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AN OBJECTIVE METHOD FOR FORECASTING TROPICAL CYCLONE INTENSITY AND MOTION USING NIMBUS-5 ESMR MEASUREMENTS AND NON-SATELLITE DERIVED DISCRIPTORS

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An empirical analysis program, based on finding an optimal representation of the data, has been applied to 120 observations of 29 1973 and 1974 North Pacific tropical cyclones. Each observation consists of a field of Nimbus-5 Electrically Scanning Microwave Radiometer radiation measurements at 267 grid points covering and surrounding the tropical cyclone plus nine other non-satellite derived discriptors. Forecast algorithms to estimate storm intensity and motion at 12, 24, 48, and 72 hours after each observation have been developed using an independent eigen screening analysis. These algorithms were based on best track data. Independent testing of these algorithms showed that the performance of most of these algorithms were better than persistence and the algorithms forecasting 24, 48, and 72 hour maximum wind speed were better than those made operationally by the Joint Typhoon Warning Center for 1973 and 1974 that did not use best track data.

INTRODUCTION

The release of latent heat (LHR) through condensation and precipitation processes is essential to the development and maintenance of tropical cyclones. With the advent of the Nimbus-5 Electrically Scanning Microwave Radiometer (ESMR-5), it has been possible to remotely measure tropical cyclone rainfall characteristics (i.e. LHR, maximum rainfall rate, rainfall rate distribution) and to relate these to storm intensity (Adler and Rodgers, 1977). To more thoroughly examine this relationship and to see whether there also exists a relationship between ESMR-5 derived tropical cyclone rainfall characteristics and storm motion, an empirical analysis method developed by the ADAPT Corporation was used to relate the ESMR-5 derived tropical cyclone rainfall characteristics to both storm intensity and movement.

ADAPT APPROACH

The general concept of the ADAPT approach is to take the data from the original high dimensional data space and transform it to a lower dimensional optimal analysis space. This is accomplished by applying a conventional transformation (i.e. Karhunen-Loeve, Eigenvector, or Principal Component) on a large number of data vectors such as those found from satellite imagery (Andrews, 1972 and Watanabe, 1965). Algorithms are then developed in the lower dimensional optimal analysis space by using an independent eigen screening technique. This technique is related to classical screening regression but differs in that the screening is performed in eigen vector space where the orthogonality eliminates all the redundancy problems associated with classical screening. The screening decision is based on an independent test (Lachenbrach and Mickey, 1968). The algorithms were developed using ESMR-5 data and the nine non-satellite derived discriptors (described in the data sampling section). The algorithms that were developed using both the satellite and non-satellite data used the non-satellite data in two ways. The first way was to use the non-satellite discriptors to bias the transformation to the optimal space so that the ESMR-5 values in the first terms of the transformation carried the same information as the non-satellite discriptors. The second way was to use the non-satellite discriptors to append the non-satellite data to the end of the ESMR-5 derived radiation values. Analysis of the derived algorithms showed that the biased ESMR-5 values were the most efficient in carrying all the information (information derived from both satellite and non-satellite variables) for these algorithms.

Since the transformation is orthogonal, the results of the algorithm can be transformed back to the original data space (i.e. the satellite imagery). Thus, the relative importance of each data vector as obtained from the satellite image will be known. In the case of the ESMR-5 observations of tropical cyclones, the transformation will tell which regions of the storms are most important for forecasting storm intensity and motion.

DATA SAMPLING

To obtain independent data, a grid consisting of a rectangular array (13° latitude x 10° longitude) of 267 points was used to extract data vectors from a "Bull's Eye" projection (Shenk et al., 1971) of the ESMR-5 brightness temperatures (T_B). The storm center was located approximately in the middle of the grid. Spacing between the inner grid points are .63° latitude and 1.25° latitude for the outer grid points. In addition to the ESMR-5 measurements there are nine non-satellite derived discriptors used for independent data. They are:

1. Day of the year.
2. Observation time.
3. Latitude of storm at the time of observation.
4. Longitude of the storm at the time of observation.
5. Maximum winds at the observation time.
6. Latitude change of storm in 12 hours.
7. Longitude change of storm in 12 hours.
8. 12 hour change in maximum winds ending at the observation time.
9. Time difference between time of observation and satellite pass.

These nine non-satellite variables were explicitly selected to be used in conjunction with satellite data.

The dependent data consist of the 12, 24, 48, and 72 hour change in maximum winds and movement that were obtained by extrapolating the 12 hour best track information for each interval. Best track data was the only objective data available for these cases.

