Tropical cyclogenesis conditions in the Southwestern Indian Ocean

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Introduction

- Southwestern Indian Ocean (SWIO) [10% of global TC activity]
- Region of study [55-100°E, 5-20°S] ▶ No Madagascar, no Mozambique Channel.

Characterize the pre-cyclonic environment and its variations
[before TS; $V_{\text{max}} < 17 \text{ m s}^{-1}$] in the SWIO → 3 methods
Available data for our study

- **ECMWF | ERA-Interim**
  - SST | 1.5° x 1.5° | 12h
  - Atmospheric variables | 0.25° x 0.25° | 6h | 1000-100 hPa

- **ESA | Meteosat-5 (1999→2007)**
  - Meteosat-7 (2007→2011)
    - Brightness temperature in the water vapour channel (5.7 – 7.1 μm)
    - TB | 5 km x 5 km | 3h

- **NOAA/NCDC | IBTrACS**
  - RSMC La Réunion (Météo-France)
  - Already developed perturbations
Mean climatic conditions in the SWIO

Over 12 seasons

Cyclogenesis in the SWIO generally occurs when:
- SST above 27 °C
- WSHR below 15 m s\(^{-1}\)
Identification of developing TS in ERA-Interim

An objective analysis from Picornell et al. (2001)

Method

- Minimum Z < 1000hPa
- Surface cyclonic circulations > 5 \( \times 10^6 \) m\(^2\) s\(^{-1}\)
- Vertical and temporal continuity

Results

- Identification of all the 63 IBTrACS TS/TC in ERA-Interim
- Average location error: ~100km
- 6 hours to 6 days before the first fix in IBTrACS

Example: Tropical cyclone CHARLY in January 2001
Intraseasonal cyclogenesis index for the SWIO
A two-step objective method

**Step 1**
Identification of relevant variables for tropical cyclogenesis

**Step 2**
Optimum linear combination of these selected variables that accurately identifies favorable environmental conditions for cyclogenetic evolution at an intraseasonal time scale
Step 1: Selection of relevant variables

- 12 thermodynamic and dynamic variables

- Probability distribution functions (PDFs) for each variable $V_i$ over the 12 seasons in 2 domains based on 1st method:
  - CGN: points within 500 km of developing cyclonic systems
  - ENV: excluding CGN and points near developed storms and remnants

- Discriminating factor

$$\delta_i = \frac{\int |PDF(CGN) - PDF(ENV)| \, dV_i}{\int PDF(CGN) \, dV_i + \int PDF(ENV) \, dV_i}$$

- 9 relevant variables
  - 7 selected with $\delta_i \geq 0.3$
    - TB, RVOR$_{1000-800}$, RIH$_{1000-800}$, DIV$_{1000-800}$,
    - RVOR$_{700-500}$, RIH$_{700-500}$, DIV$_{400-200}$
  - + 2 others:
    - SST, WSHR$_{850-200}$
Step 2: Optimum combination of relevant variables

Selected variables $V_i$ + Cyclogenesis criterion $C$ ($\propto$ storm intensification)

Normalization with mean and std dev over all 12 seasons,

$$V_i^* = \frac{V_i - M(V_i)}{\sigma(V_i)}$$

and

$$C^* = \frac{C - M(C)}{\sigma(C)}$$

Principal Component Analysis

First component gives a unique combination

Cyclogenesis index $\gamma$ for the SWIO

$$\forall n = \{ \text{lat}, \text{lon}, t \}, \quad C^*(n) \approx \gamma(n) = -0.13 \ TB^*(n) + 0.09 \ SST^*(n)$$

$$- 0.13 \ RVOR_{1000-800}^*(n) - 0.12 \ DIV_{1000-800}^*(n) + 0.13 \ RIH_{1000-800}^*(n)$$

$$- 0.12 \ RVOR_{700-500}^*(n) + 0.14 \ RIH_{700-500}^*(n)$$

$$+ 0.11 \ DIV_{400-200}^*(n)$$

⚠️ Coefficient for $\text{WSHR}_{850-200}^* < 0.01 \rightarrow \text{already favorable?}$
Example: Cyclogensis index $\gamma$

Hovmöller diagram of $\max(\gamma)$ over 5-20°S

Large zones of $\gamma \geq 0.5$

Smaller areas of $\gamma \geq 1.8$ associated with tropical perturbations

Named tropical storm / cyclone

Unnamed tropical disturbance 7

SEASON DEC 2000 — MAR 2001

$P(TS) = 0$
Space-time spectral analysis

Hayashi (1971), Wheeler and Kiladis (1999), Roundy (2012), ...

