

# Tropical Cyclones in High-Resolution Community Atmosphere Model version 5: Evaluation for Western North Pacific

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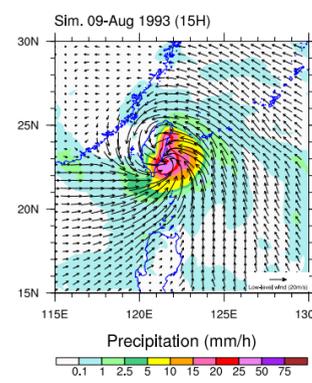
November 24, 2022

## Abstract

Climate models at high resolution ( $\sim 25$  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. On the global scale, simulations with the Community Atmosphere Model version 5 (CAM5) present a reasonable TC climatology under prescribed present-day (1980-2005) sea surface temperature (SST) and greenhouse gas (GHG) forcing. However, for the disaster-prone western North Pacific (WNP) region, biases in TC genesis frequency and location persist across various configurations. The biases under-represent the basin's share in global TC climatology, complicating the fidelity of future projections. This study addresses these model biases in WNP by evaluating the large-scale environmental controls of TC genesis in CAM5 with two aerosol configurations. Across the two configurations, the lack of mid-level moisture is consistently identified as the leading cause of the deficit in simulated WNP TC genesis. This lack of mid-level moisture in WNP TC main develop region is potentially linked to previously identified deficits in Pacific warm pool precipitation at high horizontal resolution in CAM5, as well as biases in the East Asian Summer Monsoon circulation and moisture transport. Additional CAM5 simulation experiments will explore the effect of moisture nudging on the large-scale environment and subsequent TC genesis, tracks, and intensity development. For a chosen year, simulations covering WNP peak TC season (July - October) under otherwise identical forcing (SST, GHG etc.) will be run with and without nudging the specific humidity field towards MERRA-2 reanalysis. The insight into the biases of basin-scale TC simulation under the present climate and potential improvements will help reduce the uncertainty in future-climate projections, in the interest of disaster risk management.

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

## 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 interaction. The simulation with CAM5.1 at 0.25° resolution was initialized from reanalysis on Apr. 1<sup>st</sup>, 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.

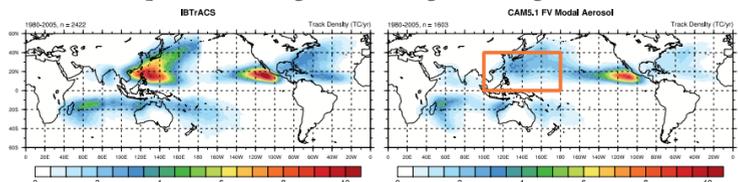


Fig. 2. Global TC track density (number of TCs within a 5° radius per year) from observation (left) and CAM5 simulation (right) for 1980-2005. The simulated global average TC frequency is lower than observation by about a third.

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.

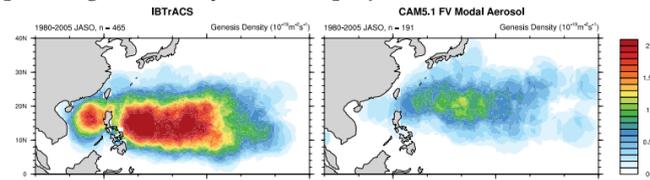


Fig. 3. Area-weighted TC genesis density (5° radius) of the JASO season for 1980-2005, from observation (left) and CAM5 simulation (right). For WNP, CAM5 simulation falls short of observation by 59%, beyond the global average bias.

## Results and Discussion

### Genesis Potential Index (GPI; Emanuel 2010)

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

Vorticity     Entropy Deficit     Potential Intensity     Vertical Wind Shear

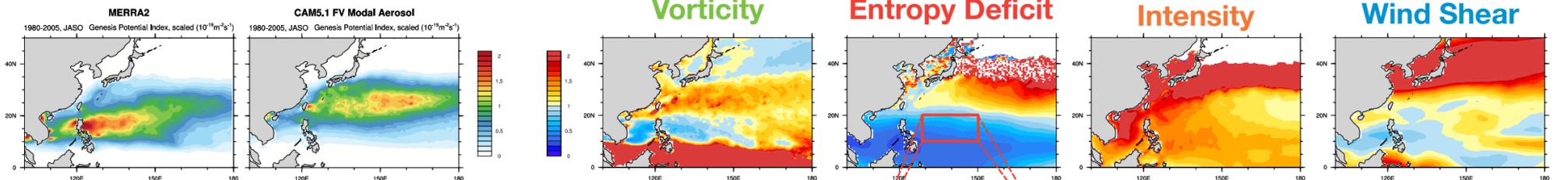


Fig. 4. JASO-average GPI for WNP, scaled by the same uniform coefficient, from observation (MERRA2, left) and CAM5 simulation (right) for 1980-2005. The biases in the large-scale environment correspond to the biases in simulated TC genesis frequency and location (shown in Fig. 3).

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?*

## Next Steps

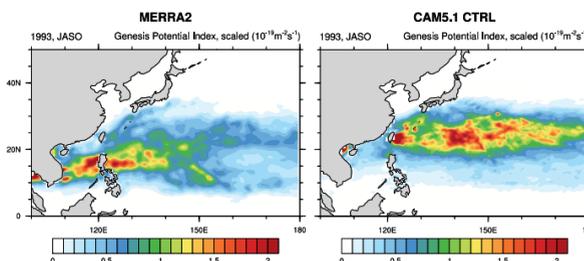


Fig. 7. As Fig. 4, but for JASO of the ENSO-neutral year 1993. CAM5 seasonal simulation (right), as described in Fig. 1, is replicating the biases in GPI, where the respective contributions from the four components are similar to that of climatology shown in Fig. 5.

- 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.

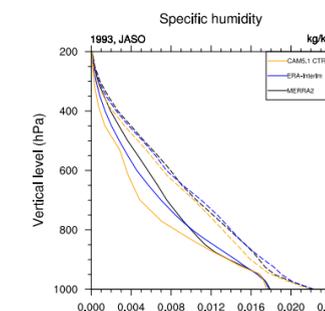


Fig. 8. As Fig. 6 Left, but for 1993. CAM5 seasonal simulation is replicating the mid-level moisture deficit seen in the 1980-2005 climatology.

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.

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.

## 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).

**Acknowledgement:** We acknowledge high-performance computing support from Yellowstone (ark:/85065/d7wd3xhc) and Cheyenne (doi:10.5065/D6RX99HX) provided by NCAR's Computational and Information Systems Laboratory, sponsored by the National Science Foundation.