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SEVERE STORM ENVIRONMENTS ON DIFFERENT CONTINENTS

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1. INTRODUCTION

Severe thunderstorm climatologies and related studies are hampered by the different reporting procedures in different countries, and the availability of observations in sparsely populated regions. We have developed a procedure for inferring hailstorm occurrences and estimating global hailstorm climatologies using satellite passive microwave brightness temperatures. In this paper, we show some satellite derived climatologies and present composited environmental conditions for inferred hailstorm cases in selected regions. Composites are constructed for the strongest subsets of storms (as seen by satellite), and for subsets with substantially weaker signatures, but still strong enough to suggest some probability of producing large hail.

Large ice hydrometeors scatter upwelling microwave radiation away from a satellite's field of view, causing brightness temperature depressions far below the thermodynamic temperature in the atmosphere. Cecil (2009) empirically related Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) measurements at 19, 37, and 85 GHz to ground-truth reports of large hail (0.75") in the United States. The probability of large hail being reported increased with decreasing brightness temperature. The 37 GHz channel seemed most useful for identifying hailstorms. The 85 GHz channel sometimes had extremely low brightness temperatures without reports of large hail, presumably because a deep column of large graupel or small hail is sufficient to scatter the shorter wavelength radiation. With the 19 GHz channel, the footprint size (~20x30 km) is too large and many cases do not produce strong signatures. Cecil's (2009) approach using TRMM precipitation features (Nesbitt et al. 2000) is used here, with the hail probabilities re-derived for the 1.00" diameter now used by the National Weather Service as a criterion for severe thunderstorms (Fig. 1).

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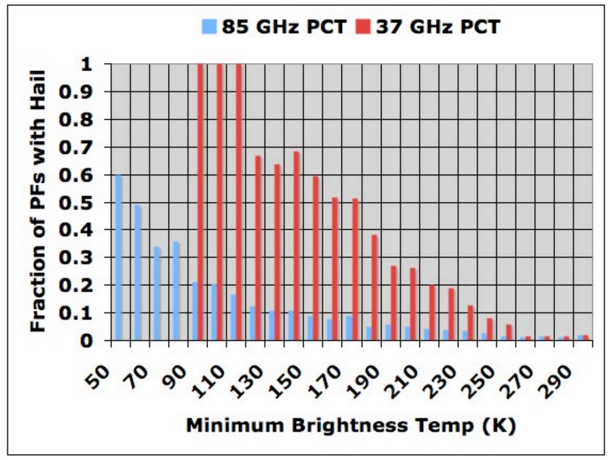

Figure 1. Fraction of TRMM precipitation features in south-central or southeast U.S. with Stormdata reports of large (1" diameter or greater) hail, as a function of precipitation feature's minimum 85 GHz PCT or 37 GHz PCT. Methodology as in Cecil (2009).

One limitation of the Cecil (2009) study is that relationships between brightness temperatures and hail may vary with meteorological regimes. An infinite number of vertical profiles of hydrometeor types and contents could yield the same brightness temperature upwelling from the column. To address this, Cecil (2010) analyzed radar-derived ice water content and vertical profiles of radar reflectivity for storms in different regions having the same upwelling 37 GHz polarization corrected brightness temperature (PCT). Profiles could generally be grouped together after identifying the region as tropical ocean, tropical land, subtropical ocean, or subtropical land. Linear fits between 37 GHz PCT and mixed-phase region ice water content were derived for each grouping. The linear fit equations were combined such that a 37 GHz PCT from tropical ocean, tropical land, or subtropical ocean could be scaled to an equivalent 37 GHz PCT from subtropical land. Using these equations, a storm over tropical land with 200 K 37 GHz PCT (for example) is expected to have the same mixed-phase region ice water content as a storm over subtropical land with 216 K 37 GHz PCT. (Values are scaled toward subtropical land because the hail validation study was performed using a subtropical land region - the southeastern and south-central United States.)

Based on these studies, we have scaled the brightness temperatures for different regions and estimated the number of hailstorms seen by TMI and by the Advanced Scanning Microwave Radiometer for Earth Observing System (AMSR-E) on the Aqua satellite. The AMSR-E brightness temperatures were also slightly scaled to account for small differences in frequency and footprint size compared to TMI. Maps of the estimated number of hailstorms are shown in Section 2. Environmental composites using NCEP Reanalysis for subsets of cases are shown in Section 3.

