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A SATELLITE CLASSIFICATION TECHNIQUE FOR SUBTROPICAL CYCLONES

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ABSTRACT: The Dvorak (1973) technique for estimating the intensity of tropical (T) cyclones from satellite pictures is frequently inapplicable for subtropical (ST) cyclones. A new technique which gives not only the intensity but also the type (tropical, subtropical) of cyclone has been derived, using guidelines similar to the Dvorak scheme, so that the two systems will intermesh when cyclones change type. These guidelines were evaluated by Miami Satellite Field Services Station (SFSS) meteorologists for a data sample of 32 cases (27 subtropical) for the period May-November 1968-74. Results indicate mean absolute wind errors comparable to those using the Dvorak technique, as well as a successful meshing of the two techniques, and the ability to distinguish between the two types of cyclones.

INTRODUCTION: The existence of subtropical cyclones under various nomenclature - "Kona" (Simpson, 1952), "hybrid" (Gray, 1968), and "semitropical" (Spiegler, 1972) - has long been recognized by tropical meteorologists. Except for the Kona storm, it was not until the advent of the weather satellites, especially the geostationary ones, that some idea of the frequency, life cycle, and wind field structure of these systems was deduced.

In an attempt to better define the surface wind field and take into account the relatively short life span of these subtropical cyclones, the National Hurricane Center (NHC) in 1972 began issuing marine/military bulletins and

24-hour forecasts on these systems rather than assigning them a tropical cyclone name and issuing more extended forecasts. After two seasons, the inapplicability of the Dvorak technique together with the lack of aircraft reconnaissance into many of these systems generated a tasked requirement at the 1973 National Oceanic and Atmospheric Administration (NOAA) hurricane conference for this study. A paper presented by Simpson (1973) at the Eighth Technical Conference on Hurricanes and Tropical Meteorology of the American Meteorological Society dealt with the energetics and developmental cycle of these systems. Hebert (1973) includes a description of the wind field structure and other information on various aspects of these cyclones.

The goals of this study were to use cloud features associated with subtropical cyclones in order to: 1.) be able to distinguish subtropical cyclones from tropical cyclones in the formative (less than gale strength) stages; 2.) be able to estimate the intensity of subtropical cyclones; 3.) have criteria which would intermesh with the Dvorak technique when systems become tropical.

DATA PROCESSING: The final data set was obtained as follows: Satellite meteorologists examined digitized mosaics for the period May-November 1968-74 for <u>all</u> cloud systems poleward of latitude 20^{0} North which gave any indication of a possible circulation center. The NHC meteorologist examined the surface analyses for the same period (without any supporting satellite pictures) for <u>all</u> low pressure systems poleward of 20^{0} North. In addition to plotted ship and reconnaissance reports, many valuable ship reports were obtained from Northern Hemisphere Data tabulations, and from NHC files, ship report sequences in daily weather packets, and some reconnaissance reports. These two data sets were then meshed for those cyclones whose winds reached gale force prior to their becoming tropical. In no case was the maximum dense overcast originally associated with a tropical system.

A total of 32 case histories were obtained for the seven year period. Of this total, five were eventually deemed extratropical, while nine of the remaining twenty-seven subtropical systems eventually became tropical. Twelve 1968-69 cases were obtained from Automatic Picture Transmission (APT) composites (ESSA 6, ESSA 8). The remaining twenty were examined with full-disc Applications Technology Satellite 3 (ATS-3) pictures. The cases were divided into those of high-level (cold low) or low-level baroclinic origins with the latter further subdivided into frontal waves and systems originating east of upper troughs but not on a front.

CLIMATOLOGY OF SUBTROPICAL STORMS: Figure 1 shows the tracks of the twenty-seven subtropical cyclones used to derive the subtropical cyclone criteria. Tropical and extratropical portions of some of these tracks are not complete. Table 1 lists the cyclones by number as indicated on the tracks together with the dates of occurrence, origin, and estimated maximum sustained wind and lowest sea level pressure during the subtropical phase. Note that the initial low-level center location was between 20^{o}-40^{o} North in all but two cases, and that the predominant motion was eastward.

