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DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

OBJECTIVE USE OF SATELLITE DATA TO FORECAST CHANGES IN INTENSITY OF TROPICAL DISTURBANCES

Meteorological Satellite Laboratory
Washington, D.C.
April 1979

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OBJECTIVE USE OF SATELLITE DATA TO FORECAST CHANGES IN INTENSITY OF TROPICAL DISTURBANCES

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ABSTRACT. Eighty-nine classified and unclassified tropical disturbances of all intensities (several hundred synoptic "cases") have been investigated to determine how high-cloud vectors and other satellite data might be used for objective forecasts of changes in intensity.

For unclassified (weak) disturbances, a 6-variable discriminator can identify many that are nondeveloping. For the remainder of unclassified disturbances, additional information is needed (probably low or middle-tropospheric variables, none of which are yet incorporated).

For classified disturbances, two modified regression equations have been developed to predict the 24-hr change in windspeed. The equations are heavily dependent upon the satellite picture classification itself, and they yield correlation coefficients with ground truth that are 0.06 to 0.08 larger than those from the picture classification alone. The equations are derived from operationally available data, and the variables are calculated by a relatively simple numerical program. It appears that introduction of low-level vorticity and the nonlinear advection of vorticity should offer further improvements.

1. INTRODUCTION

Tropical cyclone development is known to be favored by certain upper-tropospheric conditions. Riehl (1954), Sadler (1976, 1978), and many others have cited the divergent, generally anticyclonic outflow layer above tropical cyclones. Asymmetries of the upper-level outflow are emphasized by Black and Anthes (1971) and Robock (1975). Gray (1968, 1975) found that climatologically small values of the vertical shear between upper and lower levels are clearly related to areas of tropical cyclone formation. Other studies (e.g., Lewis and Jorgensen 1978) have shown that changes in the upper-level circulation sometimes are influential in the decay of hurricanes.

Prior to the advent of the geostationary satellite, high level winds were not routinely available for most tropical regions. The knowledge of upper level flows over tropical cyclones and disturbances has come from climatology, occasional reconnaissance aircraft, and inferences from large-scale synoptic patterns derived from commercial aircraft reports and the land-based rawinsonde network.[1]

Cloud displacement vectors, used as winds, are now being obtained from geostationary satellites in increasing quality and quantity. Accuracy is considered comparable to that from rawinsondes (Suchman and Martin 1976, Bauer 1976). Because tropical storms and disturbances often generate cirrus that is suitable for high-level tracers, and because certain features of the upper-tropospheric circulation are known or suspected to be influential in the development or decay of tropical cyclones, it seemed reasonable to attempt to objectively analyze the high-level wind field from cirrus vectors, and to try to use this analysis for predictive purposes.

Early diagnostic attempts using a crude index composed of divergence, vorticity, and vertical shear, seemed promising (Erickson 1974). That sample, however, was rather small (only 32 "good" cases, mostly developing storms). Subsequent study of additional disturbances gave mixed results -- more good cases but more problems! Considering the roughness of the calculations together with the great diversity and complexity represented by the tropical disturbance spectrum, it was questionable whether a much larger number of cases would yield a consistently good relation. Although these factors were acknowledged, the effort seemed justified. Chief reasons were, and are, the unique nature and increasing availability of satellite cloud vectors together with evidence that meaningful physical relations should exist between cyclone development and certain features of the high-level circulation.

A large number of cases has now been assembled, and the early apprehensions have proven at least partly correct. Storms <u>are</u> diverse and complex. The calculations <u>are</u> rather crude. And the input data, although generally of good quality, often are inadequate in quantity or distribution. Even if a perfect high-level analysis of the wind were possible, it could only partially indicate the trend in intensity of a tropical weather system.[2]

Nevertheless, it appears that analysis of the high-cloud vector field can aid diagnosis and prediction. Several individual wind-derived variables, such as divergence, vorticity, and variants thereof, were found to be significant above the 99% level when correlated with disturbance intensity or change in intensity. Nonwind variables such as sea surface temperature

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[1] In recent years, much statistical compositing of rawinsonde data near tropical cyclones also has been performed (e.g., Frank 1977, Zehr 1976, Erickson 1977, McBride 1977). Most composites are from the network of western Pacific island stations.

[2] This, of course, is because favorable high-level conditions alone are not sufficient for tropical cyclone formation. Other factors, such as high sea surface temperature (Palmén 1956) and a lower-tropospheric cyclonic disturbance (Riehl 1954), also must exist.

also are significant. Thus, a weighted index of several variables appears to contribute a modest amount of predictive information (see example, fig. 1). Variables are selected on the basis of physical reasoning, availability, and contributions to individual and multiple linear regressions.

Both classified and unclassified disturbances have been studied. A classified disturbance is one that has been assigned a T-number from satellite cloud imagery in accordance with the NESS operational tropical cyclone classification technique (Dvorak 1975). An unclassified disturbance has no T-number. The two groups are treated separately, except where otherwise indicated. In formulating the regression equations for classified disturbances, and also for verification, the maximum sustained low-level windspeed (MWS) is used for disturbance intensity and change in intensity.

The purposes of this paper are:

(1) to describe the objective analysis procedure and the computation of variables;

(2) for classified disturbances, to show results from a predictor of 24-hr change in MWS;

(3) for unclassified (weak) disturbances, to show the performance of a discriminator with respect to tropical storm development or nondevelopment.

Formulas for both classified and unclassified disturbances have been tested on independent data. Results from both dependent and independent data are presented.

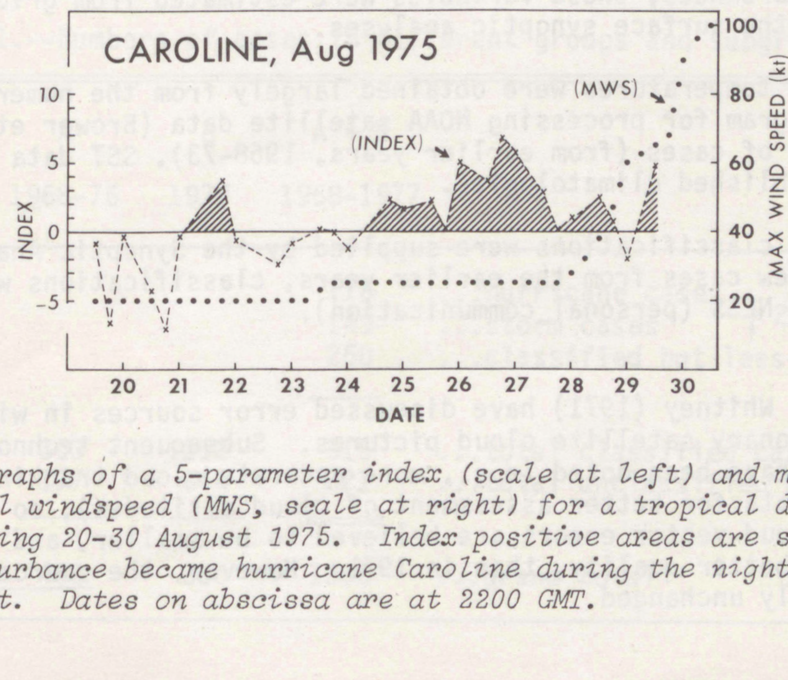

Figure 1.--Graphs of a 5-parameter index (scale at left) and maximum low-level windspeed (MWS, scale at right) for a tropical disturbance during 20-30 August 1975. Index positive areas are shaded. The disturbance became hurricane Caroline during the night of 29-30 August. Dates on abscissa are at 2200 GMT.

2. DATA

2.1 Upper-Tropospheric Winds

Data are mainly high-cloud vectors at or above the 300-mb level. (Most vectors are believed to be in the layer 180 to 250 mb). These are supplemented by 200-mb rawinsonde winds when available. Most of the high-cloud vectors were operationally determined and edited in NESS and generally are of high quality. Currently, they are produced three times daily, at 1000, 1600, and 2200 GMT.[3]

For an individual wind analysis, up to 20 vectors were accepted over a rectangular area not exceeding 20^o latitude x 20^o longitude (usually smaller). The attempt always was made to obtain at least 12 well-distributed vectors representing all quadrants surrounding the disturbance, so that the disturbance was nearly centered within the area. Unfortunately, these optimum conditions often were not met. Individual cases usually were accepted if there were at least 6 vectors, distributed over three quadrants.

2.2 Auxiliary Data

The following additional data were used: (a) location (lat./long.) and vector displacement (dir/speed) of the disturbance center, (b) sea surface temperature, (c) the disturbance classification (if classified,) and (d) the observed or estimated MWS and changes in MWS over succeeding periods of 12, 24, and 48 hours.

Disturbance location, displacement, and MWS data were obtained from best-track data and storm summaries (e.g., Lawrence 1978), where those exist. For weak disturbances, these variables were estimated from gridded satellite pictures and the surface synoptic analyses.

Sea surface temperatures were obtained largely from the numerical GOSSTCOMP program for processing NOAA satellite data (Brower et al., 1976). In a minority of cases (from earlier years, 1968-73), SST data were estimated from published climatologies.

Disturbance classifications were supplied by the Synoptic Analysis Branch, NESS. In a few cases from the earlier years, classifications were provided by V. Dvorak, NESS (personal communication).

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[3]Hubert and Whitney (1971) have discussed error sources in wind estimates from geostationary satellite cloud pictures. Subsequent technological improvements have been noted (e.g., more accurate cloud tracking, the advent of infrared data for better assessment of cloud altitudes), so that, currently, cloud vector errors are believed to be smaller, and the data generally of better quality, than in 1971. However, the sources of error are essentially unchanged.

2.3 Dependent and Independent Cases

The plan of this study was to derive formulas from 1968-76 (dependent) cases and to test those formulas on all possible 1977 (independent) cases. Generally, that plan has been followed. However, because of differences between the two groups (to be discussed later), it was decided also to reverse the procedure. Therefore, the two groups have each been used, alternatively, as both dependent and independent data. This has been done for classified and unclassified cases separately.

Table 1 shows numbers of cases in different groups and subgroups. For the period 1968-76 (group A), a total of 480 cases (i.e., 480 synoptic vector sets of up to 20 vectors each) have been collected for a variety of tropical storms and disturbances of all intensities over the North Atlantic and eastern North Pacific. Of these 480 cases, 303 are classified and 177 are unclassified. Most cases are from the years 1975-76, while a few are from earlier years back to 1968. Most disturbances of this study were followed in space and time as far as a recognizable disturbance or cloud cluster existed and for which high cloud vectors also existed. Consequently, most cyclones having lifetimes of several days are represented by a number of cases for each cyclone (up to three cases a day, for each day). A cyclone classified for only part of its life gives both classified and unclassified cases. Since weakening cyclones tend to lose their cirrus canopies, such cyclones are unavoidably under-represented.

For the period May to November 1977 (group B, table 1), all possible cases from the North Atlantic and eastern North Pacific were collected. These include 212 classified and 644 unclassified cases. Because of the effort to get as many cases as possible, and also because of better satellite coverage

Table 1.--Numbers of cases in different groups and subgroups

	A 1968-76	B 1977	A + B 1968-1977	
			116	...hurricane cases } 265
			149	...storm cases } 265
			250	...classified but less than storm
Classified	303	212	515	...total classified cases
Unclassified	177	644	821	...total unclassified cases
Total	480	856	1336	...grand total

and more high-cloud vectors than in some earlier years, the number of unclassified cases is much larger than in the earlier sample. This is one of the differences between the two data sets that led to the decision to reverse the dependent-independent roles.

The other difference is the anomalous 1977 hurricane season in the North Atlantic (Lawrence 1978), in which there were few hurricane days and in which disturbances intensified much farther north and west than usual. The eastern North Pacific also had fewer storms and hurricanes than normal (Gunther 1978). Because of this unanticipated difference between 1977 and earlier seasons, one must recognize that the two data sets, A and B, are not fully comparable.

