Augmentation of Early Intensity Forecasting in Tropical Cyclones

J. Scott Tyo
College of Optical Sciences
University of Arizona
Tucson, AZ 85721
Phone: (520) 626-8183 FAX: (520) 621-4358 E-mail: tyo@optics.arizona.edu

Elizabeth A Ritchie
Department of Atmospheric Sciences
University of Arizona
Tucson, AZ 85721
Phone: (520) 626-8183 FAX: (520) 621-6833 E-mail: ritchie@atmo.arizona.edu

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http://www.optics.arizona.edu/asl

LONG-TERM GOALS

The long-term goals of our research team are twofold:

1. To develop a suite of objective forecast tools that are based on remote sensing data and multi-parameter spatiotemporal analysis tools.
2. To understand the physical mechanisms giving rise to the observable signatures that are used for forecasting.

OBJECTIVES

In this project, we develop an objective and automatic intensity estimator of Tropical Cyclones (TCs) based on satellite infrared (IR) imagery. The proposed methodology analyzes the TC's shape or pattern to perform the intensity estimates, which will be available every 30 minutes (or depending on image acquisition availability) for the Atlantic, Eastern North Pacific and Western North Pacific basins. We are investigating the underlying atmospheric dynamics by using mesoscale modeling and comparing the modeled storms to the measured signatures.

APPROACH AND WORK PLAN

In our initial study (Pineros et al. 2008), we described a metric to quantify the axisymmetry of a TC called deviation-angle variance (DAV), whose time series was well correlated with the best-track intensity estimates from the National Hurricane Center (NHC). The deviation-angle is obtained from the gradient vectors of IR images, and it is calculated from a perfect radial extending from a central point as shown in Fig. 1a. The variance of the distribution of deviation-angles is the key variable that correlated with the TC's intensity and will allow its estimation. As shown in Fig. 1b, for an ideal vortex all the vectors within a radius are pointing to or away from the center, therefore the deviation angles are zero and also their variance (Fig. 1c) if the central point is located at the vortex's center. When a TC intensifies, its structure becomes more axisymmetric, which is reflected in a decrease of the DAV as shown in Fig. 2. This procedure is sensitive to two parameters to find: 1) the correct location of the center, which is not always well defined in the image; and 2) the radius of analysis. To overcome the first problem, every pixel is used in the image sequentially as a central reference point, the results are stored in an auxiliary matrix called map of variances (Pineros et al. 2010). Fig. 3 summarizes this process. The second problem is solved by calculating eight different maps using radii from 150 to 500 km in steps of 50 km. A time series per radius of analysis is calculated by finding the minimum DAV value in the maps. Finally, the DAV time series of the tropical cyclone is filtered to reduce some of the high-frequency oscillations in order to better compare with the 6-h best-track intensity estimates. Fig. 4 shows the filtered DAV time series using 250-km and 350-km radius of analysis.

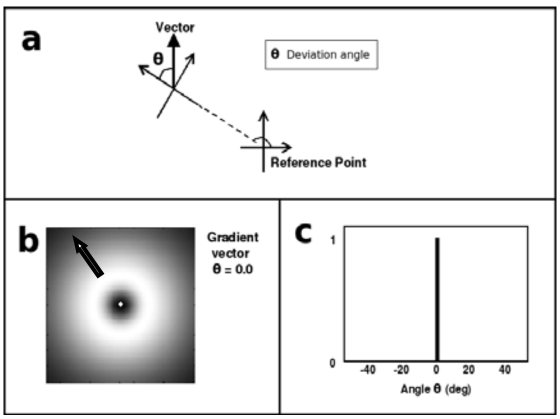

Fig. 1. a) "Deviation Angle" Calculation. The deviation angle of every gradient vector within 70 pixels, and the variance of this distribution is calculated for that reference point; b) example of the "deviation angle" for an axisymmetric vortex with the reference point in the center of the image; and c) histogram of deviation angles for the ideal vortex in b).