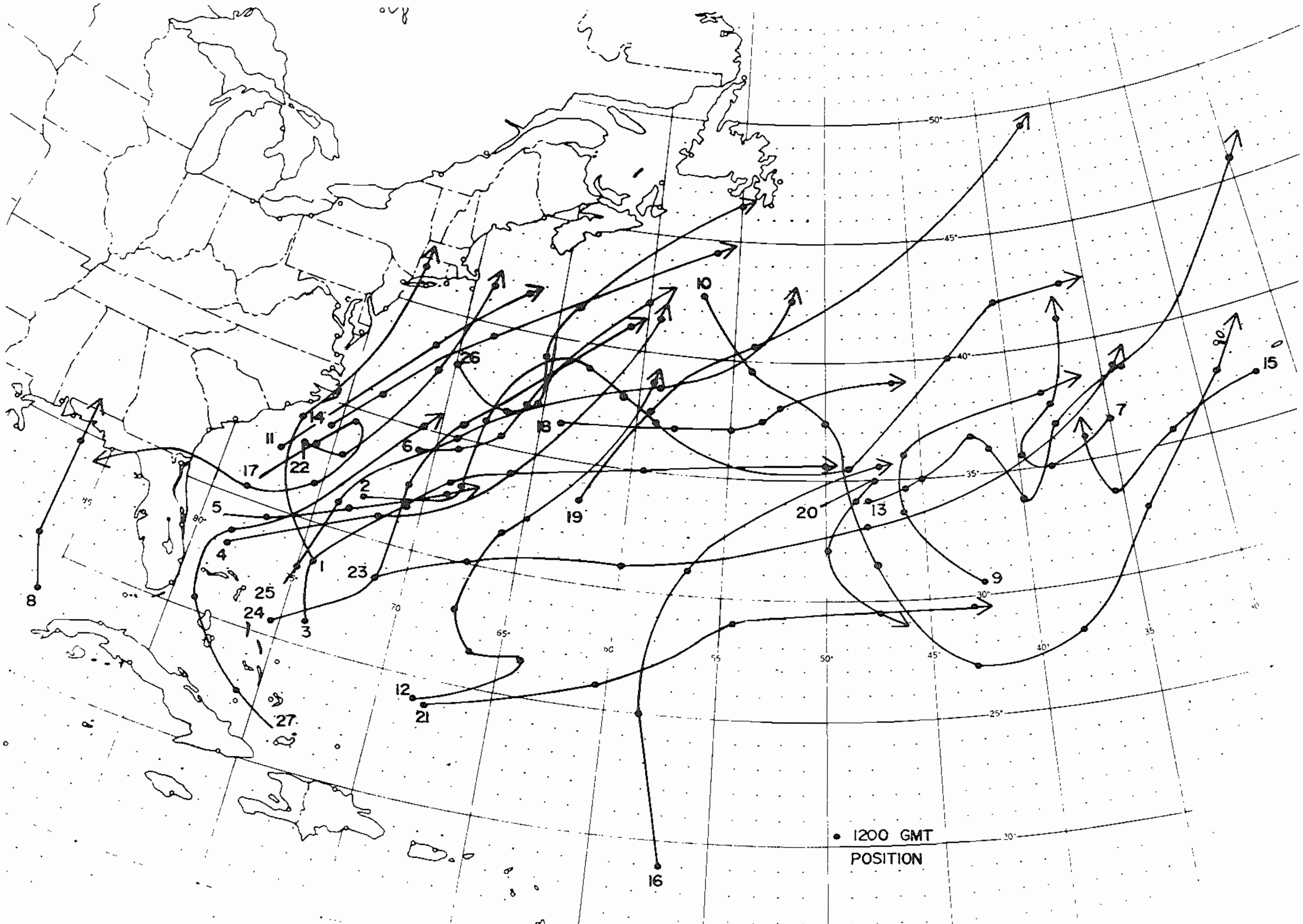

FIGURE 1. SUBTROPICAL STORMS 1968-1974.

NO.	DATE	ORIGIN	MAXIMUM SUSTAINED WIND (KNOTS)	MINIMUM SEA LEVEL PRESSURE (MILLIBARS)
1	9/ 9-11/68	B-2	50	1000
2	9/14-23/68	B-1	70	980
3	9/23-29/68	B-2	50	1001
4	6/16-19/69	B-2	40	1000
5	8/24-27/69	B-1	50	999
6	9/21-25/69	B-1	50	995
7	9/24-28/69	A	35	1005
8	9/29-10/1/69	B-2	50	996
9	10/28-31/69	B-1	50	995
10	10/30-11/6/69	A	60	992
11	8/10-12/70	B-2	45	995
12	10/12-17/70	B-2	60	991
13	10/20-28/70	B-1	60	992
14	7/ 4- 7/71	B-1	35	1005
15	9/16-19/71	B-1	40	1001
16	10/17-20/71	B-2	50	997
17	5/23-28/72	B-2	60	1001
18	8/22-27/72	B-1	60	992
19	9/18-21/72	B-1	60	990
20	11/ 1- 4/72	A	40	998
21	5/ 2- 6/73	B-2	35	1005
22	7/29-8/1/73	B-2	40	1005
23	10/ 7-11/73	B-2	75	995
24	10/23-27/73	B-2	50	985
25	7/14-19/74	B-1	45	1005
26	8/ 9-15/74	B-1	50	992
27	10/ 4- 8/74	B-1	45	1005

Table 1. Dates, origins (see page 6 for definition), estimated maximum winds (knots) and minimum sea level pressures (millibars) of subtropical storms shown in figure 1.

Figure 2 shows the initial center locations by month of genesis with the numbers 5 through 11 representing the months May through November, respectively. Nearly all developments from May through August were near the Gulf Stream, while later in the year they were farther out in the ocean. The preferred regions of development are quite obvious. Figure 3 illustrates the geographical variation of the type of origin of the systems, A-cold low, B1-frontal wave, B2-east of upper troughs but not a frontal wave. The cold lows all formed at or north of 35^{0} North, and usually had winds of gale force less than 12 hours after the surface low center formed.[1] Most frontal wave systems developed north of 30^{0} North, while systems east of upper troughs formed south of 30^{0} North except for three near the Gulf Stream. Occasionally, a system of low-level origin acquired the wind field structure of a cold low, but the reverse rarely occurred.

