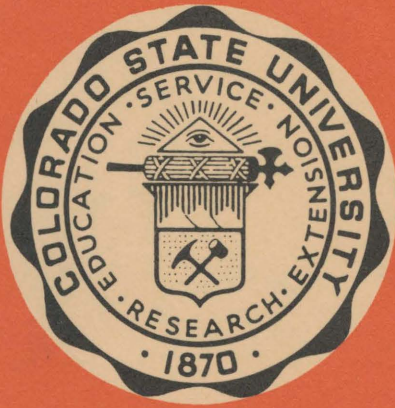


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**MONTHLY CLIMATOLOGICAL WIND  
FIELDS ASSOCIATED WITH  
TROPICAL STORM GENESIS IN  
THE WEST INDIES**

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NSF GF-287  
ESSA E-22-80-68 (G)

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## ABSTRACT

An empirical study is presented which investigates the relationship of monthly climatological wind fields to tropical storm genesis in the Gulf of Mexico and the western Caribbean. The parameters investigated are tropospheric vertical wind shear and 850 mb relative vorticity. These parameters have been shown by Gray (1967) to be strongly correlated with early intensification of tropical disturbances. The magnitude of the individual mean monthly deviations of these parameters from the long term monthly mean is specified. An estimate of the daily variations of these parameters and the ratio of daily to monthly deviations is also determined. Correlations of these parameter deviations with tropical storm genesis is presented.

Monthly vertical wind shear deviations are small, yet they show favorable correlations. Positive deviations of mean monthly 850 mb relative vorticity is strongly correlated with genesis in the Gulf of Mexico and is also favorably correlated with genesis in the western Caribbean. It is concluded that there are general circulation changes, with periods of a month or more, which produce favorable or unfavorable genesis conditions.

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## Chapter I

### INTRODUCTION

#### Background

As tropical meteorological data has improved, the problem of forecasting tropical storm genesis, deepening, movement and dissipation has received steadily increasing interest. Recently, a combined climatological and individual tropical storm statistical study by Gray (1967) has demonstrated that wind field parameters are significantly related to tropical storm development. He found that development was well correlated with cyclonic horizontal wind shear (positive relative vorticity,  $\zeta_r$ ) at 850 mb and with small tropospheric vertical wind shear (S), viz.,  $(|W_{200 \text{ mb}} - W_{850 \text{ mb}}|)$ . Gray computed the long term mean (LTM) of the monthly climatology for both of these parameters for the summer season of both hemispheres. From this computation he found that tropical storm genesis occurs exclusively in areas of strong cyclonic horizontal shear and small vertical shear.

These two parameters are physically related to tropical storm development through their enhancement of tropospheric heating. The relative vorticity ( $\zeta_r$ ) can be related to the low-level convergence and vertical motion at the top of the Ekman boundary layer from a formula by Charney and Eliassen (1949).

It is

$$w_o = \sqrt{k/2f} \zeta_{rg} \sin 2\alpha \quad (1)$$

where

$w_o$  is the vertical motion at the top of the Ekman friction layer

$k$  is the eddy-diffusion coefficient

$f$  is the Coriolis parameter

$\zeta_{rg}$  is the geostrophic relative vorticity at the top of the friction layer, and

$\alpha$  is the angle between the surface wind direction and the surface isobars. This angle is positive when the wind is blowing to lower pressure, and is approximately 10 degrees over oceans.

From (1) it is seen that positive  $\zeta_{rg}$  gives upward vertical motion, negative  $\zeta_{rg}$  downward motion. Areas of cyclonic vorticity (positive  $\zeta_r$ ) thus produce frictionally induced low level convergence and forced cumulus convection.<sup>1</sup> Given the usual sounding of the moist tropics, only vertical motion induced from convergence below 850 to 900 mb can produce a warming from condensation (Gray, 1967). The cumulus clouds will thus release their latent heat and induce a general warming of the vertical column.<sup>2</sup> The cumulus also produce cirrus shields which intercept long and short-wave radiation, thus heating

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<sup>1</sup>In the moist tropics the height of the cumulus cloud bases and the gradient level are typically at 600-700 meters.

<sup>2</sup>A mean tropospheric virtual temperature warming of 1° C causes a surface pressure fall of approximately 4 mb.

the troposphere (López, 1968). The role of the weak tropospheric vertical wind shear (S) now becomes important. Unless the vertical shear is small, the heating induced by the clouds will be carried out of the vertical tropospheric column, and the mean virtual temperature within the column cannot increase. Hydrostatic reasoning requires that the virtual temperature of the column increase if the surface pressure is to fall. Tropical storm development is thus physically related to large positive low level convergence and small tropospheric vertical shear.

#### Purpose

The interregional climatological variability in number and location of tropical storms has yet to be explained. This variability has two forms; one is the seasonal variability, the other is the difference between the number of storms in a given month from year to year. For example, in the North Atlantic the years 1933 and 1936 produced 21 and 16 storms respectively, while the years of 1925 and 1930 had but two storms each. The Gulf of Mexico experienced tropical storm genesis in the month of June every year from 1956 through 1960, but no storm genesis occurred in June between 1961 and 1966. This study will concern itself with the variability of tropical storm genesis from year to year, within a given month. An attempt will be made to determine if monthly deviations from the long term mean monthly climatological flow patterns, in the regions of genesis, are correlated with tropical storm genesis.

Tropical storm genesis will be considered a function of the low-level relative vorticity and the tropospheric vertical wind shear. Are there deviations in the monthly climatological values of these parameters which stimulate or inhibit tropical storm genesis? The strong correlation of these two parameters with subsequent tropical storm development (Gray, 1967) has stimulated the writer to attempt to correlate the monthly deviations of these parameters with monthly variability of tropical storm genesis.

Relative vorticity and vertical wind shear are combined into one term  $P = \zeta_r/S$ , which is henceforth defined as the genesis parameter. In functional form this parameter is represented as

$$P = P(\text{LTM}) + P(\Delta M) + P(\Delta D) \quad (2)$$

where

$P$  is the genesis parameter

LTM is the long term mean for each month

$\Delta M$  is the monthly deviation from the LTM, and

$\Delta D$  is the daily variation from the individual monthly mean.

Genesis conditions are assumed to be dependent on the magnitude of this term. Since storms do not occur every year during the same month, the LTM is always less than the magnitude of  $P$  needed for genesis. It is then seen that in order for genesis to take place, a positive deviation from the LTM must occur. Positive

deviations are given by relative vorticity greater and vertical shear less than the LTM. If the typical monthly deviations of P are small compared to the daily variation, then the daily variations will be primarily responsible for genesis. If the monthly deviations of P have significant magnitude, then the daily variations and monthly deviations must be considered together. It is assumed for this discussion that the average daily variations of P are quasi-independent of the monthly deviations, and have the same range from month to month. The monthly deviations, on the other hand, may be considerably different from month to month and year to year.

In that the daily variations of P dominate over the monthly deviations, it is natural to assume that the mean monthly deviation component is small. Several previous studies, however, (Andrews, 1956; Ballenzweig, 1957, 1958; and Orgill, 1960, 1961) have related 700 mb deviations of the monthly circulation in mid-latitudes to tropical storm genesis. Andrews found that the westerly wind maximum was displaced north of  $50^{\circ}$  N latitude during periods of increased tropical storm activity and south of  $50^{\circ}$  N with minimal activity. Ballenzweig found a correlation between the position of maximum westerlies and storm genesis. He found that anomalous positive easterly flow south of  $45^{\circ}$  N, strong negative height anomalies near Iceland and positive height anomalies between  $35^{\circ}$  -  $45^{\circ}$  N in the Atlantic were positively correlated with periods of increased Atlantic tropical storm activity.

