Dynamical downscaling calculations using dxPDF for Southeast Asian river basins

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1. Background and objective

Tropical cyclones (TCs) are a primary driver of high-impact rainfall and flood hazard in Luzon, Philippines, particularly over the Pampanga River Basin and the Pasig–Marikina–Laguna Lake Basin. Recent indications of intensifying heavy rainfall under warming conditions motivate a targeted assessment of how much of the projected rainfall change, which is especially the component relevant to extremes and design rainfall, can be attributed to TC-related rainfall versus non-TC rainfall. This report consolidates the current MRI-AGCM/WRF attribution workflow and preliminary results, and defines the next phase of the work: extending TC rainfall attribution using d4PDF (including +2 K experiments) to strengthen statistical robustness for TC rainfall variability and extremes.

2. Modeling framework and study design

A dynamic downscaling framework is used to generate high-resolution rainfall suitable for basin-scale attribution. Global projections from MRI-AGCM 3.2H (~60 km) and MRI-AGCM 3.2S (~20 km) provide boundary conditions for the WRF regional climate model, producing ~5 km rainfall for historical and future periods. A quantile-mapping bias correction (following Ushiyama et al., 2016) is applied using PAGASA rain gauge observations to improve basin-scale representativeness of rainfall amounts.

The analysis currently compares a historical baseline (PAST: 1979–2003) with late-century projections (2075–2100) under three future realizations indicated in the meeting material: two RCP8.5 realizations and one RCP2.6 realization. While broader indicators are computed from these simulations, the emphasis of this report is the TC rainfall attribution component and the expansion plan using large-ensemble d4PDF.

3. TC rainfall attribution methodology

3.1 MRI-AGCM/WRF attribution workflow (implemented)

In the current phase, TC rainfall attribution is implemented for the MRI-AGCM 3.2H and MRI-AGCM 3.2S forcing cases

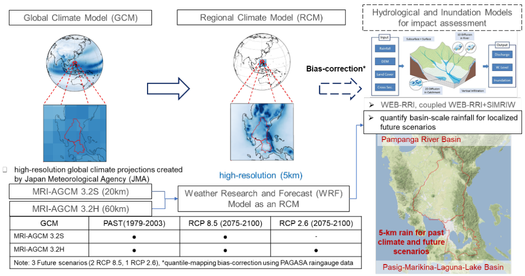

Figure 1. Flow chart of the modeling and impact-assessment framework used in this study. Global climate projections from MRI-AGCM 3.2S (~20 km) and 3.2H (~60 km) provide boundary conditions for dynamical downscaling with WRF to generate high-resolution (~5 km) rainfall.

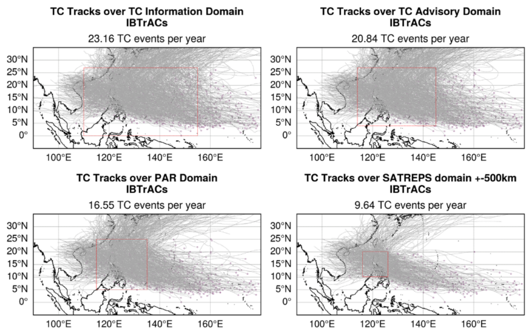

Figure 1. Definition of TC analysis domains using IBTrACS tracks. Historical IBTrACS tracks are shown for three nested domains (red boxes). Mean annual TC event counts are **23.16 events/year** (TC Information Domain), **20.84 events/year** (TC Advisory Domain), **16.55 events/year** (PAR Domain) and **9.64 events/year** (PAR Domain), illustrating how domain choice affects the sampled TC population for tracking and rainfall masking.

dynamically downscaled with WRF (~5 km). Cyclones are detected and tracked using CyTRACK (Pérez-Alarcón et al., 2024) based on MSLP and 850-hPa vorticity, using vorticity parameter guidance following Murakami et al. (2012). For each tracked cyclone, rainfall is masked within the defined TC influence region to produce separate fields of TC rainfall and