2. SATELLITE-DERIVED HAILSTORM CLIMATOLOGY

To estimate hailstorm climatologies, we smooth the 37 GHz PCT hail probabilities from Fig. 1 and apply them to the scaled TMI or AMSR-E brightness temperatures. We artificially set the probability to 0 for 37 GHz PCT > 200 K, because there are many storms with higher brightness temperatures that do not seem realistic as possible hail cases. The non-zero probabilities for high brightness temperatures in Fig. 1 are partly due to the time and space windows used in the empirical matchups - it is highly unlikely that a low-earth orbit satellite overpass will correspond precisely with the time of a hail report.

As a first test, we compare the AMSR-E derived hailstorm climatology for the United States to ground truth reports (Fig. 2). The same basic patterns are evident. The region with hailstorms estimated by AMSR-E is very similar to the region with at least 100 Stormdata large hail reports per (500 km)^2 per year - east of the Rockies, to about the Great lakes and Mid-Atlantic states, and throughout the South. AMSR-E places the maximum un eastern Kansas and Western Missouri; Stormdata reports place the maximum in central and eastern Kansas.

The AMSR-E data extends to the poles, but is limited to certain times of day - between midnight - 3:00 AM and noon - 3:00 PM local solar time, with the precise time being a function of latitude and distance from the satellite subtrack. The TMI data samples throughout the diurnal cycle, but is limited to about 38° latitude and equatorward. We primarily use AMSR-E to construct global maps of frequency of hailstorm occurrence, and use TMI to evaluate the limitations from diurnal sampling. In the United States, we can also use the Stormdata reports to evaluate the diurnal sampling (Fig. 3). In the Plains states where most of the hailstorms occur, 10-20% of reports occur between 12 - 3 AM or PM. In the eastern U.S., 20-30% of reports occur during these six hours. So hailstorms in the Plains region are likely undersampled by AMSR-E. The small number of hail reports in the west limits interpretation, but it appears that AMSR-E would over-sample hailstorms there.

Because Fig. 3 suggests different timing in three regions west-to-east, we examine the hourly percentage of hail reports for the western, central, and eastern U.S. in Fig. 4. Reports in the central U.S. are shifted slightly later in the day (peaking between 5-6 PM), with a much smaller fraction of early afternoon storms than in the west or east. The western mountains have the largest percentage of early afternoon storms.

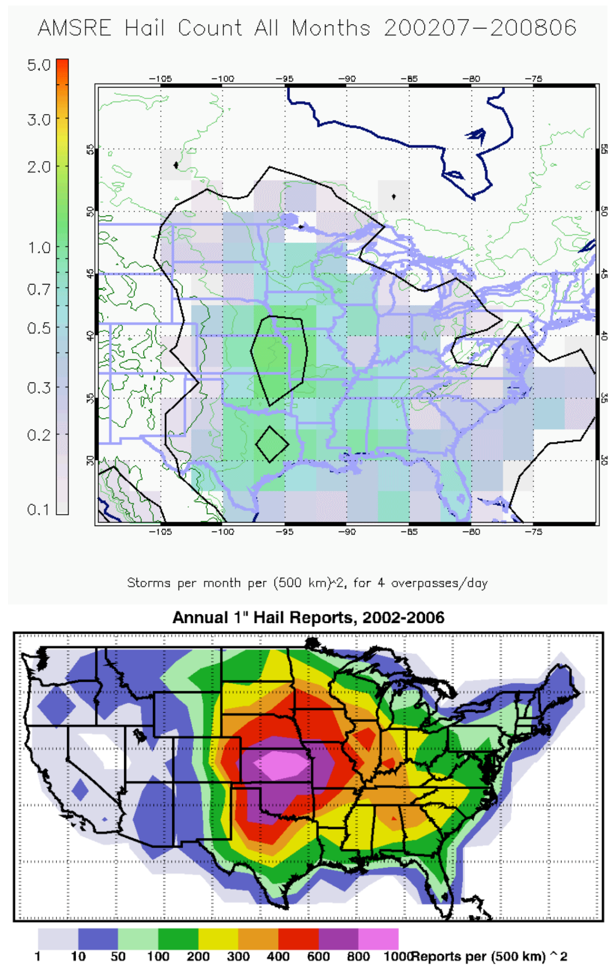

Figure 2. Top: Estimated number of hailstorms per)500 km)^2 per month from AMSR-E. Bottom: Number of Stormdata reports of 1" or larger hail per (500 km)^2 per year. Note that a single storm may have several hail reports. 2.5° grid boxes are used in each plot.

