Spatial metrics that facilitate the comparison of radar reflectivity values within landfalling tropical cyclones

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Motivation

- TC intensity forecasting uses spatial organization of clouds (Dvorak 1975)
- Yet visual inspection commonly used to assess forecast or simulation success for spatial extent of storm/high rainfall regions (e.g. Gentry and Lackmann 2010, Davis et al. 2008)
- Verification statistics only compiled for TC track and intensity
- Need exists for technique to quantify spatial patterns to compare across multiple observational datasets or with/among simulations
- Geographers measure space!

Objectives

- Present set of metrics that measure spatial distribution of radar reflectivity values for tropical cyclones

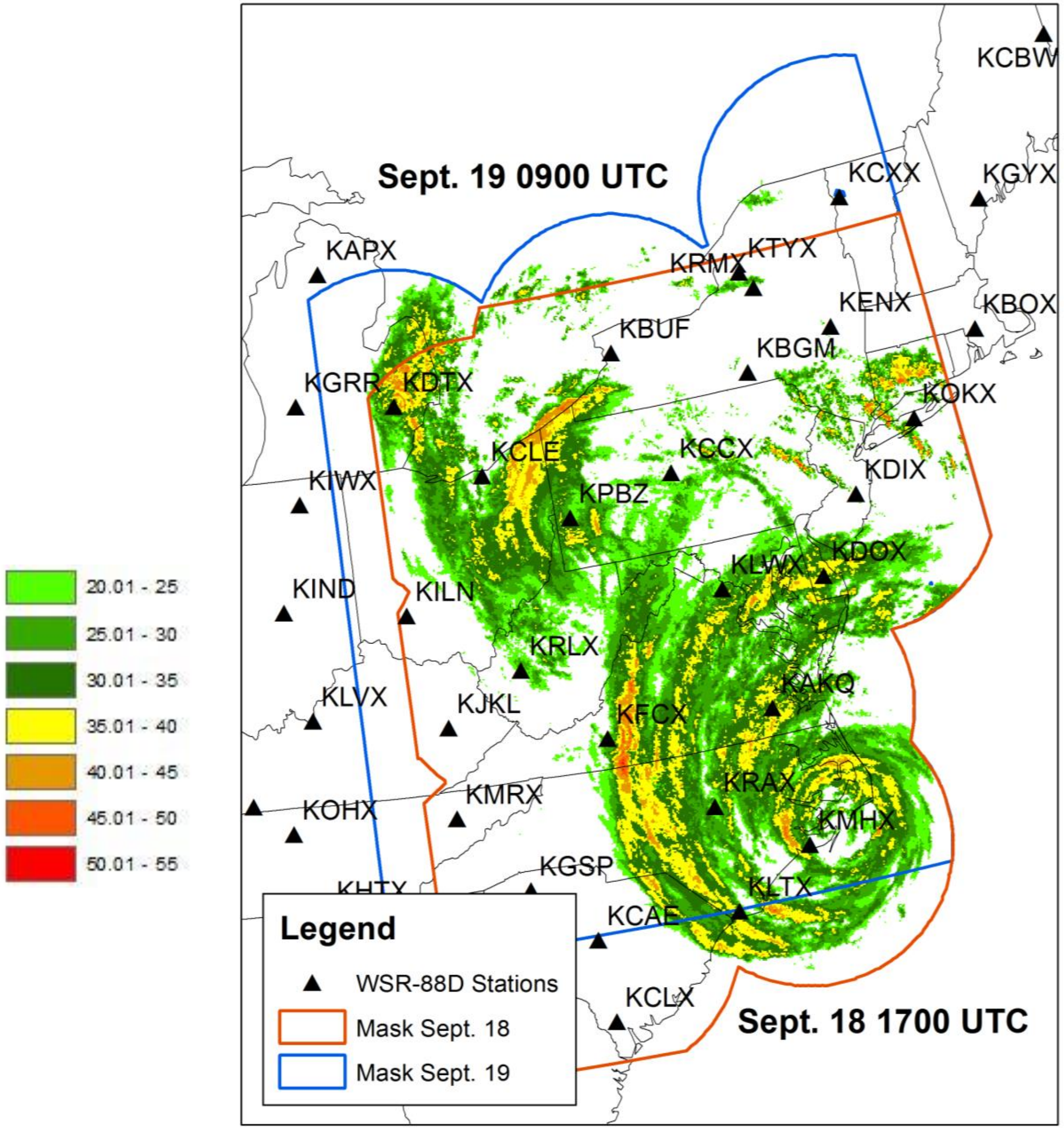
- Compare observed WSR-88D reflectivity values with simulated reflectivity from WRF simulations for a landfalling hurricane (Isabel 2003)

- Matyas, C. J., Zick. S. E. and Tang, J. 2018. Using an object-based approach to quantify the spatial structure of reflectivity regions in Hurricane Isabel (2003): Part I: Comparisons between radar observations and model simulations. *Monthly Weather Review,* DOI: 10.1175/MWR-D-17-0077.1
- Tomorrow: Stephanie Zick details the WRF simulations from our second *MWR* manuscript

