

Understanding the Microphysical Properties of Developing Cloud Clusters during TCS-08

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LONG-TERM GOALS

To improve understanding of tropical cyclone genesis is through a research program that focuses on identifying the environmental and microphysical differences between developing and non-developing cloud clusters in the western North Pacific.

OBJECTIVES

The objective is to identify the environmental and microphysical differences between developing and non-developing cloud clusters in the western North Pacific. Specific investigations include:

1. detailed investigation of genesis using observations gathered during the TCS-08 field campaign.
2. detailed investigation of genesis using remote-sensed observations from platforms that are maintained on a more permanent basis including satellite-based infrared, visible, and microwave imagers and long-range lightning detectors.
3. generalized study that aims to build an ability to detect and classify developing and non-developing cloud clusters using remote-sensing platforms alone.

Through diagnostic analysis of the detailed field observations combined with remotely-sensed platforms, insights will be gained that will contribute to improvement of the forecasts associated with tropical cyclone genesis, particularly in the western North Pacific Basin.

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APPROACH

Our overarching hypothesis is that there are significant microphysical differences between developing and non-developing cloud clusters. If these differences can be identified with high-fidelity field observations then we can take two major steps to improve understanding of tropical cyclogenesis. First, we can investigate methods to identify the differences in developing and non-developing cloud clusters ahead of time. Second, because we can measure the mesoscale environment that the cloud cluster developed in, we can better understand the mesoscale environmental conditions required to form a developing cloud cluster, and we can investigate whether the vortex-stretching and concentration necessary for cyclogenesis occurs within mesoscale (100km – 300 km) stratiform updrafts, or whether it is first achieved on the smaller scale of convective scale (~10 km) updrafts that interact and contribute individually to the mesoscale vorticity concentration. The aircraft- and satellite-based observations that were gathered during the TCS 2008 field campaign (TCS-08: <http://met.nps.edu/~tparc/TCS-08.html>) will be analyzed for insights into relationships between near-cluster environment and convective activity within the cluster, and also for relationships between convective activity and overall intensification into a tropical cyclone.

WORK COMPLETED

A lightning study using the Long-range lightning detection network (LLDN) looking at differentiation between developing and non-developing cloud clusters for the eastern North Pacific 2006 season has been published (Leary and Ritchie 2009). This work is being extended using the new Vaisala GLD360 lightning dataset to include more years to improve the statistical characterization of the cluster groups and more basins, in particular the western North Pacific.

An observational study of remotely-sensed microphysical characteristics of developing and non-developing cloud clusters is ongoing. The eastern and western North Pacific basins are the focus for this work. A database of measurements from the DMSP, TRMM, and CloudSAT satellites has been compiled and comparisons with a database of developing and non-developing North Pacific cloud clusters is being investigated.

A methodology to automate the cloud cluster tracking is being developed for the entire Pacific basin. While the immediate application is to automate the lightning flash rate counts, the automated tracking will also support the broader remotely-sensed microphysical efforts. Images are stitched together from various geostationary satellites to form a contiguous scene of the Pacific. The deviation angle variance (DAV) technique described in a companion report will be used to automatically track cloud clusters. It is clear that the rare overpasses from the polar-orbiting, and LEOS satellites will allow a statistical study of the microphysical properties of developing versus non-developing cloud clusters. However, in order to make use of the cases observed during TCS-08 a different strategy is needed. Thus, we have started running a high-resolution full-physics mesoscale model on some western North Pacific cases. In these simulations, the microphysical properties of the cloud-resolving models are varied in order to assess the impact on the formation and evolution of the tropical cyclones.