3. ANALYSIS PROCEDURES

3.1 Objective Solutions for Winds

For limited-area data where the area diameter is smaller than the perturbation wavelength, 2nd- and 3rd-degree polynomial solutions often are acceptable. Table 2 summarizes their chief advantages and disadvantages.

The numerical technique is a modified version of that described by Schmidt and Johnson (1972), as applied to the horizontal wind field. Input wind data are separated into u-v components. The program calculates best-fit polynomial equations separately for each component, using least squares regression methods. The analytical solutions for u and v then are used to specify the fields of wind, divergence, vorticity, and other quantities. For this study, the analysis was applied only to the upper troposphere -- the level of the high-cloud vectors. In principle, however, the procedure

Table 2--Advantages and disadvantages of polynomial solutions for limited-area wind data.

advantages	disadvantages
● analytical solutions possible	● occasional unrealistic solutions
● solutions (over interior of area) usually acceptable if data are well distributed	● even good solutions often are unrealistic near data perimeter
● smoothing occurs and is desirable	● sometimes too much smoothing (poor fit to input data -- large rms errors)

can be applied to wind data from any quasi-horizontal level.

Note that the input wind data for any of the individual cases of this study may have come from two or more upper-tropospheric levels (at or above 300 mb). Consequently, the solutions often are more representative of a layer rather than a given level.

Figure 2 shows the field of wind direction for a 3rd-degree polynomial solution. Locations of individual input vectors and their numerical values also are shown.

Modifications from Schmidt and Johnson (1972) include computation of four degrees of polynomial (ranging from plane fit to 3rd-degree) and the use of certain tests to eliminate unrealistic solutions. See appendix 1 for details and for examples of acceptable and unacceptable solutions.

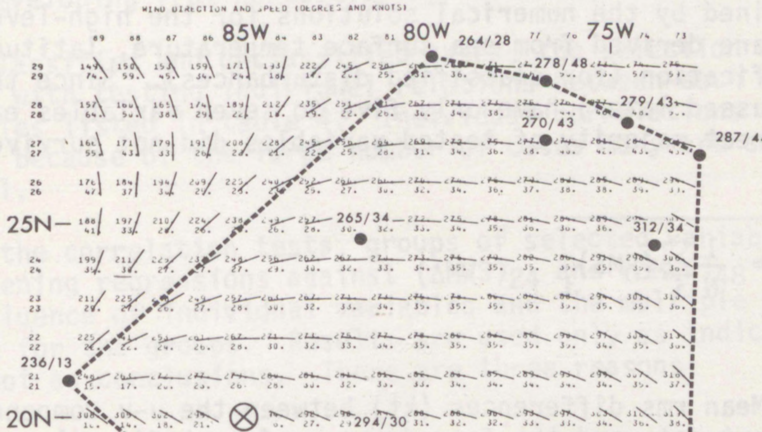

Figure 2.--Wind field from third-degree polynomial solution. Locations of disturbance center and the vector input data also are shown. Solution outside data perimeter is unrealistic.

The tests are only partly successful in eliminating or modifying unrealistic solutions. Since all objectively acceptable solutions entered the statistics, the results of this study are adversely affected by deficiencies in the model. Operationally, the addition of human experience in a man-machine mix should improve the results.

Table 3 is a summary of mean rms differences[4] between numerical solutions and their input data. This is a measure of the smoothing imposed by the solutions. The approximate 9-kt average errors of plane solutions are unacceptably large for many purposes, but some real and useful circulation features (particularly mean divergence and mean vorticity) appear to be captured. For 3rd-degree solutions, the 3- and 4-kt mean rms errors probably approach the noise level.

3.2 Variables

Many different variables, including their nonlinear variations, were formulated and tested for possible use as predictors. Most are partly or entirely determined by the numerical solutions for the high-level wind field. Others are derived from sea surface temperature, latitude, and the T-number classification (for classified disturbances). Since the predictive equations (discussed later) have only five to seven variables each, it is seen that the great majority of tested variables did not survive to final use.

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[4] "mean rms" = $\frac{1}{N}\sum_{i}(\mathrm{RMS})_i$

Table 3.--Mean rms differences (kt) between the u-v components of the input data and the four degrees of best-fit polynomial equations (from 480 cases, 1968-76 data).

Polynomial ⟶	(a)	(b)	(c)	(d)
u	9.4	7.1	6.3	4.1
v	8.9	6.9	6.1	3.0

(a) plane fit (3 variables: x, y, constant),
(b) four variables (xy, x, y, constant),
(c) 2nd-degree polynomial (6 variables),
(d) 3rd-degree polynomial (10 variables).

A number of nonsurviving variables, however, have relations with disturbance intensity or intensity change that are individually significant (as do nearly all surviving ones). In addition, some variables are derived from others; thus, the definition of one variable may involve the definition of another. All such variables are described in appendix 2.

3.3 Regression Analysis

Table 4 gives definitions of disturbance intensity and change in intensity. For classified disturbances, the chief aim was to predict $(\Delta MWS)_{24}$. The variable FI-CI (see table 13, appendix 2) is, in effect, the operationally available prediction of $(\Delta MWS)_{24}$ for classified disturbances; therefore, FI-CI is the primary variable. Other variables are selected to add information, using the technique of linear multiple regression.

For unclassified disturbances, FI-CI does not exist. The approach for these has been to formulate, from other variables, a predictor that distinguishes developing from nondeveloping disturbances.

For both classified and unclassified cases, the selection of likely variables began with testing individual relations between each variable and the four quantities listed in table 4. Individual correlations (r) generally are low, but because of the large number of cases many are significant at the 99% level.

Following the correlation tests, groups of selected variables were run through screening regressions against $(\Delta MWS)_{24}$ and $(\Delta MWS)_{48}$ to determine the relative influence of individual variables and the multiple correlation coefficients for the groups. Results are used only as indicators of helpful relations, not as conclusions. There are three reasons:

Table 4.--Definitions of disturbance intensity and change in intensity.

symbol	definition
MWS	Observed (or estimated) intensity of tropical disturbance in terms of maximum sustained wind speed (kt) at time t_o.
$(\Delta MWS)_{12}$	Observed 12-hr change in MWS (kt), beginning at t_o.
$(\Delta MWS)_{24}$	Observed 24-hr change in MWS.
$(\Delta MWS)_{48}$	Observed 48-hr change in MWS.

(1) Panofsky and Brier (1958) have pointed out that multiple coefficients blindly accepted and based on four or more variables often have little stability.

(2) Some combinations in this study that gave superior multiple correlations were not wholly realistic. This is partly because many individual variables are more highly correlated with each other than with $(\Delta MWS)_{24}$ or $(\Delta MWS)_{48}$. The lack of realism may also reflect certain deficiencies in the model.

(3) Differences between the two data groups (1968-76 cases vs. 1977 cases) are reflected in some of the individual correlation coefficients.

For these reasons, it was decided that the final equations should include only variables for which both the algebraic sign in the equation and the individual correlation with $(\Delta MWS)_{24}$ were physically realistic. This means that the equations, although not the best achievable in a purely statistical sense, are more likely to be meaningful. Variables appearing in one or more of the equations are listed in table 5.

Table 5.--Brief definition of variables appearing in equations.[5]

variable	definition
FI-CI	(Forecast Intensity minus Current Intensity)--Implied forecast of $(\Delta MWS)_{24}$, as determined from satellite picture classifications.
L	Latitude of disturbance
D	Divergence
q	Relative vorticity
MVA	Modified vorticity advection
S	Vertical wind shear
SST	Sea surface temperature

[5]For more complete definitions, including units, see appendix 2, tables 12 to 14. Variables actually used in equations may appear with one or two asterisks, denoting modifications, as explained in tables 13 and 14.

4. EQUATIONS FOR CLASSIFIED DISTURBANCES

4.1 The Influence of FI-CI

The quantity FI-CI is the forecast of $(\Delta MWS)_{24}$ determined operationally from satellite pictures and is the most influential component of the modified regression equations presented in this section; (see table 13, appendix 2, for complete explanantion of FI-CI). Although FI is considered less reliable than CI, correlations of the quantity FI-CI with available ground truth are fairly good. For the 303 classified cases of 1968-76, r = 0.66. For the 212 classified cases of 1977, r = 0.58. Ultimate truth of course is unattainable because of the verification problem -- satellite pictures themselves influence the best-track verification; therefore, these correlations probably overestimate reality. Even in reality, however, they probably remain larger than the coefficients from other individual variables. This is to be expected, since FI-CI is derived from the picture classification technique -- a synthesis of many variables, as revealed by satellite imagery.[6]

The influence of FI-CI, while beneficial overall, is not without its price. The heavy weight of that variable (in an equation to improve forecast performance) itself limits the overall improvement. Consequently, only modest increases in performance are achieved.

4.2 Results

Tables 6 and 7 gives descriptions and results, respectively, of five forecast methods: persistence, FI-CI, and three modified regression equations.

Persistence is a no-skill forecast; other methods should be better. It is included for comparison only. Similarly, eq. (1), which was developed without SST data, is included for comparison only. It is inferior to eqs. (2) and (3), which incorporate those data.

Eq. (2) is derived from the 1968-76 data sample; eq. (3) from the 1977 sample. Because of differences between the two samples (discussed earlier) and because results from both equations are nearly equal, both are presented. The statistics for (3) show it to be slightly better, overall. However, because (3) was derived from the cases of 1977 (an abnormal year), (2) may be better over a period of many years.

Table 8 is a detailed comparison of eqs. (2) and (3), showing the contributions of the individual variables in each equation. Variables are arranged roughly in descending order of importance, from left to right.

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[6]For evaluation of the accuracy of tropical cyclone intensities from satellite picture classifications, see Sheets and Grieman (1975).

Table 6.--Descriptions of the five forecast methods, (A), (B), (C), (D), (E), of table 7

	basis of forecast (of 24-hr change in MWS)	comment
(A)	persistence	forecast of no change from existing conditions.
(B)	FI-CI	from the operational picture classification technique for tropical cyclones.
(C)	regression equation (1):[7] $Forecast = 0.6(FI\text{-}CI) + 1.1L^{**} + 1.0D_a^{*} - 0.6q^{*} + 2.0MVA_a^{**} - 0.2S^{*}$	based on 303 cases from 1968-76 as dependent data -- <u>no</u> SST data.
(D)	regression equation (2):[7] $Forecast = 0.6(FI\text{-}CI) + 0.8L^{**} + 0.9D_a^{*} - 0.3q^{*} + 1.6MVA_a^{**} - 0.2S^{*} + 1.2SST^{*}$	based on 303 cases from 1968-76 as dependent data, including SST data.
(E)	regression equation (3): $Forecast = 0.6(FI\text{-}CI) + 0.5L^{**} + 0.2D^{**} - 0.5q^{**} + 1.5SST^{*}$	based on 212 cases from 1977 as dependent data (including SST data).

[7]In equations (1) and (2), subscripts (a) denote variables derived from the lowest order (plane-fit) polynomial. See appendix 2 for complete identification of variables.

The multiple correlation coefficients in tables 7 and 8 show that eqs. (2) and (3) improve on FI-CI by 0.08 for dependent data and by 0.06 for independent data. Bias, rmse, and average absolute errors (table 7) also show improvement. All methods are better than persistence, as expected.

Table 7.--Verification and comparison of five methods of prediction of the 24-hr change in MWS. Observed mean and σ values of MWS and $(\Delta MWS)_{24}$ also are shown (2 columns at left). Verifications are presented for three groupings of classified cases. The five forecast methods are (A) persistence, (B) the operational picture-classification technique, and (C, D, E) three modified linear regression equations. For (B), (C), (D), and (E), r is the linear correlation coefficient with $(\Delta MWS)_{24}$ (the observed 24-hr change in MWS, used for verification). All quantities are in knots, except r.

