Do tropical cyclone cold wakes impact storm climatology in a high-resolution global model?

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Tropical cyclones and horizontal resolution

- TC representation in global models growing increasingly more realistic at finer grid spacings
- 0.25° (~26 km) (given adequate parameterization) gives realistic spread in intensity

Zarzycki and Jablonowski, JAMES, 2014
CAM “forecast mode”

- Community Atmosphere Model (CAM) variable-resolution capabilities
- Every 12 hours (00Z and 12Z) for 2012-2013 ASO
  - ~6-7x cheaper than a globally-uniform 13 km forecast

Zarzycki et al., MWR, revised.

Sandy TPW: INIT 12Z 10/25/12
CAM “forecast mode” errors

- **Tracks** of TCs in CAM at 13km looks good...
- ... model exhibits a high bias in **TC intensity**
- Lack of convergence with resolution
Why?

• Many reasons
  • Convective parameterizations?
  • Condensate loading treatment (or non-treatment)?
  • How surface/atmosphere interactions are treated?
• Prescribed SSTs?
  • Assume unlimited heat potential, no surface energy closure

QUESTION: Is there an intensity bias at high resolution associated with prescribing SSTs in AGCM-simulations?
TC cold wakes

- TCs cool ocean surface primarily through 3 mechanisms
  - Surface fluxes
  - Advection
  - Mixing

Typhoon Ioke (2006)

Figure courtesy of Remote Sensing Systems “Storm Watch” (available at: http://www.remss.com/storm-watch)
Issues moving beyond prescribed SSTs

• Theoretically, **fully dynamical oceans** should represent TC cold wakes
  • *Expensive* at high resolution
    • “Kills” var-res atm computational gains
  • **Potential biases** in ocean SST make comparison difficult
  • **Inertia**; until recently, simulated TCs too weak
  • **Cannot isolate atmosphere** in MIPs

• **Traditional slab oceans** do not represent mixing processes; 70-90% of cold wake contribution for intense storms

Hannay et al., 2015
The simplest cold wake parameterization™?

\[
\frac{\partial SST}{\partial t} = \frac{1}{\rho_o c_p h} F_{net} - X_{cool} R_{cool} \left( \frac{SST - T_{fz}}{T_{crit}} \right) \frac{h_o}{h_{clim}} + \frac{1}{\tau} (SST_{clim} - SST)
\]

- **Traditional slab ocean**
  - Weighting function (based on surface stress)
- **Empirical cooling rate**
- **Scaling based on surface temp.** (SST ↑, forcing ↑)
- **Scaling based on mixed-layer depth** (h ↑, forcing ↓)
- **Newtonian relaxation to climatology**

Zarzycki, in prep.
The simplest cold wake parameterization™?

- Weighting function \( X_{\text{cool}} \) dictates **surface wind stress** where mixing is “activated”
- Two configurations for \( X_{\text{cool}} \)
  - **slab_1**, TC cooling saturates for winds beyond 40 m/s (e.g., Lloyd and Vecchi, 2011, J Clim)
  - **slab_2**, TC cooling increases nearly linearly as function of wind (e.g., Vincent et al., 2012, JGR-A)

Zarzycki, in prep.
Drawbacks...

- No vertical or horizontal advection
- Assumes climatological mixed-layer properties
  - TC always sees “mean” ocean state, no anomalous values for TCHP, for example
- No “long-term” modification of ocean environment
  - No memory (e.g., Hart et al., 2007)
- Questionable TC-TC interaction

Only concerned with “cheap” method of assessing direct impact of cooling under storm core in the mean sense!
Why variable-resolution?

• Variable-resolution CESM
  • Allows for regionally-high resolution in *global modeling framework*
  • No need for boundary conditions
  • Allows for regional climate studies, cheap “experimental testbed”

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Model setup

- Variable-resolution CESM v1.3.b17 (CAM v5.3.65)
  - ~26km grid spacing over NATL/NPAC
  - Default CAM5 physical parameterizations
  - 60 ensemble members
    - June-December (7 month season per member)
    - Present day average climatological forcing (SSTs, aerosols, etc.)
  - 20 traditional fixed SST, 20 slab1, 20 slab2
Example of 0.25° TC

Zarzycki and Jablonowski, JAMES, 2014
Average SST climatology...