- Only 5 metrics here but many more are possible

WSR-88D Mosaic

- Sites within 600 km of storm center
- Level II reflectivity
- Preprocessing, coordinate transformation, projection
- Reflectivity values placed onto 3 km x 3 km x 0.5 km grid
- Highest value retained, Cressman interpolation to fill gaps
- Horizontal slice at 3.5 km

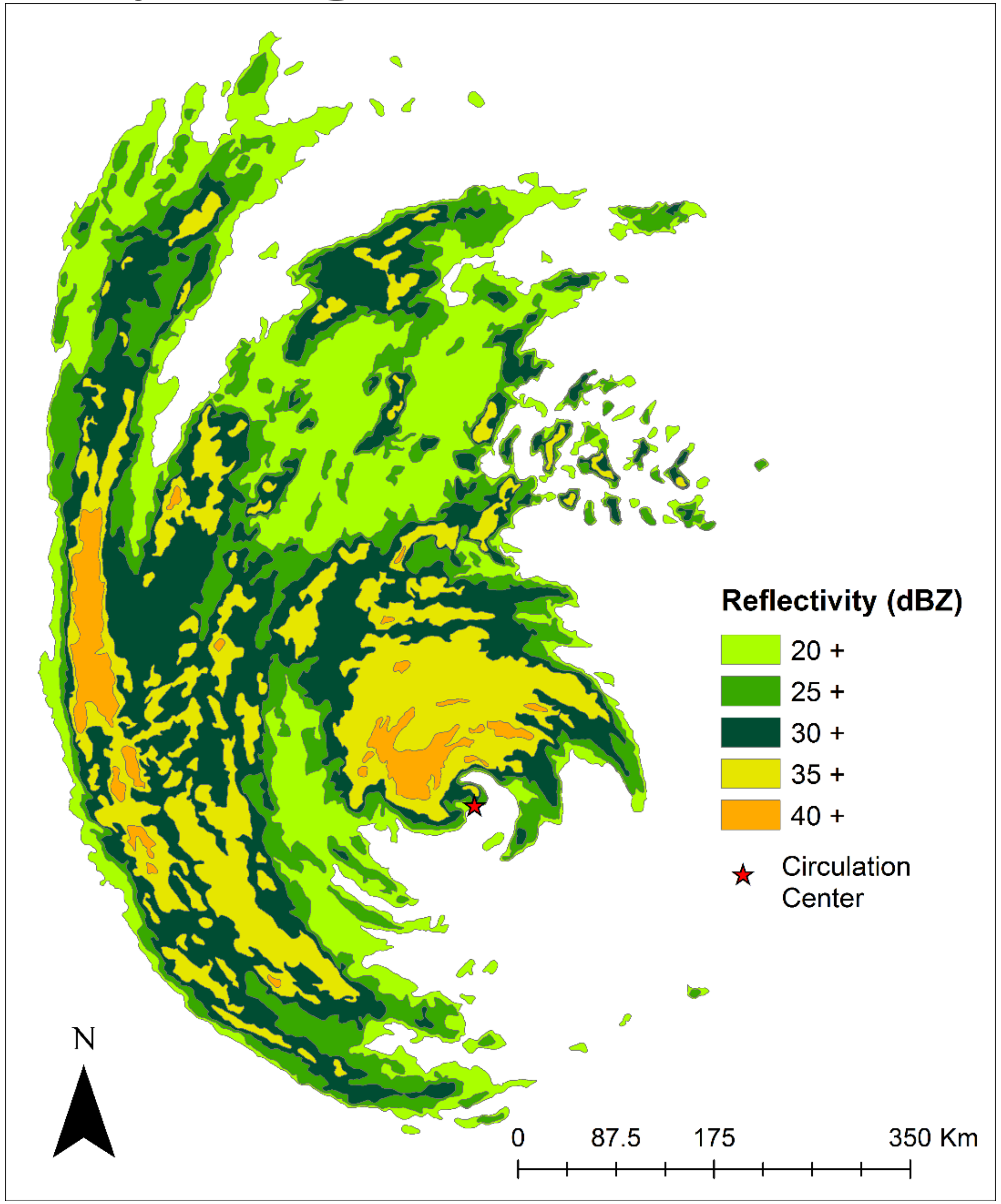


Technique profiled in Tang and Matyas (2016) *J Tech*

Identifying Reflectivity Regions

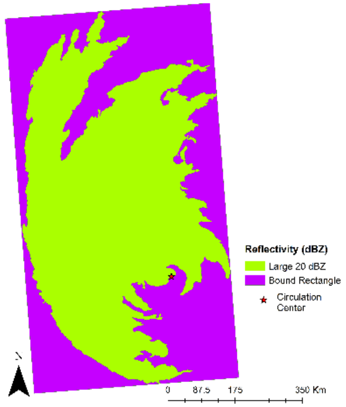
Every 30 min. 1800 18 Sept. – 0900 19 Sept.