CLASSIFICATION CRITERIA FOR DETERMINING TYPE, ORIGIN, AND INTENSITY OF CYCLONES:

The following criteria as shown in Table 2 were evaluated by National Environmental Satellite Service (NESS) meteorologists at Miami for validity. These criteria were derived by the authors after repeated inspections of the 32 cases for cloud features which would meet the goals stated in the Introduction. Except for the distinguishing characteristics of low-level origins from satellite pictures, and minor changes in wording

[1] These cold lows are quite different from the type which bore down into the middle of the subtropical ridge east through south of Bermuda during mid-summer. This latter type usually begins with a weak surface low pressure center and limited convection, and if intensification occurs, it does so over a period of several days with the system becoming tropical (warm core) by the time winds reach gale strength.

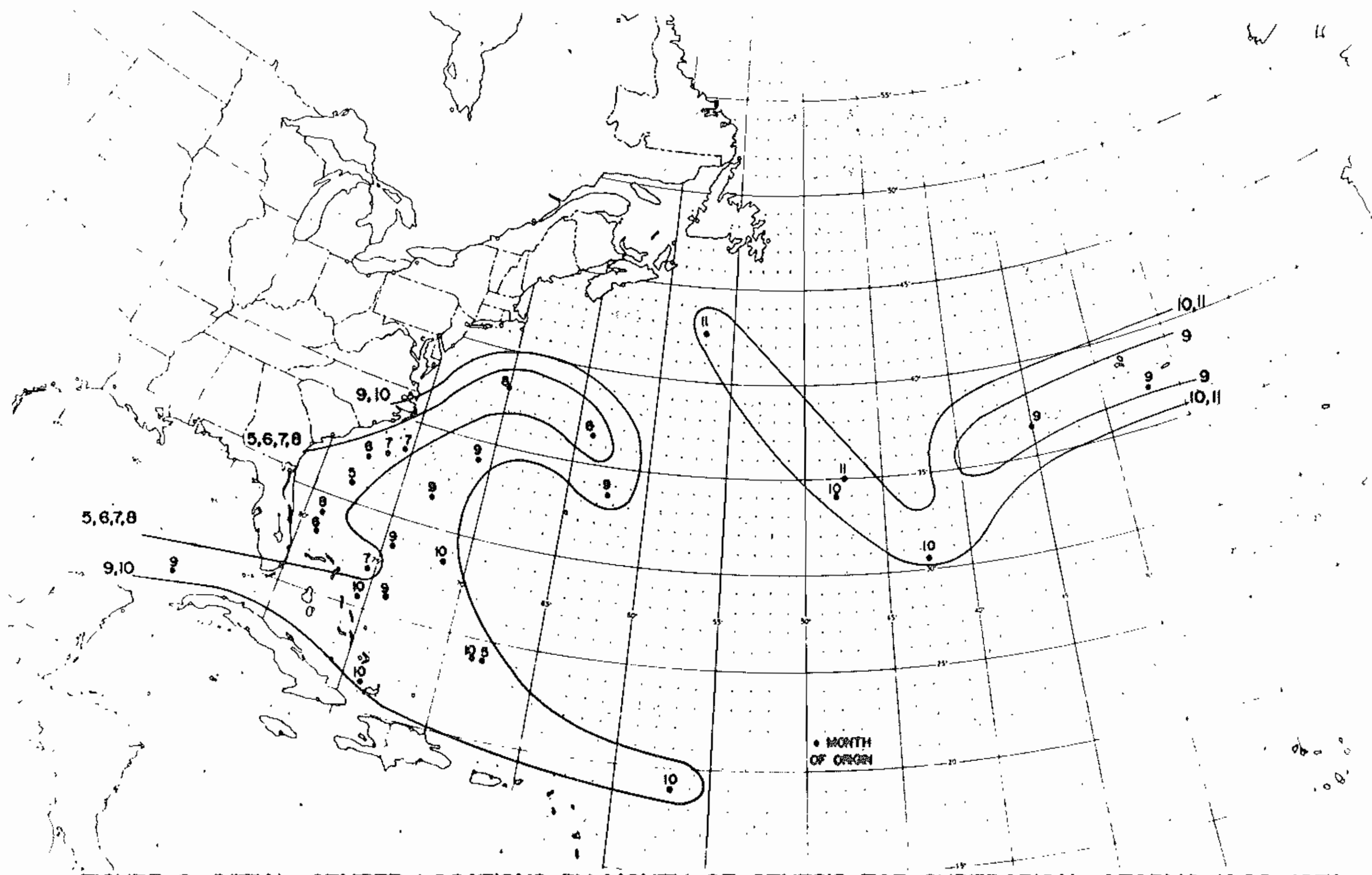

FIGURE 2. INITIAL CENTER LOCATIONS BY MONTH OF GENESIS FOR SUBTROPICAL STORMS 1968-1974.