Orgill's studies of the Pacific showed that negative height anomalies over the Bering Sea—Aleutian Islands region and intensification of the high pressure system over Japan had a positive correlation with maximum periods of typhoons.

These studies suggest that monthly anomalies of the general circulation may have a significant influence on variations of tropical storm genesis. There are, however, no studies which demonstrate the significance of monthly deviations of any wind field parameters in the tropics upon variations of storm genesis. In summary, it is the author's purpose to determine:

- 1) The value of the LTM for  $\zeta_r$ , S and P over the areas studied.
- 2) The magnitude of the monthly deviations of these parameters from the LTM.
- 3) An estimate of how the magnitude of the monthly deviations compare with the daily variations.
- 4) The correlation of the monthly deviations with tropical storm genesis.

It is realized that the data sample of this study is small. Therefore, the results should be considered as those of a pilot study, intended to indicate whether or not further research should be attempted from this viewpoint. The West Indies have the best tropical data network available. However, even in the West Indies a study as this one could not have been done earlier due to lack of representative data. It is only since the mid-1950's that the West Indies region has possessed a significantly dense set of synoptic observations.

### Area and Time of Study

Monthly wind data with enough density to calculate reliable monthly values of relative vorticity is available only in the Gulf of Mexico and the western Caribbean. (See Appendix A for computational methods.) The study is therefore restricted to those two areas.

The months from May through November for the years 1957-1966 are examined. The two genesis areas of this study are shown by broken-lined boxes in Fig. 1. In order to insure that a reasonably large sample of genesis and non-genesis periods were available, only those months that had at least one storm genesis for three of the ten years of consideration were chosen. This narrowed the study to June and September for the Gulf of Mexico and September and October for the western Caribbean.

A month was considered a genesis month if one or more cases of formation occurred and non-genesis if no formation occurred. The number of storms per year are indicated with asterisks in Tables 1 and 2. The initial reported location of each storm is plotted in Fig. 1. Genesis locations were assumed to be located one degree of latitude upstream from the point of first detection.

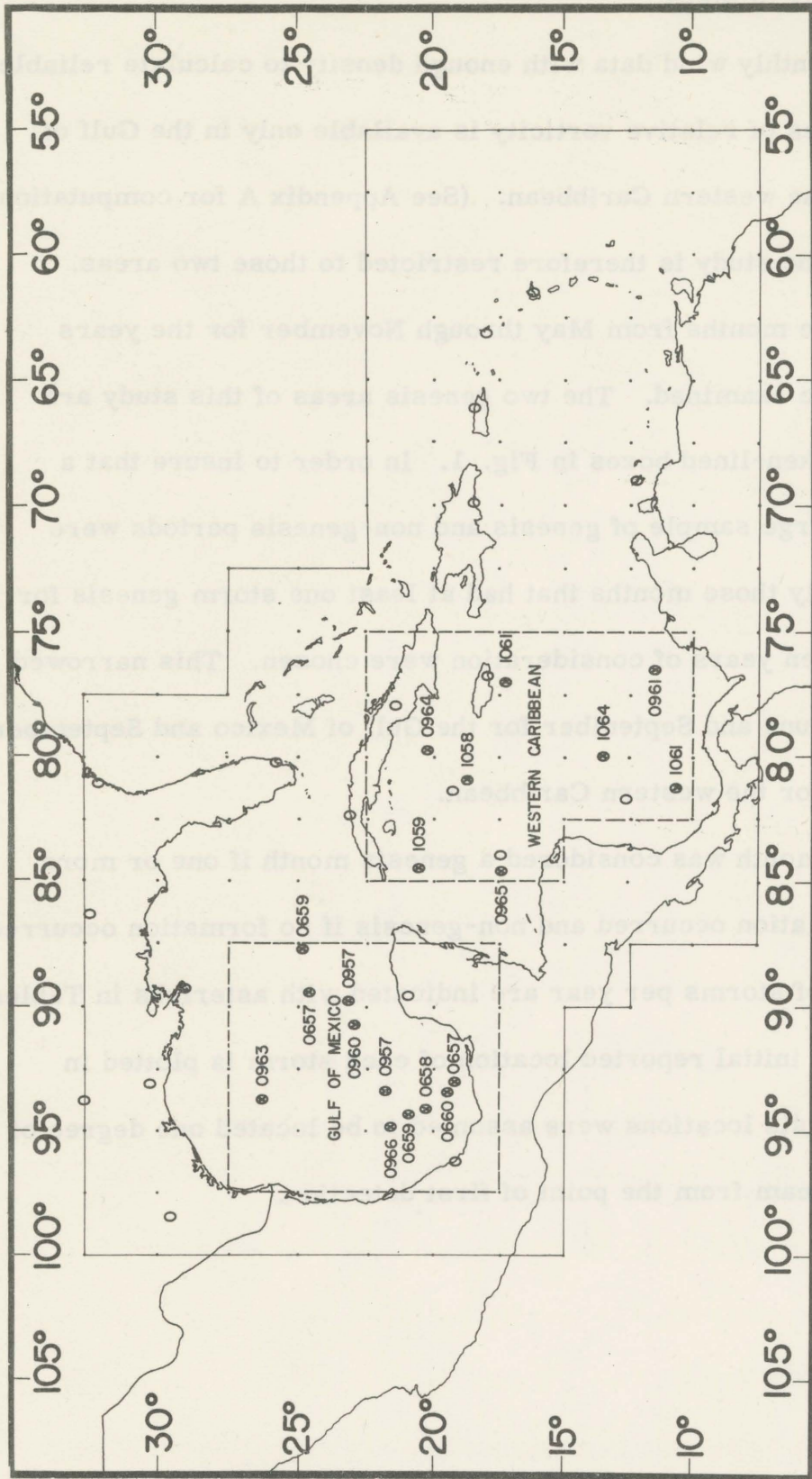


Fig. 1. The area of study. The stations used are plotted with a circle. The areas outlined with the broken lines are the areas of genesis. The lightly outlined larger area represents the area which was analyzed. Storm origins are plotted and numbered by month and year. For example, 0963 means September 1963.

## Chapter II

### RESULTS AND DISCUSSION

#### Long Term Means (LTM)

Fields of each relative vorticity term ( $\Delta v/\Delta x$ ,  $\Delta u/\Delta y$ ), relative vorticity ( $\zeta_r$ ), vertical wind shear (S) and genesis parameter (P or  $\zeta_r/S$ ) were composited for each month over the ten year period of consideration to obtain a long term mean monthly climatology (LTM). The  $\zeta_r$ , S and P parameters are presented in Figs. 2, 3 and 4 for the months of June (a), September (b) and October (c).

Relative vorticity. The  $\zeta_r$  fields (Fig. 2) show that the values are large during June when the wind gradients are high, decrease through September when the 850 mb wind gradients are the weakest and increase again in October as the westerlies push into the Gulf of Mexico. The zero line represents the dividing line between the monthly average planetary boundary layer induced rising and sinking motion. Vertical motion and storm genesis north of this line must, therefore, be due to favorable deviations from the LTM.

Vertical shear. One notices that the magnitudes of vertical (Fig. 3) and horizontal shear (relative vorticity) are closely associated. The values of each decrease from June to September and increase again in October. The very large shear in October in the northern Gulf of Mexico is a result of the southward push of the 200 mb westerlies associated with the jet stream.

