Sensitivity of Tropical Cyclone Frequency and Intensity to Cumulus Convective Activity in a High Resolution GEOS-5 Model

Young-Kwon Lim and Siegfried D. Schubert

NASA Goddard Space Flight Center
Introduction

1. It was found at the last meeting that realistic simulation of the Atlantic tropical storms and hurricanes (~0.5° resolution) was challenging relative to the other regions (e.g., Pacific).

2. Is increased (0.25°) resolution helpful for improving the simulation of the tropical cyclones in terms of storm numbers, intensity, and shape of tropical cyclone (e.g., warm core magnitude and its vertical location, maximum wind, SLP deepening, compactness of TC center, radius of maximum wind, etc.)?

3. Here we will focus on the impact of modifying the cumulus convective activity at 0.25° resolution. In particular we will examine the sensitivity to the minimum entrainment threshold.
Introduction

• **Determination of Cumulus Entrainment Limit**
  \[ \mu_m = \frac{\alpha}{D} \]
  minimum entrainment rate \((\mu)\)
  \(\alpha = \text{const} \) (positive),
  \(D = \text{PBL depth} \sim \text{Diameter for the largest convective plume}\)

• **Increase in the minimum cumulus entrainment rate** (i.e., gradually turning off the cumulus parameterization) in the model to suppress the parameterized deep cumulus convection.
Experiment and analysis

1. Three different minimum entrainment rates (strong, less strong, weak (control, default)) were applied for the active hurricane year (2005) and inactive year (2006).

2. Three member ensembles are conducted for each entrainment experiment, all at the spatial resolution of 0.25 degree.

3. We examine the model’s capability for reproducing the hurricane characteristics for two contrasting hurricane years (2005, 2006), with a focus on:

a. the sensitivity of the storm simulation to the change in cumulus entrainment threshold, and

b. how that change influences the atmospheric stability, which will determine the atmospheric circulation structures and TC characteristics
The number of Atlantic TSs (member mean) wrt. different configuration of convective cloud scale (minimum entrainment rate (referred to as MER))

<table>
<thead>
<tr>
<th></th>
<th>MER= (μ_m=1.0km^{-1})</th>
<th>MER= (μ_m=0.7km^{-1})</th>
<th>MER= (μ_m=0.4km^{-1})</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>31</td>
<td>24</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>2006</td>
<td>17</td>
<td>13</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

A) Strong MER  
B) Less strong MER  
C) Weak MER
Storm tracks wrt. different configuration of convective cloud scale (quarter-degree runs, 2005)
Scatter plot (wind vs. SLP) wrt. different configuration of convective cloud scale (2005)

A) Strong MER
B) Less strong MER
C) Weak MER

Blue: Obs., Black: Model

A) Strong MER
B) Less strong MER
C) Weak MER

- 61 m/s, 936 hPa
- 60 m/s, 943 hPa
- 56 m/s, 963 hPa
Storm tracks wrt. different configuration of convective cloud scale (quarter-degree runs, 2006)
Scatter plot (wind vs. SLP) wrt. different configuration of convective cloud scale (2006)

A) Strong MER

B) Less strong MER

C) Weak MER

Blue: Obs., Black: Model

65m/s, 935 hPa

56m/s, 955hPa

53m/s, 964hPa
Sharp warm core at upper-troposphere, compact and well-defined eye, max wind at lower elevation, small radius of max wind (less than 50km)
Vertical structure of the strong TS (2005, 2006)

Less strong MER (2005)

Less strong MER (2006)
Vertical structure of the strong TS (2005, 2006)

Weak MER (2005)

Vertical Structure (intense storm) (wind speed, T, warm core) and Evolution of 850mb wind speed & SLP at storm center

Weak MER (2006)

Vertical Structure (intense storm) (wind speed, T, warm core) and Evolution of 850mb wind speed & SLP at storm center

C) Evolution of 850mb wind (black) & SLP (blue) at storm center

- 55 m/s
- 953 hPa

- 53 m/s
- 984 hPa
How can we explain the increased storm numbers and intensity under suppression of parameterized cumulus convection?