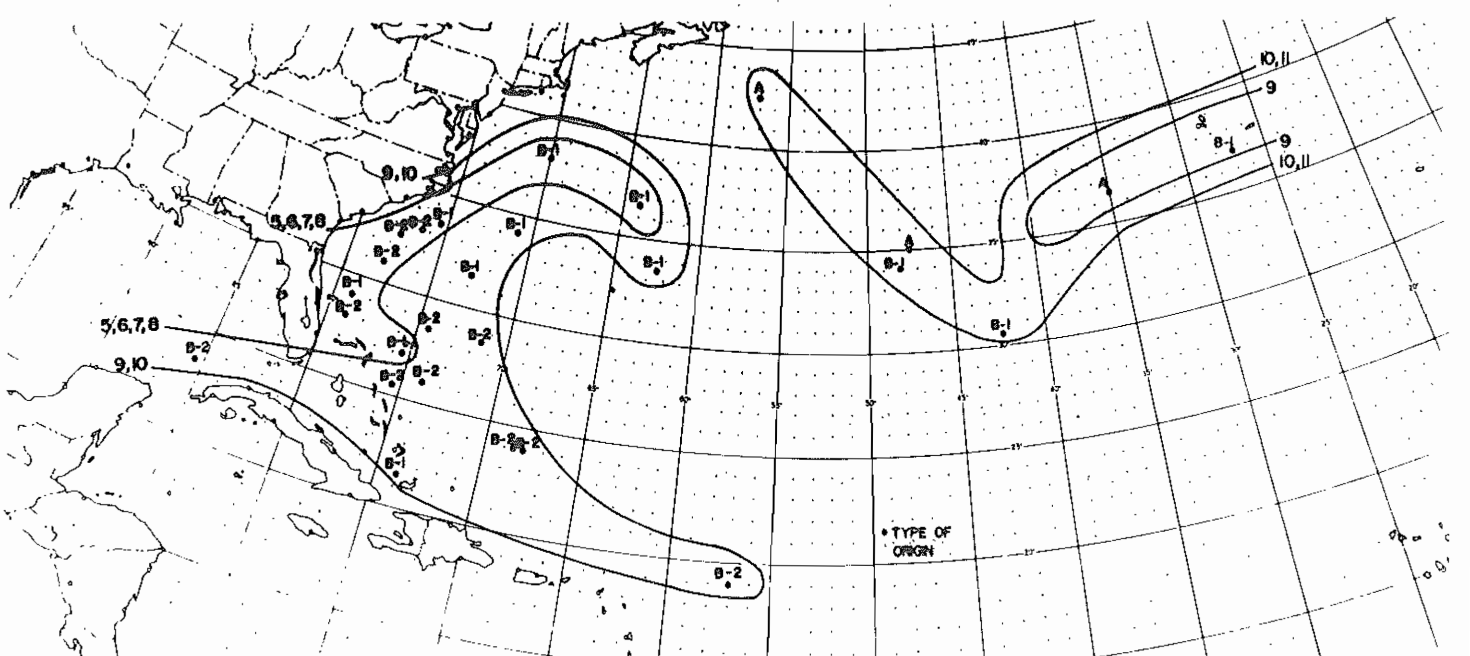

FIGURE 3. SAME AS FIGURE 2 WITH TYPE OF ORIGIN REPLACING MONTH OF GENESIS.

for the wind speed criteria estimates, these are basically the criteria originally given and verified in the evaluation results.

A. DETERMINING TYPE

	SUBTROPICAL	TROPICAL
1. Main convection	Poleward & eastward from center	Equatorward & eastward from center
2. Cloud system size	Width 15^{o} latitude or more	Width usually less than 10^{o} latitude
3. Interaction with environment	Convective cloud system remains connected to other synoptic systems (Some cold lows excepted)	Cloud system becomes isolated

B. DETERMINING ORIGIN

1. Frontal band - typical cloud structure
2. East of upper trough - amorphous convective cloud mass
3. Cold low - circular cloud pattern with limited convection near center

Table 2. Guidelines for determining type of cyclone, origin of subtropical cyclones, and estimating intensity of subtropical cyclones (subtropical cyclone criteria evaluated by analysts).

C. ESTIMATING INTENSITY

1. ST 1.5 (25-30 knots)

a.) Low level circulation center $\geq 1/2^{\circ} \leq 2^{\circ}$ latitude from poorly organized convection (not necessarily dense).

For cold lows convection may not be connected to other systems and a small area ($< 3^{\circ}$ latitude) of deep layer convection exists near the center.

2. ST 2.5 (35-40 knots)

a.) Low level circulation center $\geq 1/2^{\circ} \leq 2^{\circ}$ latitude from increased deep layer convection with greater curvature than previous day (not necessarily dense).

b.) Outer convective band 5°-10° of latitude east of the center and possibly another convective band 2°-4° west-north of center.

3. ST 3.0 (45-50 knots)

a.) Same criteria as (2) except greater curvature and better organized convection than previous day. Overcast may become dense.

b.) Evidence of banding near the center ($< 1^{\circ}$ latitude).