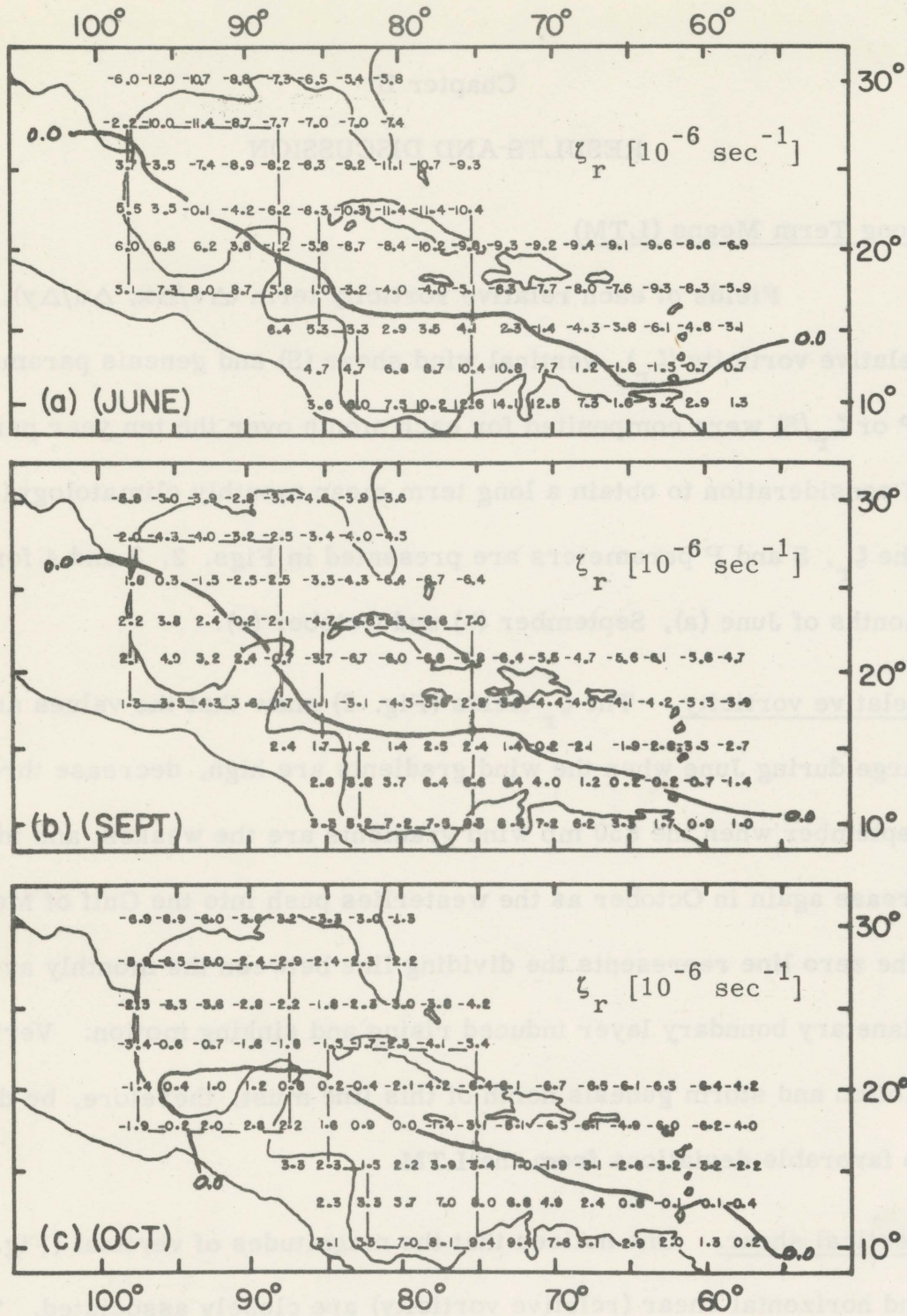


Fig. 2. The long term mean values (ten year average) of the relative vorticity ( $\zeta_r$ ) for (a) June, (b) September and (c) October.

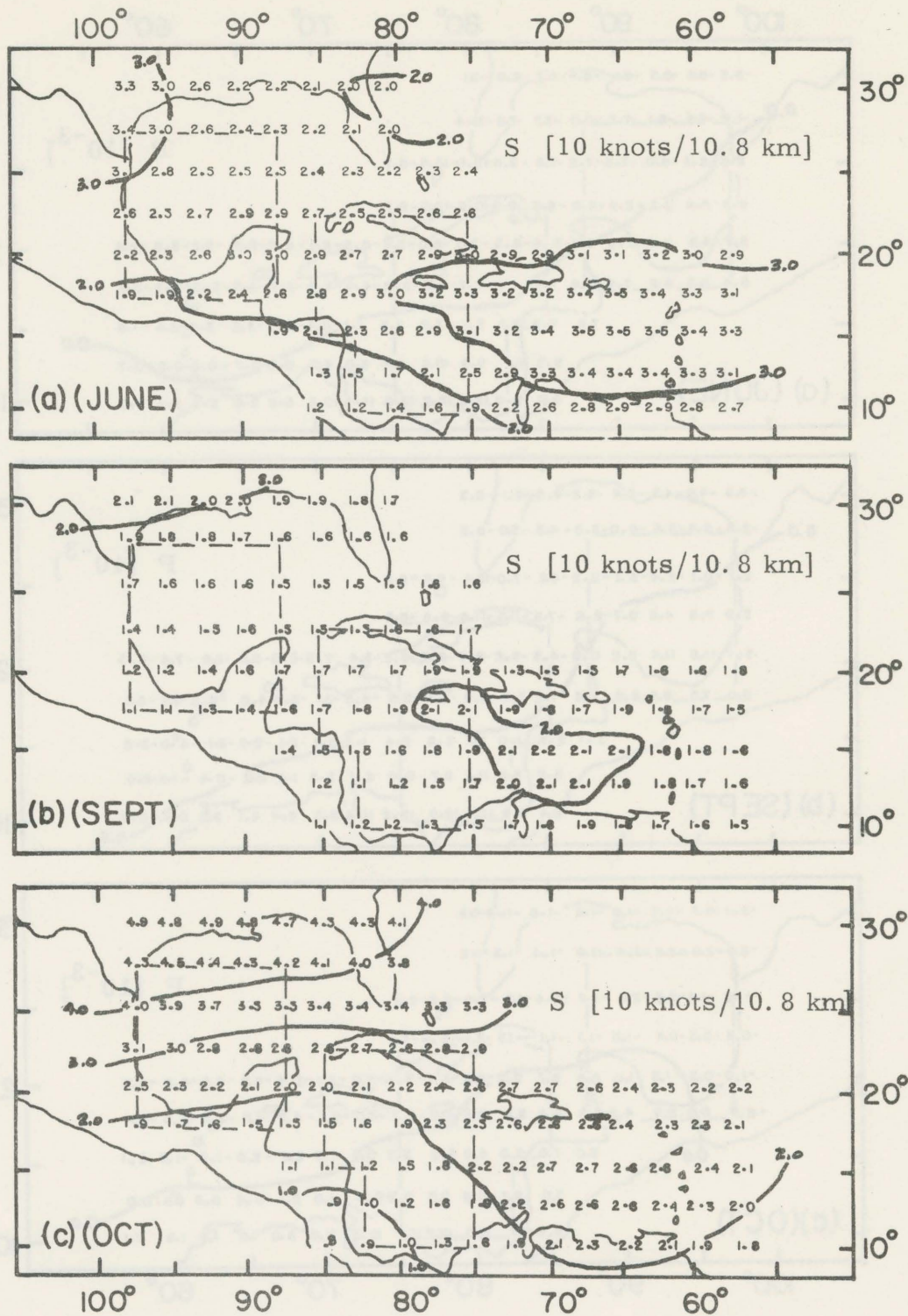


Fig. 3. The long term mean values (ten year average) of the tropospheric vertical wind shear (S) for (a) June, (b) September and (c) October.

