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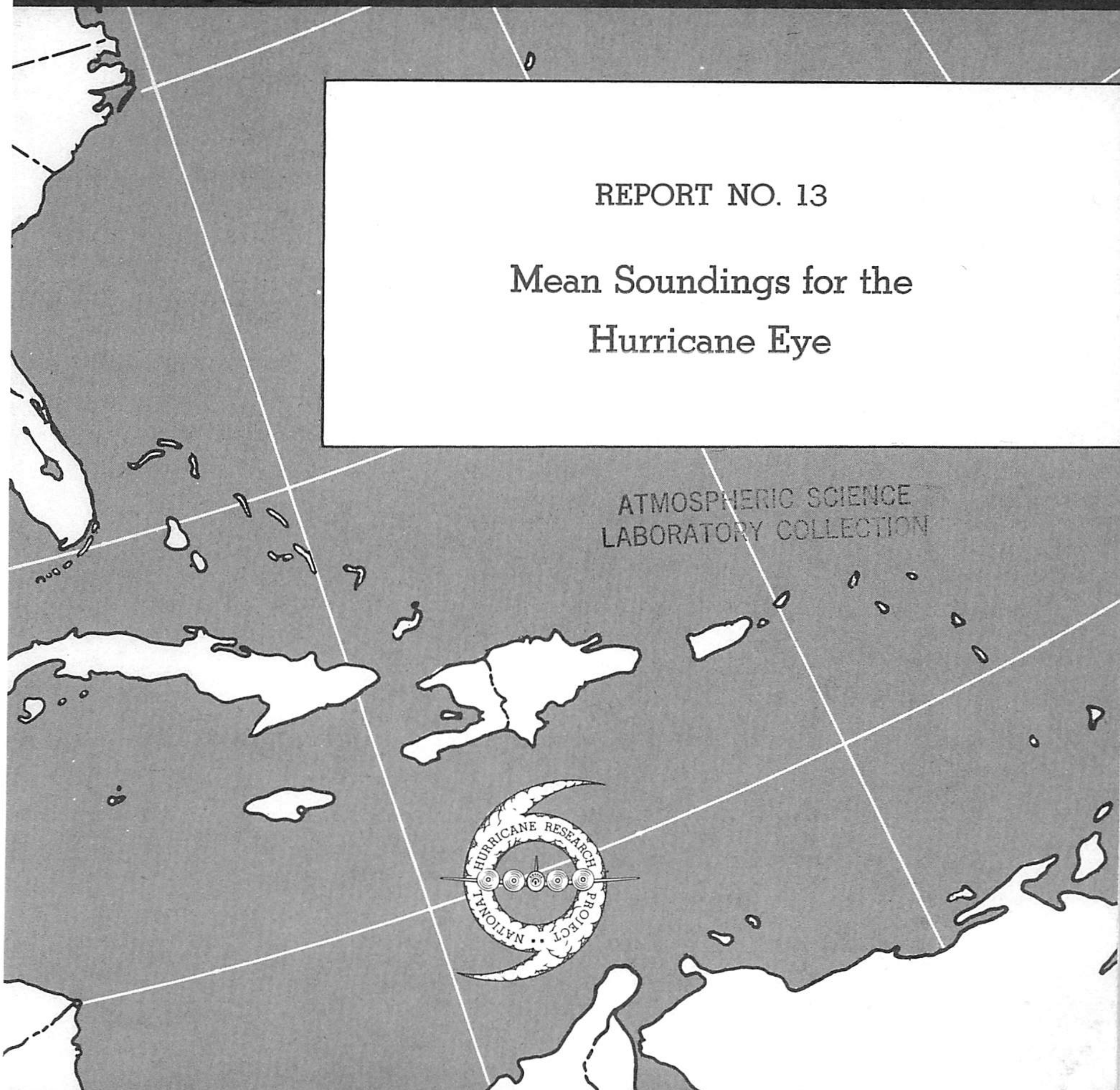

REPORT NO. 13

Mean Soundings for the Hurricane Eye

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary
WEATHER BUREAU
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NATIONAL HURRICANE RESEARCH PROJECT

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by

C. L. Jordan
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Washington, D. C.
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Commerce-Weather Bureau, Washington, D. C.

