18B.2 USING REMOTELY SENSED DATA TO DISCRIMINATE TROPICALCYCLOGENESIS

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1. INTRODUCTION

Trying to determine which disturbances out of the many convective tropical clusters forming in basins around the world is a challenge when analyzing or forecasting for the tropical season. With the few sources of data available in the tropics it is necessary to develop new methods of differentiation between ambient clusters and those maturing to hurricane strength. If there were a way to indicate which clusters were going to develop, or even narrow down the possibilities to clusters that have a high probability of development it would be an improvement.

To tackle this challenge, there must be a better understanding of what processes determine if a cluster will develop. Tropical cyclogenesis is defined as all of the events leading up to a system being designated as a tropical depression (TD) (Ritchie, 1995). These events are a combination of the large scale wind fields, pressure fields, distribution of relative humidity, and low level vorticity, (Gray, 1980).

Combining all of these variables in the right way can lead to a volatile and intense environment ripe for genesis. The processes during this period of development are of interest, because the development of a cluster into a hurricane is dependent on what happens during this stage. Convection, involving powerful vertical motions, heavy rainfall, and a deepening of vorticies are involved in the genesis period (Smith, 2000).

By isolating specific parameters during genesis there is a possibility of capturing the threshold at which genesis will occur. The specific event of interest in this study is tropical electrification. By using the amount of electrical activity in tropical storms as a proxy for deep convection we will identify an average flash rate that will indicate if the system will undergo genesis.

2. ELECTRIFICATION

Aside from being an exciting, and beautiful natural phenomena; lightning can be used to gain further insight into the atmospheric events it accompanies. In general cloud electrification begins with the precipitation process. In a cloud there are different temperature levels decreasing at a rate similar to the dry lapse rate, but slightly different due to the added latent heat released during condensation processes. Above the freezing level, the freezing process is initiated when the water droplet finds an ice nucleus (IN) to freeze upon. Typically water prefers an already established ice crystal or a very rare, only 1 in 1000, type of aerosol that closely resembles the crystalline structure of ice. If the water droplet is unable to find an appropriate IN, it continues in the updraft, cooling as it rises to temperatures as low as -40° C (Black and Hallett, 1998).

Considered supercooled water, these droplets are critical in the cloud electrification process. The higher these supercooled droplets are lifted, the more likely they are to collide with an IN (Black and Hallett, 1998). When this occurs, the droplet instantaneously freezes and begins to form a type of soft hail, called graupel. As more and more supercooled droplets freeze onto the chunk of graupel it becomes heavy and starts to fall through the cloud. Along the way the graupel collides with lighter ice crystals, and positive ions are transferred to the ice crystals and swept higher into the cloud with the updraft, and the negative ions are transferred to the graupel that are falling through the cloud (Ahrens, pg. 319). Thus a separation of charge occurs in the cloud, and the necessary conditions are available for lightning to occur. For separation of charge, and multiple types of water particles to be present in the cloud profile, there must be intense convection, thus we will use lightning as a proxy for convection.

Without the strong surface heating that occurs on land, it was uncertain whether convection could reach intensities strong enough for supercooled water to be present and charge separation to appear in the vertical

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profiles of tropical systems over water. (Black and Hallett, 1998). However, recent analysis of NASA DC-8 penetrations at 12 km, of Hurricane Bonnie in 1998 (Black *et al.*, 2003), showed that there were spherical (hard density graupel or ice), elliptical (rain droplets) particles, and particles that appeared as more of a smudge (low density, or wet grauple). The presence of soft graupel indicates that particles in the disturbance are forming high in the cloud by repeated collision with supercooled water droplets, as opposed to a raindrop freezing solid in lower levels of the cloud and being lifted to 12 km. Supercooled water in tropical systems remained unnoticed for so long because firstly, there are very few high altitude penetration flights in tropical storms, and secondly because thermal emissions from the supercooled water make it appear brighter on microwave images, allowing them to be easily confused with ice particles (Black *et al.*, 2003). Knowing there are supercooled particles present means there is a situation where lightning can form.