4. ST 3.5 (55-65 knots)

a.) Deep layer convection (frequently dense overcast) in band(s) 1°-3° latitude from the center (no central dense overcast).

b.) Outer convective band 5°-10° latitude to the east weaker than previous day, but new band may form 5°-10° latitude to the west.

c.) For systems moving rapidly eastward there may be only a dense overcast ($\geq 3^{\circ}$ latitude) about 2°-4° east of the center.

Note: In (3) and (4) if the forward speed of the system at picture (classification) time exceeds 20 knots, the excess should be added to the maximum wind speed obtained by cloud feature criteria.

Table 2 continued.

Table 3 compares the similarities and differences of the Dvorak technique with the subtropical cyclone classification technique. Some of the differences which made the Dvorak system inapplicable in the case of subtropical cyclones were the requirements for the extent of dense overcast $\geq 3^{o}$ latitude accompanied by spiral bands. Another important difference is the consideration of rapid translational speed-not a factor in most tropical cyclone wind speed estimates. Wind speed ranges were used to deduce ST numbers because the data did not allow any further refinement.

SIMILARITIES

1.) Use convective overcast.

2.) Use distance of the circulation center from overcast.

3.) ST number features selected to correspond to observed current intensity (C.I.) numbers so that ST numbers merge to Dvorak's T numbers when systems become tropical.

DIFFERENCES

1.) Considers environment in determining type.

2.) Cannot have center under central dense overcast.

3.) Translational speed excess above 20 knots added to cloud feature wind estimate.

4.) Does not require dense overcast.

5.) Does not require bands.

6.) Uses curvature of convective features for all ST numbers in the absence of bands.

7.) Intensity estimates (ST numbers) are for wind speed ranges.

Table 3. Similarities and differences between the Dvorak technique for tropical cyclones and the subtropical cyclone technique.

EXAMPLES OF SUBTROPICAL CYCLONE ST NUMBERS AND DEVELOPMENT SEQUENCES: Figure 4 gives a schematic representation of the ST numbers which were derived primarily from the examples shown in Figure 5. As in the Dvorak technique, any system with a given ST number can evolve into any other, although certain sequences are preferred. Figure 6 shows the developmental cycle of five of the subtropical storms on a day-by-day sequence from left to right. The ST or T number[2] (actually, current intensity (C.I.) number) is indicated in the lower left hand corner of each picture. Example five is an illustration of the effect of excessive translational speed. The analyst's original guideline was to add the past 24 hour motion in excess of 20 knots to the estimate obtained from cloud features. Allowing for the added 10 knots forward speed obtained by using the final guideline of the present (picture time) motion, estimates as high as 65 knots were obtained using the subtropical cyclone technique while one estimate of 25 knots from cloud features alone was made using the Dvorak technique. Reconnaissance aircraft reported 75 knots from the west at picture time!

Another illustration of the difficulty of handling these systems operationally in the past is that the first four examples in Figure 6 became tropical with winds at or exceeding hurricane force, while according to the subtropical cyclone technique the fifth example never acquired tropical characteristics. The first four were never given a tropical cyclone name, while the fifth one was!

