16D.5 THE ROLE OF CONVECTION IN DETERMINING TROPICAL CYCLONE GENESIS IN THE EASTERN NORTH PACIFIC

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1. INTRODUCTION

Annually, tropical meteorologists face the difficult task of analyzing and forecasting the tropical season in oceanic basins around the world. Primarily, the issue is determining which, out of the many clusters that form in the tropics, will develop into tropical cyclones. Finding an indicator of which clusters are going to develop, or even narrowing the possibilities to high probability cases would be an improvement.

To address this challenge, there must be a better understanding of what processes determine development. Tropical cyclogenesis is defined as all of the events leading up to a system being designated as a tropical depression (TD) (Ritchie, 1995). Necessary conditions for genesis to occur include a region of convective weather with upper-level divergence, lower-level convergence, low-level vorticity, and little vertical shear over the disturbance center (Gray 1968; 1980). However, these conditions are satisfied over long time scales in the tropical regions, yet potential disturbances rarely form into tropical cyclones. The synthesis of these variables in the right way can lead to a prime environment for genesis. The processes during this period of development are of great interest, because the development of a cluster into a hurricane is dependent on what happens during this stage.

Of the many processes occurring throughout the lifetime of a hurricane, the role of cumulus convection in tropical cyclone formation, as well as intensification and maintenance, remains one of the greatest research challenges. Although convection affects every stage of formation into a mature cyclone, from its role in both micro- and synoptic-scale environments, influencing temperature and moisture profiles, to deep transfers of mass and momentum throughout the troposphere, the convection occurring during a tropical cyclone's birth is of critical importance. Convection, involving powerful vertical motions, heavy rainfall, and a deepening of vortices are involved in the genesis period (Smith, 2000). Without the convective process, the many individual components of tropical cyclone formation could not merge and develop into a cohesive, dynamic, self-sustaining vortex.

A typical pre-tropical cyclone weather disturbance in the tropical Pacific is generally characterized by one or more mesoscale convective systems (MCSs) with embedded deep convection loosely organized about a central point (e.g., Fig. 1). They have been shown to be common in the tropical Pacific (Miller and Fritsch 1991) with approximately 12% developing into tropical cyclones in the eastern Pacific during 2006 (Leary and Ritchie 2008).

Recent studies (e.g., Simpson et al. 1997; Hendricks et al 2006; Tory et al. 2006) have emphasized the importance of convection during the genesis of tropical cyclones. Thus remotely-sensed indicators of convective activity might be used to differentiate between cloud clusters that develop and those that do not. By isolating specific parameters during genesis there is a possibility of discerning a threshold at which genesis occurs. The specific parameter of interest in this study is tropical electrification as a proxy for deep convection to examine differences in the convective processes between developing and non-developing tropical cloud clusters.

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2. CONVECTION

Early theoretical studies (Riehl and Malkus 1958) imply that cumulus convection is essential for the organization of an ambient system into a TD. Hot towers (HT) are the mode of vertical transport for high energy, moist surface air into the upper troposphere following the upward branch of the Hadley Cell. Oceanic air is brought to the upper parts of the atmosphere without entrainment, in isolated cores, embedded in a large vertical circulation of tropical air.

For a system to evolve from a weak, cold-core, wave like perturbation to an intensifying, warm-core tropical cyclone, cumulus convection must transform the horizontal vortex to a deep, vertical secondary circulation. With only the effects of surface friction, the breakdown of force balance creates an inward motion, convergence in the boundary layer, and eventually a vertical secondary circulation. Since surface friction is a function of height and topography, the convergence created can only be sustained in the boundary layer, and immediately begins to diverge from the center of the circulation (Smith, 2000). This shallow circulation only reaches depths of 1-2 km, a fraction of the 15-18 km expected of a mature tropical cyclone. To approach these depths the effects of cumulus convection and buoyancy must spin the low level vortex into the upper troposphere. The divergence above the boundary layer associated with surface friction can be overcome if a greater amount of air converges into the vortex at the same level. If a positive buoyancy field exists above the center of low level convergence, the near surface circulation can be lifted. The vacated column is then quickly filled in again with boundary layer air, resulting in a strong negative gradient of radial buoyancy dropping off away from the convective updraft (Smith, 2000). The narrower the column of buoyant air the easier it is for the vortex to be channeled to the upper troposphere (Anthes, 1982). Conservation of angular momentum causes the low level air spiraling into the vortex to reach faster speeds than the mean flow and intensify the circulation (Smith, 2000).

