Evolving Tropical Cyclone Precipitation Patterns and the Relationship to Intensity & Large-Scale Moisture

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Background

Enhanced mid-level tropospheric moisture is among the necessary ingredients for tropical cyclone (TC) genesis[1]. However, the role of large-scale moisture in modulating the intensity and structure of mature TCs is less understood[2,3,4,5]. Recent research has focused on how environmental humidity influences TC structure in idealized modeling environments and case studies[3,4,5]. Relatively few studies have investigated how large-scale moisture affects the evolution of precipitation and how that relates to intensity in the global TC record. To achieve this goal, I utilize a shape method[6] grounded in previous research that heating within the radius of maximum winds supports intensification[7,8] and that a symmetric convective pattern precedes rapid intensification periods[9,10]. Accordingly, I quantify the central, symmetric, and cohesive pattern of TC rainfall, use a moving Mann-Whitney *U*-test to determine positions where that pattern is evolving, and relate these pattern changes to TC intensity and environmental factors.

Objectives

This project's main objectives are to:

1) identify significant TC rainfall pattern changes in major northern basins: North Indian Ocean (NIO), Northwest Pacific (NWP), Northeast Pacific (NEP) & North Atlantic (NAT).
2) relate these changes to intrinsic (intensity) and extrinsic (environmental conditions) properties of the TC, with a focus on large-scale moisture.

Data

International Best Track Archive for Climate Stewardship (IBTrACS)

- 6-hourly positions and intensities, merged from individual agencies into a worldwide TC database

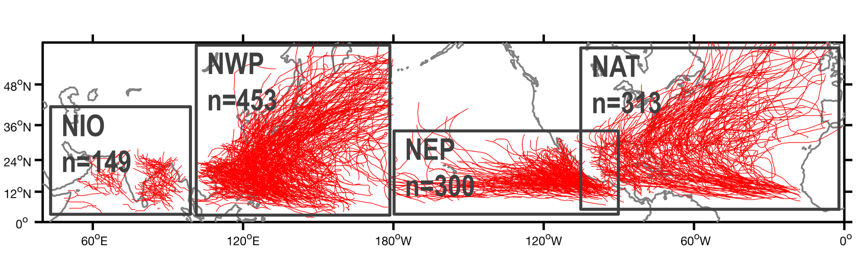


Fig 1. IBTrACS for 1998-2014 Northern Hemisphere Tropical Cyclones

Tropical Rainfall Measuring Mission (TRMM) Multi-Precipitation Analysis

- also known as TRMM-3B42
- 0.25° grid, 3-hourly

Climate Forecast System Reanalysis (CFSR)

- 0.5° grid, 6-hourly
- environmental variables: winds, RH, precipitable water, geopotential height