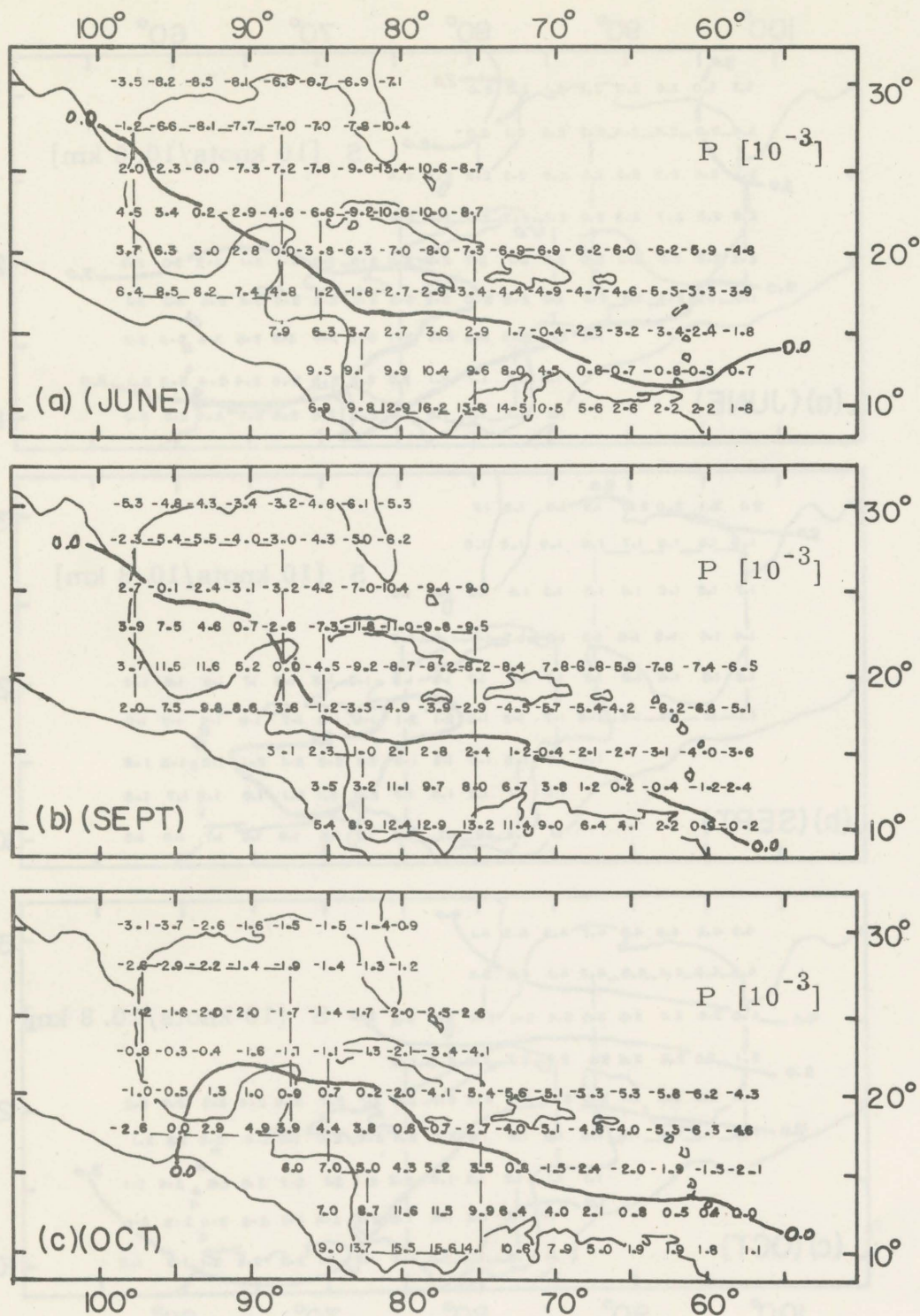


Fig. 4. The long term mean values (ten year average) of the genesis parameter (P) for (a) June, (b) September and (c) October.

Genesis parameter. The June field of P (Fig. 4a) shows that one would expect genesis in the southern portion of the Gulf and in the southern Caribbean. The Caribbean is, however, not an active producer of June storms. In September (Fig. 4b) the zero P parameter line lies in approximately the same position as in June. There is, however, an increase in the magnitude of the positive values and a decrease in the magnitude of the negative values in the Gulf. This indicates that September is more favorable for genesis in the Gulf, than is June. During October (Fig. 4c) the P values in the Gulf decrease markedly and genesis becomes completely unfavorable.<sup>1</sup> The northwestern Caribbean, however, becomes more favorable during October.

One notable feature of the mean charts is that most of the eastern Caribbean has negative relative vorticity.<sup>2</sup> The large area of negative relative vorticity would indicate sinking motion over most of the eastern Caribbean. This is correlated with the fact that the eastern Caribbean is known for its almost complete lack of tropical storm activity. During the years 1901 through 1966 only one storm (1911) has been known to have its origin in the area of the eastern

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<sup>1</sup>This large negative area of the P parameter agrees with the fact that only one storm was generated in the Gulf during October for the ten years considered.

<sup>2</sup>The negative area probably should be even larger. However, only one station (Curacao) reports monthly data in the southern portion of the eastern Caribbean and an accurate position of the maximum trades was difficult to find.

Caribbean from 70° W to 63° W. The large area of negative vorticity suppresses low-level convergence and cumulus activity, while the larger vertical wind shears inhibit area concentration of heat and tropospheric warming.

#### Magnitude of Monthly Deviations and Comparison to Daily Variations

Rather than reproduce the multitude of analyses indicated for each month, average values for the parameters  $\Delta v/\Delta x$ ,  $\Delta u/\Delta y$ ,  $\zeta_r$ , S and P were determined in the two selective areas outlined with a broken line in Fig. 1. In order to lend as much reliability to the computations as possible, all grid points in those areas were averaged together for each month and a single average monthly value for that region was determined. The use of a single area average value tends to smooth the results. However, for simplicity, single values are used.

Values for each parameter for each month are presented in Tables 1 and 2. The ten-year monthly average of each parameter in a given month was taken as the LTM. The difference between the parameter value for a given month and the LTM (the monthly deviation) is also shown.

A three month sample of individual days was used to obtain an estimate of the daily variability of  $\zeta_r$ , S and P. In order to facilitate calculations the daily variations for the Gulf of Mexico and the Caribbean were assumed to be the same.

TABLE 1

Values of the monthly relative vorticity terms, relative vorticity, vertical wind shear, genesis parameter and their deviations from the long term means for the Gulf of Mexico.

25 Grid Point Average (See Fig. 1)

JUNE								
Year	$\Delta v/\Delta x$	$\Delta u/\Delta y$	$\zeta_r$	$\Delta\zeta_{rm}$	S	$\Delta S_m$	P	$\Delta P_m$
1957	2.6	-0.4	3.0	3.3	23	3	2.4	2.2 **
1958	0.7	1.0	-0.3	0.0	25	1	-0.4	-0.6 *
1959	2.3	2.1	0.2	0.5	23	3	0.8	0.6 **
1960	0.7	-0.2	0.9	1.2	26	0	1.3	1.1 *
1961	0.2	3.0	-2.8	-2.5	27	-1	-2.2	-2.4
1962	-1.2	2.5	-3.7	-3.4	28	-2	-2.6	-2.8
1963	0.3	1.9	-1.6	-1.3	31	-5	-0.8	-1.0
1964	1.1	1.0	0.1	0.4	20	6	0.6	0.4
1965	0.5	1.3	-0.8	-0.5	27	-1	-0.5	-0.7
1966	1.5	-0.2	1.7	2.0	28	-2	2.7	2.5
LTM	0.9	1.2	-0.3		26		0.2	
SEPTEMBER								
1957	2.7	-0.6	3.3	2.8	15	0	4.9	2.8 **
1958	-1.2	1.3	-2.5	-3.0	23	-8	-2.4	-4.5
1959	-0.8	1.4	-2.2	-2.7	18	-3	-2.6	-4.6
1960	2.3	-0.6	2.9	2.4	14	1	4.4	2.3 *
1961	0.3	-0.5	0.8	0.3	16	-1	2.2	0.1
1962	0.0	1.8	-1.8	-2.3	14	1	-2.2	-4.3
1963	2.8	0.6	2.2	1.7	15	0	3.5	1.4 *
1964	0.5	0.1	0.4	-0.1	10	5	3.2	1.1
1965	2.1	0.0	2.1	1.6	9	6	7.7	5.6
1966	2.5	2.7	-0.2	-0.7	17	-2	1.3	-0.8 *
LTM	1.1	0.6	0.5		15		2.1	

\* Represents the number of storms for that month.