		Observed		Forecast 24-hr change in MWS				
				(A)	(B)	(C)	(D)	(E)
						regression eqns.		
		MWS	$(\Delta MWS)_{24}$		FI-CI	(1)	(2)	(3)
303 cases (1968-1976)	mean	51.2	6.8	0.0	7.9	6.7	6.7	6.5
	σ	27.3	16.9	0.0	14.0	13.5	13.4	12.1
	bias (error of mean)			- 6.8	+ 1.1	- 0.1	- 0.1	- 0.3
	root-mean-square error			18.2	13.0	11.8	11.5	11.7
	average absolute error			13.4	9.6	9.0	8.8	9.1
	r				.66	.72	.74	.72
212 cases (1977)	mean	34.8	2.8	0.0	5.2	4.1	3.0	3.3
	σ	16.2	15.4	0.0	11.6	12.5	12.4	10.6
	bias (error of mean)			- 2.8	+ 2.3	+ 1.3	+ 0.1	+ 0.4
	root-mean-square error			15.6	13.0	12.5	12.0	11.5
	average absolute error			10.8	9.1	9.0	8.8	8.3
	r				.58	.61	.64	.66
515 cases (1968-1977)	mean	44.5	5.2	0.0	6.8	5.6	5.1	5.1
	σ	24.7	16.4	0.0	13.2	12.7	12.9	11.4
	bias (error of mean)			- 5.2	+ 1.6	+ 0.5	- 0.1	- 0.1
	root-mean-square error			17.2	13.0	12.1	11.7	11.6
	average absolute error			12.4	9.4	9.0	8.8	8.7
	r				.64	.68	.70	.71

Table 8.--Comparison of two modified linear regression equations (nos. (2) and (3)) for predicting the 24-hr change in MWS. For individual variables within the equations, C is the algebraic coefficient of the variable and r is the individual correlation coefficient between the variable and $(\Delta MWS)_{24}$.

$$\text{Eq. (2):} \quad \mathit{Forecast} = 0.6(FI\text{-}CI) + 1.2SST^{*} + 0.8L^{**} + 0.9D^{*}_{a} - 0.3q^{*} + 1.6MVA^{**}_{a} - 0.2S^{*}$$

$$\text{Eq. (3):} \quad \mathit{Forecast} = 0.6(FI\text{-}CI) + 1.5SST^{*} + 0.5L^{**} + 0.2D^{**} - 0.5q^{**}$$

	Eq.	Dep. or Ind.	Multiple Corr. Coeff.		FI-CI	SST*	L**	D^{*}_{a}	D**	q*	q**	MVA^{**}_{a}	S*
303 cases (1968-1976)	(2)	dep.	*.74*	C	0.6	1.2	0.8	0.9		-0.3		1.6	-0.2
				r	*.66*	*.52*	*.45*	*.37*		*-.28*		*.20*	*-.19*
	(3)	ind.	*.72*	C	0.6	1.5	0.5		0.2		-0.5		
				r	*.66*	*.52*	*.45*		*.30*		*-.24*		
212 cases (1977)	(2)	ind.	*.64*	C	0.6	1.2	0.8	0.9		-0.3		1.6	-0.2
				r	*.58*	*.46*	*.47*	*.12*		*-.11*		*.32*	*-.15*
	(3)	dep.	*.66*	C	0.6	1.5	0.5		0.2		-0.5		
				r	*.58*	*.46*	*.47*		*.19*		*-.12*		
515 cases (1968-1977)	(2)	†	*.70*	C	0.6	1.2	0.8	0.9		-0.3		1.6	-0.2
				r	*.64*	*.51*	*.45*	*.30*		*-.21*		*.25*	*-.18*
	(3)	†	*.71*	C	0.6	1.5	0.5		0.2		-0.5		
				r	*.64*	*.51*	*.45*		*.25*		*-.18*		

† combined

Except for the nonwind variables and those with subscript (a) (indicating plane fit), the equations are based on 3rd-degree polynomial solutions. But results from plane solutions for all wind-derived variables are very nearly as good (differences in r are less than .005). Some individual variables, particularly MVA**, are statistically significant only if calculated from plane solutions; (see tables, appendix 2). This indicates a probable deficiency in the polynomial analysis scheme -- higher-order solutions, while fitting the data more closely, are unable to adequately represent quantities such as vorticity advection that are products of two gradients. Limited testing has been done using other objective analysis methods; results are inconclusive. Meanwhile, all the input data remain on punched cards, in the event a better analysis is developed.

4.3 Conclusions

Six points concerning equations (2) and (3) are reiterated and emphasized:

(1) The equations are derived from operationally available data, and the meteorological variables are calculated by a relatively simple numerical program.

(2) The increase in r (over that from FI-CI alone) is 0.08 for dependent data and 0.06 for independent data.

(3) Results have been determined objectively, with no manual elimination or modification of difficult cases. The introduction of experienced human judgment into a man-machine mix should improve the results.

(4) No low- or middle-tropospheric variables are included. The introduction of low-level vorticity and the nonlinear component of vorticity advection should offer further improvements.

(5) Because the correlation of FI-CI with available ground truth may overestimate reality, the superiority of equations (2) and (3) over FI-CI may be greater than indicated, although starting from a lower base. This cannot be proven with present data.

(6) Both equations are heavily dependent upon FI-CI, therefore any existing bias in FI-CI also affects the equations. A positive bias (i.e., a tendency to overforecast $(\Delta MWS)_{24}$) may be seen from table 11. This bias is pronounced for intensifying storms and hurricanes, and is discussed in Appendix 3.

5. A DISCRIMINATOR FOR UNCLASSIFIED DISTURBANCES

5.1 Discussion

The vast majority of unclassified disturbances are weak and poorly organized, with most never developing to tropical storm intensity (MWS $\geq$ 34 kt). Of those that do develop, many do so only after several days. Consequently, the relation between any developmental predictor and $(\Delta MWS)_{24}$, as expressed by a correlation coefficient, would be quite poor. A discriminator, separating eventually-developing from never-developing disturbances, appears more useful. Discrimination related to both the event of development and the time required is desirable.

5.2 Results

Table 9 gives results from formula I" (eq. (4)), which by a slight margin is considered to be the best overall discriminator, of several that were tested.

$$I'' = 1.0D_a - 1.0q_a + 0.3SST^* + 1.5L^* + 3.0MVA_a^* - 0.3S^{**} \qquad (4)$$

I" is derived from 1977 data. It is designed so that high values are favorable and low values unfavorable for subsequent storm formation. Since the results from dependent and independent data are not greatly different, tabulations also are shown for the combined group (821 cases, 1968-1977).

In table 9, cases are subdivided into nine mutually exclusive categories, according to length of time for tropical storm formation. The nine categories represent all possibilities. (By far the largest category, of course, is the one at the bottom called "never became storm"). Results are

Table 9.--Numbers of cases of I" below and above threshold 2.0 vs. nine length-of-time categories for tropical storm development. Results are presented for three groupings of unclassified disturbances (dependent data, independent data, and all combined).[8]

	Length of time (days) before becoming tropical storm	Dependent 644 cases (1977 only) ($\overline{I''}$ = 2.32)		Independent 177 cases (1968-76) ($\overline{I''}$ = 1.47)		Combined 821 cases (1968-1977) ($\overline{I''}$ = 2.14)	
		<2.0 (276)	>2.0 (368)	<2.0 (78)	>2.0 (99)	<2.0 (354)	>2.0 (467)
became tropical storm	< 0.5	0	4	0	0	0	4
	0.5 - 1.0	0	10	0	1	0	11
	1.0 - 1.5	0	11	0	6	0	17
	1.5 - 2.0	1	16	2	5	3	21
	2.0 - 2.5	2	11	2	8	4	19
	2.5 - 3.0	5	16	1	6	6	22
	3.0 - 3.5	2	14	1	8	3	22
	⩾ 3.5	37	38	8	22	45	60
never became storm		229	248	64	43	293	291

[8] In the headings for each of the three groupings, $\overline{I''}$ is the average value of I" for all cases in the group.

presented as numbers of cases of the discriminator below and above the threshold 2.0, for each category.

As an aid to interpreting table 9, it is useful to consider the two extremes theoretically possible -- perfection and no skill. A perfect discriminator would show an absolute separation of values, with zero cases in one column for all categories above a certain point on the time scale and zero cases in the other column for the categories below that point. The opposite extreme of no skill would be revealed by paired numbers above and below the threshold in roughly the same proportion for all individual categories.

Table 9 represents the real world of this study. Perfection is elusive, but discriminatory capability obviously exists! For cases in which I" < 2.0 (a threshold near the mean of all cases), it is seen that the overwhelming

Table 10.--Numbers of cases of I" below and above threshold 2.0 vs. dichotomous length-of-time categories for tropical storm development, and corresponding χ^2. Separations are at 1½ days (top), 2 days (middle), and "eventually-developing" vs. "never-developing" (bottom). Each dichotomy is for 821 unclassified cases (1968-1977).

	<2.0	>2.0	total	χ^2
became tropical storm within 36 hours	0	32	*32*	25.2
did not become storm within 36 hours	354	435	*789*	
	354	*467*	*821*	
became tropical storm within 48 hours	3	53	*56*	34.9
did not become storm within 48 hours	351	414	*765*	
	354	*467*	*821*	
eventually became tropical storm	61	176	*237*	41.0
never became tropical storm	293	291	*584*	
	354	*467*	*821*	

majority never became storms. In fact, no such case became a storm within 36 hours, and only three did so within 48 hours (combined group). By contrast, the corresponding numbers for cases in which I" > 2.0 are 32 and 53.

Table 10 gives three slightly different, condensed presentations of the same data shown for the combined group of table 9 (821 unclassified cases, 1968-1977). In each condensation, the nine time categories have been reduced to two. Separations are at 1 1/2 days, 2 days, and "all cases eventually becoming storms", respectively. The I" threshold of 2.0 remains constant throughout. The statistical "chi-square" (χ^2) test has been performed for each of the three distributions in table 10; (values appear at right). All correspond to a level of significance above 99.9%.

In summary, the discriminator I" can eliminate many nondeveloping disturbances from consideration. However, after that has been accomplished, we still are left with a large group, of which many develop and many do not. For these, additional information is needed. This result agrees with operational experience regarding favored environments; development still may not occur because other vital conditions are missing.

5.3 Suggested Improvements

The probable existence of other unmeasured but vital variables admittedly represents a large information gap within this study. It is well known that the existence of a lower-tropospheric meso- or synoptic-scale disturbance is an important precursor of tropical storms. But I" includes no low-level or middle level atmospheric variables. None have been collected for these cases. Lack of feasibility rather than lack of importance has been the reason.

This author believes that two lower-tropospheric variables, if consistently obtained, could add considerable information to I" (or to a similar indicator). Those two variables are the low-level vorticity and the nonlinear advection of low-level vorticity.

The necessary existence of the precursory disturbance, discussed long ago by Riehl (1954) and by others, in itself strongly suggests a significant relation between low-level vorticity and storm formation. Recently, Zehr (1976) and McBride (1977) have presented additional evidence in favor of the importance of low-level vorticity for storm formation. In the measurement of vorticity near tropical disturbances, satellite-observed fields of low-cloud vectors occasionally are sufficient to define excellent wind fields and wind-derived variables such as vorticity. However, the dense middle and high-cloud canopies over many disturbances often preclude obtaining sufficient low-level vectors. Even where obscuration is not a problem, short-interval pictures usually are needed, and these are not obtained routinely. For these reasons, it was judged that low-level vorticity could reasonably be estimated for only a minority of the cases of this study. Therefore, no attempt was made.

With regard to nonlinear advection of vorticity, Shapiro (1977a, b) has presented impressive evidence that this quantity is also important for tropical storm development. Again, the quantity was available only for a minority of the cases of this study; therefore, it is omitted.

In view of recent evidence for the importance of low-level vorticity and vorticity advection, and the fact that these variables (and perhaps others of significance) are omitted from the present study, it is not surprising that I" is a far-from-perfect indicator. Storms are complex. Meanwhile, one hopes that consistent and reliable measures of low-level vorticity and vorticity advection might, in the future, become routinely available for many tropical oceanic regions.