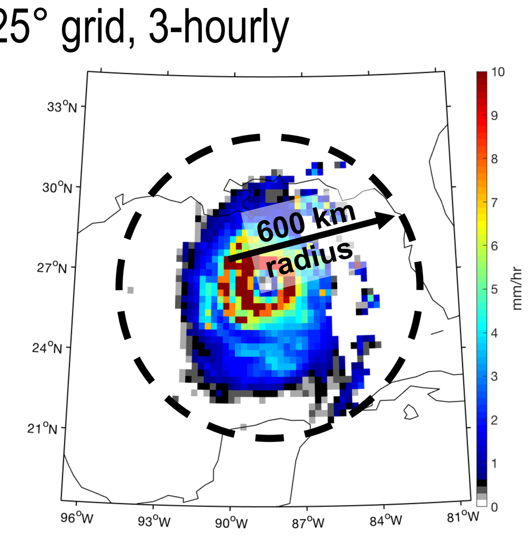


Fig 2. TMPA precipitation in Hurricane Katrina, valid 18 UTC 28 Aug 2005

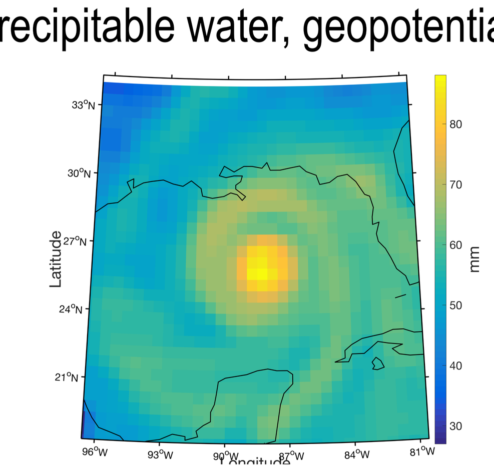


Fig 3. CFSR Precipitable Water, valid 18 UTC 28 Aug 2005

Obj. 1: Identify significant rainfall pattern change

1) DELINEATE BINARY SHAPE

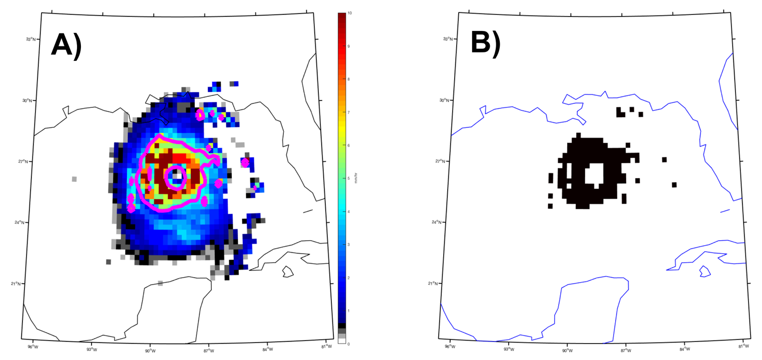
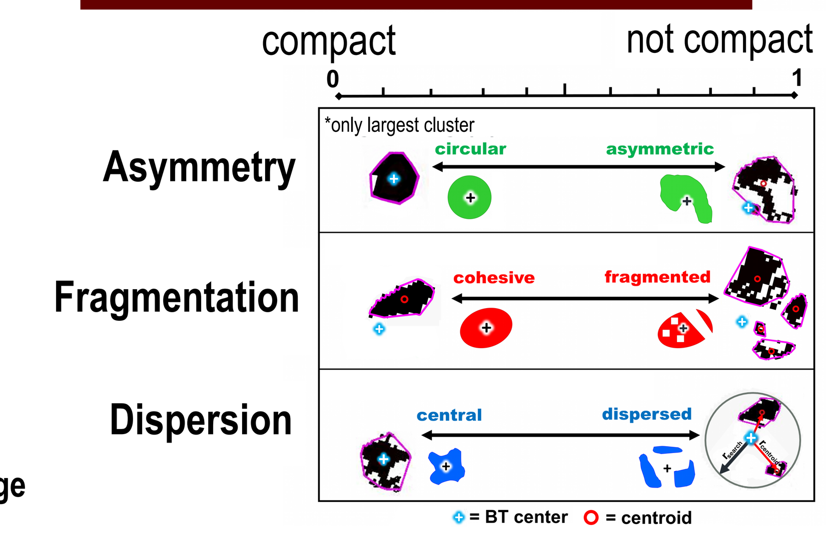


Fig 4. Demonstration of shape delineation using 90th percentile threshold with A) contour and B) binary image