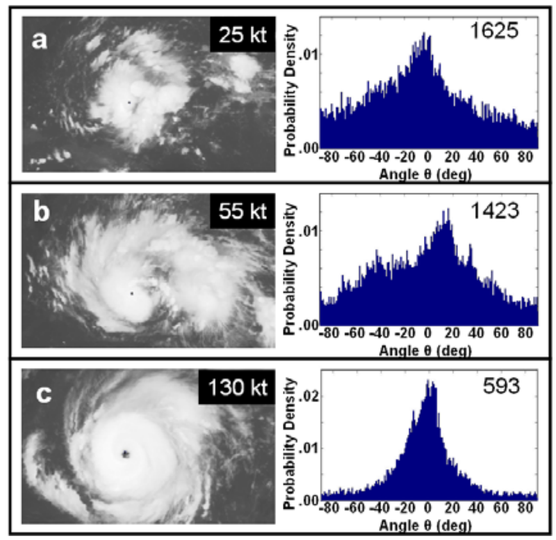

Fig. 2: Sequence of infrared images and deviation angles histograms for Hurricane Rita (2005): a) 0815 UTC 18 September 2005. Intensity: 25kt, 1009 hPa, DAV: 1625 deg^2; b) 1415 UTC 19 September 2005. Intensity: 55 kt, 997 hPa, DAV: 1423 deg^2; and c) 1415 UTC 21 September 2005. Intensity: 130kt, 932 hPa, DAV: 593 deg^2.

Once the DAV time series are obtained for all the eight radius of analysis from all the TCs in the database, eight different parametric curves relating the best-track intensity estimates with the DAV are calculated. The parametric curve with the minimum sum of square error for a particular radius is chosen as the final intensity estimator. Fig. 5 shows the optimum parametric curve obtained (350km of radius) when training with IR imagery data from 2004 to 2008 for the Atlantic basin. This curve describes the estimator, which output can be generated as soon as a new satellite is available to process.

To accomplish our technical approach, we have divided the project into four tasks.

1. Building the database of IR satellite images for 5 years over the Atlantic, Eastern North Pacific and Western North Pacific basins.

2. Calculating the DAV time series for each TC in the database. In this step, the calculation might require some parametrical adjustments of the prototype estimator developed for Atlantic to the Pacific basin.
3. This methodology will be applied to synthetic imagery from weather models in order to determine the atmospheric physics behind the DAV methodology.
4. Obtain the intensity estimator per basin by building a curve that relates the intensity with the DAV values.

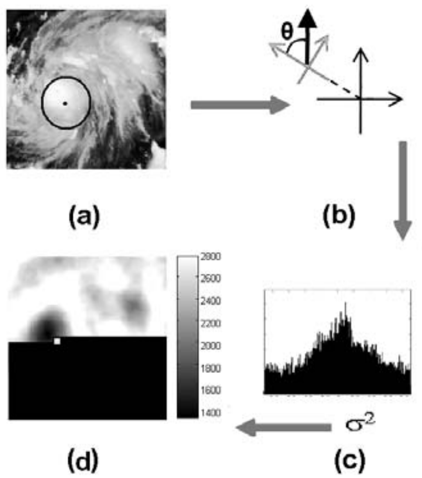

Fig. 3: Map of deviation-angle variances: a) Infrared image. The area analysed around a reference point is indicated by the black circle; b) deviation-angle calculation for a gradient vector (black arrow) relative to a radial line extending from the reference point; c) deviation-angle histogram; d) map of deviation-angle variances [deg^2].

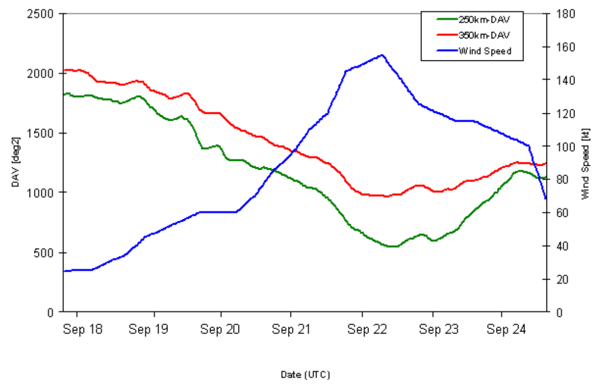

Fig. 4. Hurricane Rita (2005): time series of the best track intensity (kt) from the National Hurricane Center best track data (blue), DAV time series using a radius of 250km (green) and 350km (red). During the course of the time series 0000 local is between 0500 UTC and 0600 UTC.

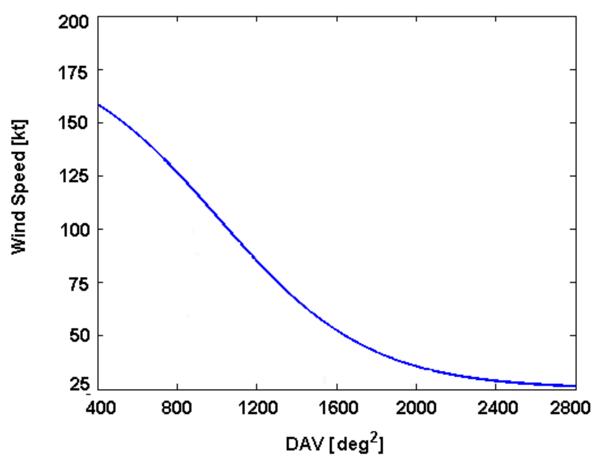

Fig. 5: 350km DAV vs best-track intensity estimates over 2004-2008 for the Atlantic basin.

