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

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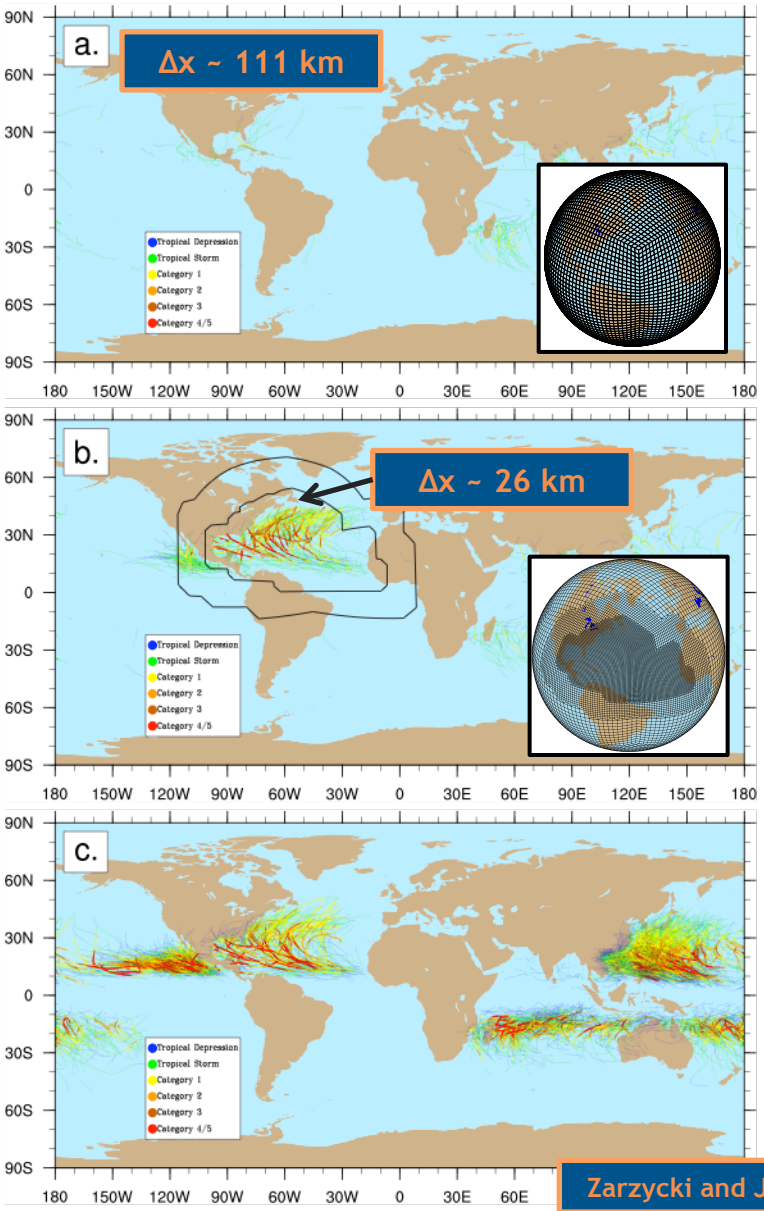
5th International Summit on Hurricanes and Climate Change
June 12th, 2015

Tropical cyclones and horizontal resolution

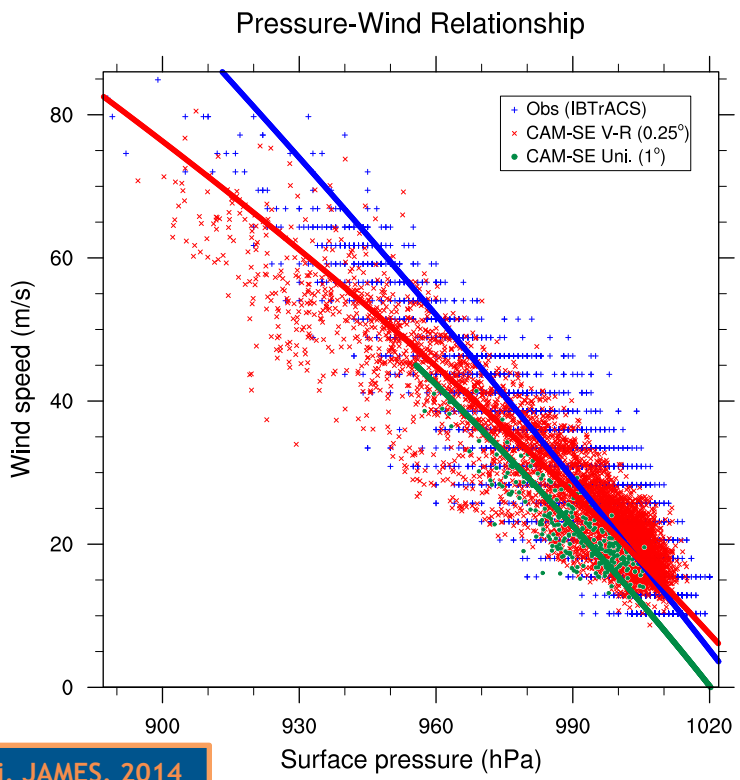
Uniform 1°

Var-res

Obs

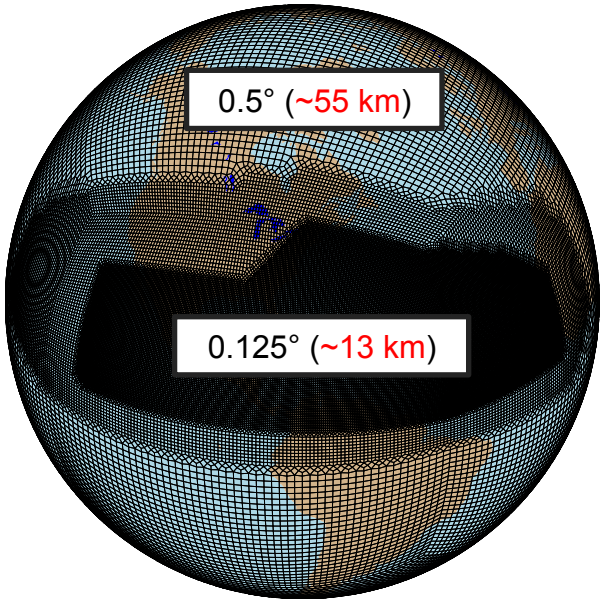


- TC representation in global models **growing increasingly more realistic at finer grid spacings**
- 0.25° (~26 km) (given adequate parameterization) gives realistic spread in intensity