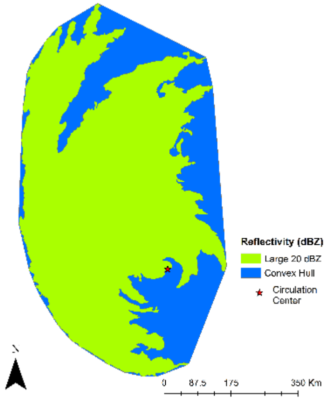
- Contours drawn along edges of reflectivity values
- Converted into polygons
- Calculations of area and centroid location relative to storm center
- Identification of the largest polygon
- Calculation of spatial metrics
    - Utilized metrics from Geography, Marine Science, Atmospheric Science, Landscape Ecology
    - Literature review: AghaKouchak et al. (2011), Jiao et al. (2012), MacEachren (1985), Massam and Goodchild (1971), Matyas (2007, 2008, 2009), Stoddart (1965), Zick and Matyas (2016)



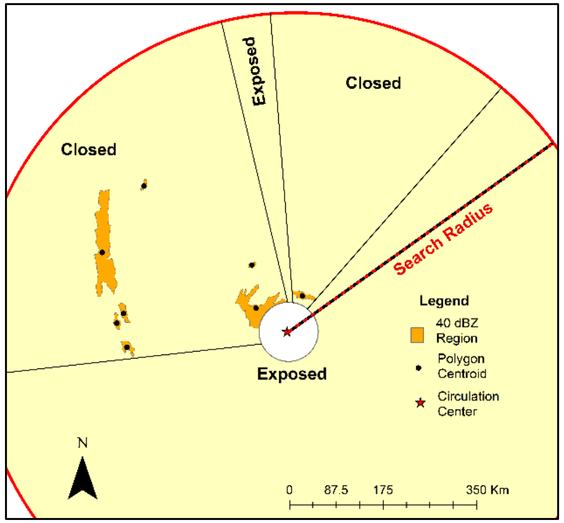
5 Spatial Metrics

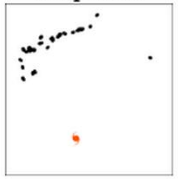
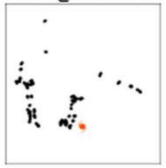
- 2 metrics for largest polygon of 20 dBZ regions



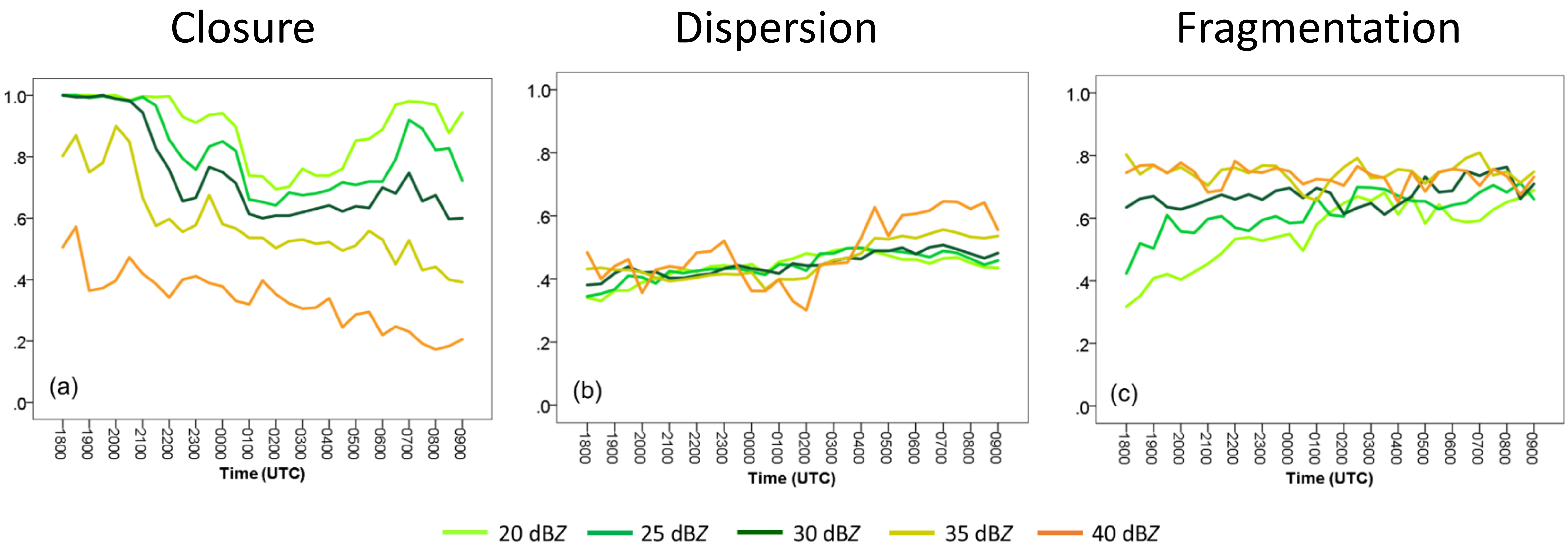


- 3 metrics include all reflectivity regions; calculated for separately for each reflectivity threshold