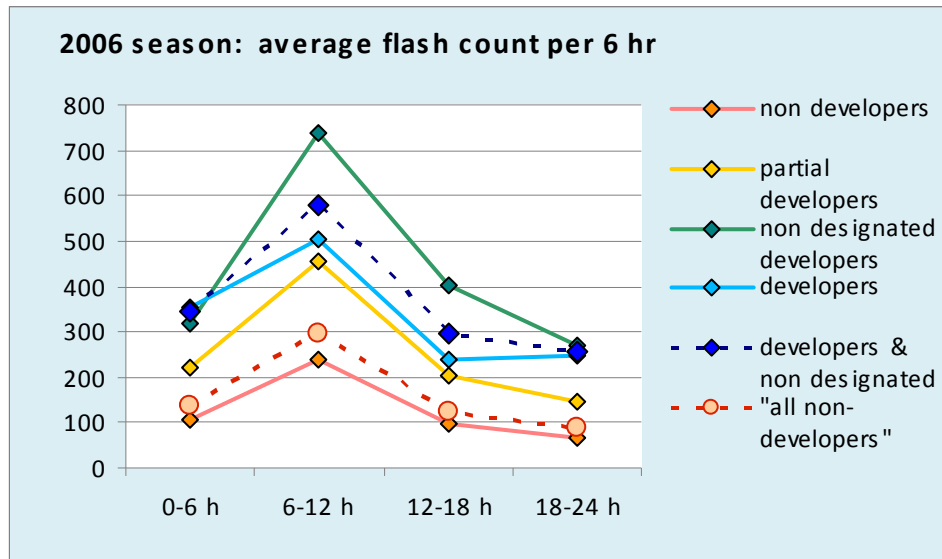


Figure 1: Average flash rates for 6-h periods for the 2006 season showing the four category classification in solid lines and combined developers (purple dashed line) and combined non developers and partial developers (red dashed line).

RESULTS

a) Lightning studies

Results using Vaisala's Long-Range Lightning Detection Network (LLDN) (Demetriades and Holle, 2005), have 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; Leary and Ritchie 2008; Leary and Ritchie 2009a, b). In this study, categories of cloud cluster development are identified in the eastern North Pacific 2006 season using lightning flash rates as an indicator of activity. Four cloud cluster classifications: 1) NHC developers (those systems declared TD by the NHC); 2) non-designated developers (those TDs that NHC did not classify); 3) partial developers (systems that had some surface forcing associated with them, but never developed a persistent closed surface circulation; and 4) non developers (all other cloud clusters that persisted for 72 hours). Figure 1 shows the average lightning strikes for 6-h periods (times are UTC on the x-axis) for the 4 categories and then combining groups 1 and 2 and groups 3 and 4. There are higher flash counts for the period 0000 UTC – 1200 UTC because detection efficiencies are higher at nighttime.

A clustering of the four groups into the two developing groups (1 and 2) and two non-developing groups (3 and 4) tested significant at the 5% level using a log-normal student's t-test (Leary and Ritchie 2009). The detection rates of these two groupings for various threshold values of lightning flash rates were calculated and plotted as an ROC curve (receiver operating characteristic curve – Figure 2). This curve summarizes the detection rate of developing cloud clusters (groups 1 and 2) compared with the false alarm rate (incorrect detection of non-developing clusters as developing clusters). The ROC curve (in tan) indicates an improvement over an earlier classification of group 1 compared to everything else (in black).

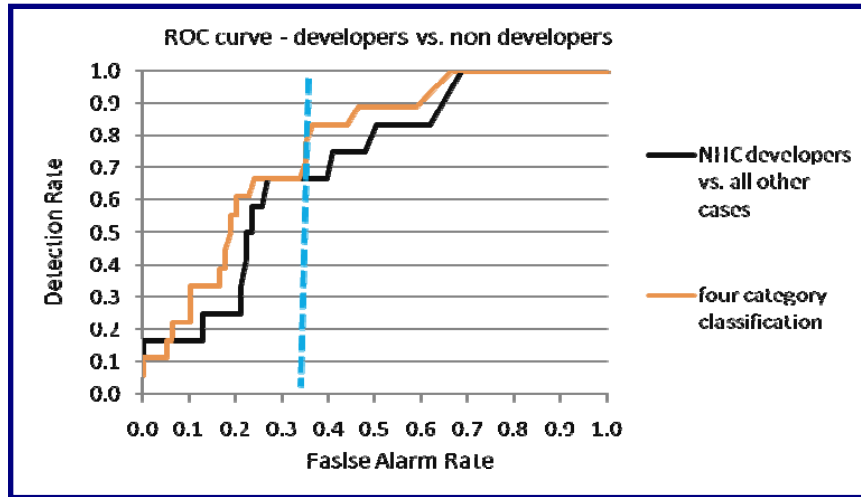


Figure 2: ROC curve for developing vs. non-developing cloud clusters using the earlier two-category classification (black line) and the final four-category classification (tan line). A detection rate of 86% and false alarm rate of 34% can be achieved using the four-category system (blue dashed line).