2) MEASURE COMPACTNESS



3) ID SIGNIFICANT (p<0.05) SHAPE CHANGES DURING TC LIFECYCLE

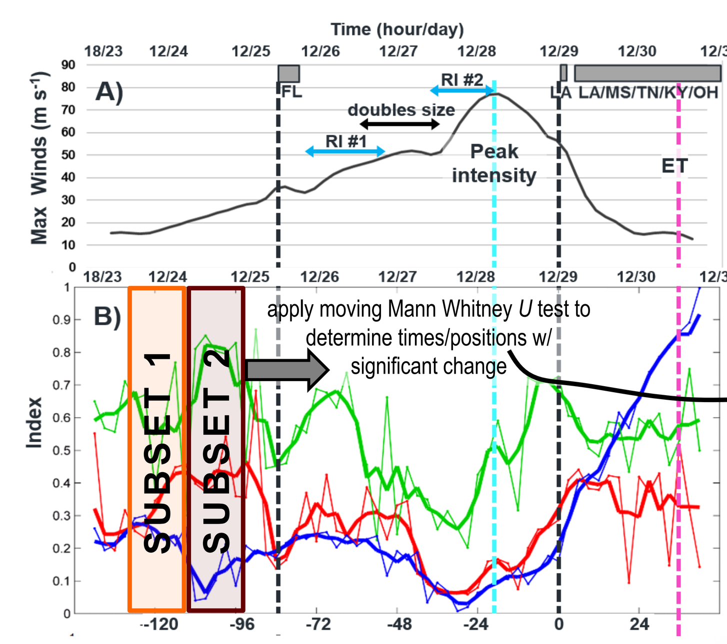


Fig 5. Timeseries of A) intensity and B) shape metric indices for Hurricane Katrina (2005)

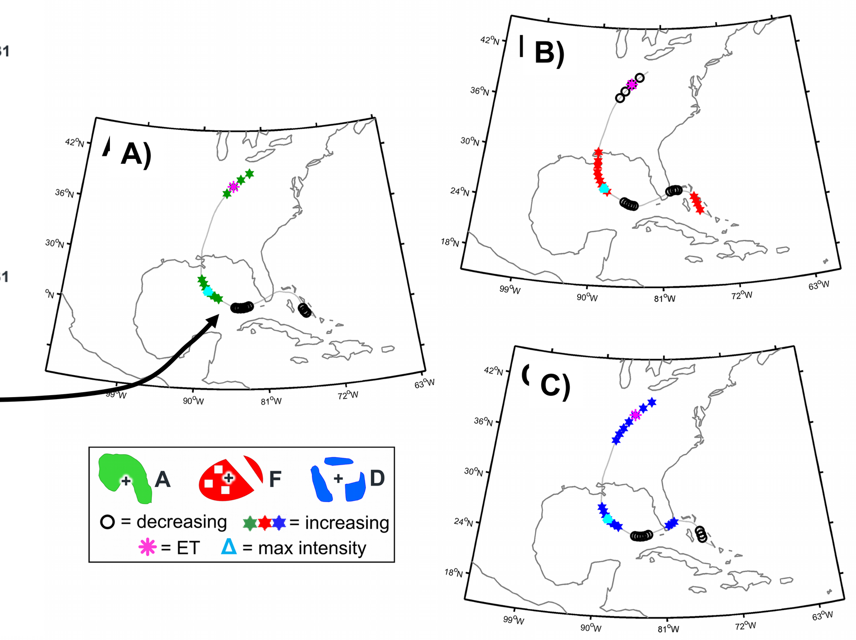


Fig 6. Along track time steps for Hurricane Katrina (2005) when moving Mann-Whitney *U* indicates significant (p<0.05) shape change

