NOTES AND CORRESPONDENCE

A Note on Several Low-Layer Features of Hurricane Eloise (1975)

Michael S. Moss and Francis J. Merceret
National Hurricane and Experimental Meteorology Laboratory, NOAA, Coral Gables, Fla. 33124
8 December 1975 and 12 April 1976

ABSTRACT

Low-level flight data from a small cloud-free area along the periphery of Hurricane Eloise (1975) reveal the existence of a well-mixed boundary layer which is capped by a near-isothermal layer. The isothermal layer is probably created by the combined effect of subsiding air and surface-induced turbulence.

1. Introduction

On 17 September 1975, the NOAA DC-6 (39C) research aircraft flew a pattern of seven levels in a small area of Hurricane Eloise to obtain preliminary information about the planetary boundary layer (PBL) structure of hurricanes. Unfortunately, there seems to be a difference of views regarding the definition of the PBL in hurricanes and other tropical circulations. This is

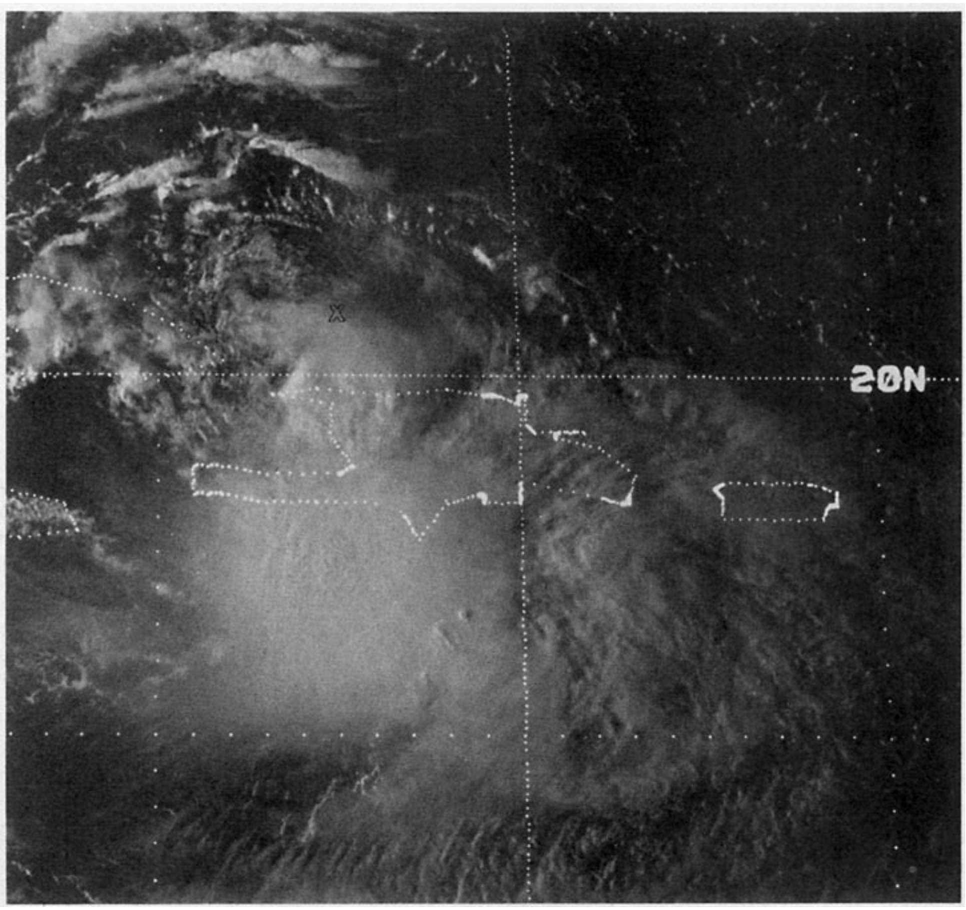

Fig. 1. SMS satellite picture (half-mile resolution) of Hurricane Eloise at 2130 GMT, the approximate time of the PBL experiment. The × denotes the location of the experiment.