The thresholds were applied to “TCS” clusters in the western North Pacific during the TCS-08 field campaign for a period of approximately three weeks when lightning data were made available to the PI (Leary and Ritchie 2009b). The LLDN systems in the western North Pacific were in preliminary testing phase, and there were some problems with the data south and southwest of Japan. However, once systems that lasted less than 72 hours were removed, preliminary results showed that the average flash counts over the lifetime of all TCS clusters in that period was 139/6h. Three out of four systems that reached TD strength according to JTWC had higher than the average flash counts and eight out of nine systems that didn’t develop into TDs had lower than average flash counts. Given the early nature and the small sample of data coming in thus far, this is a promising result.

b) Remotely-sensed satellite data

In addition to the lightning data, geostationary and NASA A-Train data have been used to analyze the relationships between remotely-sensed effective radius profiles and convective intensity. Early analysis has provided mixed results regarding the properties of cloud clusters (Johnson et al. 2010). Cloud clusters with differing levels of convection should show differences in cloud microphysics at the cloud top. Consistent with this, results that tracked two cloud clusters in the eastern North Pacific during the 2006 hurricane season that formed in similar synoptic conditions over similar sea surface temperatures suggested there may be important microphysical differences above 150 hPa (Fig. 3). The reasons for these differences are still under investigation. However, it is surmised that deep convection in developing cloud clusters may be responsible for the observed differences.