MEAN SOUNDINGS FOR THE HURRICANE EYE

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ABSTRACT

Mean soundings for the hurricane eye have been prepared for three arbitrarily defined storm intensities. The soundings, which extend to the 500-mb. level, are based on a sample of 39 dropsonde observations. Eye and "rain area" soundings for hurricane Betsy of 1956 are compared with the mean soundings.

INTRODUCTION

Several years ago the author [1] used a relatively small sample of dropsonde data for the preparation of a mean sounding for the lower 2.5km. of the typhoon* eye. In the years following, a large amount of eye dropsonde data has been taken in tropical cyclones in the Atlantic and Pacific areas. These data have not shown significant differences from the earlier sample and, therefore, no effort has been made toward preparing a revised mean eye sounding. The greatest limitation of the eye sounding has been its small vertical extent. During the past two years eye dropsonde data from the 500-mb. level have increased to the point where it is now possible to extend the mean eye sounding. However, since the data sample used in this study consists of a total of only 39 soundings the results should be considered of a tentative nature. A much larger sample could have been used for preparing mean data for the surface to 700-mb. layer, but in view of the relatively small variability at the low levels, it appeared that the investigation could justifiably be restricted to a small, homogeneous data sample.

All data used in the preparation of the mean soundings presented in this report were taken in hurricanes. However, this should not detract from the general use of the mean soundings since recent results (Jordan [2], [3]) indicate that differences in the thermal structure of the eye of hurricanes and typhoons are insignificant.

PROCESSING OF DATA

The data sample consists of 39 dropsondes made from the 500-mb. level in the eye of hurricanes Connie, Diane, Edith, Flora, and Ione of 1955 and Betsy of 1956. All observations were made during the periods when these storms were

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* The term "typhoon" will be used to refer to tropical cyclones in the western North Pacific-China Sea area; "hurricane" will be used only for tropical cyclones in the western Atlantic-Caribbean-Gulf of Mexico area.

of hurricane intensity and located in the latitude belt 20°N. to 32°N. None of the storms was in the process of rapid transition to an extratropical cyclone at these latitudes.

The central pressure in the 39 cases varied from 998 to 939 mb. Large variations of this type make it difficult to obtain meaningful averages for the lower levels since, for example, in one case the 950-mb. temperature may represent a surface value and in another case a 1500-ft. value. In preparing the mean typhoon sounding, the averaging was done using height as a vertical coordinate. This required the recomputation of all soundings and has the further disadvantage that it is difficult to compare the mean values with the normally available constant pressure data. The hurricane data used in this study have been processed in a somewhat rougher manner by arbitrarily dividing the soundings into three groups on the basis of surface pressure. The three groupings (greater than 985 mb., 984 mb. to 970 mb., and less than 970 mb.) were assumed to represent "weak", "moderate", and "intense" hurricanes, and a mean sounding has been prepared for each category. This division results in an unequal distribution in the three classes-7 "weak", 20 "moderate", and 12 "intense" - but this was unavoidable since a large proportion of the surface pressures were in a rather narrow range centered around 975 mb. The combination of all values below 970 mb. into one sounding is undesirable because of the large pressure range but there were not enough soundings for further subdivision. It could also be argued that the term "intense" should be reserved for much deeper storms.

The mean soundings have been computed from temperature and humidity values tabulated from the individual soundings at the surface, 900-, 800-, 700-, 600-, and 500-mb. levels. The relatively small number of soundings in each category and the variability exhibited by the individual soundings suggested that little would have been gained by using a greater number of levels. The determination of mean moisture was made by averaging the relative humidity, mainly because this is the moisture parameter of primary interest for comparative purposes. However, the results obtained by averaging the dew point, specific humidity, or dew point depression would not have been significantly different since the temperature range was rather small.