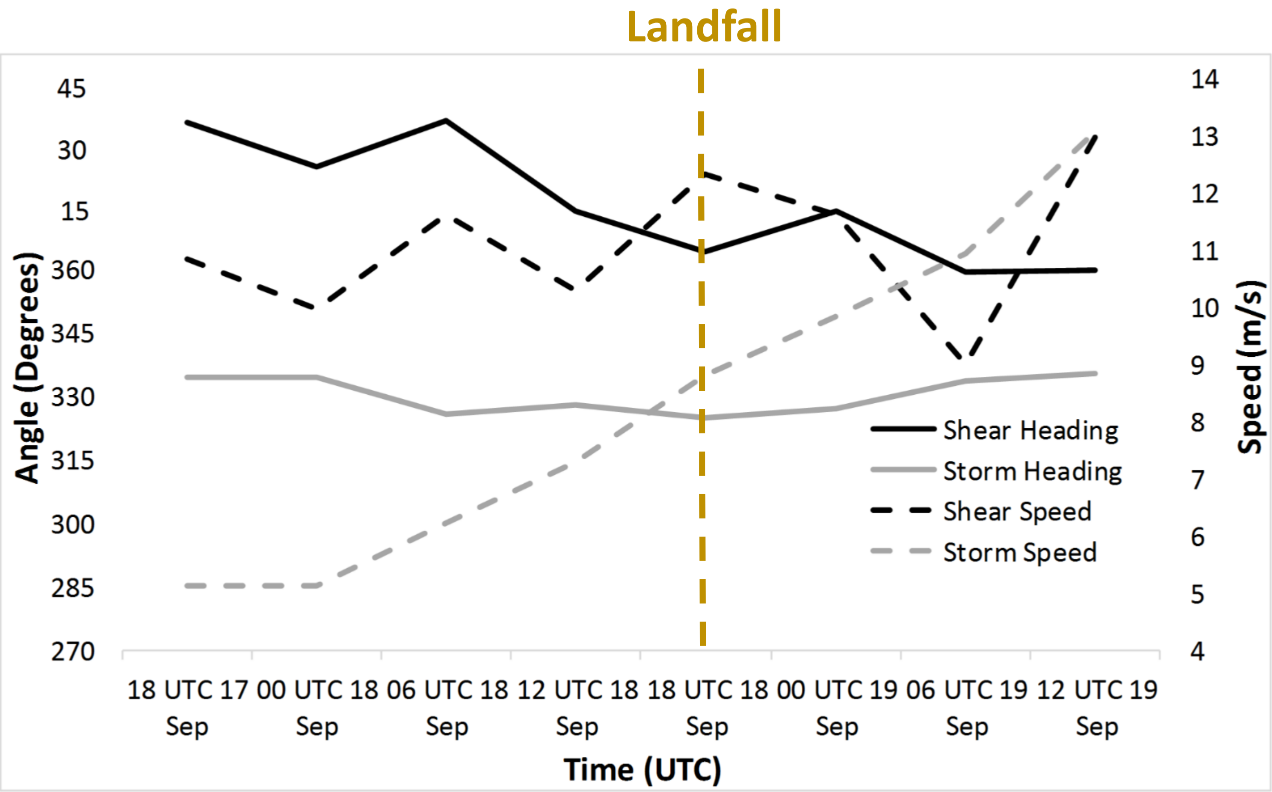
Metric	Equation	Near 0	Near 1
Circularity	$Ci = \frac{Length\ minor\ axis}{Length\ major\ axis}$	Elongated 	Circular 
Solidity	$S = \frac{Area}{Convex\ Area}$	Empty 	Filled 
Closure	$Cl = \frac{no.\ 1°\ angles\ intersecting\ polygons}{360}$	Exposed 	Enclosed 
Dispersion	$D = \sum_{i=1}^{NP} \frac{Area_i}{\sum_j^{NP} Area_j} \left(\frac{r_{centroid,i}}{r_{search}}\right)$	Centralized 	Dispersed 
Fragmentation	$F = 1 - \left(\sum_{i=1}^{NP} \frac{Area_i}{ConvexArea_i}\right)\left(1 - \frac{NP - 1}{NP + \sqrt{\#pixels}}\right)$	Cohesive 	Fragmented 

