P1.4 TOWARD A GLOBAL CLIMATOLOGY OF TROPICAL CLOUD CLUSTERS

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1. INTRODUCTION

Tropical cyclones develop from large areas of persistent, concentrated convection, and are commonly called "cloud clusters" (hereafter "CCs"). CCs are common over much of the tropical oceans. They can be associated with easterly tropical waves, the Madden-Julian Oscillation, monsoon troughs, mid-latitude fronts that extend into the sub-tropics, or just localized areas of instability.

It is rare for a CC to transform into a tropical cyclone. For example, Hennon and Hobgood (2003) showed that about 16.5% of all CCs from the 1998-2000 Atlantic hurricane seasons produced a tropical depression. A number of studies (e.g. McBride and Zehr 1981; Lee 1989; Perrone and Lowe 1986; Hennon and Hobgood 2003; Kerns and Zipser 2009) have attempted to identify differences between "developing" and "non-developing" cloud clusters with promising but mixed results.

One difficulty is the large amount of time needed to identify and catalog CCs from satellite imagery. The work presented here describes an effort to: 1) objectively identify tropical CCs in infrared (IR) imagery in an automated fashion, 2) track movements of CCs throughout their lifetime, and 3) archive the track and many characteristics of the CC to a data file that can be easily accessed by the tropical cyclone community. These data could be valuable for tropical cyclogenesis and even climate studies.

1.1 *Definition of a Cloud Cluster*

First it is necessary to define a CC so that an algorithm to detect them can be built.

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Traditionally, there have been both qualitative and quantitative definitions of a CC. Leary and Houze (1979) view CCs as a group of individual cumulonimbus towers connected by a common cirrus shield. Machado et al. (1992) looked for adjacent cloud cells with a brightness temperature (T_b) of 253 K or lower. Machado and Rossow (1993) provided an average T_b in the range of 221K-229K for another study. Kerns and Zipser (2009) used a much warmer T_b of 270 K in order to include time periods in between convective maxima.

Perhaps the most pertinent guidance for defining a CC in imagery is from Lee (1989). He stated a cloud cluster must be: 1) an independent entity, 2) at least 4° in diameter and not elongated in shape, and 3) located no farther than 17.5° from the Equator. CC size, location, and independence are among those variables used to identify CCs in this study.

1.2 *Characteristics of Cloud Clusters*

Much of our understanding of CCs comes from the GARP Atlantic Tropical Experiment (GATE). Martin and Shreiner (1981) examined 526 cloud clusters that moved through the GATE array. They found that the average lifetime of a CC is 28 hours, with a range of 6 hours to 6 days. The size of the CC was found to be highly correlated with its duration. The average CC area was 2×10^5 km^2, which corresponds to a radius of 252 km. Machado and Rossow (1993) found that 20% (80%) of a CC area is convective (stratiform) in nature.

2. DATA

GRISAT is the satellite data used to track the CCs. GRISAT is a global version of the HURSAT satellite data (Knapp and Kossin 2007) with additional remapping resolution and calibration normalization. We use the global best track dataset (IBTrACS, Knapp et al. 2010) to eliminate developed (e.g. tropical depression, storm, hurricane) cyclones from the cloud cluster database. IBTrACS contains tropical cyclone tracks from every forecast and analysis center that produces them.

3. METHODOLOGY

The algorithm identifies tropical CCs by judging a candidate's convective intensity, size, independence, and persistence. Furthermore, the CC must be located over water. Each of these parameters will be discussed below.

3.1 *Convective Intensity and Structure*

The first algorithm pass identifies satellite pixels that are colder than a pre-determined threshold value. The threshold value varies by basin and was determined by sampling IR brightness temperatures (T_b) in each basin during its respective tropical cyclone season. The top 2% coldest pixels were considered strong enough to represent deep convection. Table 1 shows the threshold T_b values; thresholds were "blended" at the basin boundaries to provide smooth transitions between basins. Values are of similar magnitude to some of the definitions of CCs presented in Section 1.1.

IBTrACS Basin	T_b Threshold (K)
North Atlantic (NA)	224
South Atlantic (SA)	227
East Pacific (EP)	228
South Pacific (SP)	221
West Pacific (WP)	219
North Indian (NI)	218
South Indian (SI)	221

Table 1. T_b thresholds used by basin.

3.2 *Size*

The size of a CC is defined as the area covered by pixels that have a temperature at or below the threshold. The distance from the geometric center of the cloud mass to farthest CC pixel must be at least 1° (~111 km) in order for the candidate to be considered large enough to be a CC. Furthermore, candidates must also have a sufficient number of cold pixels to ensure that there is enough cloud mass to fill 90% of a one degree circle drawn around the center.

