P1.8

DETECTING TROPICAL CYCLONE FORMATION FROM SATELLITE INFRARED IMAGERY

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1. Introduction

The genesis of a tropical cyclone has been a subject of study for years (McBride 1995). Although, several climatological conditions have been identified for the formation of Tropical cyclones (Gray 1979), these conditions are not sufficient and the mechanisms involved in this process are not completely understood. Forecasting techniques rely on direct and remotely-sensed measurements of environmental variables to detect, estimate and predict the formation, intensity and track of tropical cyclones. Unfortunately, direct measurements of tropical cyclones are not always available, and thus, frequently the only reliable source of information is remotely sensed. For example, one of the most used techniques to estimate the intensity of a tropical cyclone by analyzing satellite imagery was developed by Dvorak (Velden et at. 2006) and expanded in Velden et al. 1998, and Olander et al. 2007.

Tropical cyclone forecasting products typically are based on global numerical models, which are initialized and periodically corrected with environmental measurements (Bender et al. 1993; DeMaria et al. 2005). These models utilize a combination of deterministic and/or statistical equations to model the dynamics of atmospheric variables, which are subject to a grid that defines the spatial resolution of analysis. An example of this type of analysis is described by Schumacher et al. (2009), which predicts the formation of tropical cyclones within 5°x5° subregions by analyzing a set of environmental and convective variables, water vapor imagery (6.7μm) and numerical weather products. Typically, these techniques utilize the grid of analysis but do not track individually cloud clusters to identify nascent tropical cyclones. Discriminating between non-developing and developing cloud clusters is a task that can improve the performance of these types of forecasting products. An initial approach is described in Piñeros et al. (2008). In that paper, the axisymmetry of a cloud is quantified and used to describe the intensity of a tropical cyclone. This paper extends that methodology in order to discriminate developing from non-developing cloud clusters (Piñeros et al. 2010).

In the next section, the procedure of quantifying the axisymmetry of a cloud cluster is described. Section 3 presents the results. Conclusions and future work are discussed in section 4.

2. Methodology

The data that are used in this study are infrared (10.7 μm) satellite scenes with 5 km/pixel of resolution from the Geostationary Operational Environmental Satellite 12 Imager (GOES-12), which extend from 4º to 34º N latitude, and 105º to 28º W longitude Approximately 9000 half-hourly images between the months of June and December of 2004 and 2005 were processed. This set of images comprises 40 tropical cyclones including one tropical depression, one subtropical depression, one subtropical storm,

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17 tropical storms, and 20 hurricanes. In addition, there are 136 non-developing cloud clusters.

The procedure described in Piñeros et al. (2008), locates the center of a cloud cluster around which the axisymmetry is quantified. This process is performed by calculating the deviation angle from a perfect radial for each gradient vector extending from that central point for a radius of 350 km. The variance of the deviation angles distribution is the parameter that determines the axisymmetry at a particular location or center. Figure 1b-c summarizes this process for the pixel indicated in Figure 1a. The accuracy of this technique is sensitive to the correct location of the center, which may not be well defined particularly at early stages of the tropical cyclone's lifecycle. This problem is solved by repeating the deviation angle variance calculation, using all the pixels that compose cloud clusters in the entire scene as centers. However, because necessary climatological conditions are required for the formation of tropical cyclones (Gray 1979), pixels over land and below 5° latitude are removed from the analysis. In addition, those cloud clusters with low average brightness temperature (one-third of the maximum pixel value to the entire scene average within a radius of 350 km) are also removed from the analysis.

The results are stored in an auxiliary matrix or map of variances, in which low values indicate the axisymmetric structures (Figure 1d), generally observed in vortices. On the other hand, high values indicate disorganized structures, typically found in non-developing cloud clusters.

Figure 2 shows a sequence of map of variances for Hurricane Wilma (2005). This tropical cyclone was declared by the National Hurricane Center (NHC) as a tropical depression on 15 October at 1800 UTC, tropical storm on 17 October at 0600 UTC, and hurricane on 18 October at 1200 UTC. Note that the minimum value found in the map decreases as the tropical cyclone intensifies.

