An Object-Based Approach to Quantify the Influence of Cumulus Parameterization in the Spatial Structure of Precipitation in Hurricane Isabel (2003)

Stephanie Zick (Virginia Tech)

Corene Matyas (U. Florida)
Gary Lackmann (NC State)
Jingyin Tang (The Weather Company/IBM)

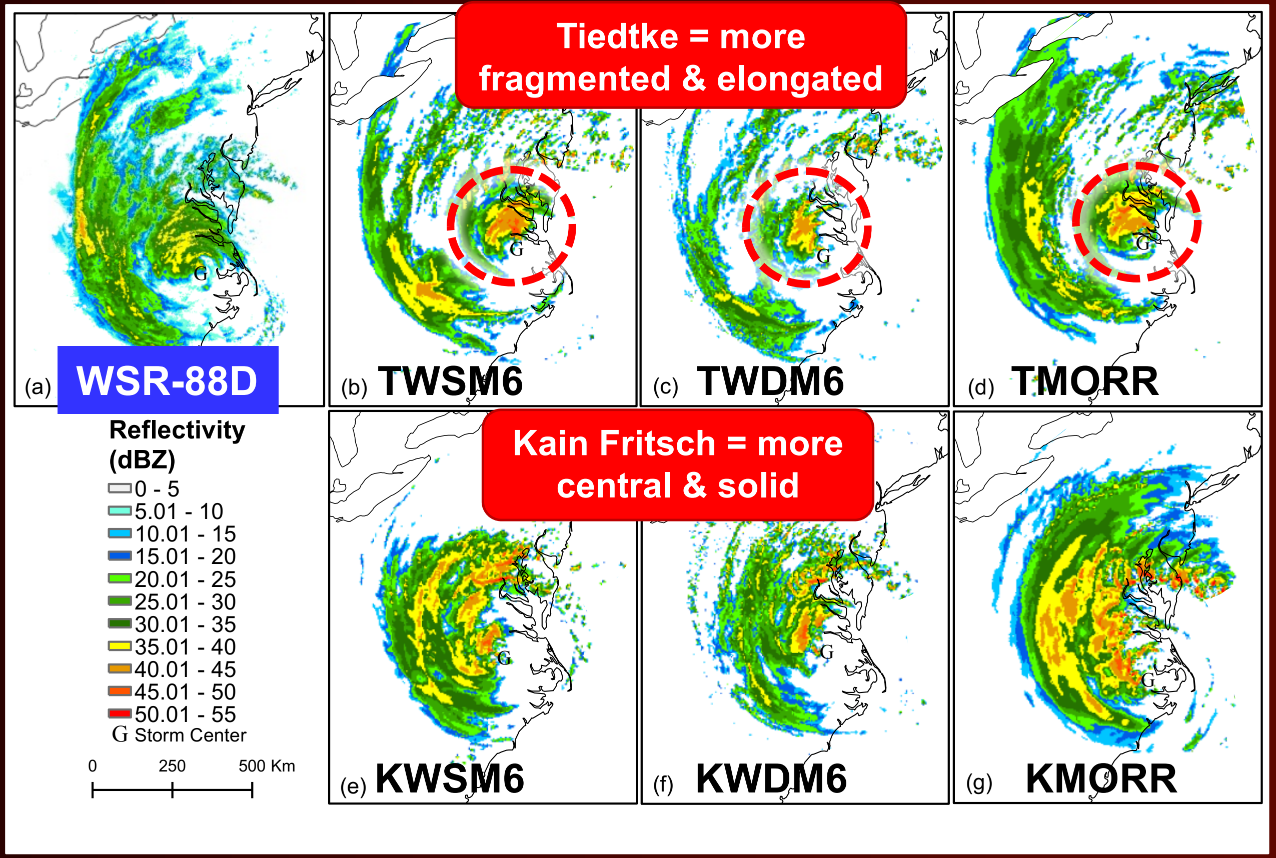
CAREER Award
BCS-1053864

Society of Women Geographers

Background & Motivation

14B.6 **Spatial Metrics that Facilitate the Comparison of Radar Reflectivity Values within Landfalling Tropical Cyclones**

Matyas, Zick, and Tang (Monthly Weather Review, 2018)



Radar and WRF model-simulated reflectivities in Hurricane Isabel (2003) plotted on a horizontal plane 3.5 km ASL

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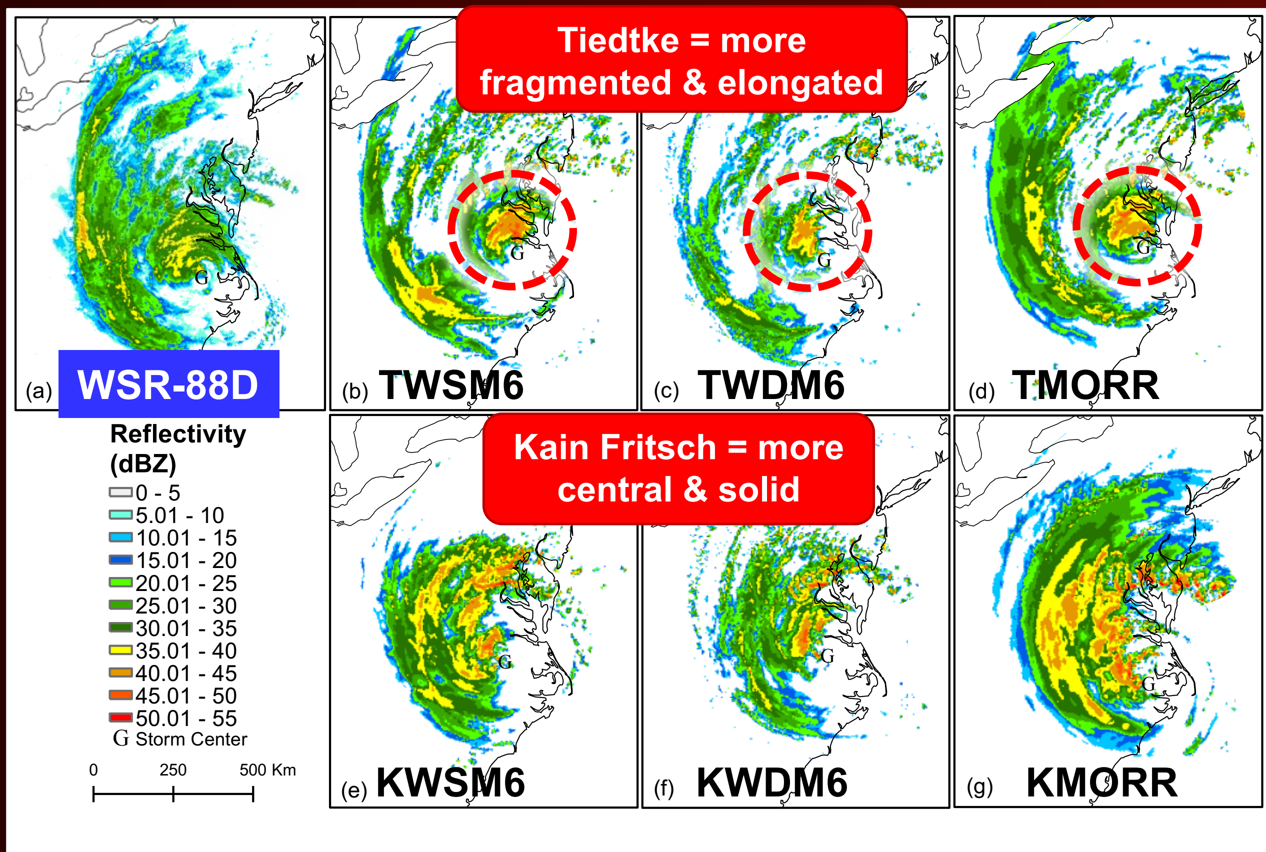
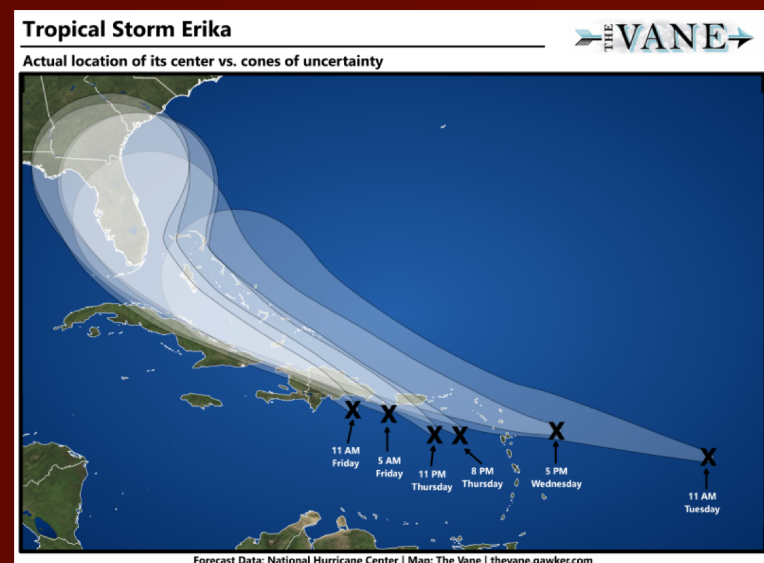




