13B.5 QUANTIFYING MORPHOLOGIC FEATURES OF REMOTELY-SENSED DATA FOR ITS USE IN A TROPICAL CYCLOGENESIS PREDICTOR

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1. INTRODUCTION

Tropical cyclone genesis is a complex process that involves interactions on many scales. The classification and prediction of these events has been difficult, in part because of a lack of basic understanding of the physical mechanisms involved. Although recently, some progress has been made in this area, classification of an actual genesis event remains a subjective process until the tropical cyclone is well defined.

The development of an objective model that can detect and predict the early stages of cyclogenesis would enable forecasters to warn on nascent systems with some confidence. Another potential benefit would be to enable better representation of the emerging tropical cyclone in numerical weather prediction models, perhaps improving forecasts from an earlier time.

Weather disturbances have been described based on measurable variables, e.g., atmospheric winds, pressure, temperature, and relative humidity. For tropical cyclones that spend much of their lifetime over the oceans, traditional sources of these measurements are scarce. However, observations that describe mesoscale characteristics of the dynamics and structure of tropical cyclones, and indeed other weather disturbances, can be extracted from satellite-based remote-sensed observations. These measurements potentially extract important information that can help to identify emerging tropical cyclones.

In this paper we discuss a technique for obtaining features associated with the shape and the dynamics of structures embedded in cloud clusters that have potential for development into tropical cyclones. As the tropical cyclone develops and intensifies these structures become more axisymmetric. Using satellite-based remotely-sensed variables, the proposed technique uses gradient vectors and coordinate transformation techniques to measure the level of symmetry of each structure. We will show examples of our technique and discuss future development.

In this paper, we describe two techniques that estimate the degree of similarity of the cloud features in satellite images, to a hurricane. These techniques are described in section 2. In section 3 we present some examples of the application of these procedures. Finally, a summary, conclusions and future work are discussed in section 4.

2. FEATURE VECTORS

Using Infra-red (IR) images, features are extracted from within the weather disturbance in order to characterize the degree of its organization. These features are characterized by the direction of the gradient of the elements that compose it. The gradient indicates the direction of the maximum changes in brightness temperature in the image. Therefore, it provides information regarding the dynamics and the structure of the shape of any cloud formation. By using the information that a strong vortex displays a well-organized, axisymmetric structure, this method provides an objective indication of the potential presence of a nascent tropical cyclone. It also shows utility in analyzing the ongoing evolution of the tropical cyclone as it develops into maturity.

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In order to predict the outcome tropical cyclogenesis (or any other outcome), a prediction system needs to be trained to use a set of feature vectors to obtain a desired behavior (in our case tropical cyclogenesis). Once the system is properly trained to recognize tropical cyclogenesis, independent data is used to see if the system can successfully reproduce the desired behavior. Therefore, an adequate selection of the feature vectors is important to assure successful training of the prediction system. In this study, we propose to measure the degree of organization of the objects that compose the weather scene in the satellite image, by measuring the directions of its gradients. The degree of similarity of these directions with those comprising an ideal tropical cyclone would indicate how close these objects are to a tropical cyclone structure.

2.1. First Approach

The first step in this procedure is to detect different objects of potential interest to us in the IR image (in our case weather disturbances that might be tropical cyclones). One or more reference points are selected that will be used to locate areas of interest. Although these points can be arbitrarily selected, an algorithm was developed to automatically choose them. If we assume that there is a single feature in the image that is a vortex, then ideally the selected point is its center.

To find the reference points, the image of interest is correlated with a circle-shaped image resembling an ideal vortex. Several shapes of this image can be used. Figure 1a shows the simplest version of a circular shape. Figure 1b and 1c show different styles of the ideal vortex with Figure 1c being the most similar to a hurricane featuring an eye and radial variation in intensity.

