

Improving our Understanding of Tropical Cyclone Genesis

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LONG-TERM GOALS

To improve understanding of tropical cyclone genesis through a research program combining high-resolution modeling and detailed observational studies to investigate detailed physical processes by which a tropical cyclone forms.

OBJECTIVES

The objective is to investigate the detailed physical processes that occur in a cloud cluster as it interacts with the immediate environment such that a tropical cyclone forms. Specific investigations include:

1. detailed investigation of the mesoscale processes associated with genesis.
2. detailed investigation of the microphysical properties that distinguish developing cloud clusters from non-developing cloud clusters.
3. simulations of real cases that develop within known favorable large-scale patterns in the western North Pacific.

Through diagnostic analysis of these experiments, insights will be gained that will contribute to improvement of the forecasts associated with tropical cyclone genesis, particularly in the western North Pacific Basin.

APPROACH

The primary question to be addressed is to understand the mesoscale and microphysical differences between cloud clusters that do develop into tropical cyclones and those that do not. Because the problem is not just an issue of the differences of structure within the cloud cluster itself, but is also an issue of how the cloud cluster interacts with the surrounding large-scale environment, a two-tiered approach is planned. In the first part of the research, the work of Ritchie 1995, Ritchie and Holland 1997, and Simpson et al. 1997 is extended via a series of simulations that incorporate the general structure of the western North Pacific environment but changes the mesoscale details of the cloud cluster under investigation. Through a series of high-resolution sensitivity simulations we can determine whether it is the *mesoscale* structure of the cloud cluster itself that determines whether it will develop into a tropical cyclone or not.

In this part of the research, simulations are run that focus on the mesoscale structure of developing and

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non-developing cloud clusters in an idealized framework at 1-km resolution to incorporate more realistic cloud microphysical processes, which are likely to be important in genesis processes where deep thunderstorms (Riehl and Malkus 1958) provide the initial energy required to initiate a tropical cyclone (Ritchie et al. 2003). Analysis of these idealized sensitivity simulations will help understand the mesoscale atmospheric conditions necessary for a cloud cluster to develop into a tropical cyclone.

In addition to the idealized simulations, several real-case simulations of western North Pacific genesis will be run. The PI has identified several large-scale patterns associated with cyclogenesis in the western North Pacific (Ritchie and Holland 1999) of which two patterns were found to be directly related to 70% of the genesis cases and indirectly related to another 12% over a 3-y period. Several recent cases of developing and non-developing cloud clusters within these large-scale patterns in the western North Pacific will be identified using lightning data (if available) or microwave imagery (Leary and Ritchie 2008). We would like to be able to run these simulations with initial conditions that accurately specify the 3-dimensional dynamic and thermodynamic structure of both cloud clusters that develop and those that do not. However, in practice this is not easy because of the lack of routine (sonde) observations over the tropical oceans. Instead, we turn to remotely-sensed observations and use engineering approaches developed by the PI and colleagues (e.g., Demirci et al. 2007; Pineros et al. 2008; Piñeros 2008) that work on hyperspectral imagery/pattern recognition techniques, and incorporate these into our analyses. A Ph.D. student working with the PI has already developed promising discriminators from IR imagery alone that map the development of individual tropical cyclones (Pineros et al. 2008; Piñeros 2008). This work will be extended to incorporate other IR and MW bands that provide information on cloud microphysical structure that may be important discriminators between developing and non-developing cloud clusters. Following this, initial conditions for the real-case simulations will be developed by incorporating those high-fidelity satellite-derived parameters that have been identified to distinguish between developing and non-developing cloud clusters into model analyses. The real-case simulations of cloud clusters should illuminate the important interactions between the mesoscale structure of the cloud cluster and the surrounding environment that either result in tropical cyclogenesis or causes the cloud cluster to dissipate without development.

WORK COMPLETED

Remotely-sensed data have been investigated for their ability to discriminate between developing and non-developing cloud clusters. In a companion study, lightning data from the Long-range Lightning Detection Network (LLDN) have been used in the eastern Pacific during the 2006 season to investigate differences in convective activity (and thus also microphysical differences) in cloud clusters (Lesley and Ritchie 2008). In addition, signals have been developed using infra-red brightness temperatures from the GOES satellites to detect: 1) intensity of a tropical cyclone; and 2) genesis of a tropical cyclone (Piñeros et al. 2008; Piñeros 2008). This work is being extended to include other years. Currently 2003 and 2004 have been completed.

The WRF model has been used to simulate:

1. real cases of tropical cyclogenesis in the eastern North Pacific and Atlantic matching cases investigated using the above remotely-sensed data;
2. real cases of non-developing cloud clusters embedded in apparently favorable conditions; and
3. idealized cases of tropical cyclone genesis.

Analysis of these cases is ongoing.

RESULTS

Recent results from a study that extracts information from remotely-sensed data to discriminate developing cloud clusters from non-developing cloud clusters has demonstrated skill in detecting genesis. The technique (Piñeros et al. 2008) is based on calculating an arbitrary cloud cluster's departure from axisymmetry: the more axisymmetric the cloud is, the more like an ideal hurricane.

