

Augmentation of Early Intensity Forecasting in Tropical Cyclones

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LONG-TERM GOALS

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

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

OBJECTIVES

Our principal objective is to develop an objective and automatic intensity estimator of Tropical Cyclones (TCs) based on satellite infrared (IR) imagery. The proposed methodology analyzes the TC's structure to estimate their intensity, 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

The deviation-angle variance technique was introduced in Pineros et al. (2008) as a procedure to objectively estimate the intensity of tropical cyclones. The level of axisymmetry of tropical cyclones is quantified by calculating the gradient of the brightness temperature field in infrared images. The deviation-angle of these gradient vectors with respect to a radial line projected from a center indicates their level of "alignment". Fig. 1a shows an example of this calculation for a single gradient vector in a brightness temperature field. In this case the center is located at the eye of the vortex. The calculation is done for every pixel within a chosen radius of the center point, and the variance of the distribution of angles quantifies the axisymmetry of the cyclone (Fig. 1b). The deviation-angle variance (DAV) decreases as the majority of gradient vectors are pointing toward or away from the center. In contrast, the DAV increases when the orientation of the vectors is disorganized, which is characteristic of

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regular non-developing cloud clusters. The point of reference was chosen by calculating the variance of the distribution of the deviation angles for every point in the scene (Pineros et al. 2010). Fig. 1c shows an example of the map of variances. Selecting the minimum DAV in the maps produces a suboptimal value in dense overcast clouds, reason why in this study the center is determined by the best-track center estimates.

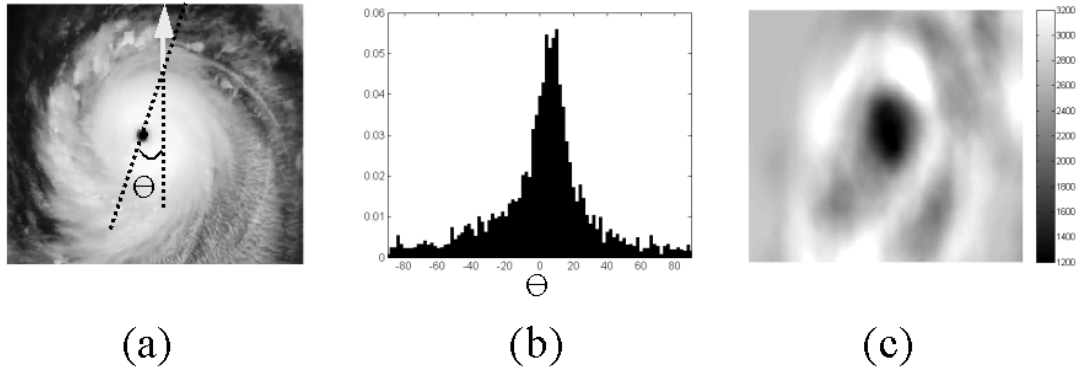


Figure 1. IR image of the Western North Pacific at 1230 UTC October 04, 2010. The image includes Typhoon Melor (72 m/s, 911 hPa): a) Deviation-angle calculation for a single gradient vector, the center is located at the eye of the tropical cyclone; b) Distribution of angles, the variance is 1216 deg²; c) Map of variances [deg²]

As described in Pineros et al. (2011), eight different radii varying from 150 km to 500 km in steps of 50 km were used to calculate the DAV signals, which are smoothed with a single-pole low pass filter (impulse response: e^{-kt}) of 0.01π rad/sample cutoff frequency (filter time constant of 100 h). After processing all the samples, the data set is divided into two groups. The first subset is used as a training set to calculate the parametric curve; the second subset tests the wind speed estimator. Fig. 2 shows the two-dimensional histogram of the filtered DAV samples (radius of 250 km) versus the best-track intensity for 40 tropical cyclones during 2007 and 2008. A sigmoid (Eq. 1) is fitted to obtain the parametric curve that describes the relation between the two variables (Fig. 2, black curve). Note that the minimum intensity allowed is 25 kt (12.86 m/s) and the maximum is 165 kt (84.9 m/s).

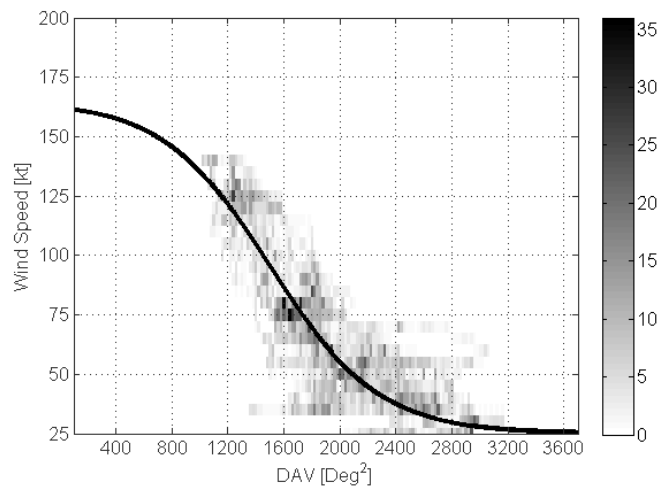


Figure 2. Two-dimensional histogram of the 250-km filtered DAV samples and best-track intensity estimates using 20-deg x 5-kt bins for 40 tropical cyclones of 2007 and 2008 in the Western North Pacific basin. The black line corresponds to the best-fit sigmoid curve for the median of the samples.

