Outline of 5 Lectures
(A Satellite-based Tropical Cyclone Module)

1. Sept. 17, 2008: TC best track definition and datasets, global distribution of TCs; Review of history of meteorological satellites, introducing different orbits, scanning patterns, and space-time samplings. Also introduce the differences between the satellites and the instruments.

2. Sept. 19, 2008: Introduction of space borne instruments including visible, IR and microwave. Will briefly talk about radiative transfer theories in different channels and rainfall retrieval algorithms from IR and microwave.

   Problem set: Due on the Oct. 6, 2008


4. Nov. 19, 2008: SeaWinds & SFMR sea surface wind retrieval; Current status of TC intensity and rainfall forecasts. Introduction of satellite-based TC intensity and rainfall prediction techniques, including DVORAK, SHIPS, and R-CLIPER.


   Problem set: Due on the Dec. 5, 2008
Motivation of Building TRMM PF Database

**NASA TRMM : PR, TMI, VIRS, and LIS**

- TRMM has 10 years of data (huge amount) from different sensors
- Traditional pixel-based or grid-based analysis methods are not efficient
- Event-based analysis method: summarize observations from individual precipitation events
Concept of Precipitation Feature (PF): An event-based analysis method, which groups the pixels with satellite-measured properties in certain criteria.

Nesbitt et al. 2000 (J of Climate)
Contribution by each feature category to total feature population and total regional rainfall.
3 Steps in Building the TRMM PF Database

1. Collocation $\rightarrow$ pixel-level data: Level 1

2. PFs are defined with different criteria using the collocated data $\rightarrow$ feature-level: Level 2

3. Generating statistics $\rightarrow$ grid-level: Level 3
TMI (1B11)  
- Tb at V10, H10, V19, H19, V21, V37, H37, V85, H85

VIRS (1B01)  
- Tb at Chi-5

LIS  
- Flashcount location, Obs time

PR (2A25)  
- Reflectivity profiles
  - Surface rain
  - PLA

PR (2A23)  
- Rain Type
  - Bright Band Height
  - Storm Height

TMI (2A12)  
- Surface Rain
  - Profiles of Cloud water
  - Cloud ice, Precip water
  - and Precip ice

Collocation

Level-1

- group by 2A25 raining pixels
- group by PR 20 dBZ ground projection
- group by 2A12 raining pixels inside PR swath
- group by TMI PCT<250 K
- grouping by VIRS T_dB1<210K
- grouping by VIRS T_dB1<235K

Calculate statistics including volumetric rain, flash counts, etc.
Add NCEP Reanalysis T, H, P, RH, U, V, w

Level-2 RPFs  RPPF's  TPFs  PCTFs  C210Fs  C235Fs

calculate the statistics at 1° x 1° grids
Add in the following products:

TRMM (3A25)  
- Surface Rain
  - Rain pixels
  - PR pixels

TRMM (3B43)  
- surface rain

TRMM (3A12)  
- surface rain

GPCP  
- Surface rain

GPI  
- Surface rain

GPCC  
- Surface rain
  - Rain Gauge Density

Level-3 RPFs  RPPF's  TPFs  PCTFs  C210Fs  C235Fs
<table>
<thead>
<tr>
<th>Acronyms</th>
<th>Definition</th>
<th>Criteria</th>
<th>Population (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPF</td>
<td>Radar Precipitation Feature</td>
<td>Pixels with 2A25 rainfall rate &gt;0</td>
<td>78.2</td>
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<tr>
<td>RPPF</td>
<td>Radar Projection Precipitation Feature</td>
<td>Pixels with 20 dBZ anywhere above ground</td>
<td>68.6</td>
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<tr>
<td>TPF</td>
<td>TMI Precipitation Feature</td>
<td>Pixels with 2A12 rainfall rate &gt;0</td>
<td>14.8</td>
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<tr>
<td>PCTF</td>
<td>TMI cold 85 GHZ PCT Feature</td>
<td>Pixels with 85 GHZ PCT &lt; 250 K</td>
<td>6.2</td>
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<tr>
<td>C210F</td>
<td>Cloud Features with 210 K</td>
<td>VIRS $T_{B11} &lt; 210$ K</td>
<td>2.8</td>
</tr>
<tr>
<td>C235F</td>
<td>Cloud features with 235 K</td>
<td>VIRS $T_{B11} &lt; 235$ K</td>
<td>20.5</td>
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<tr>
<td>C273F</td>
<td>Cloud features with 273 K</td>
<td>VIRS $T_{B11} &lt; 273$ K</td>
<td>77.2</td>
</tr>
</tbody>
</table>
Demonstration of the feature types using a severe hail storm case (Zipser et al., 2006).
Level 1 Parameters

