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Evolving Geometries in the Precipitation Patterns of 2004-2012 U.S. Landfalling Hurricanes

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CAREER Award
BCS-1053864

Introduction

Tropical cyclones (TCs) bring severe winds, storm surges, and rainfall to densely populated coastal and inland regions that are increasingly vulnerable to these weather phenomena (Cutter et. al. 2007). Water-related deaths from inland flooding and storm surge are the leading causes of TC-related fatalities (Rappaport 2014), prompting the National Weather Service (NWS) to adopt the edict, "*When you hear hurricane, think inland flooding*" (U.S. Dept of Commerce 2005). Operational TC precipitation forecasting currently relies on (1) simple statistical models (e.g.,Ebert et. al. 2011) , which do not allow for evolving patterns and (2) numerical weather prediction models, which struggle with complex interactions during landfall (Marchok et al. 2007). In this study, we develop a storm-scale conceptual model of the evolving precipitation structure in 2004-2012 U.S. landfalling TCs.

Objectives

We aim to demonstrate how shape metrics may be used to:
(a) assess the timing of significant changes to TC structure and
(b) determine preferred geographical regions for TC structural evolution within the western Atlantic, Caribbean, and Gulf of Mexico

Data

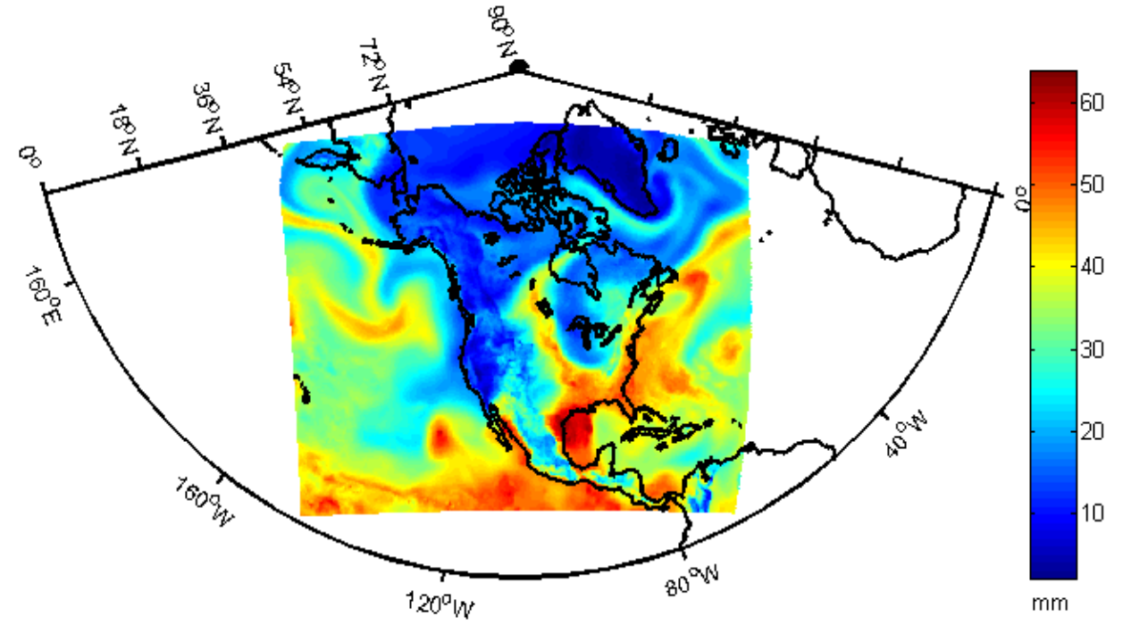

Fig 1. NARR Precipitable Water (mm) 18 UTC Jul 23 2008

- **North American Regional Reanalysis (NARR):** a hybrid model/data assimilation system intended for hydrometeorology research
- 32 km horizontal grid with 29 vertical pressure levels, avail. 8 x daily (3-hourly)
- assimilates high quality 1-hourly precipitation analyses (Mesinger et al. 2006)

- **Best track (BT)** data from the National Hurricane Center (NHC): the most accurate estimates available for TC position and intensity
- Due to data quality issues away from land, we limit this analysis to positions within 10 latitude/longitude of the U.S. coastline
- 6-hourly BT data are interpolated to 3-hourly using a spline interpolation
- NHC also provides the timing/location of landfall, maximum intensity, and extratropical transition (ET)

