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CLOUD MICROPHYSICS IN TROPICAL CYCLOGENESIS: INVESTIGATION OF DEVELOPING AND NON-DEVELOPING CLOUD CLUSTERS

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1. INTRODUCTION

It was not until recently that remotely-sensed observations from instruments on board polar-orbiting satellites became available, which permit analysis of the vertical structure of cloud clusters. These instruments include, but are not limited to, microwave imagers and sounders, lightning detectors, precipitation radars, and lidars, all of which operate at wavelengths that penetrate through the upper cirrus shield associated with deeply convective tropical systems allowing characterization of the cloud microphysical structure below. With these observations it is now possible to characterize the microphysical and radiative properties of clouds embedded within tropical cloud clusters. While these measurements do not have the temporal and spatial consistency of geostationary imagery, they offer an opportunity to determine those characteristics that distinguish pre-genesis cloud clusters from the rest of the population.

In this study all tropical cloud clusters during the eastern North Pacific 2009-2010 tropical cyclone seasons are examined using satellite- and other remotely-sensed observations to: 1) identify microphysical differences between developing and non-developing tropical cloud clusters; and 2) understand the processes underpinning those differences (Barnard and Ritchie 2014).

2. DATA & METHODS

The datasets include:

- NASA Moderate Resolution Imaging Spectroradiometer (MODIS): this is a 36-channel multispectral imager (King et al., 1997). The parameters investigated here include cloud-top temperature, cloud effective radius, cloud-top pressure, and cloud optical thickness.
- Vaisala Long-range Lightning detection Network (LLDN): lightning flashes are accumulated every 6 hours over the life times of all tracked tropical cloud clusters.
- NOAA Geostationary Satellites (GOES-E/GOES-W): stitched GOES-E and GOES-W half-hourly infrared (IR) imagery are used to track cloud clusters (Leary and Ritchie 2009) and quantify convective activity using the brightness temperatures.

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Developing Cloud Cluster: A cloud cluster is defined as "developing" if it reached at least a "TD" designation in the National Hurricane Center best track archives.

Non-developing Cloud Cluster: A cloud cluster is defined as a "strong non-developing" cloud cluster if it was tracked as a coherent weather disturbance continuously for at least 72 h in IR imagery but did not reach "TD" intensity in the best track and exhibited an average 24-h lightning flash count > 720 flashes.

All cloud clusters between 0-30°N, 80°W to the west coast of North America are tracked during the 2009-2010 May-November eastern North Pacific tropical cyclone seasons while over the ocean. The regions around the cloud clusters are filtered for all parameters above and statistics are accumulated over the entire population of developing and non-developing cloud clusters. For the purposes of this study only the 72-h period of strongest lightning flashes for the non-developing cloud clusters was used (Mazzarella and Ritchie 2012). The tracking resulted in 20 (12) developing and 28 (31) non-developing cloud clusters in 2009 (2010).

3. RESULTS

The percentage of pixels with brightness temperatures within 5°C increments were calculated for the 2009 and 2010 seasons for all developing and non-developing cloud clusters. Developing cloud clusters exhibit a higher percentage of colder cloud-top temperatures (Fig. 1). Non-developing cloud clusters exhibit almost no pixels colder than -70°C. Overall the figure suggests that there is more high-level cirrus and very cold cloud signatures in developing cloud clusters indicative of more active convection.

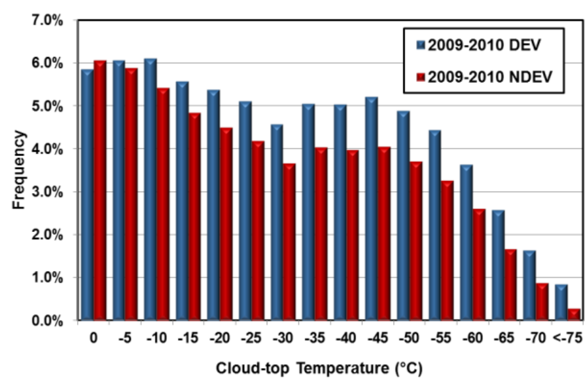

Figure 1: *Percentage of cloud top temperatures in developing and non-developing cloud clusters binned in 5°C increment bins.*