The team at the University of Arizona is composed of the following individuals:

- Arun Ganesan (University of Arizona- undergraduate student): Website interface development.
- Brian LaCasse (University of Arizona- undergraduate student): Construction of the image database and adaptation of the intensity estimator to the western North Pacific basin.
- Genevieve Valliere-Kelley (University of Arizona- graduate student): Construction of the image database and adaptation of the intensity estimator to the eastern North Pacific basin.
- Kelly Ryan (University of Arizona- undergraduate student): Synthetic image generation from mesoscale model data and mesoscale modeling.
- Miguel F Pineros (University of Arizona- Postdoctoral associate): Construction of the image database, development of the intensity estimator and real-time application for the Atlantic basin.

The team at the Naval Research Laboratory –MRY is composed of:
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- Mr. Richard Bankert (Naval Research Laboratory –MRY): Restore all available MTSAT data files from the NRL archive. Each restored file is then processed to add latitude and longitude as variables in the data files before conversion to netCDF format and placement on an ftp site for retrieval by UA and further processing.

Upcoming year work plan, tasks to complete:

1. Finish the construction of the image database for the Northwest and Northeast Pacific basins: Image storage, map projection, Matlab file conversion and TC images grouping.
   Institutions involved: UA, JTWC, NRL
2. DAV signal extraction from the Northwest and Northeast Pacific basins.
3. Adjustment of parameters and testing of the intensity estimator for the Northwest and Northeast Pacific basins.
   Institutions involved: UA
4. Synthetic data and images generation from the numerical weather model with concentration on the Atlantic basin.
   Institutions involved: UA
5. Analysis of the DAV signals calculated from synthetic images: 1) frequency components; 2) correlation with the sea surface wind speed and pressure; 3) analysis of the atmospheric mechanisms that impact the DAV signal components.
   Institutions involved: UA
6. Preparation for the live 2011 season: intensity estimator adjustment using 2004-2010 data.
   Institutions involved: UA, NHC, JTWC.
7. Website interface development
8. Provide real-time objective intensity estimates to NHC during 2011 hurricane season.
   Institutions involved: UA, NHC

WORK COMPLETED

In the first year of the project, we have fully processed the 2004 – 2009 Atlantic hurricane seasons and developed a DAV map calculation protocol. We have trained an objective intensity estimator based on historical data and applied it to the 2009 season data as a test case. In preparation for the live forecasting exercise in 2011, we have developed a real-time version of the DAV calculation protocol that will allow the objective intensity estimates to be made as data become available. In the first year, we have also developed a data handling protocol for using MT-SAT data in the western North Pacific basin. Retrieval from archive and format conversion are handled at NRL—MRY and the data then passed to UA for pre-processing of imagery data. So far 2008 is being processed. Finally, we have initiated development of a web interface that will allow our NHC and JTWC partners to access the UA forecasting database.

RESULTS

The TC intensity estimator for the Atlantic basin was trained with 2004-2008 data, and tested with 2009 as an independent set. The root mean squared error obtained is 12.9 kt (Fig. 6), which demonstrates that the TC's axisymmetry is a reliable and simple alternative to measure the TC's intensity with remote sensing data. However, two TCs in 2009 were highly overestimated and removed from the statistics: Tropical Storm Ana and Erika. These results suggest that: 1) currently the technique should be supervised; and 2) the DAV intensity estimator might be enhanced by including more variables in the model, recall that the technique only uses the orientation of the IR gradient vectors. For this last reason, we consider that including IR pixel values and the magnitude of the gradient vectors on the analysis might improve the results. In addition, initial test has proven that the technique is able to run in real-time generating results every 30 to 60 minutes.

