Using an idealized slab ocean to diagnose tropical cyclone intensity biases associated with prescribed SSTs in CAM-SE

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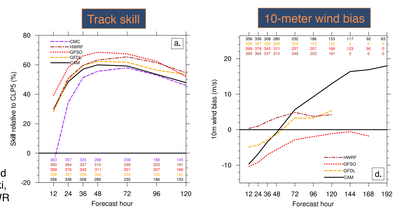
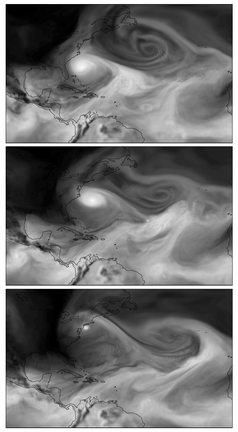
Background and Motivation

- High-resolution, tropical cyclone (TC) forecasts using variable-resolution CAM5-SE 0.125° (~14 km) show promising results
  - CAM5-SE forecasted TC **track** closely matches that of operational numerical weather prediction
  - CAM5-SE forecasted TC **intensity** poorer; storms are, on average, too strong relative to observations -> implications for climate, too



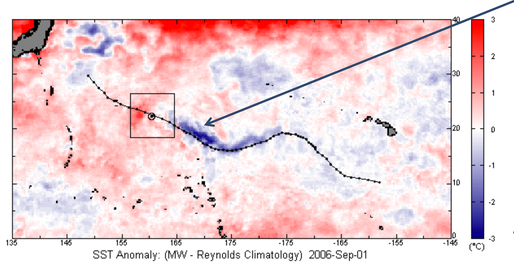
Zarzycki and Jablonowski, revised, MWR



Precipitable water forecast for Hurricane Sandy (initialized 12Z 10/25/12) using variable-resolution CAM-SE (Zarzycki and Jablonowski, revised, MWR)

Tropical cyclone cold wakes

- Overly strong storms at 0.125° in CAM5-SE may be due to host of factors including *convective parameterizations, representation of condensate loading, coupling procedure for calculation atmosphere-ocean fluxes, and* ***lack of atmosphere-induced ocean cooling***



Cold wake induced by passage of Typhoon Ioke in 2006. Black dots indicate trajectory of storm, with box denoting location of TC at time of SST analysis. Color contours are departure of observed SST from mean (Reynolds climatology). Figure courtesy of Remote Sensing Systems "Storm Watch" (available at: http://www.remss.com/storm-watch)

- TC cold wakes (negative SST anomaly) induced under/behind tropical cyclones
  - Primarily due to mixing/ advection of cooler water into mixed layer
  - Some contribution from extraction of latent/ sensible heat fluxes
- ***NEGATIVE*** **intensity feedback** (stronger TCs -> more cooling -> less available surface energy

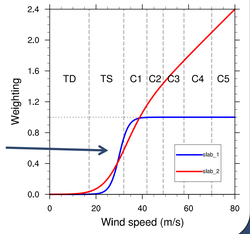
The simplest turbulence parameterization™?

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

Traditional slab ocean | Weighting function (based on surface stress) | Cooling rate | Scaling based on surface temp. | Scaling based on mixed-layer depth | Newtonian relaxation to climatology

- *SST scaling* dictates warmer SSTs have greater "potential to cool via mixing."
- Mixed-layer depth scaling dictates climatologically shallower mixed layers more susceptible to cooling
- Newtonian relaxation ensures mean SSTs match climatology
  - ***Remove typical biases from coupled simulations with prognostic ocean***

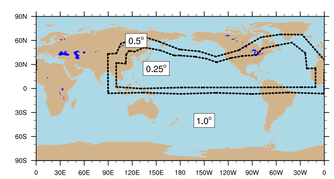
- Weighting function (X_{cool}) dictates surface wind speeds where turbulence is "activated"
- Two configurations for X_{cool}
  - **slab_1**, TC cooling saturates for winds beyond 40 m/s (e.g., Lloyd and Vecchi, 2011, JClim)
  - **slab_2**, TC cooling increases (slightly less than) linearly as function of wind (e.g., Vincent et al., 2012, JGR-A)



Goal

- Traditionally, global climate and weather models at high-resolution have forced with **prescribed SSTs** to minimize cost associated with dynamic ocean model
- Fully-coupled simulations (with dynamic ocean) are expensive and can lead to large-scale regional climate biases which impact TC climatology and make understanding coupling's impact on TCs difficult
- 0.25° CAM simulates realistic TC intensities (Zarzycki & Jablonowski (2014, JAMES), Bacmeister et al., (2014, JClim), Wehner et al., (2015, JAMES)) - **at high resolution, is there a TC intensity bias induced by lack of atm-ocean energy closure?**

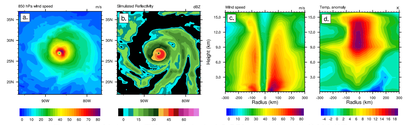
Model setup and experimental configurations



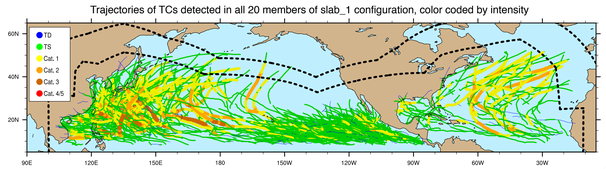
- **CAM-SE** (Taylor and Fournier, 2010, JCP)
- Use **variable-resolution** (Zarzycki et al., 2014, JClim) to "cheaply" isolate individual TC basins (as in Zarzycki and Jablonowski, 2014, JAMES)
- 0.25° (~28 km) grid spacing over North Atlantic and North Pacific basins

