Coupled WRF–WRF-Hydro Modeling of the 2020 Upper Blue Nile Flood: Sensitivity to Physics Schemes and Coupling Modes

Endalew, Negusu Tarekegn [1] and Koji Dairaku[2],
[1]Graduate School of Science and Technology, University of Tsukuba, Japan
[2]Department of Engineering Mechanics and Energy, University of Tsukuba, Japan

Motivation/Background

- **Floods in the Upper Blue Nile Basin (UBNB) are among the most damaging natural hazards in East Africa, and the 2020 event caused major socio-economic impacts.**
- **Reliable simulation of extreme floods is essential to improve flood forecasting and early warning systems.**
- **Coupled WRF–WRF-Hydro sensitivity experiments help quantify how land–atmosphere coupling influences rainfall and runoff variability in the Blue Nile Basin.**

Objective of the study

- To assess how different physics schemes and coupling modes in WRF–WRF-Hydro affect simulation accuracy of the 2020 Upper Blue Nile flood.

Description of the study area

Lake Tana is located in the Upper Blue Nile River system (Fig. 1), which is influenced by dynamic factors in both natural and human domains (Alemu et al. 2020).

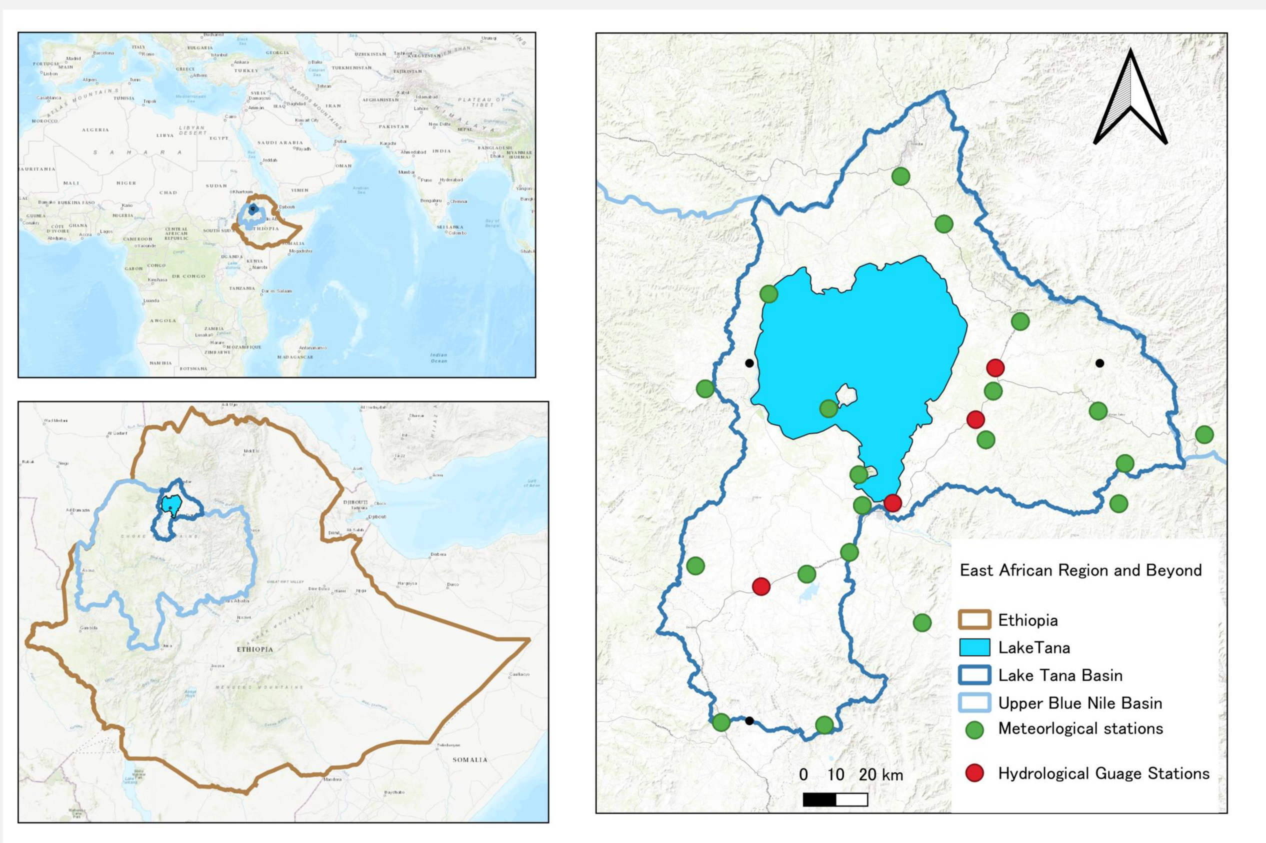

Fig 1. The Study Area Map.