Zarzycki and Jablonowski, JAMES, 2014

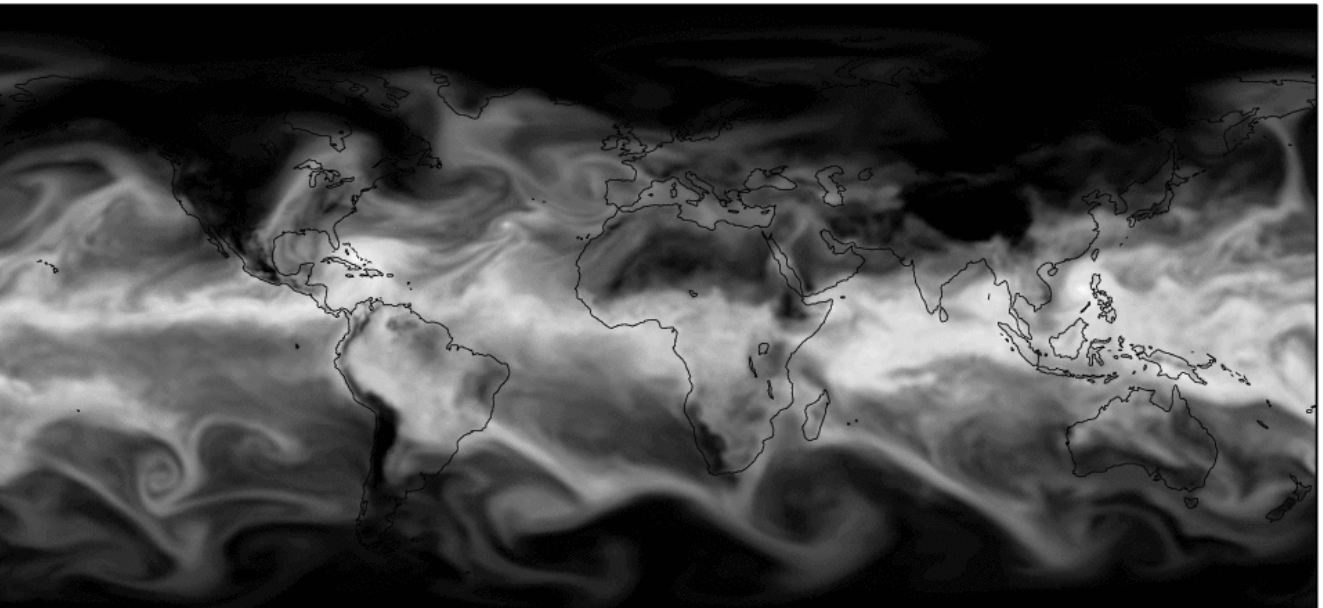
CAM "forecast mode"

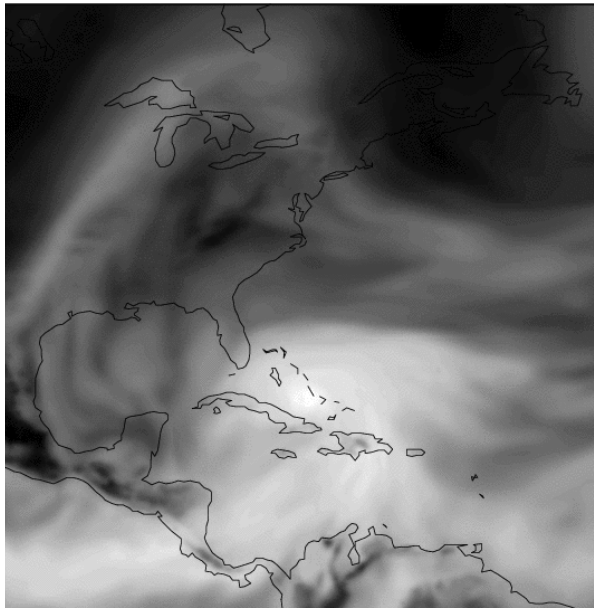


- Community Atmosphere Model (CAM) variable-resolution capabilities
- Every 12 hours (00Z and 12Z) for 2012-2013 ASO
  - **~6-7x cheaper than a globally-uniform 13 km forecast**

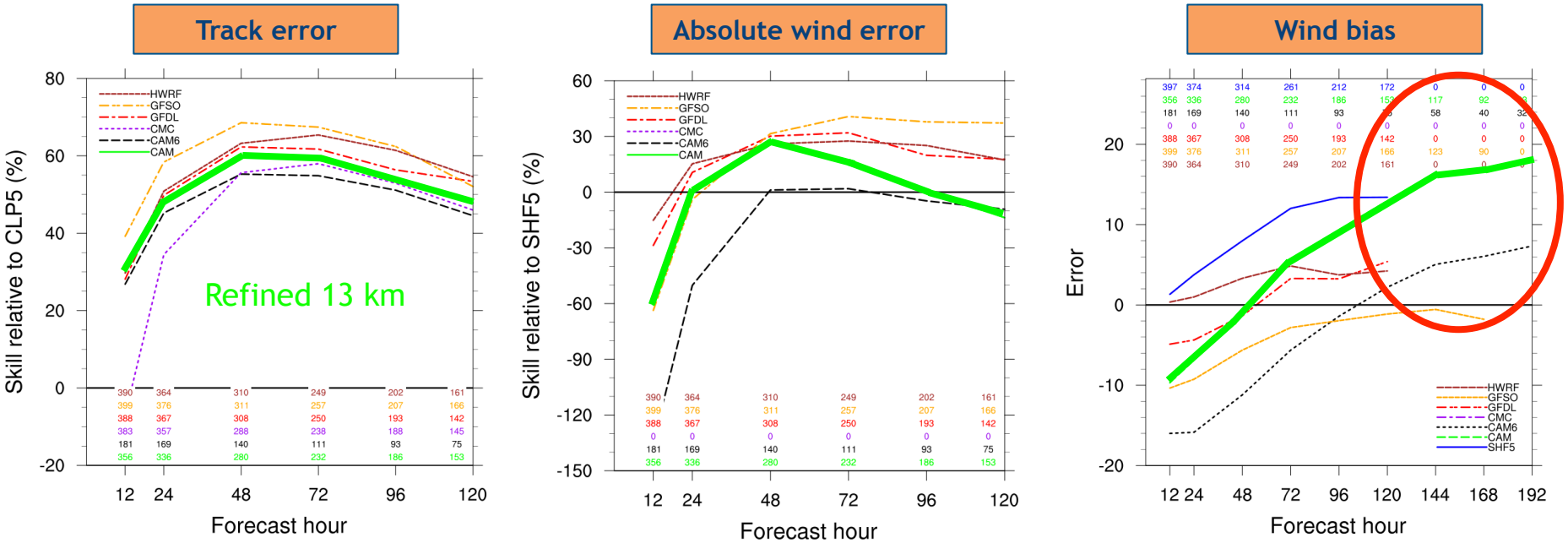
Zarzycki et al., MWR, revised.

Sandy TPW: INIT 12Z 10/25/12





CAM "forecast mode" errors



Zarzycki et al., MWR, revised.

- **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)