Source: Dennis Mersereau

Weather Research & Forecasting (WRF) Model

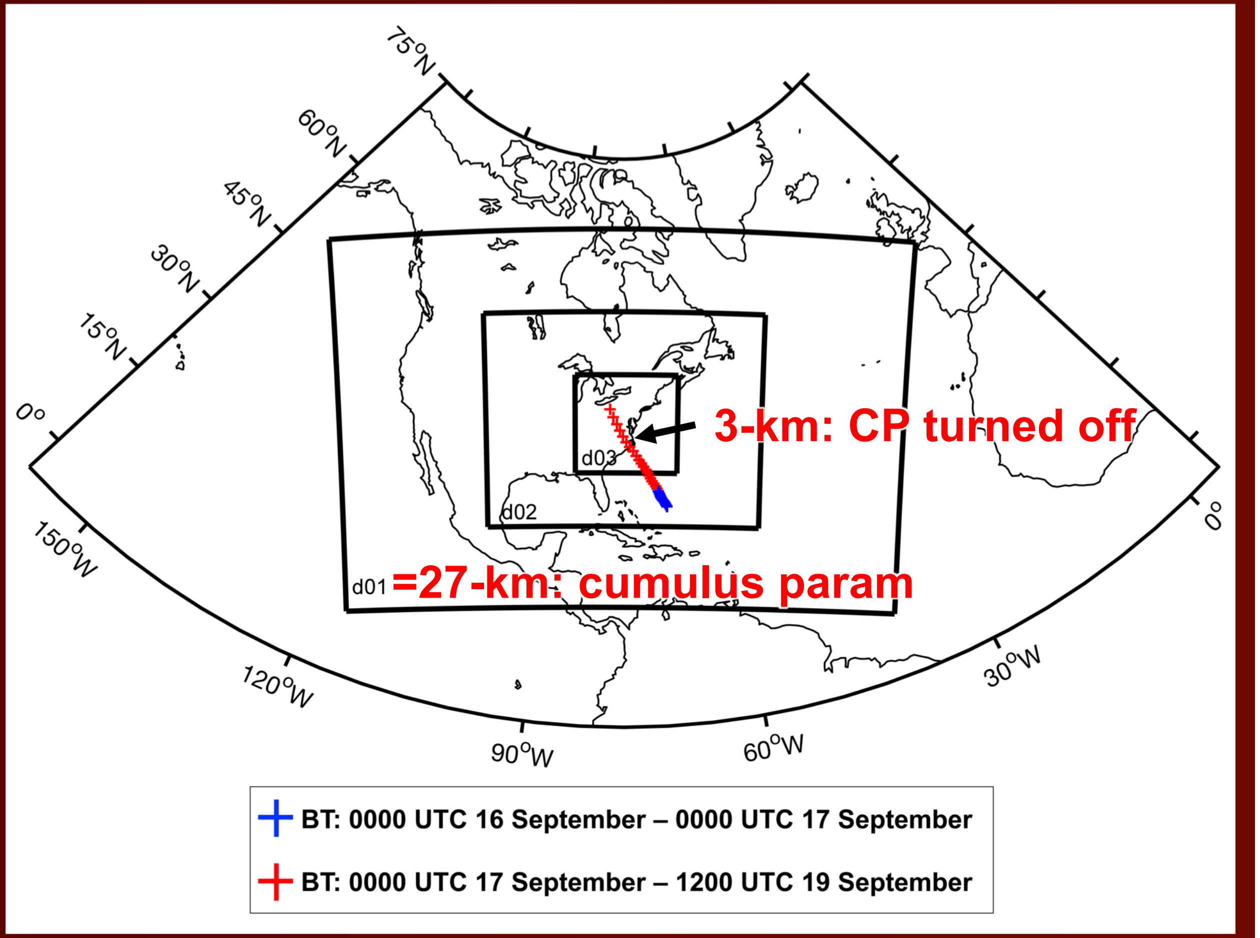
WRF-ARW v3.6.1 – dynamical core solves fully compressible non-hydrostatic equations in flux form

Domain: 27 km / 9 km / 3 km horiz resolution
40 vertical levels with 50 hPa top

Timing: d01 initialized 00 |12 UTC Sep 16 2003
d02+3 init 00 |12 UTC Sep 17 2003
two model cycles

Physics: YSU boundary layer
RRTMG longwave and shortwave radiation
WSM6 microphysics

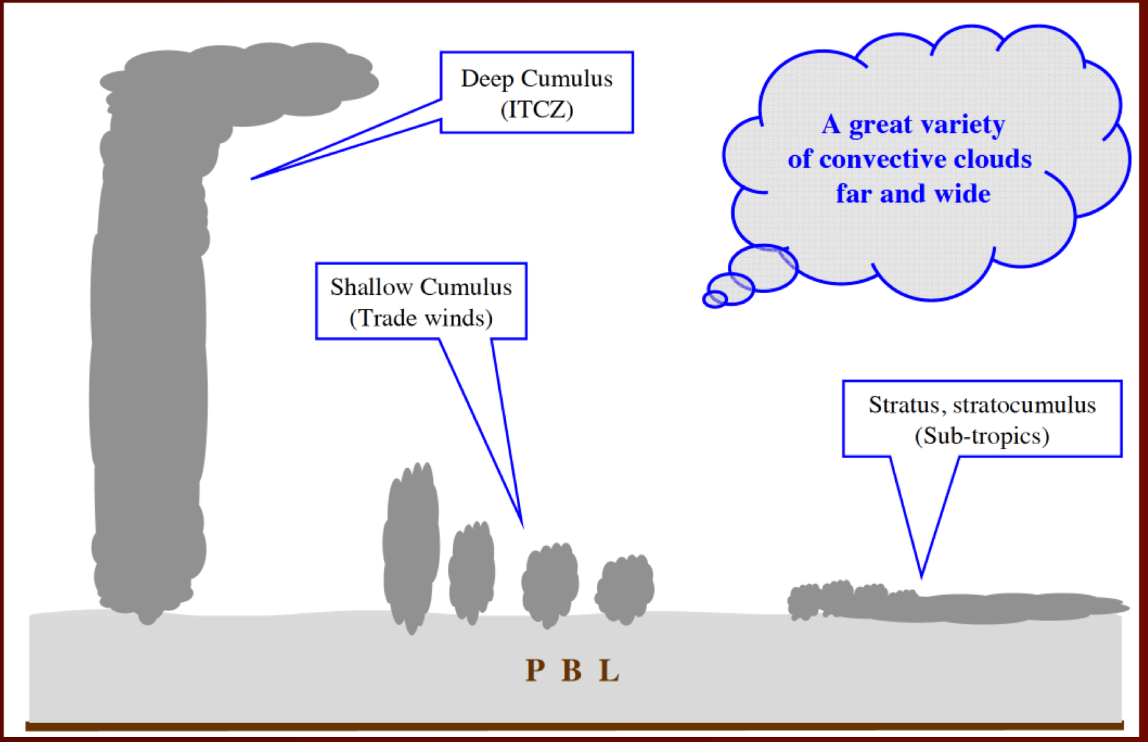
Ocean: SSTs prescribed



What is Cumulus Parameterization?

- A technique used in climate & numerical weather prediction (NWP) models to predict the collective effects of convective clouds that exist within a single grid element…

  …as a function of larger-scale processes and/or conditions



- Fundamental to precipitation prediction
- Changes vertical stability
- Redistributes and generates heat
- Redistributes and removes moisture
- Strongly affects surface heating

Slide adapted from Kain & Baldwin:
http://www.atmo.arizona.edu/students/courselinks/spring12/atmo558/Lectures/KainandBaldwin.ppt

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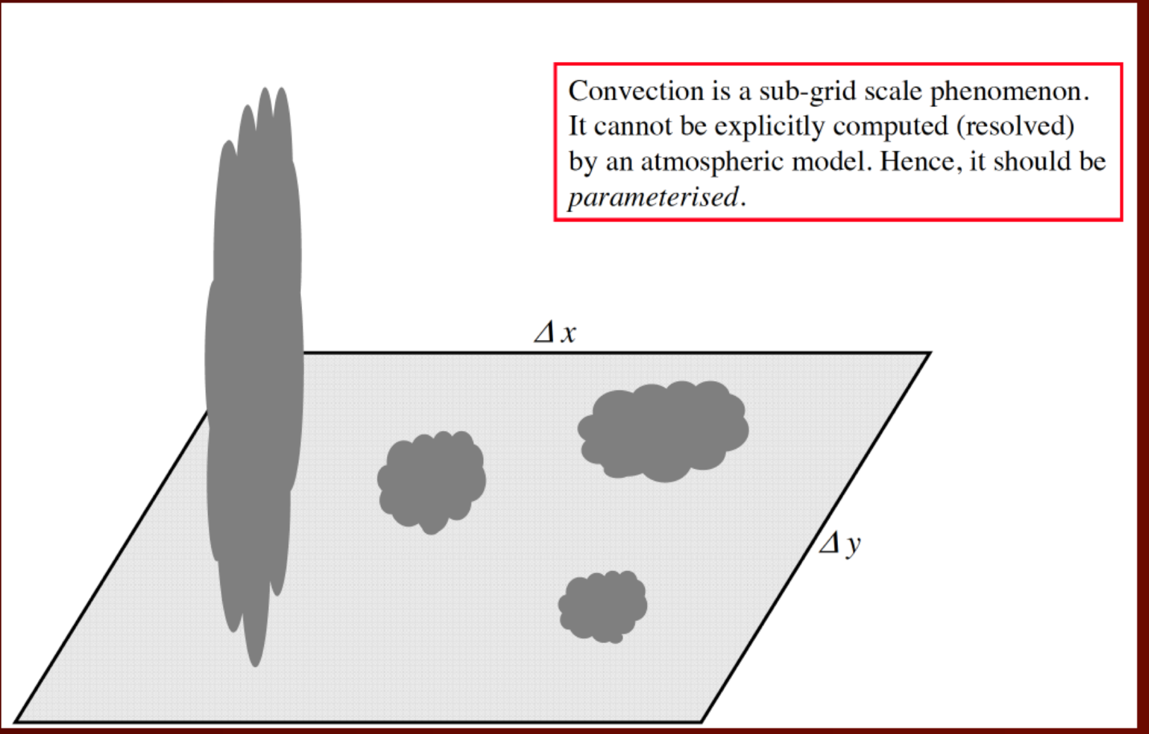

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How does the CP scheme work in a model?