We focus on moist static stability and associated atmospheric features.
Moist Static Energy

ThetaE ver. grad.

MSE and $-\partial / \partial P$ over the Atlantic (Jun–Nov)

- a) Moist Static Energy (J/kg)
- b) $-\partial (\text{EPT}) / \partial P$

**Relatively stronger theta_e decrease with height in the strong MER runs -> conditionally more unstable atmosphere**

MSE is generally similar to equivalent potential T

Black: (A) Red: (C)
Blue: (B)
Temperature and Humidity difference profile

Drier at near-surface -> requires a flux of water vapor from the ocean sfc. to the air (positive LH flux possible)

Moist at lower-level and dry at upper-level -> upward moisture flux possible

Generally cool T response to the strong MER

Black: (A) – (C)

Blue: (B) – (C)
Latent heat and Evaporative fluxes

A) Strong MER

C) Weak MER

A) - B)

C) - A)

Positive LH reflects Evap fluxes.
SH flux and Vertical T gradient at near-surface

A) Strong MER

B) SH difference

C) Weak MER

A) - C) SH doesn’t seem to contribute to moist static instability
What takes place as a result of this atmospheric instability?

(as shown on the next few slides......)

Strong upward motion, lower-level convergence and positive vorticity, moisture flux convergence, more resolved-scale convective activity -- > increased TC numbers and intensity
Vertical motion (OMEGA) and Moisture flux conv.


OMEGA and Moisture flux convergence over the Atlantic (Jun–Nov)

Stronger upward motion with larger MER (unstable condition),
larger lower-level moisture flux convergence (active moist convection possible)

Black: (A)  Red: (C)
Blue: (B)
Vorticity (850) and Near sfc. wind var. (10m)

A) Strong MER

C) Weak MER

A) - C)

Enhanced positive vorticity and variance over the TC genesis region
Lower-level Convergence (925) and Vertically integrated moisture flux convergence

A) Strong MER

C) Weak MER

A) - C) Stronger convergence and moist convection
Conclusion and Discussion

1. High-resolution (0.25 degree) with slight increase in MER produced better organized TC structures and more realistic TC numbers and intensity over the Atlantic.

2. Further increase in MER produces even stronger TCs, but tends to overestimate the TC numbers.

3. Increase in MER constrains the parameterized deep convective activity (result: increase in large-scale prcp., decrease in convective prcp.). Stronger suppression of the cumulus parameterization constructs more unstable atmosphere (LH flux, lower-level moistening and upper-atmosphere cooling contributes to development of unstable atmosphere).

4. Upward motion and moisture flux convergence is enhanced. It results in more tropical storms and hurricanes. Strong hurricane (category up to 4) is captured.
Precipitation bias (total, large-scale)

Strong MER

Less strong MER

Total

Large-scale Prcp.

A) - C)

B) - C)

Overestimated precipitation over the TC genesis region. Slight change in MER did not overestimate prcp.
Total precipitation bias (mm/day, area averaged over the Atlantic basin (90W-0E, 0N-50N)

<table>
<thead>
<tr>
<th>Year</th>
<th>A) – C)</th>
<th>B) – C)</th>
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<tbody>
<tr>
<td>2005</td>
<td>4.89 – 4.40 = 0.49</td>
<td>4.43 – 4.40 = 0.03</td>
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<tr>
<td>Obs. =3.62</td>
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<tr>
<td>2006</td>
<td>5.02 – 4.42 = 0.60</td>
<td>4.51 – 4.42 = 0.09</td>
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<tr>
<td>Obs. =3.57</td>
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</table>
Precipitation during hurricane season in 2006

Strong MER

A little strong MER

Total  Large-scale Prcp.

Mean Precipitation during NH TC season (Jun–Nov)

a) Total Prcp. (180s1000)

b) Total Prcp. (default)

c) Difference (A–B)

d) Difference (D–E)

Mean Precipitation during NH TC season (Jun–Nov)

e) Total Prcp. (180s3000)

f) Large-scale Prcp. (default)

g) Difference (A–S)

h) Difference (D–F)