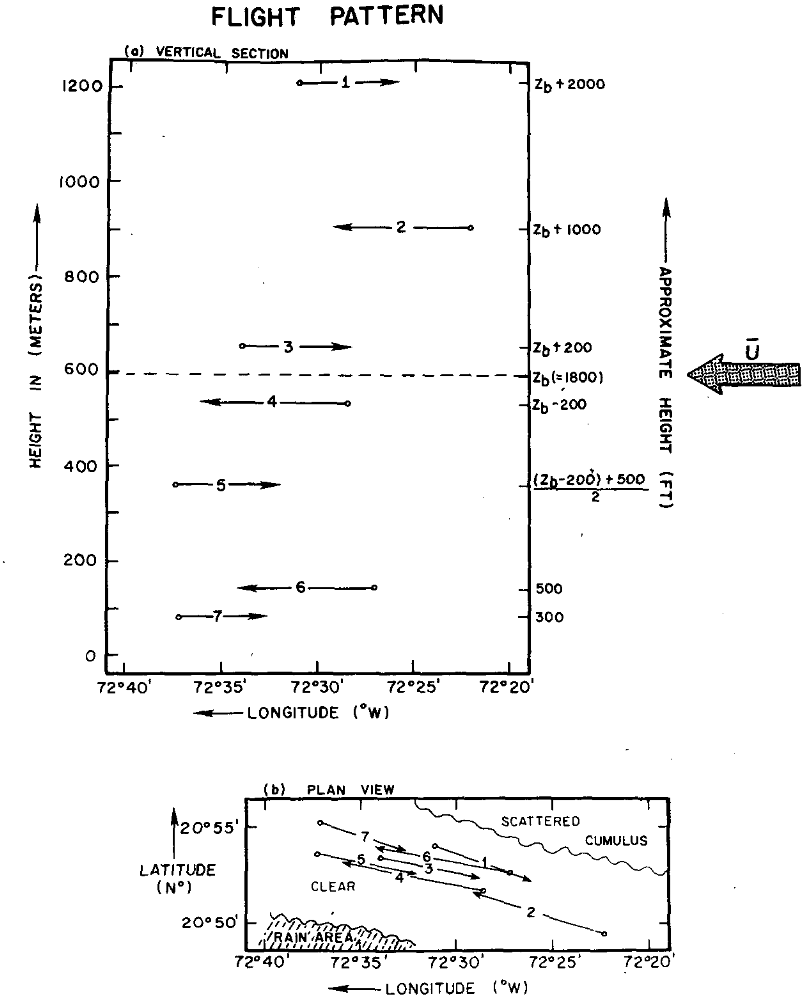

FIG. 2a. Vertical section of the actual flight pattern performed in Hurricane Eloise. The shaded arrow represents the mean wind. Note that the location of the flight legs is generally referenced with respect to the surrounding cloud base (Z_b). 2b. Plan view of the actual flight pattern performed in Hurricane Eloise. Also, a schematic representation of the weather in the area of the experiment.

because conceptual difficulties arise in attempting to apply the Ekman-theory-oriented glossary definition of the PBL (Huschke, 1959) to the tropics where the Coriolis parameter is small. Therefore, we have adopted the following definition: The PBL is the region adjacent to the earth's surface where small-scale, surface-induced turbulence occurs almost continuously in time. This definition is essentially the same as that used by Deardorff (1972) and Arakawa (1975). Worth noting is that PBL as defined here excludes reference to the turbulent regimes that result from towering cumuli.

Fig. 1 is an SMS (synchronous meteorological satellite) picture of the hurricane taken approximately at the time of the experiment. The × denotes the location of the experiment, a point along the periphery of the dense, storm-associated cloud cover. This point was approximately 100 km from the eye which was just off the northwest coast of Haiti (20°N, 72.6°W). The storm had, at most, marginal hurricane winds, and a surface pressure minimum (as deduced from the aircraft observations) of 1001.8 mb. That a substantial portion of the storm circulation was located over the mountainous terrain of Hispaniola is also apparent from Fig. 1. The effect of the orography was to render the storm rather peculiar in structure. In particular, the eye was poorly defined, the bulk of the convection was south and east of the eye, and there was a broad area of uniform gale force winds east of the eye.

