

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

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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 non-developing cloud clusters in an idealized framework at 1-km resolution to incorporate more realistic cloud microphysical processes, which are likely important in genesis processes where deep thunderstorms (hot towers, Riehl and Malkus 1961) provide the initial energy required to produce a fledgling 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 et al. 2007) to identify cloud clusters that are convective. 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. 2006; Pineros and Ritchie 2006) 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 and Ritchie 2006). 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 its ability to discriminate between developing and non-developing cloud clusters embedded within similar environments. To date, lightning data from the Long-range Lightning Detection Network (LLDN) has 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 et al. 2007). The data is not available over the western North Pacific at this time.

Large-scale patterns associated with 32 cyclogenesis events (JTWC-designated) in the western North Pacific during 2004 have been identified and categorized according to the Ritchie and Holland (1999) classes in preparation for doing some real case simulations of genesis.

The MM5 and WRF models have been configured to run at 1.8-km resolution on the Linux clusters available in the Atmospheric Sciences department. This resolution will be increased as more computing power becomes available (in the near future). Test runs have been accomplished using both these models.

RESULTS

Results using Vaisala's Long-Range Lightning Detection Network (LLDN) (Demetriades and Holle, 2005), has identified differences in the lightning flash rates associated with developing cloud clusters compared with non-developing cloud clusters both over water and over land (Leary et al. 2007). These preliminary studies show a difference between the average flash counts for developing clusters (380/6h) versus non-developing clusters (43/6h: 59/6h in July) (e.g., Figures 1 and 2). Because lightning can only occur in deeply convective clouds where ice particles and supercooled droplets coexist, (Black and Hallett, 1998), these results lead to speculation that there are important microphysical differences in developing versus nondeveloping cloud clusters.

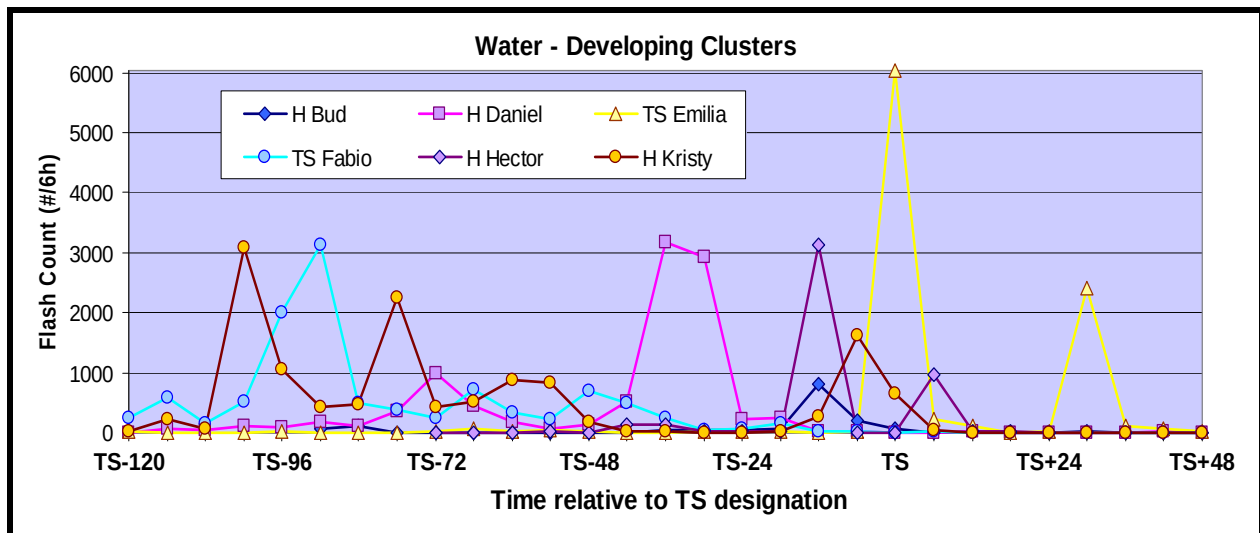


Figure 1: Flash Counts for developing cloud clusters in the eastern North Pacific during 2006 centered on a common "TS" time. July: Bud, Daniel, Emilia, Fabio. August: Hector, Kristy.