3.3 *Persistence*

All candidate CCs must persist for at least 24 hours. Once a field of candidates passes the convection and size tests, their locations are compared to CCs identified 3 hours prior to the current time. If they are within a reasonable distance, then they are considered the same cluster. If there was no match, then the t-6 field is checked. Since CCs typically exhibit irregular convection in both space and time, this is a common occurrence. If no match can be found up to 12 hours prior to the current time, then the candidate is considered a "new" CC and is recorded as such. If it is ultimately matched to a prior CC, then positions from missing times in between are interpolated.

3.4 *Independence*

Much care has been made to insure that convective maxima are unique disturbances and not part of a larger CC. In order to insure that the convection is associated with one candidate, an independence test is applied. Each candidate must be at least 1200 km from other CC candidates. If two clusters are closer than that, then the larger of the two is tracked and the smaller is considered part of the larger one. Thus, larger candidates are favored over smaller ones.

3.5 *Location*

Since tropical cyclogenesis cannot occur over land, each CC must have a geometric center over water. This eliminates most of the diurnal convective towers that form over tropical land forms. We also eliminate CC candidates that are pole ward of 30° latitude. This effectively eliminates mid-latitude and sub-tropical systems as well as concern for tracking cold cirrus clouds instead of deep convection.

3.6 *Final Processing*

During the final step, the algorithm calculates a number of statistics that describe the cluster track as a whole. Using data from IBTrACS (Knapp et al. 2010), clusters are labeled as either developing or non-developing. Cluster-cyclone matches are made based on the average distance from the cluster center to the developed tropical cyclone for each point after tropical cyclogenesis, defined here as the time

Variable	Description	Units
Latitude/Longitude	Coordinates of geometric center	degrees North/East
Weighted Lat/Lon	Coordinates of max. convection	degrees North/East
Pixel Count	Num. of pixels within threshold	
Mean T_b	Average brightness temperature	K
Minimum T_b	Coldest brightness temperature	K
Median T_b	Median brightness temperature	K
Standard Deviation of T_b	Std. deviation of brightness temp.	K
Coldest 5th Percentile T_b	5% pixels colder than this	K
Coldest 10th Percentile T_b	10% pixels colder than this	K
Maximum Radius	Largest distance around azimuth from center to edge of cluster	km
Minimum Radius	Smallest distance around azimuth from center to edge	km
Mean Weighted Radius	Average distance around azimuth from center to edge	km
Maximum Cloud Top Height	Tallest cloud top height	km
Mean Cloud Top Height	Average cloud top height	km
Translation Direction	Direction of movement	compass degrees
Translation Speed	Velocity	kt
Quality Control Flags	Identifies developing CCs, times that are interpolated, and general quality	

Table 2. List of variables included in the CC output dataset.

at which the cyclone first appears in the IBTrACS data. The track files are truncated after the genesis time and matching clusters which begin after the genesis time are removed entirely. The additional track statistics include the initial and current basins, a flag indicating if the cluster is within the active season of its basin, and a number of quality control flags. Although the algorithm also calculates a statistic for the speed and direction of the cluster, these statistics are highly sensitive to track noise and will require further refinement before they can be considered reliable statistics. The final output is generated in both netcdf format and text format; the output is described in more detail in the following section.

4. RESULTS

4.1 *Algorithm Output*

We produce a number of variables and statistics for each CC – these are summarized in Table 2. Although the algorithm has been run for the entire span of available GRISAT data, (1980 - 2008), the satellite coverage prior to 1982 does not reliably include many of the tropical development basins. Beginning in 1982,

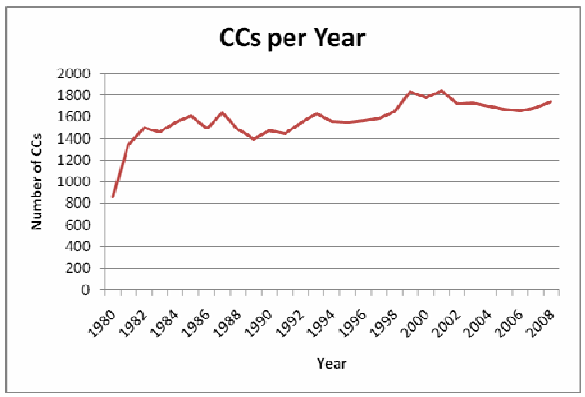

Figure 1. Total CCs identified each year.

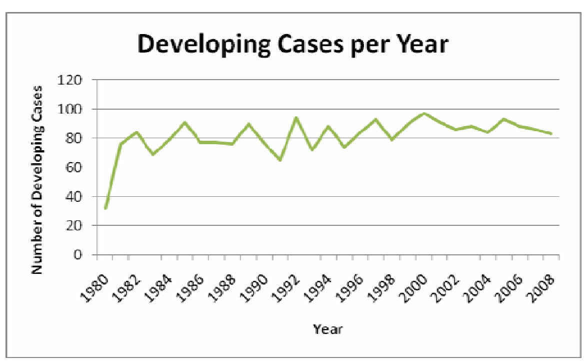

Figure 2. Developing CCs by year.