- Area = 15,077 km² (Dessie et al., 2014).
- Surface area of Lake Tana ~ 3500 km² (Mulat et al., 2018).

Methods

Model setup

- WRF nested domains: D01 = 9 km, D02 = 3 km.
- Cumulus: D01 (ON) ; D02 (OFF).
- Initial/boundary conditions: ERA5 and NCEP–GFS.
- Vertical grid = 45, 45 Vertical levels
- Model Top = 50hpa

Coupled hydrology

WRF-Hydro driven by WRF precipitation/meteorology.
Streamflow compared with observations.

24-member multi- physics ensemble

PBL = MYJ

MP ¥ LSM	Noah	Noah-MP
WSM5	x	X
WSM6	x	x
WDM5	x	x
WDM6	x	x
Thompson	x	x
Morrison	x	x

PBL = YSU

MP ¥ LSM	Noah	Noah-MP
WSM5	x	x
WSM6	x	x
WDM5	x	x
WDM6	x	x
Thompson	x	x
Morrison	x	x

Evaluation

- Precipitation: CHIRPS, MSWEP, TAMSAT + stations.
- Metrics: CC, RMSE, Bias; POD, FAR, TS.
- Hydrology: observed vs simulated hydrographs.

.- Other physics options held constant across experiments

Results

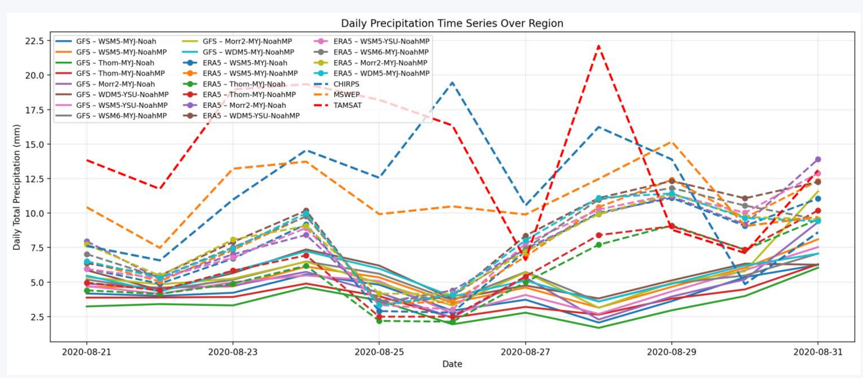

Fig. 2. Daily precipitation time series (Aug 21–31, 2020):
WRF experiments (GFS &ERA5) vs reference datasets.

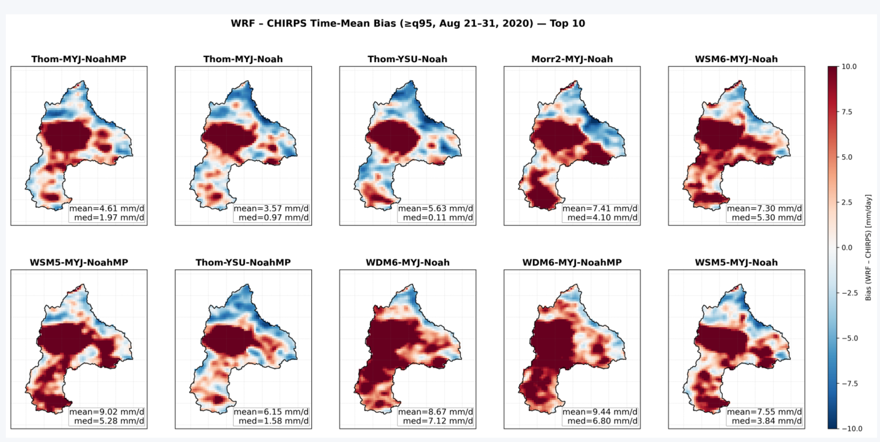

Fig. 3. Mean precipitation bias (WRF – CHIRPS), Aug 21–31, 2020: best physics configurations.

