The MJO, ENSO and Atlantic Basin Rapid Intensification

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Climate Diagnostics and Prediction Workshop
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Outline

- Data
- ENSO’s Impacts on Atlantic Basin TCs and RI
- MJO’s Impacts on Atlantic Basin TCs and RI
- Impact of combined ENSO/MJO index on Atlantic Basin TCs and RI
- Conclusions and Future Work
Data Sources

- **ENSO Index:** Multivariate ENSO Index (MEI) – take August-October average – highest ten years (El Niño), middle 16 years (neutral) – lowest ten years (La Niña)

- **MJO Index:** Wheeler-Hendon (WH) Index – uses OLR and 200- and 850-mb zonal wind components – available since 1974, except for 1978 when OLR was unavailable (120-Day Mean and ENSO removed)

- **MJO-ENSO Index:** Developed by WH – Includes 120-Day Mean and ENSO

- **TC Statistics:** National Hurricane Center’s best track

- **Large-Scale Analysis:** NCEP/NCAR Reanalysis I
ENSO’s Impacts on Atlantic Basin TCs and RI
**FIG. 2.** Number of hurricane days (given at top of lines) in El Niño and non-El Niño years from 1900 to 1982.

**FIG. 6.** Deviational upper tropospheric (~200 mb) outflow wind patterns due to enhanced deep-cumulus convection in the eastern tropical Pacific in moderate and strong El Niño years. These wind patterns are hypothesized to result from anomalously warm eastern Pacific water. [Numbers indicate upper-air stations at Swan Island (1), Grand Cayman (2), Kingston, Jamaica (3), Curacao (4), San Juan (5), St. Maarten (6) and Barbados (7)].
Average per Year 24-Hour Periods for Systems Undergoing RI for Various Thresholds – All Atlantic Basin TCs

- **La Niña**
- **Neutral**
- **El Niño**

Thresholds:
- 25 kt
- 30 kt
- 35 kt
- 40+ kt
Average per Year 24-Hour Periods for Systems Undergoing RI for Various Thresholds – MDR TCs (7.5-22.5°N, 75-20°W)

La Niña
Neutral
El Niño
Tracks of 24-Hour RI >= 30 Knots for MDR TCs in La Niña vs. El Niño (1974-2010)

La Niña

El Niño

151 24-Hour RI Events

21 24-Hour RI Events
Percentage Chance of All Atlantic Basin TCs and TCs Forming in the MDR in Each Phase of ENSO Having a RI Event of 25 Knots, 30 Knots, 35 Knots and 40+ Knots Over 24 h

<table>
<thead>
<tr>
<th>ENSO Phase</th>
<th>25 kt</th>
<th>30 kt</th>
<th>35 kt</th>
<th>40 kt</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All TCs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La Niña</td>
<td>53%</td>
<td>43%</td>
<td>29%</td>
<td>23%</td>
</tr>
<tr>
<td>Neutral</td>
<td>46%</td>
<td>36%</td>
<td>22%</td>
<td>14%</td>
</tr>
<tr>
<td>El Niño</td>
<td>39%</td>
<td>27%</td>
<td>17%</td>
<td>12%</td>
</tr>
</tbody>
</table>

| **MDR TCs** |       |       |       |       |
| La Niña    | 67%   | 58%   | 39%   | 32%   |
| Neutral    | 60%   | 50%   | 35%   | 23%   |
| El Niño    | 36%   | 28%   | 20%   | 12%   |
MJO’s Impacts on Atlantic Basin TCs and RI
July-October 200_mb Velocity Potential Anomalies Associated with the Madden-Julian Oscillation (MJO) – as defined by the Wheeler-Hendon (WH) index
SLP

Phase 1-2 –
Phase 6-7

850-mb U

200-mb U

700-mb RH
[RMM1, RMM2] Phase Space for 23-Jun-2012 to 01-Aug-2012
A westerly phase