$$f(\sigma^2) = \frac{140}{1 + \exp(\alpha(\sigma^2 + \beta))} + 25 \quad [kt], \quad (1)$$

The intensity estimation is performed by calculating new filtered DAV signals and applying the parametric curve obtained in the training phase.

The development of a tropical cyclone intensity estimator for each ocean basin consists of the following tasks:

1. IR satellite imagery database construction
2. DAV signal calculation per TC
3. DAV-Intensity Parametric curve calculation
4. Testing the obtained parametric curve (estimator) with a different data set

The team at the University of Arizona is composed of the following members (italicized members are no longer working on the project):

- J. Scott Tyo, PI, (Optical Sciences – Professor)
- Elizabeth A. Ritchie, co-PI (Atmospheric Sciences - Professor)
- Miguel F Pineros (Postdoctoral associate, Optics): Construction of the image database, development of the intensity estimator and real-time application for the western North Pacific basin.
- Kelly Ryan (ATMO – M.S. Student): Synthetic image generation from mesoscale model data and mesoscale modeling.
- Kim Wood (ATMO - Ph.D. Student): Construction of the image database, development of the intensity estimator and real-time application for the eastern North Pacific basin.
- Wiley Black (Optics - Ph.D. Student): Website application design
- *Genevieve Valliere-Kelley (University of Arizona, M.S. Student, Graduated 2011): Incorporated best-track center fixes to improve intensity estimates; initial development in the eastern North Pacific basin.*
- *Brian LaCasse (Optics – Undergrad, Graduated 2011): Preprocessing of MTSAT data*
- *Arun Ganesan (ECE – Undergrad, Graduated 2011): Processing of GOES data*

The team at the Naval Research Laboratory –MRY is composed of:

- Mr. Jeffrey Hawkins (NRL – MRY)
- Mr. Richard Bankert (NRL -- MRY): Restore all available MTSAT data files from the NRL archive. Each restored file is then processed to netCDF format and placement on an ftp site for retrieval by UA and further processing.

The team members at JTWC – Honolulu are:

- Mr. Matthew Kucas (JTWC – Tech Development): assess genesis and intensity estimates for operational use in the western North Pacific. Assess website for operational utility
- Mr. James Darlow (JTWC – Tech Development):

The team members at NHC – Miami are:

- Mr. James Franklin(Branch Chief – Hurricane Specialist Unit): assess genesis and intensity estimates for operational use in the North Atlantic. Assess website for operational utility

Upcoming year work plan, tasks to complete:

1. Finish the construction of the image database for the eastern North Pacific basin:

Image storage, map projection, Matlab file conversion and TC images grouping.

Institutions involved: UA

2. DAV signal extraction from the eastern North Pacific basin.

3. Adjustment of parameters and testing of the intensity estimator for the eastern North Pacific basin.

Institutions involved: UA

4. Synthetic data and images generation from the numerical weather model with concentration on the Atlantic basin. Institutions involved: UA

5. Website interface application: UA, JTWC, NRL

WORK COMPLETED

Second year work completed includes:

- We have enhanced the tropical cyclone intensity estimator developed for the Atlantic. The procedure does not require strict supervision as the initial version of the algorithm developed in the first year of the project. The new method used best-track storm fixes as the points to compute the DAV signal. We have trained the estimator with the data from the years 2004 to 2009, and tested it with the cases of 2010.
- We obtained MTSAT data for use in the western North Pacific basin and developed preprocessing utilities that allow us to compute the DAV signal.
- We have also developed the estimator for the western North Pacific basin utilizing a similar methodology to that in the Atlantic basin. We processed the images of the years 2007 and 2008 to calculate the estimator, and 2009 as a testing set.

RESULTS

The intensity estimator for the Atlantic has been improved from the initial version. The minimum root mean square error (RMSE) is 12 kt for 2010, but values as low as 10.0 kt have been achieved for some historical years. In addition, the estimator has been partially characterized by calculating its performance according to intensity bins and magnitude of vertical wind shear. The main findings are that there is a general bias in the intensity errors that increases in magnitude as the intensity of the TC increases. In the North Atlantic basin, RMSE for tropical storm category is 11 kt, hurricane categories 1-3 is 12.5 kt, category 4 is 18 kt and category 5 is 33 kt. The main reason for such a high error at the high intensity end of the spectrum is a lack of training samples at this level of intensity that results in a parametric curve that is too low. However, the category 5 samples are only 2% of the total and 90% of the samples have an error of 12.5 kt or less.

