MICROPHYSICAL PROPERTIES OF DEVELOPING VERSUS NON-DEVELOPING CLOUD CLUSTERS DURING TROPICAL CYCLOGENESIS

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1. INTRODUCTION

Significant progress has been recently made in the prediction of tropical cyclone track and intensity forecasts, but one of the aspects of the life-cycle that is not well understood are the processes involved in genesis. The question remains how a tropical disturbance transforms itself into a self-sustaining warm-core system.

Gray (1968) identified several necessary conditions for tropical cyclogenesis that exist throughout most of the tropics for most of the year. There have been several studies on the importance of scale interactions and their relation to the development of mesoscale convective vorticies.(e.g. Simpson, et al. 1997, Ritchie and Holland 1997) More recently, modeling studies (e.g. Hendricks et al. 2004, Montgomery et al. 2006) have shown that storm-scale "vortical hot towers" (VHTs) are necessary for genesis.

Using Vaisala's Long-Range Lightning Detection Network, Leary and Ritchie (2009) determined that there were differences in the flash count rate between developing and non-developing cloud clusters, which were taken as proxies for differences in the convection. Cloud clusters with differing levels of convection should show differences in cloud microphysics at the cloud top. Cloud microphysics generally refers to the interactions between solid, liquid, and gaseous water in a cloud, as well as intersections with other substances such as cloud condensation nuclei. However, in previous modeling studies of tropical cyclogenesis, these processes were generally confined to being parameterized by the terminal velocity of the ice particles. There have been few modeling studies investigating the differences in actual cloud microphysics.

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We hypothesize that vortical hot towers leave a microphysical signature that can be detected from satellite imagery several hours after they dissipate. In this presentation, we will investigate this hypothesis using quantities calculated from polar-orbiting satellites.

2. METHODOLOGY

Two cloud clusters were identified in the north eastern Pacific Ocean during the 2006 hurricane season that formed in similar synoptic conditions over similar sea surface temperatures. The developing cloud cluster was tracked from 7/12 through 7/22, while the non-developing cluster was tracked from 7/4 to 7/16. One of the cloud clusters eventually developed into Hurricane Daniel. Here we present a case study looking at similarities and differences between the microphysical properties of

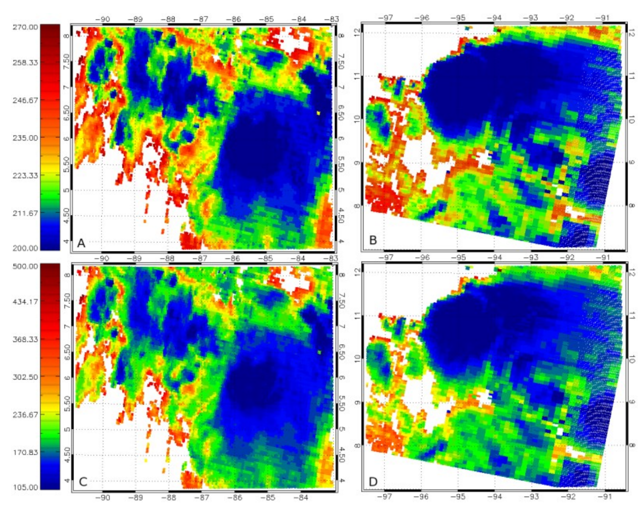

Figure 1: Cloud top temperature (colorbar in Kelvin, top row) and pressure fields (colorbar in hPa, bottom row) for a developing (right column) and non-developing (left column) cloud cluster. Both images are taken approximately 12 hours after cloud cluster identification.

the two cloud clusters.

This study uses satellite data obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) which is in a near-polar orbit and covers the entire Earth once every 1-2 days. MODIS offers several advantages over satellites in geostationary orbits. The spatial resolution is higher which allows for the identification of smaller objects. It also allows the combination of its 36 bands in novel ways to produce physically meaningful quantities. Standard MODIS products include the cloud top temperature, cloud top pressure, cloud phase, effective radius, and cloud optical depth.

Cloud clusters were tracked using the methodology outlined in Leary and Ritchie (2009). Using their cloud cluster position estimates from the 6-hour temporal resolution geostationary data, we estimated the position based on a linear interpolation to the time of the MODIS overpass. Upon visual inspection of the resulting images, this approach gives a good match with the outlines of the cloud cluster.