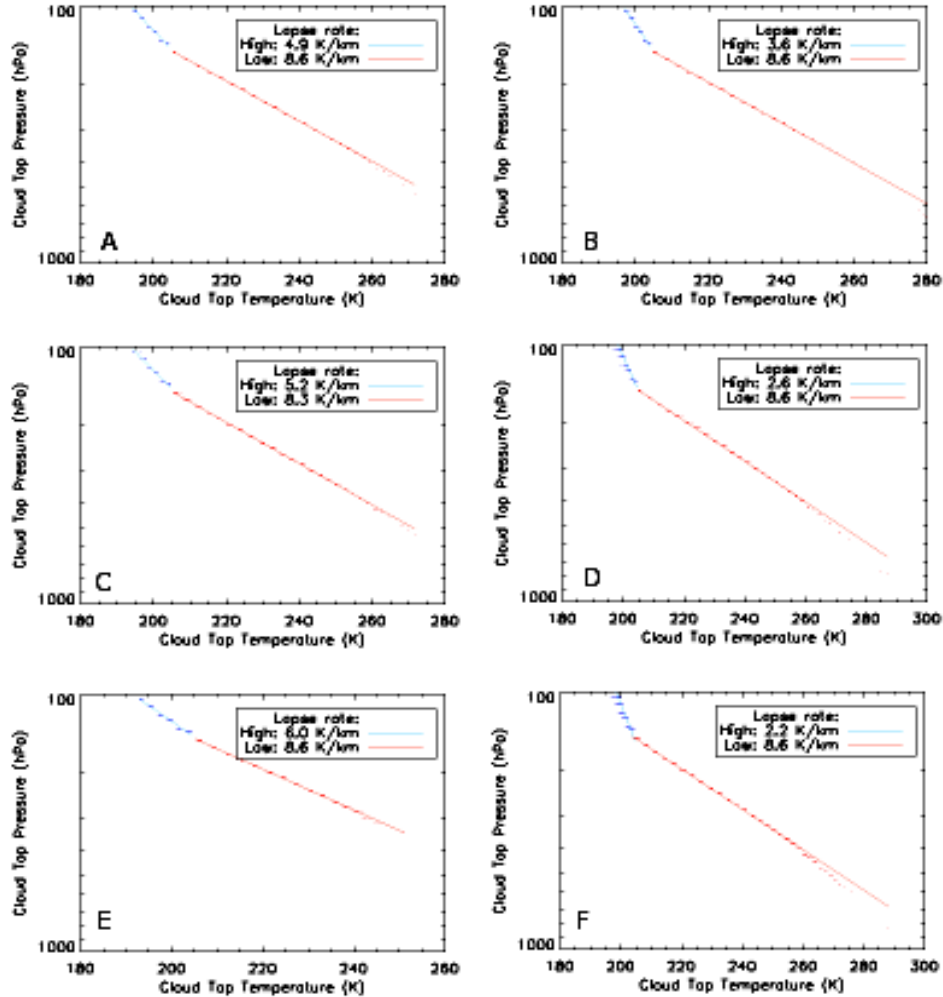


Figure 3: Lapse rate for developing (right column) and non-developing (left column) cloud cluster. The three rows represent snapshots at 12 (top), 36 (middle) and 60 (bottom) hours after the cloud cluster was first identified. Below 150 hPa (red points), the lapse rate shows little difference between the two clusters. Above the 150-hPa level (blue dots), the lapse rate for the developing cluster is always more isothermal than the non-developing cluster at the same time.

c) High resolution model sensitivity simulations

Some high-resolution (1.67-km) sensitivity simulations have been performed using Typhoon Mawar (2005) from the western North Pacific to demonstrate considerable differences in both the development of (Fig. 4), and the microphysical structure of (Fig. 5), the storm depending on what particular microphysics (cloud-resolving) scheme is used in the model. These simulations prove the concept that the mesoscale model can be used to investigate details of important microphysical properties in developing versus non-developing cloud clusters. Ongoing diagnostics that are currently being created out of the model data include maps of the cloud top pressure versus cloud top temperature in order to directly compare with the satellite observations of developing versus non-developing cloud clusters.

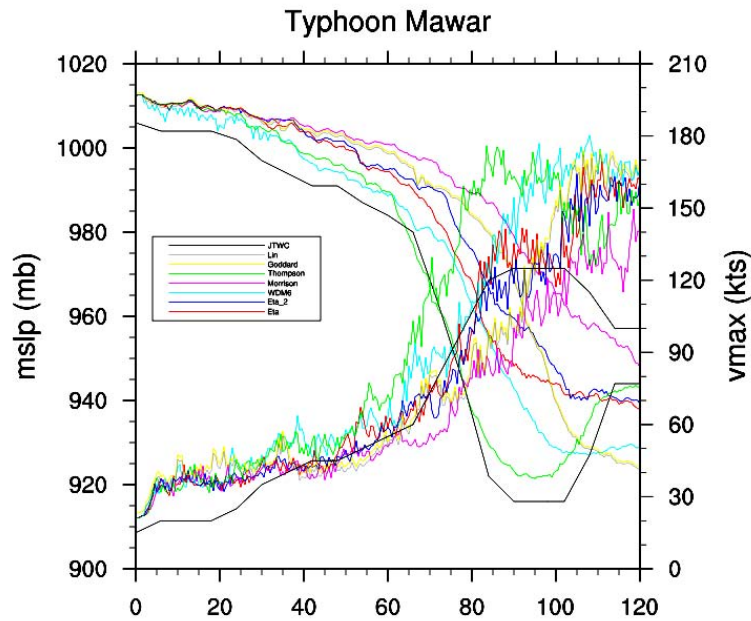


Figure 4: Intensity traces of simulated Typhoon Mawar (2005) showing sea-level pressure on the left axis and maximum wind speed on the right axis. There is considerable differences in both the speed at which Mawar develops and the final minimum sea-level pressure depending on which microphysics (cloud-resolving) scheme is chosen. All other factors are kept the same in the model setup.