Figs. 2a and b illustrate the flight pattern. The vertical section (Fig. 2a) shows that the flight legs alternated into and out of the wind. The first leg (leg 1) was at an altitude of $Z=1213$ m and subsequent legs were at lower levels. The final leg (leg 7) was at $Z=85.7$ m. The duration of each leg was 2 min and the total flight operation lasted 35 min. The length of the legs varied from 9.6–14.4 km depending on the ground speed. The plan view depicted in Fig. 2b demonstrates that the legs were very nearly vertically stacked. This figure also schematically illustrates that the experiment was performed in a clear region with scattered cumulus to the north-northeast and the edge of the broad, hurricane-associated rain area less than 10 km to the south-southwest. These observations further indicate that the experiment took place along the outer edge of the storm circulation. Pertinent quantities measured by sensors aboard the aircraft were air temperature, dewpoint temperature, horizontal vector wind velocity, and horizontal turbulent velocity fluctuations. The bulk data for the results presented in the following section were sampled every 10 s and the turbulence data had a bandwidth of 2500 Hz encompassing a range of wavelengths from approximately 4 cm to 50 m.

2. Mean vertical profiles and turbulence data

Figs. 3–7 present, respectively, the vertical profiles of potential temperature, specific humidity, horizontal wind speed and direction, temperature and relative humidity. To determine the various profiles, the individual data were averaged along each leg. The figures are fairly representative of the instantaneous profiles because 1) the central pressure and character of the circulation did not change during the flight operation, and 2) the standard deviations of the quantities (Table 1) are small relative to the means.

The mean profiles of potential temperature (Fig. 3), specific humidity (Fig. 4), and horizontal wind speed and direction (Fig. 5) clearly exhibit the characteristics of a well-mixed PBL (Deardorff, 1972) below 590 m which was the cloud base height in the surrounding

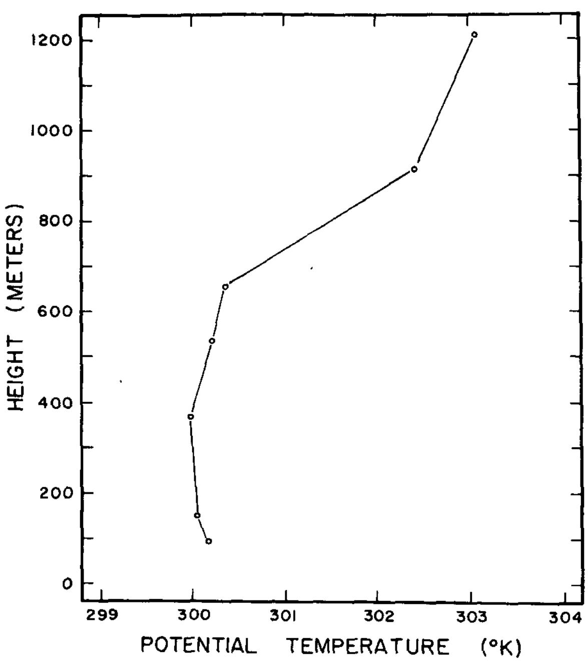

FIG. 3. Low-layer vertical profile of potential temperature obtained from the periphery of Hurricane Eloise.

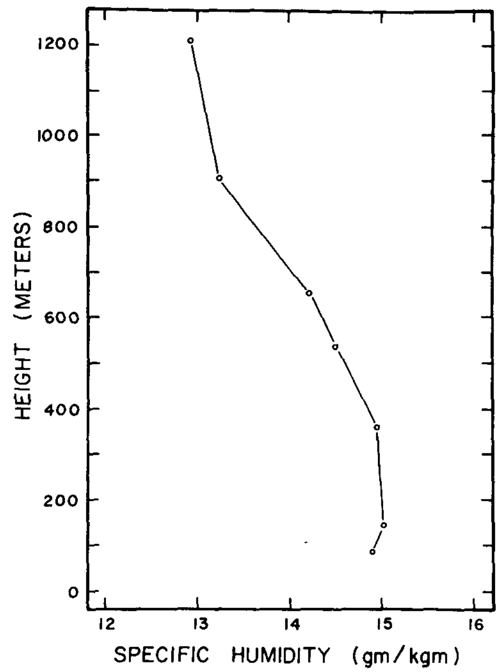

FIG. 4. As in Fig. 3 except for specific humidity.