[2] T numbers used in this study were those in use during 1974

FIGURE 4. SCHEMATICS OF ST NUMBER PATTERNS

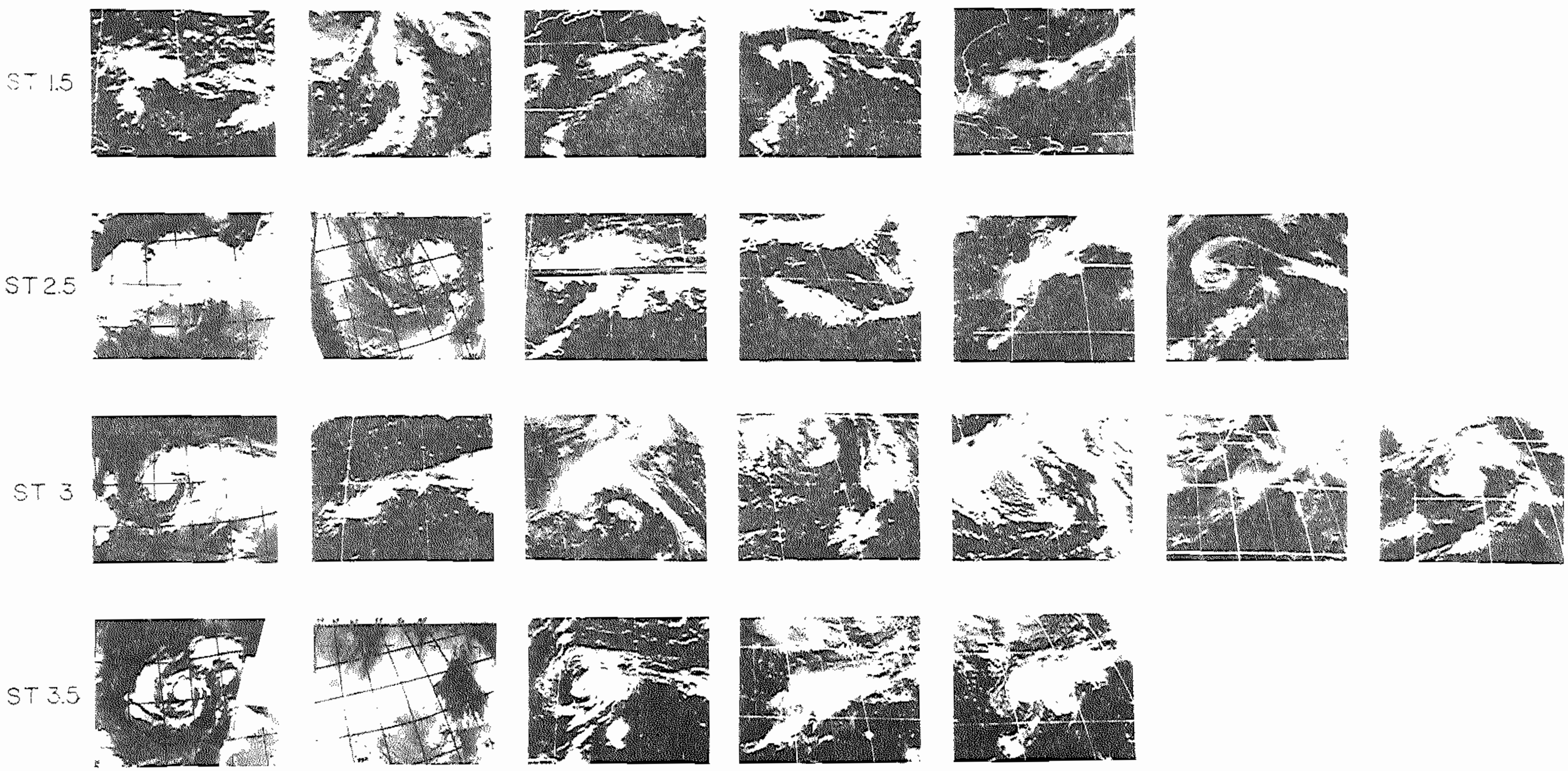

FIGURE 5. EXAMPLES OF ST NUMBER PATTERNS.