Figure 1 shows the cloud top pressure and temperature for the two case study cloud clusters. By visual inspection, it could not be determined which of the two will develop into a tropical cyclone, if either. Both clusters have areas of extremely cold (<70 C) and extremely high (<120 hPa) clouds with regions of lower, warmer clouds. Most of the scenes are completely covered by ice phase clouds, so they occurred after the initial deep convection leading to the development of a cirrus anvil.

Effective radius is defined as the third moment of the cloud drop size distribution divided by the second moment. This gives an average size particle weighted by the scattering efficiency. It is one of the two quantities used in general circulation models to parameterize radiation along with the cloud optical depth.

$$r_e = \frac{\int_{r_1}^{r_2} r^3 \cdot n(r) \cdot dr}{\int_{r_1}^{r_2} r^2 \cdot n(r) \cdot dr} \qquad (1)$$

Where r_e is the effective radius, r is the radius, and n(r) is the number of cloud droplets of size r.

Cloud optical depth is defined as the vertical integration of the extinction. Optical depth provides a measure of the radiative thickness of a cloud. Cirrus clouds have a low optical depth, while areas of deep convection have optical depth greater than 100.

$$\tau = \int_0^{\infty} \int_{r_1}^{r_2} Q \cdot \pi \cdot r^2 \cdot n(r) \cdot \cos(\theta) \cdot dr \cdot ds \qquad (2)$$

Where τ is the optical depth, Q is the scattering efficiency, and θ is the zenith angle.

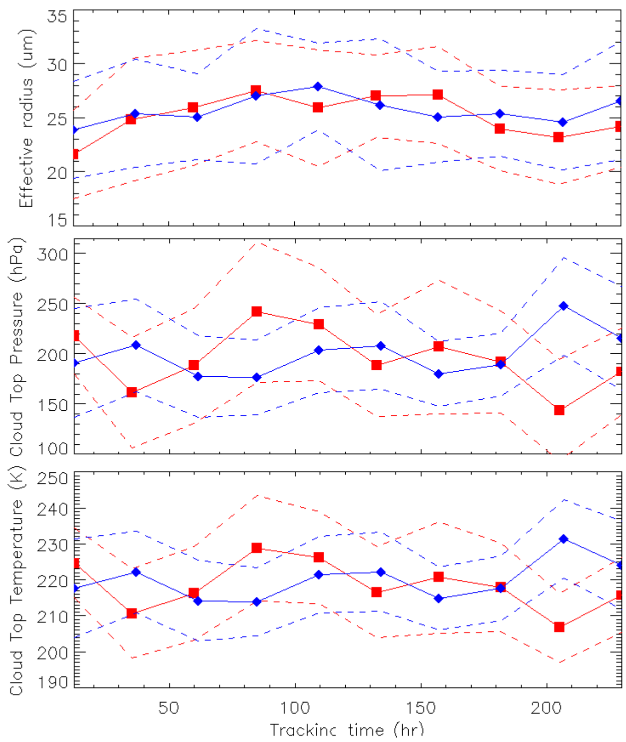

Figure 2: Time evolution of the mean cloud top temperature, pressure, and effective radius for both the developing (red) and non-developing (blue) cloud cluster. Dashed lines represent the 95% confidence intervals.

3. RESULTS AND DISCUSSION

Leary and Ritchie (2009) found that the lightning flash rate peaked around six hours after cloud clusters were first identified. The associated convection likely peaks at around the same time. However, the temporal resolution of MODIS is around 1 day so we are not able to see if cloud microphysics have significant departures at that time scale. Figure 2 shows that time evolution of the mean effective radius, cloud top temperature and cloud top pressure for both of the cloud clusters studies. The solid lines represent the arithmetic mean and the dashed lines are the 95% confidence intervals. There is no statistically significant differences between the developing and non-developing cloud clusters.