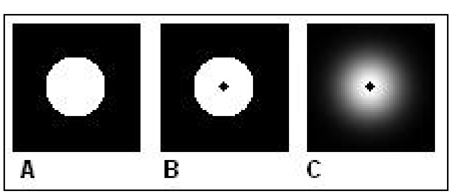

Figure 1: Templates used to correlate the satellite image. The maxima of this operation are a set of reference points indicating centers of the vortex.

The result of the correlation process is an image, where the pixels with a maximum value indicate the areas where the original image mostly resembles a vortex. The positions of these pixels are extracted and used as the reference points.

The next step in the process is to calculate the gradient of the brightness temperatures, its angle and its "relative angle" to a chosen reference point for every pixel in the image. The gradient is calculated from the horizontal and the vertical derivative by using a well-known kernel such as the Sobel's template (Gonzalez and Woods 2002). Figure 2 shows an example of a regular cloud as observed in IR imagery; its gradient is shown in Figure 3.

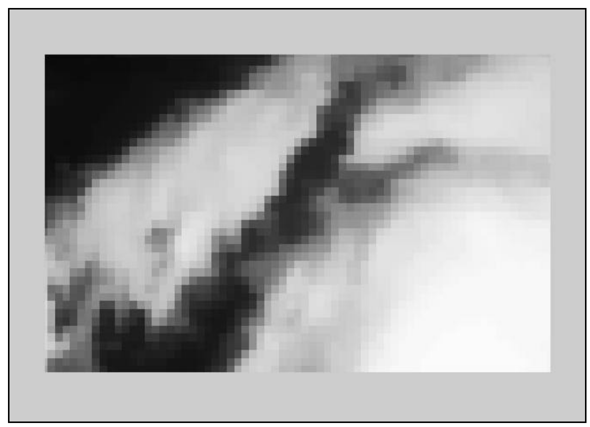

Figure 2: Infrared image of a regular cloud from a geostationary operational environmental satellite (GOES).

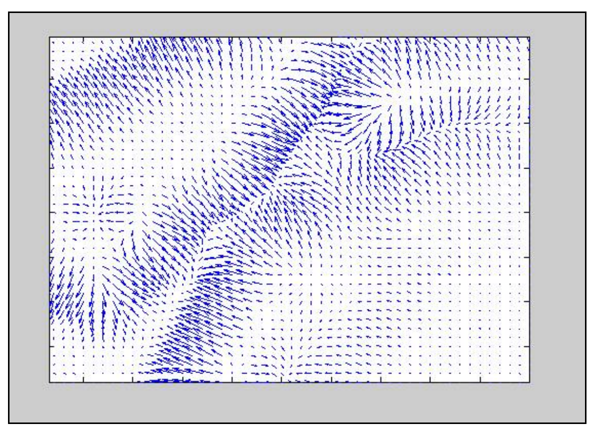

Figure 3: Gradient of the brightness temperatures in the image shown in Figure 2.

The "relative angle" of a gradient vector is calculated using a rotated coordinate system. This system is rotated by following the imaginary line drawn from the reference point to its origin (Figure 4). The vector is decomposed in radial and azimuthal components (cylindrical coordinate system). This calculation is repeated for each gradient vector within a radius to the chosen reference point. This radius is chosen according to the resolution of the image.

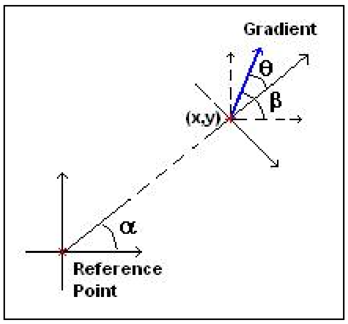

Figure 4. "Relative Angle" Calculation.

Finally, for each gradient, an angle of interest (θ) is found by subtracting the gradient's angle (β) with the absolute angle (α). By performing this operation for each reference point, the variance of the resultant angles can be used as a measurement of the "organization" of its surroundings. Whereas for an ideal vortex this variance should be zero, for a regular cloud there will be a high variance due to the fact that not only is the reference point not well-defined, but also the gradient is extremely unordered.