4) MAP SIGNIFICANT (p<0.05) STRUCTURE (& INTENSITY) CHANGES

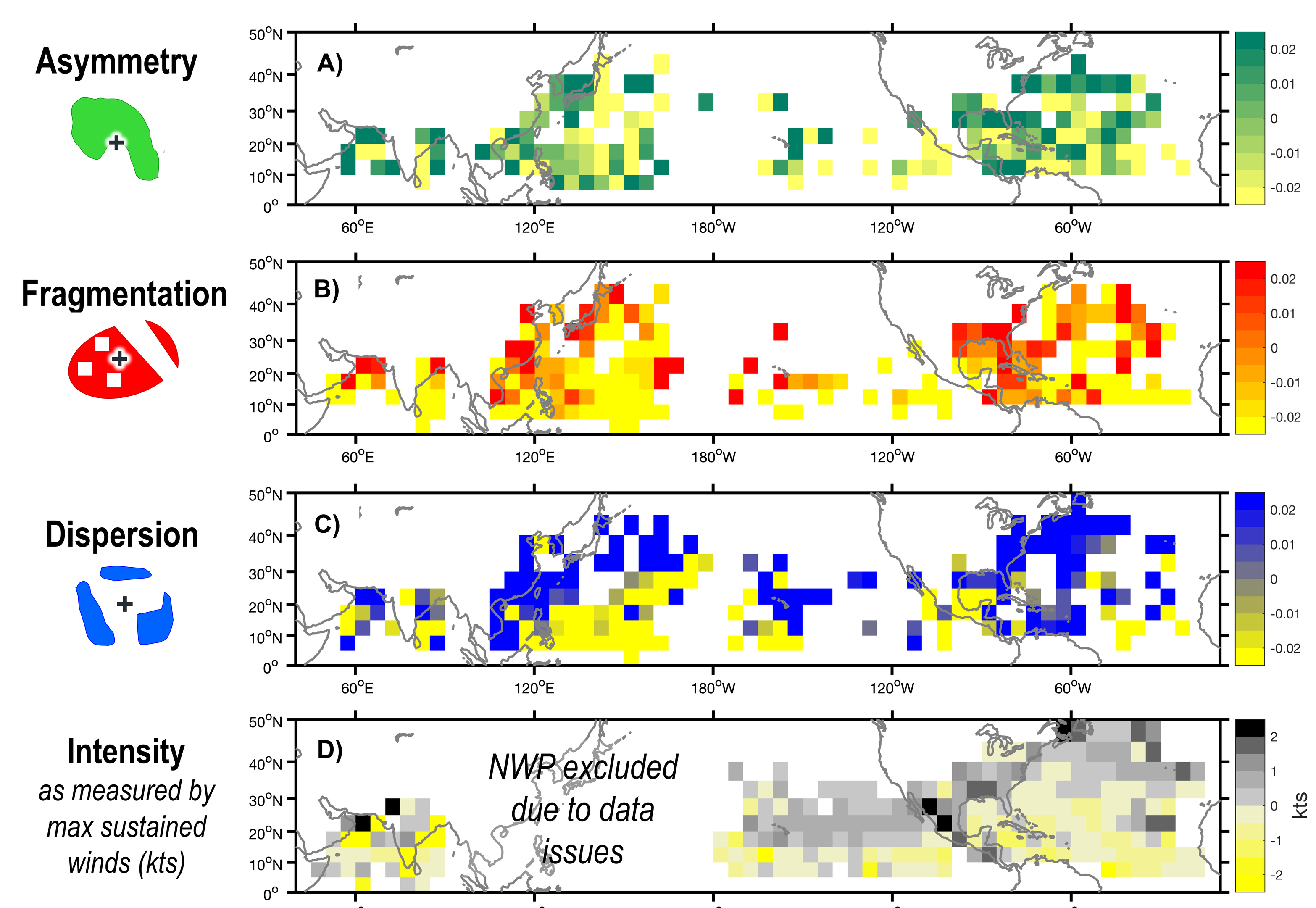


Fig 7. Average significant (p < 0.05) A) asymmetry, B) fragmentation, and C) dispersion trends and D) intensity changes (no stat test) within 5° x 5° latitude-longitude gridboxes for 1998-2014 Northern Hemisphere TCs.

Obj. 2: Relate to intensity & environment (NAT)

INTENSITY

Correlations indicate significant (p<0.01) relationships between intensity and compactness, particularly dispersion. However, in prognostic terms, 3-hr asymmetry and fragmentation trends are slightly stronger predictors of intensification.

Note: low correlations are due to high frequency variability, including a marked diurnal cycle.