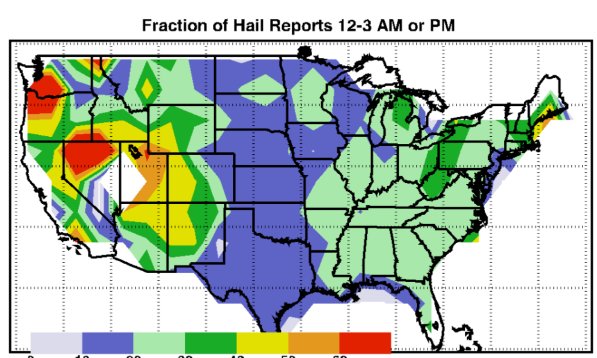

Figure 3. Percentage of Stormdata hail reports between midnight - 3 AM and noon - 3 PM local solar time, generally the window for AMSR-E observations.

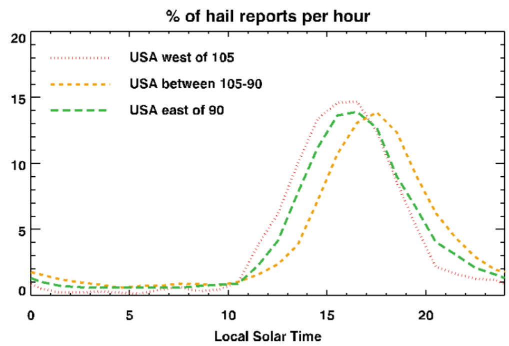

Figure 4. Percentage of Stormdata large hail reports each hour (local solar time), for Western U.S., Central U.S. (105°-90° W), and Eastern U.S.

Applying this method to AMSR-E observations globally yields the estimated hailstorm frequencies in Fig. 5. Some of the areas highlighted in prior studies are also shown here, but the satellite observations bring a uniformity of measurements that is lacking in ground-based climatologies. Northern Argentina and Paraguay have the most estimated hailstorms in the AMSR-E climatology, with other active regions including the Central U.S., Bangladesh, Pakistan, Central and West Africa, and far Southeast Africa. Hailstorms are estimated on the Canadian prairie and as far as 66° N in Russia. With less landmass in the southern hemisphere, very few are estimated south of 40° S. Few are estimated over the oceans, away from continents.

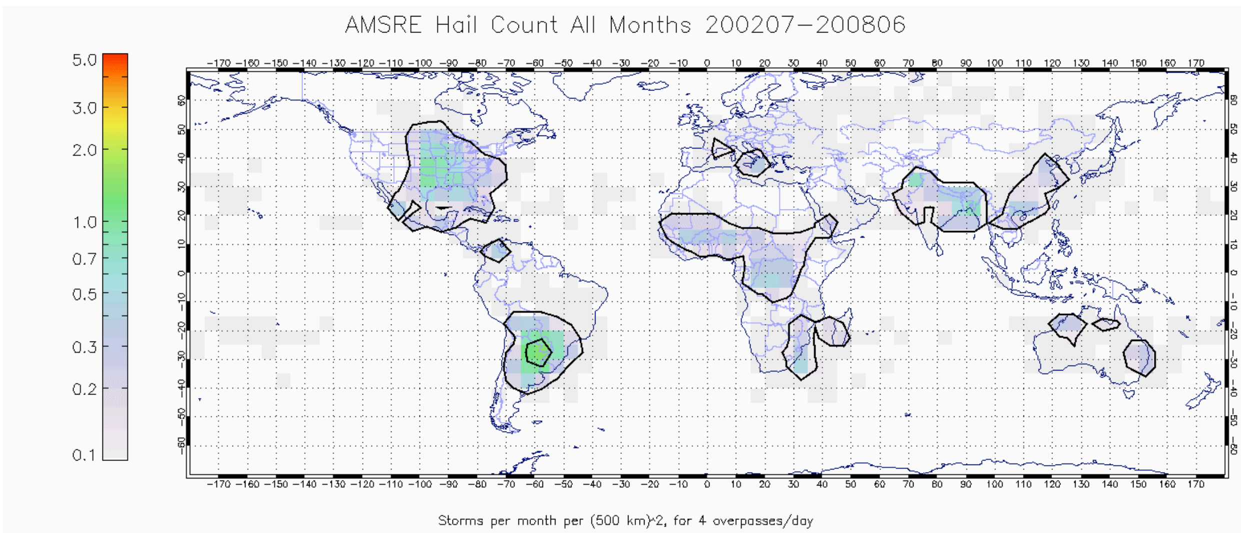

Figure 5. Hailstorm frequency of occurrence estimated from AMSR-E 36 GHz PCT, July 2002 - June 2008. Units are storms per (500 km)^2 per *month*, using 2.5° grid spacing.