Conceptual models of tropical cyclone formation revolve around the power contributed by cumulus convection. Conditional instability of the second kind (CISK) is based on the symbiosis of a large scale vortex combining with cumulus convection to create a self-sustaining cycle of surface convergence leading to convection and latent heat release, which then amplifies the surface low causing increased surface convergence (Ooyama 1964; Charney and Eliassen 1964). More widely accepted, a wind-induced surface heat exchange (WISHE) explains the primary mode of tropical cyclone intensification by pulling heat from the ocean to aid in cumulus convection. The rapid transport of heat into the upper troposphere enhances the surface wind circulation and convergence into the system (Ooyama 1969; Rotunno and Emanuel 1987). In both scenarios the intense convective plumes produced take the form of HTs.

The most likely scenario for formation of a HT is within an environment containing excess amounts of cyclonic vorticity. Many MCSs and associated MCVs develop throughout the tropics and MCVs commonly contribute to the evolution into tropical cyclones (e.g., Harr et al. 1996; Ritchie and Holland 1997; Simpson et al. 1997), and there may provide the cyclonic vorticity-rich environment for HT development. More recently HTs have been re-examined in numerical simulations. Hendricks et al. (2004) found that in a vorticity-rich environment, ζ_a ~10^{-4} s^{-1}, intense convection favors the formation of narrow plumes (approximately 10 km) of cyclonic vorticity. Aided by warm moist air from the ocean's surface, buoyant plumes stretch and extend through the depth of the troposphere. These plumes act to produce intense mesoscale vortex tubes, which occur on the order of 10-30 km and are referred to as vortical hot towers (VHTs) (Hendricks *et al.* 2004), which occur in multiples and on relatively short time scales (approximately 1 hour). Mergers of these convectively-generated vortices and a trend toward axisymmetric orientation enhance the likelihood a particular disturbance will achieve genesis (Montgomery 2001). In addition, the large-scale vorticity converges into the MCV and smaller VHTs due to the ensuing convective activity, whether pulsing, or steady (Montgomery et al. 2006; Tory et al. 2006).

If VHTs form in the real atmosphere, they must be accompanied by deep, intense convection. Presumably the greater the convective activity, the greater the likelihood that genesis of a particular cloud cluster will occur. Thus, convective activity is theorized to be an integral part of the genesis process and an observational network capable of measuring the electrical activity within cloud clusters could be used to determine whether there are differences in convective activity in cloud clusters that develop into tropical cyclones compared with those that do not.

3. ELECTRIFICATION

Generally, cloud electrification occurs when a variety of precipitation particles are present within a cloud with a vertical extent to well below freezing. Supercooled droplets are critical components of cloud electrification. As more supercooled droplets freeze on to the graupel it becomes heavy enough to fall back through the cloud and collide with lighter ice crystals. During the processes positive charge is transferred to the ice crystals, which are lofted high into the cloud with updraft leaving a negative charge on the graupel that is falling through the cloud. Thus, there is an accumulation of negative charge in the lower parts of the cloud where the heavier graupel resides, and positive charge in the upper parts of the cloud, resulting in a separation of charge in the cloud. The highest electrification is located with the smallest ice crystals, in the lowest temperatures of the cloud (Takahasi 1978). When the separation of electric charge in the cloud is large enough, the necessary conditions are available for lightning to occur. For a cloud to contain an appreciable number of ice crystals, supercooled water drops, and graupel, there must be intense updrafts present, and by association, intense convection.

After an electrical discharge occurs, the charge centers in the cloud are reduced and the process repeats. The more intense the convective updrafts, the more rapidly charge separation can redevelop within the cloud allowing multiple flashes to occur in rapid succession. When convection becomes organized enough for the updrafts to be uninterrupted by the downdrafts, a continuous repetition of charge separation and discharge will occur. Furthermore, the rate at which lightning discharges indicates the intensity of convective updrafts. Therefore, as long as lightning can be detected, it may be possible to use lightning as a proxy for deep convection.

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. Tropical cyclones also have their beginnings in deeply convective cloud clusters. Lightning produced by deep convection can be an important feature that allows us to track, and monitor the location and strength of the system, as well as providing a means to distinguish which cloud clusters will undergo genesis and which ones will not. If deep convection is indeed one of the distinguishing features of the cloud clusters that develop compared to those that do not, then the amount of lightning flash rates of the cloud clusters should allow us to ascertain developing from non-developing cloud clusters. Using data collected and processed by the Vaisala Long-Range Lightning Detection Network (Demetriades and Holle 2005), it may be possible to find a difference in the average lightning flash rates that occur in developing tropical convective systems as opposed to cloud clusters that never reach full development.