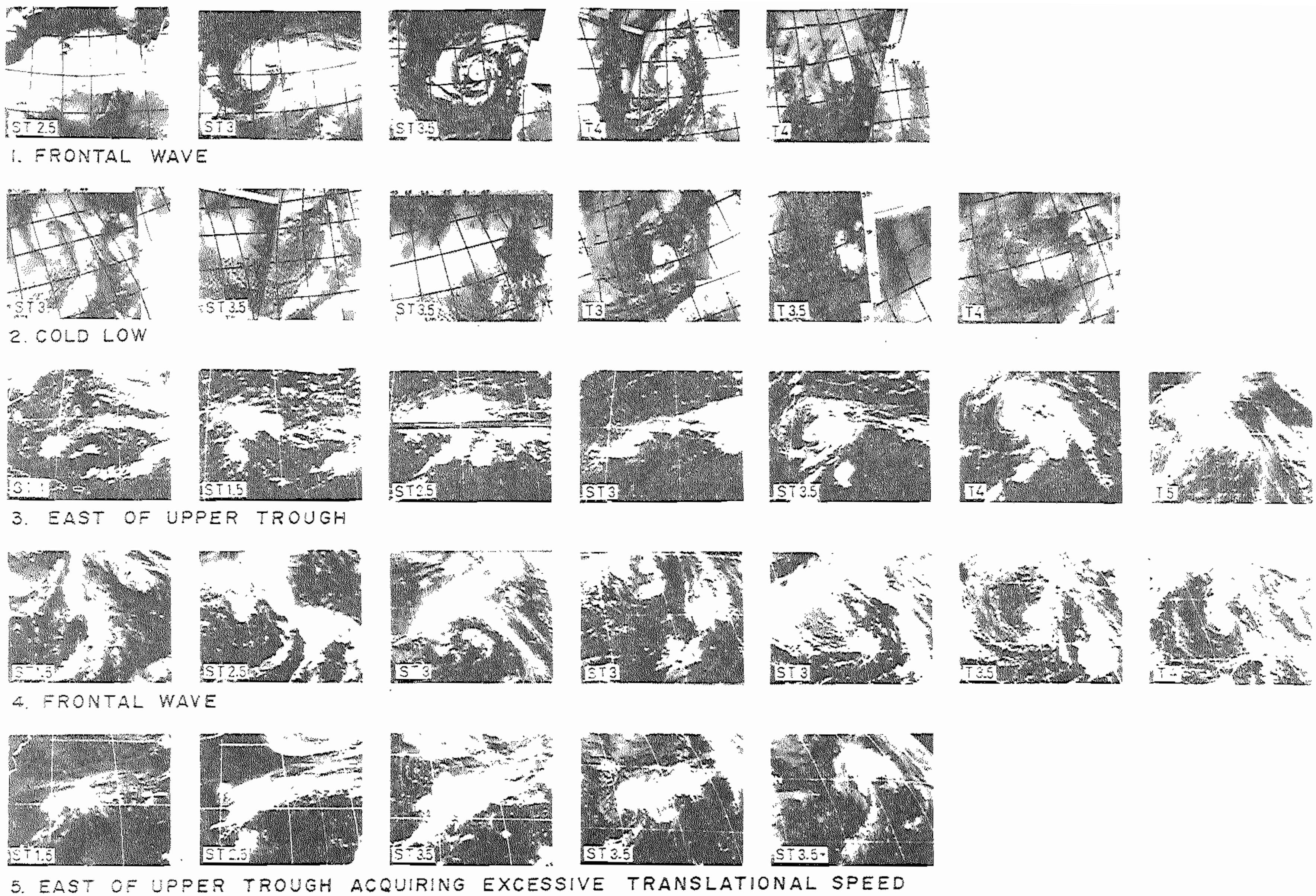

FIGURE 6 EXAMPLES OF SUBTROPICAL CYCLONE DEVELOPMENT

Obviously, these examples do not cover all of the configurations which subtropical cyclones can take for various intensities (ST numbers). One type of development which cannot be readily discerned by satellite pictures occurred in the Gulf of Mexico in June of 1974. There was little evidence of a circulation within a broad, dense band of convection, yet a 1000 mb low with winds of 45-55 knots moved across Florida. In two other cases with the same wind speeds the circulation center was barely discernible.

RESULTS OF EVALUATION OF SUBTROPICAL CYCLONE CLASSIFICATION CRITERIA BY SFSS ANALYSTS: Photographs of each case were given to analysts one at a time. After one day's classification was made, the next photograph (picture times approximately 24 hours apart) was made available. No restraints were imposed on intensity estimates (i.e., no development curve as in the Dvorak technique) other than the 24 hour trends in curvature, convection, and organization of the system.

A. CENTER LOCATION. Center location errors were only of secondary interest in this study, as it was felt the high resolution Geostationary Operational Environmental Satellite (GOES) pictures and movie loops will eliminate much of the difficulty experienced using APT and ATS-3 still pictures. However, since the criteria for intensity estimates included distance of the low level circulation center from the convection ($\geq 1/2^{o} \leq 2^{o}$ latitude), in order to correctly evaluate the criteria the center locations were verified by $1/2^{o}$ latitude increments. The analysts had been told to give center locations to the nearest $1/2^{o}$ of latitude because of the poor resolution and gridding errors of the data sample.

Table 4 gives an indication of the difficulty in locating centers. Table 5 reaffirms the increase in center location accuracy with increasing intensity as shown by Sheets and Grieman (1975), and almost all verification studies. The statistics include some tropical and a few extratropical centers, but would change little for only subtropical centers.

	Percent
Correct center ($\leq 2^{o}$ latitude from control)	75 (330)
No center when control had one	13 (56)
Incorrect system center ($>4^{o}$ from control)	5 (23)
Incorrect center ($>2^{o} \leq 4^{o}$ from control)	7 (29)
	(438)
Center when control had none	4 (21)
Control had 146 centers (x 3 analysts = 438 cases)	
Control had 171 pictures (x 3 analysts = 513 cases)	

Table 4. Center location difficulty expressed in differences from control centers. Figures in parentheses are the number of cases.

^{o}Lat	<35 knots		35-50 knots		>50 knots	
$0 \leq 1/2$	28.9%	53.6%	38.5%	67.9%	38.7%	77.4%
$>1/2 \leq 1$	24.7%		29.4%		38.7%	
$>1 \leq 2$	16.5%		19.8%		21.6%	
$>2 \leq 4$	13.4%	29.9%	8.0%	12.3%	1.0%	1.0%
>4	16.5%		4.3%		-	

Table 5. Center location errors in degrees of latitude (^{o}Lat) from control by cyclone strength for all cases (tropical, subtropical, extratropical).

B. ORIGIN/TYPE IDENTIFICATION. As indicated in the Data Processing section and the Introduction, the guidelines for evaluation attempted to discern between types of cyclones, and their origins. Because of a difference in interpretation between surface analyses (control) and satellite appearance (analysts), distinction between the two classes of low-level origin was poor. These guidelines have been revised to rely more on the satellite appearance. The attempt to distinguish between the two low-level origins was made because it was believed that frontal waves intensified and/or acquired tropical characteristics more rapidly than the other class. While there is some evidence in the data that this is true, the limited sample precludes a definite conclusion. However, systems of all three subtropical origins appear to have higher initial intensities than do tropical systems at the time of center formation.

Table 6 shows the results of this aspect of the evaluation. Since analysts were expecting subtropical cyclones, identification of extratropical systems was not too good. The goal of having the two techniques merge when subtropical cyclones become tropical was successfully met. Of ten systems initially designated tropical by control at some point in the developmental cycle all three analysts made correct calls within ± 1 day on the <u>same</u> <u>eight</u> <u>cases</u>! Of the other two tropical systems one was deemed not to be tropical in the post analysis, and the other became tropical just prior to moving inland (called by one analyst). Out of 146 total pictures with centers only 3 were designated tropical versus control's subtropical.