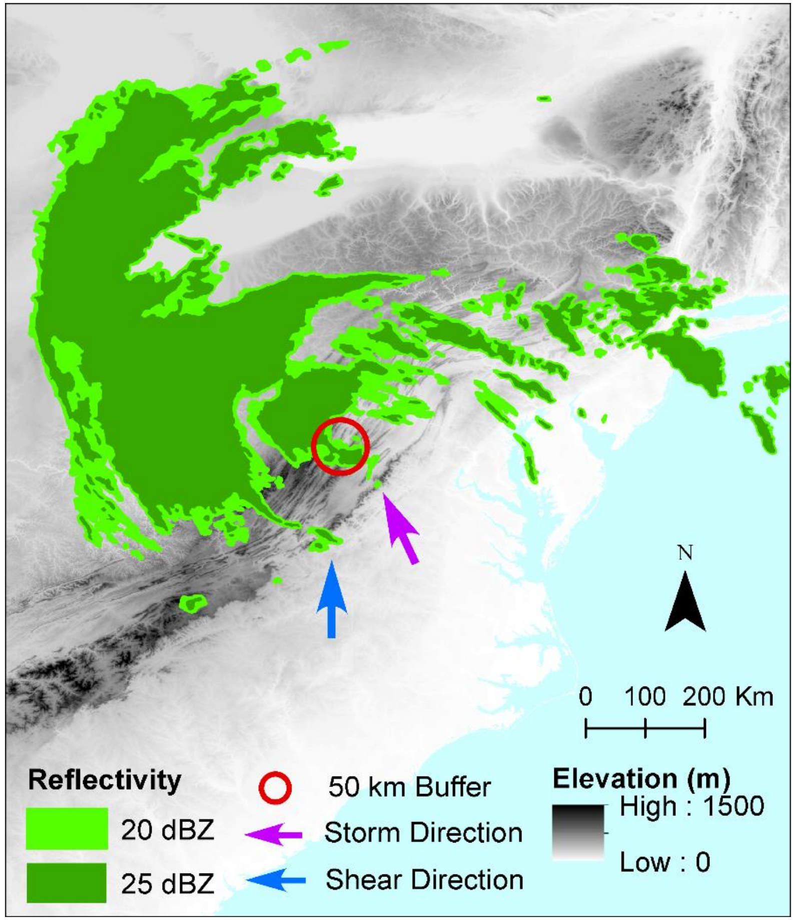
Comparing Metrics Across Reflectivity Thresholds



- All significantly correlated with time save 35 and 40 dB*Z* fragmentation
- 20, 25, 30 dB*Z* significant correlated – stratiform precipitation
- 35 and 40 dB*Z* significantly correlated – convective rainfall

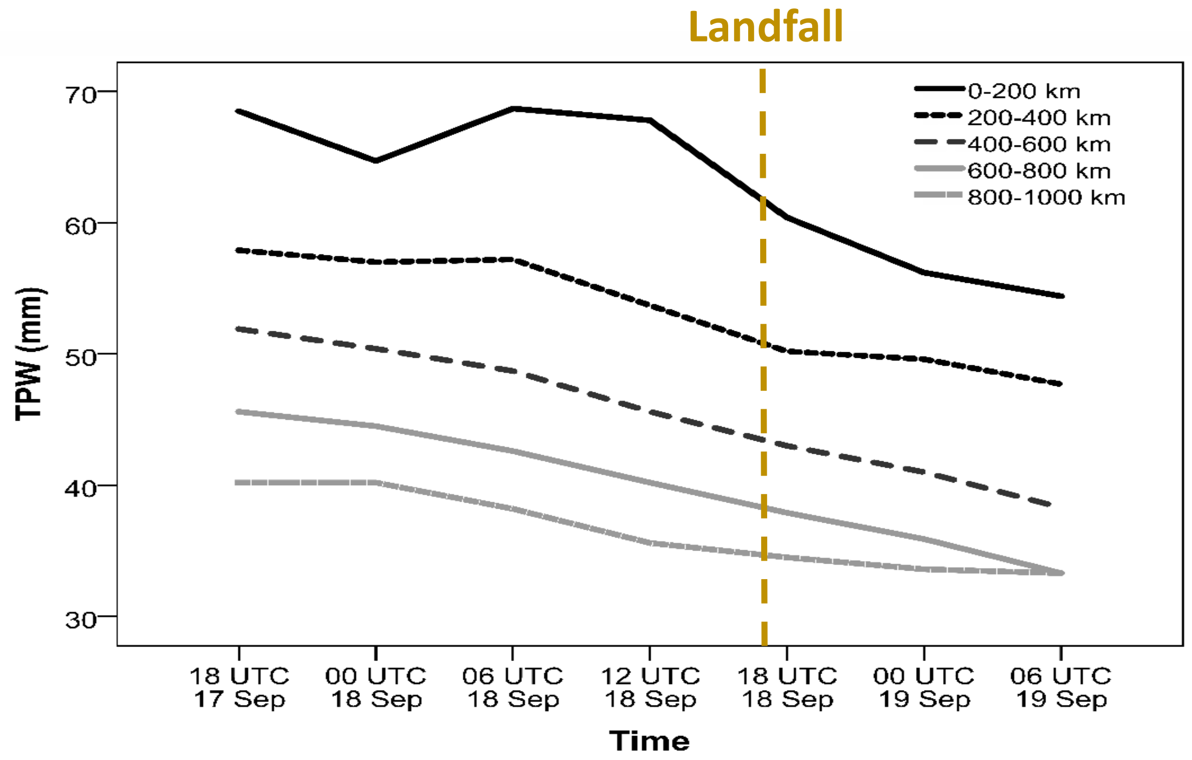
Vertical Wind Shear, Storm Motion, Topography