A similar tendency is obtained when looking at accumulated lightning flash rates. Figure 2 shows the average lightning flash rates per 6 hours over each cloud cluster population. There is a tendency for higher lightning activity in developing cloud clusters with a strong diurnal signal and maximum flash rates between midnight and sunrise typical of oceanic convection. Lightning flashes are indicative of deep convection with mixed-phase microphysical processes and the higher rate of lightning flashes suggests that, on the average, more active deep convection is associated with developing cloud clusters.

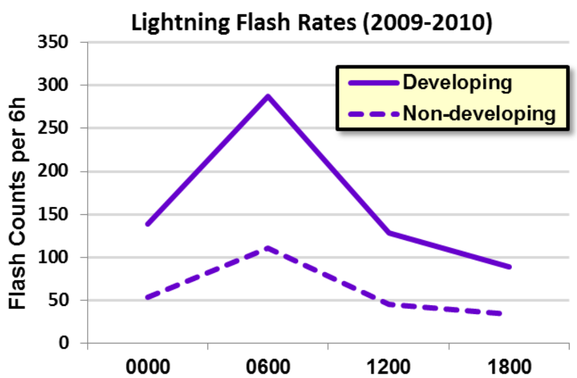

Figure 2: *Flash counts per 6 hours for developing and non-developing cloud clusters averaged over the 2009-2010 season. Note the diurnal maximum between midnight and sunrise local time.*

Furthermore, a similar picture emerges when microphysical parameters from the MODIS instrument are plotted. Figure 3 shows the COT versus CER for each population of cloud clusters over the 72 hours of strongest lighting flashes for non-developing and the 72 hours prior to TD designation for the developing cloud clusters. Despite the overall higher frequency of counts being higher for the developing cases, there is a similar shape to both plots. There are two maxima apparent, one for optically thin and small particles (thin high cirrus), and a second stronger maximum for larger particles in thicker clouds. These maxima are indicative of thin, high cirrus, and thicker, deeper cloud associated with deep convective processes.

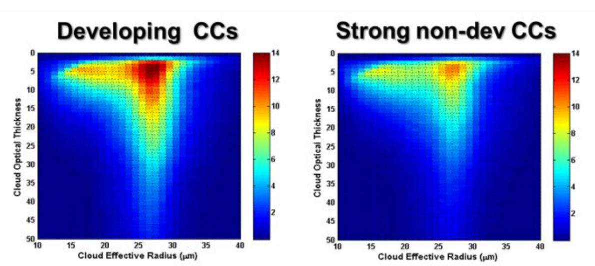

Figure 3: *Cloud effective radius versus Cloud optical thickness for developing (72 hours prior to TD) and non-developing (highest 72 hours of lightning flashes) cloud clusters.*

These results all support the well-known concept that deep convection is important for genesis processes and perhaps suggest that while convective processes occur in all tropical cloud clusters it is perhaps that pre-genesis cloud clusters have more and deeper convective activity. However, it can be shown that there are non-developing cloud clusters that exhibit higher amounts of lightning than many pre-TD cloud clusters, at least in the eastern North Pacific. Figure 4a shows the average 24-h lightning flash rates for developing and non-developing cloud clusters and Fig. 4b shows an example of several cases where non-developing cloud clusters exhibited much higher lightning flash rates than developing cloud clusters.