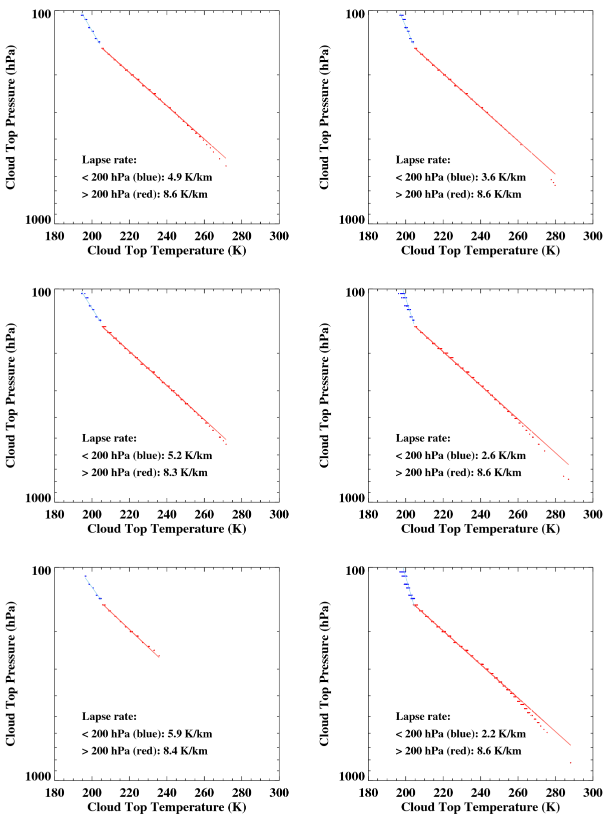

Figure 3: Lapse rate for developing (right column) and non-developing (left column) cloud cluster. The three rows represent snapshots at times of 12 (top), 36 (middle) and 60 (bottom) hours after the cloud cluster were first identified. The red points represent the lapse rate below 150 hPa, while the blue points are above 150 hPa. Below 150 hPa, the lapse rate shows no change either temporally or between developing and non-developing cluster. Above 150 hPa, the lapse rate for the developing cluster is always more isothermal than the non-developing cluster at the same time.

However, this is not unexpected. Individual cloud clusters cover a large spatial extent and the variation in microphysics over this region are likely to be large compared to the mean. Further, if such a large discrepancy existed between the microphysics of developing and non-developing clusters it is likely that it would have been noticed soon after the development of satellites capable of deriving such quantities.

Figure 3 shows the relationship between the cloud top pressure and cloud top temperature for each of the two cloud clusters. This represents an average lapse rate near the top of the cloud for the entire cloud cluster. While the time resolution is not small enough to resolve 6 hours since cloud development identified as important in Leary and Ritchie (2009), there are noticeable differences between the lapse rates between developing and non-developing clusters at pressures lower than 150 hPa, especially at 36 and 60 hours.

For all the pixels with pressures greater than 150 hPa regardless of whether the cloud cluster developed or not, or the time since the the cloud cluster was identified have extremely similar lapse rates of around 8.6 K/km. This is only slightly less than the dry adiabatic lapse rate of 9.8 K/km. One might expect that the lapse rate be nearer to the moist adiabate of ~5.0 K/km. Although, this isn't really the vertical lapse rate of temperature, it's a derived lapse rate from the cloud top pressures and temperatures over a fairly wide area.

The major difference is seen at pressures less than 150 hPa. 12 hours after cloud cluster identification, the lapse rates above 150 hPa have started to separate, with the developing cloud cluster being more isothermal. At 36 hours this is more apparent, with the developing cloud cluster having a lapse rate of 2.6 K/km compared to 5.2 K/km for the non-developing cluster.

Figure 4 shows the spatial patterns of the effective radius and the cloud optical depth screened for only pixels with cloud top pressure lower than 150 hPa. Focusing attention on the upper-right cell, there appears to be regions of both large and small effective radii where the cloud optical depth and cloud top temperature (not shown) are nearly constant. Since these high clouds are likely regions of deep convection, the areas of low effective radius are likely the “core” with the regions of higher effective radius being the generated cirrus that has begun to mix with the drier environment.

The lower-left cell shows a similar pattern but does not have the extreme small effective radii. These two areas are both likely regions of deep convection due to their low pressure, low temperature, small effective radius, and large optical depth. However, because of their large spatial extent, they are unlikely to be current hot towers. However, these regions could be the fingerprint remains of old hot towers.

The vortical nature of these regions is less clear. There appears to be semi-circular patterns within the upper-right cell, but since the next snapshot of this system is more than 24 hours in the future, it is unknown if there was vorticity within the cell.