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REFERENCES

Bauer, Kenneth G., 1976: "A Comparison of Cloud Motion Winds with Coinciding Radiosonde Winds," Monthly Weather Review, Vol. 104, No. 7, pp. 922-931.

Black, Peter G., and Richard A. Anthes, 1971: "On the Asymmetric Structure of the Tropical Cyclone Outflow Layer," Journal of the Atmospheric Sciences, Vol. 28, No. 8, pp. 1348-1366.

Brower, Robert L., Hilda S. Gohrband, William G. Pichel, T. L. Signore, and Charles C. Walton, 1976: "Satellite Derived Sea-Surface Temperatures from NOAA Spacecraft," NOAA Technical Memorandum NESS 78, U. S. Department of Commerce, National Environmental Satellite Service, Washington, D. C., 74 pp.

Dvorak, Vernon F., 1975: "Tropical Cyclone Intensity Analysis and Forecasting from Satellite Imagery," Monthly Weather Review, Vol. 103, No. 5, pp. 420-430.

Erickson, Carl O., 1974: "Use of Geostationary-Satellite Cloud Vectors to Estimate Tropical Cyclone Intensity," NOAA Technical Memorandum NESS 59, U. S. Department of Commerce, National Environmental Satellite Service, Washington, D. C., 37 pp.

Erickson, Steven L., 1977: "Comparison of Developing vs. Non-Developing Tropical Disturbances," Atmospheric Science Paper No. 274, Colorado State University, Fort Collins, Colorado, 81 pp.

Frank, William M., 1977: "The Structure and Energetics of the Tropical Cyclone I. Storm Structure," Monthly Weather Review, Vol. 105, No. 9, pp. 1119-1135.

Gray, William M., 1968: "Global View of the Origin of Tropical Disturbances and Storms," Monthly Weather Review, Vol. 96, No. 10, pp. 669-700.

Gray, William M., 1975: "Tropical Cyclone Genesis," Atmospheric Science Paper, No. 234, Colorado State University, Fort Collins, Colorado, 121 pp.

Gunther, Emil B., 1978: "Eastern North Pacific Tropical Cyclones of 1977," Monthly Weather Review, Vol. 106, No. 4, pp. 546-558.

Hebert, Paul J., 1978: "Intensification Criteria for Tropical Depressions of the Western North Atlantic," Monthly Weather Review, Vol. 106, No. 6, pp. 831-840.

Hubert, L. F., and L. F. Whitney, Jr., 1971: "Wind Estimation from Geostationary-Satellite Pictures," Monthly Weather Review, Vol. 99, No. 9, pp. 665-672.

Lawrence, Miles B., 1978: "Atlantic Hurricane Season of 1977," Monthly Weather Review, Vol. 106, No. 4, pp. 534-545.

Lewis, Billy M., and David P. Jorgensen, 1978: "Study of the Dissipation of Hurricane Gertrude (1974)," Monthly Weather Review, Vol. 106, No. 9, pp. 1288-1306.

MacDonald, Alexander E., 1977: "On a Type of Strongly Divergent Steady State," Monthly Weather Review, Vol. 105, No. 6, pp. 771-785.

McBride, John E., 1977: "Observational Analysis of the Differences between Developing and Non-Developing Tropical Disturbances," --paper presented at the Eleventh Technical Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society, December 13-16, 1977, Miami Beach, Florida.

Palmén, E., 1956: "Formation and Development of Tropical Cyclones," Proceedings of the Tropical Cyclone Symposium, Brisbane, December 1956, Melbourne, Australia, pp. 213-231.

Panofsky, Hans A., and Glenn W. Brier, 1958: Some Applications of Statistics to Meteorology, The Pennsylvania State University, University Park, Pa., 224 pp.

Riehl, H., 1954: Tropical Meteorology, McGraw-Hill Book Co., Inc., New York, ch. 11, pp. 281-357.

Robock, Alan, 1975: "On the Eddy Structure of Hurricanes," Quarterly Journal of the Royal Meteorological Society, Vol. 101, No. 429, pp. 657-663.

Sadler, James C., 1976: "A Role of the Tropical Upper Tropospheric Trough in Early Season Typhoon Development," Monthly Weather Review, Vol. 104, No. 10, pp. 1266-1278.

Sadler, James C., 1978: "Mid-Season Typhoon Development and Intensity Changes and the Tropical Upper Tropospheric Trough," Monthly Weather Review, Vol. 106, No. 8, pp. 1137-1152.

Schmidt, Phillip J., and Donald R. Johnson, 1972: "Use of Approximating Polynomials to Estimate Profiles of Wind, Divergence, and Vertical Motion," Monthly Weather Review, Vol. 100, No. 5, pp. 345-353.

Shapiro, Lloyd J., 1977a: "Tropical Storm Formation from Easterly Waves: A Criterion for Development," Journal of the Atmospheric Sciences, Vol. 34, No. 7, pp. 1007-1021.

Shapiro, Lloyd J., 1977b: "A Criterion for the Development of Tropical Storms from Easterly Waves," --paper presented at the Eleventh Technical Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society, December 13-16, 1977, Miami Beach, Florida.

Sheets, Robert C., and Paul G. Grieman, 1975: "An Evaluation of the Accuracy of Tropical Cyclone Intensities and Locations Determined from Satellite Pictures," NOAA Technical Memorandum ERL WMPO-20, Weather Modification Program Office, Environmental Research Laboratories, U. S. Department of Commerce, Boulder, Colorado, 36 pp.

Suchman, David, and David W. Martin, 1976: "Wind Sets from SMS Images: An Assessment of Quality for GATE," Journal of Applied Meteorology, Vol. 15, No. 12, pp. 1265-1278.

Zehr, Raymond M., 1976: "Tropical Disturbance Intensification," Atmospheric Science Paper No. 259, Colorado State University, Fort Collins, Colorado, 91 pp.

Riehl, H., 1954: Tropical Meteorology, McGraw-Hill Book Company, Inc., New York, 392 pp.

Robock, Alan, 1975: "On the Eddy Structure of Hurricanes," Quarterly Journal of the Royal Meteorological Society, Vol. 101, No. 429, pp. 657-663.

Sadler, James C., 1976: "A Role of the Tropical Upper Tropospheric Trough in Early Season Typhoon Development," Monthly Weather Review, Vol. 104, No. 10, pp. 1266-1278.

Sadler, James C., 1978: "Mid-Season Typhoon Development and Intensity Changes and the Tropical Upper Tropospheric Trough," Monthly Weather Review, Vol. 106, No. 8, pp. 1137-1152.

Schmidt, Phillip J., and Donald R. Johnson, 1972: "Use of Approximating Polynomials to Estimate Profiles of Wind, Divergence, and Vertical Motion," Monthly Weather Review, Vol. 100, No. 5, pp. 345-353.

Shapiro, Lloyd J., 1977a: "Tropical Storm Formation from Easterly Waves: A Criterion for Development," Journal of the Atmospheric Sciences, Vol. 34, No. 7, pp. 1007-1021.

Shapiro, Lloyd J., 1977b: "A Criterion for the Development of Tropical Storms from Easterly Waves," --paper presented at the Eleventh Technical Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society, December 13-16, 1977, Miami Beach, Fla.

Sheets, Robert C., and Paul G. Grieman, 1975: "An Evaluation of the Accuracy of Tropical Cyclone Intensities and Locations Determined from Satellite Pictures," NOAA Technical Memorandum ERL WMPO-20, Weather Modification Program Office, Environmental Research Laboratories, U. S. Department of Commerce, Boulder, Colorado, 36 pp.

Suchman, David, and David W. Martin, 1976: "Wind Sets from SMS Images: An Assessment of Quality for GATE," Journal of Applied Meteorology, Vol. 15, No. 12, pp. 1265-1278.

Zehr, Raymond M., 1976: "Tropical Disturbance Intensification," Atmospheric Science Paper No. 259, Colorado State University, Fort Collins, Colorado, 91 pp.

APPENDIXES

Appendix 1. THE OBJECTIVE ANALYSIS TECHNIQUE

The input data for upper-tropospheric wind analyses are cirrus vectors at or above 300 mb (supplemented by 200-mb rawinsonde winds, where available). The numerical program accepts up to 20 vectors in a rectangular area not exceeding 20° latitude x 20° longitude. A minimum of 12 vectors, representing all quadrants surrounding the disturbance, is preferred. Figure 3 shows examples of good, marginally acceptable, and unacceptable vector distributions.

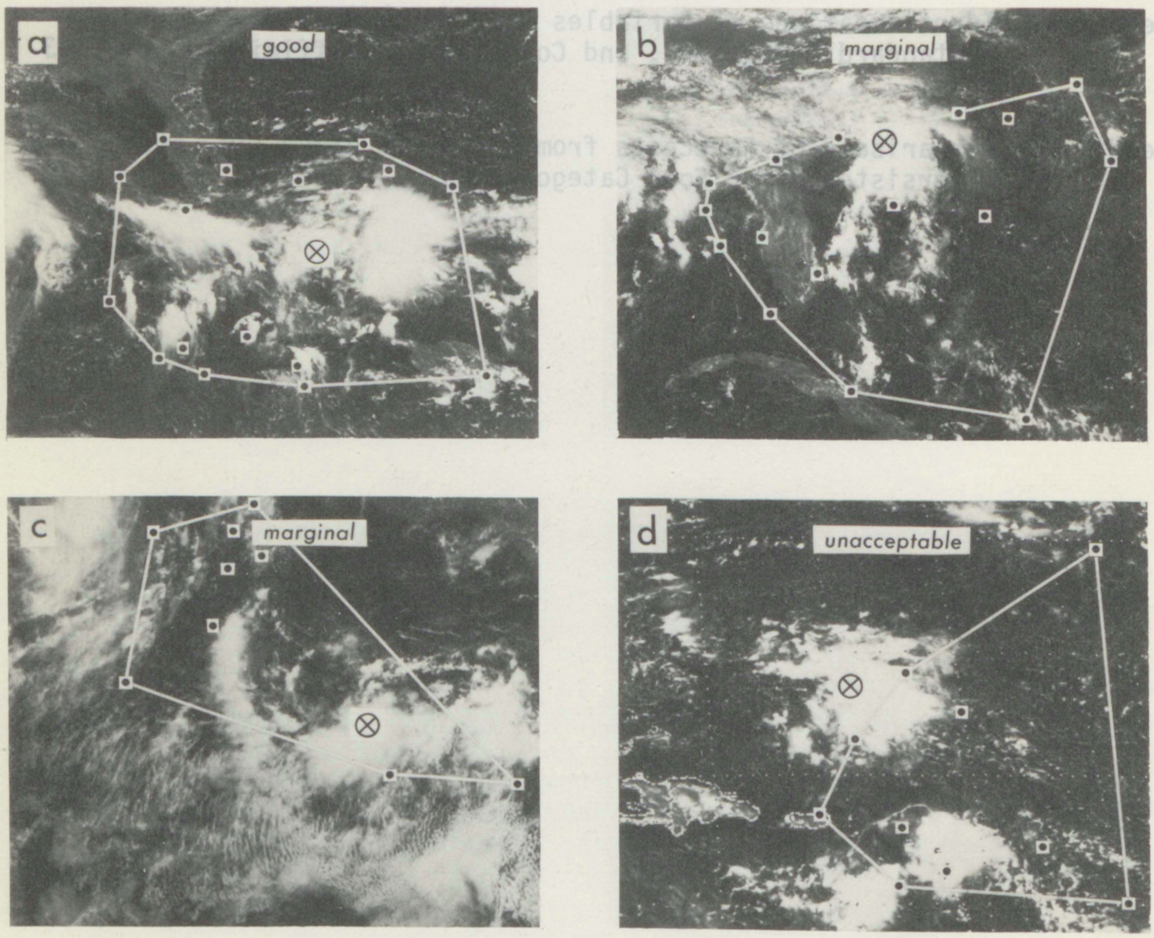

Figure 3.--Examples of good, marginal, and unacceptable vector distributions, relative to disturbance center (⊗): (a) good--16 vectors, all quadrants represented; (b) acceptable but marginal--disturbance center near data perimeter; (c) acceptable but marginal--only 9 vectors, poorly distributed; (d) unacceptable--disturbance center outside data perimeter. Data areas (enclosed by white lines) are roughly 10 to 15 degrees of latitude in diameter.