3.1 Long-Range Lightning Detection Network

Vaisala controls the United States National Lightning Detection Network (NLDN), which is a collection of sensors across the country, operating between 0.5 and 400 kHz. These sensors detect lightning flashes that produce peak frequencies near 10 kHz and extend into the Very Low Frequency (VLF) band in the interval from 3-30 kHz. The earth-ionosphere structure and the ability for NLDN sensors to operate over a broad range of frequencies allow the VLF signals that reflect between the earth's surface and the ionosphere to be detected by the Long-Range Lightning Detection Network (LRLDN) up to thousands of kilometers away (Demetriades and Holle 2005).

The distance traveled by the VLF signal affects what is received by the land-based sensor because of attenuation due to reflection between the Earth's surface and the ionosphere. Daylight efficiency is decreased when the signal is diminished from encountering abundant charged particles created by photodissociation of molecules high in the atmosphere. Detection efficiency of the LRLDN is highest at night when these ions are not present to interrupt the VLF signal propagation. Mainly affected is the amplitude of the discharge, thus this parameter will not be used in this study. However, the detection of discharges is considered to be fairly accurate near the coasts, with efficiencies as high as 90-99% accurate, but with efficiency tapering off with increased distance from the coasts. The daytime efficiency in the region of study ranges from 70% – 1%, with a few clusters propagating into very inefficient areas (Pessi *et al.* 2008). In some areas efficiency corrections of daytime flashes did not meet the efficiency threshold for this study and flash counts during the daytime hours were frequently set to zero. These clusters are not removed from consideration because the night time efficiency is high enough to provide 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, and for this reason the raw data were used.

4. METHODOLOGY

The geographical boundaries of the study include the average genesis locations and direction of propagation of tropical cyclones in the eastern North Pacific basin between 0ºN – 30ºN, and 80ºW – 130ºW (Fig. 1). Two populations of cloud clusters during 2006 were tracked using Geostationary Observational Environmental Satellites (GOES-8 and GOES-9) infrared imagery every 6 hours from their first emergence as a deeply convective cluster with cloud top temperatures were less than -55ºC until dissipation. Due to the diurnal nature of convection there is often suppression of cloud tops from midday to afternoon. For this reason if a cluster had achieved the threshold of cold cloud tops but then abated, it was included in the study as long as the cloud-top-temperatures did not fall below the threshold for more than 12 hours.

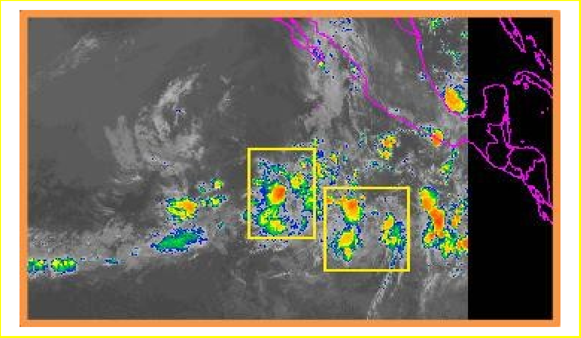


Figure 1: Yellow boxes are examples of tropical cloud clusters in the eastern North Pacific, while the orange border represents the boundaries of the study (0˚-30˚N – 80˚-130˚W). Image is from the GOES-West satellite and is valid for 1200 UTC on 9 July 2006. The black areas represent areas that must be analyzed on GOES-East.

All systems designated as tropical depressions (or more intense) in the National Hurricane Center (NHC) best track archives, and did not move over land make up the developing category. Upon inspection, tropical convection over land experienced flash rates orders of magnitude higher than oceanic convection. This drastic increase of flash rates over land and the difference in external forcing on the system resulted in rejection from the study of any disturbance that began to develop over land. A system was considered a tropical depression when deep, organized convection accompanied 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 by Ritchie and Holland (1999) when examining the 24 hours prior to tropical cyclone formation alerts issued by the Joint Typhoon Warning Center in order to classify tropical cyclogenesis in the western North Pacific.