The distribution of the variances in the gradient vectors is used to determine when a cloud object around a reference point is organizing into a vortex. Figure 5 is an example of this analysis when applied to a tropical storm. Figure 6 shows a similar analysis for a mature hurricane. Note the large spread of the histogram in Figure 5 associated with a large departure in the gradient vectors from an ideal vortex. In contrast, by 21 September, Hurricane Rita is a well-structured vortex, and the corresponding histogram shows a large peak at 0 angle and very little spread.

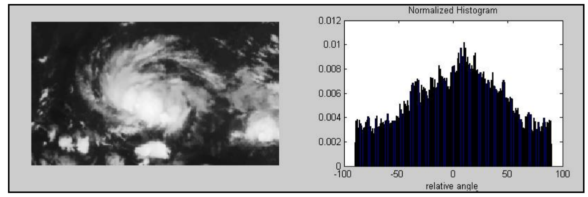

Figure 5: Infrared image of Tropical Storm Rita (18 September 2005. Wind Speed: 30kt) and its relative angles histogram (variance: 1953).

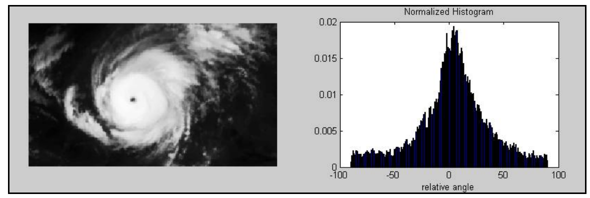

Figure 6: Infrared image of Hurricane Rita (21 September 2005. Wind speed: 122kt) and its relative angles histogram (variance: 1136).

2.2. Second Approach

A second technique was developed to extract local features related to the shape of a surrounding feature to a reference point. This technique finds curves that provide a measurable interpretation of the similarity of the angles on a set of gradients with an ideal vortex.

A reference point and a set of gradients and angles are found using the same method as in the previous section. Using this result, a new image is created that shows the magnitudes of the subtracted angles. This process is demonstrated in Figure 7, Figure 8 and Figure 9. Next, these values are translated to a polar coordinate system with the reference point (red point) as the center of the system (Figure 10).

The representation of an ideal vortex using the polar coordinate system is a blank (zero angle value) image. Therefore, a straight line drawn from a point from the left to the right border of the image represents a circle on the original Cartesian plane. Similarly, the degree of "straightness" of any curve drawn on Figure 10 is a representation of how close the contour is to a perfect circumference. In this next step of the technique, a contour is drawn, with a common start and end point, through the "minimum angle path" of the polar-coordinate image.

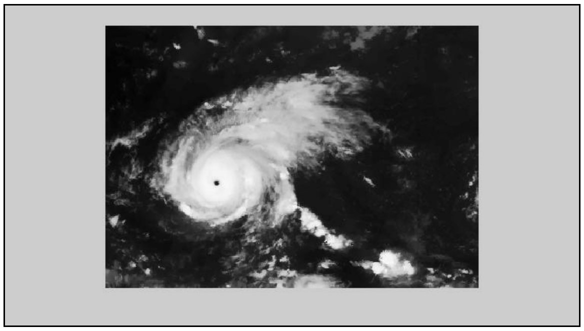

Figure 7: Infrared Image of Hurricane Rita. 21 September 2005. Wind speed: 152kt

Figure 8: A representation of the gradient for Figure 7 using the magnitude (grey-shading) of the angles.