For each case, for u and v separately, four degrees of polynomial are computed. In ascending order, they are:

(a) plane fit (3 variables: x, y, constant),
(b) four variables (xy, x, y, constant),
(c) 2nd-degree polynomial (6 variables),
(d) 3rd-degree polynomial (10 variables).

For each polynomial, the analytical solutions for u and v then are used to specify wind, divergence, vorticity, and other quantities. Either point values or mapped field quantities are available. For the predictive equations, only point values are used.

Figure 4 shows four windfields, representing the four degrees of polynomial solution for a particular set of input vectors. Figure 5 displays fields of divergence and vorticity from a 3rd-degree solution.

Each of the higher-order solutions (above the plane fit) is obtained in sequence, as follows:

(1) One bogus vector, located at the disturbance center, is obtained from the preceding lower-order solution and is added to the input data. In addition, if the preceding solution shows $D > 0$ and $q < 0$ at that location, the bogus vector is weighted toward the disturbance vector displacement, the degree of weighting being proportional to D and inversely proportional to q.

(2) For u and v separately, the x-y coordinate axes are rotated, and candidate solutions tested, at each of eighteen 5^o increments (from 0^o to 90^o) to select the solution with the lowest rmse.[9]

(3) u and v solutions are combined and point calculations of seven variables (u, v, D, q, Q, VA, MVA) are recorded for each of three locations: the disturbance center, the grid center, and the centroid of the input data. At each of the latter two locations, comparisons with the preceding lower-order solution are made in order to detect unrealistic solutions. The acceptance criteria are:

(a) $|D - D'| \leqslant 4.0$,
(b) $|q - q'| \leqslant 4.0$,
(c) $|u - u'| \leqslant$ (10.0 + rmse of preceding solution),
(d) $|v - v'| \leqslant$ (10.0 + rmse of preceding solution),

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[9] Ignoring this procedure usually (but not always) makes little difference in the final solution. If axes are not rotated, average results are slightly inferior, but considerable machine time is saved.

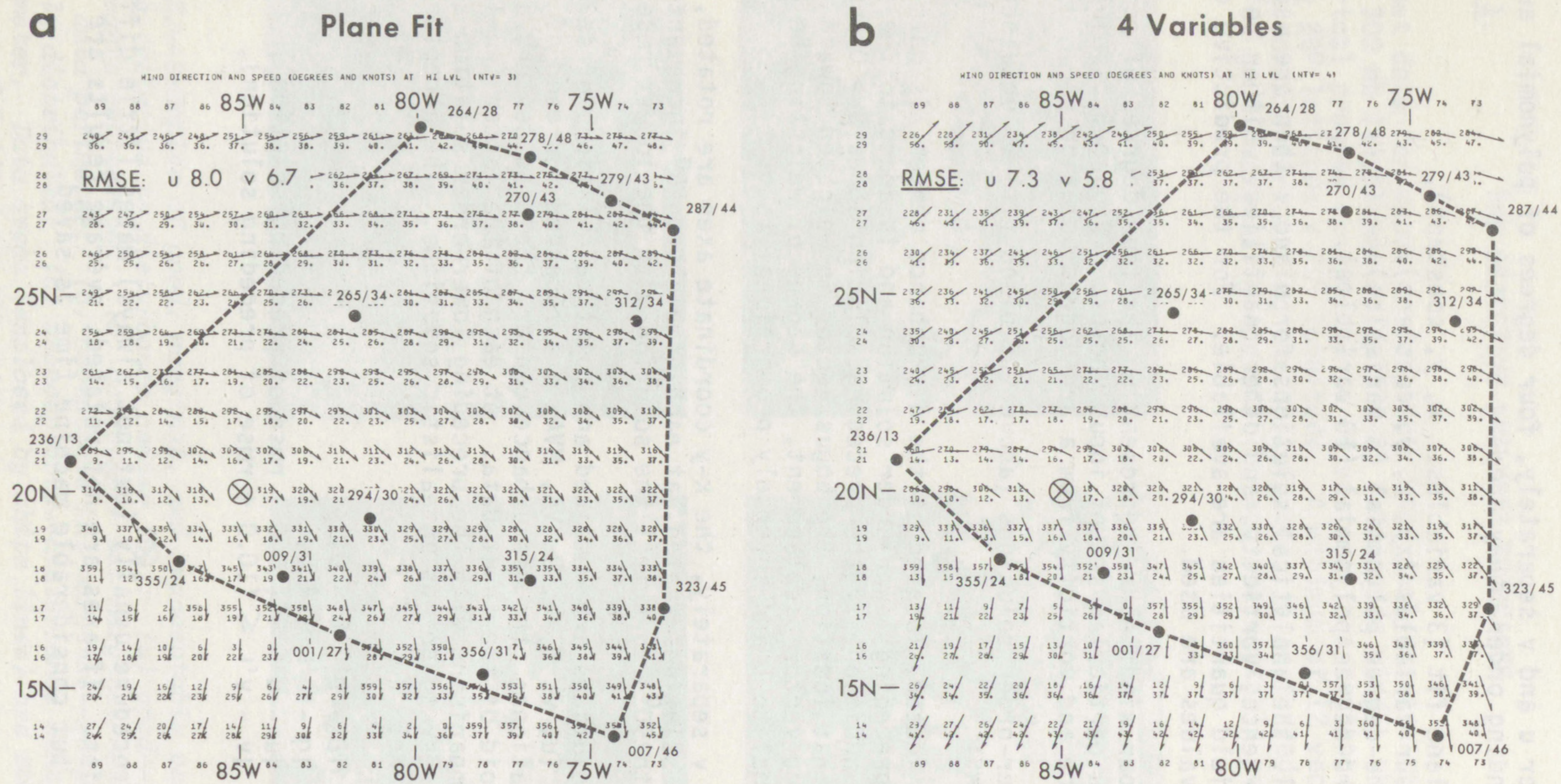

Figure 4.--Windfields for four degrees of polynomial solution for an individual case: (a) plane fit, (b) 4 variables, (c) 2nd-degree polynomial (6 variables), (d) 3rd-degree polynomial (10 variables). The rms errors and locations of disturbance center and input data also are shown.

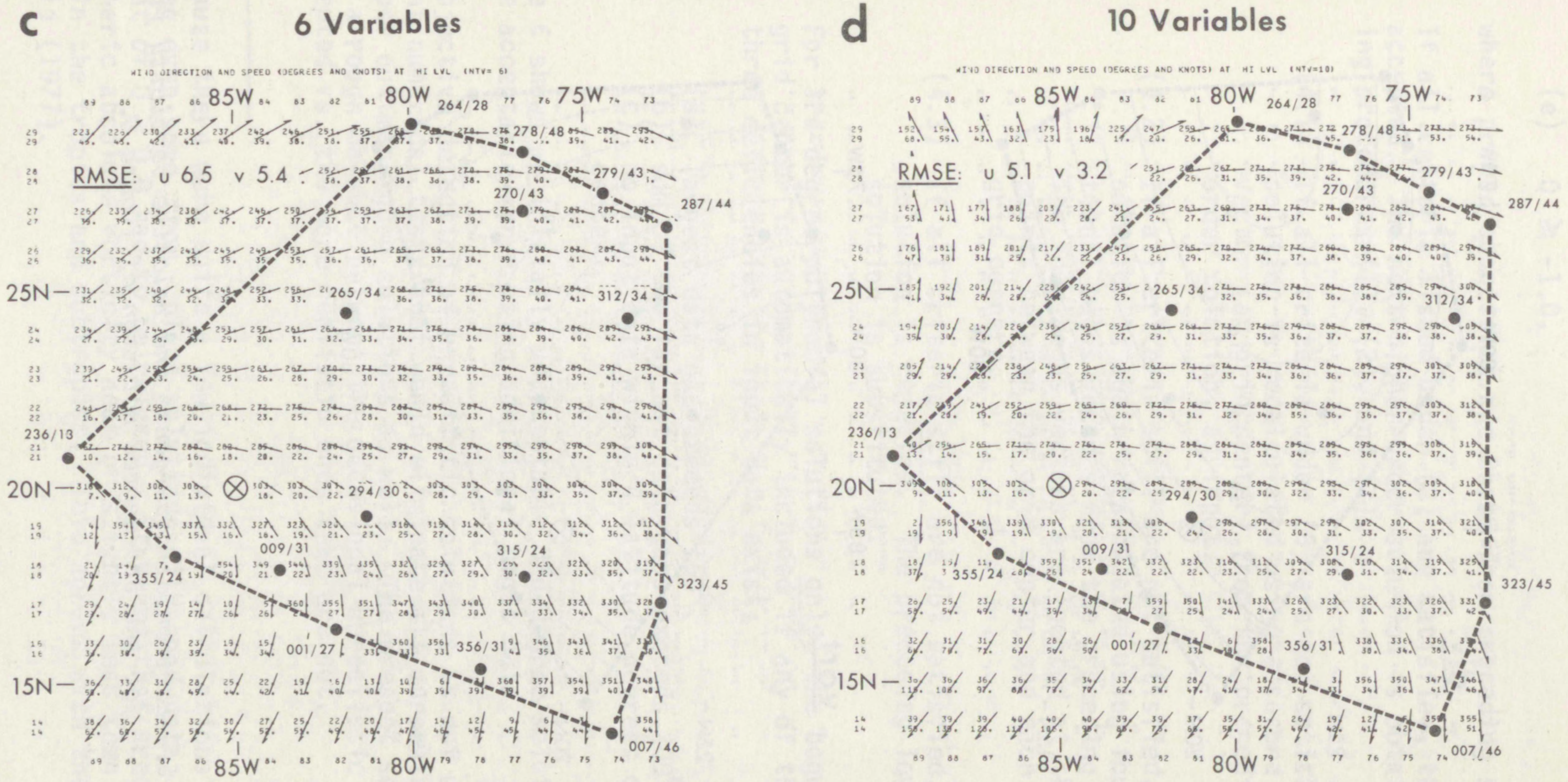

Figure 4.--continued. (See legend for (a) and (b)).