Investigation of cloud electrification assures us that only deeply convective clouds have the necessary components (strong vertical updrafts and supercooled water) to separate charge within the cloud and produce an electrical discharge. It is also known that tropical cyclones have their beginnings in deeply convective tropical cloud clusters. Lightning formed by the deep convection can be an important feature that allows us to track, and monitor the current location and strength of the system, as well as providing a means for distinguishing which cloud clusters will undergo genesis and which ones will not. Using data collected and processed by Vaisala from their Long-Range Lightning Detection Network, it may be possible to find a difference in the average lightning frequency that occur in developing tropical convective systems opposed to cloud clusters that never reach any stage of development.

2.1 Long-Range Lightning Detection Network

Vaisala controls the National Lightning Detection Network (NLDN), which is a collection of sensors across the United States that operate between 0.5 and 400 kHz. These sensors detect lightning flashes with peak frequencies near 10 kHz which fall into the Very Low Frequency (VLF) band ranging from 3-30 kHz. VLF ground waves as well as Low Frequency waves are attenuated quickly and are not useful in the region of tropical cyclogenesis being examined. Due to the earth-ionosphere structure, and the ability for NLDN sensors to operate over a broad band of frequencies, the VLF signals that reflect between the earth's surface and the ionosphere can be detected. The Long-Range Lightning Detection Network (LRLDN) can sense flashes up to thousands of kilometers away (Demetriades and Holle, 2005). The distance traveled by the VLF signal affects the quality of the signal when it is received at the sensor on land because of the number of times the signal must reflect between the Earth's surface and the ionosphere. During the daylight hours, when free electrons and ions are being produced by the photodissociation of molecules high in the atmosphere, the efficiency of the network decreases and fewer flashes are detected. Detection efficiency of the LRLDN is highest at night when the ionosphere is "uncharged," meaning there are less free electrons and ions in the atmosphere to attenuate the VLF signal during its propagation.

Mainly affected is the accuracy of the discharge amplitude, thus this parameter will not be discussed. The location of the charge, given by longitude and latitude is considered to be fairly accurate near the coasts, with efficiency tapering off further into the oceans. The daytime efficiency in the area concerned in this study (0 – 30 N, and 80 W – 130 W) ranges from 70% – 1%, with a few clusters propagating into very inefficient areas.

The reason these clusters are not removed from consideration is because the night time efficiency is high enough to give us confidence in the raw flash counts. When corrected for detection efficiency the overall results for the average night time flash rates do not differ from the raw data. Correction of the daytime detection efficiency for the average flash rates did not meet the efficiency threshold for this study and were set to zero. For this reason the raw data was used.

Another helpful parameter for efficiency of the LRLDN is the addition of the PacNet sensors from Hawaii. Although none of the clusters examined travel as far west as Hawaii, the sensors extend the area of efficiency further south than would be possible without the PacNet (Vaisala, 2006).

The complete LRLDN contains the NLDN and lightning detection networks from a number of other countries to give more thorough coverage of the oceans. Using data from the NLDN many studies have been done to investigate hurricane development and intensity (Molinari *et al.*, 1999; Demetriades *et al.*, 2006; Corbosiero and Molinari, 2002). In developed tropical systems lightning flashes can appear in distinct patterns. Spatial patterns of lightning flashes have been seen to outline the eyewall, intense rainbands, and stratiform cloud cover. Not all areas of a mature storm exhibit the same amount or intensity of electrical discharges (Molinari *et al.*, 1999; Corbosiero and Molinari, 2002). The outer rainbands, a consequence of intense convection, typically have the highest flash density of the storm (Demetriades *et al.*, 2006).

3. METHODOLOGY

In hopes of better tropical storm prediction the same technique that is applied to study known developed hurricanes can be used to compare developers prior to their designation as a tropical depression by the National Hurricane Center (NHC) and non-developing cloud clusters. This can be done by evaluating whether systems that develop show any differences in their lightning signatures compared with those that dissipate.