- Default "out of the box" **CAM5** physics
- 7 month, initial-condition perturbed CESM ensembles, initialized on May 1st
- Analyze tropical cyclone trajectories and intensity from **June-November** (TC season)
- 60 simulations
  - 20 fixed SST
  - 20 slab_1 config
  - 20 slab_2 config

1,943 detected storms across the 60 simulations

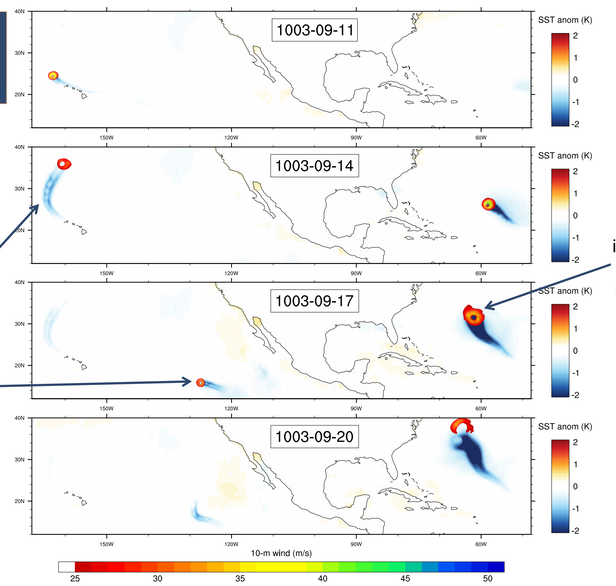


Example of intense TC simulated at 0.25° resolution in CAM-SE. From Zarzycki and Jablonowski, 2014, JAMES



Example of simulated cold wakes

Ensemble member #3, slab_1 configuration

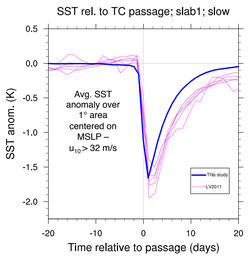


Small, moderate intensity, fast moving TCs

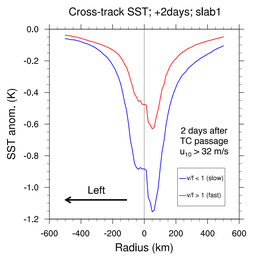
Large, intense, slow moving TC

Snapshots of SST departure from mean climatology (red-blue, right labelbar) over-contoured with 10-meter wind speed (rainbow, bottom). Successive panels are three days apart.

Comparing simulated SST cold wakes with observations

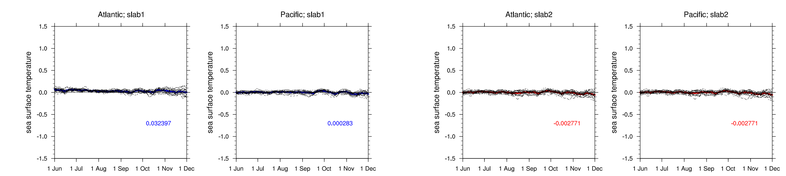


- Magnitude and temporal evolution of cold wake response matches observations (Lloyd and Vecchi, 2011, JClim)
- Recovery slightly too fast

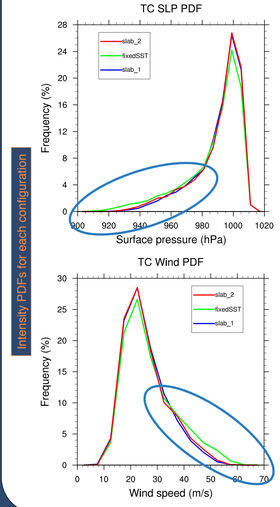


- Cross-track cooling larger on right side of storm (in NH)
- Qualitative agreement with observations (e.g., Shay and Brewster, 2010, MWR) and models (e.g., Vincent et al., 2012, JGR-A)

- Average SST over refined nest in both Atlantic and Pacific Oceans in slab configurations within 0.03 K of climatological, prescribed SSTs
- Relaxation behavior of parameterization results in large-scale SST fields being **essentially identical between fixed and interactive SST simulations**



Intensity reduction with cold wake parameterization



		fixed SST	slab_1	slab_2
MSLP (hPa)	***Mean***	987.4	990.6	990.3
	Lowest 5%	946.7	957.9	955.4
	Lowest 1%	927.6	942.6	939.2
	Lowest 0.1%	914.6	926.6	928.1
	Min	902.4	915.5	922.4
10-m wind (m/s)	***Mean***	27.2	25.5	25.7
	Highest 5%	47.0	41.6	42.6
	Highest 1%	54.2	48.5	49.4
	Highest 0.1%	58.8	54.9	54.3
	Max	63.0	58.6	57.0

- Longer "tail" at extreme intensities (low SLP, high surface winds) with fixed/prescribed SST
- Both slab oceans show shortening of tail (higher SLP, lower winds) -> **negative intensity feedback from induction of SST cold wake**
- **Extremes show larger signal** but both means and extremes shift weaker with slab ocean
- slab_2 shows stronger signal in tail

Conclusions

- Slab ocean w/ turbulence parameterization is highly idealized (and somewhat empirical) but **produces TC cold wakes which agree with observational/ simplified modeling studies**
- Average basin-wide SST with slab configurations essentially identical to control configuration with fixed SSTs
- Computationally efficient; negligible added cost
- **Both mean & extremes of intensity distributions weaker with slab ocean**
- Largest differences are in **tail of distribution** (extremes)
- **Indicates climate models pushing into regimes where prescribing SSTs problematic for TC studies**
- Next steps? Mixed-layer model? Addressing coupled SST biases in CESM?