$\Delta v/\Delta x, \Delta u/\Delta y, \zeta_r$  [ $10^{-6} \text{ sec}^{-1}$ ]

S [knots/10.8 km]

P [ $10^{-3}$ ]

$\Delta\zeta_{rm} = (\zeta_r - \text{LTM})$

$\Delta S_m = (\text{LTM} - S)$

$\Delta P_m = (P - \text{LTM})$

TABLE 2

Values of the monthly relative vorticity terms, relative vorticity, vertical wind shear, genesis parameter and their deviations from the long term means for the western Caribbean.

28 Grid Point Average (See Fig. 1)

SEPTEMBER								
Year	$\Delta v/\Delta x$	$\Delta u/\Delta y$	$\zeta_r$	$\Delta\zeta_{rm}$	S	$\Delta S_m$	P	$\Delta P_m$
1957	-0.7	-0.9	0.2	0.7	19	-3	2.3	2.8
1958	0.6	0.3	0.3	0.8	18	-2	2.1	2.6
1959	-0.2	1.4	-1.6	-1.1	17	-1	-4.3	-3.8
1960	1.0	0.9	0.1	0.6	9	7	-0.3	0.2
1961	0.2	-0.6	0.8	1.3	15	1	2.5	3.0 *
1962	0.3	1.6	-1.3	-0.8	20	-4	0.1	0.6
1963	0.5	1.3	-0.8	-0.3	18	-2	0.4	0.9
1964	-0.2	1.5	-1.7	-1.2	13	3	-0.9	-0.4 *
1965	0.3	-0.4	0.7	1.2	19	-3	1.2	1.7 *
1966	-0.2	2.2	-2.4	-1.9	14	2	-7.3	-6.8
LTM	0.2	0.7	-0.5		16		-0.5	
OCTOBER								
1957	1.6	1.5	0.1	-1.3	25	-6	0.5	-3.4
1958	2.5	2.1	0.4	-1.0	25	-6	0.6	-3.3 *
1959	0.8	1.1	-0.3	-1.7	15	4	1.5	-2.4 *
1960	1.2	1.8	-0.6	-2.0	20	-1	2.0	-1.7
1961	3.3	-1.4	4.7	3.3	12	7	13.3	9.4 **
1962	1.0	1.0	0.0	-1.4	17	2	2.5	-1.4
1963	4.4	0.1	4.3	2.9	25	-6	6.2	2.3
1964	3.4	0.1	3.3	1.9	13	6	6.5	2.6 *
1965	2.3	2.4	-0.1	-1.5	22	-3	2.8	-1.1
1966	2.2	0.6	1.6	0.2	14	5	3.1	-0.8
LTM	2.3	0.9	1.4		19		3.9	

\* Represents the number of storms for that month.

$\Delta v/\Delta x$ ,  $\Delta u/\Delta y$ ,  $\zeta_r$  [ $10^{-6}$  sec $^{-1}$ ]

S [knots/10.8 km]

P [ $10^{-3}$ ]

$\Delta\zeta_{rm} = (\zeta_r - \text{LTM})$

$\Delta S_m = (\text{LTM} - S)$

$\Delta P_m = (P - \text{LTM})$

The average ratios of the mean absolute daily to mean absolute monthly deviations were found to be

$$\left| \Delta \zeta_{rd} \right| / \left| \Delta \zeta_{rm} \right| = 5.5/1.4 = 3.9 \quad (3)$$

$$\left| \Delta S_d \right| / \left| \Delta S_m \right| = 8.0/3.1 = 2.6 \quad (4)$$

$$\left| \Delta P_d \right| / \left| \Delta P_m \right| = 9.0/2.3 = 3.9 \quad (5)$$

where the subscript m represents monthly and the subscript d represents the daily deviations. The daily variations are thus observed to be three to four times larger than the monthly deviations. This difference does not obscure the importance of the monthly deviations as shown below.

It was assumed in the beginning that the daily variations are, in general, independent of the monthly deviations. The average daily variations are expected to have no (or little) monthly dependence, while the monthly deviations may be positive or negative from one year to the next. In order to show the maximum influence of the monthly deviations it is necessary to show the comparison of the average daily variations to the maximum ( $\text{Max } \Delta_m$ ) positive or negative monthly deviations. These were found to be

$$\left| \Delta \zeta_{rd} \right| / \left| \text{Max } \Delta \zeta_{rm} \right| = 5.5/3.4 = 1.6 \quad (6)$$

$$\left| \Delta S_d \right| / \left| \text{Max } \Delta S_m \right| = 8.0/8.0 = 1.0 \quad (7)$$

$$\left| \Delta P_d \right| / \left| \text{Max } \Delta P_m \right| = 9.0/9.0 = 1.0 \quad (8)$$

It is significant to note that during periods of maximum monthly deviations, the monthly deviations are as important as the average daily variations. Therefore, it would make considerable difference to the genesis potential if the daily variations were superimposed on much below average or much above average mean monthly conditions.

#### Correlation of Monthly Deviations with Tropical Storm Genesis

Correlation of the monthly deviations of each of the parameters with tropical storm genesis is presented in the form of two-by-two contingency tables as represented in Table 3.

TABLE 3

Model of contingency tables used to present correlations.

Genesis  
Years

Non-Genesis  
Years

A	B
D	C

Positive      Negative

Monthly Deviations From LTM

If genesis months occurred with all positive deviations from the LTM and non-genesis months occurred with all negative deviations, then all cases would fall in blocks A or C. However, if for a given month the LTM was much larger than necessary for genesis, a small negative deviation might occur and we could still have genesis. In such a case the month would fall in block B. Since

no sector of the two areas studied had genesis every year during a given month, we can assume that the LTM is never so favorable that storms occur with negative deviations from the LTM. With this argument a month falling in block B must represent genesis which occurred during a short period (i. e. , few days) of very large favorable deviation from an unfavorable monthly mean, thereby showing that storm genesis is not a function of monthly deviations alone.

Months falling in block D represent one of two conditions. First, if the LTM is positive but far below the value needed for genesis, a small positive deviation might occur but genesis would still not take place. Secondly, suppose a monthly deviation is positive and large enough to give the needed value of P for genesis, yet genesis does not occur. It would then be obvious that positive deviations might be necessary but are not sufficient for genesis, i. e. , there could be other parameters which affect tropical storm genesis. Either of these conditions would allow a month to fall into block D.

Relative vorticity. The contingency tables in Fig. 5a show that the relative vorticity  $\zeta_r$  is well correlated with genesis in the Gulf of Mexico during both months. The correlations for the western Caribbean are not as good, but are still considered favorable since months in block D do not violate the hypothesis of the importance of monthly parameters. The composites for each area and for the combination of both areas are also presented.