B easterly phase

Maloney and Hartmann (2000)
Normalized Values for Various TC Parameters in the Atlantic basin from 1974-2007 based on MJO Day of Formation

<table>
<thead>
<tr>
<th>MJO Phase</th>
<th>NS</th>
<th>NSD</th>
<th>H</th>
<th>HD</th>
<th>MH</th>
<th>MHD</th>
<th>ACE</th>
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</thead>
<tbody>
<tr>
<td>Phase 1</td>
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<td>1.8</td>
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<tr>
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<td>4.6</td>
<td>76.7</td>
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<tr>
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<td>30.8</td>
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<td>14.7</td>
<td>1.4</td>
<td>2.8</td>
<td>56.0</td>
</tr>
<tr>
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<td>25.5</td>
<td>3.5</td>
<td>12.3</td>
<td>1.0</td>
<td>2.8</td>
<td>49.4</td>
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<tr>
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<td>22.6</td>
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<td>9.5</td>
<td>1.2</td>
<td>2.1</td>
<td>40.0</td>
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<tr>
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<td>1.1</td>
<td>35.7</td>
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<tr>
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<td>2.0</td>
<td>33.2</td>
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<td>10.4</td>
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<table>
<thead>
<tr>
<th>MJO Phase</th>
<th>NS</th>
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<th>H</th>
<th>HD</th>
<th>MH</th>
<th>MHD</th>
<th>ACE</th>
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</thead>
<tbody>
<tr>
<td>Phase 1-2</td>
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<td>4.3</td>
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<td>1.9</td>
<td>4.9</td>
<td>76.5</td>
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<tr>
<td>Phase 6-7</td>
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<td>21.5</td>
<td>2.5</td>
<td>7.5</td>
<td>1.0</td>
<td>1.5</td>
<td>34.6</td>
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</tbody>
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<table>
<thead>
<tr>
<th>MJO Phase</th>
<th>NS</th>
<th>NSD</th>
<th>H</th>
<th>HD</th>
<th>MH</th>
<th>MHD</th>
<th>ACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1-2 / Phase 6-7</td>
<td>1.6</td>
<td>1.8</td>
<td>1.7</td>
<td>2.4</td>
<td>2.0</td>
<td>3.2</td>
<td>2.2</td>
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</table>
### Normalized number of 24-Hour periods for TCs undergoing RI – in the MDR (1974-2010) – MJO Amplitude Greater than One

<table>
<thead>
<tr>
<th>MJO Phase</th>
<th>25 kt</th>
<th>30 kt</th>
<th>35 kt</th>
<th>40+kt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>22.0</td>
<td>13.7</td>
<td>8.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Phase 2</td>
<td>22.4</td>
<td>14.6</td>
<td>9.3</td>
<td>6.8</td>
</tr>
<tr>
<td>Phase 3</td>
<td>6.9</td>
<td>2.8</td>
<td>1.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Phase 4</td>
<td>14.5</td>
<td>9.0</td>
<td>4.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Phase 5</td>
<td>6.8</td>
<td>4.8</td>
<td>2.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Phase 6</td>
<td>6.8</td>
<td>3.9</td>
<td>1.9</td>
<td>0.6</td>
</tr>
<tr>
<td>Phase 7</td>
<td>1.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Phase 8</td>
<td>5.8</td>
<td>4.5</td>
<td>2.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Phase 1-2 / Phase 6-7</td>
<td>5.4</td>
<td>6.3</td>
<td>7.2</td>
<td>18.6</td>
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</table>
Percentage Chance of TCs Forming in the MDR in Each Phase of the MJO Having a RI Event of 25 Knots, 30 Knots, 35 Knots and 40+ Knots Over 24 h – MJO Greater than one SD