	Percent
Correct origin (A, B1, or B2)	52 (50)
Correct origin (either A or B)	78 (75)
Correct type (all cases)	88 (84)
Correct type (extratropical cases omitted)	98 (82)
Correct calls (± 1 day) on systems which became tropical	83 (25)
Incorrect calls naming subtropical systems tropical	5 (3)

Table 6. Correct determination of origin (cold low, frontal wave, east of upper trough) and type (tropical, subtropical, extratropical) of cyclones compared to control's initial evaluation. Figures in parentheses are the number of cases.

C. INTENSITY ESTIMATES. In addition to the primary goals of this study, a secondary goal was to eliminate a negative bias in maximum wind estimates which showed up consistently in verification statistics of the Dvorak technique. Also, although ST numbers are for ranges of wind speeds, the analysts were allowed to give actual wind speed estimates to the nearest five knots in order to evaluate the criteria for details.

While center locations and evaluation of origin/type were only done once, the three analysts (two inexperienced, one experienced) were asked to go through only the subtropical cyclone cases a second time, using the control center locations, revised origin/type designations, and only the subtropical cyclone classification criteria-again to evaluate the technique guidelines for details. This might be expected to bias the results the second time around, even though the analysts did not know the results of the first evaluation for individual pictures or cases. Therefore, another experienced analyst not associated with the first evaluation was given this same information.

Results of the intensity estimates are given in Table 7 in three ways: 1.) in terms of absolute mean error, standard deviation, and bias, in knots; 2.) in terms of deviations in knots from control estimates by 5 knot intervals (cumulative percentages); 3.) in terms of deviations in ST numbers from control estimates (cumulative percentages).

The top line of each determination is for all 32 cases (tropical, subtropical, extratropical) where the analysts could use either the Dvorak technique or the subtropical cyclone guidelines, depending on the applicability. One analyst tried to use the Dvorak technique all of the time, stretching the criteria, a second mostly the subtropical cyclone criteria, and the third about fifty-fifty of each. The second line is from the same sample for only subtropical cyclones with center locations within 2^{o} latitude of control (correct centers). The third line shows the results using the centers furnished by control. Numbers in parentheses are for the fourth (independent) analyst. The last line is a direct comparison for those subtropical cyclone cases where the analysts made two evaluations.

Absolute mean errors, standard deviations, and biases obtained using the subtropical cyclone technique are very similar to figures presented by Sheets and Grieman (1975) and Gaby et al (1975) for the Dvorak technique. The only significant difference is in the reduction of the negative bias to near zero.

		Absolute mean error	Standard deviation	Bias
All types (D/HP)		9.2	8.2	-4.1
Subtropical types-correct centers (D/HP)		8.9	7.9	-4.4
Subtropical types-correct centers (HP)		8.5 (8.0)	7.1 (6.8)	-0.2 (2.4)
Subtropical types-direct comparison (D/HP vs HP)	D/HP HP	8.4 8.8	7.5 6.9	-3.9 0.9

Table 7a. Comparison of intensity estimates in knots versus control estimates using combined Dvorak/Hebert-Poteat (D/HP) guidelines and Hebert-Poteat (HP) guidelines only. Figures in parentheses are for independent analyst-see text.

Deviations in knots		0	± 5	± 10	>± 10
		%	cum. %	cum. %	cum. %
All types (D/HP)		20	52	73	100
Subtropical types-correct centers (D/HP)		19	56	74	100
Subtropical types-correct centers (HP)		17 (20)	54 (58)	77 (78)	100 (100)
Subtropical types-direct comparison (D/HP vs HP)	D/HP HP	19 15	56 51	74 75	100 100

Table 7b. Same as 7a except expressed in deviations in knots from control estimates.

Deviations in ST numbers		0	± ½	± 1	>± 1
		%	cum. %	cum. %	cum. %
All types (D/HP)		44	61	89	100
Subtropical types-correct centers (D/HP)		43	63	88	100
Subtropical types-correct centers (HP)		43 (44)	65 (71)	92 (90)	100 (100)
Subtropical types-direct comparison	D/HP HP	45 40	62 68	88 93	100 100

Table 7c. Same as 7a except expressed in deviations in ST numbers from control estimates.

Parts b and c of Table 7 show similar results for the two techniques when errors are presented in terms of deviations in knots and ST numbers. The only significant difference in these two parts is found in the last line of part c. Analysts were able to get higher percentages of the cases within 1/2 and 1 ST number using the subtropical cyclone criteria even though they showed no appreciable improvement in actual wind estimates. Although not presented here, the absolute range of errors in wind estimates was 70 knots, comparable to those observed using the Dvorak technique. The error range of ST numbers was two - the maximum possible in this technique.

CONCLUSIONS AND RECOMMENDATIONS. This initial attempt at classifying subtropical cyclones appears to have met the designated goals. While having the advantage of the Dvorak criteria as a starting point, the limited sample, picture quality, and lack of supporting "ground truth" (i.e., aerial reconnaissance, land stations, ships in the center) in many of the cases allows for much refinement of this technique. Operational use of the technique during the next few years together with the much higher resolution GOES data should result in more specific criteria.

This technique was developed for the North Atlantic. The basic features of this technique <u>may</u> be applicable to other tropical regions. As with all studies about tropical and subtropical weather, however, the relationship between the basic cloud features and observed winds and pressures <u>for those specific areas should be determined from the regional data</u>.

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