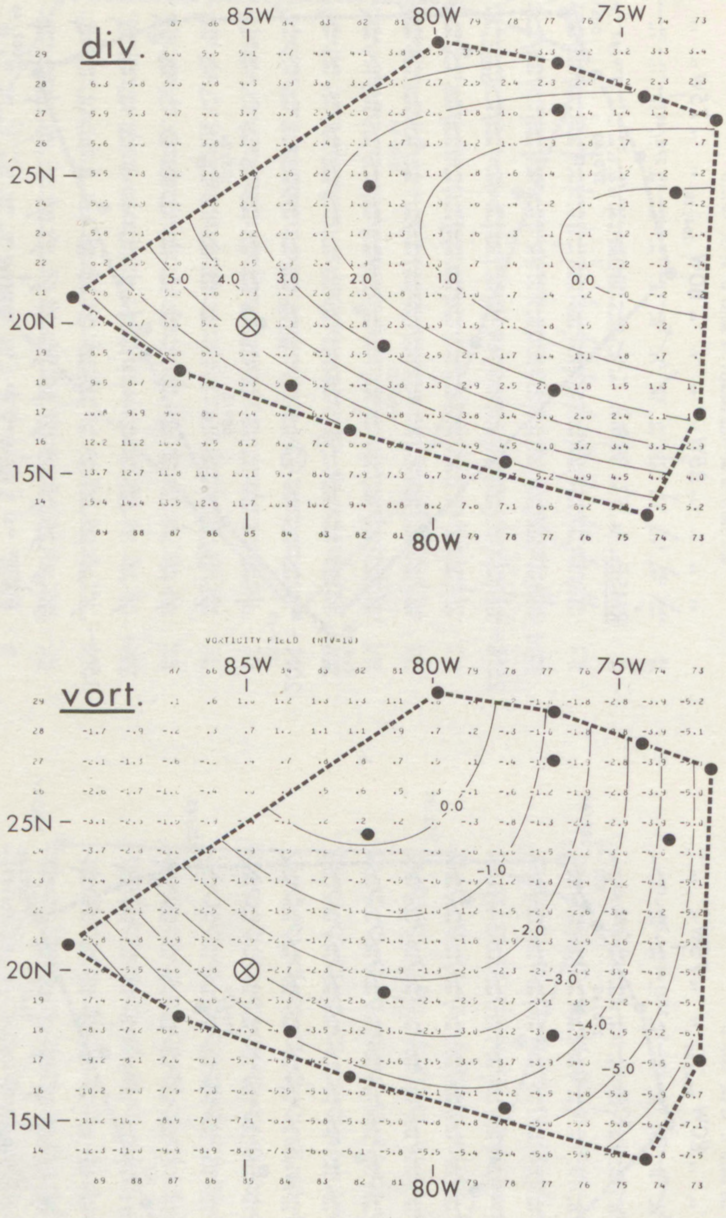

Figure 5.--Horizontal divergence and relative vorticity fields for the 3rd-degree solution of figure 4.

(e) $Q \geqslant -1.0$,

where primed quantities are those from preceding solution.[10]

(4) If all criteria listed under (3) are satisfied, the solution is accepted. The next higher-order solution is obtained by repeating procedures (1), (2), and (3).

(4.1) If all criteria under (3) are not satisfied, the solution is recalculated using a second bogus vector (at grid center) from the preceding lower-order solution, as input.

(4.2) If all criteria still are not satisfied, the solution is again recalculated using four additional bogus vectors from the preceding solution. The four bogus vectors are located at the midpoints between the grid center and each of the grid corners.

(4.3) If all criteria still are not satisfied, the solution is rejected. The preceding lower-order solution is substituted.

(5) For 3rd-degree polynomial solutions only, the bogus vector at grid center is automatically included if any of the following three deficiencies in input data exist:

(a) largest data gap exceeds 150°,
(b) sum of two largest data gaps exceeds 200°,
(c) no input data within 4 latitude degrees of grid center.

Figure 6 shows an initially unacceptable 3rd-degree solution together with the acceptable rerun using additional bogus data.

The objective detection of unrealistic solutions is not wholly successful. Stringent numerical tests that would eliminate all unrealistic solutions would toss out many good solutions as well. The present scheme appears to achieve a rough balance between the occasional unrealistic solutions that are accepted vs. the more realistic ones that are not.

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[10] Because there were quite a few individual calculations of $Q < 0.0$, including even some from plane solutions with good data, an earlier requirement of $Q \geqslant 0.0$ had to be relaxed. It seems that areas of upper-tropospheric absolute vorticity near or slightly less than zero are rather common in the tropics and subtropics. This agrees with the findings of MacDonald (1977).

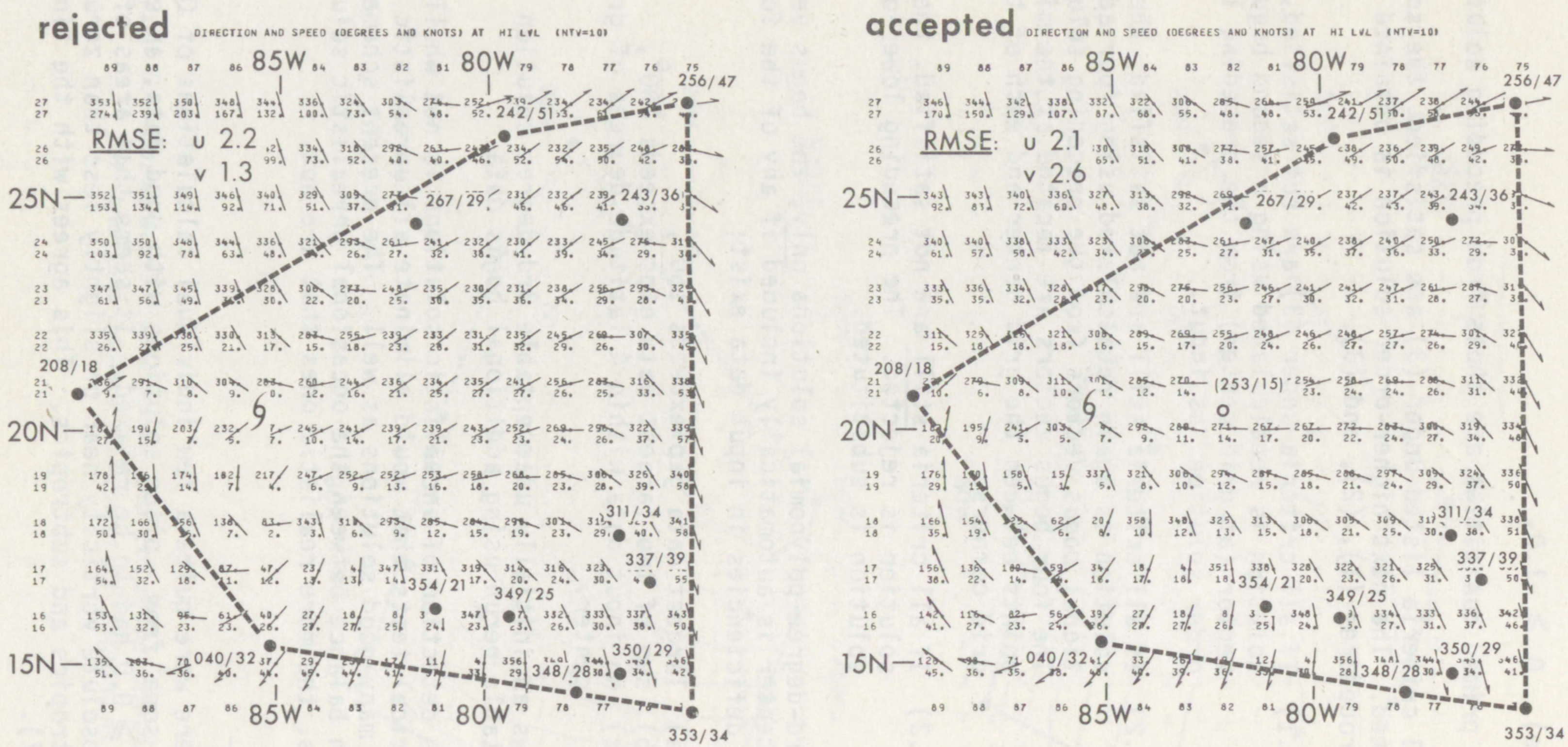

Figure 6.--*A rejected 3rd-degree solution (left), and the acceptable recalculation using additional center-point bogus data (right). Solutions outside data perimeter are unrealistic.*

Figure 7 is an example of an objectively acceptable solution that on further examination is seen to be unrealistic, and which gave a poor result. This Gulf of Mexico disturbance, 28 August 1977, later became hurricane Anita. Two crucial vectors, west and southwest of the disturbance center, are fit very poorly; (see documentation, table 11). The vectors indicate substantial high-level outflow from the disturbance, and in all probability are correct. An experienced meteorologist familiar with the synoptic situation would have rejected or modified this numerical solution, thereby implying greater divergence, more anticyclonic vorticity, and increased storm potential. This is a good example of how an operational man-machine mix might improve the machine-only results reported in this study.

Table 11.--Solution errors for two crucial vectors, 28 August 1977, 1600 GMT. See illustration, figure 7.

		Vector location	
		25.4°N, 87.1°W	22.7°N, 87.3°W
Observed wind (deg/kt)		123/32	119/23
Solution wind (deg/kt)		120/18	092/17
Errors of solution	u (kt)	- 11.0	- 2.7
	v (kt)	- 8.2	- 10.3

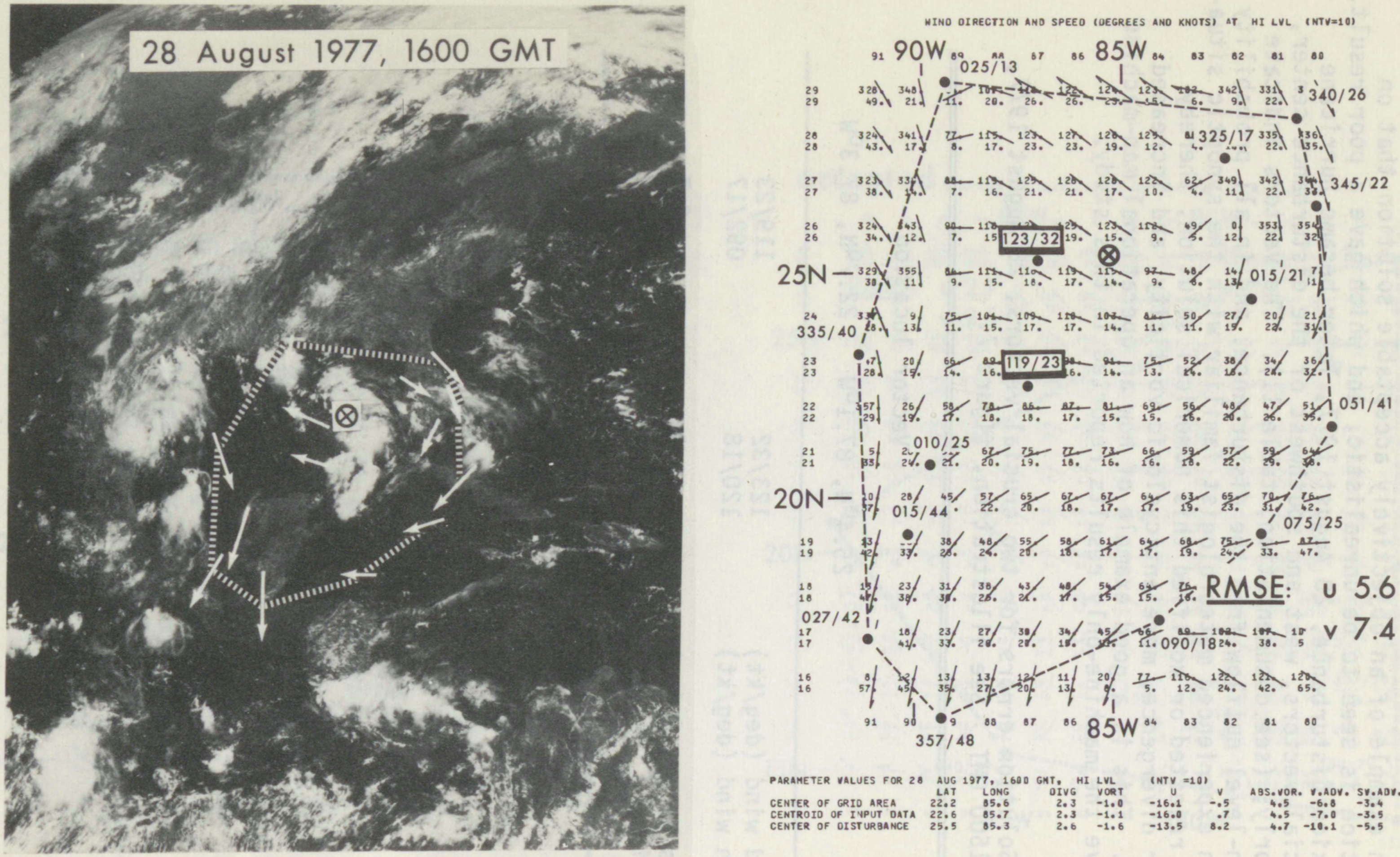

Figure 7.--An objectively acceptable solution (right) that gave a poor result. Data perimeters on picture and solution are geographically the same, despite different perspectives. This Gulf of Mexico disturbance (28 August 1977, 1600 GMT) later became hurricane Anita.