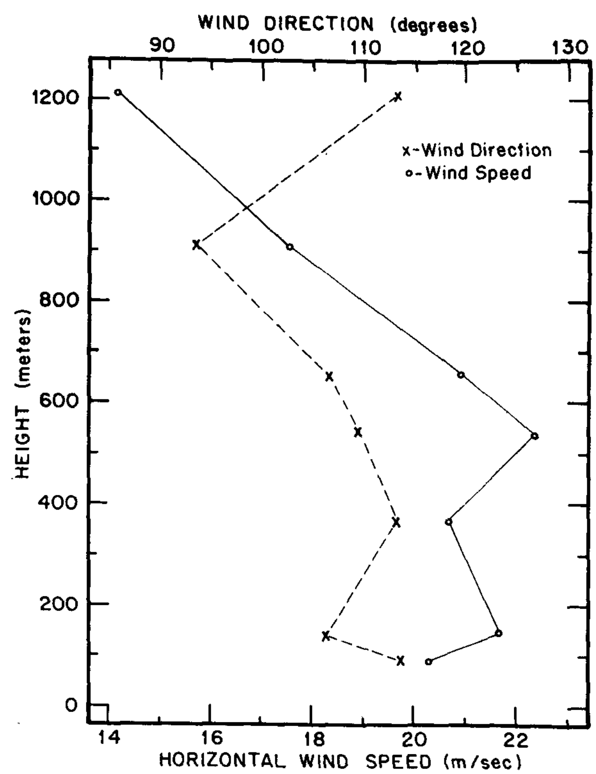

FIG. 5. As in Fig. 3 except 3 horizontal wind speed (solid curve) and direction (dashed curve).

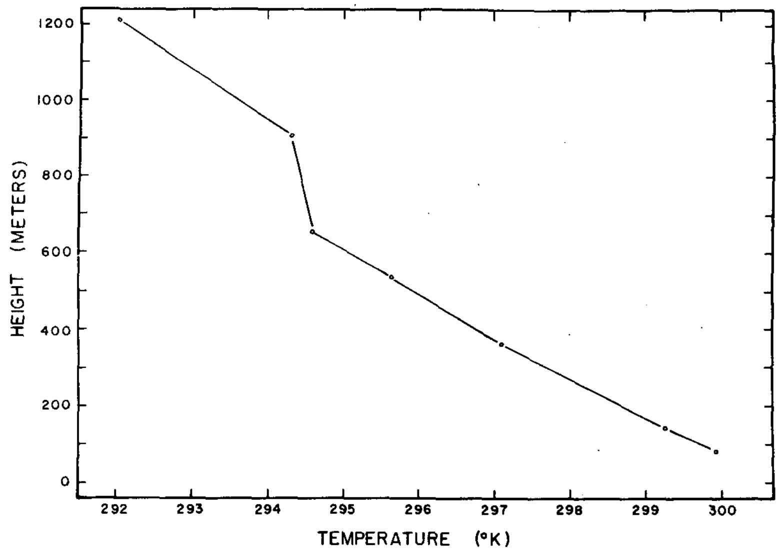

FIG. 6. As in Fig. 3 except for temperature.

region. The temperature profile (Fig. 6) shows a nearly isothermal layer just above 590 m. Of particular interest is that if the lapse rate across the isothermal layer is destabilized by the standard deviations listed in Table 1, the layer would still be relatively stable. If, on the other hand, the lapse rate is stabilized by the standard deviations, the isothermal layer becomes an inversion. For completeness, the relative humidity profile (Fig. 7) is presented to show that the air is drier at the top than at the base of the isothermal layer.