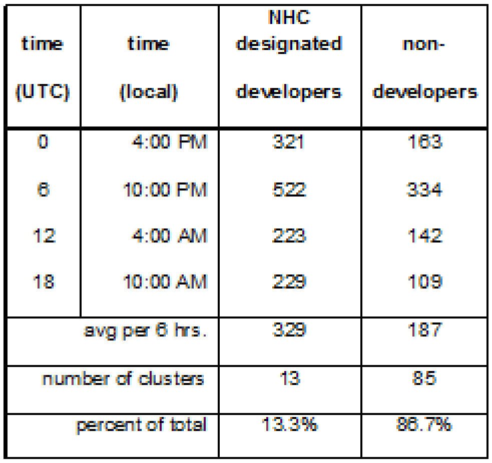
The non-developing category included all clusters that sustained convection for at least 72 hours and did not move over land or fall below cloud top temperatures of -55ºC for more than 12 hours. Only clusters that were still active but propagated out of the boundaries (west of 130ºW), and clusters that joined already existing disturbances were kept in the study if they did meet the 72 hour time requirement.

5. RESULTS AND DISCUSSION

5.1 Developers vs. non-developers

Ninety-eight individual convective cloud clusters developed in the specified region in May to November of 2006. Of the 21 storms identified by the NHC only thirteen of these qualifies as over-water clusters and reached TD status or greater, and 85 maintained convection for 72 hours and were tracked but did not develop into TDs according to the NHC.

The overall flash counts in non-developing clusters were approximately 125 flashes per 6 hrs lower than the developing clusters (Table 1). This large difference clearly suggests there is good differentiation between the two populations, and is a promising indicator that a threshold value to differentiate developing from non-developing cloud clusters can be found.



time (UTC)	time (local)	NHC designated developers	non-developers
0	4:00 PM	321	163
6	10:00 PM	522	334
12	4:00 AM	223	142
18	10:00 AM	229	109
avg per 6 hrs.		329	187
number of clusters		13	85
percent of total		13.3%	86.7%

Table 1: Average counts of lightning flashes per 6 hrs in the 2006 season for NHC designated developing cloud clusters versus all other convective clusters.

The largest separation was during the 0000-1200 UTC time period with developing storms averaging approximately 180 flashes more per 6 hrs (Table 1). Larger counts during the late afternoon to early morning can be attributed to a tendency for increased oceanic convective activity during the nighttime hours. In addition, the broadened detection efficiency of the LRLDN at night causes a bias in the detected nighttime flash counts as compared with the daytime hours. Although smaller, the actual counts and differences in the daytime rates for developing and non-developing cloud clusters scale relative to the efficiency of the daytime detection.

5.2 Four category classification

During the analysis of non-developing cloud clusters it became quickly apparent that some disturbances were quite unlike the rest of the population. Figure 2 shows a time series of 6 hourly flash counts for all non-developing cloud clusters during July 2006. Two particular cloud clusters that had one 6 hr. period where flash counts exceeded 5000, more than any developing tropical cyclone during that month, and overall average flash counts for their duration of over 450 flashes per 6h. These systems were tracked throughout their lifetime using QuikSCAT imagery, an ocean surface wind product from NASA, and evidence was found in both cases for the existence of a near-surface circulation that could support and enhance convection in that region. In fact, for one cluster there was evidence that the circulation reached tropical depression strength for a period of ~5 days (Fig. 3). Therefore, a careful analysis of all non-developing cloud clusters was undertaken using the QuikSCAT imagery and as a result, two additional categories were defined. These were non-designated developers (systems that reached TD strength but were not so designated by the NHC) and partial developers, which were systems that developed circulation at the surface but either did not continue for more than 24 hours, or never developed a closed tropical cyclone-scale circulation. The final four categories are defined as:

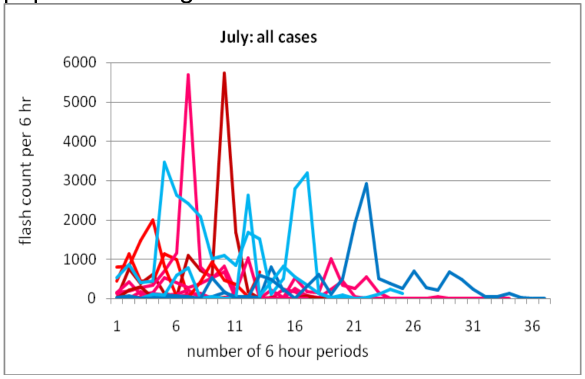


Fig. 2: Time series of all cases in July 2006. Red and pink lines are non-developers. Blue lines are developers. The two peaks in red and pink are the flash counts for the anomalous July cloud clusters discussed.