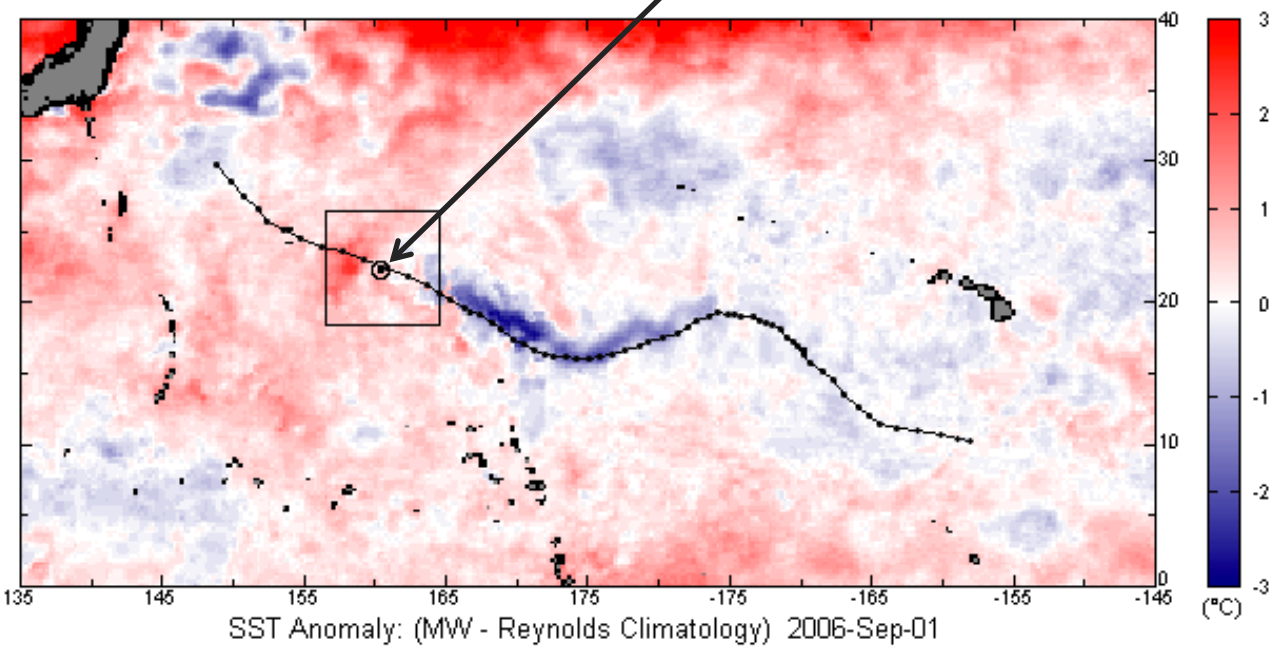
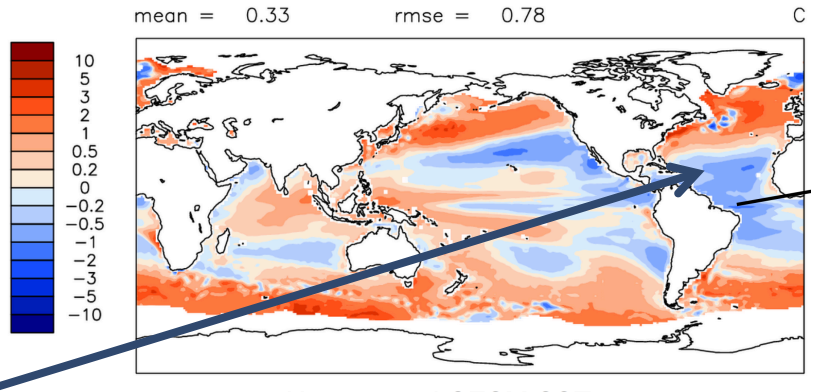


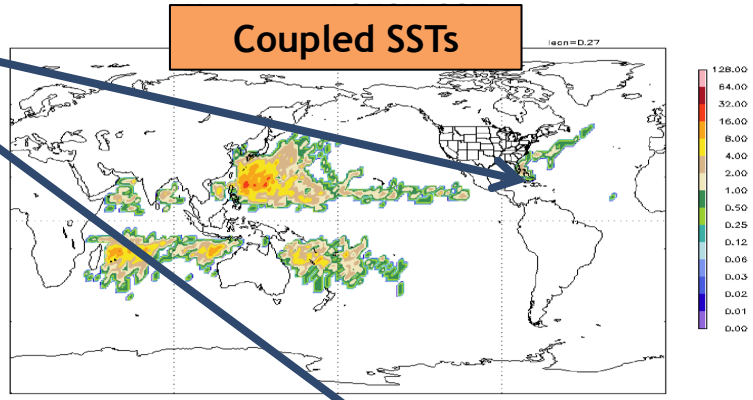
Figure courtesy of Remote Sensing Systems "Storm Watch" (available at: http://www.remss.com/storm-watch)

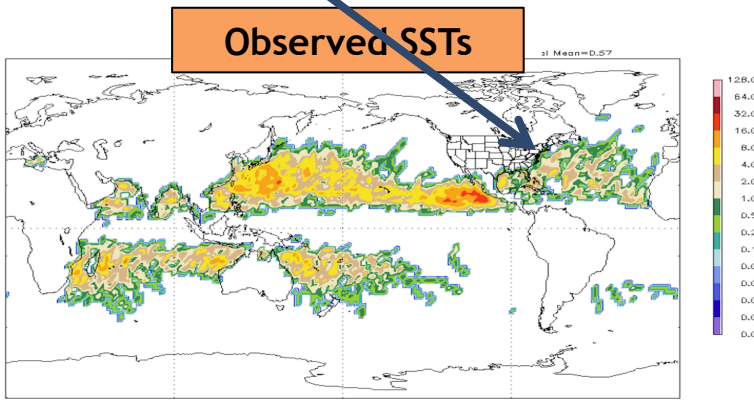
Issues moving beyond prescribed SSTs

- 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**

Small et al., JAMES, 2014







Hannay et al., 2015

The simplest cold wake parameterization™?

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

Traditional slab ocean

Weighting function (based on surface stress)

Empirical cooling rate

Scaling based on surface temp. (SST ↑, forcing ↑)

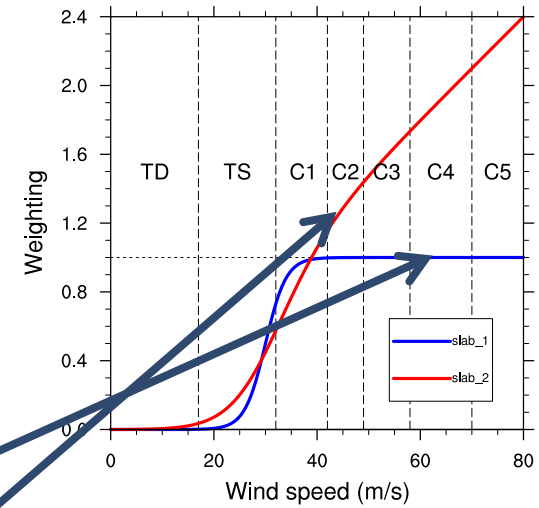
Scaling based on mixed-layer depth (h ↑, forcing ↓)

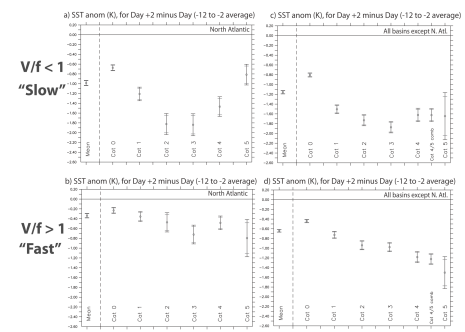
Newtonian relaxation to climatology

Zarzycki, in prep.

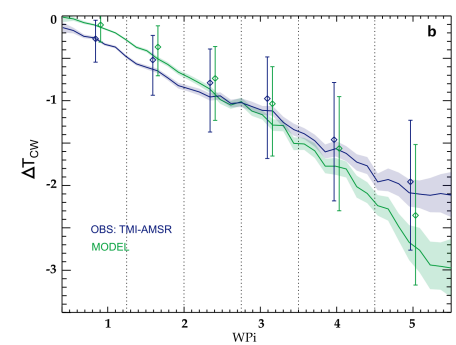
The simplest cold wake parameterization™?

- Weighting function (X_{cool}) dictates **surface wind stress** where mixing 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 nearly linearly as function of wind (e.g., Vincent et al., 2012, JGR-A)





Lloyd and Vecchi, 2011, Fig. 4



Vincent et al, 2012, Fig. 6

Zarzycki, in prep.

