Discriminating the Roles of Anthropogenic GHGs and Aerosols on Tropical Cyclone Frequency from Downscaling CMIP6 Models

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1. Introduction

Tropical cyclones (TCs) are highly destructive natural disasters, yet projections of TC activity remain highly uncertain. To better understand the impacts of different anthropogenic forcings – specifically greenhouse gases (GHG) and aerosols – on TCs, we utilized the Columbia HAZard Model (CHAZ) to downscale single-forcing experiments from 11 CMIP6 models with synthetic TC tracks from 286,000 total simulation years to investigate the contribution of anthropogenic forcings on tropical cyclone variations. Our analysis focused on changes in the distribution of TCs in the North Atlantic (ATL) and Western North Pacific (WNP) basins. We then used the formulation of the genesis component of CHAZ, the tropical cyclone genesis index (TCGI), as a constraint to quantify the relative contribution of each environmental variable to each forcing. Additionally, an alternative TC genesis formulation, the Genesis Potential Index (GPI), was used to quantify the relative contributions.

2. Methods

Singal Forcing experiments

- Historical Forcing (hist)
- Natural Forcing (nat)
- Anthropogenic Greenhouse Gases (GHG)
- Anthropogenic Aerosols (aer)

Genesis of Tropical Cyclone

(a) Tropical Cyclone Genesis Index (TCGI; Lee et al. 2020)

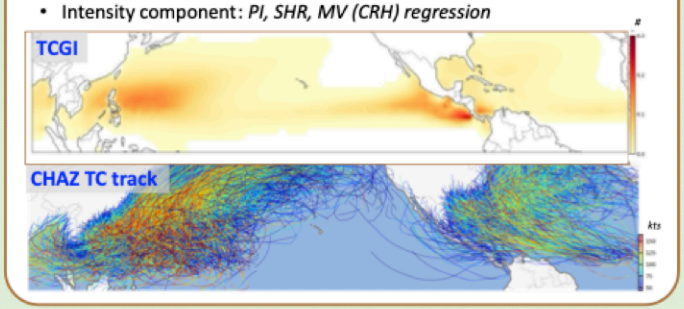
$$TCGI = exp(b + b_{\eta}\eta_{850,c} + b_{MV}MV + b_{PI}PI + b_{SHR}SHR)$$

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

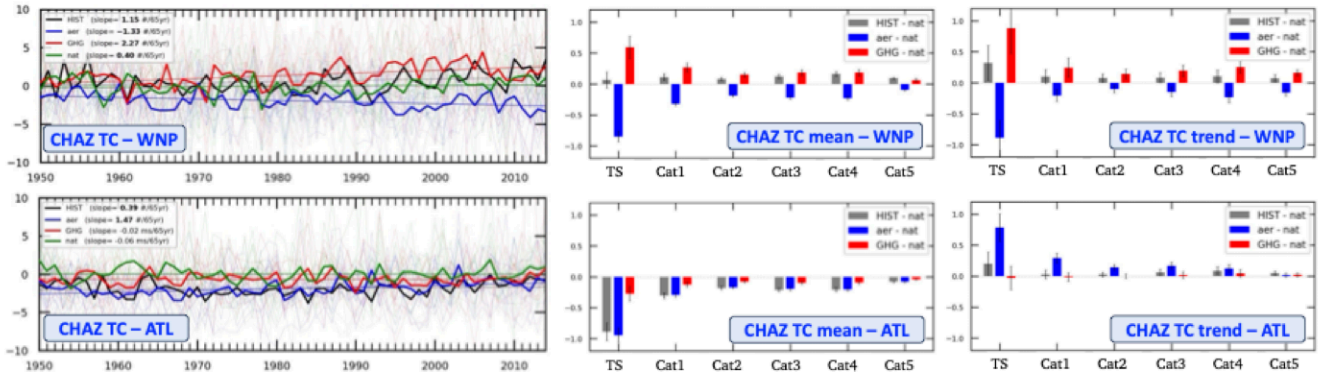
$$GPI = |\eta|^3 \chi^{-\frac{4}{3}} MAX((PI - 35ms^{-1}), 0)^2 \times (25ms^{-1} + SHR)^{-4}$$