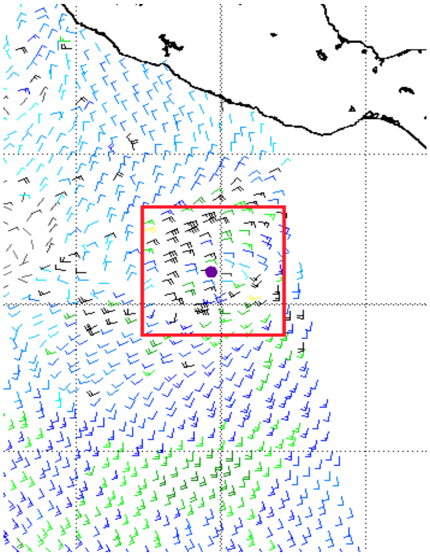


Figure 3: Sample QuikSCAT imagery for a non-developing cloud cluster in July that exhibited flash counts higher than the NHC-designated developers in a 6-h period: 30 July 2006

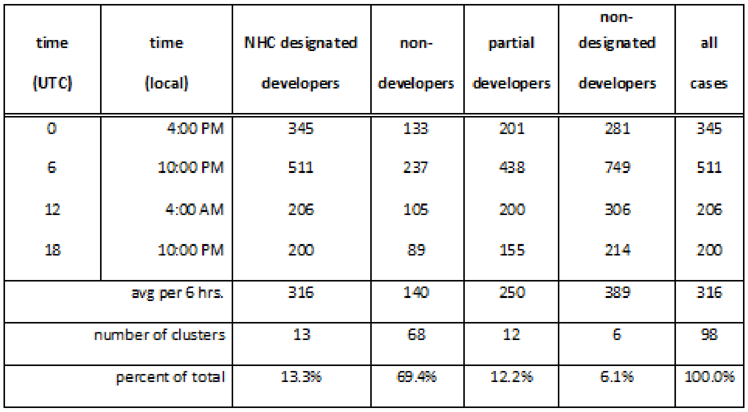
NHC-Designated Developers: This category only includes tropical cyclones that have been designated as a TD or stronger by the NHC. By their definition a tropical depression is a closed surface circulation with sustained winds less than 33 m s^{-1}. The total duration of the NHC-designated developer is determined by the length of the convective activity that can be seen from the satellite, not according to the date of TD designation by NHC. Lightning counts for this category only include flashes in the system prior to TS designation as we are interested in the lightning signal during the genesis period only.

Non-Designated Developers: Non-developing clusters that exhibit the same characteristics as the NHC-designated developers for an extended period of time, but are not recorded in the NHC best-track archive. If a closed surface circulation with wind speeds exceeding 25 kts can be identified in the QuikSCAT imagery for a minimum of 3 days the system is considered to be physically developing. An example of such a system is shown in figure 2. Note that we are not attempting to replace the NHC best track. However, there are physical characteristics associated with these un-named cloud clusters that closely resemble TDs, Thus any tracking system based purely on physical observations such as lightning flashes (and by inference, convective activity) will not differentiate these systems from those named as TD by the NHC.

Partial Developers: Also showing characteristics of the NHC-designated developers, these storms display either a loose circulation or are imbedded in an open-wave that is not closed in the large scale pattern. Partial developers may begin to rotate or have signs of development, but do not persist as a closed surface circulation for more than a few hours. Although these clusters are considered physically to be non-developing they have periods of large-scale, low-level circulation and surface wind speeds greater than 25 kts that can organize and enhance convection.

Non-Developers: The non-developing clusters are those cases that do not meet criteria for any higher level of development.

