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

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Background & Motivation

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


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

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


Reflectivity (dBZ)
0 - 5
5.01 - 10
10.01 - 15
15.01 - 20
20.01 - 25
25.01 - 30
30.01 - 35
35.01 - 40
40.01 - 45
45.01 - 50
50.01 - 55

Figure (a) to (g) illustrate the spatial metrics and their comparison with different models:

- **Tiedtke**: more fragmented & elongated
- **Kain Fritsch**: more central & solid

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 |TC Sep 16 2003
d02+3 init 00 |12 |TC Sep 17 2003
two model cycles

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

**Ocean**: SSTs prescribed

3-km: CP turned off

27-km: cumulus param
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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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.

\[
\frac{d\theta}{dt} = P_{\text{rad}} + P_{\text{conv}} + P_{\text{cond/evap}} + P_{\text{hdiff}} + P_{\text{vdiff}} + P_{\text{sfc}}
\]

\[
\frac{dq_v}{dt} = P_{\text{conv}} + P_{\text{cond/evap}} + P_{\text{hdiff}} + P_{\text{vdiff}} + P_{\text{sfc}}
\]

\[
\frac{du}{dt} + \frac{1}{\rho} \frac{\partial p}{\partial x} - f \nu = (P_{\text{conv}}) + P_{\text{hdiff}} + P_{\text{vdiff}} + P_{\text{sfc}}
\]

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

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# Model Simulation: CP schemes

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<th>BOTH are mass flux schemes &amp; incl. shallow convection</th>
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| 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 mods |

**Source:** ECMWF

TS simulation accounts for entrainment of momentum into the convective plume from the surrounding air.
## Model Simulation: CP schemes

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<td>Tiedtke with zero momentum (zTS, zTS+12)</td>
<td>- momentum tendencies set to zero</td>
<td></td>
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Source: ECMWF

**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
RQCUTEN(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
```

In module cu_tiedtke.F

**link to microphysics**

**entrainment/detrainment**

**mass flux**

**downdrafts**

**precip**

**updrafts**
Traditional Measures of Model Skill

little insight into differences in simulated storms!

expect TS to be weakest:

- u, v momentum transferred vertically

TRACK: 3-km sims

INTENSITY: 27-km sims

- d02 and d03 initialized for 091600 sims
- d02 and d03 initialized for 091612 sims

expect TS to be weakest: u, v momentum transferred vertically
Traditional Measures of Model Skill

Little insight into differences in simulated storms!
Shape Metrics

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

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<tr>
<th>Metric</th>
<th>Near 0</th>
<th>Near 1</th>
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<tr>
<td>Circularity</td>
<td>Elliptical</td>
<td>Circular</td>
</tr>
<tr>
<td>Solidity</td>
<td>Empty</td>
<td>Filled</td>
</tr>
<tr>
<td>Closure</td>
<td>Exposed</td>
<td>Enclosed</td>
</tr>
<tr>
<td>Dispersion</td>
<td>Central</td>
<td>Dispersed</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>Cohesive</td>
<td>Fragmented</td>
</tr>
</tbody>
</table>

20 dBZ objects at Landfall
Dispersion Shape Metric
Zick & Matyas (Annals of the AAG, 2016)

\[ D = \sum_{i=1}^{\text{polygons}} \frac{\text{Area}_i \left( \frac{r_{\text{centroid},i}}{500 \text{ km}} \right)}{\sum_j \text{Area}_j} \]

- Area weight
- How central?

Central

Dispersion (D)

\[ \text{BT center} \quad \text{= centroid} \]

R = 0.59

Best Track Winds (m/s)
Shape Metrics (20 dBZ)

Simulated Radar Reflectivities at 3.5 km ASL at 1800 UTC 18 Sep

Polygons associated with Reflectivity Regions > 20 dBZ

Measure and compare Dispersion (D)

0 1
DISPERSION

3-km Tiedtke (TS)

higher dispersion

3-km altered Tiedtke (zTS)

lower dispersion

(f) 3-km (20 dBZ) dispersion

Time (UTC)

Dispersion

KFS  TS  zTS
KFS+12  TS+12  zTS+12
STRUCTURE DURING COARSE DOMAIN SPIN-UP

radial velocity ($V_R$)

tangential velocity ($V_T$)

10-m $V_T$

10-m $V_R$

d02/3 init

eyewall contracts

10-m $V_T$

10-m $V_R$

broader inflow

27-km sims
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
- Limitations:
  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

Tiedtke (TS)

Kain Fritsch (KFS)

altered Tiedtke (zTS)