MEAN HURRICANE SOUNDINGS

The mean soundings for the three arbitrarily defined classes of hurricanes are shown in figure 1. The mean temperature and humidity and their ranges for each storm class are also shown in tabular form (table 1). The details of these soundings are doubtful for several reasons. The "weak" and "intense" soundings are probably biased by the fact that most of the soundings in each class came from single storms: Edith in the "weak" category, and Ione in the "intense" category. Also, comparison of the range in the different categories (table 1) is questionable because of the unequal number of soundings in the three classes. However, such considerations should have only minor effects on the gross features of the soundings discussed below.

The surface temperature value is essentially constant for the three classes but at all upper pressure surfaces a progressive temperature increase is shown from the weak to the intense storms. Even if the values are compensated for variations in height equivalent to the surface pressure difference, warming

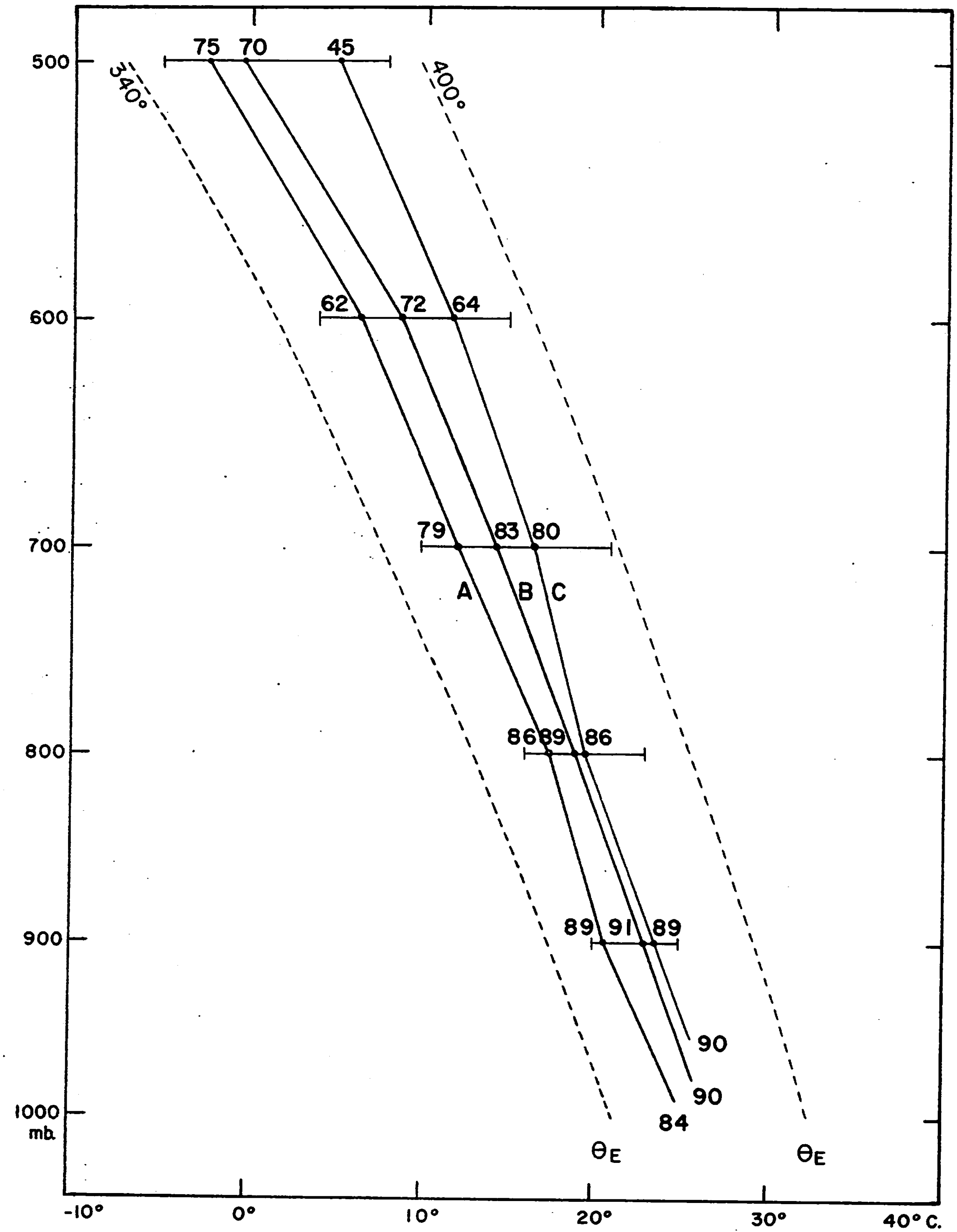

Figure 1. Mean hurricane eye soundings for the "Weak", "Moderate" and "Intense" categories (curves A, B and C, respectively). Temperature range in the complete data sample is shown graphically at each computation level. Pseudoadiabats are shown as sloping dashed lines. Relative humidity in percent is plotted at each computation level.