- At every grid point, predictive variables change at each time step as a function of a number of processes, including convection…
- When activated, a CP scheme computes the changes in temperature and moisture (and possibly cloud water, momentum, etc.) that would occur at each vertical level if convection developed in the given grid-point environment

temperature

$$\frac{d\theta}{dt} = P_{rad} \boxed{+ P_{conv}} + P_{cond/evap} + P_{hdiff} + P_{vdiff} + P_{sfc}$$

water vapor

$$\frac{dq_v}{dt} = \boxed{P_{conv}} + P_{cond/evap} + P_{hdiff} + P_{vdiff} + P_{sfc}$$

momentum

$$\frac{du}{dt} + \frac{1}{\rho}\frac{\partial p}{\partial x} - fv = (P_{conv}) + P_{hdiff} + P_{vdiff} + P_{sfc}$$

*All CP schemes adjust temperature and moisture, but only some adjust momentum

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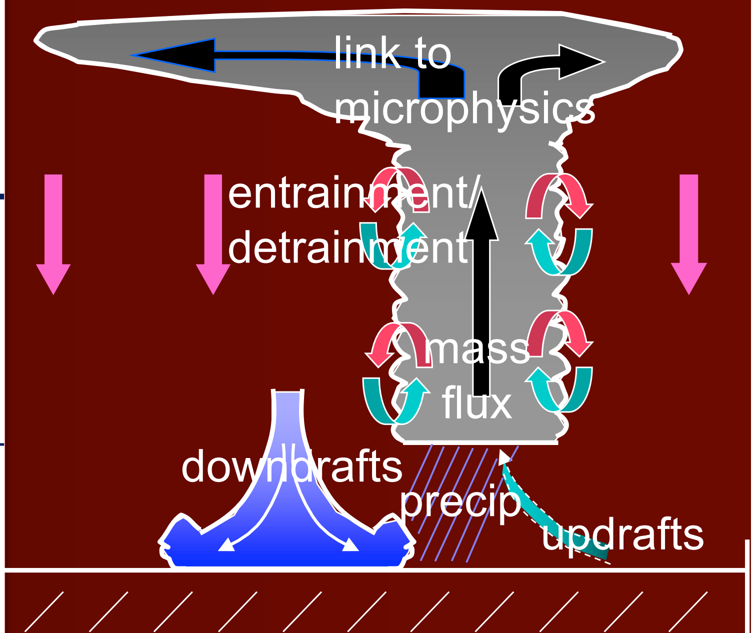
Model Simulation: CP schemes

Model Simulations	BOTH are mass flux schemes & incl. shallow convection	Operational Models
Kain-Fritsch (KFS, KFS+12) *(Kain and Fritsch 1990, Kain 2004)*	- Cloud, rain, ice and snow detrainment - **No horizontal convective momentum transport**	- COAMPS-TC 2010-14; - The GFS uses a similar scheme for shallow convection
Tiedtke (TS, TS+12) *(Tiedtke 1989, Zhang et al. 2011)*	- Cloud and ice detrainment - **Includes horizontal convective momentum transport**	- NCAR-MMM AHW 2011-13; - ECMWF uses scheme based on Tiedtke 1989 with modifs



Source: ECMWF

TS simulation accounts for entrainment of momentum into the convective plume from the surrounding air

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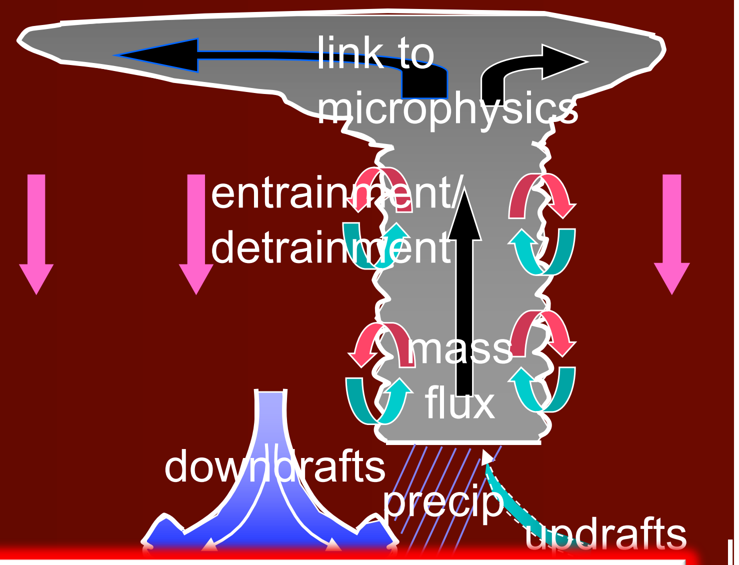
Tiedtke with zero momentum (zTS, zTS+12)	- momentum tendencies s to zero	