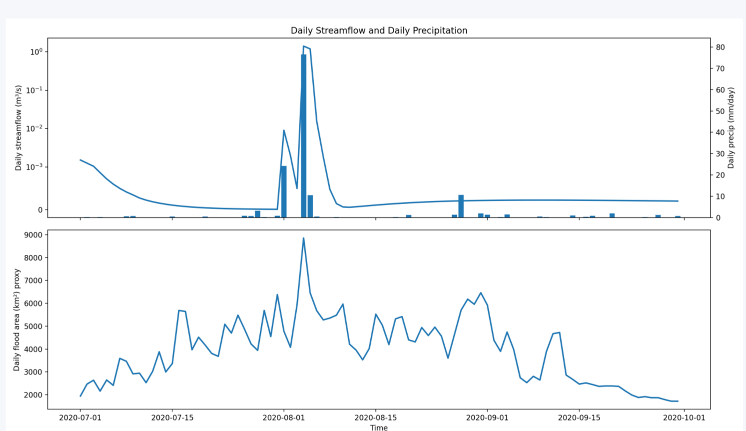

Fig. 4. 2020 flood evolution (Jul–Sep): daily precipitation, streamflow, and flooded-area proxy (peak early Aug).

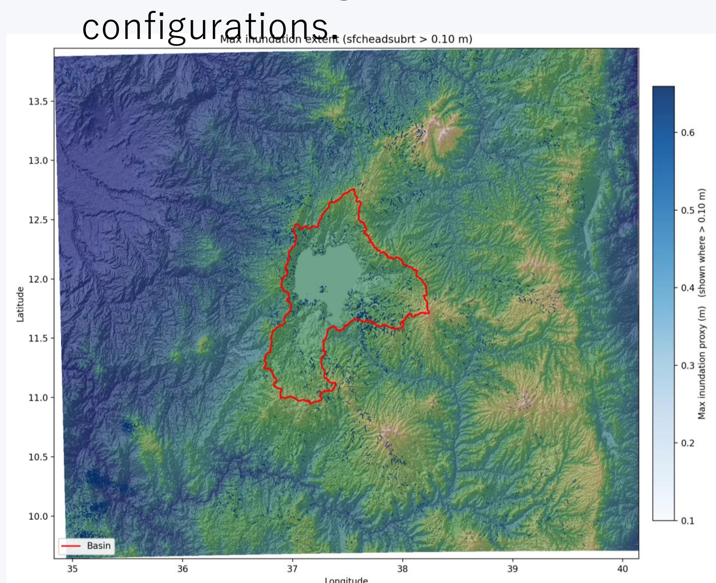

Fig. 5. Maximum simulated inundation extent in the 2020 flood (sfcheadsurt > 0.10 m), UBNB.

Key findings & Future work

- The performance of WRF simulations is highly sensitive to the choice of microphysics, with Thompson and Morrison schemes consistently outperforming others.
- ERA5 initial and boundary conditions yielded better results than GFS, especially for simulating intense rainfall events in complex terrain.
- During the 2020 flood period (July–September 2020, with a peak in early August), the WRF-driven WRF-Hydro simulation indicates maximum inundation concentrated
- Future work will evaluate the impact of online (two-way) coupling in WRF–WRF-Hydro relative to offline (one-way) coupling. on the eastern Lake Tana floodplain and along downstream reaches of the Upper Blue Nile Basin.

Acknowledgment

This research is supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT): Monbukagakusho Scholarship (International Resilience Engineering Program Powered by Industry-Academia Collaborated PBL: 22016)

References

1. Deng, C., Chi, Y., Huang, Y., Jiang, C., Su, L., Lin, H., Jiang, L., Guan, X., & Gao, L. (2023). Sensitivity of WRF multiple parameterization schemes to extreme precipitation event over the Poyang Lake Basin of China. Frontiers in Environmental Science, 10. https://doi.org/10.3389/fenvs.2022.1102864
2. Dixit, A., Sahany, S., Mishra, S. K., & Lehner, F. (2025). Optimizing WRF-Hydro Calibration in the Himalayan Basin: Precipitation Influence and Parameter Sensitivity Analysis. Journal of Hydrometeorology, 26(3), 345–363. https://doi.org/10.1175/JHM-D-24-0096.1
3. Sofokleous, I., Bruggeman, A., Michaelides, S., Hadjinicolaou, P., Zittis, G., & Camera, C. (2021). Comprehensive methodology for the evaluation of high-resolution wrf multiphysics precipitation simulations for small, topographically complex domains. Journal of Hydrometeorology, 22(5), 1169–1186. https://doi.org/10.1175/JHM-D-20-0110.1