To try and distinguish an indicator that a particular disturbance will undergo genesis, cloud clusters in the Eastern North Pacific Basin were tracked for the entire span of their convective life. Identifying differences between systems that go through genesis and those that don't two groups were tracked: developing and non-developing clusters. The developing category includes all systems that are designated as tropical depressions (or more intense) by the NHC, and do not move over land. Upon inspection, tropical systems that move over land experience flash rates orders of magnitude higher than those over water. Due to the drastic increase of flash rates over land and difference in external forcing on the system, any disturbance that spends any time over land is excluded from the study. A system is considered a tropical depression when deep, organized convection accompanies a closed surface circulation with sustained wind less than 33 kts (www.nhc.noaa.gov, 4/4/07). A similar method of genesis classification was used examining the 24 hours prior to tropical cyclone formation alerts issued by the Joint Typhoon Warning Center when classifying tropical cyclogenesis in the Western Pacific (Ritchie and Holland, 1998).

The non-developing category includes all clusters that remained convective for 72 hours and did not move over land. Only clusters that were still active but propagated out of the boundaries (West of 130 W), and clusters that joined already existing disturbances were kept in the study if they did meet the 72 hour time requirement.

Both populations were tracked every 6 hours using GOES-East and West based infrared satellite imagery. A center location was determined for each cluster at each time period, and a latitude/longitude boundary containing the systems' deeply convective regions was recorded. Lightning flash data from the LRLDN was filtered to identify any strokes associated with the particular system being tracked, and differences between developing and non-developing cluster flash data were determined.

4. RESULTS AND DISCUSSION

4.1 Initial Results

Fifty-six cloud clusters in July, August, and September of 2006 were tracked resulting in 6 NHC designated developers and 50 non-developing clusters. Overall, the average for all periods for flash counts in non-developing clusters is approximately 275 flashes per 6 hrs higher than the developers (Table 1). The largest separation was during the 0 to 6 UTC time period with developing storms averaging approximately 350 flashes more per 6 hrs. Comparison of the average flash counts for the developers and non-developers indicates some differentiation between the two populations however, some individual clusters exhibit flash counts of similar magnitude to the NHC designated developers. It is possible there are some differences in clusters producing flash counts of this magnitude.

time (UTC)	**time (local)**	**NHC designated developers**	**non-developers**
0	4:00 PM	528	171
6	10:00 PM	690	371
12	4:00 AM	325	166
18	10:00 AM	358	117
	avg per 6 hrs.	479	205
percent of all cases		10.70%	89.30%

Table 1: averages flash counts per 6 hrs for the 2006 season. Initial classification of only NHC designated developers and non-developing cloud clusters.

4.2 Re-assessment of categorization

During evaluation of non-developing clusters in the month of July it became quickly apparent some disturbances were quite unlike the rest of the population. There were two particular clusters; July-5 and July-6 (Fig. 1), that did not exhibit overall high flash count rates for their duration, but both did have one 6 hr. period where flash counts exceeded any of the developing systems for that month.

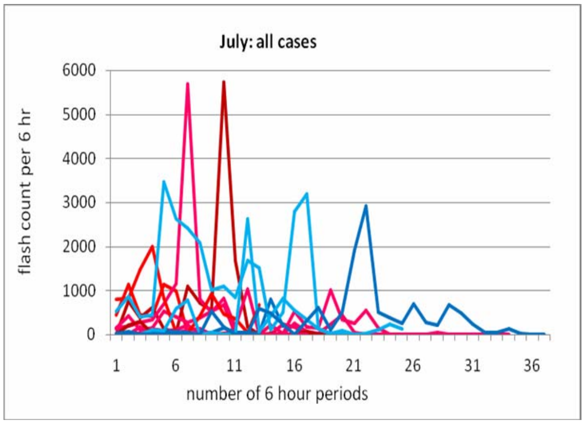

Fig. 1: Time series of all cases in July 2006. Red and pink lines are non-developers. Blue lines are developers.

In search of non-developing clusters anomalous to the group, all systems were tracked throughout their lifetime with QuikSCAT images, an ocean surface wind product from the NASA TRMM satellite. When tracking the surface winds of the clusters from the 2006 season it became clear all cases could not be grouped as strictly non-developing or developing. A four category classification was developed to fit the different features made apparent by the QuikSCAT imagery.