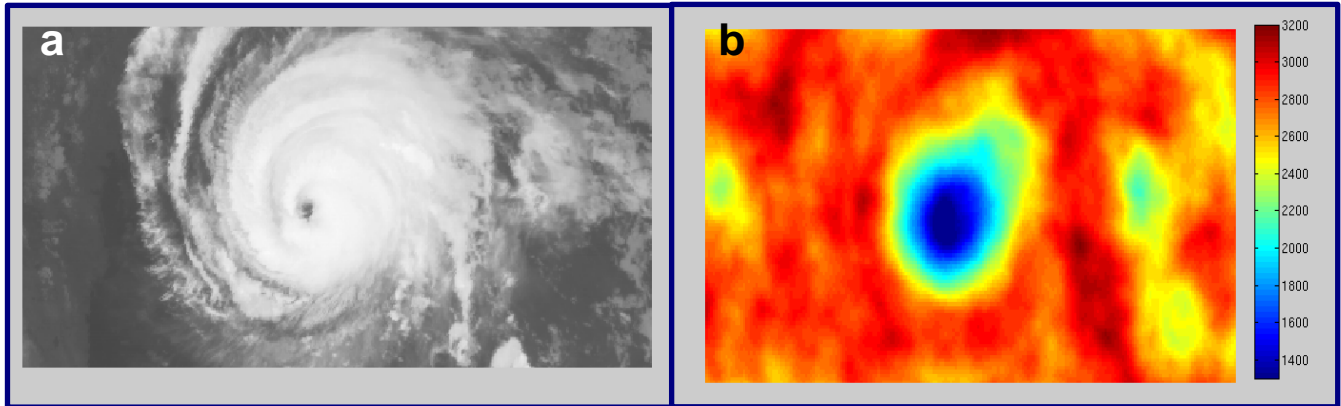


Figure 1: a) infrared image for Hurricane Katrina (2005); and b) the corresponding spatial variance pattern. Minimum variance values indicate both the center of the system and are used to develop the time series that correlates with genesis and intensity. This center-finding technique is also being assessed for its ability to objectively identify the actual center of the storm, particularly at very early stages.

When the calculated value dips below a threshold value of variance the cloud cluster will continue to develop into a tropical storm. The technique can detect genesis up to 100 hours in advance with a mean detection time of 30 hours in advance over the 2005 Atlantic season. In 2005, the technique detected 95% of the developing cloud clusters, and had a false alarm rate of 24%. This ratio can be varied depending on the threshold chosen.

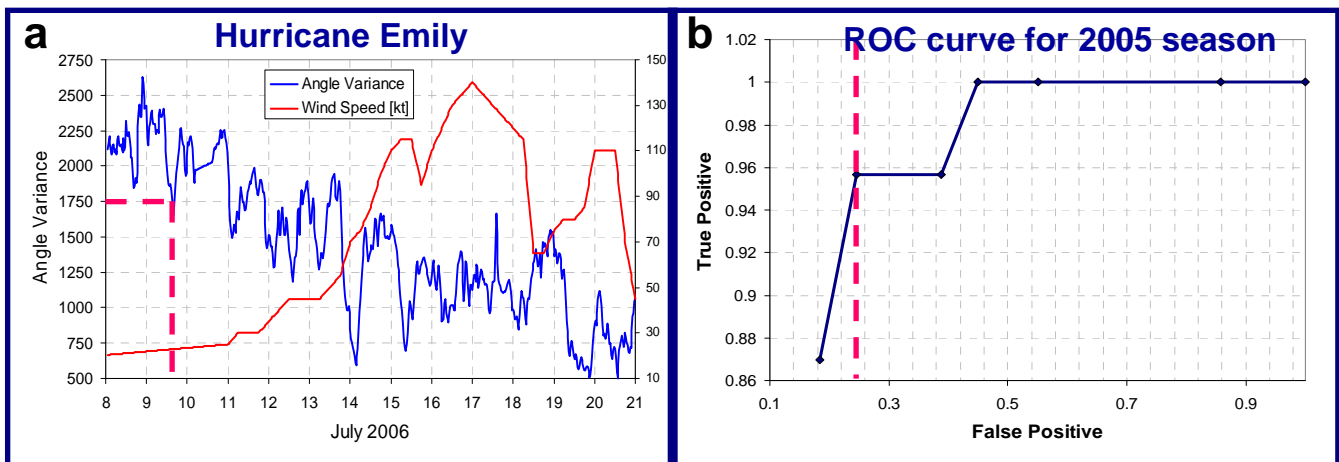


Figure 2: a) Time series for Hurricane Emily (2005) in blue with NHC best track intensities in red (on right axis). The dashed pink line indicates the first time the variance reaches a value of 1750 at ~30 h before NHC begins warning on the system and ~57 hours before the system reaches 35 kts; and b) Preliminary receiver operating characteristic (ROC) curve for detection of developing cloud clusters using the infrared technique described in Piñeros et al. (2008) for 2005 Atlantic storms.