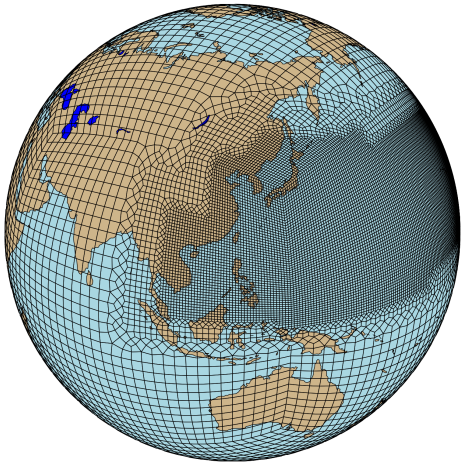
Drawbacks…

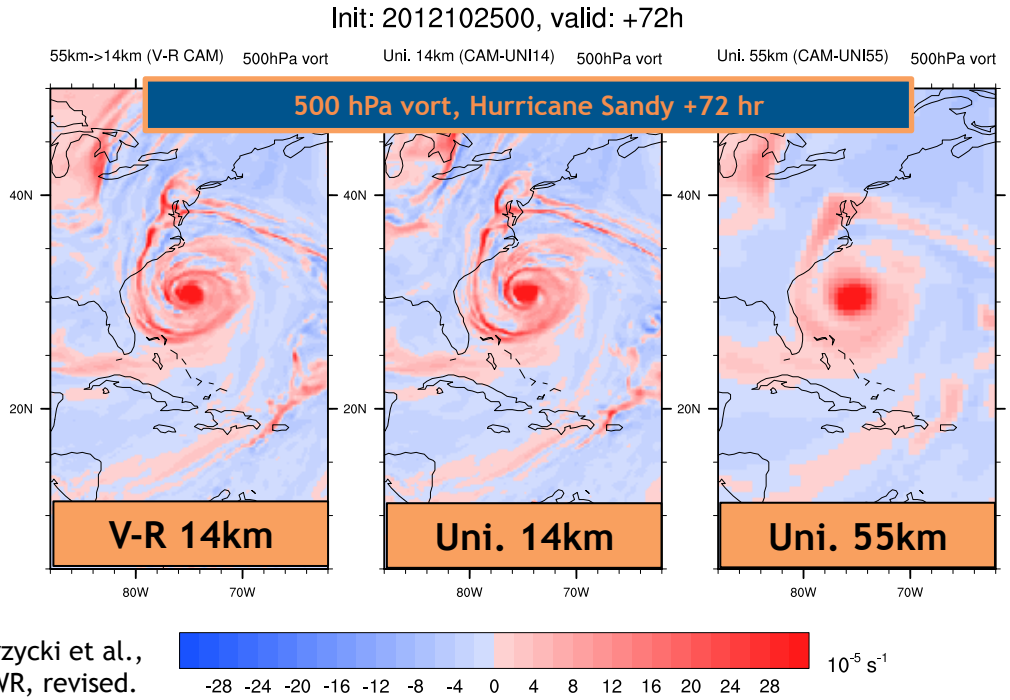
- No vertical or horizontal advection
- Assumes climatological mixed-layer properties
  - TC always sees "mean" ocean state, no *anomalous* values for TCHP, for example
- No "long-term" modification of ocean environment
  - No memory (e.g., Hart et al., 2007)
- Questionable TC-TC interaction

Only concerned with *"cheap" method* of assessing *direct impact of cooling under storm core* in the *mean sense*!

Why variable-resolution?

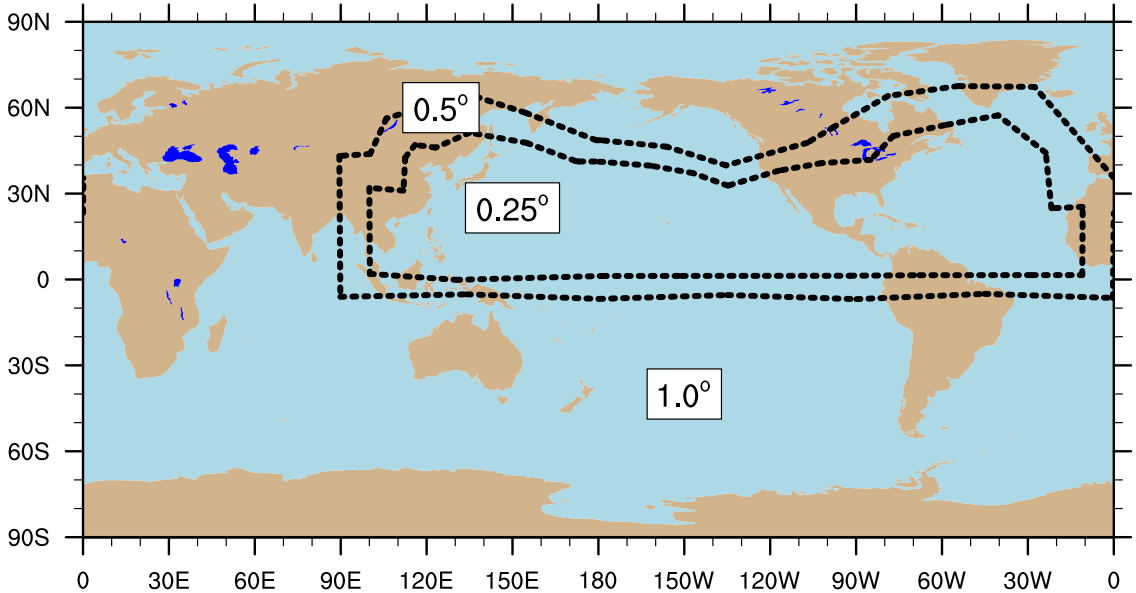
- Variable-resolution CESM
  - Allows for regionally-high resolution in ***global modeling framework***
  - No need for boundary conditions
  - Allows for regional climate studies, cheap "experimental testbed"

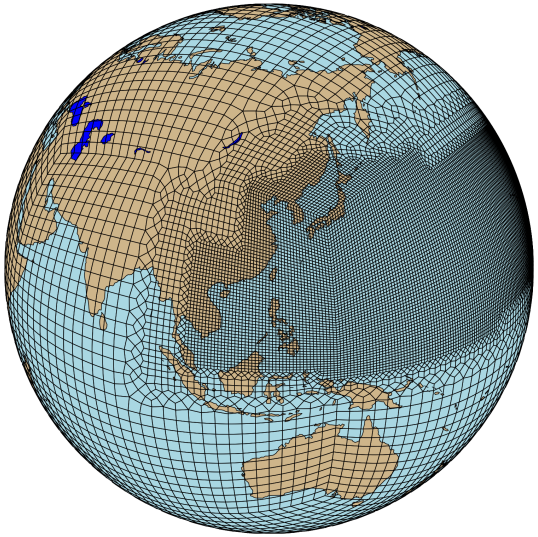




Zarzycki et al., MWR, revised.