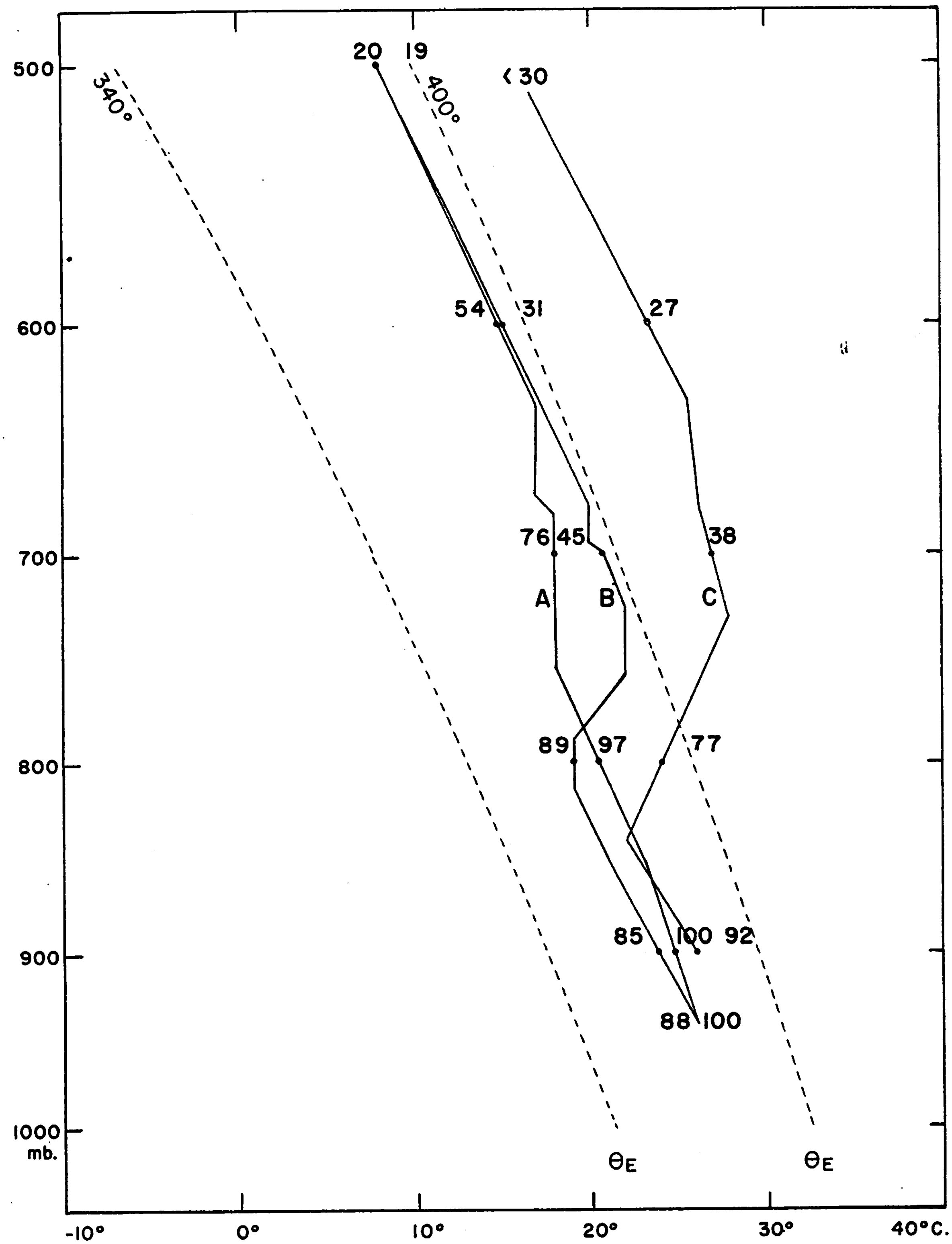

Figure 2. Individual soundings in deep storms on the same format used in Figure 1. Curves A and B are the two most intense cases in the present data sample (hurricane Ione with central pressure of 939-mb. in both cases) and curve C is for typhoon Marge, 1951 (central pressure 900-mb).

Table 1. Mean values and range of temperature (°C) and relative humidity (percent) for the "Intense", "Moderate" and "Weak" classes of hurricanes.

TEMPERATURE

	MEAN			RANGE		
	Intense	Moderate	Weak	Intense	Moderate	Weak
Surface	25.7	25.7	24.9	27-25	30-24	27-23
900 mb.	23.6	22.9	20.8	25-22	29-21	23-19
800 mb.	19.3	19.0	17.4	23-16	23-17	19-16
700 mb.	16.6	14.4	12.1	21-14	18-11	14-10
600 mb.	11.8	8.7	6.4	15-7	12-6	9-4
500 mb.	5.1	-0.4	-2.4	8-2	4-(-5)	0-(-4)

HUMIDITY

	MEAN			RANGE		
	Intense	Moderate	Weak	Intense	Moderate	Weak
Surface	90	90	84	100-78	100-73	100-67
900 mb.	89	91	89	100-69	100-72	100-82
800 mb.	86	89	86	100-52	100-74	99-71
700 mb.	80	83	79	100-45	100-55	90-58
600 mb.	64	72	62	90-31	89-50	83-42
500 mb.	45	70	75	79-19	100-20	87-51

is still indicated at levels above 800 mb. The tendency for progressive warming with increased storm depth is further supported by individual cases (figure 2). The two most intense cases in the present data sample are shown along with a sounding made in typhoon Marge of 1951 when the central pressure was 900 mb. These soundings indicate that in the very deep storms the warming extends to somewhat lower levels. Therefore, the total range shown in figure 1 and table 1 would certainly be increased above the 900-mb. level by inclusion of data from extremely deep storms. For example, three dropsonde observations made in typhoon Nina of 1953, when the surface pressure was in the range 893 to 883 mb., showed 700-mb. temperatures in the range 27°-29°C. and 600-mb. temperatures of 26°-27°C. The relatively large variations in temperature in the 800 to 600-mb. layer in the "intense" category (table 1) are consistent with the large changes which have been noted over short time intervals within this layer in individual cases (cf. Simpson [4]).

No significance is attached to the fact that the lapse rates for the "weak" and "moderate" categories are roughly equal to the moist adiabatic rate (figure 1). These soundings would, however, be warmer on any given isobaric surface than moist adiabatic soundings for the rain area of the storm because the surface pressure is appreciably lower.