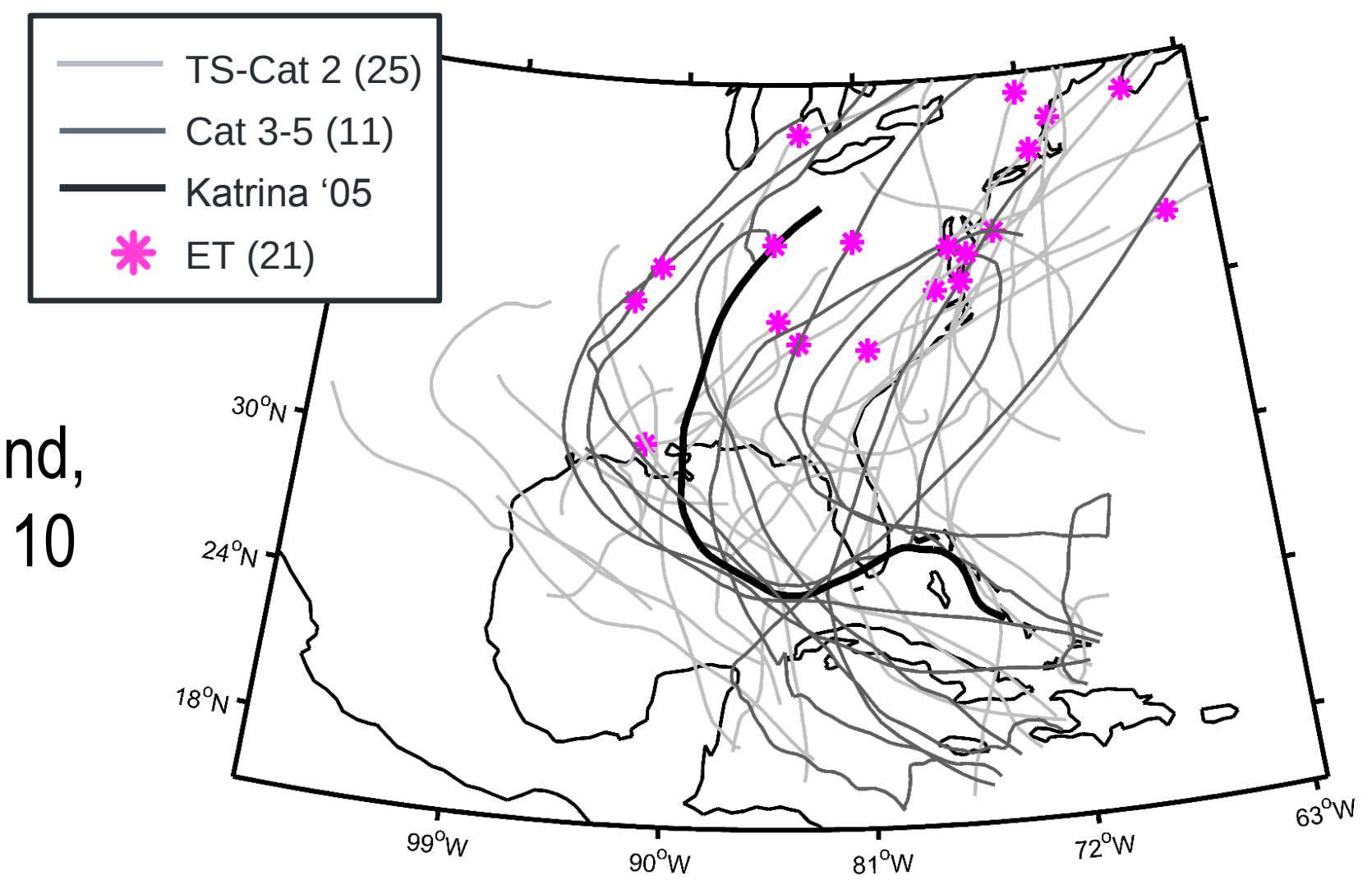

Fig 2. 2004-2012 U.S. landfalling tropical cyclone (TC) tracks, subset by intensity category and time of extratropical transition (ET), based on best track data