FORECAST ALGORITHMS

Regression algorithms were developed to forecast 12, 24, 48, and 72 hour tropical cyclone maximum winds and latitude and longitude displacement using the two data combinations. The results of independently testing these algorithms are shown in Tables 1 and 2. These tables summarize the performance of the algorithms by comparing the mean error made by persistence forecast calculated from best track and the Joint Typhoon Warning Center (JTWC) operational forecast (not based on best track) with the mean error made by the algorithms. The JTWC forecast were not for the same storms used in this study but were for the same period.

Table 1
Performance of Wind Speed Forecast Algorithms

Algorithm	Persistence	JTWC	Satellite Alone	Satellite plus Conventional
Max Wind Forecast	Kts	Kts	Kts	Kts
12 hr	6.8	9.2	15.1	6.1
24 hr	20.0	14.0	15.1	10.3
48 hr	39.0	19.0	18.3	13.0
72 hr	55.0	23.0	19.2	16.6

Table 2
Performance of Position Forecast Algorithms

Algorithm	Persistence	Satellite Alone	Satellite plus Conventional
Latitude Forecast	NM	NM	NM
24 hr	57.0	65.4	53.1
48 hr	132.0	132.0	110.0
72 hr	220.0	183.0	168.0
Longitude Forecast	NM	NM	NM
24 hr	63.0	86.8	56.5
48 hr	157.0	190.0	142.0
72 hr	275.0	279.0	220.0

Columns 1 through 5 in Table 1 respectively delineate the algorithm, mean errors made by persistence, JTWC, the satellite alone, and the combination of satellite plus non-satellite data. The format in Table 2 is the same except that there is no information on the JTWC forecast. The persistence forecast for the longer time periods are too large since the best track data for the past 12 hours were used to determine these forecast.

ANALYSIS OF ALGORITHMS

Examination of the tables reveal that the performance of the wind speed algorithms are showing the greatest improvement. This is not surprising since ESMR-5 is measuring latent heat release in a tropical cyclone (an index of storm intensity) and that current and 12 hour maximum wind speeds are part of the non-satellite data. A significant result apparent from examining these tables is that the satellite derived algorithms out performed the persistence maximum wind forecast for 24, 48, and 72 hours as well as the JTWC operational maximum wind forecast for 48 and 72 hours. In addition, by adding the non-satellite derived discriptors, which are easily obtainable for most storms, the performance is substantially greater for all algorithms. Even better performance should be realized for these satellite algorithms if more ESMR-5 observations of tropical cyclones were available. Similar results were found by Gentry et al. (1978) when the results from their 24 hour tropical cyclone maximum wind regression equations were compared with persistence. The regression equations were developed to forecast tropical cyclone 24 hour maximum wind speeds utilizing satellite measured infrared equivalent blackbody temperature of the storm (an index of LHR) alone and together with the changes in maximum winds during the preceding 24 hours and the current maximum winds (both obtained from best track).

An important ADAPT output for understanding the physics behind an algorithm is the relative importance map obtained by transforming the algorithm from the lower dimensional space back to the original data space. Figure 1 is such a plot. On this figure, the 19 x 19 array represents the grid that was used to sample the ESMR T_B (center of the storm represented by a box with an X inside). The higher the number the greater the importance for each data space variable (Blank is least

	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	
	1									10										20
19	1	2				1			1				1	1	1					
18	1	1	1	1			1				1	1	1	2		1				
17														1	1					
16						1	2	1				1		1		1				
15					1	3							2		1	1				
14					1	1				1	1		1		1	1	1	2	3	
13	1			1		2		2	3	1	1		2			2	3	3	3	
12		1			1		1				3		2			1	1	2	3	
11		1	3		2			3		1	2	2	2					1	1	
10		1	2	1	1				1		1		1							
9	1	1	1				2		⊠		1	2	1							
8	1	1			1	2		2	2		2			1						
7	2	1		1		1	1	1				1			1	1	1	1	1	
6	2	1		1	2											2	2	2	3	
5	2	1	1		2	1	1	1					1		2	2	3	3	3	
4	1	1					1	2	2		1	1		2	3	1	1	1	2	
3				2	2	1	1		1		1			1	1				1	
2		1		1	1	1	2		1						1	1	1			
1	1	1	1				1		1					1	2	2	2	1		
	1									10										20

Fig. 1—The importance of the 267 data space variables to estimate the 24 hour maximum winds.

important). The cluster of the larger values in the grid indicates that the importance of these areas of the storm in estimating 24 hour wind speed are probably related to the configuration and intensity of the rain bands around the center. There appears to be more information (greater number of 2's and 3's) east of the center.

SUMMARY

The application of the ADAPT representation and the independent screening regression technique to derive tropical cyclone intensity and movement forecast algorithms have shown encouraging results towards improving the accuracy of wind forecast relative to persistence and the JTWC operational forecast and long term position forecasts relative to persistence. With an increase in the number ESMR observations of tropical cyclones, a further improvement in the performance of these forecast algorithms would be expected.

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