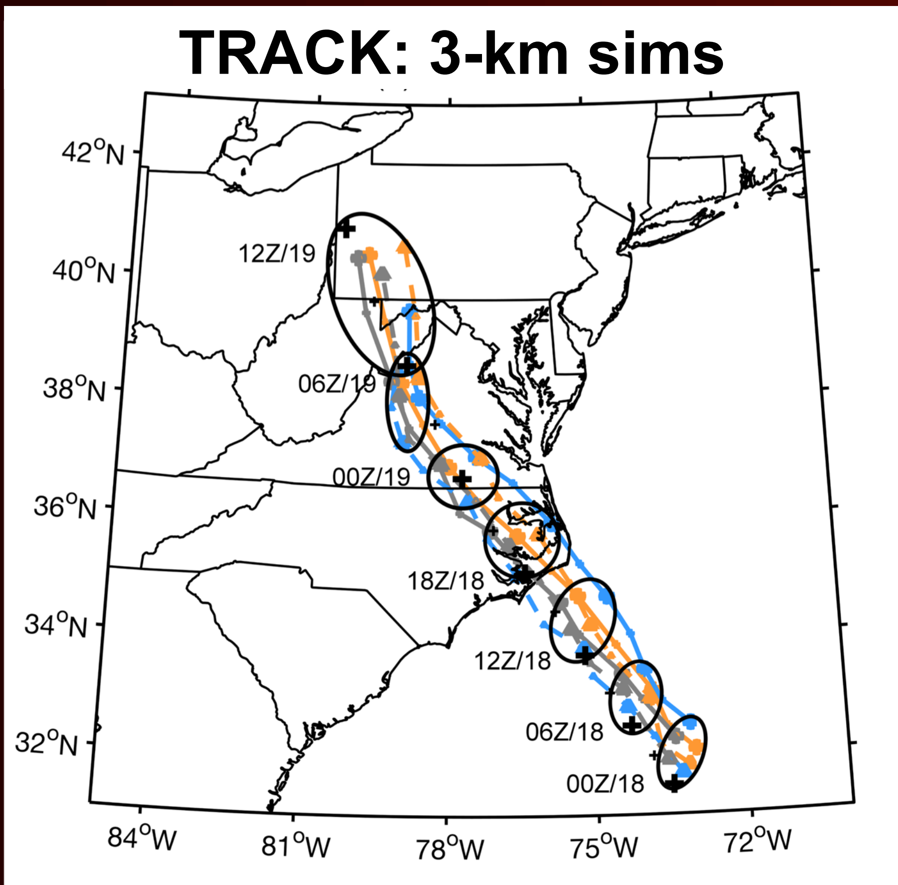


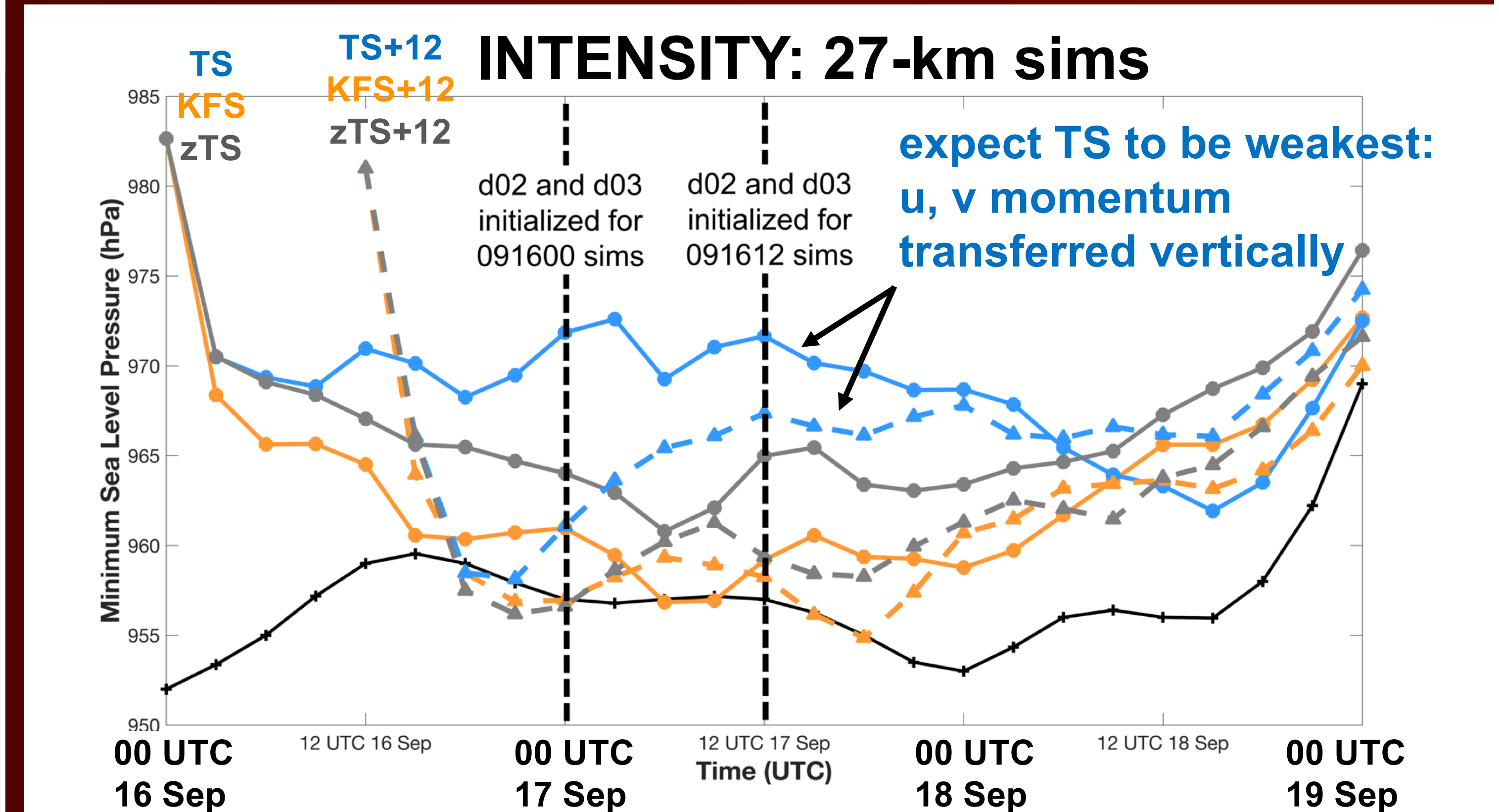
In module_cu_tiedtke.F

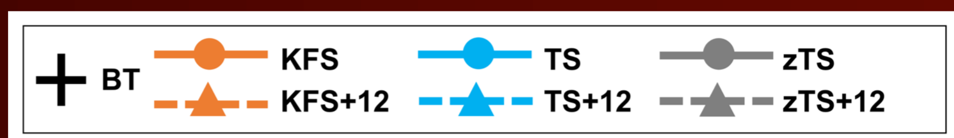
```
      DO K=KTS,KTE
        zz = kte+1-k
        DO I=ITS,ITE
          RTHCUTEN(I,K,J)=(T1(I,zz)-T3D(I,K,J))/PI3D(I,K,J)*RDELT
          RQVCUTEN(I,K,J)=(Q1(I,zz)-QV3D(I,K,J))*RDELT
!           RUCUTEN(I,K,J) =(U1(I,zz)-U3D(I,K,J))*RDELT
!           RVCUTEN(I,K,J) =(V1(I,zz)-V3D(I,K,J))*RDELT
          RUCUTEN(I,K,J)=0
          RVCUTEN(I,K,J)=0
        ENDDO
      ENDDO
```

Traditional Measures of Model Skill

little insight into differences in simulated storms!







Traditional Measures of Model Skill

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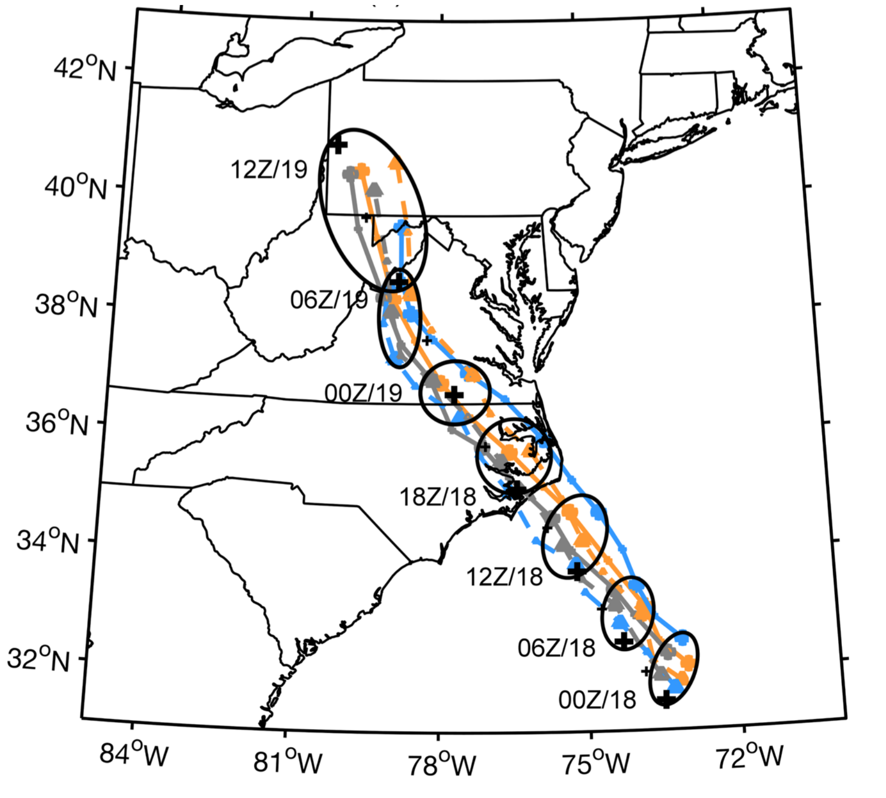
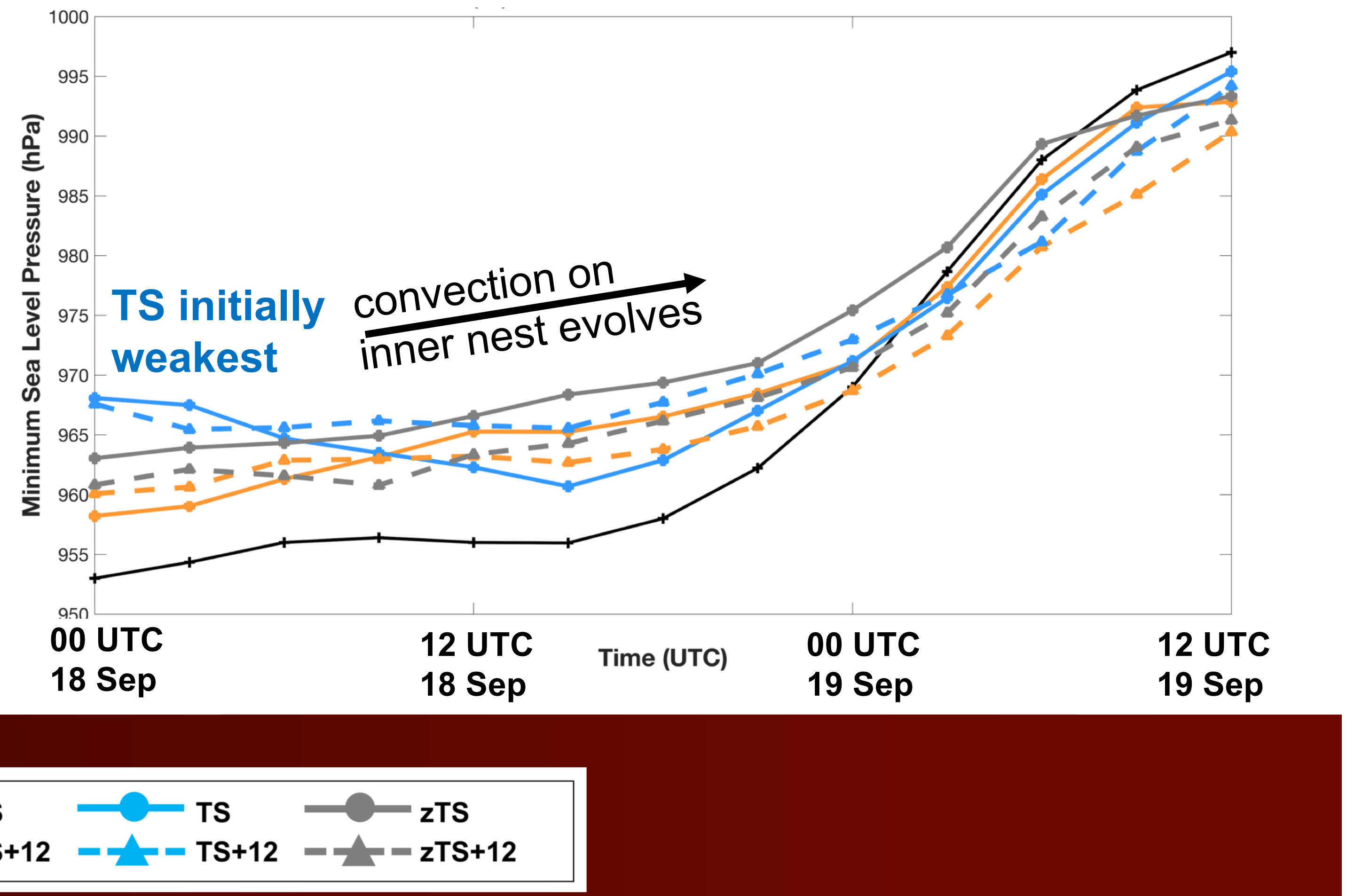
TRACK: 3-km sims