1. General: orbit number, time, lat, lon, etc.
2. From PR: dBZ profile, rain_2A25 profile
3. From TMI: TBs, rain_2A12, LWC_2A12, IWC_2A12
4. From LIS: flash count, flash rate
5. From VIRS: TBs from Channel 1-5
Level 2 Parameters

1. General: orbit #, grp #, time, PF center_lat & lon
2. From PR: Maxnsz, Max6km, Max9km, Max20dbz, Max40dbz, Maxdbz profile, Volrain, Volrain_20db, Nmcs, Rainmcs, Npixels, Nmcs, so on and so forth.
3. From TMI: Npixel2a12, Min85pct, Min37pct, Volrain_2a12, rainmcs_2a12, etc.
4. From LIS: flash count, flash_total
5. From VIRS: Nch4le210, 235, 273(#of PR pixels with Tb11<=210), Median value of Tbs
6. From NCEP reanalysis: T, u, v, w, Rh, etc.
Level 3 Parameters

Monthly mean, max, or total of previous parameters.
Dimension:[80, 360, 8]
Tropical Cyclone Related PF (TCPF) Database

TC Best Track
TC Locations and Maximum Wind, etc.

TRMM PF Level-2
TRMM statistical parameters (See Liu et al. 2008)

If (distance between TC center and PF center less than 500-km)

TRMM TCPF Level-1 (Pixel)

Yes

TRMM TCPF Level-2 (PFs)

Statistics Calculation Combination

TRMM TCPF Level-3 (Grid)

No

TRMM non-TCPF Level-1 (Pixel)

TRMM non-TCPF Level-2 (PFs)

Statistics Calculation Combination

TRMM non-TCPF Level-3 (Grid)
### Number of TCs and TCPFs for each basin and each year during 1998-2006

<table>
<thead>
<tr>
<th>Year</th>
<th>ATL</th>
<th>EPA</th>
<th>NWP</th>
<th>NIO</th>
<th>SIO</th>
<th>SPA</th>
<th>Total</th>
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<td>23</td>
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<td>2003</td>
<td>16</td>
<td>16</td>
<td>23</td>
<td>3</td>
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<td>2004</td>
<td>15</td>
<td>12</td>
<td>31</td>
<td>5</td>
<td>16</td>
<td>5</td>
<td>84</td>
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<td>2005</td>
<td>28</td>
<td>15</td>
<td>24</td>
<td>6</td>
<td>18</td>
<td>8</td>
<td>99</td>
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<td>2006</td>
<td>10</td>
<td>19</td>
<td>21</td>
<td>6</td>
<td>15</td>
<td>8</td>
<td>79</td>
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<td><strong>Total</strong></td>
<td><strong>137</strong></td>
<td><strong>133</strong></td>
<td><strong>219</strong></td>
<td><strong>44</strong></td>
<td><strong>150</strong></td>
<td><strong>88</strong></td>
<td><strong>771</strong></td>
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<th>Year</th>
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<th>TCPS</th>
<th>TCPS</th>
<th>TCPS</th>
<th>TCPS</th>
<th>Total</th>
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<td>4824</td>
<td>1252</td>
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<td>5465</td>
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<td>1976</td>
<td>17592</td>
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<td>6760</td>
<td>690</td>
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<td>1827</td>
<td>19663</td>
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<td>4182</td>
<td>1740</td>
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<td>1473</td>
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<td>2881</td>
<td>7118</td>
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<td>4085</td>
<td>1070</td>
<td>19606</td>
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<td>5118</td>
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<td>7425</td>
<td>772</td>
<td>5750</td>
<td>1978</td>
<td>23165</td>
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<tr>
<td>2004</td>
<td>5231</td>
<td>1617</td>
<td>9591</td>
<td>970</td>
<td>4371</td>
<td>740</td>
<td>22520</td>
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<td>2005</td>
<td>8023</td>
<td>1990</td>
<td>7125</td>
<td>1217</td>
<td>3299</td>
<td>1482</td>
<td>23136</td>
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<td>2006</td>
<td>2268</td>
<td>2935</td>
<td>5951</td>
<td>825</td>
<td>2820</td>
<td>1500</td>
<td>16299</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>40560</strong></td>
<td><strong>19174</strong></td>
<td><strong>61675</strong></td>
<td><strong>7261</strong></td>
<td><strong>37037</strong></td>
<td><strong>16628</strong></td>
<td><strong>182335</strong></td>
</tr>
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</table>
Table 1: Characteristics of TRMM TCPFs and non-TCPFs