Objective 1: Timing of TC structural evolution

Step 1: Construct a binary image of TC precipitation

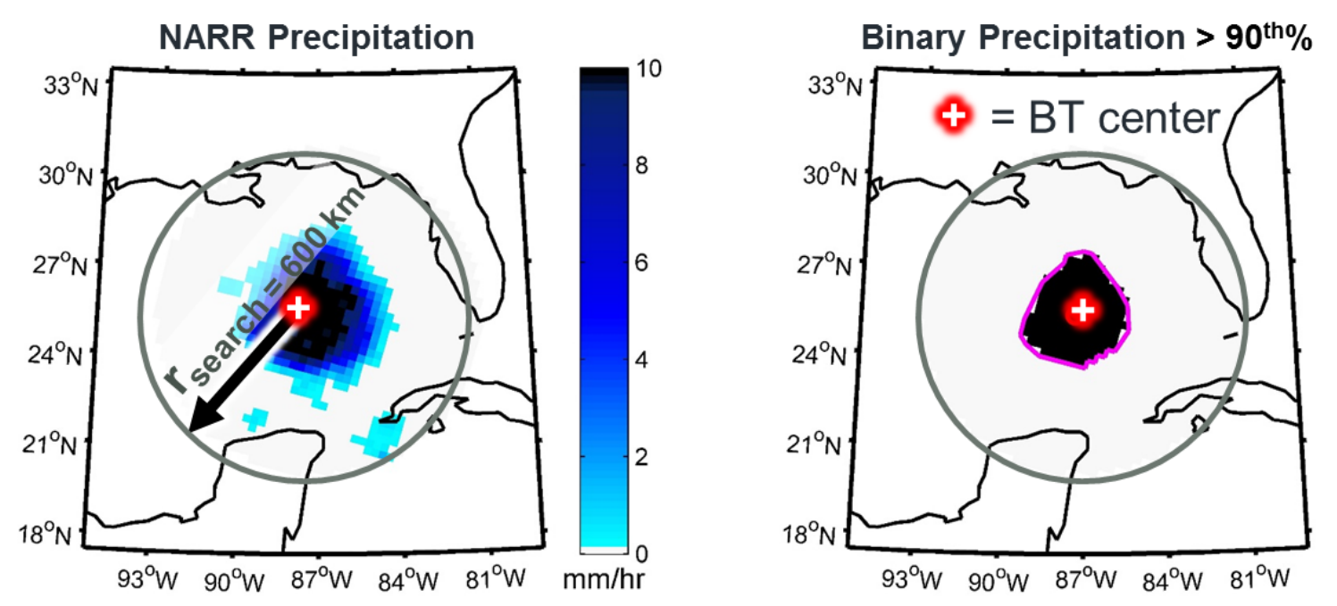

Fig 3. Demonstration of NARR TC precipitation shield and delineation of binary shape(s)

To construct the binary image, we apply a search radius of 600 km from the TC center, and only precipitation > 90th percentile is retained for the subsequent shape analysis

Step 2: Quantify shape using metrics that encompass TC structure

We quantify the spatial distribution of TC precipitation using three compactness measures (MacEachren 1985) that encompass characteristic geometries of TCs moving into the mid-latitudes: asymmetry (A), fragmentation (F), and dispersiveness (D).