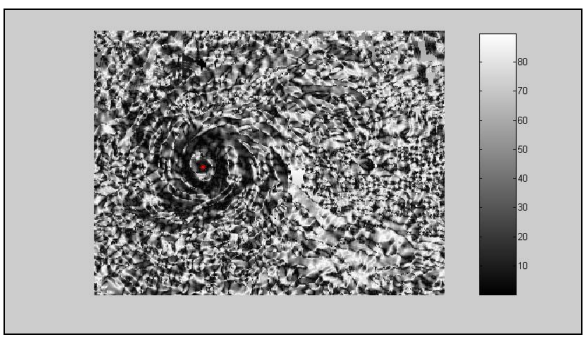

Figure 9: A representation of the magnitude (grey-shading) of the relative angles in Figure 8.

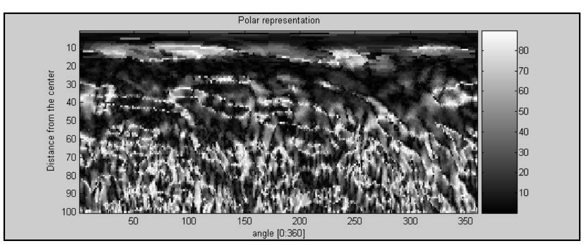

Figure 10. Polar coordinate representation of the angles in Figure 9. The reference point lies along the top of the figure. The y-axis is distance from the reference. The x-axis is angle (0-360 degrees). The magnitude of the angle is indicated by the grey shading.

To find this “minimum angle contour”, an initial straight line is drawn connecting the end markers. Then, this line is deformed to a curving shape, without modifying its initial and ending position. It is intended that the points that compose this curve, be located on the darkest regions of the image, corresponding to the areas where the gradients are oriented closest to a perfect vortex in the original Cartesian plane.

The procedure used to deform the mentioned curved, is analogous to the one used by the active contours algorithm (also known as “snakes”, Xu and Prince 1997). In this procedure, the image is modeled as a potential field, where a hypothetical mass is under the influence of external forces that drive its final location. For this system, these forces are defined to have a similar behavior as the electrical force. A new force representing the “elasticity” of the curve is added. Therefore, the black regions attract the points of the curve, while the white regions repel them. However, these points cannot separate too much from each other due to the elastic properties of the curve. An example of this process is shown in Figure 11. The red line indicates the initial condition and the green curve, the final.

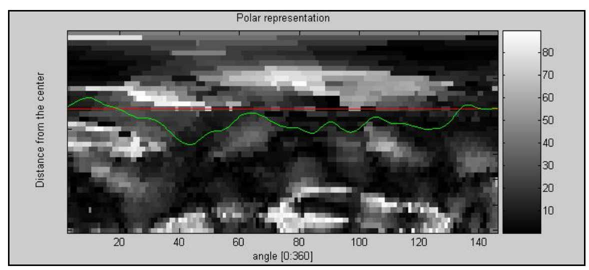

Figure 11. Example of curve deformation in a polar-coordinate representation of the relative angles.

The criteria used to find a vortex in these results uses the derivative of the extracted curve to find the amount of straight segments in the curve. The straighter the curve the closer to the ideal vortex the feature is.

Figure 12 shows the polar-coordinate representation of the relative angles and the calculated curve for the cloud feature in Figure 13. The red line exhibits the maximum straight segment. The calculated curve is shown on the original Cartesian plane (see Figure 13).

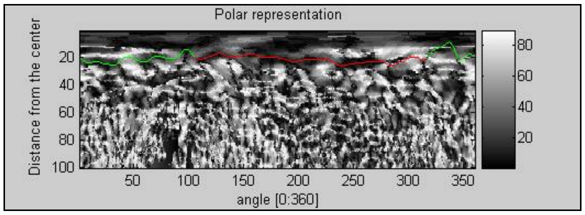

Figure 12: Polar representation of the Relatives Angles for Figure 13.