The TMI data (not shown) allows better sampling, although restricted to the tropics and subtropics. In this dataset, Bangladesh has slightly more hailstorms estimated than Northern Argentina and Paraguay. The sample sizes are not large enough to crown one location as the "champion". In most places, 20-30% of the TMI-estimated hailstorms occur during the roughly 12 - 3 AM or PM AMSR-E sampling window. It is slightly less in Central and West Africa, and also in the South Central U.S. (as also seen in Fig. 3). This suggests the AMSR-E measurements might undersample those regions.

The diurnal cycle of TMI-estimated hailstorms is plotted in Fig. 6 for the regions having the most cases. Almost all these regions peak in the late afternoon - evening. The southeast South America (Argentina, Paraguay, Uruguay, southern Brazil) peak extends later in the night, to almost midnight. AMSR-E has a better chance of seeing hailstorms just after midnight there and in Bangladesh than in other regions.

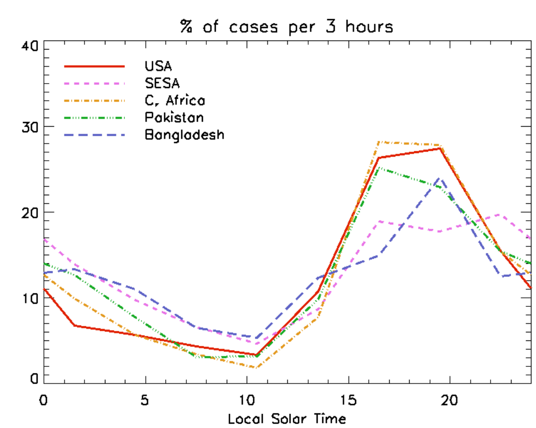

Fig. 6. Percentage of TMI-estimated hail cases in three hour increments of local solar time for south central / southeastern U.S., Southeast South America, Central Africa, Pakistan, and Bangladesh.

3. STORM ENVIRONMENTS

Environmental conditions are taken from NCEP Reanalysis for individual storms sampled by TRMM. In a given region, storms are grouped into two categories for comparison: intense (37 GHz PCT < 140 K) and moderate (37 GHz PCT 180 - 220 K). Referring back to Fig. 1, the storms in the intense category are highly likely to have large hail, while those labeled “moderate” are actually rather strong storms with around 25% of them having large hail. The intention here is to compare environments of the strongest storms with those of others that are also strong, but not extreme.

Preliminary results suggest that intense storms tend to occur with greater thermodynamic instability (Fig. 7), stronger upper level jets (Fig. 8), and stronger low level jets (Fig. 9). For the coldest 37 GHz precipitation features, it was found that a combination of high CAPE and high shear was needed in the vast majority of regions. This seemed especially true for precipitation features over the subtropical Americas. Notable exceptions included precipitation features over Pakistan and Bangladesh, where low CAPE values were often associated with cold 37 GHz brightness temperatures. Many aspects of the composite environments for southeastern South America are presented by Felix (2010). For example, the median Lifted Index (Fig. 7) for intense southeastern South America cases (< -6 K) is more unstable than the 75^{th} percentile Lifted Index for the more moderate cases.

In composites for the south-central and southeast U.S., the 250 hPa jet (Fig. 8) is much further south for the intense storms than for the moderate storms. The intense storm locations are somewhat clustered toward the equatorward entrance region of the jet. In the moderate storm composite, the upper level jet is far removed, over southeastern Canada (not shown). At 925 hPa (Fig. 9), the intense storms tend to be located toward the northwestern edge of a strong low level jet where southerly and westerly flow converges. The moderate storm composite has weaker southerly flow and less convergence near the storm locations (not shown).

The composites for southeastern South America also feature intense storms near the equatorward entrance region of a stronger 250 hPa (Fig. 8) jet, compared to the moderate storms. The intense storms are located near the nose of a strong northerly low level jet, with a cyclone about 500 km to the west in the 925 hPa composite (Fig. 9). The low level flow pattern for the moderate storm composite has similar directions but weaker wind speeds.

For intense storms in Bangladesh and east India, the upper level jet (Fig. 8) is located to the northwest. Flow there is much stronger in the intense storm composite than in the moderate storm composite, which has the jet much further north and much weaker across Central Asia (not shown). Pre-monsoon season severe thunderstorms in that region are sometimes called “Nor’westers”. In 925 hPa composites (Fig. 9) for both sets of storms, strong southwesterly flow over the Bay of Bengal turns to weaker southerly flow neat the location of the storms. The low level southwesterly flow is much stronger in the intense storm composite.