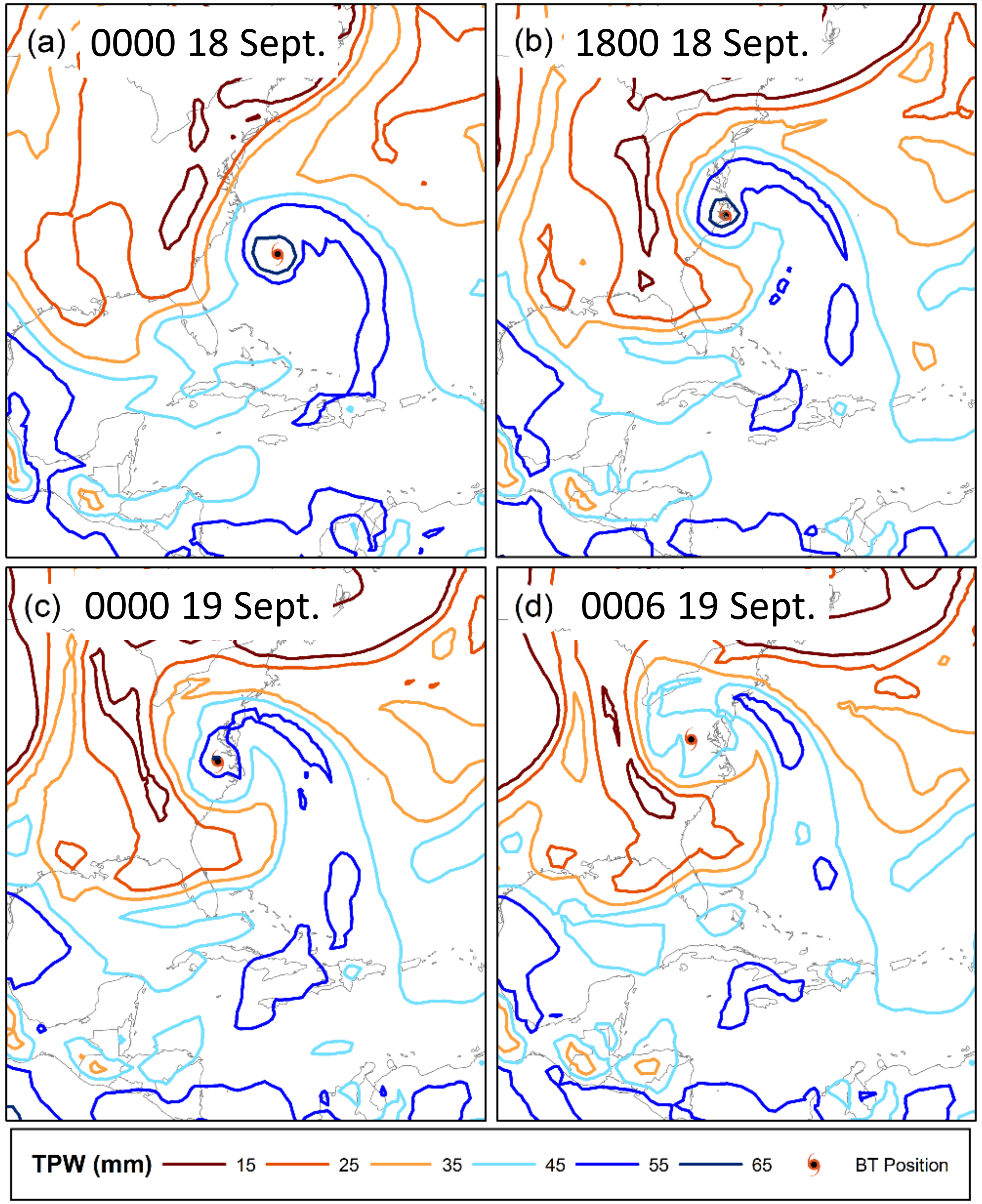




- Topography: increased closure 0300 - 0700?
- Centroids of 20 dB*Z* reflectivity regions located 35°-55° left of shear vector; shifted from 5° right to 20° left of storm motion vector
- As ET progresses, closure, circularity, solidity should decrease; dispersion, fragmentation should increase

Moisture Conditions as Isabel Experienced ET





- As moisture decreases, closure/solidity should decrease and dispersion/fragmentation should increase
- Matyas (2017): 45 mm TPW extending from deep tropics contributes to high rainfall
- Throughout, western edge of 45 mm co-locates with edge of outermost rainband
- Future work to investigate these moisture tails

Comparisons with WRF Simulations (20 dBZ)