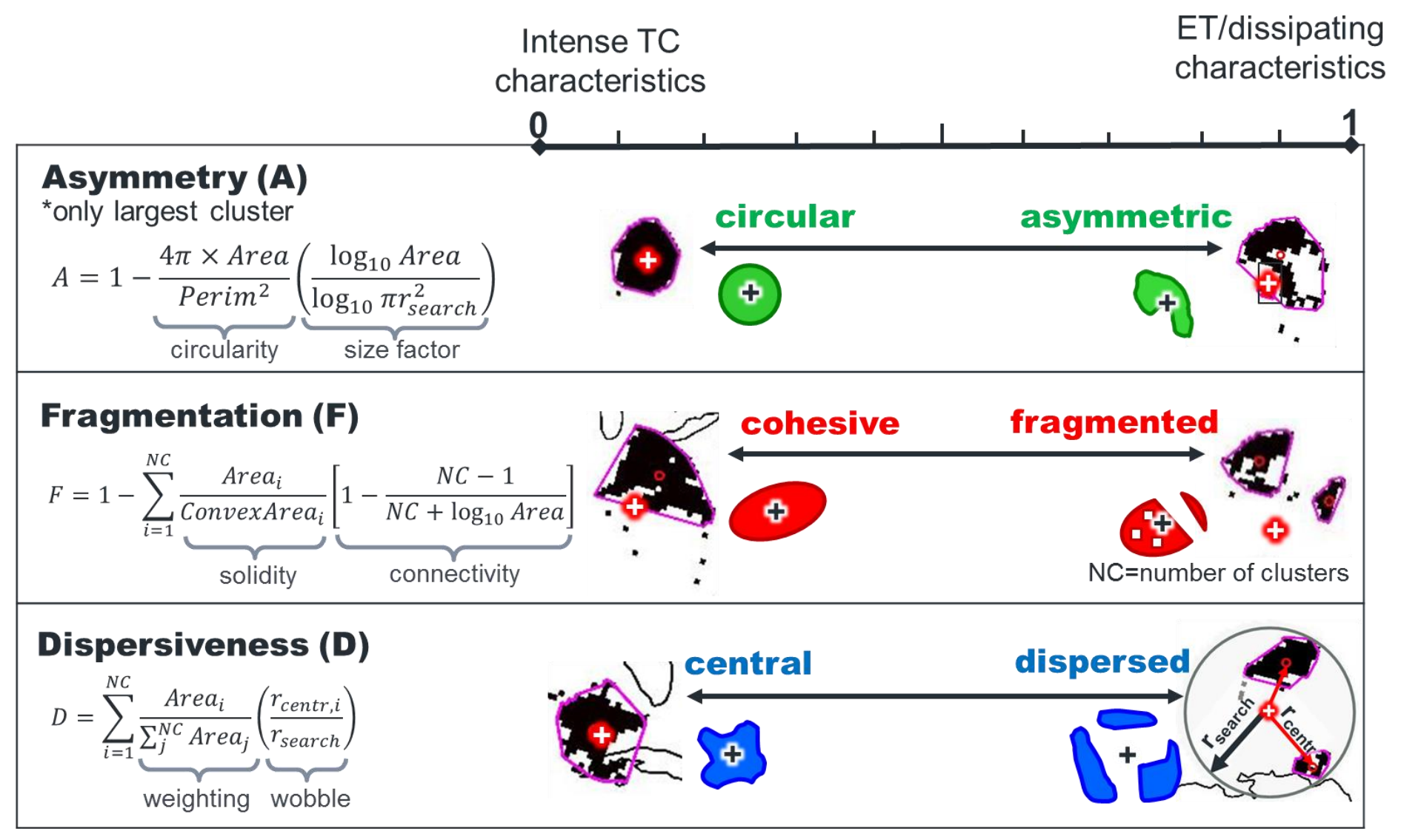

Fig 4. Summary of Shape Metrics

Step 3: Moving Mann Whitney *U*-test to determine restructuring times

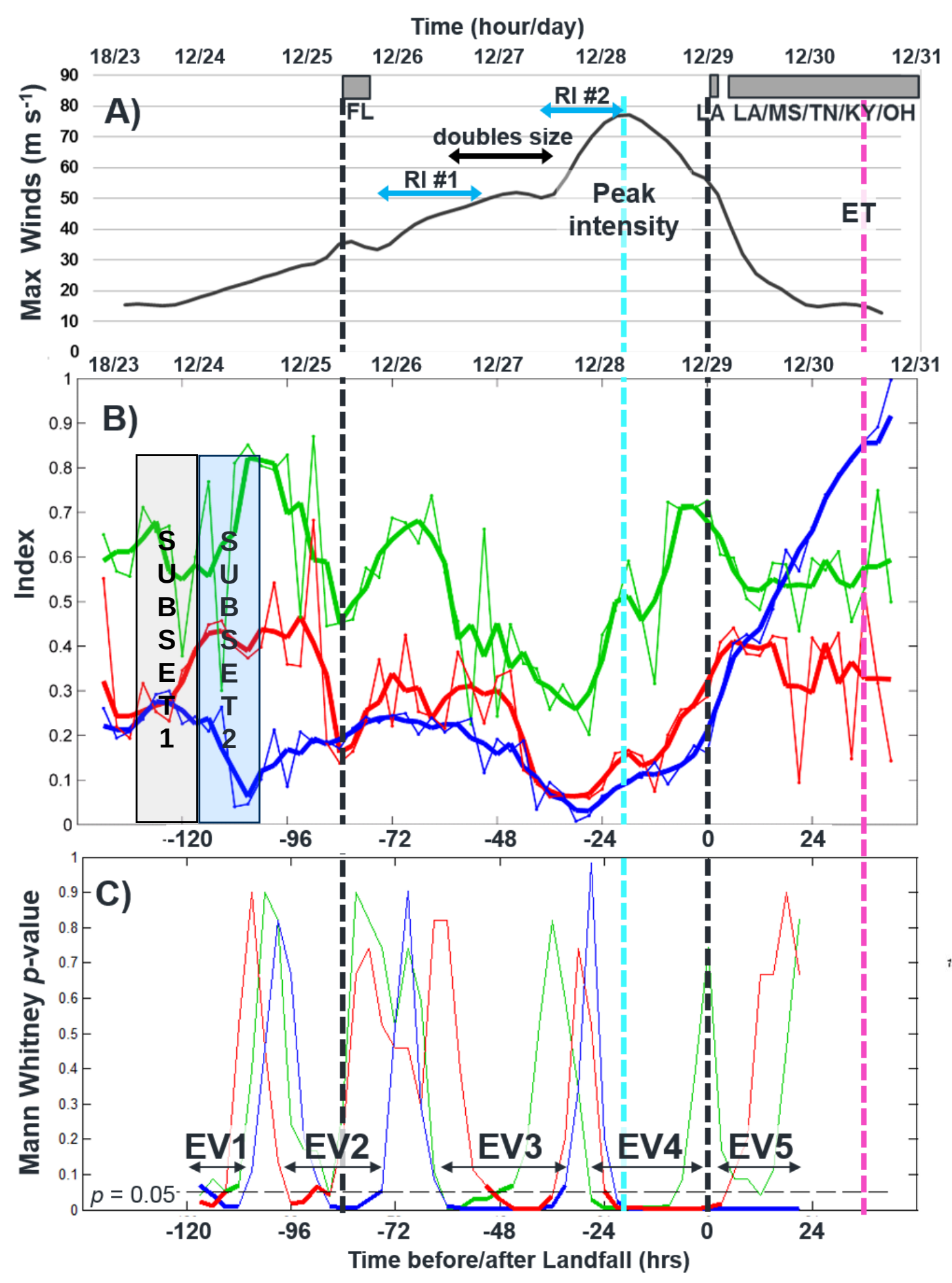

Fig 5. Hurricane Katrina (2005) results: (A) Intensity, (B) shape metrics, and (C) Mann Whitney U-test

Finally, we apply a moving Mann-Whitney *U* test to determine significant ($p < 0.05$) points in the evolution of precipitation structure.