**Index γ and \( V_i^* \)**

**Bilinear trend**

**Space-Time Spectral Analysis**

**Westward waves**
- Slow \( T > 10 \) days
  - “Equatorial Rossby Waves” (ER)
  - Wavenumber not discussed

**Eastward waves**
- Fast \( T \leq 10 \) days
  - “Mixed Rossby-Gravity Waves” (MRG)

**Stationary waves**
- Fast \( T \leq 20 \) days
  - “Kelvin Waves”

**Fast \( T > 20 \) days**
- “Madden-Julian Oscillation” (MJO)

1. Data and environment
2. TS identification in ERA
3. Cyclogenesis index \( γ \)
4. Spectral analysis

3rd method
Example: Wave mode decomposition

PVE: Percentage of TB* variance explained by each of the 6 modes

MJO active phase identified on Wheeler’s diagram (RMM1, RMM2)
Influence of wave modes on cyclogenesis

Percentage of $\gamma$ and $V_i^*$ variance explained by each of the 6 modes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Weight in $\gamma$</th>
<th>Bi-linear</th>
<th>Stationary</th>
<th>W ward Slow ER</th>
<th>W ward Fast MRG</th>
<th>E ward Fast Kelvin</th>
<th>E ward Slow MJO</th>
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<tr>
<td>$\gamma$</td>
<td>1</td>
<td>29</td>
<td></td>
<td>27</td>
<td>9</td>
<td>4</td>
<td>26</td>
<td>96</td>
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<tr>
<td>TB*</td>
<td>-0.13</td>
<td>1</td>
<td>29</td>
<td>18</td>
<td>7</td>
<td>6</td>
<td>33</td>
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<td>SST*</td>
<td>+0.09</td>
<td>54</td>
<td>13</td>
<td>21</td>
<td>0</td>
<td>1</td>
<td>13</td>
<td>104</td>
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<tr>
<td>RVOR*1000-800</td>
<td>-0.13</td>
<td>11</td>
<td>19</td>
<td>40</td>
<td>20</td>
<td>6</td>
<td>11</td>
<td>107</td>
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<tr>
<td>DIV*1000-800</td>
<td>-0.12</td>
<td>7</td>
<td>29</td>
<td>28</td>
<td>12</td>
<td>12</td>
<td>17</td>
<td>105</td>
</tr>
<tr>
<td>RIH*1000-800</td>
<td>+0.13</td>
<td>3</td>
<td>29</td>
<td>35</td>
<td>11</td>
<td>5</td>
<td>17</td>
<td>100</td>
</tr>
<tr>
<td>RVOR*700-500</td>
<td>-0.12</td>
<td>18</td>
<td>19</td>
<td>35</td>
<td>17</td>
<td>5</td>
<td>12</td>
<td>106</td>
</tr>
<tr>
<td>RIH*700-500</td>
<td>+0.14</td>
<td>5</td>
<td>27</td>
<td>29</td>
<td>7</td>
<td>2</td>
<td>27</td>
<td>97</td>
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<tr>
<td>DIV*400-200</td>
<td>+0.11</td>
<td>3</td>
<td>29</td>
<td>19</td>
<td>10</td>
<td>11</td>
<td>34</td>
<td>106</td>
</tr>
</tbody>
</table>

~70% of the variance of $\gamma$ in 2000-2001 is controlled by wave phenomena

Similar results over the 12 seasons in the SWIO:

65% wave phenomena, of which 28% ER, 8% MRG, 6% Kelvin and 23% MJO
Conclusion

• **3 objective methods for the SWIO**
  ▫ Identification of developing cyclonic perturbations in ERA-Interim data → A longer cyclogenesis phase
  ▫ Creation of an intraseasonal index as a linear combination of relevant environmental variables → Favorable conditions for cyclogenesis
  ▫ Space-time spectral analysis on index and relevant variables → Links between tropical cyclogenesis and equatorial waves

• **Further possible work**
  ▫ Other basins? North Atlantic?
  ▫ Other reanalyses? NCEP/NCAR? MERRA?

Thank you.
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