TC Downscaling – Columbia Hazard model (CHAZ) (Lee et al. 2020)

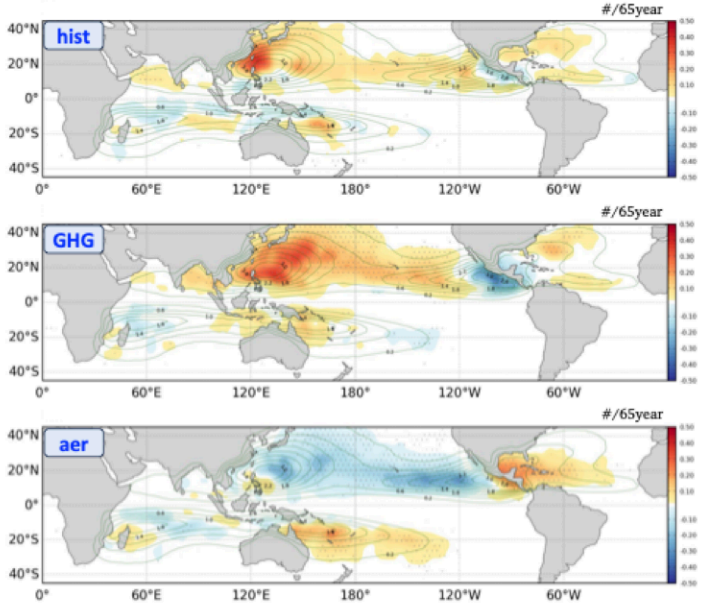
- Genesis component : *TCGI-CRH*
- Track component : *beta drift*
- Intensity component: *PI, SHR, MV (CRH) regression*



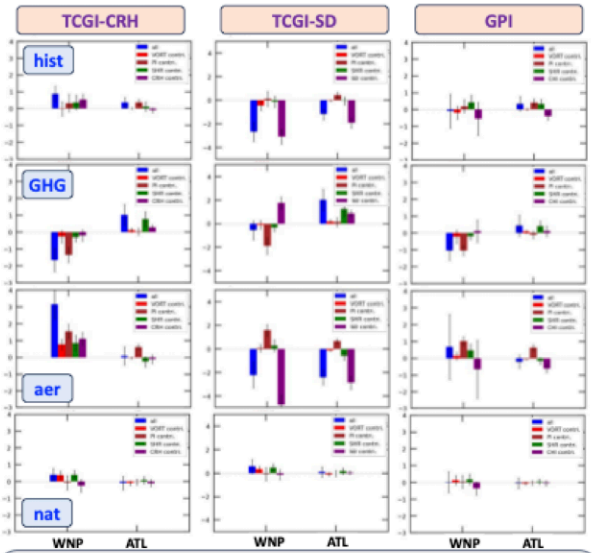
3. Results – TC frequency anomaly



4. Track Density Trend Changes



5. Predictors Contribution to TC Trend



The contribution of predictors on three different tropical cyclone genesis (TCGI-CRH, TCGI-SD, GPI) for fully varying variables (all), Vorticity contribution (VORT contri), Potential Intensity contribution (PI contri), Wind shear contribution (SHR contri), and humidity variability contribution (CRH/SD/CHI)

6. Summary

This single-forcing study demonstrates regionally distinct influences of greenhouse gases and aerosols on TC frequency in WNP and ATL while highlighting the pivotal roles of potential intensity, wind shear, vorticity, and moisture in shaping these changes, and revealing substantial uncertainties (particularly in moisture-related processes and aerosol–cloud interactions) that underscore the need for further investigation into the environmental drivers of TC frequency trends across different basins.

References:
Emanuel, K. (2010). Tropical cyclone activity downscaled from NOAA-CIRES reanalysis, 1908–1958. *Journal of Advances in Modeling Earth Systems, 2*(1).

Lee, C. Y., Camargo, S. J., Sobel, A. H., & Tippett, M. K. (2020). Statistical–dynamical downscaling projections of tropical cyclone activity in a warming climate: Two diverging genesis scenarios. *Journal of Climate, 33*(11), 4815-4834.