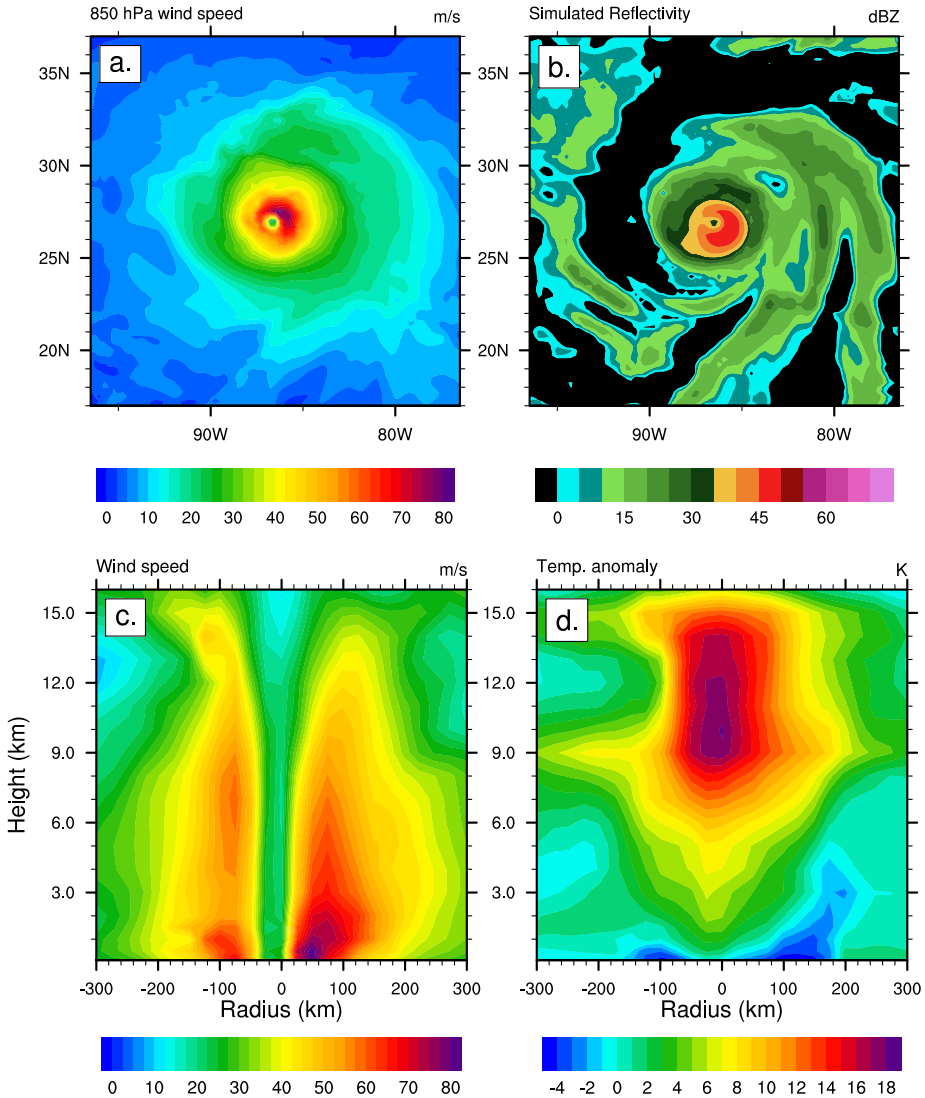
Model setup





- 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

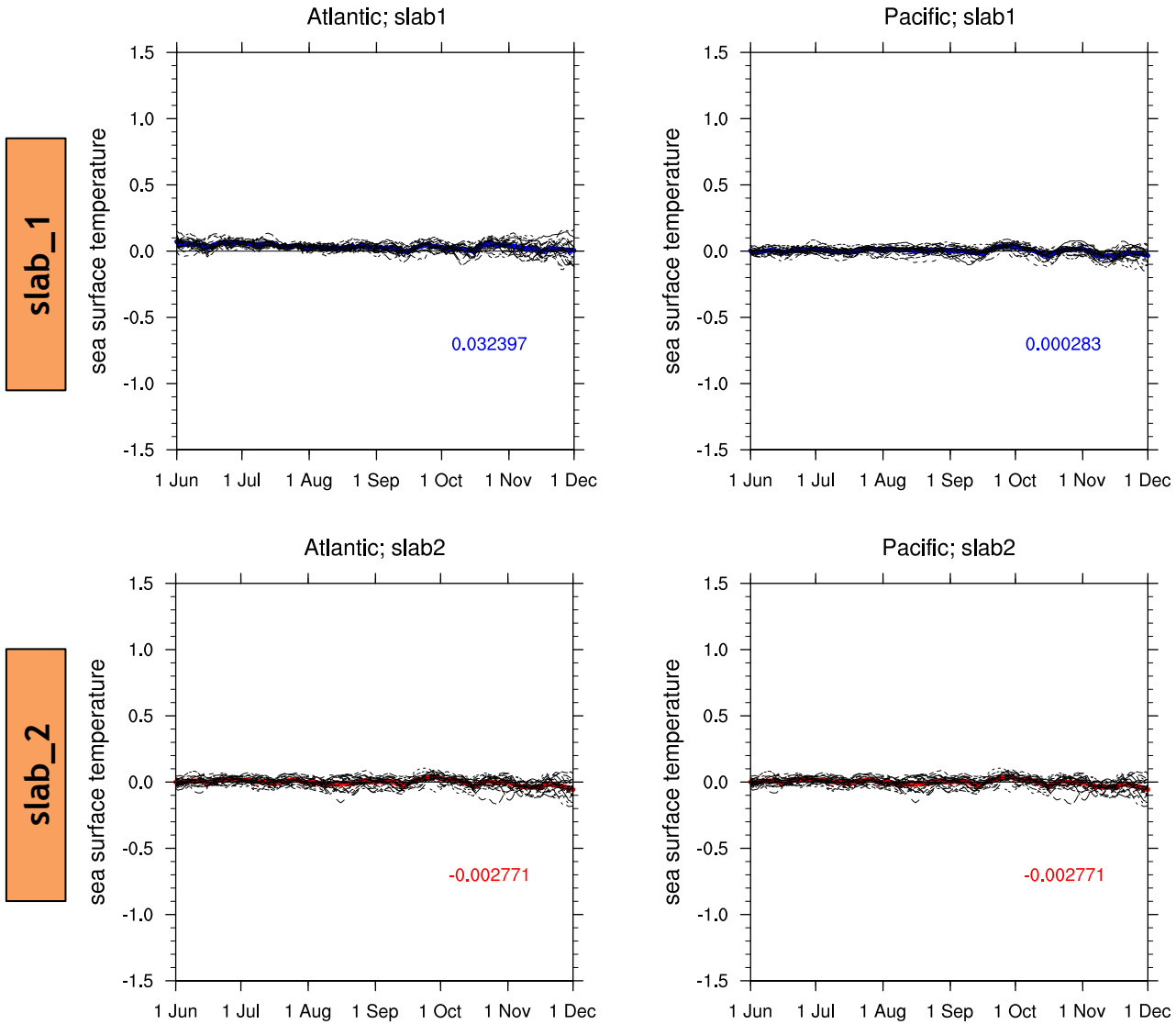
Example of 0.25° TC



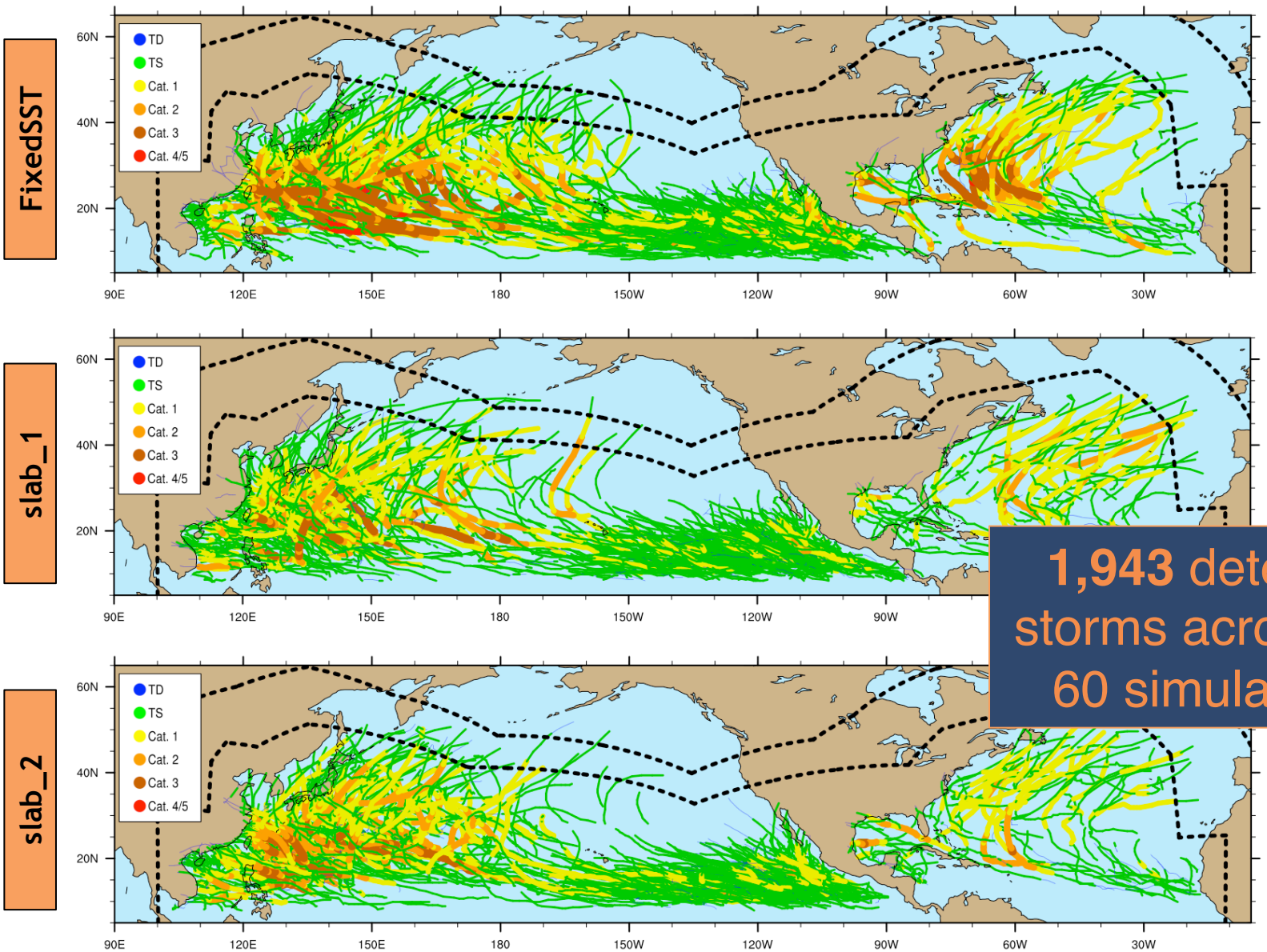