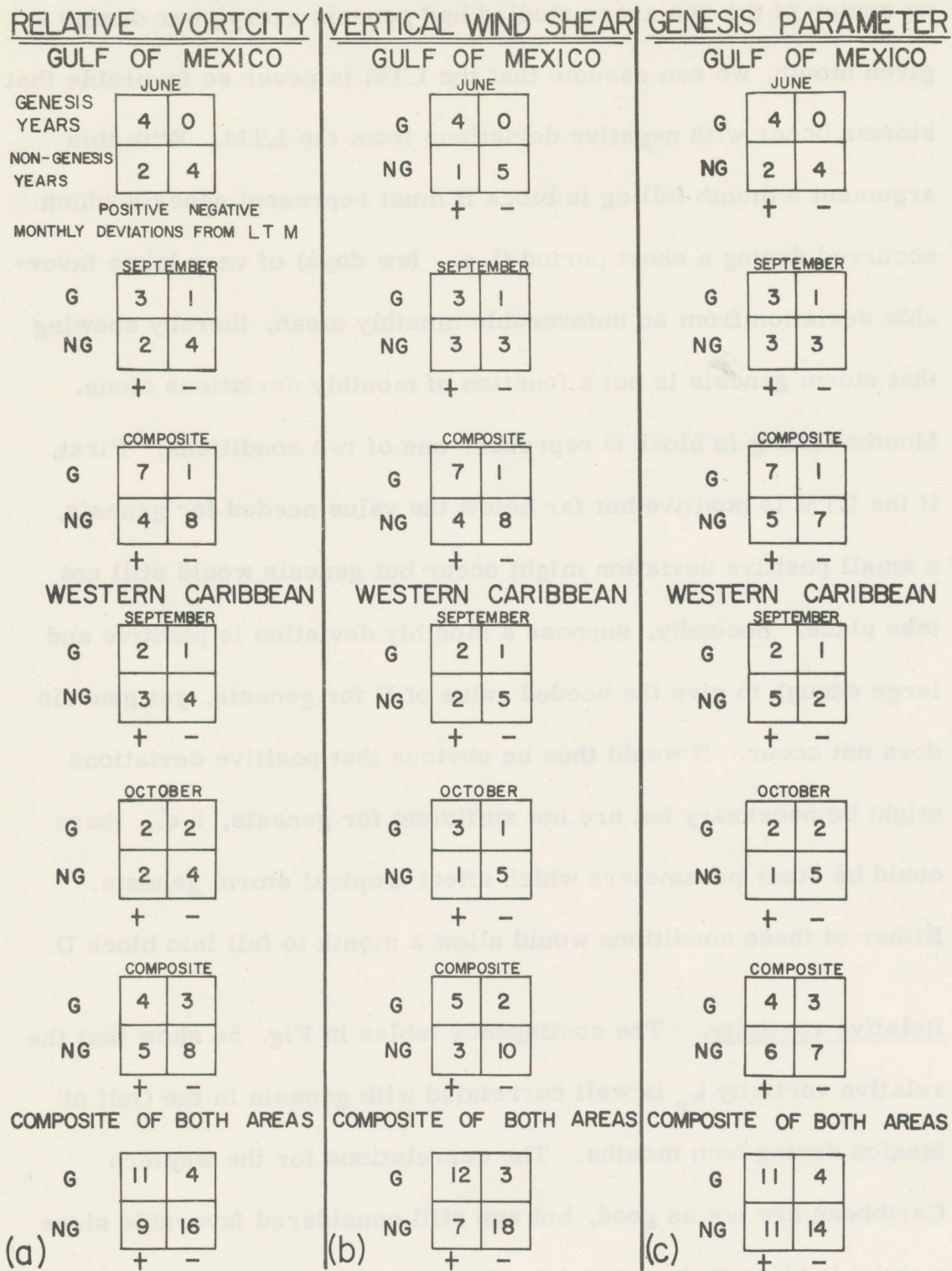


Fig. 5. Two-by-two contingency tables showing the correlation of the monthly deviations from the LTM of (a) relative vorticity, (b) vertical wind shear and (c) genesis parameter with tropical storm genesis.

Vertical shear. The correlations between genesis and mean monthly deviations of the tropospheric vertical wind shear are portrayed in Fig. 5b. The values are almost identical to those of the vorticity in the Gulf of Mexico. In the western Caribbean the correlation is much better, showing that the monthly vertical shear deviations are well correlated with genesis in both areas of study. The magnitudes of these monthly deviations are, however, very small and of much less significance than the relative vorticity deviations.

Genesis parameter. Correlation of the genesis parameter P with tropical storm genesis is shown in Fig. 5c. It is seen that the parameter  $\zeta_r/S$  is almost a reflection of the  $\zeta_r$  correlation, being only slightly less favorable. Genesis occurred in only one of twenty cases in the Gulf and three of twenty cases in the Caribbean when monthly deviations of the genesis parameter were negative. It is felt that this result would not have been obtained if the monthly climatology was not an important genesis feature.

#### Composites of the Parameters

Due to the strikingly good correlations in the Gulf of Mexico and the favorable correlations in the western Caribbean, it was decided to look at the average of the components for genesis and non-genesis months. These favorable correlations with monthly deviations suggest that there was some significant changes in the monthly general circulation that affected the areas during months with genesis and months without genesis.

Fig. 6 presents composited data for the Gulf of Mexico. In June and September, it is noted that there is a change in the  $\Delta v/\Delta x$  and  $\Delta u/\Delta y$  components (first and second column respectively of each group) during genesis and non-genesis periods, with the primary change being in the  $\Delta v/\Delta x$  component. The values of  $\zeta_r$  (third column of each group) reflect these changes showing large positive deviations for genesis months and large negative deviations for non-genesis month. As previously noted, very little change is observed for average vertical shear values (column four). Results of the  $\zeta_r/S$  or P parameter calculations are shown in the last column.<sup>3</sup> It is seen that P has a large positive deviation from the LTM during genesis months.

Fig. 7 gives the same composites for the western Caribbean. In September, the  $\Delta u/\Delta y$  term is most responsible for changes in  $\zeta_r$  while the  $\Delta v/\Delta x$  term is most responsible for the changes in  $\zeta_r$  during October. In both months the deviations of  $\zeta_r$  and P are positive for genesis and negative for non-genesis. There is no deviation in the vertical shear for genesis during September. In October, smaller vertical shear is found to occur with genesis.

A composite of the above terms for all months studied is shown in Fig. 8. The relative vorticity shows very favorable positive deviations for genesis and negative deviations for non-genesis. The

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<sup>3</sup>The value of P presented here represents an average of P at several points, therefore  $\bar{P} \neq \bar{\zeta}_r/\bar{S}$ .

vertical shear has no deviations. The importance of the monthly deviation of the relative vorticity is clearly evident.<sup>4</sup>



<sup>4</sup>It might be felt that the increased vorticity was a function of the storms presence in the area. Appendix B shows that the days with storms did not bias the climatology.