WRF simulations of a developing cloud cluster in the Atlantic shows resemblance to actual satellite imagery of the same system as well as characteristic convective development expected from both the infrared and lightning studies (Penny and Ritchie 2008). A time series of the variance signal from the WRF simulation of Emily has been constructed and reproduces the main structure of the infrared signal. The model fields are being used to help us understand and decode the high-frequency oscillations in the variance signal that allows us to develop a better understanding of the relationship between convective pulses and storm intensity.

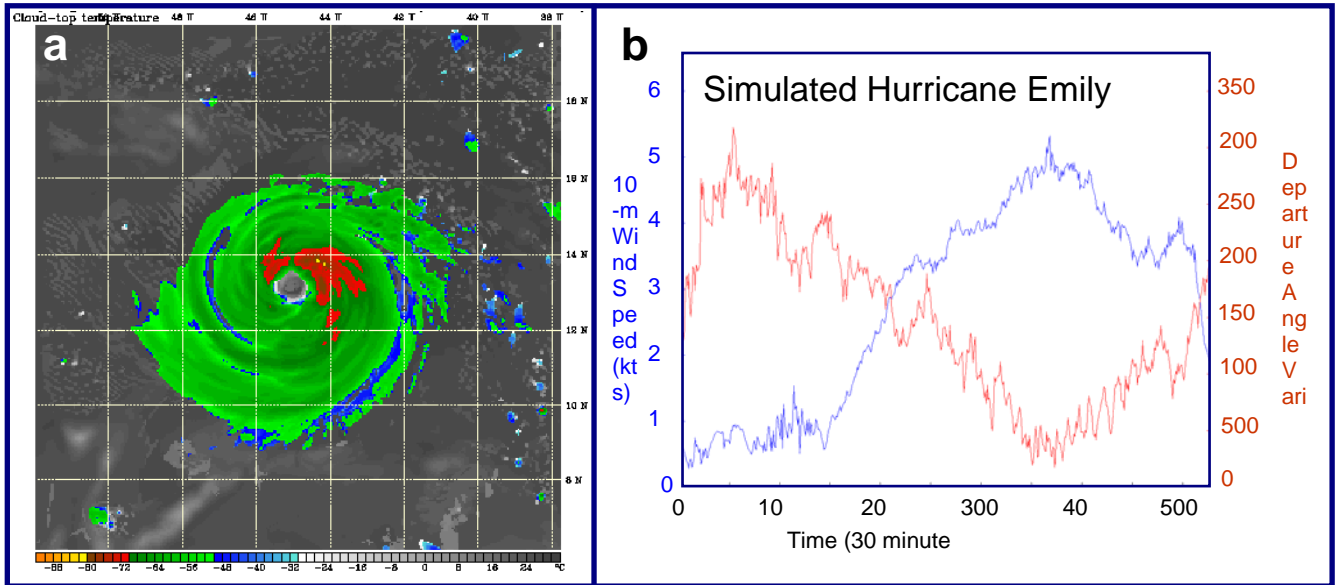


Figure 3: a) Simulated cloud-top temperatures for Hurricane Emily (2005) in the Atlantic basin; and b) Variance of the cloud-top temperatures calculated as in Piñeros et al (2008a) in red, and simulated 10-m wind speed in blue showing the negatively correlated relationship between the variance signal and intensity.

IMPACT/APPLICATIONS

A combined observational and numerical simulation study of North Pacific and Atlantic tropical cyclone genesis is being conducted. An approach is planned that will allow detailed and systematic study of the detailed mesoscale properties of potential cloud clusters and the vital interactions between these and the favorable large-scale environments in which tropical cyclones finally emerge. It is important to understand these relationships to improve the forecasting of both location and timing of tropical cyclogenesis. In addition, the documentation of high-resolution structural responses in the cloud clusters during tropical cyclogenesis will allow us to gain more insight into the physical processes that lead to genesis. The greatest value-added asset would be the possibility of more accurate prediction of genesis based on a conceptual model built from the results of the satellite analysis and systematic simulations. Thus, a potential exists for direct forecast application from the increased understanding that would result from analysis of these types of complete data.

RELATED PROJECTS

Understanding the microphysical properties of developing cloud clusters during TCS-08

N00014-08-1-0410, PI: Elizabeth A. Ritchie.

This project aims to better understand the convective and larger-scale differences between developing and non-developing cloud clusters using high-fidelity observations collected during the TCS-08 field campaign along with remotely-sensed observations. These observations will help guide and constrain high-resolution simulations of real cases in the western North Pacific during the TCS-08 period.

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- Penny, A. B., and E. A. Ritchie: Tropical cyclogenesis: A modeling comparison between developing and non-developing cloud clusters. *Proceedings of the 28th Conference on Hurricanes and Tropical Meteorology, Orlando FL, Apr 28-May 2008.*

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