Diurnal Cycle of ASCAT-Identified Cold Pools and associated Convective Systems in the Maritime Continent and South China Sea

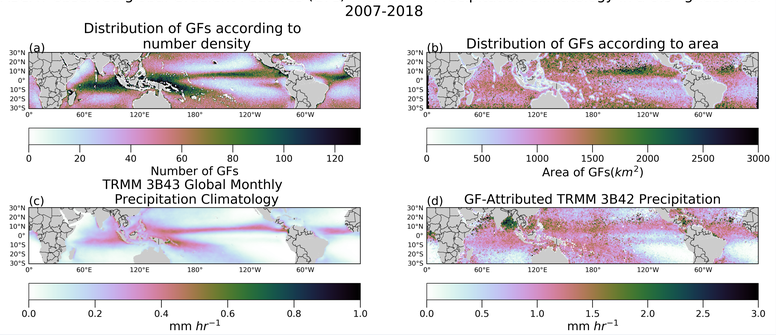
Stephen W. Nesbitt[1], Piyush Garg[1], Timothy J. Lang[2], George Priftis[3], Themis Chronis[3]

[1]University of Illinois Urbana-Champaign, [2]NASA Marshall Space Flight Center, Alabama, [3]University of Alabama-Huntsville

Introduction

- Mesoscale convective cold pools are known to alter the turbulent air-sea fluxes in the regions of active convection such as maritime tropics.
- Satellite-based Ocean Vector Wind instruments have proven to be useful in observing these mesoscale outflows corresponding to convective cold pools (Kilpatrick et al., 2015).
- A new storm-centric, tensor-based wind-gradient identification algorithm identifies gradients associated with convective cold pools and other boundaries such as land-sea breeze fronts. We term these ***as Gradient Features or GFs***; analyzed over tropical oceans (2007-2018) using horizontal winds from Advanced Scatterometer (ASCAT-A).

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



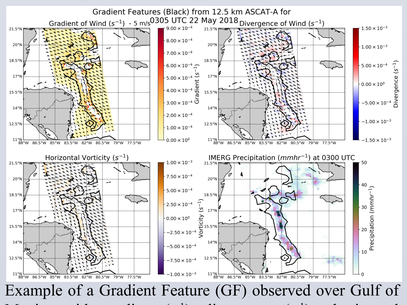
Research Questions

- Is the diurnal variability and characteristics of GFs (i.e., cold pools far from coasts) associated with mesoscale convective systems is tightly related to the life cycle of parent convection?
- What is the relationship between GFs and their environments with respect to propagation of Madden-Julian Oscillation (MJO) and Boreal Summer Intra-Seasonal Oscillation (BSISO)?

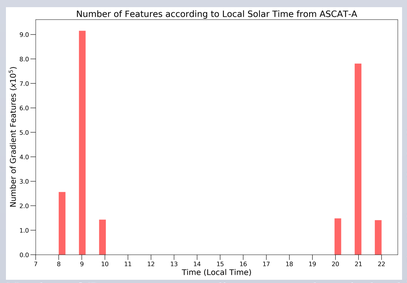
Data and Methodology

Variables	Source	Resolution	Time Period
U & V winds (ms^{-1})	ASCAT-A	12.5 km Field of View (FOV)	2007-2018
Precipitation (mm/0.5hour)	Global Precipitation Measurement (GPM-IMERG)	0.1^{o}x0.1^o	2007-2018
Precipitation (mm/3hour)	Tropical Rainfall Measurement Mission (TRMM) 3B42	0.25^{o}x0.25^o regridded to ASCAT FOV	2007-2018
Air and Sea Surface Temperature (K) and specific humidity (g/kg)	Modern Era Retrospective Reanalysis (MERRA-2)	0.5^{o}x0.625^o regridded to ASCAT FOV	2007-2018
Air Density (Kg/m^3)	Modern Era Retrospective Reanalysis (MERRA-2)	0.5^{o}x0.625^o regridded to ASCAT FOV	2007-2018

- Magnitude of horizontal wind gradient is calculated from ASCAT using: $|\nabla\vec{V}| = \begin{bmatrix} \frac{\partial u}{\partial x} + \frac{\partial v}{\partial x} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial y} \end{bmatrix}$
- Polygons (GFs) were identified using gradient thresholds corresponding to 6.8 x 10^{-5} s^{-1} and 1.2 x 10^{-4} s^{-1}. Two thresholds are used here to first reduce the background noise and then to remove the bias in cold pool identification due to low gradients based on WRF simulations.
- Delaunay triangulation was applied to subdivide the irregular polygon into individual triangles.
- Computational concept of α-shapes was applied to connect the perimeters of triangles to get the edges of the polygon and create the ***concave hull***.



Example of a Gradient Feature (GF) observed over Gulf of Mexico with gradient (s^{-1}), divergence (s^{-1}) , horizontal vorticity (s^{-1}) and GPM precipitation (mm/0.5hour).