Zarzycki and Jablonowski, JAMES, 2014

Average SST climatology…

Mean basin SST difference from climo

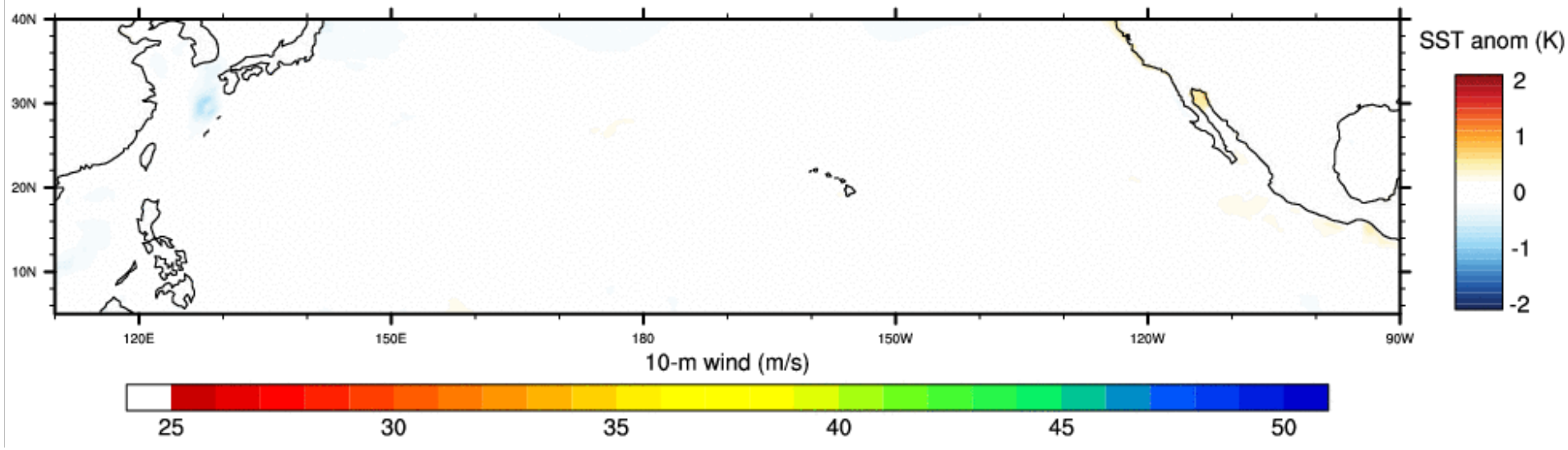


Trajectories



1,943 detected storms across the 60 simulations

What do cold wakes look like?