Spearman's r	VMAX	DV+6	DV+12	DV-6	DV-12
Asymmetry	**−0.152**	*-0.097*	*-0.064*	**−0.128**	**−0.140**
Asym 3-hr Trend	*0.054*	**-0.131**	**-0.127**	*-0.038*	*-0.004*
Fragmentation	**-0.378**	-0.060	*-0.053*	*-0.078*	*-0.093*
Frag 3-hr Trend	*0.060*	**-0.131**	*-0.097*	*-0.028*	*-0.027*
Dispersion	**-0.621**	-0.056	*-0.041*	*-0.091*	**−0.106**
Disp 3-hr Trend	**-0.106**	-0.091	*-0.049*	**−0.424**	**−0.478**

Table 1. Spearman's correlation for shape metrics (ASYM, FRAG, DISP) and 3-hour shape metric trends (ATRD, FTRD, DTRD) versus intensity (VMAX) and intensity change at subsequent (+6, +12 hrs) and preceding (-6, -12 hrs) time intervals (in NAT, over ocean, pre-ET). Bolded quantities indicate significance at a 99% confidence level. *Note that (most) correlations are negative, indicating an association between compactness and intensity/intensification.*

ENVIRONMENT

Spearman's r	D200	C850	SHRS	SHRD	DZNS	SSTS	RHLO	RHMD	MFC2	MFC6
Asymmetry	**0.103**	*0.078*	*0.054*	**0.149**	*0.011*	**−0.167**	**0.101**	**0.184**	*0.033*	*-0.086*
Fragmentation	*0.061*	**0.303**	**0.127**	**0.113**	*0.025*	**−0.118**	**0.316**	**0.357**	**−0.142**	*-0.049*
Dispersion	**0.109**	**0.400**	**0.255**	**0.359**	*0.069*	**−0.308**	**0.276**	**0.230**	**−0.110**	*0.012*

Table 2. Spearman's correlations for shapes versus environmental variables (in NAT, over ocean, pre-ET). Bolded quantities indicate significance at a 99% confidence level. *Note that negative correlations indicate an association w/ compact TC shapes* Environmental variables are defined similar to SHIPS and include 200 mb divergence (D200), 850 mb divergence (D850), 850-500 mb shear (SHRS), 850-200 mb shear (SHRD), north-south geopotential height gradient (DZNS), sea surface temperatures (SSTS), 850-700 mb RH (RHLO), 700-500 mb RH (RHMD), and moisture flux convergence w/in 200 km (MFC2) and 600 km (MFC6)

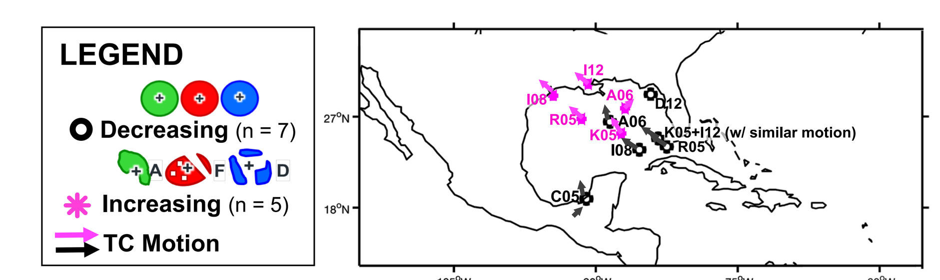


Fig 8. to left displays positions and motion vectors for TCs included in the composites below (in Fig 9). Black circles and magenta asterisks correspond to whether the storms display decreasing or increasing shape metrics, respectively.