In the western North Pacific, the RMSE for 12 tropical cyclones during 2009 is 15.7 kt (Fig. 3). The RMSE is higher for intensities above 64 kt; in particular the error is 19.2 kt for intensities greater than 113 kt. In contrast, for tropical storm intensities the RMSE is 13.75 kt. The RMSE for 80% of the samples is below 10.9 kt and 13 kt for 90% of them.

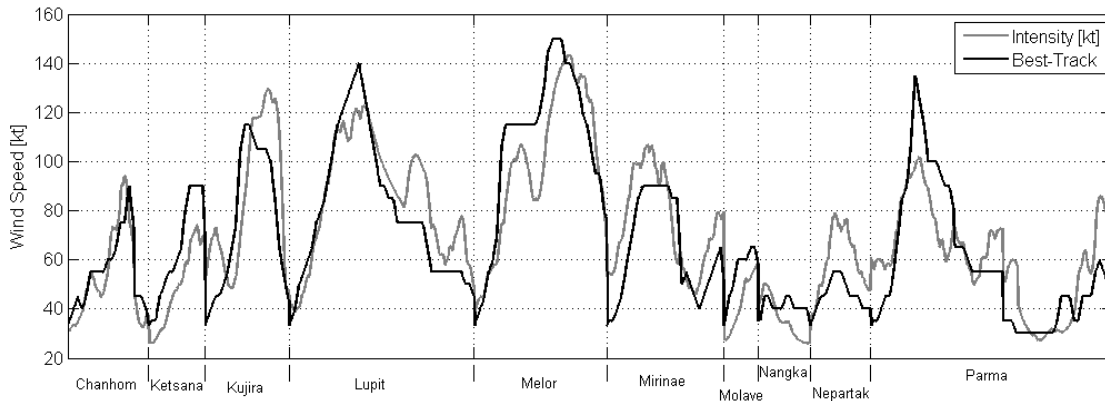


Figure 3. Intensity estimates and best-track intensities for 2009, using 2007 to 2008 to calculate the parametric curve. The RMSE is 15.7 kt.

IMPACT/APPLICATIONS

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 (e.g., Ritchie et al. 2003). 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 infrared imagery, has a good performance, does not use pattern classification, and is a completely independent estimate of intensity. For this reason, this technique can enhance the actual TC intensity estimations generated by forecast centers around the world.

TRANSITIONS

National Security

We are working with our NHC partners to transition our product to the forecasters for use in the 2012 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 website application has 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 co-PI organized 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 and Western North Pacific from GOES and MTSAT IR Imagery,” funded by the NOAA HFIP Program, 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 Extratropical 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 western North Pacific.

REFERENCES

Dvorak, V. F, 1975: Tropical cyclone intensity analysis and forecasting from satellite imagery. *Mon. Wea. Rev.*, 103, no. 5, 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.

Piñeros, 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.

Ritchie, E. A., J. Simpson, T. Liu, J. Halverson, C. Velden, K. Brueske, and H. Pierce, 2003: Chapter 12. Present day satellite technology for hurricane research: A closer look at formation and intensification. *Hurricane! Coping with disaster*, R. Simpson, ed. AGU Publications. 249-891.

Velden, C. S., B. Harper, F. Wells, J. L. Beven, II, R. Zehr, T. Olander, M. Mayfield, C. Guard, M. Lander, R. Edson, L. Avila, A. Burton, M. Turk, A. Kikuchi, A. Christian, P. Caroff, and P. McCrone, 2006a: The Dvorak tropical cyclone intensity estimation technique: A satellite-based method that has endured for over 30 years. *Bull. Amer. Meteorol. Soc.*, 87, 1195–1210.

Velden C. S., C. S., B. Harper, F. Wells, J. L. Beven, II, R. Zehr, T. Olander, M. Mayfield, C. Guard, M. Lander, R. Edson, L. Avila, A. Burton, M. Turk, A. Kikuchi, A. Christian, P. Caroff, and P. McCrone, 2006b: Supplement to: The Dvorak tropical cyclone intensity estimation technique: A satellite-based method that has endured for over 30 years. *Bull. Amer. Meteorol. Soc.*, 87, S6–S9.

PUBLICATIONS

Piñeros, M. F., E. A. Ritchie, and J. S. Tyo, 2011: Estimating Tropical Cyclone Intensity from Infrared Image Data in the western North Pacific. *Wea. Forecasting*. (*In preparation*)

Piñeros, M. F., E. A. Ritchie, and J. S. Tyo, 2011: Estimating Tropical Cyclone Intensity from Infrared Image Data. *Weather and Forecasting*, *In press*. Available at <http://journals.ametsoc.org> in early online releases.

Piñeros 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

Piñeros, 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.

Ritchie, E. A., G. Valliere-Kelley, M. F. Piñeros, and J. S. Tyo: Improved tropical cyclone intensity estimation using infrared imagery and best track data. *Wea. Forecasting* (*in preparation*).