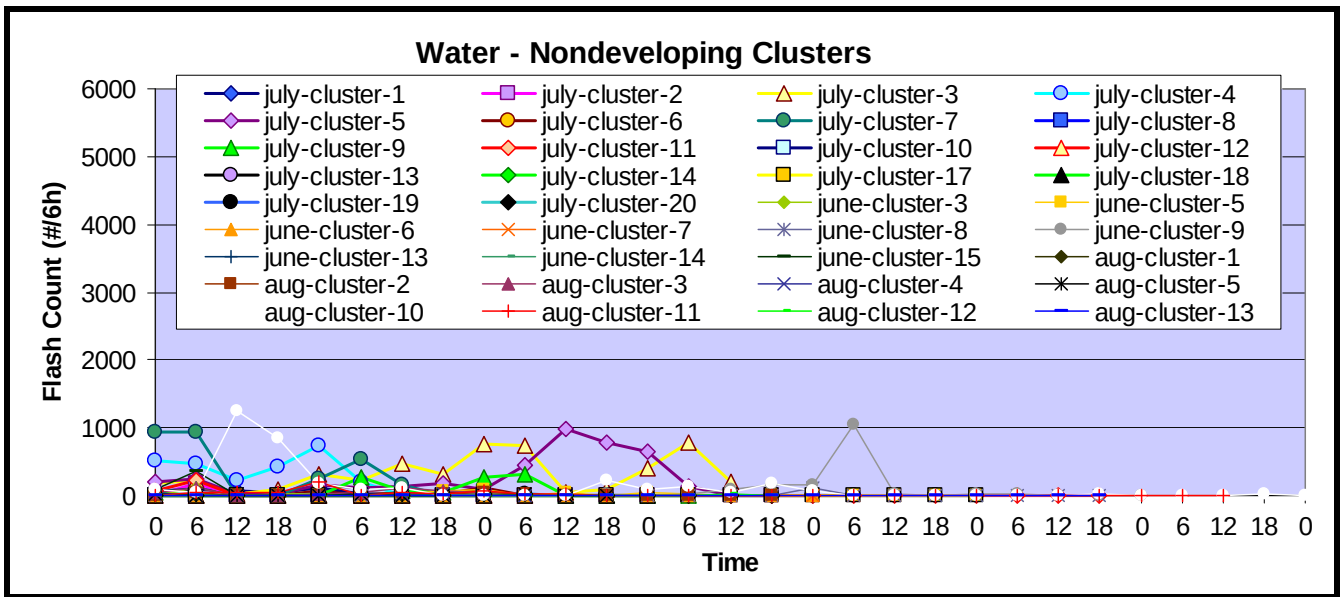


Figure 2: Time series of flash counts for non-developing clusters in June - August 2006.

Note that some “non-developing” clusters in Fig. 2 appear to have occasionally high flash counts, comparable to the flash counts for developing clusters. We have looked in more detail at aug-cluster-10, which has one flash count of over 1200 flashes per 6-h period. In this case, examination of QuikSCAT data showed a closed surface circulation with a scale of about 6 degrees latitude and surface winds of at least 45 knots (rain flagged). While it was not designated as a “TD” by NHC, it seems likely that genesis processes were occurring in this cluster.

Preliminary simulations using MM5 of a developing cloud cluster in the western North Pacific show some resemblance to actual satellite imagery of the same system as well as characteristic convective development along the lines expected from the lightning data analysis with deep convection at a maximum during the early hours of the morning (Figure 3). The lightning data analysis found 143 flashes between 0600 UTC and 1200 UTC, and 140 flashes between 1200 UTC and 1800 UTC on this day. While not the most active 24-h period (that occurred on the 15th August when TD designation was made), this is still a good indication of convective activity.