Number of Features corresponding to every hour in local solar time.

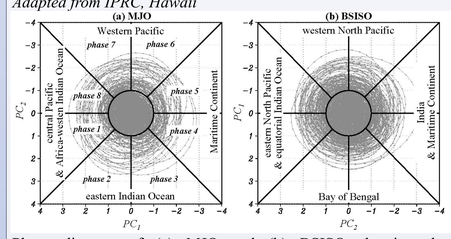
- In the first figure on the left, white patches are the rain-flagged areas in winds.
- The second figure on the left shows the number of features corresponding to local solar time over tropical oceans.
- GF maxima is observed at 9 AM and 9 PM respectively, thus allowing us to analyze the diurnal variation of GF convection.
- Latent and Sensible heat fluxes were obtained by using temperature, humidity and density from MERRA-2 and winds from ASCAT-A using bulk aerodynamic formulae as follows:

$$Q_s = \rho C_p C_s U_{10}(t_s - t_a)$$
$$Q_L = \rho L_E C_L U_{10}(q_s - q_a)$$

Q_S = Sensible heat flux
Q_L = Latent Heat Flux
C_p = Specific heat capacity of air
L_E = Latent heat of Evaporation
C_S/C_L = Sensible/latent heat transfer coefficient
U_{10} = wind speed at 10m above sea surface
t_s/t_a = Sea and Air temperature
q_s/q_a = Specific humidity at sea-surface and 10m above

Diurnal Variation of GFs

Adapted from IPRC, Hawaii



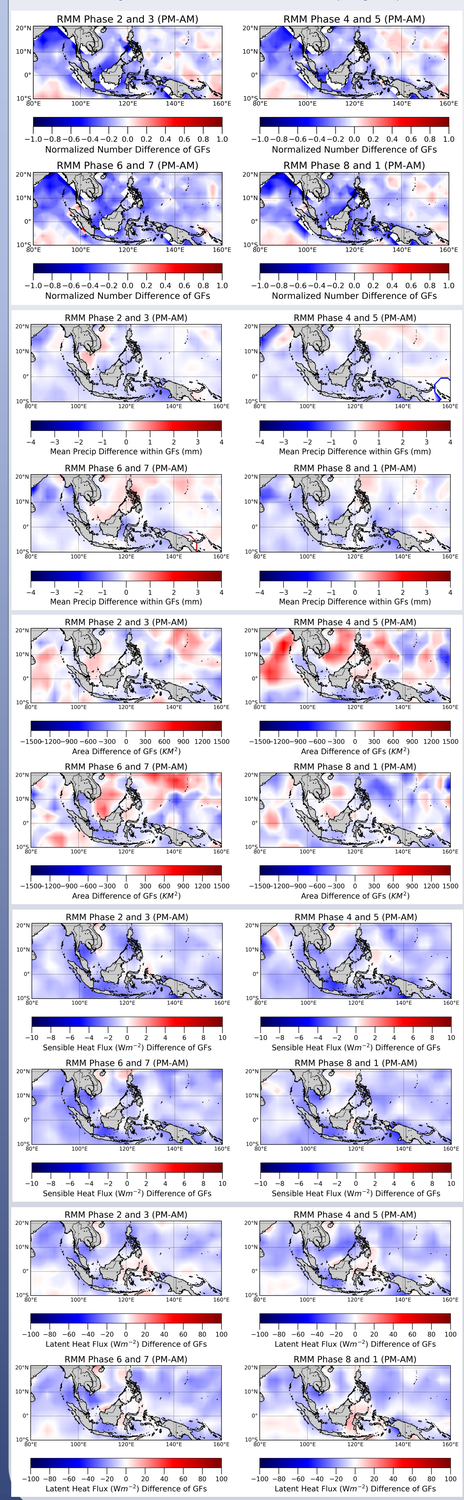
Phase diagram of (a) MJO and (b) BSISO showing the propagation of the Intra-seasonal oscillations over the tropics.

- The phase-diagram depicts the propagation of MJO and BSISO in 8 phases.
- This study only takes cases where for MJO: $\sqrt{PC_1^2 + PC_2^2} > 1.$

BSISO: $\sqrt{PC_1^2 + PC_2^2} > 1.5$

- The primary reason to choose cases for BSISO amplitude > 1.5 is to only consider the strong cases happening in boreal summer and reduce the noise in the signal.
- Number, area (km^2), precipitation (mm), sensible and latent heat flux (Wm^{-2}) of Gradient Features (GFs) in 3° lat-lon box for Morning (AM) and Evening (PM) hours according to the local solar time histogram are calculated.
- The difference (PM-AM) between the above variables was calculated on each grid point which are evaluated in the following sections.