Appendix 2. IDENTIFICATIONS OF VARIABLES AND TABLES OF MEANS, STANDARD DEVIATIONS, AND CORRELATION COEFFICIENTS

Table 12.--Descriptions of 8 basic variables (calculated from the analytical solutions for the high-level wind field) [11]

symbol	variable	(units)	description (or comment)
u	west-east wind component	(kt)	(westerly components positive)
v	south-north wind component	(kt)	(southerly components positive)
s	vertical wind shear	(kt)	vector speed difference between the horizontal displacement of the low-level disturbance and the calculated upper-level wind vector over the disturbance.
D	horizontal divergence	($s^{-1} \times 10^5$)	
q	relative vorticity	($s^{-1} \times 10^5$)	
Q	absolute vorticity	($s^{-1} \times 10^5$)	
VA	vorticity advection	($s^{-1} \times 10^5$ per day)	$VA = -V \cdot \nabla Q$, (where V is the total wind vector).
MVA	modified vorticity advection	($s^{-1} \times 10^5$ per day)	vorticity advection relative to the moving center of the disturbance.

[11] S and MVA are partly dependent upon the horizontal vector displacement of the low-level center of the disturbance.

Table 13.--Descriptions of auxiliary variables, not dependent upon the calculated high-level wind field

symbol	variable	(units)	description (or comment)
T	T-number classification of tropical disturbance	--	obtained from the operational tropical cyclone classification technique (Dvorak, 1975).
CI	Current Intensity of tropical disturbance (in terms of MWS)	(kt)	
FI	24-hr Forecast Intensity of tropical disturbance (in terms of MWS)	(kt)	
FI-CI	Forecast 24-hr change in disturbance intensity (in terms of MWS)	(kt)	
L	Latitude of disturbance	(degrees)	
L*	Nonlinear latitude factor for unclassified disturbances	--	$L^* = 1 - \left(\frac{10}{L}\right)^3$ (gives negative weighting at very low latitudes).
L**	Nonlinear latitude factor for classified disturbances	--	depends upon both L and T (gives negative weighting north of 30N in Atlantic and north of 15N in eastern Pacific west of 112W).
SST	sea surface temperature	(^{o}C)	
SST*	nonlinear sea surface temperature factor	--	depends upon both SST and T, with high values of SST (> 26.5) having greatest positive weight at intermediate T (T3), and low values of SST (< 26.5) having greatest negative weight at maximum T (T8). At the threshold, or neutral, value of SST (26.5), SST* = 0, for all T.

Table 14.--Descriptions of 11 derived variables[12]

symbol	variable	formula	comment
v*	modified v-component	$v^* = 3 - \frac{\lvert v+15 \rvert}{5}$	gives greatest weight to northerly (negative) wind components of 15 kt.
S*	modified vertical shear	$S^* = \left(\frac{S}{10}\right)^2$	nonlinear shear factor, proportional to S^2.
S**		$S^{**} = \left(\frac{S-5}{10}\right)^2$	nonlinear shear factor (if $S \leqslant 5$, $S^{**} = 0$)
D*	modified divergence	$D^* = D\left(2.25 - \frac{\lvert 2.5-T \rvert}{2.0}\right)$	D, nonlinearly weighted by T, with greatest weight at T2.5.
D**		$D^{**} = D\left(2.0 - \frac{\lvert 2.0-T \rvert}{2.0}\right)$	D, nonlinearly weighted by T, with greatest weight at T2.0.
q*	modified vorticity	$q^* = q(3.0 - \lvert 3.0-T \rvert)$ (if $T \geqslant 6$, $q^* = 0$)	q, nonlinearly weighted by T, with greatest weight at T3.0.
q**		$q^{**} = q\left(2.0 - \frac{\lvert 2.0-T \rvert}{2.0}\right)$	q, nonlinearly weighted by T, with greatest weight at T2.0.
MVA*	modified vorticity advection[13]	$\lvert MVA^* \rvert \leqslant \lvert (Q+1.0)(D+1.0) \rvert$	MVA, partially limited by the calculated values of D and Q.
$\overline{MVA^*}$		$\overline{MVA^*} = \frac{MVA^*_1 + MVA^*_2 + 2MVA^*}{4}$	binomially weighted mean value of MVA*.
MVA**		$MVA^{**} = MVA^*\left(1 - \frac{10}{L}\right)$ (if $L \leqslant 10$, $MVA^{**} = 0$)	MVA*, further modified by a latitude factor that gives greater weight at higher latitudes and zero weight at $L \leqslant 10$.
$\overline{MVA^{**}}$		$\overline{MVA^{**}} = \frac{MVA^{**}_1 + MVA^{**}_2 + 2MVA^{**}}{4}$	binomially weighted mean value of MVA**.

[12] These variables are derived from their respective counterparts among the 8 basic variables and, similarly, are wholly or partially dependent upon the calculated analytical solutions for the high-level wind field.

[13] In the formulas for $\overline{MVA^*}$ and $\overline{MVA^{**}}$, the subscripts 1 and 2 denote calculations at the center of the grid and the centroid of the input data, respectively.

Table 15.--Means, standard deviations (σ), and individual correlation coefficients (r) for each of the 8 basic variables, for four degrees of polynomial solution (a, b, c, d), and for three groupings of classified cases. Individual correlation coefficients are with respect to $(\Delta MWS)_{24}$. Underlined coefficients are significant at the 99% level. (See table 12 for identification of basic variables.)

		303 classified cases (1968-1976)				212 classified cases (1977 only)				515 classified cases (1968-1977)			
		u	v	S	D	u	v	S	D	u	v	S	D
(a)	mean	1.8	1.2	15.4	1.2	4.9	1.1	17.2	0.9	3.1	1.1	16.1	1.1
	σ	15.4	10.1	9.3	1.0	16.0	11.8	9.2	0.8	15.7	10.8	9.3	0.9
	r	-.07	$\underline{-.19}$	-.11	$\underline{.33}$	-.10	$\underline{-.32}$	-.15	.08	-.09	$\underline{-.24}$	$\underline{-.14}$	$\underline{.26}$
(b)	mean	1.0	1.2	14.7	1.4	3.4	1.4	16.0	1.2	2.0	1.3	15.3	1.3
	σ	14.9	9.9	8.7	1.3	15.6	11.7	9.0	1.0	15.2	10.7	8.8	1.2
	r	-.06	$\underline{-.17}$	-.13	$\underline{.23}$	-.11	$\underline{-.35}$	$\underline{-.21}$	.10	-.09	$\underline{-.25}$	$\underline{-.17}$	$\underline{.20}$
(c)	mean	-0.4	2.1	15.2	1.4	0.2	2.3	15.9	1.2	-0.1	2.2	15.4	1.3
	σ	16.2	10.8	8.9	1.4	15.9	13.1	8.8	1.3	16.1	11.8	8.7	1.4
	r	-.05	$\underline{-.21}$	-.14	$\underline{.25}$	-.08	$\underline{-.29}$	$\underline{-.18}$	.13	-.07	$\underline{-.24}$	$\underline{-.16}$	$\underline{.22}$
(d)	mean	-1.3	3.0	14.6	2.0	-1.0	3.4	14.7	1.8	-1.2	3.2	14.7	1.9
	σ	16.3	10.8	8.9	1.9	15.5	12.6	8.7	1.9	16.0	11.5	8.8	1.9
	r	-.06	$\underline{-.18}$	$\underline{-.17}$	$\underline{.27}$	-.08	$\underline{-.28}$	-.14	.17	-.07	$\underline{-.22}$	$\underline{-.15}$	$\underline{.23}$
		q	Q	VA	MVA	q	Q	VA	MVA	q	Q	VA	MVA
(a)	mean	-1.6	3.6	-0.1	0.3	-1.9	2.9	-0.1	0.3	-1.7	3.3	-0.1	0.3
	σ	1.7	2.2	1.0	1.0	1.4	2.0	1.1	1.0	1.6	2.2	1.0	1.0
	r	$\underline{-.20}$	$\underline{-.23}$	$\underline{.18}$	$\underline{.21}$	-.02	-.02	$\underline{.32}$	$\underline{.28}$	$\underline{-.12}$	$\underline{-.13}$	$\underline{.24}$	$\underline{.24}$
(b)	mean	-1.6	3.6	0.3	0.7	-2.0	2.8	0.3	0.6	-1.7	3.3	0.3	0.6
	σ	1.8	2.4	1.7	1.8	1.3	2.0	1.5	1.4	1.6	2.3	1.6	1.7
	r	$\underline{-.23}$	$\underline{-.24}$	.03	.08	.01	-.01	$\underline{.17}$	$\underline{.22}$	$\underline{-.14}$	$\underline{-.14}$	.08	$\underline{.13}$
(c)	mean	-1.7	3.5	0.2	0.6	-2.0	2.8	0.4	0.6	-1.8	3.2	0.3	0.6
	σ	2.0	2.6	2.8	2.3	1.5	2.2	2.0	1.8	1.8	2.4	2.5	2.1
	r	$\underline{-.21}$	$\underline{-.23}$	-.02	.07	-.03	-.03	.02	.01	$\underline{-.14}$	$\underline{-.14}$	-.01	.05
(d)	mean	-1.5	3.6	-0.0	0.5	-1.8	3.0	0.4	0.6	-1.6	3.4	0.2	0.5
	σ	2.7	3.1	3.7	3.0	2.0	2.6	3.3	2.6	2.4	2.9	3.6	2.9
	r	$\underline{-.23}$	$\underline{-.25}$	-.04	.01	-.08	-.07	.08	.07	$\underline{-.17}$	$\underline{-.17}$	-.00	.03

Table 16.--Means, standard deviations (σ), and individual correlation coefficients (r) for each of 4 auxiliary variables not dependent upon the calculated high-level wind field, for three groupings of classified cases. Individual correlation coefficients are with respect to $(\Delta MWS)_{24}$; each is highly significant. For each grouping of classified cases, the variables FI-CI, L**, and SST* all contribute to the best overall multiple correlation with $(\Delta MWS)_{24}$. (See table 13 for identification of auxiliary variables.)

	303 classified cases (1968-1976)				212 classified cases (1977 only)				515 classified cases (1968-1977)			
	FI-CI	L**	SST	SST*	FI-CI	L**	SST	SST*	FI-CI	L**	SST	SST*
mean	7.95	-1.3	27.4	0.5	5.15	-2.0	26.4	-0.4	6.80	-1.6	27.0	0.1
σ	14.0	3.7	1.6	2.2	11.6	5.6	1.8	2.2	13.2	4.6	1.8	2.2
r	.66	.45	.45	.52	.58	.47	.41	.46	.64	.45	.44	.51

Table 17.--Means, standard deviations (σ), and individual correlation coefficients (r) for each of 8 derived variables, for four degrees of polynomial solution (a, b, c, d), and for three groupings of classified cases. Individual correlation coefficients are with respect to $(\Delta MWS)_{24}$. Underlined coefficients are significant at the 99% level. Within each grouping of classified cases, rectangles indicate variables contributing to the best multiple correlation with $(\Delta MWS)_{24}$. (See table 14 for identification of derived variables.)