<table>
<thead>
<tr>
<th></th>
<th>TCPFs</th>
<th>Non-TCPFs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ATL</td>
<td>EPA</td>
</tr>
<tr>
<td>Mean PF Size</td>
<td>1447</td>
<td>1494</td>
</tr>
<tr>
<td>Mean 2A25 Volumetric Rain (km$^2$ mm/hr)</td>
<td>5,714</td>
<td>5,258</td>
</tr>
<tr>
<td>Mean 2A12 Volumetric Rain (km$^2$ mm/hr)</td>
<td>4,984</td>
<td>5,138</td>
</tr>
<tr>
<td>Mean Minimum 85 GHz PCT (K)</td>
<td>256</td>
<td>260</td>
</tr>
<tr>
<td>Mean Minimum 37 GHz PCT (K)</td>
<td>268</td>
<td>272</td>
</tr>
<tr>
<td>Mean Flash Count (#)</td>
<td>0.20</td>
<td>0.06</td>
</tr>
<tr>
<td>Mean Maximum 20 dBZ Height (km)</td>
<td>5.43</td>
<td>5.32</td>
</tr>
<tr>
<td>Mean Maximum Near Surface dBZ</td>
<td>33.0</td>
<td>31.5</td>
</tr>
</tbody>
</table>
An application of TCPF database on TC Intensity Change Study

Is tropical cyclone intensity change related to the strength of its convective precipitation features?

Using 9 years of TRMM data to search for an answer
Motivation

- SHIPS model does not have any parameter related to convective intensity. However, early studies suggest that hot towers (Simpson et al. 1998) and convective bursts (Steranka et al. 1986) near the eye can be related to tropical cyclone (TC) intensity change.
- Kelly et al. (2004, 2005) found that the chance of intensification increases when one or more hot towers exist in the TC’s eyewall using TRMM PR and WSR-88D data for selected Atlantic TCs during 1998-2003 (for TRMM) and 1995-2005 (for WSR-88D).
- While the forecasting of TC intensity change has been quite difficult, the forecasting of rapid intensification (RI) has been particularly challenging.
- R. Rogers (2008 TRMM conference talk) found that TRMM PR reflectivity profiles decrease less (more) rapidly with height at high altitude for RI (non-RI) cases after a convective burst.
Objectives

- Rank the strength of a TC’s convective precipitation features in the eyewall (EW) stratified by the TC’s intensity change: *i.e.*, non-intensifying (NonIN) and intensifying (IN) including rapid intensifying (RI) and slow intensifying (SI) stages using a 9-yr (1998-2006) TRMM Precipitation Feature (PF) database.
- Evaluate the probability of RI/IN when the TC’s strongest eyewall (EW) PF contains one or more hot towers.
- Compare environmental factors (SST, vertical wind shear, moisture) for IN (RI and SI), and NonIN cases.
Data and Methodology

• Based on 9 years (1998-2006) of the UU TRMM Precipitation Feature (PF) database, Tropical Cyclone related PFs (TCPFs) are identified for over 700 TCs in six basins: Atlantic (ATL), East Pacific (EPA), Northwest Pacific (NWP), North Indian Ocean (NIO), South Indian Ocean (SIO), and South Pacific (SPA).

• Manually select TRMM orbits in which TC EW is well-observed. Then we select the strongest EW PF from each orbit. We have a total of 1054 such EW PFs to be analyzed.