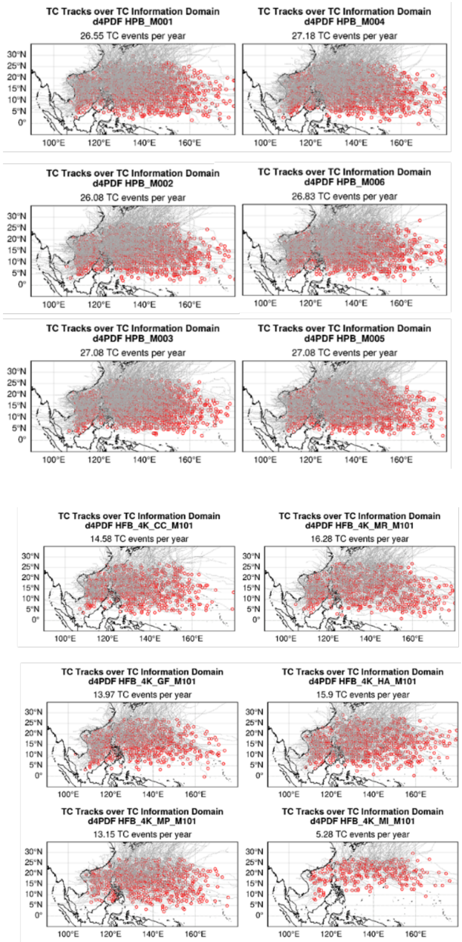

Figure 3. d4PDF tropical cyclone tracks over the TC Information Domain. TC tracks are shown for multiple d4PDF ensemble members (present-climate and +4K warming experiments), with the mean annual TC event count indicated in each panel. The large-ensemble sampling will be leveraged to attribute basin rainfall by pairing the existing d4PDF track catalogue with rainfall fields to partition TC-related and non-TC rainfall, including extension to the +2K scenarios.

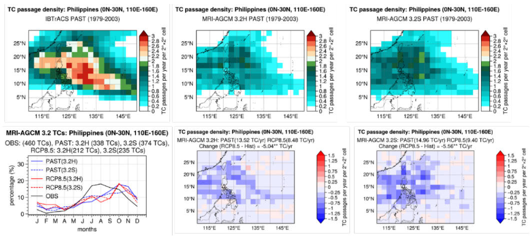

Figure 4. Preliminary TC passage density results over the Philippines region (0–30°N, 110–160°E). Historical TC passage density from IBTrACS (1979–2003) is compared with MRI-AGCM 3.2H/3.2S simulations (top), with the monthly occurrence climatology shown (bottom--left).

non-TC rainfall, which are then used to quantify contributions to changes in mean rainfall and, in subsequent steps, extreme rainfall diagnostics (e.g., high percentiles and design rainfall).

Storm selection is performed within a broad regional window (0–30°N, 110–160°E) and events are retained for basin attribution when storm tracks intersect the SATREPS domain within a defined influence radius (10°). To document sensitivity to tracking-region definition, the workflow references nested domains (TC Information Domain, TC Advisory Domain, and Philippine Area of Responsibility or PAR Domain, SATREPS domain), demonstrating how domain choice affects sampled TC counts and the resulting rainfall attribution.

3.2 Extension to d4PDF (planned +2K and +4K)

For d4PDF, TC tracks are already available for each ensemble member and will be used as the primary storm catalogue for TC rainfall attribution. Rather than re-tracking cyclones from scratch, the existing d4PDF tracks will be filtered to the same analysis domain logic used in the MRI-AGCM/WRF workflow and paired with rainfall fields to apply consistent masking and separation into TC-related and non-TC rainfall. Where needed, the CyTRACK-based procedure can be re-applied to d4PDF fields as a sensitivity check and to ensure methodological consistency across datasets.