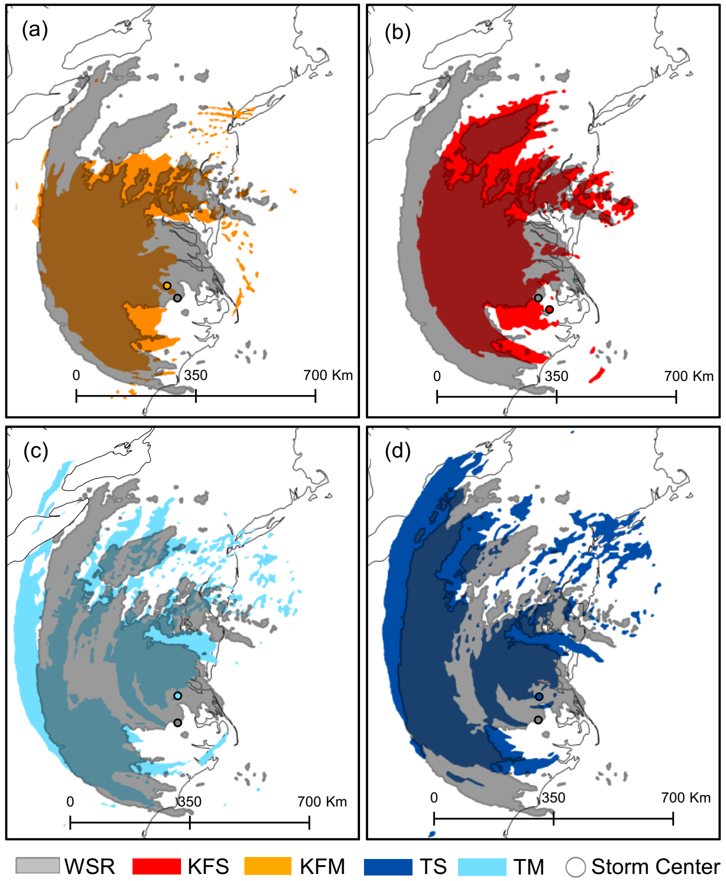


INTENSITY: 3-km sims



Shape Metrics

Delineation of 20 (and 40) dBZ objects & measurement of shape



20 dBZ objects at Landfall

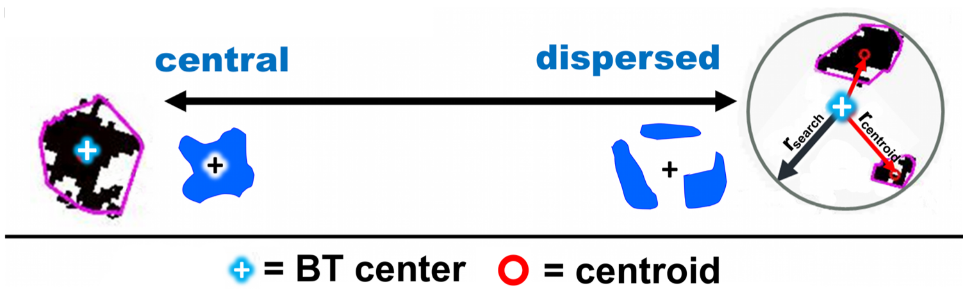
Metric	Near 0	Near 1
Circularity	Elliptical	Circular
Solidity	Empty	Filled
Closure	Exposed	Enclosed
Dispersion	Central	Dispersed
Fragmentation	Cohesive	Fragmented

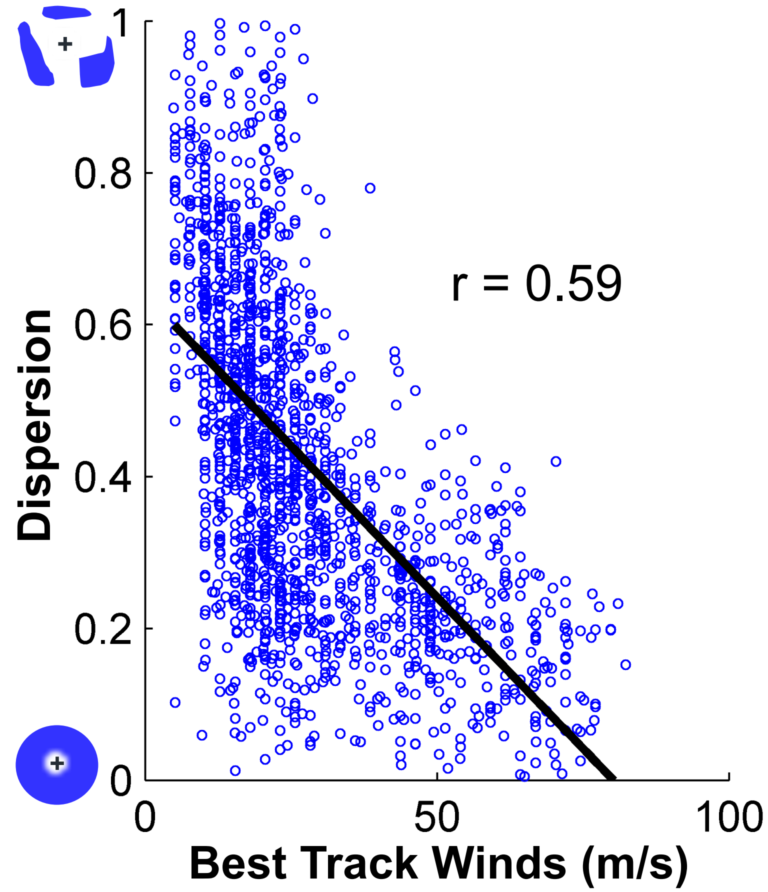
Dispersion Shape Metric

Zick & Matyas (Annals of the AAG, 2016)

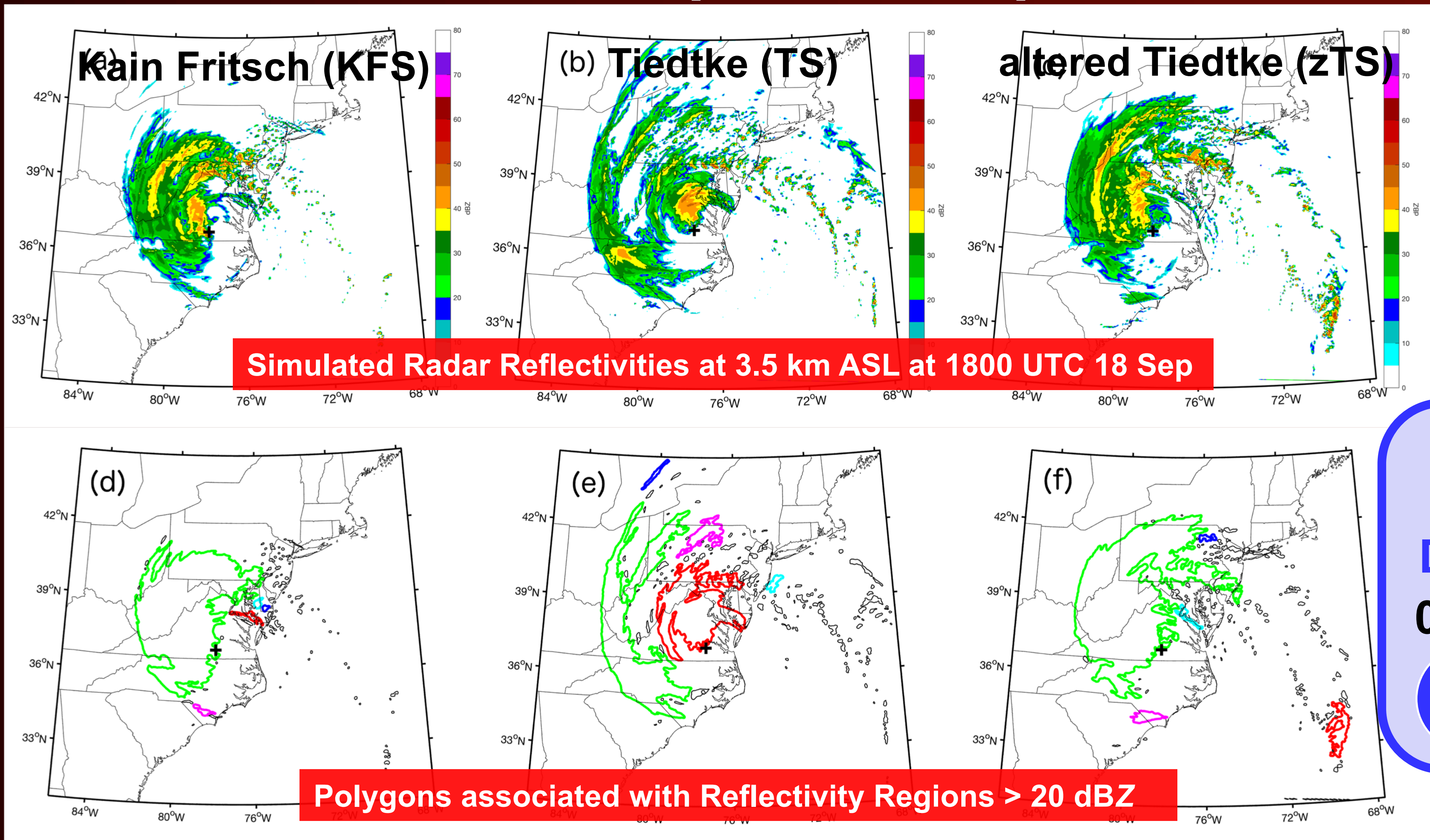
Dispersion (D)

