Tropical Cyclones in High-Resolution Community Atmosphere Model version 5 (CAM5): Large-Scale Controls for Western North Pacific

Stony Brook University School of Marine and Atmospheric Sciences

Xiaoning Wu[1], Kevin A. Reed[1], Michael F. Wehner[2], Julio T. Bacmeister[3], Patrick Callaghan[3]

[1]Stony Brook University, [2]Lawrence Berkeley National Laboratory, [3]National Center for Atmospheric Research

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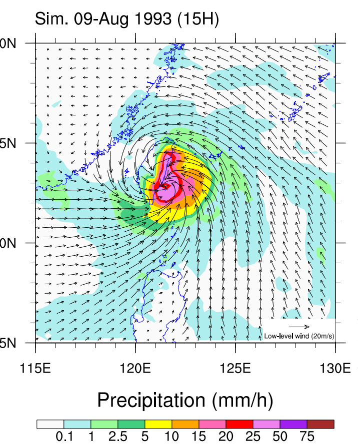
Motivation



Climate models at high resolution (~25 km horizontal grid spacing) can permit realistic simulations of tropical cyclones (TCs), thus promising the investigation of these high-impact extreme events under present and future climates.

Fig. 1. Example snapshot of TC precipitation and wind field, capturing the topographic interation. The simulation with CAM5.1 at 0.25° resolution was initialized from reanalysis on Apr. 1st, 1993, and ran freely through October. Multiple TCs developed through WNP peak season, Jul.-Oct. (JASO).

On the global scale, simulations with CAM5 present a reasonable TC climatology under prescribed present-day (1980-2005) sea surface temperature and greenhouse gas forcing.

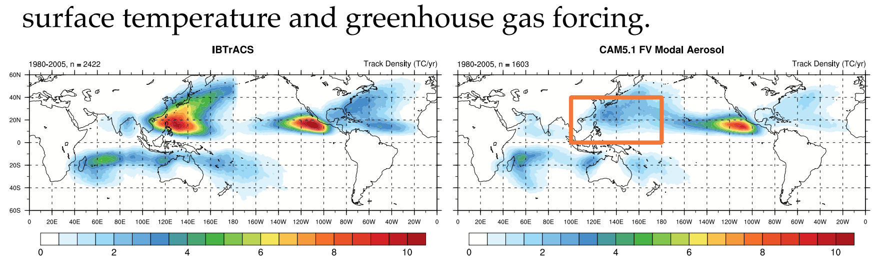


Fig. 2. Global TC track density (number of TCs within a 5° radius per year) from observation (left) and CAM5 simulation (right) for 1980-2005. The simulated global average TC frequency is lower than observation by about a third.

However, for the disaster-prone Western North Pacific (WNP) region, biases in TC genesis frequency and location under-represent the basin's share in global TC climatology, complicating the fidelity of future projections.

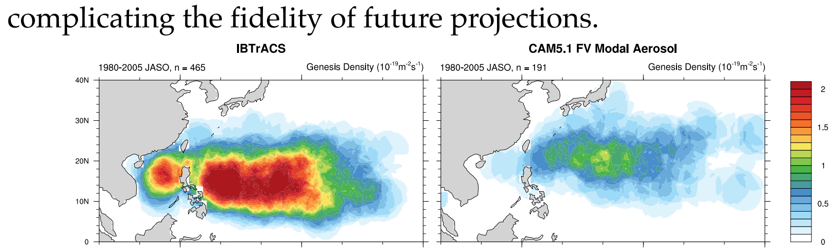


Fig. 3. Area-weighted TC genesis density (5° radius) of the JASO season for 1980-2005, from observation (left) and CAM5 simulaton (right). For WNP, CAM5 simulation falls short of observation by 59%, beyond the global average bias.

Results and Discussion

Genesis Potential Index (GPI; Emanuel 2010)

$$\text{GPI} = (|\text{Vort}_{850}|)^3 \times \chi_{600}^{-4/3} \times (\text{Max}(\text{PI}-35, 0))^2 \times (25+\text{VWS})^{-4}$$

Vorticity — Entropy Deficit — Potential Intensity — Vertical Wind Shear

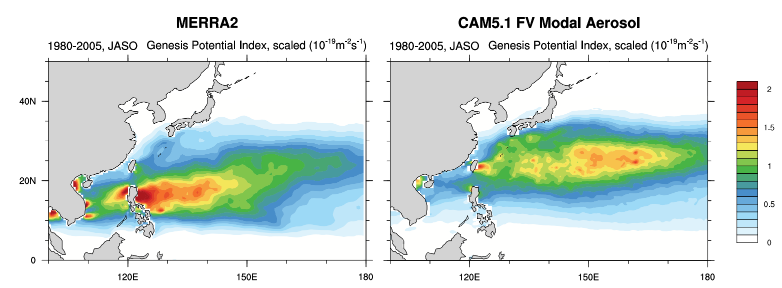


Fig. 4. JASO-average GPI for WNP, scaled by the same uniform coefficient, from observation (MERRA2, left) and CAM5 simulation (right) for 1980-2005. The biases in the large-scale environment correspond to the biases in simulated TC genesis frequency and location (shown in Fig. 3).