<table>
<thead>
<tr>
<th></th>
<th>N=EWPFs</th>
<th>N=storms</th>
<th>ATL</th>
<th>EPA</th>
<th>NWP</th>
<th>NIO</th>
<th>SIO</th>
<th>SPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>44</td>
<td>39</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>1</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>SI</td>
<td>515</td>
<td>221</td>
<td>114</td>
<td>57</td>
<td>181</td>
<td>29</td>
<td>98</td>
<td>36</td>
</tr>
<tr>
<td>IN</td>
<td>559</td>
<td>227</td>
<td>119</td>
<td>65</td>
<td>193</td>
<td>30</td>
<td>110</td>
<td>42</td>
</tr>
<tr>
<td>NonIN</td>
<td>495</td>
<td>191</td>
<td>143</td>
<td>73</td>
<td>130</td>
<td>25</td>
<td>89</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>1054</td>
<td>255</td>
<td>262</td>
<td>138</td>
<td>323</td>
<td>55</td>
<td>199</td>
<td>77</td>
</tr>
</tbody>
</table>
Accepted Example: TRMM Observations of Hurricane Cindy (1999)
Rejected Example: SPA TC ID# 1999-22

(a) VIRS T_{511} (K)

(b) PR max reflectivity projection (dBZ)

(c) 2A12 rain rate (mm/hr)

(d) 85GHz PCT (K)

(e) 2A23 storm height (km)

(f) 37GHz PCT (K)
Data and Methodology (Cont.)

• NCEP reanalysis (6 hourly, 2.5x2.5 degree lon/lat resolution) is used for obtaining environmental parameters for each PF.

• TC maximum wind intensity is obtained every six hour from NHC and JTWC. To calculate the 24-h intensity change, we interpolate to find the intensity 12 hours before and after an overflight of TRMM.

• RI is defined as approximately the 95\textsuperscript{th} percentile of 24-h intensity changes of global TCs during 1998-2006. This is equal to a maximum sustained surface wind speed increase of 30-kt (Kaplan and DeMaria 2003).
CFAD (Contoured Frequency by Altitude Diagram) of Maximum Reflectivity Profiles for RI, SI, IN, Non-In EW PFs
Mean & Median Profiles of Maximum Reflectivity for RI, SI, IN, Non-In EW PFs
CDFs of Min. 85GHz PCT, Min. 37GHz PCT, Min. Tb11, and Max. 20 dBZ Echo Height
Chance of RI When Hot Tower (HT) Exists

Define HT: Maximum 20 dBZ echo height > 14.5 km (same as Kelly et al. 2004)

<table>
<thead>
<tr>
<th></th>
<th>N=EWPFs with HT</th>
<th>N=Total EWPFs</th>
<th>Percentage of EWPFs with HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>12</td>
<td>44</td>
<td>27.27%</td>
</tr>
<tr>
<td>SI</td>
<td>105</td>
<td>515</td>
<td>20.39%</td>
</tr>
<tr>
<td>IN</td>
<td>117</td>
<td>559</td>
<td>20.93%</td>
</tr>
<tr>
<td>NonIN</td>
<td>57</td>
<td>495</td>
<td>11.52%</td>
</tr>
<tr>
<td>Chance of RI</td>
<td>6.90%</td>
<td>4.17%</td>
<td></td>
</tr>
<tr>
<td>Chance of SI</td>
<td>60.34%</td>
<td>48.86%</td>
<td></td>
</tr>
<tr>
<td>Chance of IN</td>
<td>67.24%</td>
<td>53.04%</td>
<td></td>
</tr>
</tbody>
</table>

The chance of RI/IN increases when HT exists, but not substantially. HT is neither a necessary nor a sufficient condition for RI.
CDFs of NCEP Surface Air Temperature, Wind Shear, TPW, and Low- to Mid-level Mixing Ratio
Summary

1. A relationship does exist between TC intensity change and the strength of its convective precipitation features.

2. The mean/median profiles of maximum reflectivity are stronger for EWPFs that undergo RI than SI, and IN than NonIN.

3. Cumulative distribution functions (CDFs) show that the rapidly intensifying (intensifying) TC will have a lower minimum 85/37 GHz PCT and IR Tb11 and higher maximum 20 dBZ height than those of the slow intensifying (non-intensifying) TC.

4. The chance of RI/IN increases when a hot tower exists, but not substantially. A hot tower is neither a necessary nor a sufficient condition for RI.

5. The occurrence of IR/IN is governed not only by the convective processes, but also environmental factors. Our results indicate that the median value of NCEP surface air temperature (vertical shear magnitude) for RI cases is higher (lower) than that for non-RI cases. Similar trend is seen for moisture parameters, but less obvious.