<table>
<thead>
<tr>
<th>MJO Phase</th>
<th>25 kt</th>
<th>30 kt</th>
<th>35 kt</th>
<th>40+ kt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84%</td>
<td>74%</td>
<td>53%</td>
<td>42%</td>
</tr>
<tr>
<td>2</td>
<td>69%</td>
<td>62%</td>
<td>42%</td>
<td>35%</td>
</tr>
<tr>
<td>3</td>
<td>56%</td>
<td>22%</td>
<td>11%</td>
<td>11%</td>
</tr>
<tr>
<td>4</td>
<td>62%</td>
<td>54%</td>
<td>38%</td>
<td>23%</td>
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<tr>
<td>5</td>
<td>47%</td>
<td>41%</td>
<td>29%</td>
<td>12%</td>
</tr>
<tr>
<td>6</td>
<td>38%</td>
<td>23%</td>
<td>23%</td>
<td>8%</td>
</tr>
<tr>
<td>7</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>8</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
<td>20%</td>
</tr>
</tbody>
</table>

| Phase 1+2 | 76%   | 67%   | 47%   | 38%    |
| Phase 6+7 | 33%   | 22%   | 22%   | 6%     |
Combined ENSO/MJO Impacts on Atlantic Basin TCs and RI
Anomalous Vertical Motion Associated with WH-Combined Index – Solid Lines represent anomalous vertical motion associated with MJO, dashed lines represent anomalous vertical motion associated with ENSO
<table>
<thead>
<tr>
<th>MJO Phase</th>
<th>Days per Phase</th>
<th>200-mb U</th>
<th>850-mb U</th>
<th>200-850 mb U</th>
<th>SST</th>
<th>SLP</th>
<th>700 mb RH</th>
<th>300 mb ω</th>
<th>OLR</th>
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<tbody>
<tr>
<td>1</td>
<td>327</td>
<td>-1.60</td>
<td>0.09</td>
<td>-1.69</td>
<td>0.00</td>
<td>-0.25</td>
<td>0.49</td>
<td>-0.38</td>
<td>-0.86</td>
</tr>
<tr>
<td>2</td>
<td>484</td>
<td>-3.73</td>
<td>0.79</td>
<td>-4.53</td>
<td>0.08</td>
<td>-0.41</td>
<td>1.08</td>
<td>-1.69</td>
<td>-2.70</td>
</tr>
<tr>
<td>3</td>
<td>327</td>
<td>-2.49</td>
<td>0.60</td>
<td>-3.10</td>
<td>0.10</td>
<td>-0.19</td>
<td>0.75</td>
<td>-0.11</td>
<td>-0.06</td>
</tr>
<tr>
<td>4</td>
<td>370</td>
<td>0.80</td>
<td>-0.23</td>
<td>1.03</td>
<td>0.03</td>
<td>0.10</td>
<td>-0.36</td>
<td>-0.46</td>
<td>1.20</td>
</tr>
<tr>
<td>5</td>
<td>420</td>
<td>0.91</td>
<td>-0.29</td>
<td>1.20</td>
<td>-0.07</td>
<td>0.56</td>
<td>-1.06</td>
<td>2.18</td>
<td>3.47</td>
</tr>
<tr>
<td>6</td>
<td>347</td>
<td>1.18</td>
<td>-0.76</td>
<td>1.94</td>
<td>-0.13</td>
<td>0.55</td>
<td>-1.44</td>
<td>1.51</td>
<td>1.56</td>
</tr>
<tr>
<td>7</td>
<td>325</td>
<td>1.51</td>
<td>-0.55</td>
<td>2.06</td>
<td>-0.16</td>
<td>0.37</td>
<td>0.20</td>
<td>0.99</td>
<td>0.22</td>
</tr>
<tr>
<td>8</td>
<td>299</td>
<td>3.42</td>
<td>0.34</td>
<td>3.08</td>
<td>0.16</td>
<td>-0.73</td>
<td>0.34</td>
<td>-2.04</td>
<td>-2.83</td>
</tr>
<tr>
<td>Phases 2+3</td>
<td></td>
<td>-3.11</td>
<td>0.70</td>
<td>-3.81</td>
<td>0.09</td>
<td>-0.30</td>
<td>0.92</td>
<td>-0.90</td>
<td>-1.38</td>
</tr>
<tr>
<td>Phases 7+8</td>
<td></td>
<td>2.47</td>
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<td>2.57</td>
<td>0.00</td>
<td>-0.18</td>
<td>0.27</td>
<td>-0.52</td>
<td>-1.30</td>
</tr>
<tr>
<td>Phases 2+3 – Phases 7+8</td>
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<td><strong>-5.58</strong></td>
<td><strong>0.80</strong></td>
<td><strong>-6.38</strong></td>
<td><strong>0.09</strong></td>
<td><strong>-0.12</strong></td>
<td><strong>0.65</strong></td>
<td><strong>-0.37</strong></td>
<td><strong>-0.08</strong></td>
</tr>
</tbody>
</table>
Tracks of TCs undergoing RI of at least 30 knots in 24 hours