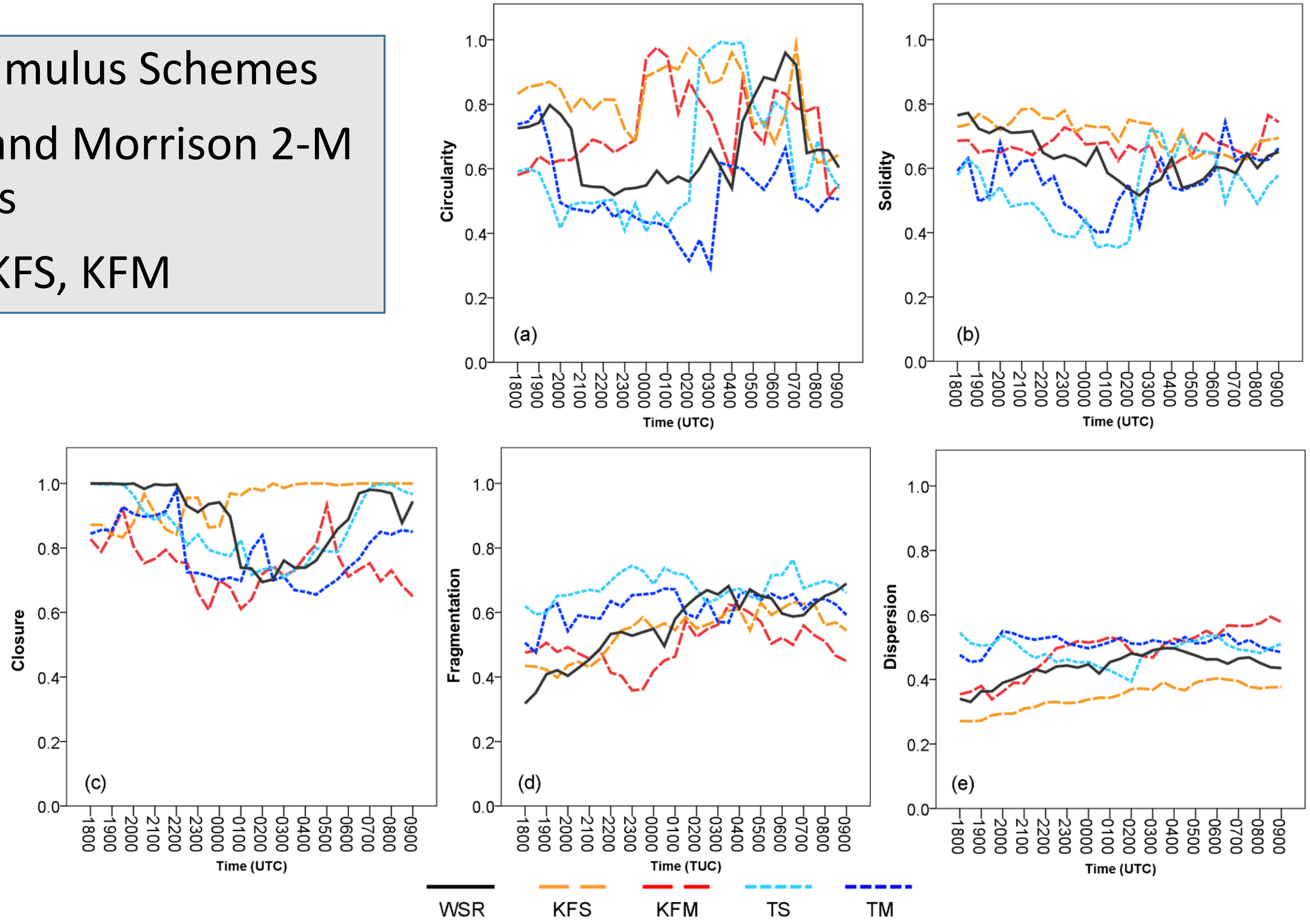
Tiedtke and Kain-Fritsch Cumulus Schemes

