Assessment of potential future changes in TC activity in the Philippines under different ENSO Phases in HighResMIP GCMs

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ABSTRACT

The El Niño–Southern Oscillation (ENSO) is a primary mode of climate variability that modulates tropical cyclone (TC) activity through its influence on large-scale environmental conditions. In the Philippines, where TC impacts are substantial, understanding ENSO-driven variability is critical for risk assessment under ongoing anthropogenic warming. However, key gaps remain: most studies are basin-scale, rely on coarse-resolution models that poorly resolve TC structure and regional processes, and usually assess ENSO-dependent TC projections at the basin scale rather than at a country level. This study addresses these gaps by combining long-term observations (1980–2024) with high-resolution global climate models from the CMIP6 High Resolution Model Intercomparison Project (HighResMIP). Five HighResMIP models were evaluated to assess their ability to reproduce ENSO–TC activity and to examine projected changes over the Philippines under future climate conditions. Simulations from the near-future period (2015–2050) under the SSP5-8.5 scenario were analyzed with TCs detected by using the TRACK and TempestExtremes algorithms. Observational data were obtained from IBTrACS, while ENSO phases were defined using the Oceanic Niño 3.4 index. Composite, correlation, and statistical analyses were applied to evaluate model performance, characterize ENSO-dependent TC variability, and quantify projected changes in TC frequency, intensity, and genesis location.

Results show that ENSO significantly modulated TC activity in the Philippines, with distinct patterns observed across phases. During El Niño, an eastward displacement of TC genesis locations led to reduced TC frequency within the PAR and a higher occurrence of more Super Typhoons. In contrast, during La Niña conditions, there's a westward shift in TC genesis, resulting in more clustered track density in the western region and higher frequencies of weaker systems (TS and STS). Meanwhile, the Neutral phase showed the highest overall TC frequency among all ENSO phases.

The CMIP6 HighResMIP Multi-model Ensembles, with both tracking algorithms, reproduced the seasonal variability of TCs across ENSO phases. However, TC frequency during peak seasons was generally underestimated by both algorithms. Furthermore, the intensity of stronger TCs was also underestimated, which was attributed to the presence of positive vertical wind shear bias in the models.

Future projections show a decrease in TC frequency over the Philippines during Neutral and La Niña-like conditions, with reductions of approximately 9–24% (Neutral) and 14–23% (La Niña) depending on the tracking algorithm. In contrast, TC activity during El Niño-like conditions is projected to increase by about 9–30%. In terms of intensity, results show clearer model divergence. The TRACK algorithm projects a weakening of TC intensity, with a reduction in mean maximum wind speed of approximately ~0.3–3.0 m s^{-1} and a corresponding increase in minimum MSLP of ~0.5–8.0 hPa, indicating generally weaker future TCs. In contrast, TempestExtremes indicates a tendency toward slight intensification, with increases in mean maximum wind speed of approximately ~0.5–1.0 m s^{-1}, particularly under Neutral conditions. Despite these differences, both algorithms consistently show reduced sensitivity of intensity to ENSO phase compared to frequency changes. Overall, this study showed that ENSO will continue to influence TC activity over the Philippines in a changing climate, and high-resolution models help improve projections but still have uncertainties.

Keywords: Tropical cyclones, El Nino Southern Oscillation, Anthropogenic Climate Change, High resolution global climate modeling, CMIP6, Philippines