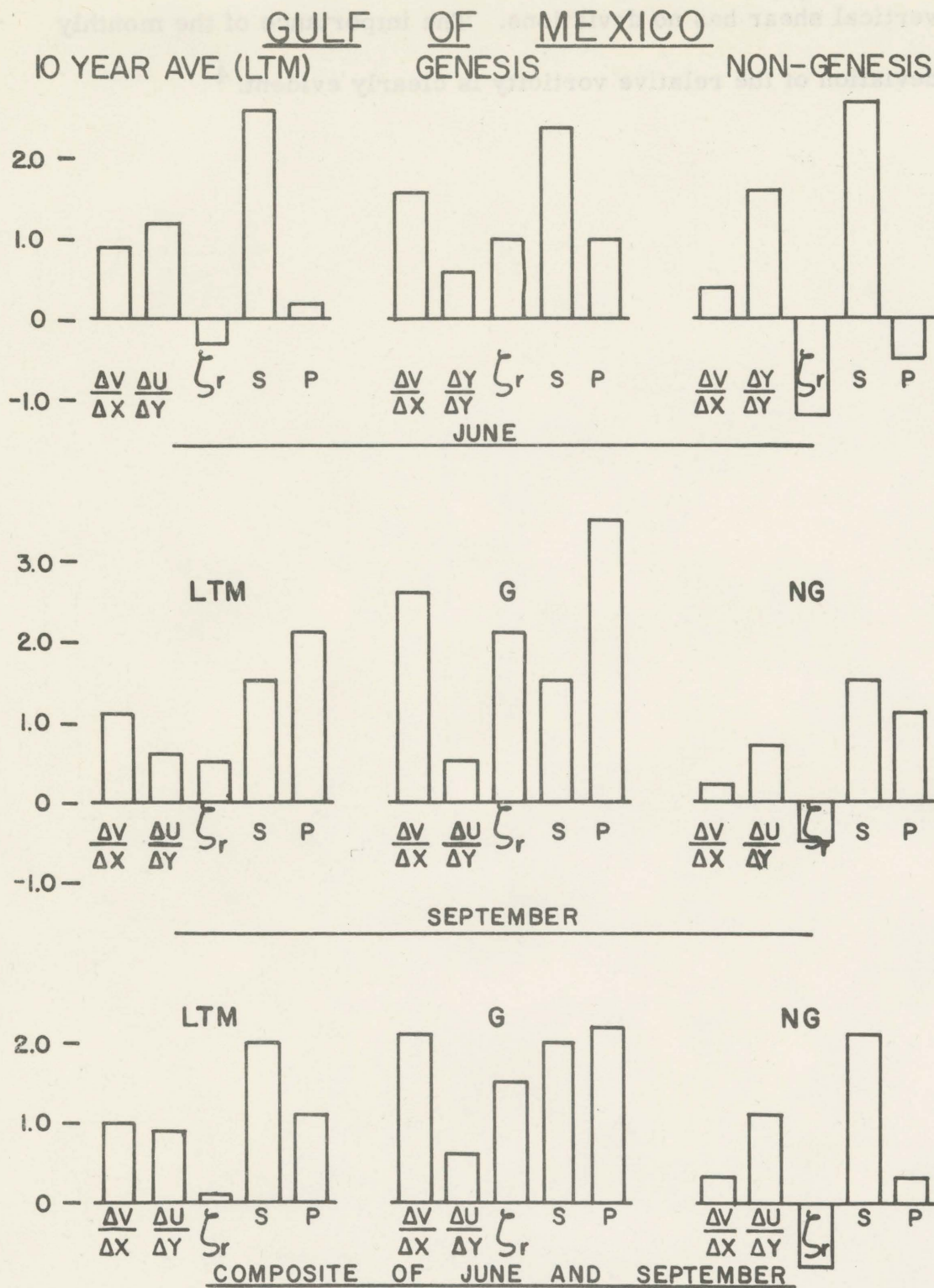


Fig. 6. Composites for the long term means, genesis years and non-genesis years in the Gulf of Mexico.  $\Delta v/\Delta x$ ,  $\Delta u/\Delta y$ , and  $\zeta_r$  are in units of  $10^{-6} \text{ sec}^{-1}$ ; S is expressed in units of 10 knots per 10.8 km and the values for P are times  $10^{-3}$ .

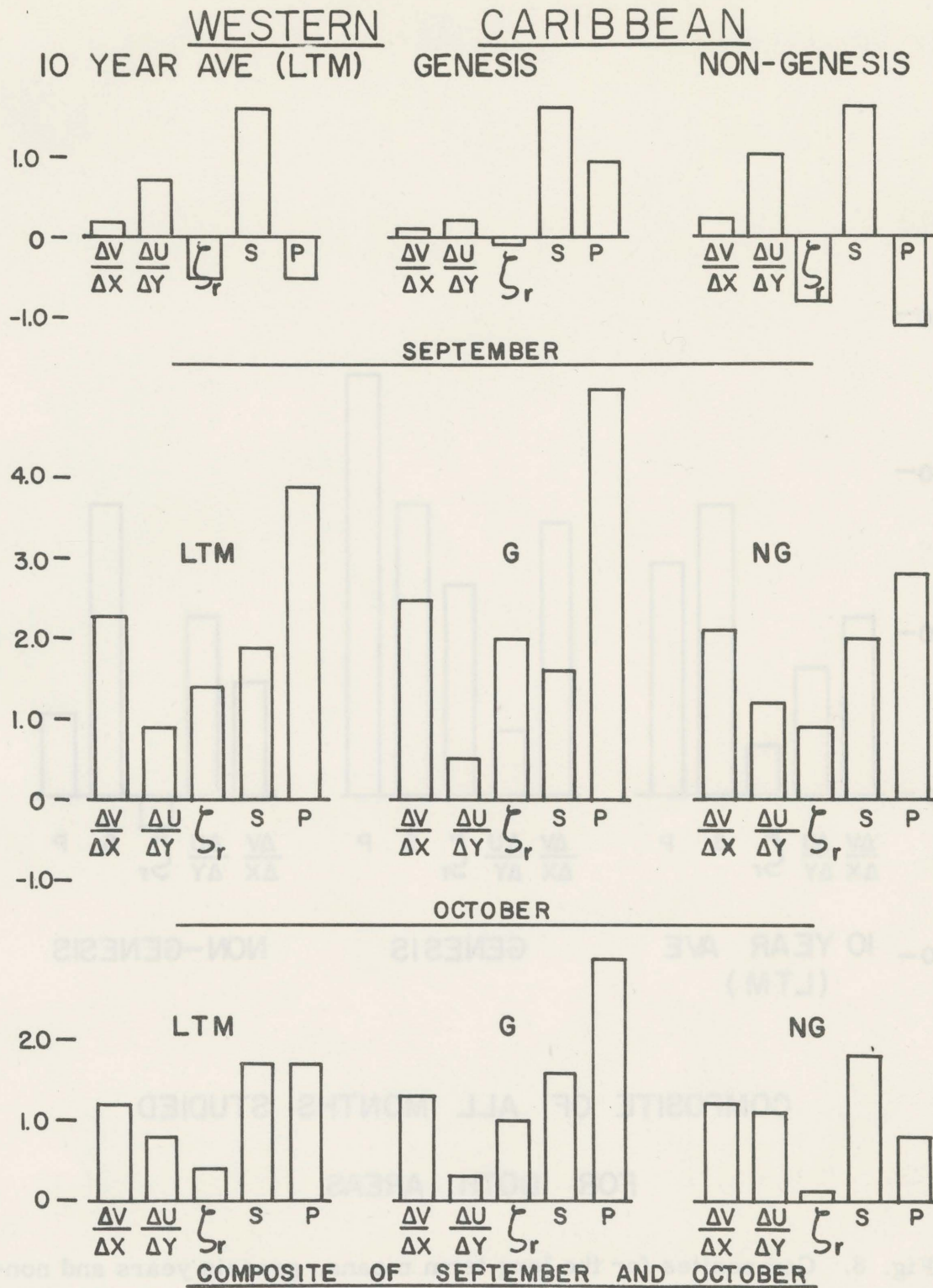


Fig. 7. Composites for the long term means, genesis years and non-genesis years in the western Caribbean.  $\Delta v/\Delta x$ ,  $\Delta u/\Delta y$  and  $\zeta_r$  are in units of  $10^{-6} \text{ sec}^{-1}$ ; S is expressed in units of 10 knots per 10.8 km and the values of P are times  $10^{-3}$ .