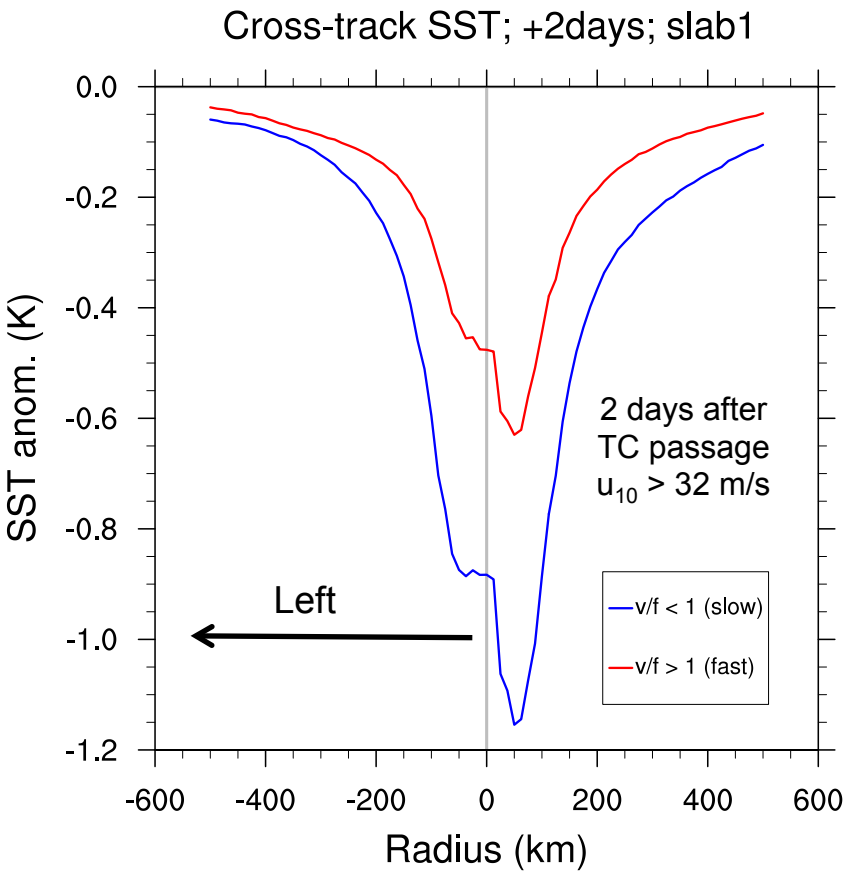


~6 week movie Sept.-Oct. slab_1 ensemble member #3

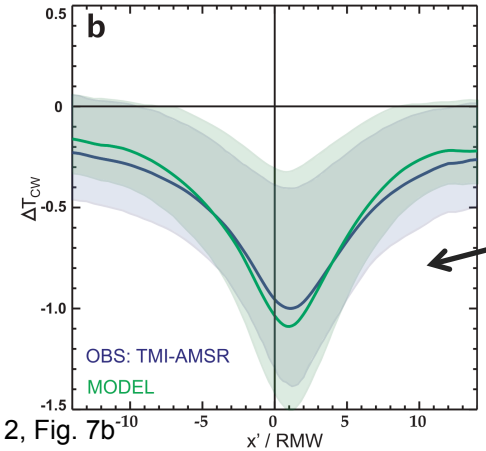
10-m wind contoured rainbow (bottom), SST anom. red/blue (left)

Cross-track cooling

Zarzycki, in prep.



- 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

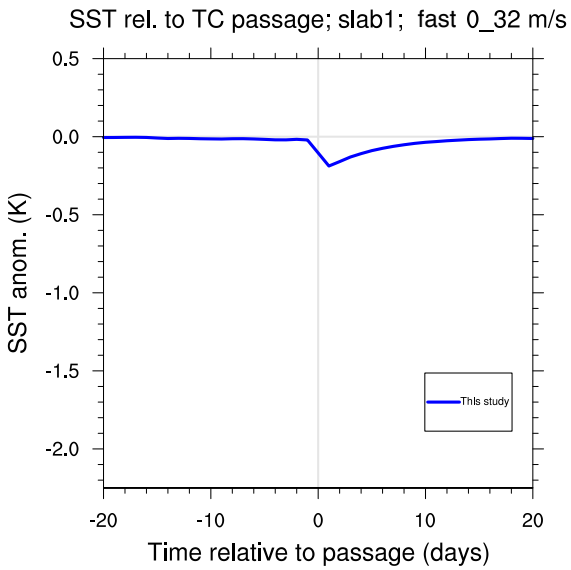
Zarzycki, in prep.

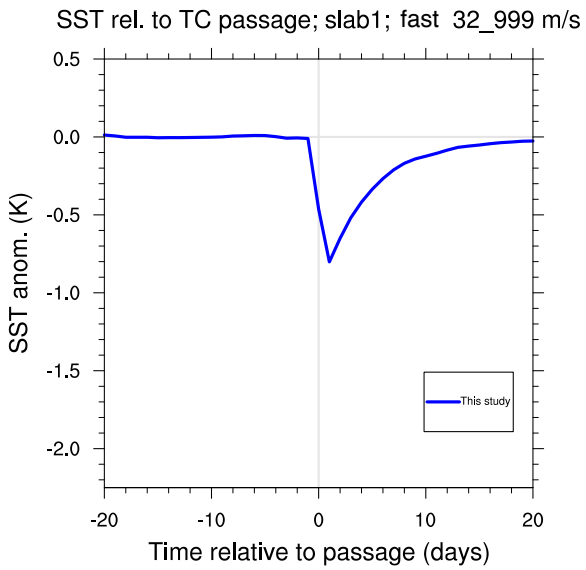
slab1, all members, avg. SST anomaly over 1° area centered on MSLP

u_{10} < 32 m/s (TD + TS)

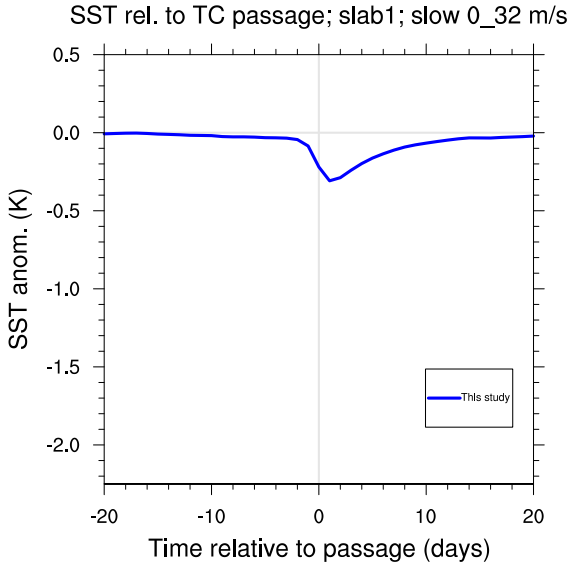
u_{10} >= 32 m/s (HURR)