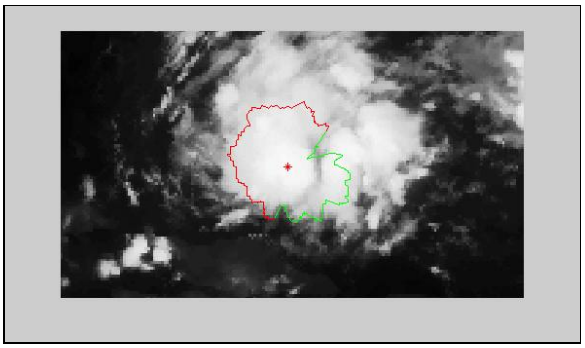

Figure 13: Cartesian representation of the curve calculated in Figure 12 (See Table 1, Image 2).

3. Experimental Results

To test the procedure, a hurricane system was analyzed using the above-mentioned techniques. This system is comprised of a series of infrared satellite images taken during 18 – 21 September 2005 for Hurricane Rita. They show the evolution of Hurricane Rita from a tropical depression through a mature hurricane.

Table 1 shows the characteristics obtained for a single reference point on the set of images that comprise the hurricane system. These characteristics are the variance obtained using the first technique, and the length of the maximum straight region obtained using the second technique. The result is given as the percentage of the length of these regions (arcs) on the total length of the contour.

As shown in Table 1, the variance tends to decrease as long as the tropical cyclone is intensifying. It appears to increase again right at the end of the period of investigation. This behavior is shown in Figure 14. The opposite tendency is found using the second described technique (see Figure 15). This behavior is consequent with the expected results of a hurricane development, due to the fact that a tropical cyclone becomes more symmetric when it develops.

Image	Date and Time	Wind Speed (kt)	Angle Variance	Length of Arc (%)
1	18-sep, 0815Z	26	2034	36
2	18-sep, 1015Z	26	2011	51
3	18-sep, 2215Z	35	1953	34
4	19-sep, 0915Z	52	2495	100
5	19-sep, 1415Z	56	1709	68
6	19-sep, 1715Z	61	1146	55
7	19-sep, 2015Z	61	1654	100
8	19-sep, 2315Z	61	1829	74
9	20-sep, 1015Z	61	1507	98
10	20-sep, 1315Z	61	1704	59
11	20-sep, 1815Z	87	1719	63
12	21-sep, 0315Z	96	1312	100
13	21-sep, 0915Z	104	1207	84
14	21-sep, 1415Z	122	1136	95
15	21-sep, 2215Z	152	909	100
16	21-sep, 2315Z	152	1139	100

Table 1. Results for Techniques One and Two when applied to Hurricane Rita. September 18-21, 2005.

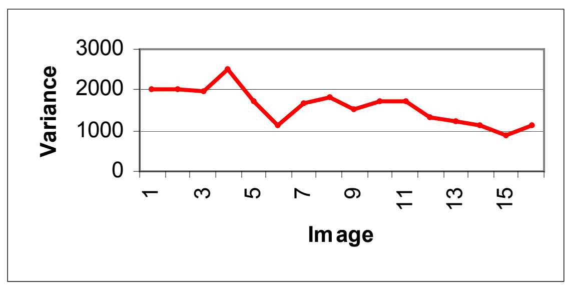

Figure 14: Variance of relatives angles for the sequence shown in Table 1.

Figure 15: Length of the maximum straight region of the total length on the contour for the sequence shown in Table 1.

4. Conclusions

The results shown in the previous section are an encouraging indication of the ability of our techniques to analyze organized structures within cloud features in infra-red imagery. Also, distinctive shapes can be identified using these objective techniques.

In particular, the analysis of the gradients found in the features that comprise a weather image, can be used to measure the degree of vortical structure within a tropical cyclone.

Future development includes developing this technique into a predictive tool for tropical cyclogenesis as well as an objective tool for now-casting tropical cyclone intensity from satellite imagery. Plans include incorporating other types of remotely-sensed data such as microwave imagery into the technique

5. Acknowledgments

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Web Site: http://www.nhc.noaa.gov

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