Madden-Julian Oscillation (MJO)



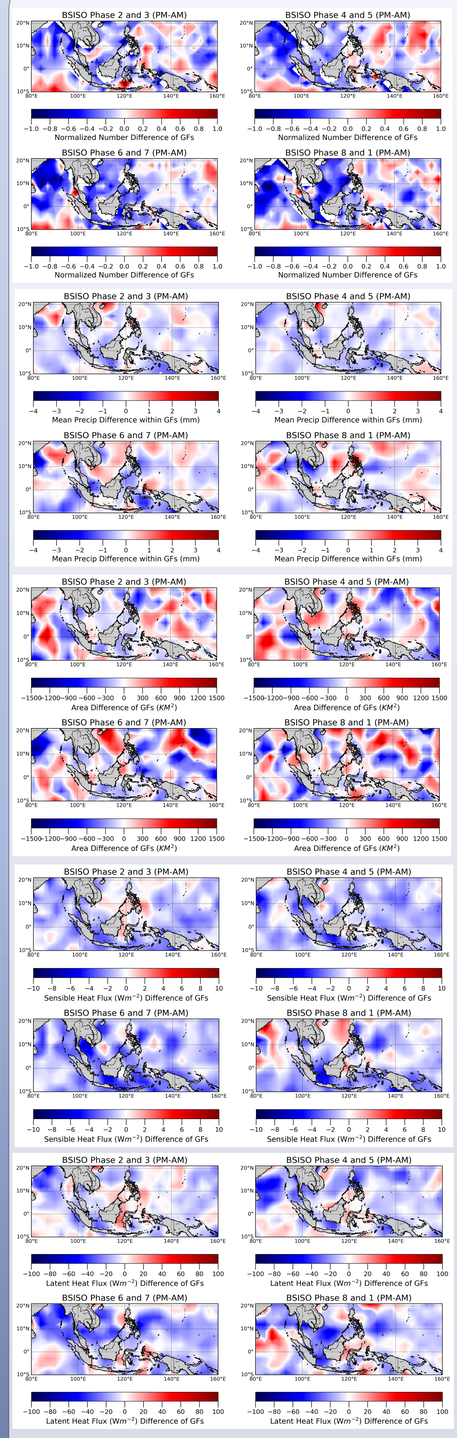
Dynamics

- Number and Precipitation of GFs relate well with Peatman et al. (2014) where they showed a strong precipitation signal in the morning hours over coasts.
- Contrary to number and precipitation of GFs, area shows a maxima during evening hours over coasts which also changes significantly with MJO phase.
- Evening GF area maxima can be explained based on the life cycle of convection – as the system initiates, grows and matures, the size of cold pool increases due to intensification of downdrafts within the system.

Surface Fluxes

- Sensible heat flux being a function of winds, sea surface temperature (SST) and air temperature theoretically should increase when there is a wind or temperature gradient and therefore we observe high SH fluxes when there are more GFs, i.e. in morning.
- Latent heat flux; also a function of winds, humidity at sea surface and 10 m above, shows an increase in the presence of steep wind and humidity gradients, i.e. within GFs.

Boreal Summer Intra-Seasonal Oscillation (BSISO)



Dynamics

- The overall diurnal signal patterns are similar to what was observed in MJO but the diurnal convective signature is stronger in BSISO especially in Bay of Bengal and South China Sea.
- The primary reasoning behind stronger diurnal signal could be related to strengthened mesoscale convection during boreal summer by virtue of BSISO and Asian monsoon over the maritime continent, leading to enhanced cold pool activity in the region.

Surface Fluxes

- The major differences between MJO and BSISO heat fluxes is the presence of regions of sensible and latent heat maxima over Bay of Bengal and South China Sea during evening hours.
- This suggests that Asian monsoon in combination with BSISO leads to strong land-sea breeze circulation, thus producing stronger diurnal convective signature in all the parameters.

Conclusions

- The newly-devised GF technique is able to identify features likely to be tropical oceanic mesoscale cold pools for the given period.
- ASCAT-A being a sun-synchronous satellite provides us an opportunity to examine a diurnal signal in GFs.
- The MJO propagation changes the overall diurnal characteristics of these gradient features.
- The BSISO shows a stronger diurnal signature in GF properties as compared to MJO.

References

Kilpatrick, T. J., & Xie, S. P. (2015). ASCAT observations of downdrafts from mesoscale convective systems. *Geophysical Research Letters*, *42*(6), 1951-1958.

Peatman, S. C., Matthews, A. J., & Stevens, D. P. (2014). Propagation of the Madden–Julian Oscillation through the Maritime Continent and scale interaction with the diurnal cycle of precipitation. *Quarterly Journal of the Royal Meteorological Society*, *140*(680), 814-825.

Acknowledgements

The authors would like to acknowledge the support of NASA Ocean Vector Winds Science Team (OVWST) support through the grant NNH17ZDA001N-OVWST. The authors would also like to thank the department of atmospheric sciences, university of Illinois Urbana-Champaign for providing computing and other infrastructure to successfully conduct the research.

Please contact Prof. Stephen W. Nesbitt (snesbitt@illinois.edu) or Piyush Garg (pgarg7@illinois.edu) for any queries regarding the research.