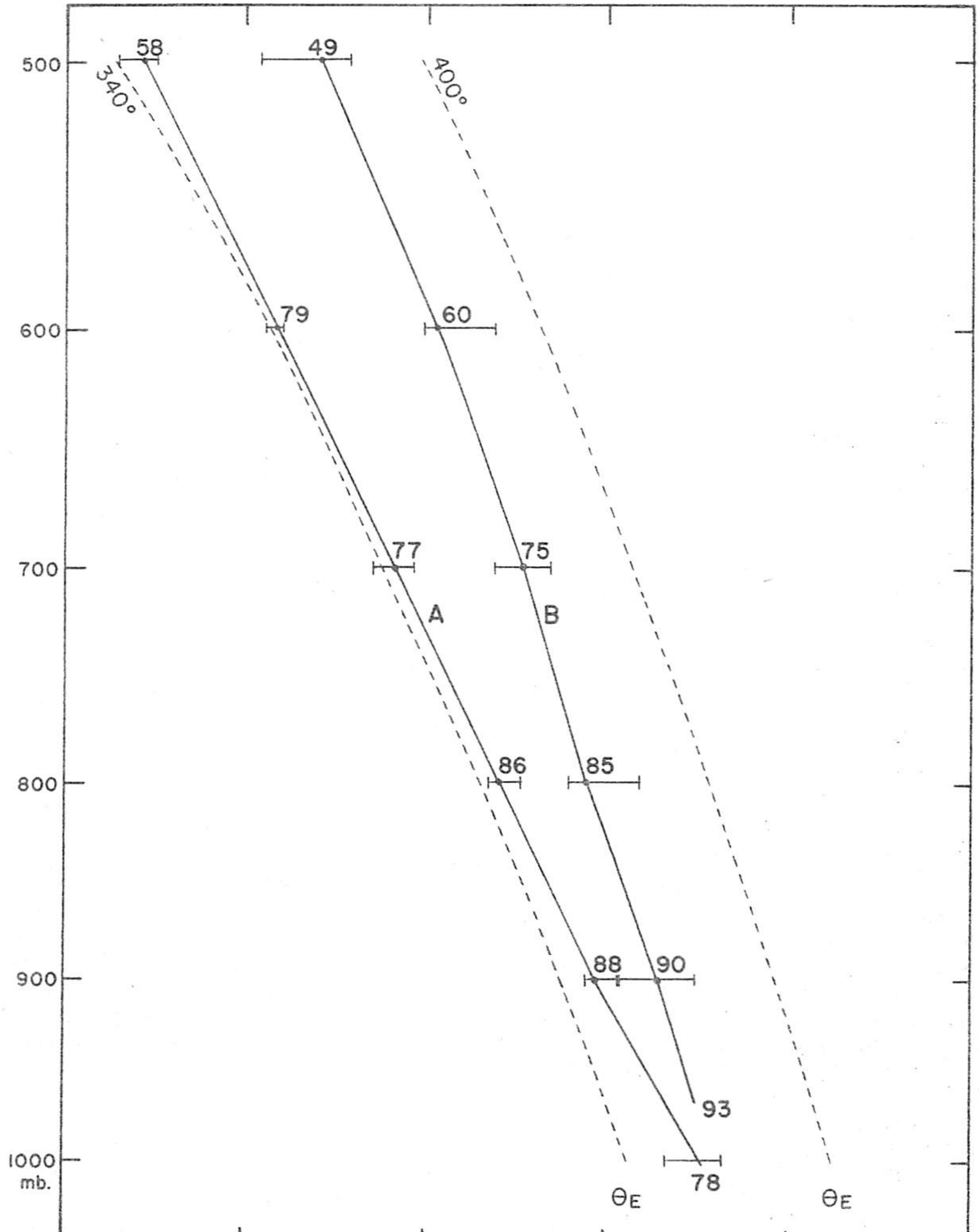

Figure 3. Mean "rain area" and eye soundings for hurricane Betsy, 1956 (curves A and B, respectively) on same format used in Figure 1. Temperature range is shown graphically for each sounding at the computation levels.