Based on this classification scheme, a total of 18 cases were re-classified from non-developing to either non-designated developers or partial developers and the flash counts for each category were recalculated (Table 2). Although the non-developers make up the majority of the cases, i.e. 69.4% were categorized as a non-developing cloud cluster, this group only produced 36.5% of the electrical activity throughout the tropical season and the average flash count was 140 per 6 hours (Table 2), the lowest flash counts in any 6-h period. Partial developers and NHC-designated developers made up 12.2% and 13.3% of the 2006 season respectively, but the developers produced slightly more lightning strikes per season, 28.3% compared to the 22.6% for the partial developers. The developers also had a higher average per 6 hour with 364 flashes, compared to 250 for the partial developers (Table 2). The non-designated developers were only 5.1% of the total population, but produced 12.7% of the electrical activity at 295 flashes per 6 hours, only approximately 70 flashes per hour less than the developing systems (Table 2).



time (UTC)	time (local)	NHC designated developers	non-developers	partial developers	non-designated developers	all cases
0	4:00 PM	345	133	201	281	345
6	10:00 PM	511	237	438	749	511
12	4:00 AM	206	105	200	306	206
18	10:00 PM	200	89	155	214	200
	avg per 6 hrs.	316	140	250	389	316
	number of clusters	13	68	12	6	98
	percent of total	13.3%	69.4%	12.2%	6.1%	100.0%

Table 2: Average flash counts per 6 hours for the 2006 season using the four category classification.

5.3 Receiver operating characteristic analysis

To test the idea of a threshold value of lightning counts above which a cloud cluster will develop into a TD, the average 6-h flash count over the lifetime of each cloud cluster was calculated and plotted as a function of the time of day, and a receiver operating characteristic (ROC) curve was derived. Used as a method of signal detection, the ROC curve compares two datasets (sensitivity and specificity, where the sensitivity represents the proportion of positive cases correctly identified, or true positives, and the specificity represents the proportion of correctly identified negative cases, or true negatives) while applying a variable threshold of detection to each population. The variable threshold for detection allows different thresholds to be applied to the same situation to analyze which level will provide the best detection and the lowest false alarm possibility.

For our purposes, a positive case will be a developing cloud cluster and a negative case will be a non-developing cloud cluster. The sensitivity in this study monitors the detection rate of positive cases (DR), and represents the percentage of developers out of all of the developers that had flash counts higher than the threshold for comparison during that period. The false alarm rate (FAR) is found by taking 1 minus the specificity (SPC), and accounts for the percentage of non-developers (or negative cases) out of the total of all non-developers that did not pass the threshold for comparison at that period. The detection rate and false alarm rate are given by

$$\mathrm{DR} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}} \qquad (1)$$

$$\mathrm{FAR} = 1 - \frac{\mathrm{TN}}{\mathrm{TN}+\mathrm{FP}} = 1 - \mathrm{SPC} \qquad (2)$$

where TN is the number of true negatives, or non-developer with flash counts below the threshold, TP is the number of true positives, or developers with flash counts above the threshold, FP is the number of false positives, or a non-developer with flash count above the threshold and FN is the number of false negatives.

Figure 4 shows the ROC curve plotted for the detection rate versus the false alarm rate for the cloud cluster average flash counts. The dashed line is the "equal chance" line. Because the ROC curve lies above the "equal-chance" line, our system has added predictability compared with, for example, tossing a coin. We can slide a vertical line along the x axis and choose a threshold value that will give us a DR for a given FAR based on the dataset. In figure 4, a threshold value of 210 flash counts per 6h (grey dashed line) over the life of the cluster gives a DR of 66.7% for a FAR of 26.7%. That is, we would expect that if we used a threshold of 210 flash counts per 6-h period over the life of the cluster (or up to TS designation for NHC developers), then we would correctly predict a cloud cluster to develop into a TD 66.7% of the time and incorrectly predict a non-developing cloud cluster to develop into a TD 26.7% of the time. If we wished to have a higher DR a lower threshold of average flash counts could be used, consequently the FAR would also increase.

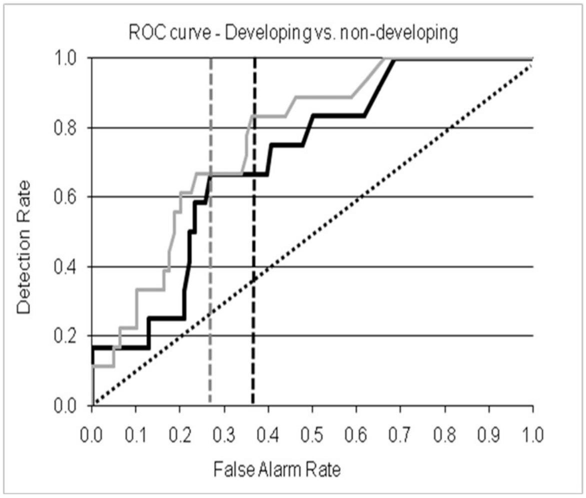


Figure 15: ROC curve for NHC-designated developers versus all other cases (black solid line) and re-grouped four category classification (grey solid line). The diagonal line represents an equal chance line for the two categories. The grey dashed line represents the threshold for differentiation between these two groups with 66.7% detection rate and a 26.7% false alarm rate. The black dashed line represents the threshold for differentiation between these two groups with 36% false alarm rate and an 83% detection rate.