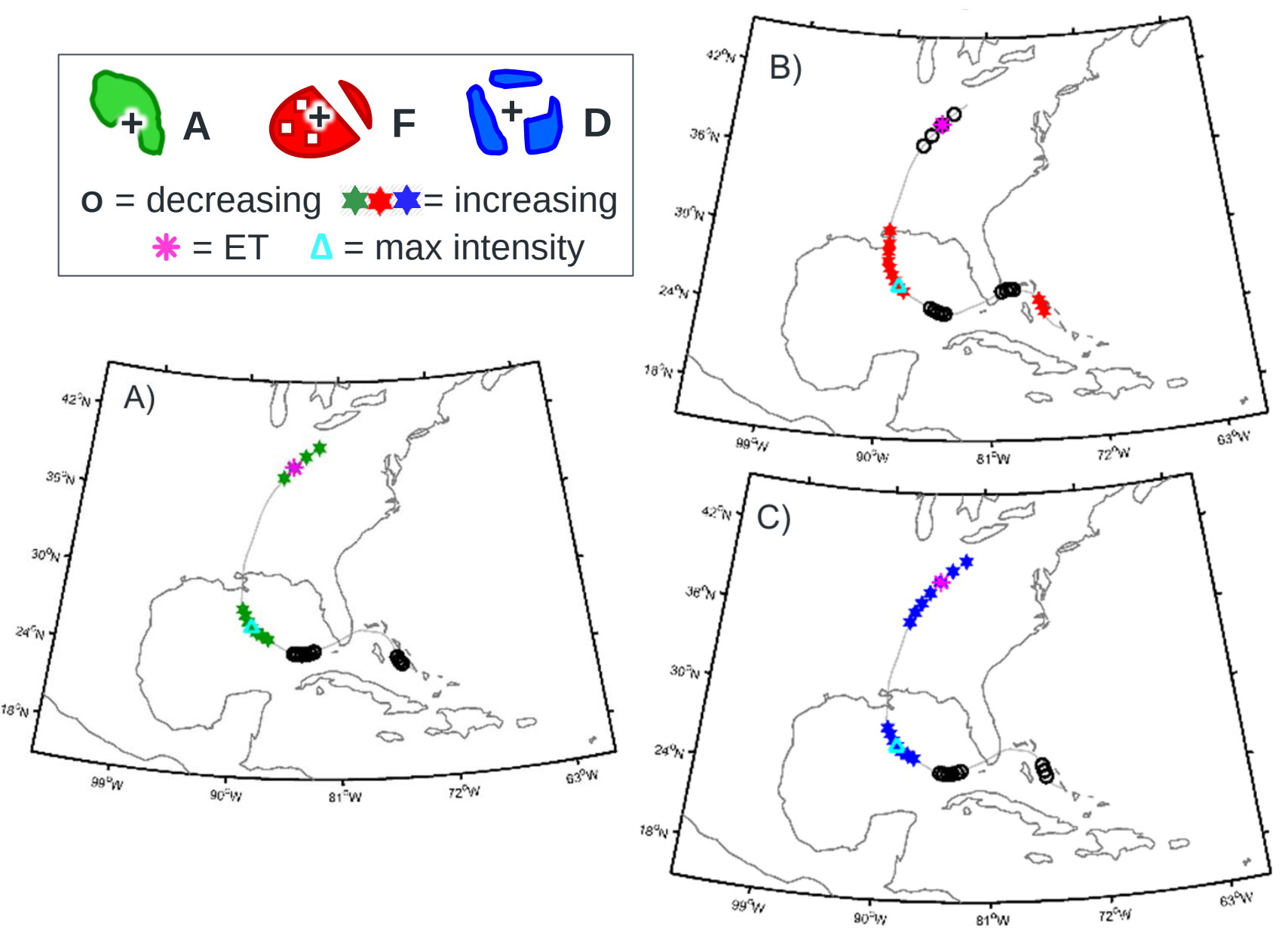

Fig 6. Along-track placement of times steps when moving Mann Whitney *U*-test for (A) asymmetry, (B) fragmentation, and (C) dispersiveness indicates an evolving precipitation structure with $p < 0.05$ for Hurricane Katrina (2005).

Statistically significant structural changes are observed in Hurricane Katrina during 5 time periods (EV1, EV2, etc.) that coincide with the observational storm history. This includes a significant increase in asymmetry, fragmentation, and dispersiveness 6 hours (24 hours) prior to the timing of peak intensity (landfall).