		303 classified cases (1968-1976)				212 classified cases (1977 only)				515 classified cases (1968-1977)			
		S*	S**	D*	D**	S*	S**	D*	D**	S*	S**	D*	D**
(a)	mean	3.2	1.9	2.1	1.7	3.8	2.3	1.6	1.4	3.5	2.1	1.9	1.6
	σ	4.1	3.2	1.9	1.6	3.6	2.8	1.5	1.4	3.9	3.0	1.7	1.5
	r	-.13	-.14	.37	.35	-.17	-.17	.12	.16	-.15	-.16	.30	.29
(b)	mean	2.9	1.7	2.3	1.8	3.4	2.0	2.1	1.9	3.1	1.8	2.2	1.8
	σ	3.7	2.9	2.3	1.9	3.5	2.6	1.9	1.7	3.6	2.8	2.1	1.8
	r	-.15	-.15	.28	.28	-.23	-.23	.14	.17	-.19	-.19	.23	.23
(c)	mean	3.0	1.8	2.4	1.9	3.3	1.9	2.1	1.9	3.1	1.8	2.3	1.9
	σ	3.6	2.8	2.5	2.2	3.6	2.8	2.3	2.1	3.6	2.8	2.4	2.1
	r	-.16	-.17	.29	.27	-.20	-.21	.17	.17	-.18	-.18	.25	.23
(d)	mean	2.9	1.7	3.3	2.7	2.9	1.7	3.2	2.8	2.9	1.7	3.3	2.8
	σ	3.7	2.9	3.4	2.9	3.5	2.7	3.4	3.1	3.6	2.8	3.4	3.0
	r	-.19	-.20	.32	.30	-.15	-.15	.19	.19	-.18	-.18	.27	.25
		q*	q**	MVA*	MVA**	q*	q**	MVA*	MVA**	q*	q**	MVA*	MVA**
(a)	mean	-2.7	-2.1	0.3	0.2	-3.6	-3.0	0.3	0.1	-3.1	-2.5	0.3	0.1
	σ	3.6	2.5	1.0	0.6	3.1	2.3	1.0	0.6	3.4	2.4	1.0	0.6
	r	-.32	-.28	.22	.20	-.03	-.06	.28	.32	-.19	-.17	.24	.25
(b)	mean	-2.6	-2.1	0.7	0.5	-3.7	-3.2	0.6	0.4	-3.1	-2.5	0.7	0.4
	σ	3.8	2.6	1.8	1.4	3.1	2.3	1.4	1.0	3.6	2.5	1.6	1.2
	r	-.33	-.28	.10	.07	-.01	-.06	.22	.20	-.19	-.17	.14	.12
(c)	mean	-2.8	-2.2	0.7	0.5	-3.9	-3.3	0.6	0.4	-3.2	-2.7	0.6	0.4
	σ	4.5	3.0	2.2	2.3	3.4	2.6	1.7	1.3	4.1	2.9	2.0	1.6
	r	-.30	-.26	.08	.03	-.03	-.09	.01	.01	-.19	-.17	.06	.03
(d)	mean	-2.5	-2.2	0.5	0.4	-3.4	-3.0	0.6	0.4	-2.9	-2.5	0.5	0.4
	σ	5.8	3.9	2.8	2.1	4.2	3.5	2.5	1.8	5.3	3.8	2.6	2.0
	r	-.28	-.24	.03	-.00	-.11	-.12	.08	.07	-.21	-.18	.04	.02

Appendix 3. COMPARISONS OF FORECASTS FROM FI-CI, EQUATION (3), AND PERSISTENCE FOR FOUR CATEGORIES OF T-NUMBER

Significant differences exist between the performances of the three predictors, FI-CI, eq. (3), and persistence, when the results are stratified by disturbance intensity. Most noticeable is the large positive bias exhibited by FI-CI in strong storms and hurricanes, in contrast to the near-zero bias of that predictor in weak storms and disturbances. This and other findings are presented in this appendix.

Cases are separated into four categories of T-number: 0.5 to 1.5, 2.0 to 3.0, 3.5 to 4.5, and 5.0 or more. Although the T-number classification does not always translate directly into intensity, the relation is close. Therefore, the four respective categories correspond roughly to: (1) weak disturbances, (2) weak storms, (3) strong storms and minimal hurricanes, and (4) strong hurricanes. Those four categories, in ascending order, are the abscissa scale of all figures in this appendix.

Figure 8 shows the average 24-hr change in MWS for the observed verification ($(\Delta MWS)_{24}$ -- heavy dotted line) as well as for the three predictors. The performance of each predictor may be assessed by comparison with the observed. Because there are more intensifying than weakening cases, the observed $(\Delta MWS)_{24}$ is positive for all four T-number categories, and especially so for the category 2.0 to 3.0.

In figure 8, it is seen that the performance of both FI-CI and eq. (3) is very good for the lower two categories, far outshining persistence. However, the same is not true for the higher categories, where FI-CI has a large positive bias, and eq. (3) has a smaller but still positive bias. In the highest category (5.0 or more), persistence is better than either FI-CI or eq. (3)!

Figure 9 is a comparison of average absolute errors. In this, both FI-CI and eq. (3) are better than persistence in all categories, but the improvement is greatest for the category 2.0 to 3.0. As in figure 8, the performances of FI-CI and eq. (3) are nearly the same for the lower two categories, with eq. (3) becoming somewhat better than FI-CI for T-numbers 3.5 and up.

The question naturally arises as to the cause of the positive bias in FI-CI for higher intensity storms. Because figures 8 and 9 are based on all 515 classified cases, it seemed desirable to make separate tests on (a) the 303 cases of 1968-76 vs. the 212 cases of 1977, and (b) developing cases vs. steady or weakening cases, to see if differences exist.

Figure 10 shows the algebraic mean error of FI-CI for three groupings of classified cases: the 303 cases of 1968-76, the 212 cases of 1977, and all 515 cases. The overall positive bias is even larger for the 1977 sample

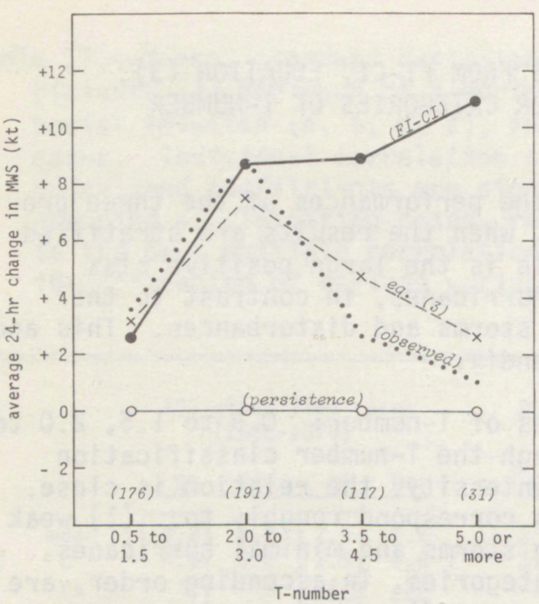

Figure 8.--Average 24-hr change in MWS, as a function of T-number, for 3 forecast methods: (a) persistence, (b) the operational picture-classification technique (FI-CI), and (c) equation (3). The average observed 24-hr change also is shown (dotted line). From 515 classified cases for 1968-1977. Numbers of cases for each T-number grouping are shown in parentheses.

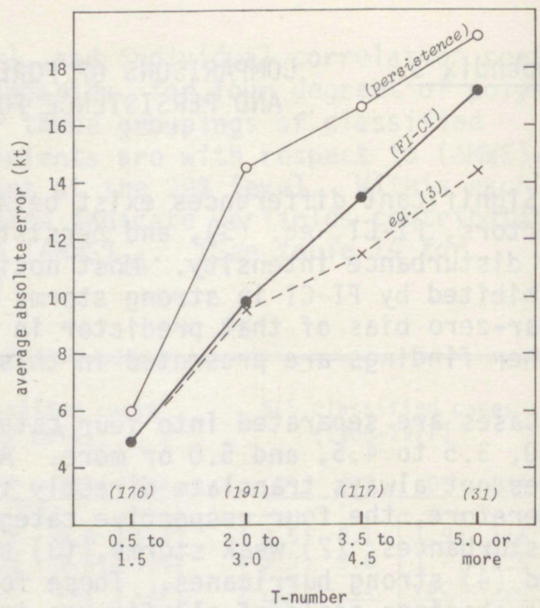

Figure 9.--Average absolute error, as a function of T-number, for 3 methods of prediction of the 24-hr change in MWS. From 515 classified cases for 1968-1977. Numbers of cases for each T-number grouping are shown in parentheses.

than it is for the earlier sample, but because 1977 was an abnormal year, that may not be significant. What does seem significant is the fact that the generally larger bias at the higher T-numbers occurs for both groups.

Finally, figure 11 is again the algebraic mean error, this time subdivided into developing cases and steady or weakening cases. The graph for all cases together also is shown, and is the same as in figure 10. The positive bias is much larger for developing cases than for steady or weakening cases. Thus, the positive bias problem seems to be concentrated in strong storms and hurricanes that are still developing at the time of their latest classification. For these, the forecast change, FI-CI, seems frequently unable to identify or predict early weakening trends. After weakening has been established, the performance is much better.

Relative to the above conclusion, the reader should keep the following items in mind as possible contributing factors:

(1) the feedback of satellite picture classifications into the verification,

(2) that this study includes only those cases where sufficient high-level vectors exist. (This may have introduced a bias; many other strong storms exist without sufficient vectors.)

(3) that the classification scale is nonlinear in MWS, favoring larger errors at larger values of CI and FI.

The classification system has been modified in recent years to permit earlier trend reversals. This may have reduced the positive bias, but seems not to have eliminated it.

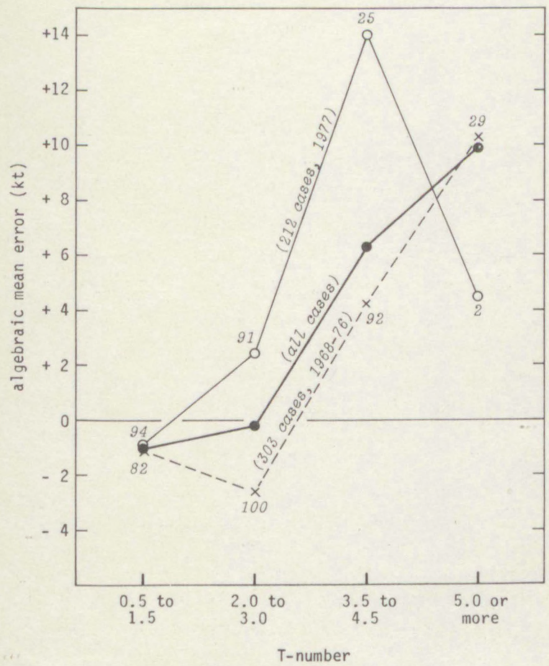

Figure 10.--Algebraic mean error (bias) of FI-CI, as a function of T-number, for three groupings of classified cases. Numbers of cases for each T-number grouping are shown on graph.

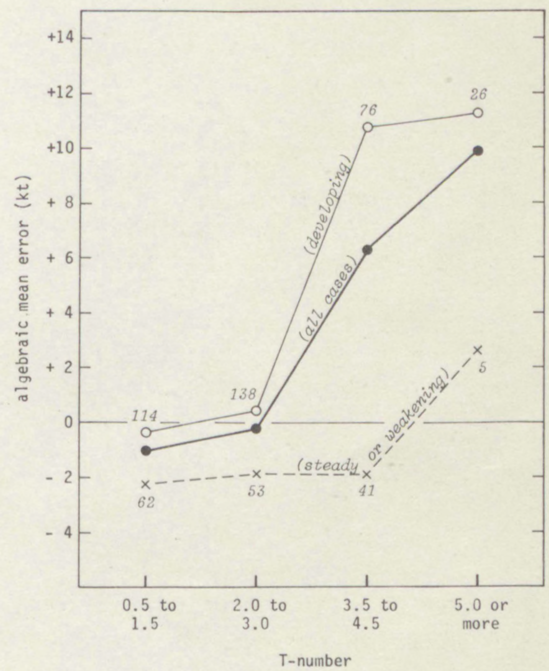

Figure 11.--Algebraic mean error (bias) of FI-CI, as a function of T-number, for "developing" cases, "steady or weakening" cases, and for all cases together (515 classified cases for 1968-1977). Numbers of cases for each T-number grouping are shown on graph.

(Continued from inside front cover)

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