1 – Designated Developers: the same as in the initial classification, any system recognized as a TD by the NHC.

2 – Non-Designated Developers: any cluster with a closed surface circulation with wind speeds exceeding 30 kts that can be identified in the QuikSCAT imagery for multiple days.

3 – Partial Developers: clusters that exhibit a loose circulation or are imbedded in an open-wave and also have surface wind speeds greater than 30 kts for multiple days

4 – Non-Developers: all other clusters lasting 72 hrs or meeting previously mentioned criteria

When the previously mentioned clusters, July-5 and July-6, were re-evaluated with the four category classification, both were removed from the non-developing group. Figure 2 is a QuikSCAT image for cluster July-5. This system was categorized as a partial developer. Even though there is a 40 kt observation and very distinctive turning of the winds, this pattern is only intermittent throughout the disturbances lifetime. Rain-flagged, or black, barbs are underestimates of wind observations in areas of heavy precipitation. All of the convective clusters in this study are accompanied by heavy precipitation, which is the reason 30 kts was used as a threshold for partial development instead of the 33 kts required by the NHC (http://manati.orbit.nesdis.noaa.gov/, 4/21/08).

time (UTC)	time (local)	NHC designated developers	non-developers	partial developers	non-designated developers	all cases
0	4:00 PM	528	126	248	318	178
6	10:00 PM	690	286	513	633	382
12	4:00 AM	325	115	227	458	173
18	10:00 AM	358	80	170	299	131
avg per 6 hrs.		479	149	294	424	215
total number		6	39	7	5	56
percent of all cases		10.7%	69.6%	12.5%	7.2%	100.0%

Table 2: averages flash counts per 6 hrs for the 2006 season. Four category classification.

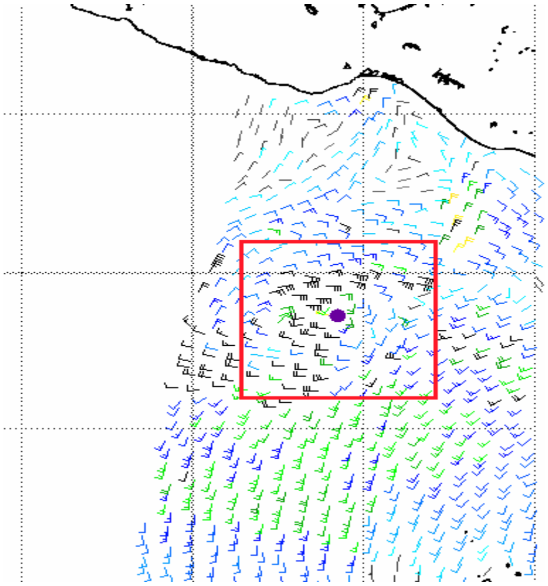

Fig. 2: QuikSCAT imagery on 7/3/06. Cluster July-5 was reclassified as a partial developer.

The best example of a non-designated developer in the 2006 season also occurs in

July. Cluster 13 is so intensely electrified it skews the 6 hr average flash count for the12-18 UTC period, raising the non-designated developer value above that of the NHC designated developers. A very clear, closed circulation and rain-flagged observations of winds up to 35 kts are present in the QuikSCAT wind product (Fig. 3). The closed circulation remained consistent throughout multiple days of the system's duration.

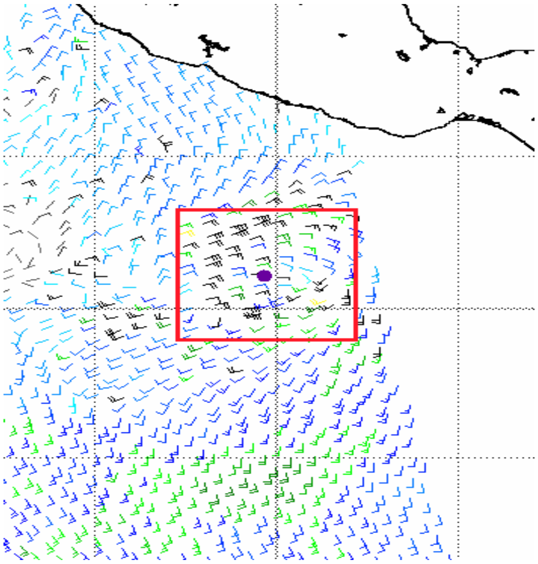

Fig. 3: QuikSCAT imagery on 7/30/06. Cluster July-13 was reclassified as a non-designated developer.