Importantly, the d4PDF component will include not only present-climate simulations but also the +2K and +4K warming experiments, which provide a controlled warming framework to isolate thermodynamic effects on TC rainfall and extremes. Incorporating the +2K and +4K experiments will improve confidence in identifying robust changes in TC rainfall characteristics that are not dependent on a single late-century emissions pathway.

4. Preliminary results (MRI-AGCM/WRF; RCP8.5 focus)

4.1 TC passage density and evaluation against observations

As an initial evaluation of simulated TC activity, TC passage density from MRI-AGCM historical simulations is compared with IBTrACS (1979–2003) over the Philippines sector. The comparison provides a baseline for interpreting RCP8.5 changes and for assessing whether spatial TC passage patterns and seasonal timing are reasonably captured.

4.2 Mean rainfall attribution (TC vs non-TC) under RCP8.5

The RCP8.5 − PAST decomposition indicates a consistent contrast between rainfall components across the SATREPS domain encompassing both basins shown in Figure 5. Non-TC rainfall exhibits predominantly increases (positive anomalies), whereas TC-related rainfall exhibits predominantly decreases (negative anomalies). These preliminary results suggest that projected increases in mean rainfall under RCP8.5 are driven primarily by non-TC rainfall intensification, while the TC component contributes a net reduction to the basin-mean change. This interpretation remains provisional and will be revisited after completing the corresponding extreme-rainfall attribution using

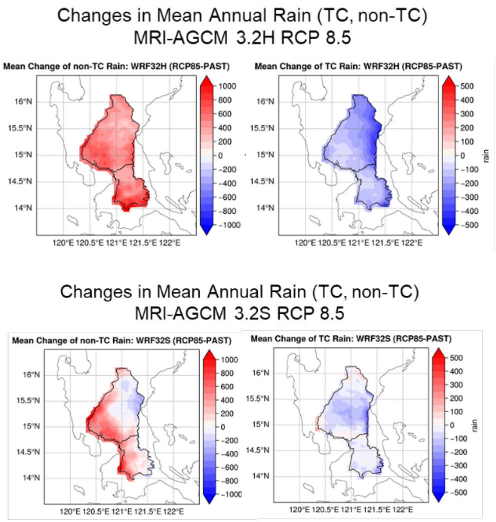

Figure 5. Preliminary mean rainfall attribution under RCP8.5 (RCP8.5 − PAST) for the SATREPS domain. Spatial patterns of the mean change in non-TC rainfall (left panels) and TC-related rainfall (right panels) are shown for WRF downscaling driven by MRI-AGCM 3.2H (left pair) and 3.2S (right pair).

the same TC vs non-TC decomposition framework.

5. Next steps (d4PDF-focused)

1. Downscale 30 years for six ensemble members per period, covering the present-climate baseline and the warming (+2K and +4K) experiments, using a consistent WRF configuration and output protocol.
2. Make the d4PDF TC rainfall attribution by using the existing d4PDF TC track catalogue as the storm database and implement the full masking/decomposition workflow to generate TC-related and non-TC rainfall fields (with optional CyTRACK re-tracking as a sensitivity check).
3. Complete MRI-AGCM/WRF extreme-rainfall attribution by extending the current decomposition beyond mean rainfall to extreme rainfall diagnostics (e.g., 99th percentile, ≥50 mm/day frequency, and design rainfall) to establish a consistent benchmark before d4PDF scaling.
4. Validate d4PDF TC activity and rainfall signals by evaluating TC passage density and seasonal cycle against IBTrACS, then assess basin-scale TC rainfall climatology and spatial footprints for the baseline period.
5. Finally after downscaling d4pdf dataset and validation of the TC tracking, quantify TC rainfall contribution to extremes with uncertainty by calculating TC rainfall fraction and TC contribution to heavy rainfall and return-period design rainfall for each basin, and derive uncertainty ranges using the six-member, 30-year sampling both +2K and +4K.

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