Identification and Characterization of Tropical Atmospheric Cold Pools using Spaceborne Scatterometer, Precipitation and Modeling

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Motivation

• Cold pool tracking and representation is an arduous task as they intersect and new cold pools form on their boundaries (Tompkins 2001; Feng et al., 2015).

• We aim to get a deeper insight into the evolution of tropical oceanic cold pools to better characterize the multi-scale tropical storm dynamics.

• Cold pools from older thunderstorms can merge into a mesoscale cold pools and can initiate secondary convection as observed in MCSs (Fujita, 1969; Johnson and Hamilton, 1988).

• Therefore we are trying to create a new identification metric to better identify these cold pools and their storm environments over tropics.

• We are also matching the ASCAT overpasses with TRMM and GPM-IMERG precipitation in combination with MERRA-2 reanalysis products to get a holistic perspective of cold pools over oceans.
Gradient Features (GFs) Identification

- The hypothesis lies on identifying closed areas of steep gradients in horizontal winds, termed as Gradient Features (GFs).

\[ |\nabla \vec{V}| = \begin{bmatrix} \frac{\partial u}{\partial x} + \frac{\partial v}{\partial x} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial y} \end{bmatrix} \]

- We have developed a new storm-centric, tensor-based approach to identify horizontal wind gradient.

- The figure shows two examples of cold pools that can be identified from ASCAT, (a) MCS and (b) shallow cumulus cloud clusters.
Gradient Feature Identification Algorithm Version 2.0

1. **Calculate Horizontal Wind Gradient**
   - Using numpy convolve2d, first derivative of zonal and meridional wind is calculated

2. **Label the feature using regionprops**
   - Scipy regionprops was used to label each feature satisfying the given threshold

3. **Remove all the features having less than 4 pixels**
   - Remove all the features having less than 4 pixels to create a well-connected polygon

4. **Apply Delaunay Triangulation**
   - Delaunay triangulation was applied to subdivide the irregular polygon into individual triangles

5. **Apply the concept of $\alpha$ shapes**
   - Applying the $\alpha$ shape function to connect the perimeters of triangles to get the edges of the polygon

6. **Identify Concave Hull**
   - Voila! You have your Gradient Feature
Example of GF on 22 May 2018
WRF-ARW Validation of GF Thresholds

- WRF v4.0 simulated 9-km data regridded to 12.5 km was used to validate the threshold and the performance of GF technique.
- The model ran for 15 days (00Z 17 October 2011 to 18Z 01 November 2011 during active MJO period.
- FFT filtered $T_v$ anomaly threshold of -1.5 K was used to identify thermal cold pools in the model.
- GF-identified cold pools were then tested against thermal cold pools to obtain various success indices.
Horizontal Wind Gradient ($s^{-1}$) and Virtual Temperature Anomaly (K) on 18Z 01 November 2011

Statistical indices for GF Identification from WRF on 18 UTC 01 November 2011

Critical Success Index (CSI)

Bias

False Alarm Ratio (FAR)
Buoy Validation Results
Buoys used for GF validation

Thermal Cold Pools are identified if:
(Kilpatrick et al., 2015)

\[
\begin{align*}
T(t+1) - T(t) &\geq -1.5 \degree C \\
T(t+2) - T(t) &\geq -2 \degree C
\end{align*}
\]
Gradient Features (GFs) Polygon Buffer

Polygon with 0.1° buffer

Polygon with 2.5° buffer

Original GF Polygon
Calculation of Success Indices from Buoys

<table>
<thead>
<tr>
<th>Air Temperature (T)</th>
<th>YES (Gradient Feature (GF) YES)</th>
<th>NO (Gradient Feature (GF) NO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>( A = \text{Hits (If GF exists within the thermal cold pool period)} )</td>
<td>( B = \text{Missed events (No GF Present even though a thermal cold pool exists)} )</td>
</tr>
<tr>
<td>NO</td>
<td>( C = \text{False alarms (GF is present although no thermal cold pool exists).} )</td>
<td>( D = \text{Correct rejections (Both the parameters don’t have a cold pool)} )</td>
</tr>
</tbody>
</table>

\[
P_{\text{OD}} = \frac{A}{A + B}\]
\[
F_{\text{AR}} = \frac{C}{A + C}\]
\[
S_R = 1 - F_{\text{AR}}\]
Global Climatology of ASCAT-Identified Cold Pools

ASCAT-observed global Gradient Features (GFs) with TRMM Precipitation Climatology in a 0.5° gridbox for 2007-2018

(a) Distribution of GFs according to number density

(b) Distribution of GFs according to area

(c) Number of GFs TRMM 3B43 Global Monthly Precipitation Climatology

(d) GF-Attributed TRMM 3B42 Precipitation
Summary and Conclusions

• GF technique is able to identify pockets of mesoscale downdrafts corresponding to tropical oceanic convective systems.

• WRF-simulated wind gradient-identified cold pools match well with thermal cold pools.

• ASCAT-identified gradient features validates well with in-situ buoy-identified thermal cold pools over tropical Indian, Pacific and Atlantic Ocean.

• Global climatology of GFs (Number) is corresponding well with TRMM precipitation, thus providing evidence that GFs are related to parent convective signatures.
Questions?
Delaunay Triangulation and Alpha Shapes

Mathematically, Delaunay triangulation says that for a set \( P \) of points in \( d \)-dimensional Euclidian space, no point in \( P \) is inside the circum-hypersphere of any \( d \)-simplex.

Alpha Shape is the concave hull of the triangulated polygon to give the connected outer edges of the polygon.
**Gradient Feature (GF)**

<table>
<thead>
<tr>
<th>Virtual Temperature ($T_v$)</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>$A = \text{Hits (Intersection of GF and } T_v \text{ is } \geq 50% \text{ of area of } T_v)$</td>
<td>$B = \text{Missed events (Intersection of GF and } T_v \text{ is } &lt; 50% \text{ of the area of } T_v)$</td>
</tr>
<tr>
<td>NO</td>
<td>$C = \text{False alarms (No intersection between GF and } T_v)$</td>
<td>$D = \text{Correct rejections (Both the parameters don’t have a cold pool)}$</td>
</tr>
</tbody>
</table>

**Calculation of Success Indices from WRF**

- **Critical Success Index**
  \[
  CSI = \frac{A}{A + B + C}
  \]

- **False Alarm Ratio**
  \[
  FAR = \frac{C}{A + C}
  \]

- **Bias**
  \[
  Bias = \frac{(A + B)}{(A + C)}
  \]