The clusters were then re-grouped into two final categories: developers, including both NHC-designated and non-designated developers; and non-developers, including partial developers (the hardest to distinguish) and completely non-developing cloud clusters (the majority of the cases), which produces a good separation. The NHC-designated developers and the non-designated developers are both appear to have physical characteristics of developing systems and are grouped together for comparison to the non developing group, which contains the partial and non developing categories. With this new classification of convective clusters the ROC analysis is preformed and the new curve (grey solid line) compared to the original curve (black solid line). There is some improvement in the predictability with the new classification scheme. For the same threshold value of 210 flash counts per 6h, a 3% decrease in the false alarm rate is achieved while maintaining the same detection rate of 66.7%. Alternatively, for a FAR of 36%, the old ROC curve predicted a DR of 66.7% (threshold 125) and the new curve has a DR of 83.3% (threshold 110; black dashed line). Thus, the new ROC curve is noticeably improved from the initial classification implying an improved probability of forecasting cases genesis through lightning flash detection.

6. CONCLUSIONS

Cloud clusters in the eastern North Pacific were identified and tracked in infrared satellite imagery during May to November 2006 and categorized according to whether they developed into tropical cyclones or dissipated. LRLDN lightning flashes were then filtered for each cloud cluster and analyzed for electrical activity. The underlying assumption was that a higher flash count~~s~~ corresponds to greater convective activity within the cloud cluster and a higher likelihood of development into a tropical cyclone. The lightning discharge rates were analyzed to determine not only whether there was a difference in the convective activity of cloud clusters that develop into tropical cyclones compared with those that do not, but also to see whether there was a threshold of electrical activity that could be used to predict the development a particular system.

Initially the average flash counts per 6 hours for the 98 clusters were separated into two groups: NHC-designated developers; and all other storms. There was clear differentiation between the two populations with developers having an average 125 more flashes per 6 hours than non developing clusters. The highest flash counts were detected during the afternoon through the nighttime hours partly because of a tendency for oceanic convection to occur at night and partly because of an increased efficiency in the lightning detection system during the nighttime hours. To determine the most favorable threshold to distinguish between developing and non developing clusters, a ROC curve of the average 6-h flash counts for all cloud clusters was plotted with developers designated as positive cases and non-developers as negative cases. The ROC curve clearly showed that a threshold value of average flash counts provided improved predictability over equal chance. However, further investigation of individual non-developing cloud clusters that failed the threshold test suggested that there were levels of development of individual clouds clusters that were not appropriately identified with the original 2-category classification scheme. Using QuikSCAT imagery, all the original non-developing cloud clusters were re-classified based on convective activity and low-level circulation characteristics.

The new four category classification included: 1) NHC-designated developers (12.2%); 2) non-designated developers, which developed persistent low-level circulation and high levels of convective activity (6.1%); 3) partial developers, which contained brief periods of weak circulation or open wave low-level wind field patterns (12.2%); and 4) non developers, which echibited no low-level open wave features in the wind field but persisted in satellite imagery for 72 hours or more (69.4%).

Although it is not clear why the non-designated category were not labeled as TDs in the best track database, in terms of electrical activity they were indistinguishable from NHC-designated developers. For the purposes of determining genesis, the threshold of electrical activity would be most useful if it could differentiate between the partial and non-developing cloud clusters and the first two categories. An ROC curve was plotted and an improvement in detectability over the original two-class system was found. Using a threshold that provides the same 66.7% detection rate in the initial classification, the false alarm rate was reduced by 3% by including the non-designated developers in with the developers for analysis. Alternatively, a detection rate of 83% could be achieved with a false alarm rate of 36% with the new classification scheme.

While these results were extremely encouraging, the thresholds apply more appropriately to the peak season of June-September when 68% of the total cases examined formed. The number of cloud clusters in the months of May, October, and November were too low to allow representative sampling of all four classifications of cloud clusters.