Using the mean data, we applied Deardorff's (1972) parameterization scheme to compute a Monin-Obukhov length (L) for the well-mixed layer. The applicability of Deardorff's technique to hurricanes has been demonstrated by Moss and Rosenthal (1975). They utilized bulk low-level data from Hurricanes Daisy (1958) and Inez (1966) to compute drag coefficients via Deardorff's approach and found excellent agreement with those coefficients computed as residuals to the budget studies for these two storms. For Hurricane Eloise, we found $L=-525$ m which closely corresponds to the observed depth of the well-mixed layer. This result is a good indication that the low-level turbulence is mainly mechanically (shear) generated. A detailed discussion on the diagnostic application of Deardorff's scheme to compute L is given by Moss and Rosenthal (1975). Fig. 8 is a small-scale horizontal wind velocity spectrum obtained during leg 5 from a hot-film anemometer (see Merceret, 1976). Here, we observe the existence of an inertial subrange commencing at scales of $\sim$30 m and terminating at $\sim$20 cm. Similar spectral distributions were obtained for the remaining legs in the well-mixed layer. These observations are also consistent with the hypothesis that the turbulence there, for the most part, is mechanically (shear) generated. No buoyancy effects appear in the finestructure at these levels, at least at scales smaller than 50 m.

3. Conclusions and discussion

Although data from a weakly-defined, orographically-influenced storm (Hurricane Eloise 1975) have been presented in this paper, we conjecture that a low-level peripheral stable layer is a feature common to most hurricanes. The reason for this is, in part, that the hurricane periphery is characterized by suppressed

TABLE 1. Standard deviations of potential temperature, specific humidity, horizontal wind speed and direction, temperature and relative himidity at various levels.

Level height (m)	Potential temperature (K)	Specific humidity (g kg^{-1})	Horizontal wind speed (m s^{-1})	Horizontal wind direction (deg)	Temperature (K)	Relative humidity (%)
1213.0	0.174	0.17	0.53	2.34	0.178	1.57
907.6	0.298	0.20	0.70	2.17	0.279	2.10
656.7	0.246	0.56	0.50	2.36	0.250	4.42
536.1	0.159	0.60	0.40	2.25	0.169	4.03
362.2	0.073	0.51	1.16	1.71	0.091	2.79
142.6	0.100	0.32	1.38	3.11	0.117	1.55
85.7	0.078	0.21	1.04	2.36	0.083	0.94

convection caused by subsiding air (Miller, 1967). In the absence of turbulent mixing, the associated dry adiabatic warming would tend to create a stable layer at the surface. However, because of the action of surface-induced turbulence, the height of the stable layer is elevated. For the storm described here, the PBL turbulence was for the most part mechanically generated. The depth of the well-mixed layer approximately coincided with the cloud base height of the surrounding environment. Noteworthy is that the vertical distribution of variables described here is not unique to the hurricane periphery but is also observed in the undisturbed tradewind environment (see, e.g., Garstang and Betts, 1974).

Finally, a similar stable layer may also exist between some hurricane rainbands. As with the peripheral domain, the regions between rainbands are characterized by suppressed convection that may result from compensating subsidence between the bands (Gentry, 1964). Furthermore, Moss and Rosenthal (1975) have presented indirect evidence that the underlying PBL's are well-mixed by mechanically-generated, surface-induced turbulence. Thus, the physical mechanisms for maintaining a low-level stable layer appear to be the same as those for the periphery. If, indeed, large areas of the hurricane PBL are well-mixed and capped by stable layers, then the implications for modeling can be quite significant (Lilly, 1968; Geisler and Kraus, 1969; Deardorff, 1972).

