Extreme Weather (Extreme rainfall); Global Climate Models and Downscaling Techniques; Climate-Hydrology coupling

Endalew Negusu Tarekegn; Nguyen Ngoc Kim Hong; Fumia Aoki, and Koji Dairaku

Department of Engineering Mechanics and Energy (Regional Hydroclimate Laboratory)

1. Project Purpose

This project aims to enhance the accuracy of regional climate and hydrological projections by evaluating the sensitivity of WRF and WRF-Hydro model outputs to various physical parameterization schemes. It focuses on topographically complex and climate-sensitive regions, including the Upper Blue Nile Basin, the Lake Tana sub-basin, East Africa, and the Southeast of the Greater Mekong Subregion. The study refines estimates of precipitation variability, water balance, and extreme hydroclimatic events through high-resolution simulations. Particular emphasis is placed on the role of local features such as land use, lake dynamics, and topography. It also investigates the benefits of model coupling, statistical downscaling, and bias correction approaches. In regions with limited observational data but high vulnerability, such as Lake Tana, the study helps identify optimal model configurations and improve rainfall projections. Ultimately, the project supports a broader international goal of providing high-resolution climate information that enables governments and stakeholders to develop informed adaptation and risk reduction strategies tailored to local and regional climate risks.

2. Results

Fifteen WRF simulations were conducted using various combinations of cumulus, land surface, and planetary boundary layer (PBL) schemes, with CHIRPS data serving as the observational benchmark. Configurations incorporating spectral nudging produced more accurate precipitation estimates over mountainous regions. These results underscore the importance of large-scale atmospheric constraints and land-surface feedback in regional precipitation modeling.

In parallel, a hybrid statistical downscaling approach was applied using outputs from five CMIP6 GCMs. This process improved the spatial resolution from ~100 km to 9 km across both historical (1981–2014) and future periods (2015–2100) under SSP1-2.6 and SSP5-8.5 scenarios. The resulting daily datasets—including precipitation, surface air temperature, minimum and maximum temperatures, and relative humidity—enable more detailed assessments of localized climate extremes and compound events across the region.

3. Roles of the MCRP and its significance

This project was made possible through access to the MCRP-L supercomputing environment, particularly the Pegasus and Wisteria clusters at the Center for Computational Sciences, University of Tsukuba. These high-performance computing resources were essential for conducting computationally demanding WRF and WRF-Hydro simulations across multiple high-resolution domains (down to 1 km), long simulation periods, and ensemble configurations driven by different climate-forcing datasets.

The experiments involved extensive sensitivity testing of cumulus, land surface, and boundary layer schemes, along with spectral nudging and extended spin-up periods, all of which significantly increased computational, and storage demands. The MCRP environment enabled efficient parallel processing, large-memory access, and high-speed data handling, allowing the team to complete seasonal-scale simulations, ensemble evaluations, and post-processing within limited timeframes.

Additionally, MCRP resources accelerated the data processing pipeline, substantially reducing the time required for model initialization, downloading reanalysis data, running test cases, and preparing simulation inputs. This capacity not only ensured the project's success but also contributed to MCRP's broader mission of advancing climate modeling, hydrological prediction, and resilience research in data-scarce, climate-sensitive regions.

4. Future plan

The project will extend to WRF-Hydro to couple atmospheric and land-surface processes. Additional experiments will explore feedback between soil moisture and precipitation, and long-term simulations using bias-corrected CMIP6 GCMs will be conducted for regional hydroclimate projections.

5. Publications and conference presentations

(1) Journal papers

(2) Presentations

(3) Others

Supercomputer	Use	Allocated resources*		
		Initial resources	Transferred resources**	Additional resources
Cygnus	Yes/**No**			
Pegasus	**Yes**/No	2560		
Wisteria/BDEC-01	**Yes**/No	25600		
	*in units of node-hour product ** If the budget transfer was performed, fill in here, such as "+2000" and "−1000".			