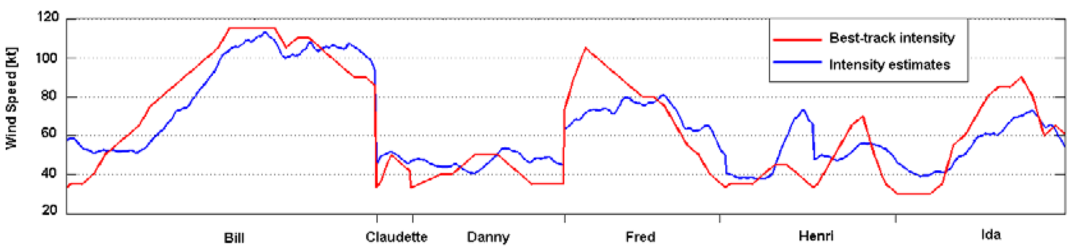

Fig. 6. Estimate intensity results for 2009 using 2004 to 2008 to training the system. The RMSE is 12.9 kt.

IMPACT AND APPLICATIONS

Quality of Life

To estimate and predict the TC's intensity, forecast centers make use of in-situ measurements that are expensive and not always available. On the other hand, satellite-based imagery provides a key, reliable source of measurements over the data-sparse tropical oceans. Several procedures have been developed to estimate the TC's intensity from satellite imagery, among the most known ones are the Dvorak technique (Dvorak 1975), and the Advanced Dvorak Technique (ADT) developed by Olander and Velden (2007). Although the first technique is widely used, it is also subjective and produces quite different estimates depending on the operator. The second technique is still being developed and has sensitive technical steps that can affect its performance (e.g. the TC pattern selection), but shows a lot of promise. The technique developed in this research is simple, easy to implement, uses only IR imagery, has a good performance, does not use pattern classification, and is a completely independent estimate of intensity. This technique has also shown the potential to describe the TC intensity trends and fluctuations through the DAV time series. For these reasons, the methodology proposed in this research has the potential to directly impact the way the forecast centers estimate TC intensity over the open ocean.

TRANSITIONS

National Security

We are working with our NHC partners to transition our product to the forecasters for use in the 2011 Atlantic hurricane season. We are also working with JTWC with hopes of transitioning by the end of 2011.

Quality of Life

Besides the papers published in scientific journals, a set of programs and a protocol have been developed at the University of Arizona, which will be executed by and tested by the National Hurricane Center (NHC) and Joint Typhoon Warning Center (JTWC).

Science Education and Communication

The PIs are organizing a special symposium at the 2011 AMS Annual Meeting in Seattle focused on communicating information on hurricane science and hurricane forecasting to the public.

The PIs as well as several of the students and researchers working on this project are developing a pilot Adopt-A-School program in Tucson that focuses on STEM education in Title 1 Elementary Schools.

RELATED PROJECTS

There are two additional projects in the research group that are related to the long-term goals.

1. “Predicting Tropical Cyclone Formation in the Atlantic Basin from GOES IR Imagery,” funded by the *NOAA HFIP Program*, 2009 – 2010 (funding pending for 2010 – 2011) and is focused on identifying and predicting tropical cyclogenesis. We are using both brightness temperature and water vapor imagery data to identify organized systems at the very early stages (prior to TD designation). This project uses a modified version of the DAV calculation for its forecast
2. “Enhancing Forecasts of Tropical Cyclone Extra tropical Transition By Statistical Pattern Recognition,” funded by the *NSF Atmospheric Sciences Division*, 2007 – 2011. In this project we are using advanced machine learning methods to develop forecasting tools to be applied to the problem of extratropical transition in the northwest pacific.

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Dvorak, V.F., 1975: Tropical Cyclone Intensity Analysis and Forecasting from Satellite Imagery. *Mon. Wea. Rev.*, 103, 420–430.

Olander, T. L. and C.S. Velden, 2007: The Advanced Dvorak Technique: Continued Development of an Objective Scheme to Estimate Tropical Cyclone Intensity Using Geostationary Infrared Satellite Imagery. *Wea. Forecasting,* 22, 287–298.

Pineros, M. F., E. A. Ritchie, and J. S. Tyo, 2008: Objective Measures of Tropical Cyclone Structure and Intensity Change From Remotely Sensed Infrared Image Data. *IEEE Transaction on Geoscience and Remote Sensing*, 46, no. 11, 3574-3580.

PUBLICATIONS

Pineros M. F., Ritchie E. A., Tyo J. S., 2010: Detecting Tropical Cyclone Formation from Satellite Infrared Imagery. 29th Conference on Hurricanes and Tropical Meteorology, Tucson, AZ, USA

Pineros, M. F., E. A. Ritchie, and J. S. Tyo, 2010: Detecting tropical cyclone genesis from remotely-sensed infrared image data. *IEEE Geoscience and Remote Sensing letters*, **7**:826 – 830 (2010)