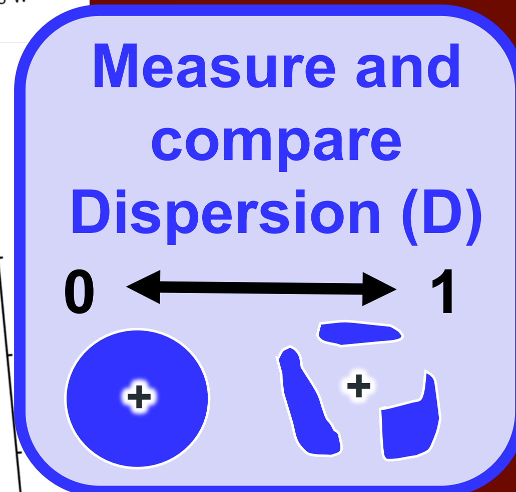
$$D = \sum_{i=1}^{\#polygons} \underbrace{\frac{Area_i}{\sum_j Area_j}}_{\text{area weight}} \underbrace{\left(\frac{r_{centroid,i}}{500\text{ km}}\right)}_{\text{how central?}}$$



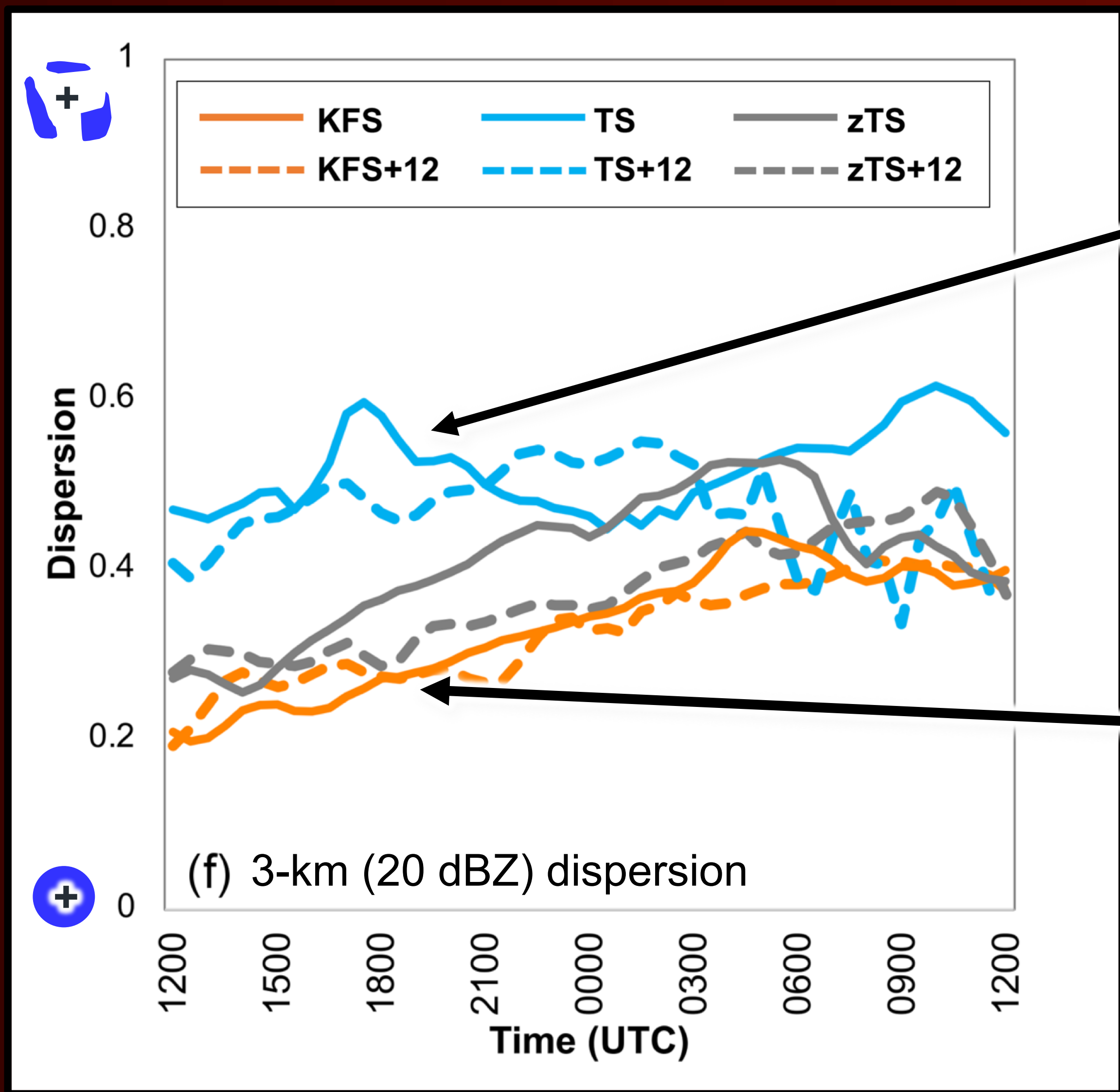


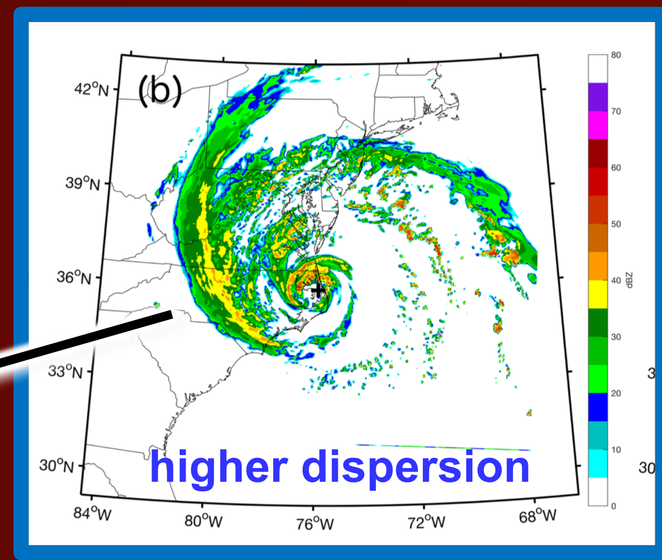
Shape Metrics (20 dBZ)