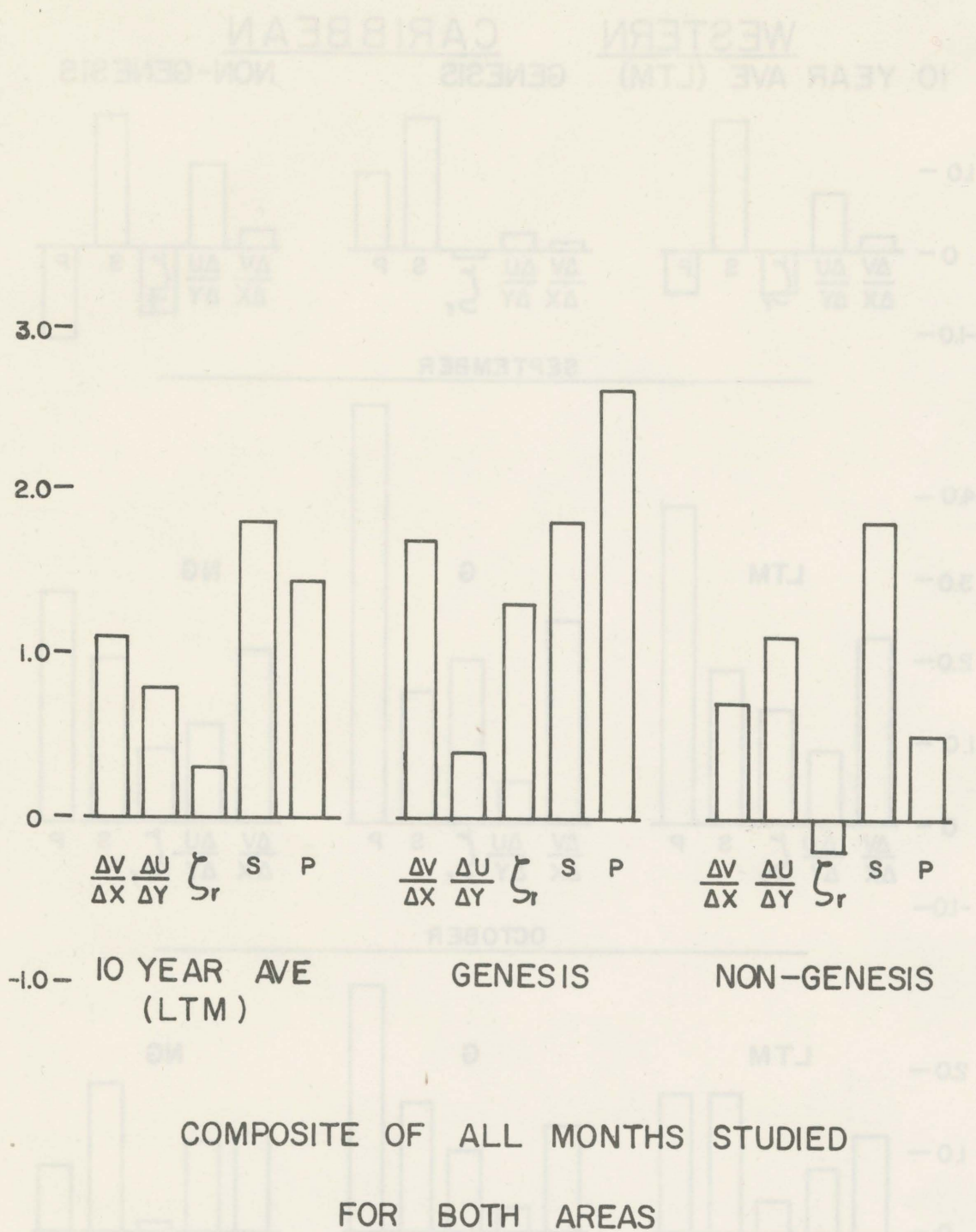


Fig. 8. Composites for the long term means, genesis years and non-genesis years in the Gulf of Mexico and western Caribbean combined.  $\Delta v/\Delta x$ ,  $\Delta u/\Delta y$  and  $\zeta_r$  are in units of  $10^{-6} \text{ sec}^{-1}$ ; S is expressed in units of 10 knots per 10.8 km and the values for P are times  $10^{-3}$ .

### Chapter III

#### CONCLUSIONS

This study shows that there are significant monthly circulation changes which may induce favorable or unfavorable conditions for tropical storm genesis within any month. Positive monthly deviations of the 850 mb relative vorticity are well correlated with storm genesis in the Gulf of Mexico, and to a lesser extent with genesis in the western Caribbean. The monthly deviations of vertical wind shear are also correlated with storm genesis but the magnitude of the deviations is small and not felt to be of large importance. Variations of the monthly value of the genesis parameter ( $\zeta_r/s$ ) are primarily determined by the variations of the relative vorticity of which the  $\Delta v/\Delta x$  term is dominant. Monthly changes in the east-west gradient of the meridional wind component thus have a significant correlation with storm genesis. These monthly changes are not at all obvious from inspection of the West Indies daily weather maps.

This study appears to have enough credence to warrant careful additional assessments of these parameters by agencies responsible for monitoring tropical storms. With improvement of long range forecasting techniques, long-range storm genesis outlooks might become feasible.

## ACKNOWLEDGMENTS

The author wishes to express his appreciation to Professor William M. Gray for his guidance and encouragement during this period of research. The help in compiling and reducing the data by G. Odle, M. Abdullah and D. Ingraham, is deeply appreciated. The helpful discussions with Captain Ronald F. Wachtmann are particularly valued. A grateful thanks goes to my wife, Barbara, whose understanding during this period of research has been extremely helpful in the completion of this work. This research was done while the author was under an Air Force Institute of Technology scholarship. Compilation of the data was accomplished under partial sponsorship of an NSF and ESSA Grant.

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## APPENDIX A

## CALCULATION PROCEDURES AND DATA REPRESENTATIVENESS

Calculation Procedures

The monthly mean data was converted into zonal and meridional components at the 850 mb (closest reported level to the top of the friction layer) and at the 200 mb (center of action in the upper troposphere) levels for each month of June, September and October from 1957 through 1966. The 850 mb zonal and meridional components were analyzed for each month by linear interpolation. These components were interpolated at each grid point on and inside the thin solid line in Fig. 1. Relative vorticity was then computed, taking into account the variations of  $\Delta x$  with latitude. The magnitude of the vertical wind shear ( $|W_{200 \text{ mb}} - W_{850 \text{ mb}}|$ ) was calculated at each grid point from the individual zonal and meridional components, thus

$$S = |\vec{S}| = \sqrt{(u_{200} - u_{850})^2 + (v_{200} - v_{850})^2} \quad (9)$$

The genesis parameter P was determined at each point by dividing the relative vorticity by the vertical wind shear.

Data Representativeness

Monthly winds are an average of at least 25 days (See Data References). Because of this large mean data sample at each plotted

point, no smoothing was permitted in the analyses. Due to the sparsity of data in the southern Gulf of Mexico and the southern Caribbean the subjective analysis may not have always been quantitatively representative. The differences noted here, however, are large and believed to be reliable. These inherent data deficiencies are not felt to be of the magnitude to significantly alter the conclusions drawn.

## APPENDIX B

## "STORM DAY" INFLUENCES ON CLIMATOLOGICAL AVERAGES

During the eight months used as the genesis period of Fig. 6 the Gulf of Mexico was influenced on 31 days by storms that formed in it, passed through it, or were nearby. The daily zonal and meridional components of each station was averaged for the above 31 days and the vorticity of these "storm days" was computed. The magnitude of each of the vorticity terms is shown in Table 4. From the table it is seen that the storms did not bias the data toward higher positive monthly vorticity. This results from the small number of storms during each individual month, and the fact that outside the immediate area of the storm the vorticity is small or negative. For a study of these parameters in the Pacific where the number of "storm days" per month is large, the data would surely be affected by the storms' presence.

TABLE 4

Vorticity Values ( $10^{-6} \text{ sec}^{-1}$ )

	<u>No. Days</u>	<u><math>\Delta v/\Delta x</math></u>	<u><math>\Delta u/\Delta y</math></u>	<u><math>\zeta_r</math></u>
Values for all days	240	2.1	0.6	1.5
"Storm days"	31	1.6	0.5	1.1
Days without storms	209	2.2	0.6	1.6

