Why are tropical cyclones so intense in CAM5 at ultra-high resolutions?

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Tropical cyclones and horizontal resolution

- Tropical cyclone representation significantly more realistic at finer grid spacing in CAM

Zarzycki and Jablonowski, JAMES, 2014

Upwelling longwave flux at top of model

Typhoon Haiyan 4-day forecast

Δx ~ 111 km

Δx ~ 26 km

Δx ~ 12 km
CAM-SE “forecast mode”

- 0.125° (~13 km)
- 0.5° (~55 km)
CAM-SE “forecast mode”

- Every 12 hours (00Z and 12Z) from August 1\textsuperscript{st} to November 1\textsuperscript{st} for 2012-2013
- 8 day forecast = $\approx 1.5$ hours of wall clock time on 800 cores (NCAR Yellowstone)
  - $\approx 6-7x$ cheaper than a globally-uniform 13 km forecast

Zarzycki et al., in prep.
CAM-SE “forecast mode” control

- Refinement improves both track, intensity skill
- Track behavior of TCs looks good...
- ... CAM exhibits a high bias in TC intensity, especially as the solution moves away from initial state
CAM5 pressure-wind relationship

\[ \Delta x \sim 26 \text{ km} \]

\[ \Delta x \sim 13 \text{ km} \]

Pressure-Wind Relationship

- Obs (IBTrACS)
- CAM-SE V-R (0.25°)
- CAM-SE Uni. (1°)
Idealized, high-res TC sensitivity ensembles

Model configuration:
- Aquaplanet
- $\Delta t = 1800$ sec / default CAM5 physics
- SST = 29° C
- Reed-Jablonowski (2012) TC
- TC initialized at $10^\circ$ N
- Tropical vertical temperature/moisture profiles
- No background flow, beta drift

- 9 member ensemble
  - Perturb initial vortex of location by $\Delta x/2$
  - Ensemble average provides robust results, “smooth” behavior

Zarzycki et al., MWR, 2014
Preliminary sensitivity runs

- **Control**: Default CAM5 physics, ($d_{\text{time}} = 1800s$)
- **No deep**: No ZM deep convection (is convection not "turning off" enough)
- **Modified $\tau$**: Decrease convective relaxation from 3600s -> 900s (is convection too "inactive?" e.g., Williamson, QJRMS, 2013)
Day 8: Storm has generally reached maximum intensity/steady state
Vertical temperature anomaly

Control

\( \tau = 0.25 \tau \)

No deep
Moisture profiles

PRECT

DTCOND

Radially-integrated within 300 km
CLUBB sensitivity runs

- **Control**: Default CAM5 physics, $d_{\text{time}} = 1800\text{s}$
- **CLUBB**: CLUBB with MG1.0, ZM
CLUBB structural differences

- CLUBB - weaker, shallower storm
- Broader inflow/outflow
- RMW moves from \(\sim 5\Delta x\) to \(\sim 13\Delta x\)
CLUBB structural differences

Vertical velocity (pressure)  Pa/s

Control

Vertical velocity (pressure)  Pa/s

CLUBB
CLUBB forecasts

- CAM-CLUBB outperforms CAM5 with respect to intensity at lead times > 72 hours in 14 km forecast simulations
Interactive ocean?

• Generally, AMIP-style GCM/NWP models run with prescribed SSTs (unlimited heat, no energy closure)
• Strong TCs induce cold wake, negative feedback on intensity
Slab ocean with simplified turbulence

\[ SST_{t+\Delta t} = SST_t - \left( \frac{(LHF + SHF)}{C_s} - C_x(u^2 + v^2)^{1/2} \right) \Delta t \]

- 15-25% of cold wake due to fluxes
- 75-85% to upwelling/mixing/Ekman

Surface fluxes

*Crude* turbulence formulation
Slab ocean results

![Graph showing MSLP and Wind (m/s) over days for slab and control scenarios.](image-url)
Summary

• At high resolution ($\Delta x \sim 25$ km) CAM5 appears to produce TCs stronger than observed

• Sensitivities
  - Turning “up” or “down” CAM5 deep convection (ZM) results in weaker cyclone, structural differences
  - CLUBB/MG1 produces weaker storms, better “skill” but less structurally consistent with observations
  - Realistic SST forcing implies ocn-atm interaction becoming non-negligible at higher resolutions

• Next steps?
  - Understand dynamical behavior
  - Condensate loading? Surface drag? CLUBB-MG2? UNICON?
  - Increase vertical resolution?
  - Comparison with LES (CM1?) ($\Delta x \sim o(100 m)$)
  - Non-hydrostatic CAM-SE? (see next talk?)