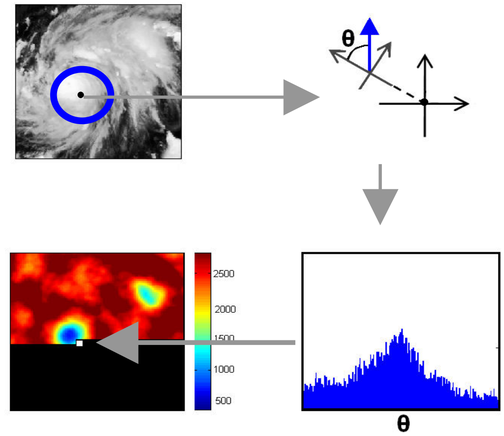

Figure 1. Map of deviation-angle variances: a) Infrared image. The area analyzed around a reference point is indicated by the black circle (350 km); b) deviation-angle calculation for a gradient vector (blue arrow) relative to a radial line extending from the reference point; c) deviation-angle histogram; d) map of deviation-angle variances [deg^2].

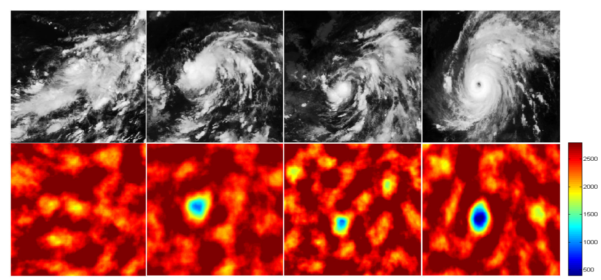

Figure 2. Map of variances for Hurricane Wilma (2005): a) 13 October 2015 UTC, actual intensity is not reported at this stage by the NHC, map minimum value (MMV): 2173 deg^2; (b) 15 October 1345 UTC, 25 kt, 1004 mb, MMV: 1648 deg^2; (c) 17 October 0615 UTC, 35 kt, 1000 mb, MMV: 1616 deg^2; (d) 21 October 0015 UTC, 130 kt, 924 mb, MMV: 1189 deg^2.

The minimum deviation angle variance in the map is used to determine whether a cloud cluster has enough level of axisymmetry to be classified as a developing tropical cyclone. If the minimum deviation angle variance in a cloud cluster is less than a threshold value, the cloud cluster is identified as undergoing genesis. The detection time is defined as the moment that pixels reach the threshold and this is compared with the time when the NHC classifies the tropical cyclone as a tropical depression. It is possible to choose threshold values that either maximize the number of detections of genesis, or minimizes the false alarms. Thus, the system is tested using a range of threshold values. The system can be also defined in terms of tropical storm or hurricane designation, and these statistics are also kept.

3. Results

A set of thresholds values from 1350 to 2000 deg^2 in steps of 50 was applied to detect tropical cyclones. The results are compared to the NHC best track to obtain the true detection, false positive rate (false alarms) and the detection time. Note that in the example of Figure 2b, Hurricane Wilma is detected using the threshold of 1650 deg^2, approximately 4h before the NHC designated it as tropical depression, 40h before tropical storm, and 70h before hurricane.

The results of the detection with respect to the tropical depression designation are summarized in a receiver operating characteristic (ROC) curve in Figure 3. The time detection for each threshold is shown in Figure 4. The lowest threshold (1350 deg^2) only detects 45% of the total number of tropical cyclones, with a mean detection time of 40h after the tropical depression designation, but also produces the lowest false positive rate (1%). On the other hand, the highest threshold (2000 deg^2) is a poor criterion of detection, which produces the maximum number of false alarms (136), the maximum true positive rate (95%), and the best detection time (28.5h) before the tropical depression designation. Perhaps, the optimal balance between the true positive rate, false positive rate and the time detection, is obtained in the knee of the ROC curve, between the values of 1500 and 1750 deg^2. For example, the threshold value of 1700 deg^2 generates 93% true positive rate, 15% false positive rate and a mean time detection of –0.6h.