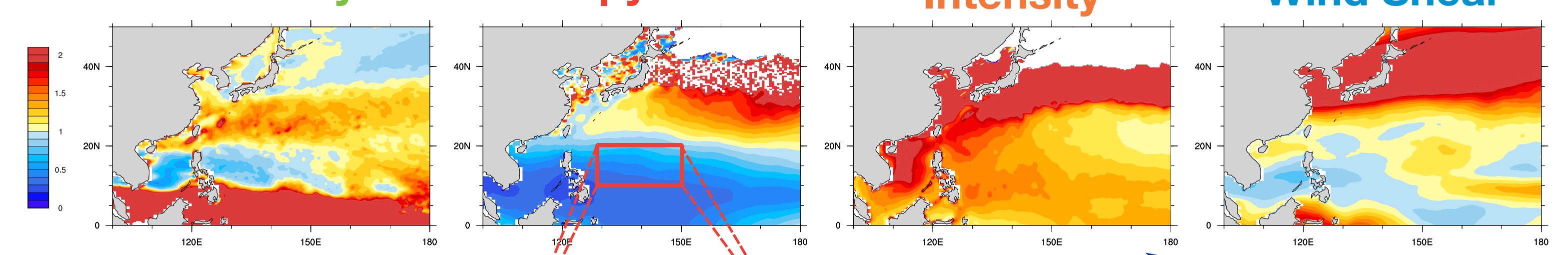


Fig. 5. The four components' respective contribution to simulated GPI bias by ratio, averaged over JASO for 1980-2005. The color scale highlights the divide at 1 (blue: underestimation of GPI, red: overestimation of GPI) and saturates beyond 2.

The analysis of GPI components reveals *the lack of mid-level moisture* in WNP TC main development region as the leading cause of the deficit in simulated TC genesis. This lack of moisture is potentially linked to:

- Previously identified deficits in Pacific warm pool precipitation at high horizontal resolution in CAM5 (Bacmeister et al., 2014);
- Biases in the East Asian Summer Monsoon circulation and moisture transport.

The follow-up main research question: *If the simulation of mid-level moisture/thermodynamic environment improves, will the simulated TC climatology improve in response?*

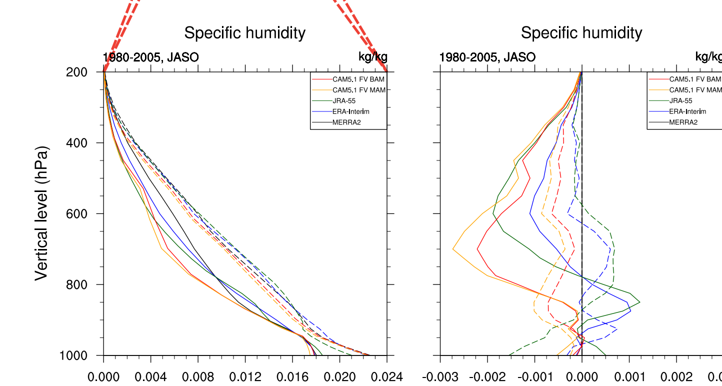


Fig. 6. Vertical profiles from reanalyses and CAM5 simulation, averaged over 10-20°N, 130-150°E (highlighted area in Fig. 5), JASO 1980-2005. Left: specific humidity (dashed lines represent saturation specific humidity); Right: differences with respect to MERRA2.

Next Steps

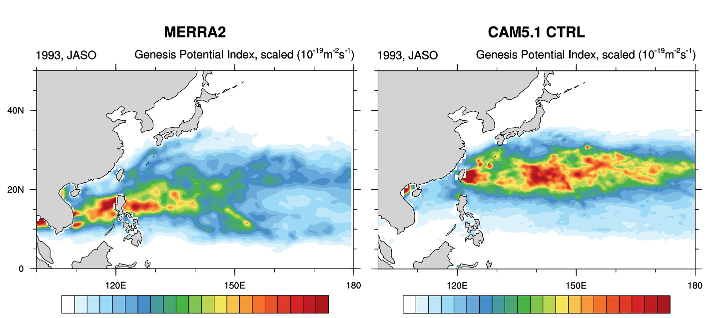


Fig. 7. As Fig. 4, but for JASO of the ENSO-neutral year 1993. CAM5 seasonal simulation (right), as described in Fig. 1, is replicating the biases in GPI, where the respective contributions from the four components are similar to that of climatology shown in Fig. 5.

- Additional CAM5 simulation experiments will explore the effect of moisture/temperature nudging on the large-scale environment and subsequent TC genesis and development.
- The exploration of potential improvements will help reduce the uncertainty in future-climate projection of TCs, with the benefit of informing disaster risk management decisions.

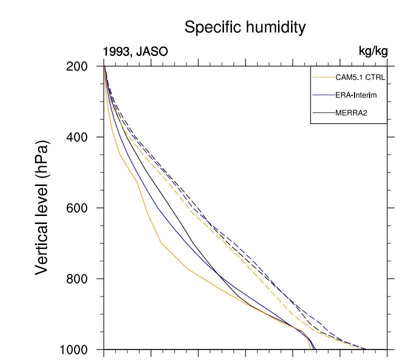


Fig. 8. As Fig. 6 Left, but for 1993. CAM5 seasonal simulation is replicating the mid-level moisture deficit seen in the 1980-2005 climatology.

Data and Methods

- **Observation:** GPI components from Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA2, Gelaro et al., 2017); TC tracks from the International Best Track Archive for Climate Stewardship (IBTrACS, Knapp et al., 2010).
- **Simulation:** CAM5.1 finite-volume dynamical core with prescribed sea surface temperature and modal aerosol model at 0.25° horizontal resolution, for both decadal (1980-2005) and seasonal (Apr.-Oct., 1993) runs; TCs from three-hourly outputs by GFDL tracker (Zhao et al., 2009).

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xiaoning.wu.1@stonybrook.edu