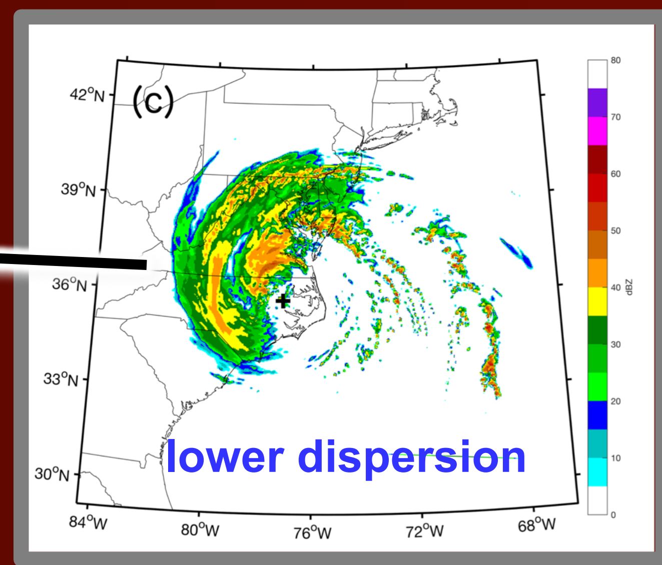


DISPERSION



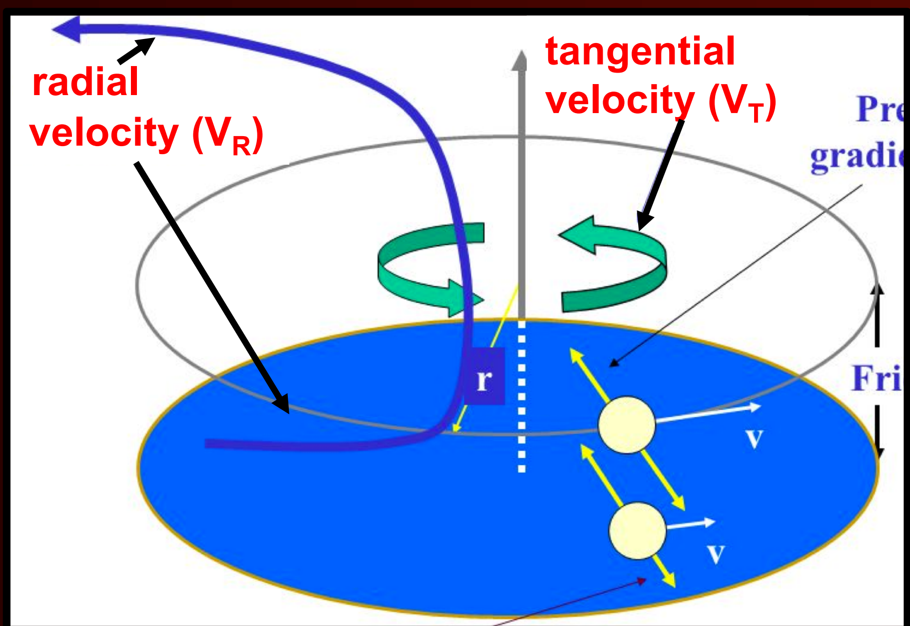


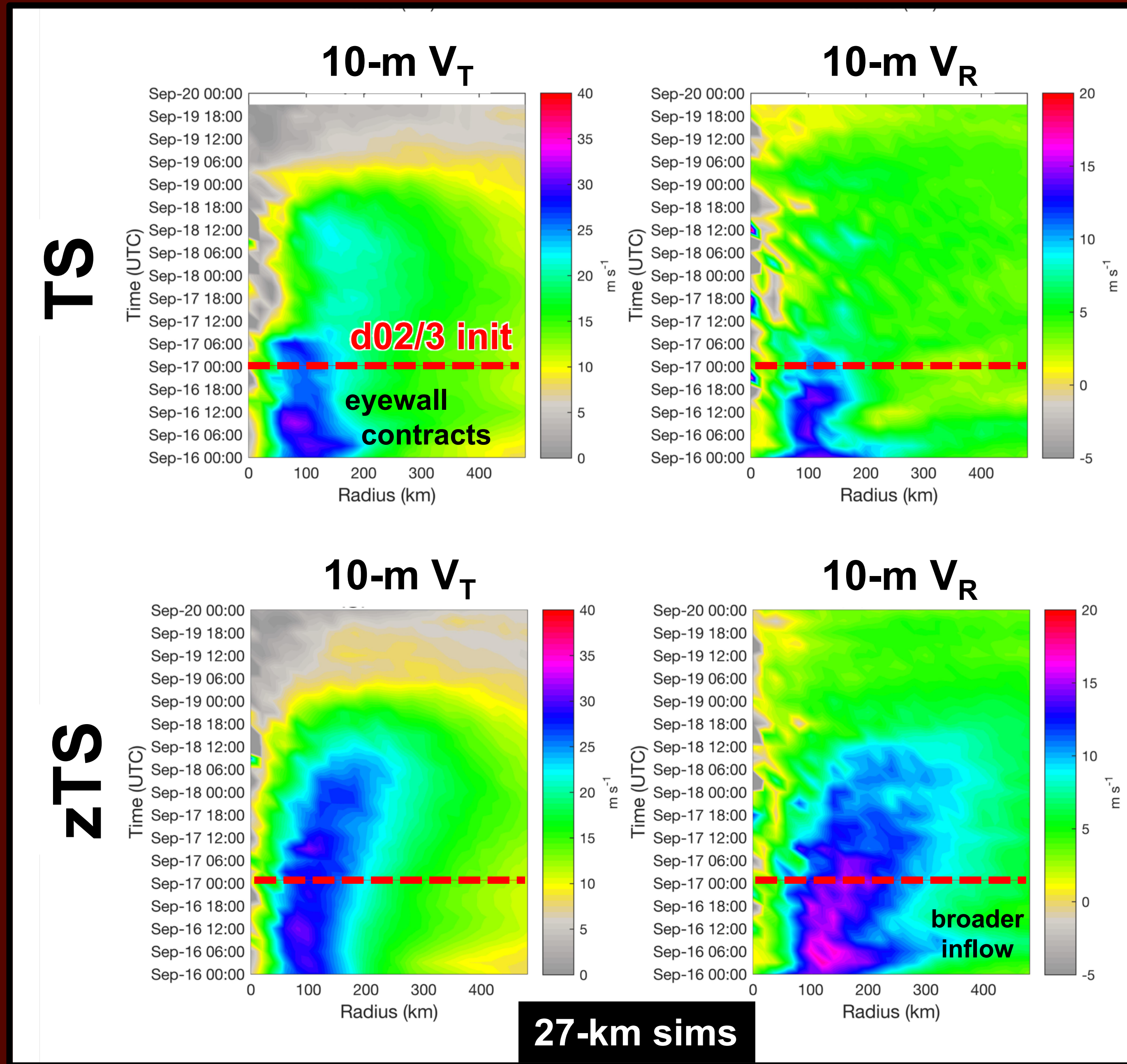
3-km Tiedtke (TS)



3-km altered Tiedtke (zTS)

STRUCTURE DURING COARSE DOMAIN SPIN-UP



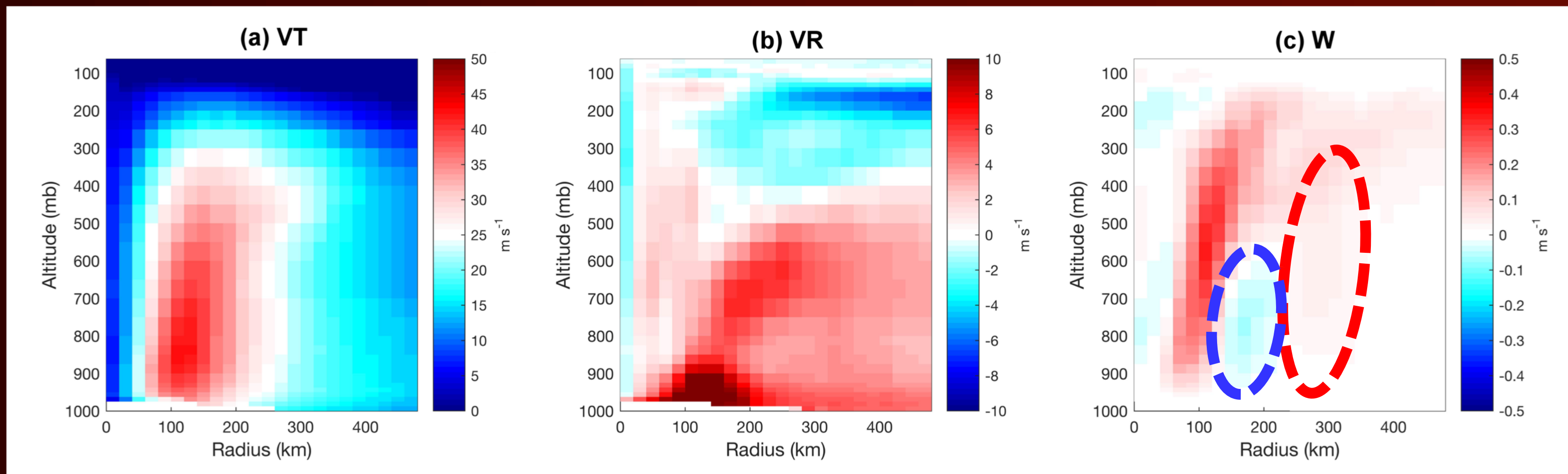


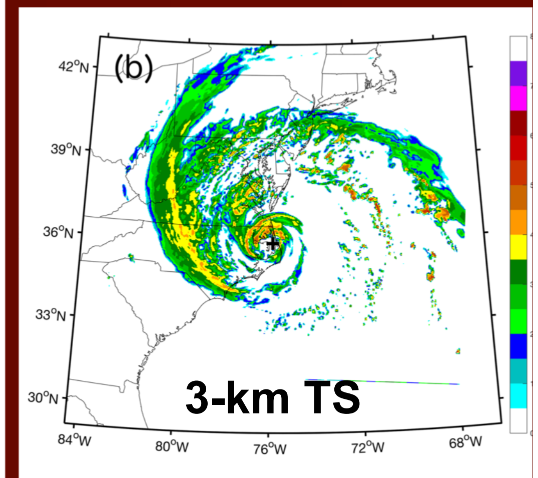
Azimuthally averaged structure (Z-R plots)