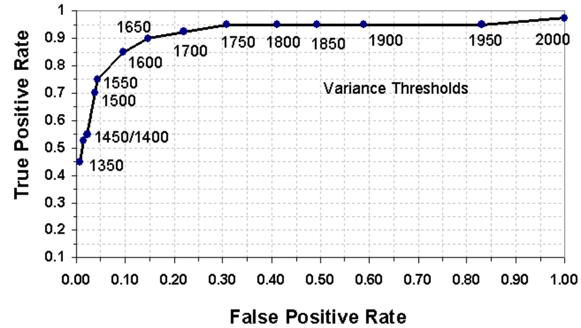

Figure 3. Receiver operating characteristics (ROC) curve for storm detections during 2004 and 2005 for deviation-angle variance threshold values from 1350 to 2000 deg^2.

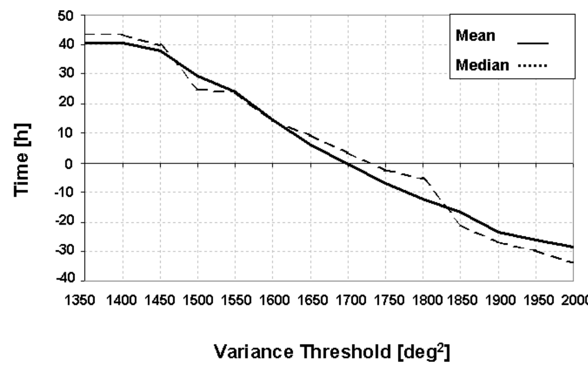

Figure 4. Mean and median time of detection of tropical cyclones for deviation-angle variance threshold before being classified as Tropical Depressions by NHC during 2004 and 2005.

4. Discussion and Conclusions

This paper describes how to extend the technique described in Piñeros et al. (2008) to discriminate developing from non-developing cloud clusters. The technique quantifies the level of organization or axisymmetry of cloud clusters using every pixel in the scene as reference or center. The point with the highest axisymmetry is compared to a set of threshold values to characterize the performance of the technique, which is described in terms of three parameters: true positive and false positive rate, and detection time. Detections are compared to the NHC best track database in order to classify true positives and false alarms; and to obtain the detection time. The early detection of axisymmetric structures is used to distinguish nascent tropical cyclones from non-developing system. The balance between the true positive and false positive rate, and the detection time will establish the threshold value chosen to detect the genesis of a tropical cyclone. In particular, the threshold of 1700 deg^2, produces about zero detection time, 93% true positive rate, and 15% false alarms.

Applying the threshold value of 1700 deg^2, this technique detected two cloud clusters that showed a defined circulation of 30 kt according to QuikSCAT imagery. Since these cases were not reported as tropical depressions by the NHC (see Table I), they were classified as false alarms; however, they might be reconsidered as positive detections. In addition, thirteen African waves (9.6%) were also detected as developing tropical cyclones with the threshold of 1700 deg^2. Although these atmospheric disturbances can have winds higher than 30 kt and axisymmetric structures, they do not show a defined circulation in QuikSCAT imagery.

TABLE I
DEVELOPING CLOUD CLUSTERS DETECTED AND CONFIRMED BY QUIKSCAT

Date (MMDDYY) /Time (UTC)	Latitude [°N]	Longitude [°W]
082305/0915	15	36
101305/0145	32	65

Currently, the technique is being adjusted for water vapor imagery (6.7 µm). A subset of 2500 images comprising 13 tropical cyclones was processed. The threshold value of 1450 deg^2 is producing similar rates to the threshold of 1700 deg^2 with infrared images; however, the detection time is improved to approximately –5h. According to the partial results using water vapor imagery, these images improve the time detection but also increase the false alarm rate. In addition, a temporal filter that reduces false alarms is being developed. Consequently, the following step consists of combining the infrared and water vapor images. These results can enhance current forecasting models by adding a new feature related to the organization of the cloud clusters.

5. Acknowledgment

Best track data were obtained from the NOAA National Hurricane Center, FL website at http://www.nhc.noaa.gov. QuikSCAT imagery were downloaded from:
http://manati.orbit.nesdis.noaa.gov/quikscat/.
This research was supported by the Office of Naval Research under grant N00014-07-1-0185 and by the State of Arizona under a Technology and Research Initiative Fund Student Fellowship.

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