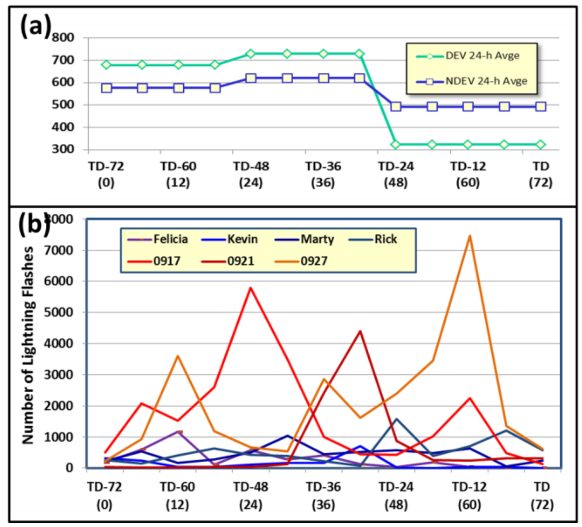

Figure 4: *a) average 24-h flash counts for all developing (aqua) and non-developing (blue) cloud clusters; and b) some individual developing (blues) and non-developing (reds) cloud clusters.*

Furthermore, Figure 4a is suggestive that while there may be overall higher flash rates (a.k.a. deep convection) in developing cloud clusters, there is a process whereby there is considerable deep convection in the 24-72 hours prior to TD, with a lull in activity for the last 24 hours prior to TD designation. This is supported in the MODIS observations when separated into 24-h bins with the same suggestion of more activity in the early periods and a lull just prior to TD designation compared with the non-developing cloud clusters, which appear to be more uniform in their progression through time (Figure 5).

There is also some interesting evidence in the MODIS cloud-top temperature and cloud-top pressure observations, which suggest that: 1) there are warmer pixels at lower pressures in developing cloud clusters; and 2) that the warming of those pixels occurs in the last 24-h period prior to TD designation (Figure 6). Note that a similar warming occurs in the non-developing cloud clusters (not shown), but about 1-2 K cooler between 95 and 105 hPa. The total temperature difference at those pressure levels over the 72-h period is approximately

1.5 K (Figure 6b). Note that this is a cloud-pixel signal, not a clear-air signal. However, it could be an intriguing early indication of warming in the upper troposphere.

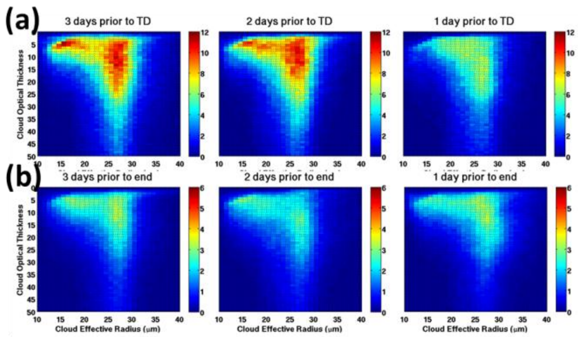

Figure 5: *a) average 24-h flash counts for all developing (aqua) and non-developing (blue) cloud clusters; and b) some individual developing (blues) and non-developing (reds) cloud clusters.*

4. CONCLUSIONS

In general, convection is more active in pre-genesis cloud clusters than in non-developing cloud clusters, although this is not true of all individual cases. However, the microphysical evolution of the cloud clusters during the 72-h leading up to genesis appear to differ from the non-developing cloud clusters with more, and more active convection early in the 72-hour period, and a more quiescent period in the 24 hours just prior to TD designation. This is supported by the overall lightning activity, the cloud-top-temperatures (not shown) and the MODIS observations, which all are suggestive of more activity in the earlier 48 hours. While this development could be an artifact of the NHC tracking procedures it could also be a real process and merits further investigation.

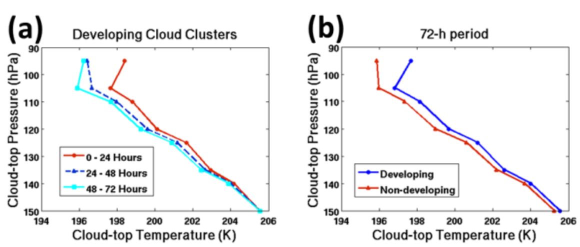

Figure 6: *a) median cloud-top-temperature versus cloud-top-pressure for each 24-h period for developing cloud clusters. A similar pattern occurs for non-developing cloud clusters but with less overall warming; and b) the 72-h comparison between developing and non-developing cloud clusters.*

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5. REFERENCES

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