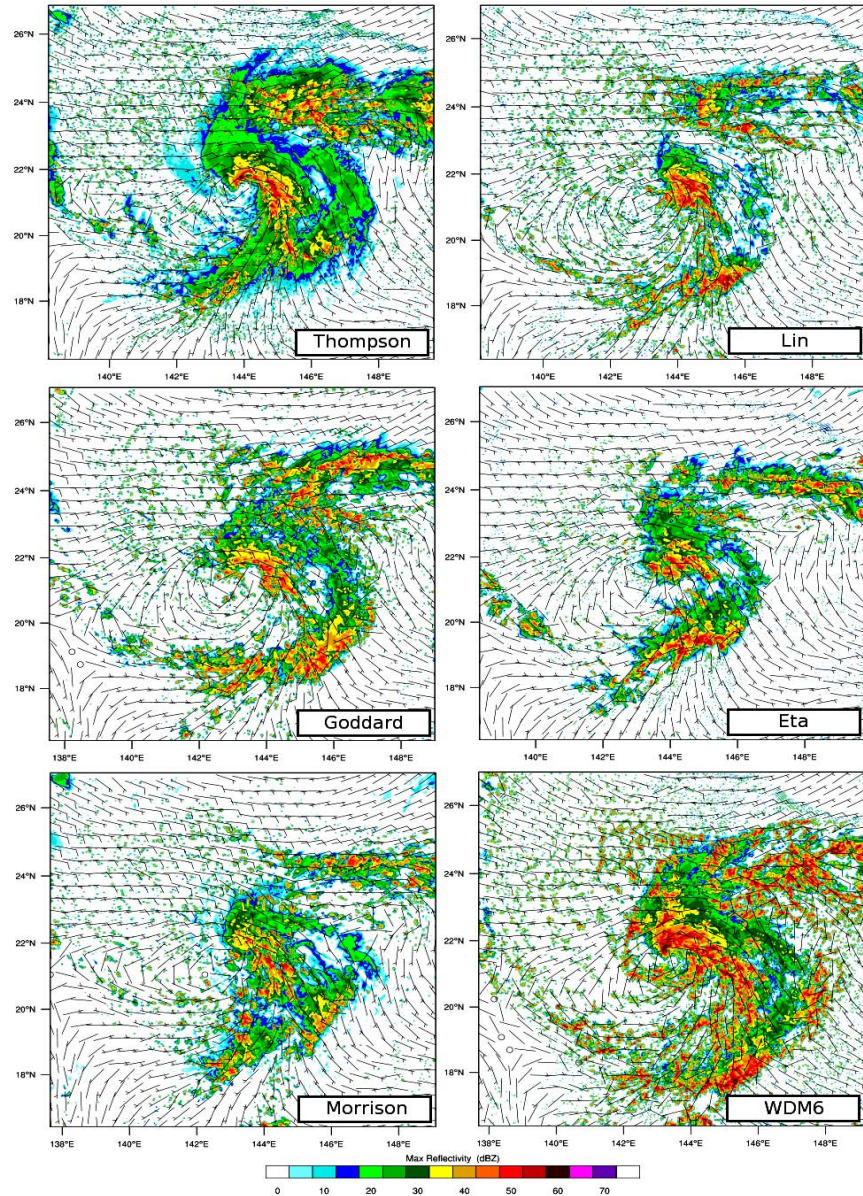


Figure 5: Simulated radar reflectivities at 36-h of simulation using the WRF model at 1.67-km spatial resolution highlighting the different convective structures obtained using different microphysical (cloud-resolving) schemes. The Thompson scheme (top left) produced a central sea-level pressure trace that most resembled the Joint Typhoon Warning Center best track intensity. However, note that the wind speed estimates are very different from the best track.

IMPACT/APPLICATIONS

An observational study of North Pacific tropical cloud clusters is being conducted. The microphysical properties of the cloud clusters (as observed from remotely-based instruments as well as special field-program platforms) are studied to see if there are clear differences in the convective structure of cloud clusters that develop compared with those that don't. 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 development of a technique that will help to accurately predict genesis of tropical cyclones using remotely-sensed data. There is already potential for this technique shown with the use of the LLDN data. Our plan is to add the GLD360 lightning data to improve the technique and make it more robust particularly for regions where the LLDN has extremely low detection efficiency.

RELATED PROJECTS

None.

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