Figure 5 shows the relationship between cloud optical depth and effective radius. In the ice phase (panel B) , there is a distinctive backwards-L shape. The vertical portion of the shape is thought be consistent with mixing processes.

As an air parcel rises in a convective tower, it does so nearly adiabatically and when it reaches the top of the troposphere it begins to mix with stratospheric air and dry air outside the core. As it does so, the optical thickness of the cloud will reduce. Depending on the relationship between the mixing timescale and the evaporation timescale will determine how the effective radius changes. If mixing is much slower than evaporation, then the smaller cloud droplets will evaporate more quickly than the large drops and the effective radius would increase. If the evaporation rate is much slower than the mixing rate then all the droplets will be evaporated at about the same rate and the effective radius will not change appreciably. This process is apparent in the vertical node in Figure 5.

The horizontal node is not well understood. There appears to be a process that modifies the effective radius but does not change the optical depth. This is seen not only in the ice clouds but in the lower mixed phase and liquid clouds as well. Reasons that would explain these observations are still being investigated.

4. SUMMARY AND CONCLUSION

This case study looked at the difference between a developing and non-developing cloud cluster. These two clusters originated in the same location, followed similar ground tracks, and the non-developing cluster survived for more than a few days, making them a good choice for in-depth study. The effective radius and cloud optical depth were looked at in detail.

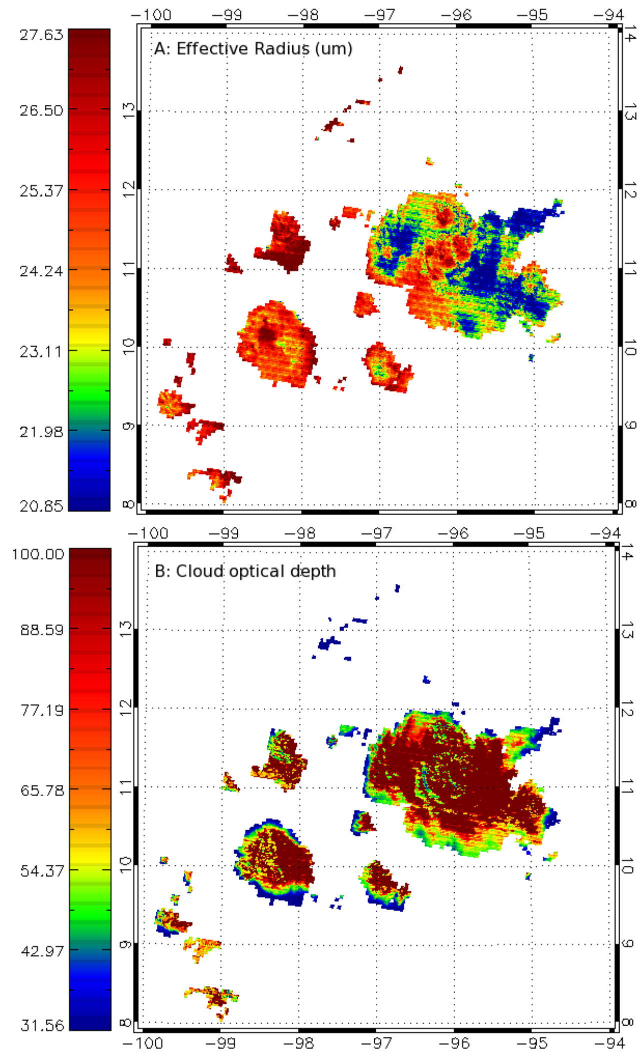

Figure 4: Cloud top effective radius (top) and cloud optical depth (bottom) for a developing cloud cluster looking at pixels where the pressure is less than 150 hPa. Both images taken approximately 12 hours after cloud cluster identification and correspond to in figure 3d.

In a modeling study of cloud microphysics, Penny and Ritchie (2008) found that a cloud cluster that developed had similar cloud top pressures and temperatures even though the developing cloud cluster had stronger updrafts. The observational results from this case study confirm that there were no statistically significant difference between cloud top temperature, pressure or effective radius for the chosen cloud clusters.

Looking at how the cloud top temperature varied with cloud top pressure showed that below 150 hPa the differences between a developing and non-developing cloud cluster are negligible. However, above 150 hPa, the developing cloud cluster had a much more isothermal profile. This was possibly due to the presence of significant overshooting tops into the stratosphere from hot towers. It was not possible to determine if these convective elements were of a vortical nature.