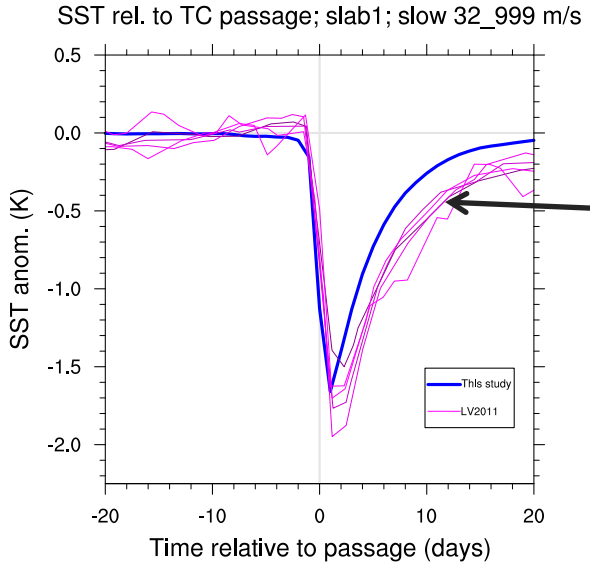
Fast-moving





Slow-moving

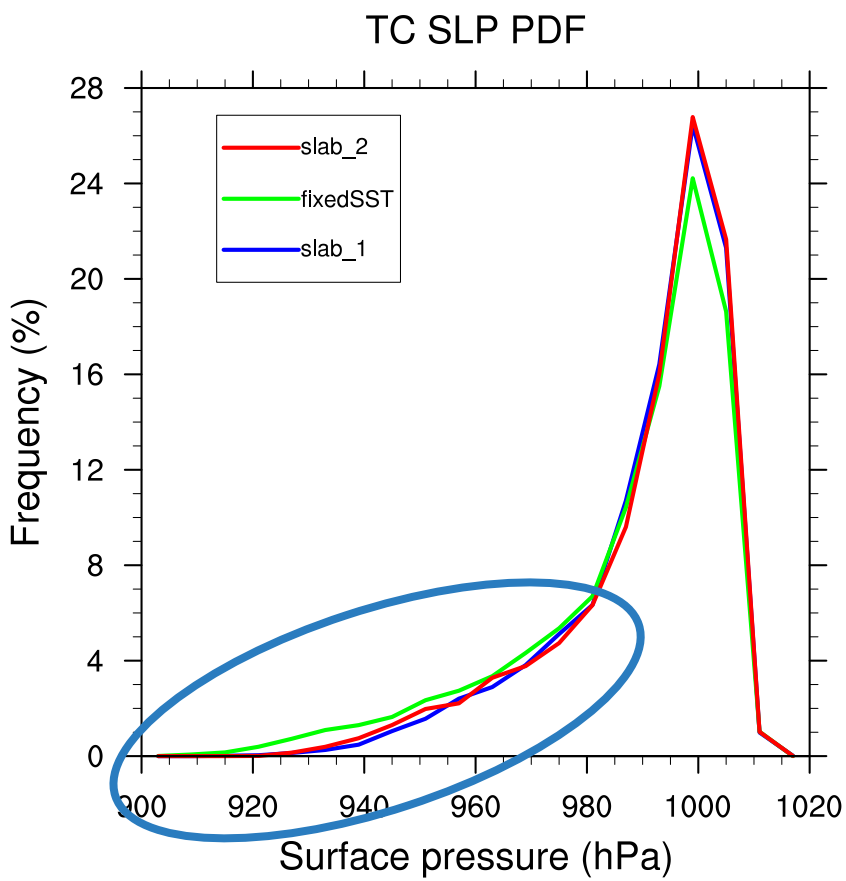


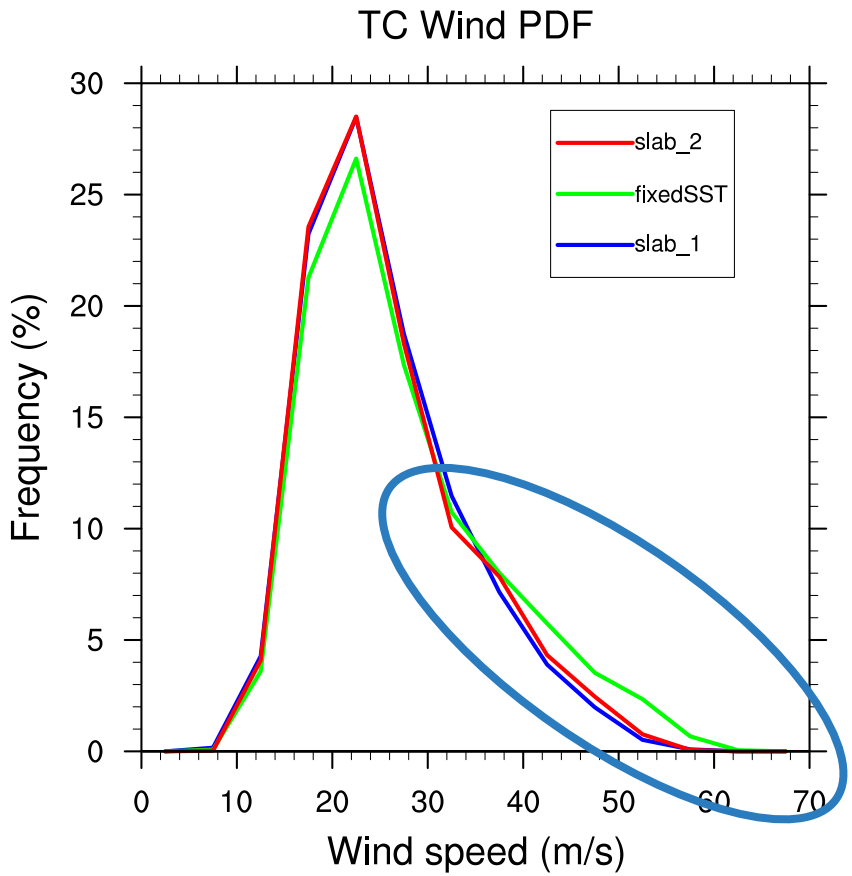


Observed slow-moving **hurricanes** (by S-S cat) from Lloyd and Vecchi (2011)

Intensity PDFs

Zarzycki, in prep.





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

Intensity statistics

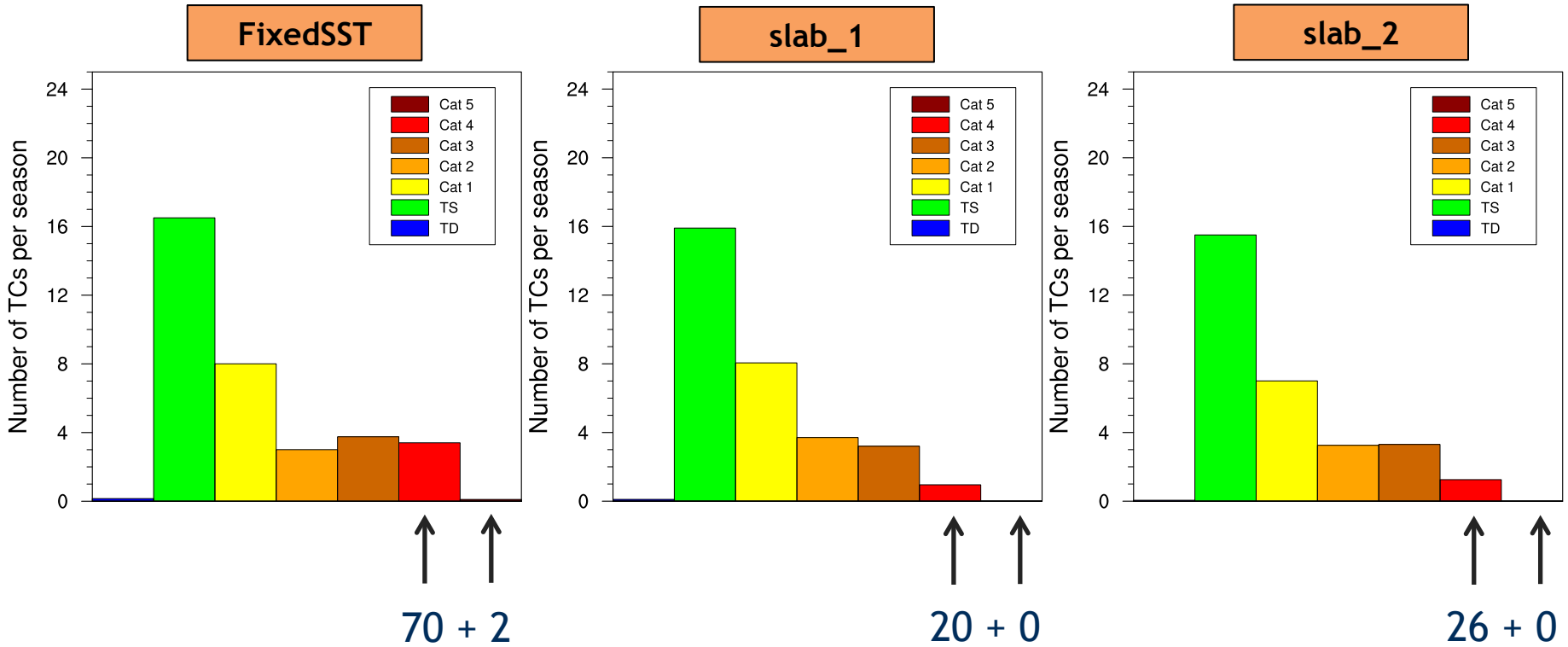
Zarzycki, in prep.

		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

"Categorizing" storms…

Zarzycki, in prep.

Storms binned by Saffir-Simpson scale (max intensity)



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/tunin?
  - 1-D mixed-layer model (happy medium?)
  - Reverse experiment?
  - Address ocean model biases in CESM