The relative humidity values show insignificant differences in the three mean soundings up to the 700-mb. level. The relatively low humidity shown at the 600-mb. level in the "weak" sounding is not considered significant since only seven soundings were used in preparing this mean. In contrast, the decrease in the relative humidity between the "moderate" and "intense" soundings at the 600-mb. and 500-mb. levels is considered a noteworthy feature. This tendency is supported by the low humidities shown in the individual cases of intense storms (figure 2). Values as low as 30 percent at 600 mb. and 20 percent at 500 mb. were reported and, in two of three cases, the 700-mb. humidity was quite low. In typhoon Nina of 1953 the relative humidity at the 700-mb. level was less than 35 percent in three soundings when the dropsonde computations showed surface pressures below 895 mb., and at one time the humidity at flight level - about 10,000 feet - was only 14 percent.

In the past, several investigators, including the author [1], have been inclined to disregard some reports of high humidity within the eye of tropical cyclones. On the basis of the evidence shown by the soundings used in this study, there is no reason to believe that the humidity measurements in the eye are subject to any large consistent error. Perhaps the cases of high humidities within the eye should be taken as evidence of convective mixing into the eye from the outside. The humidity depends not only on the intensity of mixing but also on the rate of descent. The deeper storms may be drier at the upper levels because of stronger descent within the eye rather than because of decreased mixing across the eye boundary.

The mean soundings show a number of features which may be useful in preparing a more complete model of the hurricane eye. The temperature and humidity values near the surface are roughly the same for all three categories of hurricanes but the depth of the layer of small temperature and humidity variability decreases with increased storm intensity. The deeper storms show a marked tendency for warming and drying above the 700-mb. level, and the largest variability is shown at or near the top of the soundings.

The temperature variability within each hurricane category is sufficiently small (table 1) so that the mean soundings should be useful as approximations in individual cases where the surface pressure is known. However, the large range shown for the relative humidity suggests that these values would be of little value as estimates in individual cases. Storms deeper than those included in the present data sample would be expected to show warmer mean temperatures and lower humidities - above the 800-mb. level - than the mean "intense" sounding. The individual soundings presented in figure 2 should offer some assistance in approximating conditions in such cases.

MEAN SOUNDINGS FOR HURRICANE BETSY

Mean data for an individual hurricane - Betsy of 1956 - are presented for the purpose of comparison with the means previously discussed. In addition, use is made of rawinsonde data in the vicinity of the storm for a discussion of the mean thermal structure of this hurricane. Mean soundings for the eye and for the "rain area" have been prepared in the manner previously described. The mean eye sounding is based on six dropsondes made while the storm was south of 30°N. latitude and during the time that the surface pressure was between 974 and 960 mb. The mean sounding for the "rain area" is based on seven rawinsonde observations taken 40 to 70 miles from the storm center.

Hurricane Betsy was a very small storm with hurricane force winds in only a very narrow band surrounding the eye and the surface pressure was only slightly below normal at 75-100 miles from the storm center. Nevertheless, the hurricane remained in relatively steady state for several days and exhibited most of the characteristics normally associated with tropical cyclones. Because of the small size of the storm, a large number of rawinsonde observations were made near the storm center. However, it is very likely that most of the individual soundings in the "rain area" were made during periods when the wind and weather activity were relatively light. Therefore, the "rain area" sounding may not truly represent conditions at times of rain, which are closely associated with passages of spiral bands, but, instead, may more closely represent mean conditions in areas between rain bands.