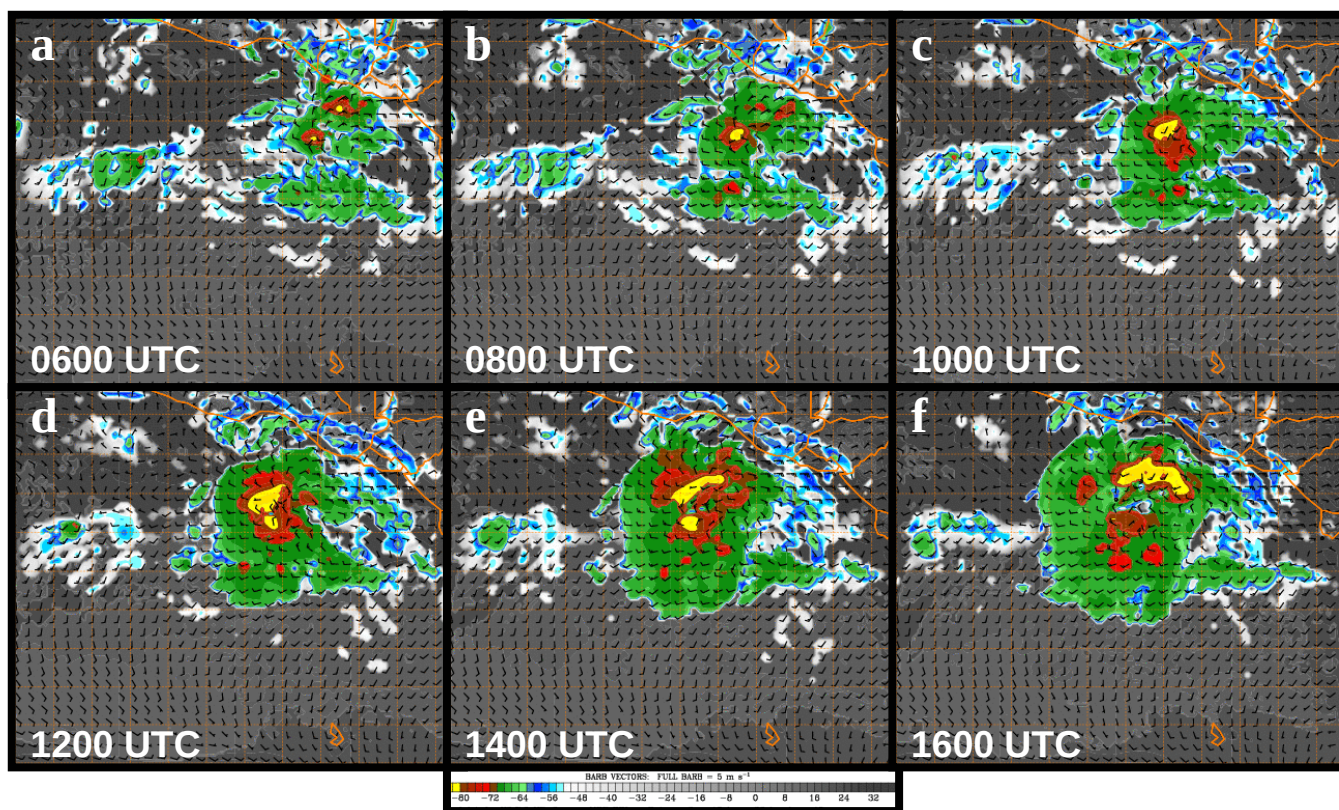


Figure 3: Simulated cloud-top temperatures for pre-Hurricane Hector in the eastern North Pacific on 14 August 2006 from Midnight to 10:00 am local time capturing the maximum in the diurnal cycle.

IMPACT/APPLICATIONS

A combined observational and numerical simulation study of North Pacific 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

None

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