in 27-km simulations, time averaged 0-24 hours

27 km

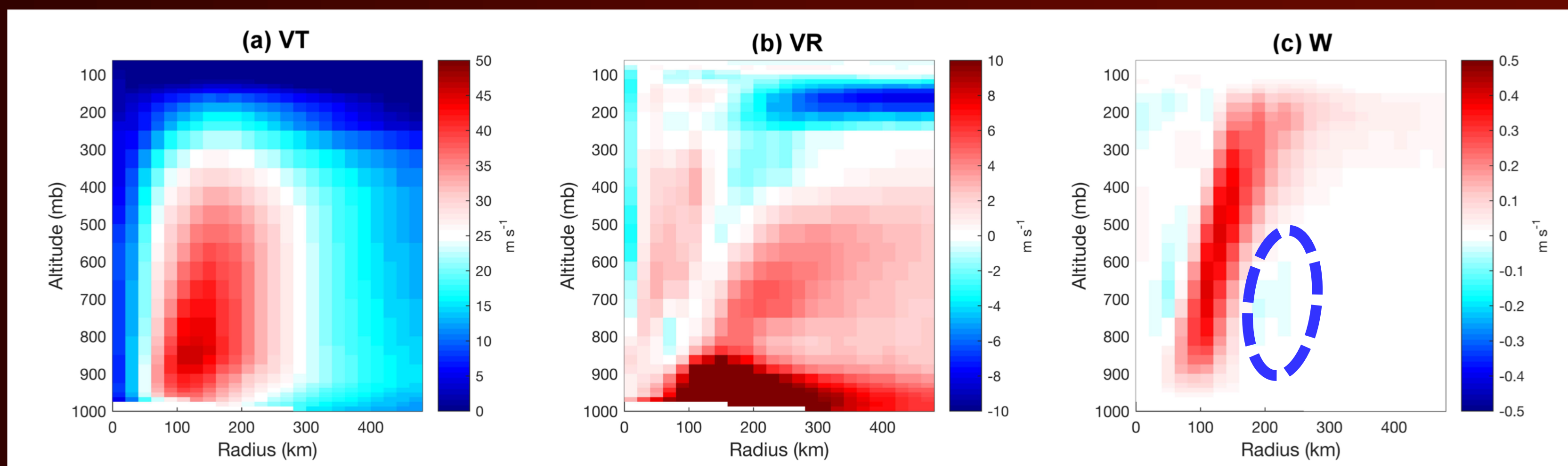
TS

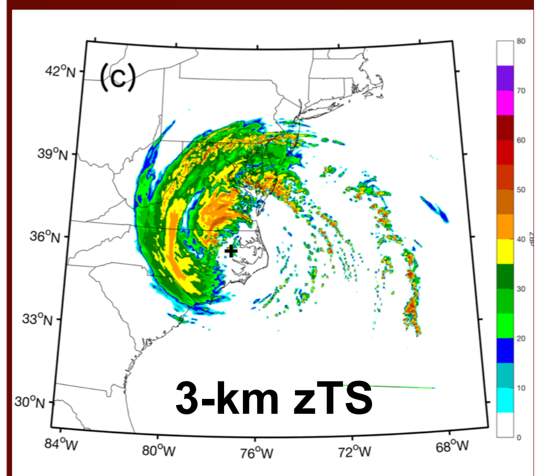




27 km

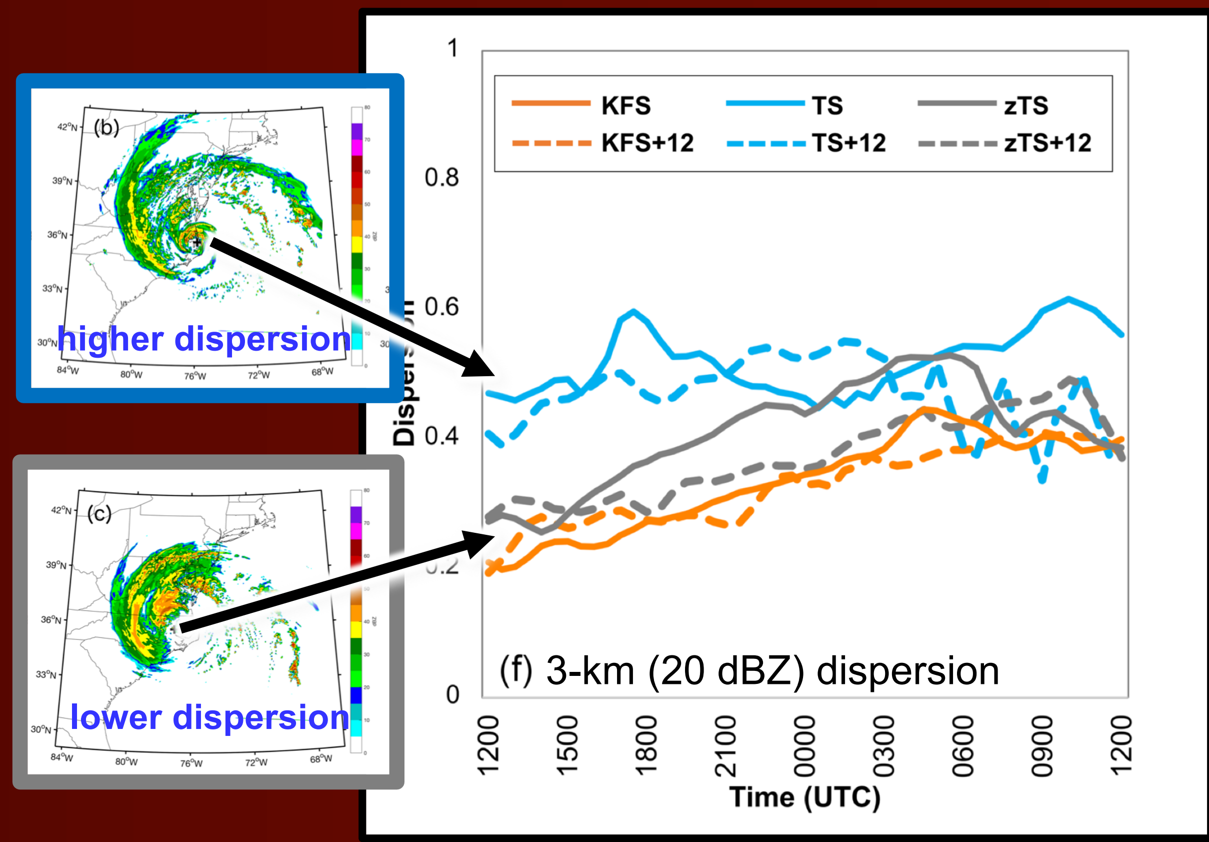
zTS





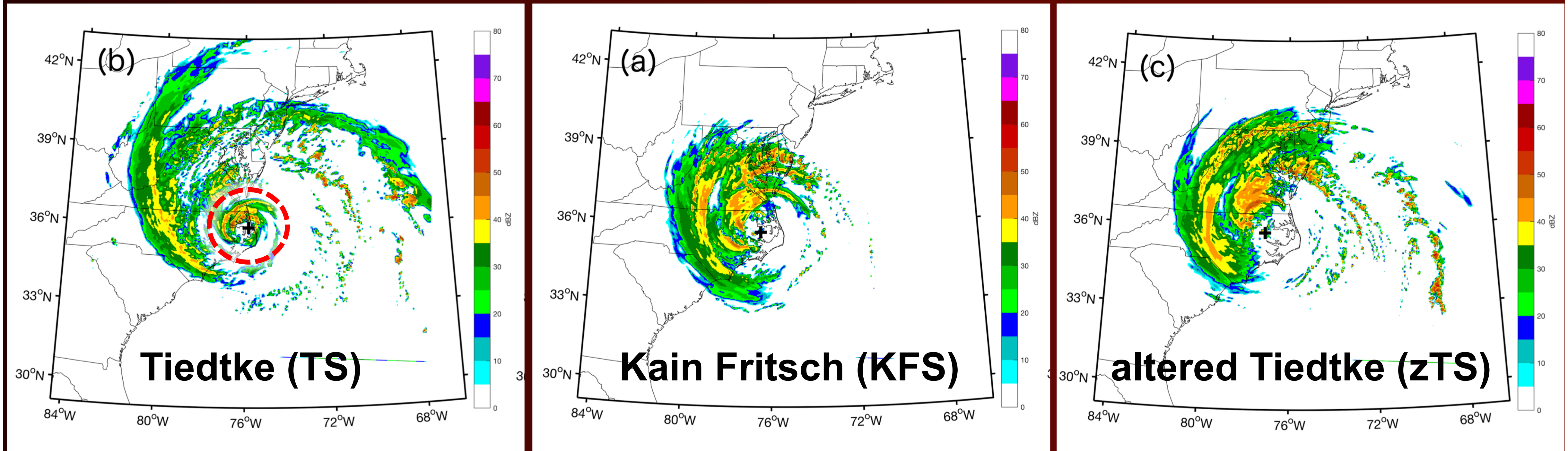
Conclusions

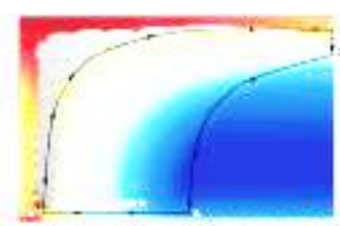
- Traditional metrics insufficient for evaluating influence of CP scheme
- Spatial metrics reveal significant (p<0.05) differences in structure
- <u>Limitations:</u>
  1) Results can be counterintuitive:
     - ➤ TS has smaller inner core
     - ➤ more rain outside core
     - ➤ higher dispersion
  2) Can be sensitive to threshold: convective (35-40 dBZ) vs. stratiform (20-30 dBZ)



Thank you! Questions?

Email: sezick@vt.edu





feedback?

VirginiaTech
College of Natural Resources and Environment

Evelyn L. Pruitt Award

CAREER Award BCS-1053864

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