WRF 6-class single moment and Morrison 2-M Microphysics

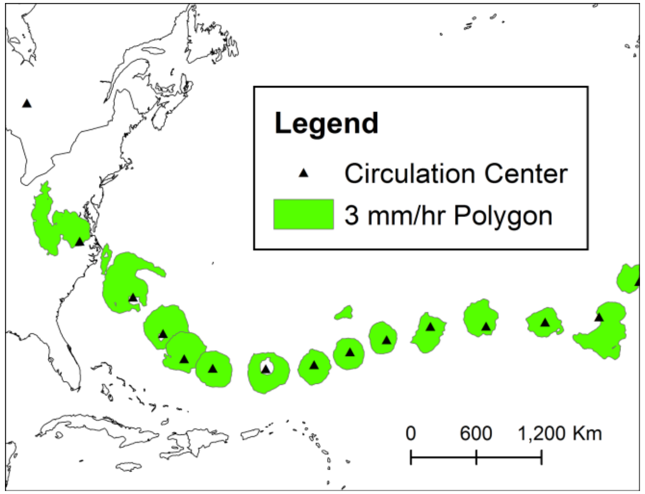
Acronyms: TS, TM, KFS, KFM

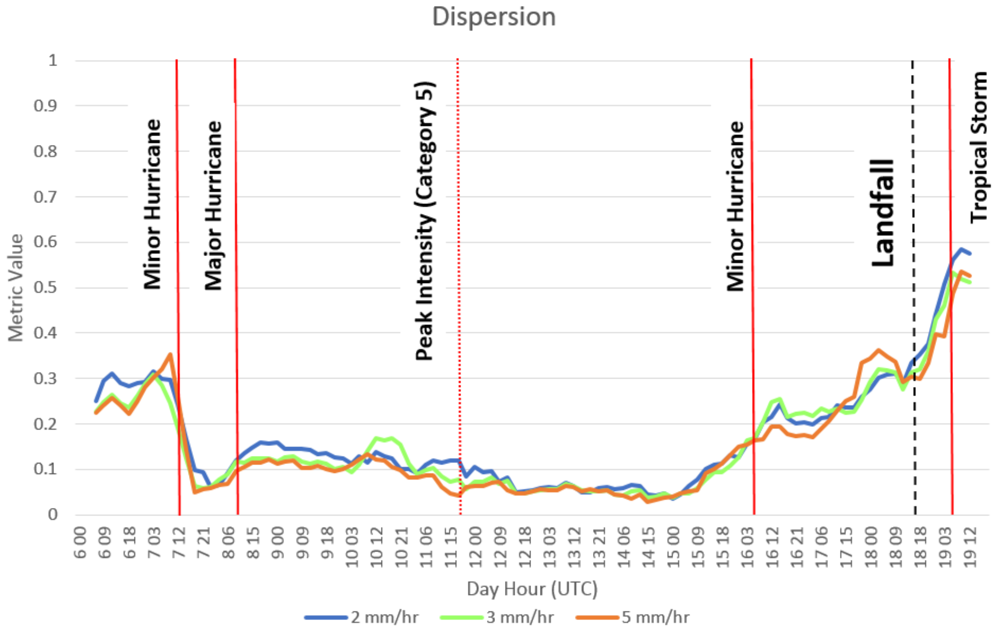
Strongest Correlations with WSR:
- TS/TM: circularity and closure
- KFS/KFM: dispersion and fragmentation

Take Home Messages:
- KF too circular, lacks outer rainbands
- T too spread out and fragmented but outer rainbands match well

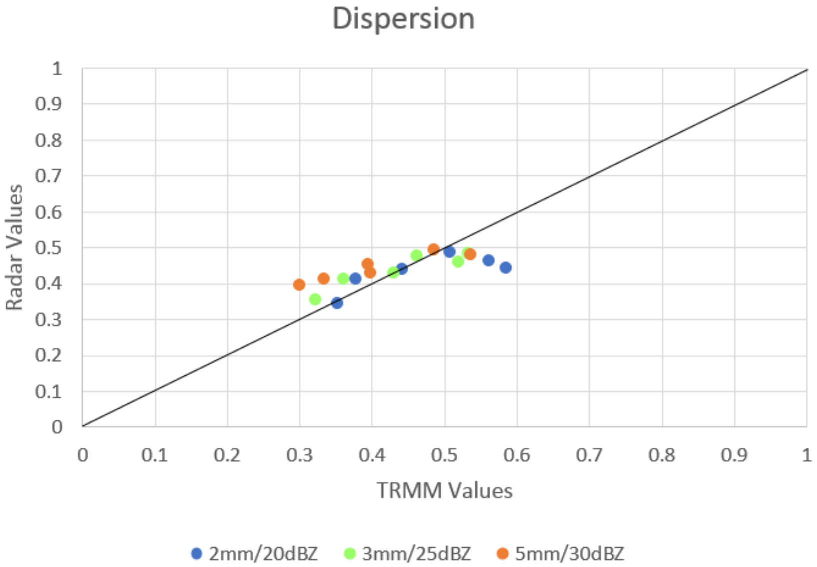


Comparisons with TRMM 3B42 Data





5 overlapping times



Condition	*Dispersion*
Maximum Wind Speed	**-0.83**
Storm Motion Speed	0.20
Deep-Layer Wind Shear Speed	**0.26**
Shallow-Layer Shear Speed	**0.26**
Lower-Troposphere Moisture	0.23
Middle-Troposphere Moisture	**0.39**
High-Troposphere Moisture	**0.39**

- Spatial metrics useful to compare WSR-88D reflectivity regions to TRMM 3B42 rain rate regions
- Dispersion exhibited best results and strongest correlations with storm and environmental conditions
- All metrics strongly correlated with V_{max} (-0.7 or 0.8) expected (Dvorak 1975)
- Also statistically significant correlations with moisture across the board
- Correlations with shear weaker, not significant for circularity

Conclusions and Future Research

- Spatial metrics separate stratiform and convective regions
- As Isabel made landfall and underwent ET, rainfall regions became less solid, enclosed less of the circulation center, and became more fragmented and dispersed
- Storm shape sensitive to convective parameterization in WRF
- Dispersion: good metric across varying spatial scales (e.g., TRMM 3B42)

- Add displacement for improved correlation with vertical wind shear (Zhou and Matyas, in revision *JAMC*)
- Consider orientation to identify possible topographical influences
- Calculate closure over multiple radial distances to separate inner core and outer rainbands (Matyas 2015 IHC conference)

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