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Advancing Terrestrial ECVs through High-Resolution Hydrological Modeling: Insights from the 4DHydro Project

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Accurate representation of terrestrial Essential Climate Variables (tECVs) is crucial for practically understanding the Earth's climate system and supporting policy decisions. This study initiates benchmarking practices within the Land Surface/Hydrologic Model (LSM/HM) communities by integrating high-resolution data with hyper-resolution hydrological modelling. The European Space Agency (ESA)-funded 4DHydro project employs six advanced LSM/HMs: Community Land Model (CLM), GEOfram, mesoscale Hydrologic Model (mHM), PCRaster Global Water Balance (PCR-GLOBWB), TETIS, and wflow_sbm.

We benchmark, calibrate, and analyze scalability using consistent EMO1 precipitation forcings, focusing on 1 km spatial resolution. We introduce a novel multi-basin (MB) calibration technique based on streamflow data from the Po, Rhine, and Tugela River basins, highlighting its impact on model performance. Scalability analysis evaluates computational trade-offs and performance improvements at higher resolutions while ensuring flux matching. The study includes 34 simulations addressing water balance closure to enhance tECVs.

Key findings explore the advantages of high-resolution modelling, introducing a reference benchmark dataset of 1 km hydrological simulations, optimal gauge selection for MB calibration, and comparative performance of different LSMs and HMs in flux matching across spatial scales. These insights contribute to advancing the integration of high-resolution data with hydrological

modelling, promoting consistent and accurate terrestrial ECVs at regional and continental scales.