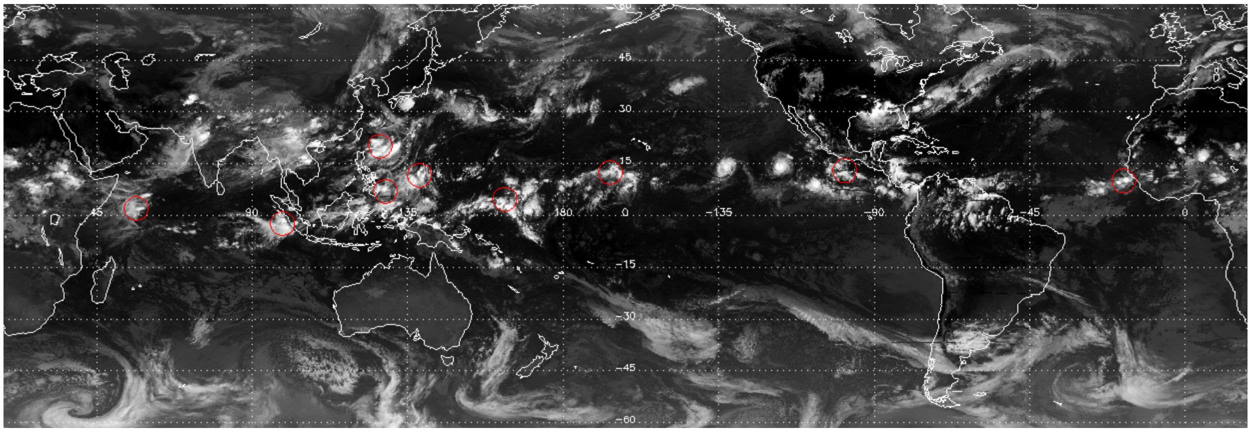

Figure 3. Global IR image for 21 UTC 9 August 1999. Identified CC are circled in red.

most of the basins have consistent satellite coverage with the exception of the western half of the North and South Indian Ocean basins.

The impact of the inconsistent coverage can be seen in the abnormally low number of CCs identified in 1980. Figure 1 depicts the number of CCs identified globally during each year and Figure 2 depicts the number identified developing cases which occurred each year. Figure 3 shows a satellite image with identified clusters highlighted by red circles. Mature cyclones are evident in the eastern Pacific but are filtered out of the algorithm. Figure 4 shows a sample track from a cloud cluster that formed during the 1999 Atlantic season.

In total, there were 45,708 identified CCs during the 1980-2008 period. Of these, 2,362 were developing cases (~5%). During the 1982-2008 period, there were, on average, 1611.4 CCs identified each year of which 83.4 were developing cases. While the CC data for 1980 and 1981 will be included in the dataset, these years are too incomplete for use in analyzing global trends.

4.2 *Research Applications*

The sheer number of cloud clusters identified and catalogued, in addition to the computation of the satellite size and intensity parameters, makes this dataset particularly useful for tropical cyclogenesis studies. There are 2,362 global developing cases (out of 45,708 CCs) from the 1980-2008 period – a large database that can be used to discriminate developing from non-developing storms. The satellite parameters (e.g. extent of cold cloud tops, magnitudes of cloud top temperatures, concentration of cold clouds) can also be easily incorporated into tropical cyclogenesis prediction studies.

Information on the nature and changes of CCs can also be extracted with this dataset. To our knowledge there has never been a time series of cloud clusters this long (29 years); the data approach climatological averaging periods and may present evidence of climate shifts. For example, connections may be made between the relative favorability of tropical cyclone development by basin through time.

It is also quite possible that the data will provide evidence of "missed" tropical depressions or storms in the global best track data. With global satellite coverage of the ocean basins since the 1970s, it is highly unlikely that strong tropical cyclones have escaped detection. However, immature storms without obvious eye or circulation features could have easily been overlooked by a forecast center.

Figure 4. Track map for CC#957 from 1999. The cluster existed from 12 UTC 9 July through 21 UTC 11 July.

5. CONCLUSIONS AND FUTURE WORK

5.1 *Summary*

A description of the algorithm used to produce a global database of tropical cloud clusters is presented. The global nature, long temporal period, and archived meteorological variables of the dataset presents many opportunities for further research.

5.2 *Future Work*

Version 1 of the cloud cluster data is currently being checked for errors and inconsistencies. We anticipate that the data will be released by the end of 2010.

Development is already underway for version 2. The first phase will result in an operational cloud cluster tracker that will update a webpage and database in near real-time. The operational tracker will serve a secondary purpose of keeping the research database updated as new global clusters develop.

Version 2 will also include a significant increase in the amount of metadata in the database. Using the NCEP/NCAR reanalysis, we will calculate or retrieve several atmospheric and oceanic variables to include, such as sea surface temperature, vertical wind shear, and maximum potential intensity.

Finally, the dataset will be added into a relational database that will allow fast access to specific data requests.

5.3 References

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5.4 *Acknowledgments*

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