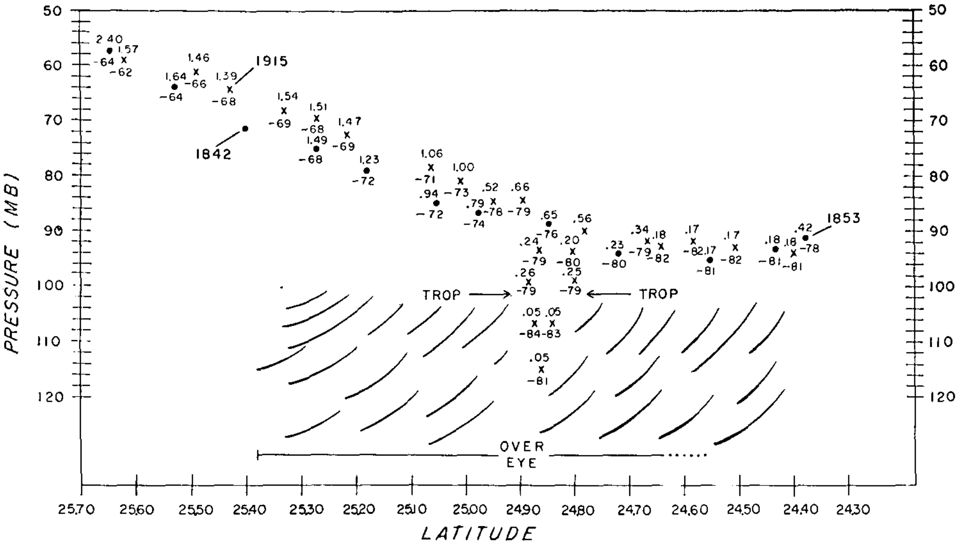

Fig. 3. Cross section of U-2 flight over Isbell with some observations of ozone mixing ratio (μgm gm^{-1}) and of temperature (°C). Dots refer to observations on southward leg and crosses to those on return leg. Hatching shows regions of cirrus-type clouds. Projection of lower level eye is shown.

clouds were present over the eye from 10 or 11 km up to 16.4 km (tropopause level). These clouds are probably anvil cirrus break-offs from the convective activity on the forward side of the storm with some of the anvil cirrus having been overtaken by the northeastward moving eye. The presence of these thick clouds in the eye indicate that subsidence, which plays an important role in a hurricane eye, must have been negligible above 10 or 11 km. A vertical cross section using some of the temperature and ozone observations of the flight is shown in Fig. 3.

The reliability of the observations can be estimated by noting that the data from the two passes over the storm are in substantial agreement. The observations in the 90–95 mb range of the lower stratosphere can be used to examine the variation across the storm. These data extend from a position over the center of the eye to a point about 70 km to the south over the "open" sector of the storm. Temperatures over the center appear to be 2–3C higher; however, the ozone measurements show no significant variation in the horizontal direction. Since the vertical gradient of ozone is quite pronounced at our level of interest, we conclude that the indicated temperature gradient is not significant, and that no important horizontal variation of the vertical motion field exists over the sampled portion of the stratosphere.

3. Tropopause profile in Isbell

The slope of the tropopause in the vicinity of the storm was estimated from a composite chart where the indicated pressure height of the tropopause was placed relative to the eye at the time of the particular observation. This chart is shown in Fig. 4 where data is limited to the forward side of the storm. We see that the tropopause rises toward the storm about 20 mb (1.1 km) from a point 175 n mi to one at 50 n mi, giving an approximate slope of 1:200. The tropopause, however, appears to be horizontal over the core of the storm, that is, from the wall clouds to the eye. This character-