Mean basin SST difference from climo
Trajectories

1,943 detected storms across the 60 simulations
What do cold wakes look like?

~6 week movie Sept.-Oct. slab_1 ensemble member #3
10-m wind contoured rainbow (bottom), SST anom. red/blue (left)
Cross-track cooling

- Cross-track cooling larger on **right side of storm** (in NH)
- Qualitative agreement with observations (e.g., Shay and Brewster, 2010, MWR) and models (e.g., Vincent et al., 2012, JGR-A)

Vincent et al., 2012, Fig. 7b
Time evolution of SST anomaly

\[ u_{10} < 32 \text{ m/s (TD + TS)} \]

- SST rel. to TC passage; slab1; fast 0_32 m/s

\[ u_{10} \geq 32 \text{ m/s (HURR)} \]

- SST rel. to TC passage; slab1; fast 32_999 m/s

Observed slow-moving hurricanes (by S-S cat) from Lloyd and Vecchi (2011)

slab1, all members, avg. SST anomaly over 1° area centered on MSLP
Intensity PDFs

TC SLP PDF

TC Wind PDF

PDF of all 6-hourly SLP and 10-m wind speed hits
## Intensity statistics

<table>
<thead>
<tr>
<th>MSLP (hPa)</th>
<th>fixed SST</th>
<th>slab_1</th>
<th>slab_2</th>
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<tbody>
<tr>
<td>Mean</td>
<td>987.4</td>
<td>990.6</td>
<td>990.3</td>
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<tr>
<td>Lowest 5%</td>
<td>946.7</td>
<td>957.9</td>
<td>955.4</td>
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<td>Lowest 1%</td>
<td>927.6</td>
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<td>939.2</td>
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<tr>
<td>Lowest 0.1%</td>
<td>914.6</td>
<td>926.6</td>
<td>928.1</td>
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<tr>
<td>Min</td>
<td>902.4</td>
<td>915.5</td>
<td>922.4</td>
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</table>

<table>
<thead>
<tr>
<th>10-m wind (m/s)</th>
<th>fixed SST</th>
<th>slab_1</th>
<th>slab_2</th>
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<tbody>
<tr>
<td>Mean</td>
<td>27.2</td>
<td>25.5</td>
<td>25.7</td>
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<tr>
<td>Highest 5%</td>
<td>47.0</td>
<td>41.6</td>
<td>42.6</td>
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<tr>
<td>Highest 1%</td>
<td>54.2</td>
<td>48.5</td>
<td>49.4</td>
</tr>
<tr>
<td>Highest 0.1%</td>
<td>58.8</td>
<td>54.9</td>
<td>54.3</td>
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<tr>
<td>Max</td>
<td>63.0</td>
<td>58.6</td>
<td>57.0</td>
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</tbody>
</table>
“Categorizing” storms...

Stroms binned by Saffir-Simpson scale (max intensity)

**FixedSST**

- Cat 5
- Cat 4
- Cat 3
- Cat 2
- Cat 1
- TS
- TD

**slab_1**

- Cat 5
- Cat 4
- Cat 3
- Cat 2
- Cat 1
- TS
- TD

**slab_2**

- Cat 5
- Cat 4
- Cat 3
- Cat 2
- Cat 1
- TS
- TD

Number of TCs per season

70 + 2

20 + 0

26 + 0
Summary

• (Very) empirical model of mean cooling under TCs, but **produces satisfactory approximation of under- and near-core TC cooling for “free”**

• Isolate SST cooling as potential mechanism in TC intensity sensitivity in global climate models

• As expected, cooling primarily impacts **tail of distribution**
  • Weakens strongest 1% storms by MSLP by 12-15mb

• Consideration for high-resolution prescribed SST experiments capable of producing “major hurricanes”

• Where can we go?
  • Further complexity/tuning?
  • 1-D mixed-layer model (happy medium?)
  • Reverse experiment?
  • Address ocean model biases in CESM