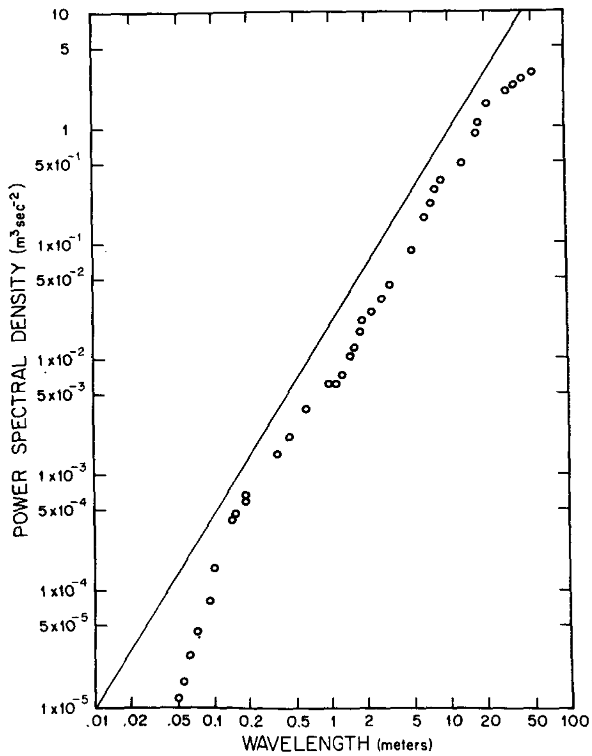

Fig. 8. Power spectral distribution of the streamwise wind component from data obtained along leg 5 (see Fig. 2a) from the periphery of Hurricane Eloise. The solid line denotes the 5/3 slope characteristic of an inertial subrange.

Acknowledgments. The writers are especially indebted to Dr. Stanley L. Rosenthal for his many useful suggestions in the preparation of the manuscript. We also thank Dr. Walter J. Koss, Dr. Robert C. Sheets, Mr. Peter G. Black and Mr. Hugh E. Willoughby. Finally, we thank Mr. Brian E. Rice for his help with acquiring and processing the data.

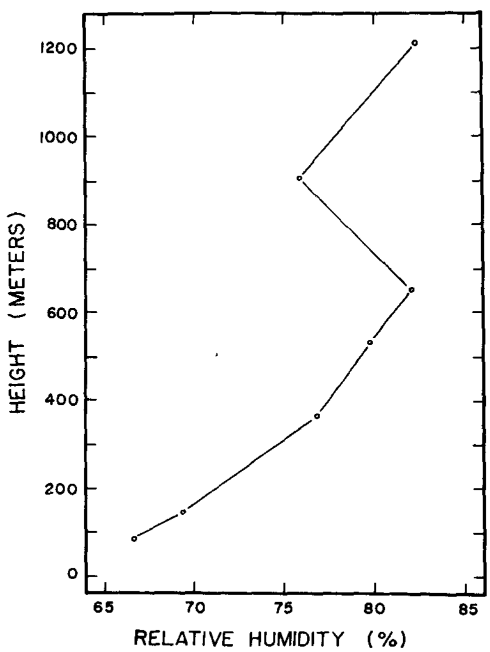

Fig. 7. As in Fig. 3 except for relative humidity.

REFERENCES

Arakawa, A., 1975: Modelling clouds and cloud processes for use in climate models. *The Physical Basis of Climates and Climate Modeling*, GARP Publ. Ser. No. 16, WMO-ICSU Joint Organizing Committee, 183–197.

Deardorff, J. W., 1972: Parameterization of the planetary boundary layer for use in general circulation models. *Mon. Wea. Rev.*, **100**, 93–106.

Garstang, M., and A. K. Betts, 1974: A review of the tropical boundary layer and cumulus convection: Structure, parameterization and modeling. *Bull. Amer. Meteor. Soc.*, **55**, 1195–1205.

Geisler, J. E., and E. B. Kraus, 1969: The well-mixed Ekman boundary layer. *Deep-Sea Res.*, **16**, 73–84.

Gentry, R. C., 1964: A study of hurricane rainbands. NHPP Report No. 69, National Hurricane Research Laboratory, Miami, 85 pp.

Huschke, R. E., Ed., 1959: *Glossary of Meteorology*. Amer. Meteor. Soc., p. 426.

Lilly, D. K., 1968: Models of the cloud-topped mixed layers under a strong inversion. *Quart. J. Roy. Meteor. Soc.*, **94**, 292–309.

Merceret, F. J., 1976: Measuring atmospheric turbulence with airborne hot-film anemometers. *J. Appl. Meteor.*, **15**, 482–490.

Miller, B. I., 1967: Characteristics of hurricanes. *Science*, **157**, 1389–1399.

Moss, M. S., and S. L. Rosenthal, 1975: On the estimation of planetary boundary layer variables in mature hurricanes. *Mon. Wea. Rev.*, **103**, 980–988.