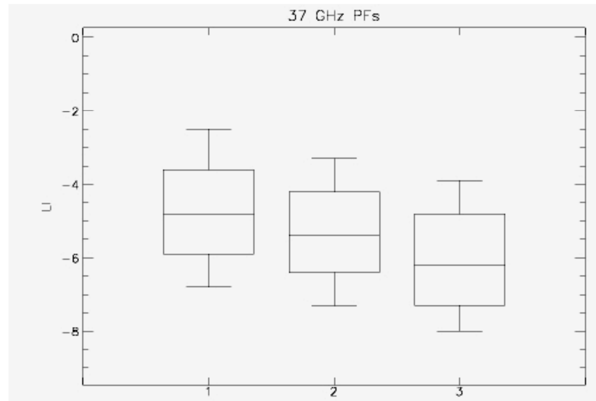

Figure 7. Lifted Index for Southeast South America storms with 37 GHz PCT (1) 180-220 K; (2) 140-180 K; (3) < 140 K. Box encloses the 25th to 75th percentiles; whiskers extend from the 10th to 90th percentiles; the median is denoted by the horizontal line inside the box.

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REFERENCES

Cecil, D. J., 2009: Passive microwave brightness temperatures as proxies for hailstorms. *J. Appl. Meteor. Clim.*, **48**, 1281-1286.

Cecil, D. J., 2010: Relating passive 37 GHz scattering to radar profiles in strong convection. *J. Appl. Meteor. Clim., in press*.

Felix, M. O., 2010: The environments of extreme precipitation features in southeastern South America. M.S. Thesis, Univ. Alabama - Huntsville, Dept. of Atmos. Sci.

Nesbitt, S. W., E. J. Zipser, and D. J. Cecil, 2000: A census of precipitation features in the tropics using TRMM: Radar, ice scattering, and lightning observations. *J. Clim.*, **13**, 4087-4106.

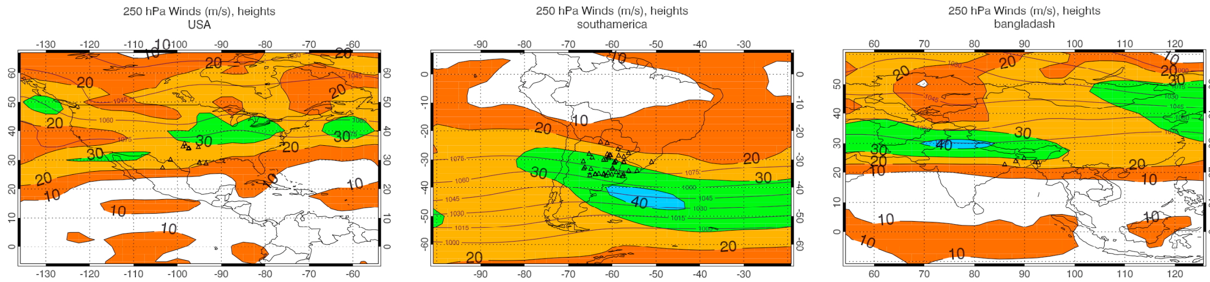

Figure 8. Composite 250 hPa geopotential height and wind speed for intense storms in south-central and southeast United States; southeast South America; Bangladesh and east India.

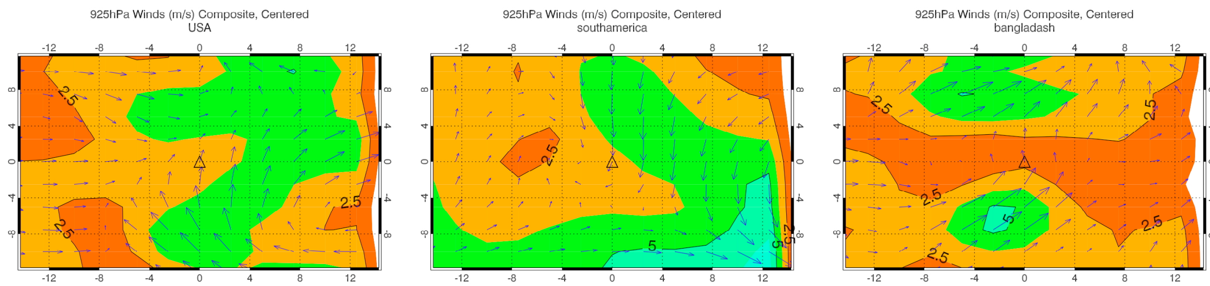

Figure 9. As in Fig. 8, but for 925 hPa flow composited relative to storm location.