Effects of Cumulus Parameterization on U.S. Midwest Summer Precipitation Prediction

by

Climate-Weather Research and Forecasting Model (CWRF)

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Motivation

It is a long-standing problem for current weather and climate models to accurately predict precipitation key features, especially the frequency and intensity of precipitation, and regional variations of diurnal cycle.

Problem I:
Most models tend to produce too frequent light rain, and underestimate the frequency and intensity of heavy rain.

Dai 2006, J. Climate

(a) Percentage contribution to annual total precipitation
(b) Annual precipitation frequency
Motivation

Problem II:
Model rainfall peaks too early in daytime, and some regional features, such as the nocturnal precipitation maxima observed over the U.S. Central Plains, are generally missed.

The local solar timing of the maximum of the diurnal cycle of precipitation

Lee et al. 2007, J. Hydrometeorol.


We will focus on cumulus parameterization because it plays a major role in regulating rainfall diurnal cycle
Objectives

Drizzling problem

Rainfall peaks too early in daytime

Deficiency in representing subgrid scale convection through cumulus parameterization, and its interaction with other physical processes

To better quantify the existing models errors, CWRF will be applied to predict the 1993 and 2008 summer floods over U.S. Midwest and examine their sensitivities to the cumulus parameterizations.
# Cumulus Parameterization Schemes in the CWRF

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>ECP (Ensemble Cumulus Parameterization, modified from G3)</strong></td>
<td>multiple cumulus closures and variants that can be selectively used with different weight</td>
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<tr>
<td><strong>ZML (Zhang-McFarlane parameterization modified by Liang)</strong></td>
<td>quasi-equilibrium assumption free tropospheric large-scale forcing.</td>
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<tr>
<td><strong>G3 (Grell and Dvénéyi 2002)</strong></td>
<td>Ensemble cumulus closures</td>
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<td><strong>MIT (Emanuel 1991)</strong></td>
<td>quasi-equilibrium assumption</td>
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<td><strong>GR (Grell 1993)</strong></td>
<td>quasi-equilibrium assumption</td>
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<tr>
<td><strong>CSU (Pan and Randall 1998)</strong></td>
<td>quasi-equilibrium assumption</td>
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<tr>
<td><strong>NKF (New Kain-Fritsch)</strong></td>
<td>remove the CAPE in a convective timescale</td>
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<tr>
<td><strong>TDK (Tiedtke scheme)</strong></td>
<td>remove the CAPE in a convective timescale</td>
</tr>
<tr>
<td><strong>BMJ (Bett-Miller-Janjic)</strong></td>
<td>Convective adjustment scheme</td>
</tr>
<tr>
<td><strong>GFDL (Donner 1993, Donner et al. 2001)</strong></td>
<td>remove the CAPE in a convective timescale</td>
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<td><strong>NSAS (New Simplified Arakawa-Schubert)</strong></td>
<td>quasi-equilibrium assumption</td>
</tr>
<tr>
<td><strong>SAS (Simplified Arakawa-Schubert)</strong></td>
<td>quasi-equilibrium assumption</td>
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ECP greatly reduces the wet bias over ocean in G3, NKF and ZML schemes. This is achieved by using cloud work function tendency closure.
1993 JJA U.S. Midwest Mean Precipitation (mm/day)

Summer Regional Mean

Taylor Diagram for Daily Precipitation

U.S. Midwest: [100°W-87°W, 36°N-42°N]  ECP has the highest correlation 0.63
2008 May-July Mean Precipitation

OBS  ECP  G3  GR  NKF

BMJ  ZML  MIT  CSU

TDK  GFDL  SAS  NSAS
2008 MJJ U.S. Midwest Mean Precipitation (mm/day)

Summer Regional Mean

Taylor Diagram for Daily Precipitation

ECP & G3 has the highest correlation 0.60
Observed (OBS), NCEP reanalysis (R2) and CWRF with the ECP cumulus scheme simulated: a) number of rainy days, b) rainfall intensity (mm/day), and c) daily rainfall 95th percentile (mm/day)

Precipitation Frequency and Intensity — 1993 JJA
Observed (OBS), NCEP reanalysis (R2) and CWRF with the ECP cumulus scheme simulated: a) number of rainy days, b) rainfall intensity (mm/day), and c) daily rainfall 95th percentile (mm/day).
Gremlin scheme well captures the observed diurnal variation, but slightly underestimates the nighttime rainfall peak value.
Eastward Propagating Diurnal Signals

1993 JJA mean precipitation (mm/day) and 850-mb wind diurnal departure from the daily mean (m/s) in 3-h interval from the NARR (a), CWRF with the ECP (b) and Grell (c) schemes.
Conclusion

- For U.S. Midwest summer precipitation, moisture convergence closure performs best over the land, while cloud work function tendency closure is superior over the ocean.

- CWRF with ECP cumulus scheme performs well in predicting precipitation frequency and intensity, especially for the extreme events.

- U.S. Midwest summer rainfall diurnal cycle is sensitive to cumulus parameterizations. Grell scheme most realistically reproduces the nocturnal precipitation peaks and their associated eastward propagation of convective systems from east of Rockies.

- Trigger function determines when convection occurs. Further study will be focused on investigating the critical trigger function(s) that enable the Grell scheme to capture the observed diurnal feature.