Upon separation, results of average flash count per 6 hr increase in value with the level of development achieved. The lowest group is the non-developers averaging 149 flashes per 6 hrs. Also on the low end of the development scale are the partial developers, which average 294 flashes per 6 hrs. At the very top, and incredibly close in value are the non-designated developers and NHC designated developers, averaging 424 and 479 flashes per 6 hrs respectively. With a differential of only 55 flashes per 6 hr it seems plausible the non-designated developers could be categorized with the NHC designated developer group.

Comparing the average of all cases for the 2006 season with the 4 categories of development shows a clear division between the groups (Fig. 4). The non-developers, as expected, fall below all three levels of development. Separating the non-developers from the developing and semi-developing populations is the average of all cases. For any cluster, the average value of a 6 hr period can be compared to the average of all cases for that same 6 hr period to determine whether the cluster should be in consideration for one of the levels of development.

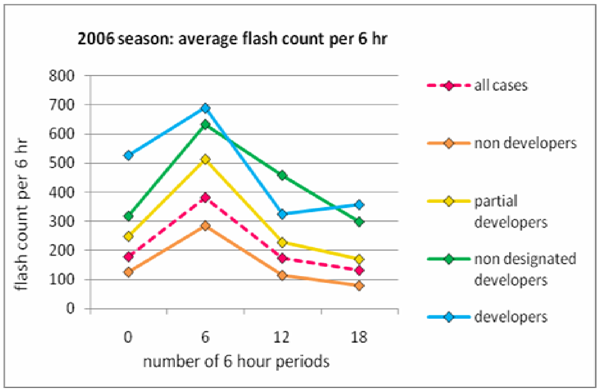

Fig. 4: average flash counts per 6 hr period for 2006 season. Dashed pink line is the average of all cases, interpreted as a threshold for development in a tropical convective cluster.

Although this threshold only includes the 2006 season, addition of multiple seasons could provide a more complete climatology for the occurrence of lightning in tropical storms in the ENP. Even more exciting is the possibility of determining thresholds that could be used operationally as a prediction tool in determining whether tropical cyclogenesis is in a disturbance's future.

5. CONCLUSION

Prediction of tropical cyclogenesis may be attainable from examining the frequency of lightning flashes in organized clusters. Although a preliminary threshold for development has been suggested, without a climatology of multiple seasons, exact values for average flash counts per 6 hr periods cannot be assessed. Regardless, this study has confirmed our original hypothesis that lighting is an indicator of tropical cyclogenesis.

For a more conclusive analysis further research should be done including multiple seasons allowing for the expansion of the NHC designated developer population. Non-developing clusters occur more frequently than developing ones, but having a range of large scale patterns non-developing clusters are imbedded in can improve understanding of deterrents to genesis as well indicators of genesis.

With a broader range of data, a more accurate climatology can be created and a more detailed breakdown of the four populations can be assessed. More than anything, this study has opened the door to many future research opportunities.

6. FUTURE WORK

This study is going to continue and expand in many different directions. Firstly, a more complete climatology of the ENP will be compiled and a climatological threshold for development can be found. Additionally, this product could be tested as a tool for determining which clusters will undergo tropical cyclogenesis, and hopefully used in the future for forecasting TD designation.

From the already existing set of filtered lightning data, analysis can be done to look for signatures of intensification in developers post-genesis. It is possible the properties of electrification in tropical storms can lead to unique characteristics currently unknown in multiple phases of developing storms maturation. In addition there will be examination of the non-developing cloud-clusters and NHC designated developers that were tracked over land to see if the results found over water hold constant over land.

AKNOWLEDGEMENTS

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