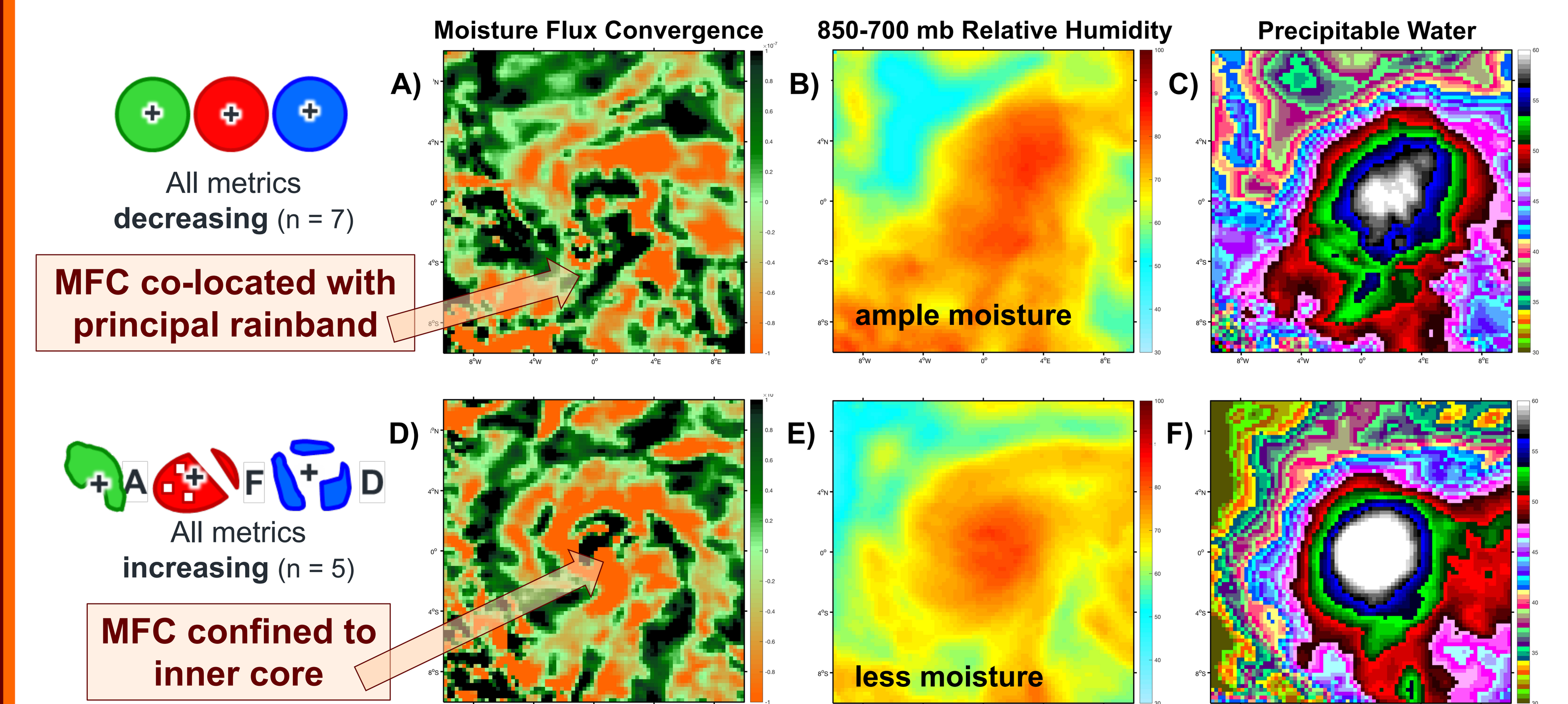


Fig 9. Environmental moisture composites for (left) moisture flux convergence, (middle) 850 mb Relative Humidity, and (right) precipitable water. Top A-C (bottom D-F) correspond to storms that display decreasing (increasing) shape metrics.

Key Results & Conclusions

Fig 7 shows preferred regions for evolving TC structure, e.g. in the NAT increasing compactness occurs in the main dev. region and southeastern Gulf of Mexico (GoM). Focusing on GoM landfalls, TCs becoming more compact are situated with ample moisture to the equatorward side and display an active principal rainband that appears to be an important conduit for moisture (Fig 9). Future work will examine if this is a consistent finding for a broader set of TCs in all basins.

References: [1] Gray, *Mon. Wea. Rev.*, 1968. [2] DeMaria & Kaplan, *Wea.* Forecasting, 1994. [3] Hill & Lackmann, *Mon. Wea. Rev.*, 2009. [4] Ying & Zhang, *J. Atm Sci.* Japan, 2012. [5] Wu et. al, *Atmos. Chem.* Phys., 2015. [6] Zick & Matyas, *Annals Amer. Assoc. Geog.*, 2016. [7] Schubert & Hack, *J. Atmos. Sci*, 1982. [8] Susca-Lopata et. al., *Mon. Wea. Rev.*, 2015. [9] Kieper & Jiang, *Geophys. Res. Lett.*, 2012. [10] Rogers et al., *Mon. Wea. Rev.*, 2014.