Phases 2-3
43 TCs

Phases 7-8
3 TCs
Normalized number of 24-Hour periods for TCs undergoing RI – in the MDR (1974-2010)

<table>
<thead>
<tr>
<th>WH-Combined Index</th>
<th>25 kt</th>
<th>30 kt</th>
<th>35 kt</th>
<th>40+kt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>20.8</td>
<td>13.1</td>
<td>7.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Phase 2</td>
<td>24.2</td>
<td>17.4</td>
<td>11.0</td>
<td>8.9</td>
</tr>
<tr>
<td>Phase 3</td>
<td>35.8</td>
<td>21.4</td>
<td>9.5</td>
<td>5.8</td>
</tr>
<tr>
<td>Phase 4</td>
<td>4.6</td>
<td>3.2</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Phase 5</td>
<td>8.1</td>
<td>5.7</td>
<td>3.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Phase 6</td>
<td>3.5</td>
<td>1.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Phase 7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Phase 8</td>
<td>2.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Phase 2-3 / Phase 7-8</td>
<td>29.0</td>
<td>38.2</td>
<td>∞</td>
<td>∞</td>
</tr>
</tbody>
</table>
Percentage Chance of TCs Forming in the MDR in Each Phase of the WH-Combined Index Having a RI Event of 25 Knots, 30 Knots, 35 Knots and 40+ Knots Over 24 h

<table>
<thead>
<tr>
<th>WH-Combined</th>
<th>25 kt</th>
<th>30 kt</th>
<th>35 kt</th>
<th>40 kt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>77%</td>
<td>46%</td>
<td>38%</td>
</tr>
<tr>
<td>2</td>
<td>69%</td>
<td>66%</td>
<td>47%</td>
<td>47%</td>
</tr>
<tr>
<td>3</td>
<td>83%</td>
<td>71%</td>
<td>50%</td>
<td>33%</td>
</tr>
<tr>
<td>4</td>
<td>42%</td>
<td>33%</td>
<td>25%</td>
<td>17%</td>
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<td>67%</td>
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<tr>
<td>8</td>
<td>33%</td>
<td>33%</td>
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<td>0%</td>
</tr>
<tr>
<td>Phase 2+3</td>
<td>75%</td>
<td>68%</td>
<td>48%</td>
<td>41%</td>
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<tr>
<td>Phase 7+8</td>
<td>17%</td>
<td>17%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Conclusions and Future Work

• Combining anomalies driven by ENSO (on the seasonal timescale) and the MJO (on the sub-seasonal timescale) makes for a powerful predictor for TC formation as well as RI.

• TC alterations appear to be primarily driven by fluctuations in vertical wind shear anomalies.

• Can the combined MJO/ENSO index aid in predictions of rapid intensification?

• Does the MJO/ENSO index show similar levels of skill in other tropical cyclone basins?