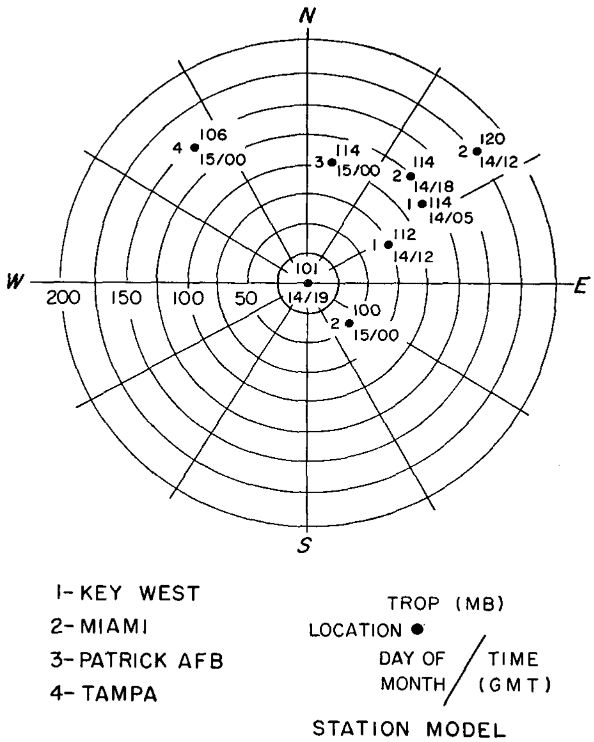

Fig. 4. Composite map of tropopause pressure heights where observations are positioned relative to location of eye at time of observation. Data at center (eye) obtained from U-2 when eye was 35 n mi NNW of Key West.

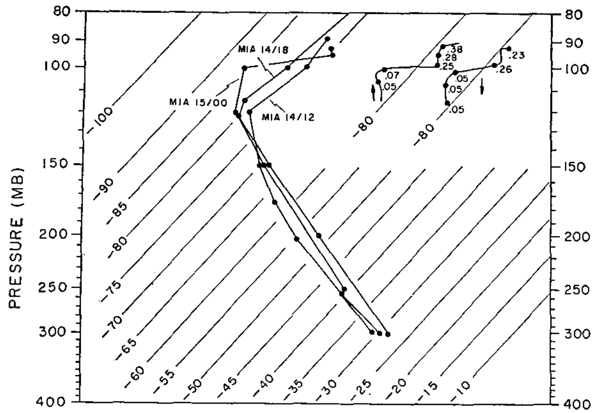

FIG. 5. Temperature sounding from Miami and the U-2 where U-2 data are displaced to the right. Ozone mixing ratio (μgm gm^{-1}) values are also shown.

istic of horizontal uniformity in the upper level projection of hurricane cores was shown earlier in this paper to be the case in the south sector of Isbell in the 90–95 mb height range. In addition, we have already referred to a similar feature in hurricane Ginny where its influence was not detectable above the 200-mb level.

Another way to view the tropopause data is simply to study the time changes at a point in the path of the eye. Miami was the best situated station in this respect, although the eye passed nearly 75 km to the northwest. This qualification about the relative position of the eye at 0000 GMT 15 October is acceptable here because this sounding closely resembled one made over the eye by the U-2. Three radiosonde observations at Miami were made at 6-hr intervals, the upper portion of these being shown in Fig. 5. The arrival of a higher and colder tropopause is clearly shown. Included in Fig. 5 are two soundings derived from the U-2 penetration over the eye. The excellent agreement between the two soundings is obvious; in each case, the tropopause is sharply defined from the temperature and ozone data. The ozone mixing ratio changes by a factor of five over a few millibars of height. Agreement between the aircraft soundings and the 15 October Miami sounding is quite satisfactory.

4. Conclusions

The tropopause structures observed in hurricanes Ginny and Isbell, and in hurricane Arlene (analyzed by Stear) are consistent with Riehl's model which depicts the tropopause as a high dome (near the 100-mb level) over the storm's core. In addition, in the case of Isbell, the tropopause in the forward portion of the storm was found to have a slope of 1:200 between points 50 and 170 n mi from the eye.

TABLE 1. Pressure in surface eye and height of top of warm core.

Hurricane	Date	Height of warm core (mb)	Pressure in eye (mb)
Ginny	22 Oct. 1963	200	989
Isbell	14–15 Oct. 1964	140	974
Arlene	9 Aug. 1963	125	974
Isbell	14 Oct. 1964	120	964
Storm used in Riehl's model	17 Sept. 1947	100	947

The detailed constant pressure data obtained by the U-2 at high altitudes support Riehl's contention that temperature variations above 100 mb need not be invoked to explain the hurricane pressure field. Another significant feature is in regard to the warm core in hurricanes. The warm core is due largely to subsiding motions and is related to the low surface pressure in the eye. Jordan (1952) correlated the height of the base of the stable layer in eyes with the central pressures. His correlation would imply that the lower the base of the warm core, the lower the central pressure. Using the same reasoning, one would expect that the height of the top of warm core would be correlated with the surface pressure. This contention appears to be supported by the data in Table 1 which considers only the storms discussed in this paper. The data for Isbell for October 14 were based upon the 0500 and 1200 GMT radiosondes from Key West. At 1200 GMT Isbell was a little southwest of Key West and it had attained its lowest pressure of 964 mb. It should be pointed out that the non-synoptic nature of most of the data introduces some uncertainty about the determination of the warm core.

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