7. FUTURE WORK

Thus, future work includes expanding dataset to include upcoming tropical seasons using Vaisala's anticipated Global Lightning Dataset 360 (GLD360) to continue building a climatology of tropical electrification and possibly expand to other basins worldwide. In this way a more representative sample from all months of the tropical cyclone season for the eastern North Pacific and other basins may be obtained. In addition, we would like to use forthcoming data to test a prediction scheme that assigns a threshold of development based on the number of flashes per 6h. This is not a true prediction system as it will not be possible to know *a priori* the average flash counts over the life of a cloud cluster that is currently in existence. In order to create a true prediction system, the data will be examined to determine whether there are time-dependent patterns in the 6-h counts that discriminate the 4 categories of development.

Also, since convection is integral in tropical cyclone genesis, an analysis of the range of convection will be performed on the 2006 eastern North Pacific tropical season. The lightning flash rates of the four categories of development will be compared to the aerial extent of low (-55ºC to -64 ºC), middle (-65ºC to -74ºC), and high (-75ºC and colder) convection to find the lighting flash density of different systems.

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8. REFERENCES

Charney, J. G., and A. Eliassen, 1964: Ont he growth of the hurricane depression. *J. Atmos. Sci.*, **21**, 68-75.

Demetriades, N.W.S., and R.L. Holle, 2005: Long-range lightning applications for hurricane intensity. Preprints, Conference on Meteorological Applications of Lightning Data, January 9-13, San Diego, California, American Meteorological Society, 9 pp.

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

Gray, W.M., 1980: Observational and theoretical aspects of tropical cyclone genesis. *Dept. Atm. Sci., CSU,* Report under Grant 80523, 1-71.

Harr, P. A., M. S. Kalafsky, and R. L. Elsberry, 1996: Environmental conditions prior to formation of a midget tropical storm during TCM-93. *Mon. Wea. Rev.*, **124**, 1693-1710.

Hendricks, E. A., M. T. Montgomery, and C. A. Davis, 2004: On the role of “vortical” hot towers in the formation of tropical cyclones. *J. Atmos. Sci.*, **61**, 1209-1232.

Leary, L. A., and E. A. Ritchie, 2008: Using remotely sensed data to discriminate tropical cyclogenesis. AMS 28th Conference on Hurricanes and Topical Meteorology, *Orlando, Florida*, April 29, 2008.

Miller, D., and J. M. Frisch, 1991: Mesoscale convective complexes in the western Pacific region. *Mon. Wea. Rev.,* **119**, 2978-2992.

Montgomery, M. T., H. D. Snell, and Z. Yang, 2001: Axisymmetric spindown dynamics of hurricane-like vorticies. *J. Atmos. Sci.*, **58**, 421-435.

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.

Ooyama, K. V., 1964: A dynamical model for the study of tropical cyclone development. *Geofis. Int.*, **4**, 187-198.

Ooyama, K. V., 1969: Numerical simulation of the life cycle of tropical cyclones. *J. Atmos. Sci.*, **26**, 3-40.

Pessi, A., S. Businger, K. L. Cummins, N. W. S. Demetriades, M. Murphy, B. Pifer, 2008: Development of a Long-Range Lightning Detection Network for the Pacific: construction, calibration, and preformance. *Journal of Atmospheric and Oceanic Technology.* (in press)

Riehl, H., and J. S. Malkus, 1958: On the heat balance in the equatorial trough zone. *Geophysical*, **6**, 503-538.

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

Ritchie, E.A., and G. J. Holland, 1999: Large-scale patterns associated with tropical cyclogenesis in the western north pacific. *Mon. Wea. Rev.,* **127***,* 187-203.

Rotunno, R., and K. Emanuel, 1987: An air-sea interaction theory for tropical cyclones. Part I: Evolutionary study using a non-hydrostatic numrical model. *J. Atmos. Sci.*, **44**, 542-561.

Simpson, J., E. A. Rithchie, G. J. Holland, J. Halverson, and S, Stweart, 1997: Mesoscale interactions in tropical cyclone genesis. *Mon. Wea. Rev.,* **125**, 2643-2661.

Takashi, T., 1978: Riming electrification as a charge generating mechanism in thunderstorms. *J. Atmos. Sci.*, **35**, 1536-1548.

Tory, K. J., M. T. Montgomery, and N. E. Davidson, 2006: Prediction and diagnosis of tropical cyclone formation in an NWP system: Part I: The critical role of vortex enhancement in deep convection. *J. Atmos. Sci.*, **63**, 3077-3090.