Objective 2: TC structural change in US landfalling TCs

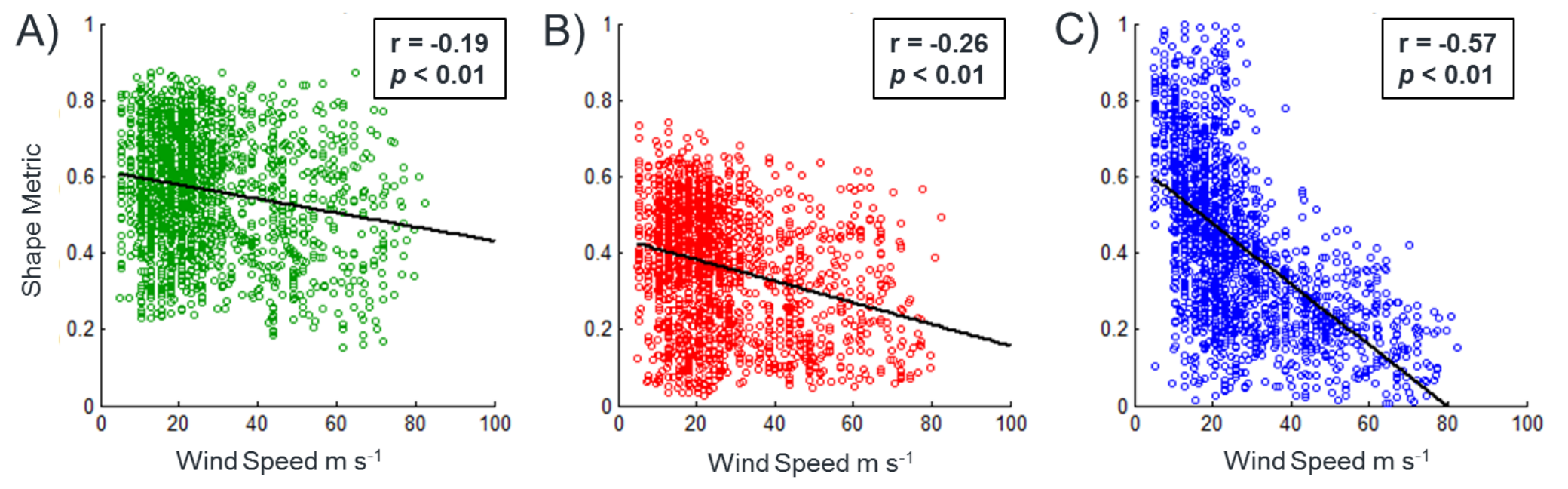

Fig 7. Scatter plots of TC intensity, measured by maximum sustained wind speed, versus (A) asymmetry, (B) fragmentation, and (C) dispersiveness. Least squares regression lines are overlaid.

Asymmetry and fragmentation display weak but significant negative correlations with TC intensity. Dispersiveness is more strongly negatively correlated. Variance is expected due to storm motion, shear, and other environmental factors (e.g. Chen et. al. 2006).

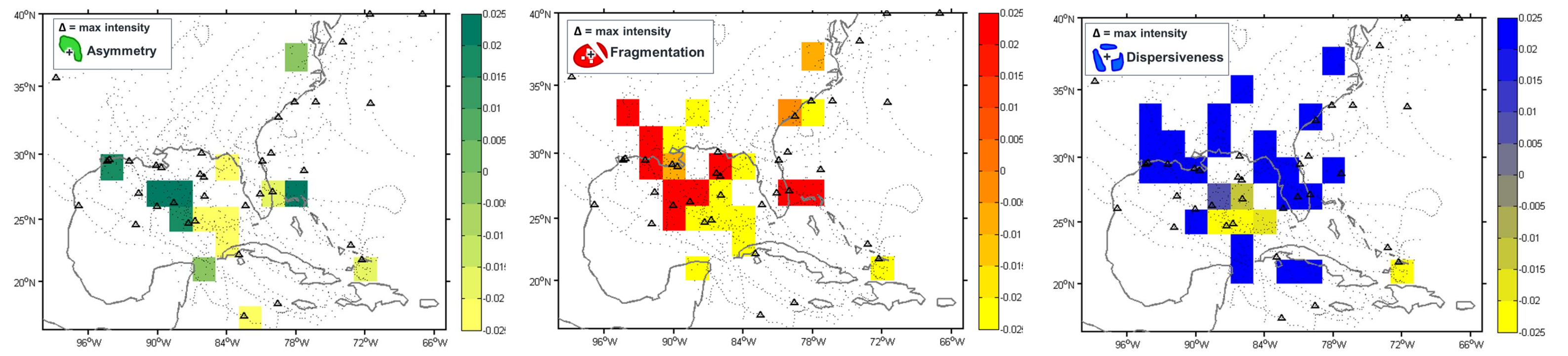

Fig 8. Mean shape metric trends within 2° × 2° lat-lon grid boxes, calculated by averaging 3-hr trends when a Mann-Whitney *U* test indicates a significantly ($p < 0.05$) evolving pattern

(1) As TCs move into the southern and eastern Gulf of Mexico, precipitation becomes increasingly circular, cohesive, and centrally organized.
(2) For TCs moving on westward tracks into the western Gulf of Mexico, precipitation becomes more asymmetric, fragmented, and dispersed.
(3) For TCs moving north- and northeast-ward into the panhandle and Big Bend regions of Florida, precipitation becomes more circular and cohesive but dispersed from the TC center.

Conclusion

To more accurately forecast TC rainfall, the evolving precipitation pattern needs to be closely monitored. Additionally, meteorologist may supplement current rainfall forecasting methods with this conceptual model of evolving precipitation structure within the western Atlantic and Gulf of Mexico regions. Future work will investigate the influence of synoptic-scale dynamics and large-scale moisture availability on the observed structural changes

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