The Betsy eye sounding (figure 3) is quite similar to the mean "intense" sounding (figure 1) in respect to both temperature and humidity. The largest differences occur in the vicinity of 700 to 600 mb. where the Betsy sounding is slightly over 1°C. colder. The individual soundings for Betsy were very similar and the variations were less than indicated in table 1. For example, the relative humidity at the 500-mb. level varied only between 45 and 55 percent in the six cases and the maximum temperature range at any level was only 5°C.

The "rain area" sounding is roughly moist adiabatic through much of the upper layer but the humidities are considerably below saturation. The possibility that most of the soundings were taken between rain bands may help to account for this feature. The relative humidities in the eye are appreciably lower than those for the "rain area" only at the 600-mb. and 500-mb. levels. However, even at these levels the specific humidity is greater in the eye than in the "rain area". Soundings just outside the eye could be expected to show nearly saturated conditions and considerably warmer temperatures than in the 40-70-mile ring. Therefore, specific humidities in the inner core of the storm surrounding the eye were undoubtedly somewhat greater than those shown for the eye.

The eye sounding becomes progressively warmer than the "rain area" with height and attains a difference of nearly 10°C. at the 500-mb. level. Some of the temperature difference can be attributed to the large decrease in the height of the pressure surfaces between the "rain area" and the eye. For example, the 900-mb. surface was over 1200 ft. lower in the eye than in the "rain area". However, the height difference decreased with altitude and was less than 700 feet at 500 mb. while the temperature difference increased rapidly.

Nearly all the temperature gradient in hurricane Betsy in the lower troposphere was concentrated between the 40-70-mile ring and the eye. Mean data for the ring 100-135 miles from the center, based on an average of 10 cases, were very little different from the 40-70-mile averages, at levels up to 400 mb., and neither departed more than about 1°C. from mean conditions (table 2). The relatively cold temperatures in the 40-70-mile ring at the lower levels can probably be attributed to the increase of cloudiness and rain near the storm center. At upper tropospheric levels, the temperature differences between the 40-70 and 100-135-mile rings are larger. These temperatures also represent larger anomalies from mean conditions than those shown at lower levels. The warming in the middle and upper troposphere in the "rain area" of most hurricanes is undoubtedly larger than indicated by the data from hurricane Betsy.

Table 2. Mean temperatures (°C.) from hurricane Betsy, from August soundings for West Indies area (Jordan [2]) and from Schacht's midnight hurricane sounding [5].

	BETSY			MEAN WEST INDIES (AUGUST)	MEAN HURRICANE (SCHACHT)
	Eye	40-70 mi.	100-135 mi.		
1000 mb.	(25.0)*	25.3	26.5	26.4	25.3
900	22.9	19.6	20.4	20.5	19.8
800	19.0	14.2	15.0	14.9	14.8
700	15.5	8.3	8.6	8.8	9.3
600	10.7	1.7	1.3	1.5	2.9
500	4.1	-5.7	-5.9	-6.8	-5.7
400		-16.2	-16.6	-17.6	-15.6
300		-30.8	-31.9	-33.1	-30.6
250		-40.8	-41.6	-43.2	-40.8
200		-52.8	-54.3	-55.0	-52.9
150		-67.0	-68.1	-67.2	-67.2
125		-73.0	-72.9	-71.5	-74.8
100		-73.8	-73.5	-72.8	-76.7
80			-71.5	-69.1	-71.0

*Surface value.

Even the mean hurricane data prepared by Schacht [5] (table 2) are slightly warmer than the 40-70-mile data from Betsy, although more than two-thirds of Schacht's 14 cases were over 100 miles from the storm center and some were nearly 200 miles out.

Apparently the thermal structure of Betsy differed significantly from other hurricanes mainly in respect to scale. However, the smaller size of this storm had little effect on the structure of the eye since the mean eye sounding for Betsy (figure 3) shows only minor differences from the mean "intense" sounding (figure 1). In fact, many of the individual eye soundings were very similar to the mean "intense" sounding.

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