It was also shown that both developing and non-developing clusters have a unique "inverted-T" shape in their optical thickness-effective radius phase diagram. It was postulated that the vertical lobe of this T was due to entrainment mixing. However, the processes that cause the horizontal lobe are still under investigation.

Hopefully, further study of the differences in cloud microphysics between more developing and non-developing cloud clusters will lead to a better understanding of why some cloud clusters undergo genesis but most do not.

Acknowledgments
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References:

Gray, W.M., 1968: Global view of the origin of tropical disturbances and storms. *Mon Wea. Rev.*, **96**, 669-700.

Hendricks, E.A., M.T. Montgomery, and C.A. Davis, 2004: The role of vortical hot towers in the formation of Tropical Cyclone Diana (1984). *J. Atmos. Sci.*, **61**, 1209-1232.

Leary, L. A., and E. A. Ritchie, 2009: Lightning flash rates as an indicator of tropical cyclogenesis in the eastern North Pacific. *Mon. Wea. Rev*. **137**, 3456-3470.

Montgomery, M.T., M.E. Nicholls, T.A. Cram, and A.B. Saunders, 2006: A Vortical Hot Tower Route to Tropical Cyclogenesis. *J. Atmos. Sci.*, **63**, 355-386.

Penny, A. and E.A. Ritchie, 2008: Tropical cyclogenesis: A modeling comparison between developing and non-developing cloud clusters. 28th Conference on Hurricanes and Tropical Meteorology.

Ritchie, E.A., and G.J. Holland, 1997: Scale interactions during the formation of Typhoon Irving. *Mon. Wea. Rev.*, **125**, 1377-1396.

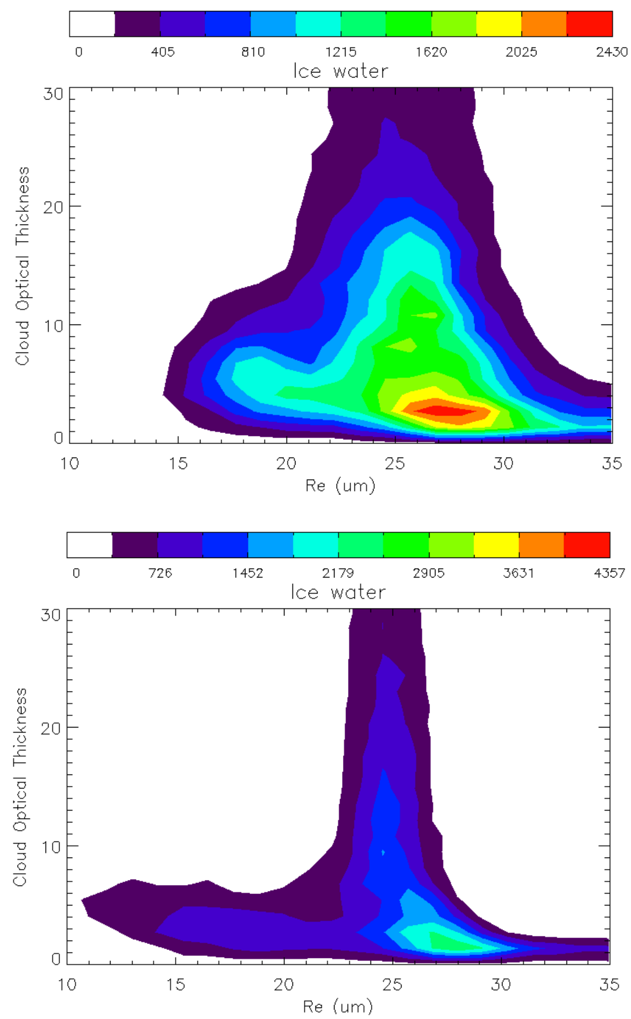

Figure 5: Phase diagram of cloud optical depth and effective radius for a non-developing (top) and developing (bottom) cloud cluster. Warmer colors indicate a higher percentage of pixels falling into that region. Both have a "backwards L" (or "upside-down" T) shape, which is more visible in the bottom pane. This shape is common among both developing and non-developing clusters.