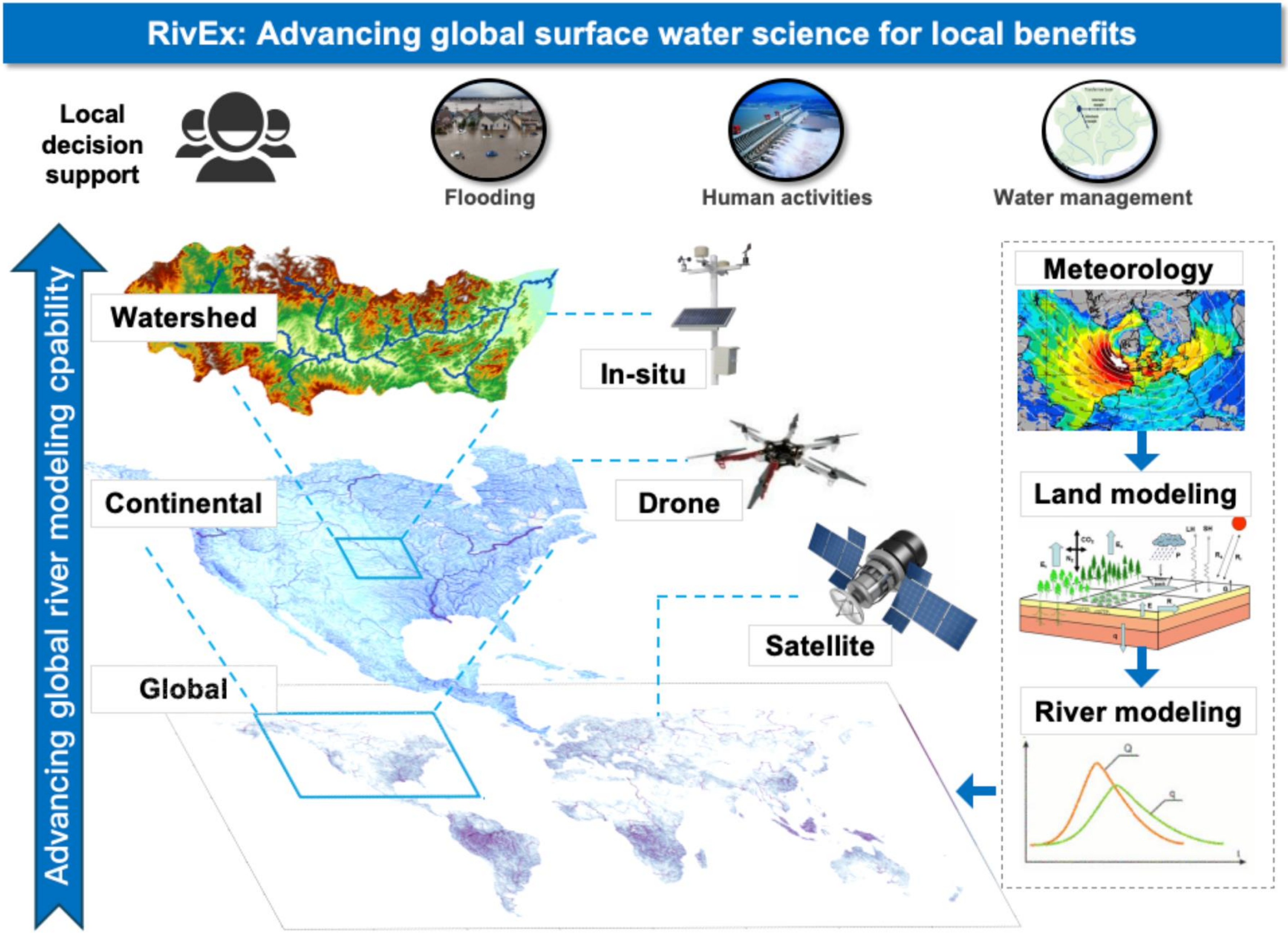

RivEx: Advancing global surface water science for local benefits
Local decision support
Flooding
Human activities
Water management
Advancing global river modeling cpability
Watershed
Continental
Global
In-situ
Drone
Satellite
Meteorology
Land modeling
River modeling

The River Experiment Initiative: Advancing Global Surface Water Science for Local Societal Benefits

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The writing is on the proverbial wall for Earth's freshwater stores: ice sheets are melting (Shepherd et al., 2012), aquifers are emptying (Famiglietti, 2014), reservoirs are drying (Yao et al., 2023), and glaciers are losing mass (Gardner et al., 2013), with varied implications for endorheic and exoreic basins around the world. Our "working capital" of freshwater is changing, therefore challenging the human right to safe and clean water for drinking and sanitation (United Nations, 2010) for the world's rapidly growing population. These trends may lead to an increasing reliance on other freshwater sources. While Earth's rivers have a tiny storage, their mighty flow makes them the most renewable and most accessible and hence most sustainable (Oki and Kanae, 2006) source of freshwater. The management of our freshwater portfolio may very well gradually include a "cash flow" perspective using this sustainable freshwater source. The powerful flow of rivers is also a great cause for concern because floods are consistently among the world's most disastrous natural hazards, ranking first in the number of events and in the number of people affected, second in economic cost, and fourth in total deaths (United Nations Office for Disaster Risk Reduction, 2020). Yet surprisingly little is known about spatiotemporal variations of global surface water stores and fluxes, induced by both natural and anthropogenic processes (Cooley et al., 2021; Bonnema et al., 2022).

Earth's rivers and lakes are currently facing pressing environmental and societal challenges. Extreme flood events are expected to increase with a changing climate (Milly et al., 2002), hence leading to devastating damages to human life, assets, and property, further aggravated by human development on floodplains. Water resources and river biodiversity are threatened by human population growth and global environmental change (Vorosmarty et al., 2010). The administration of transboundary basins is increasingly challenging as water management is largely impacted by drivers such as historical, legal, economic, and cultural differences, which could create or increase geopolitical tensions among neighbor nations (UNEP, 2016). Nutrient exports through rivers are primarily responsible for dead zones in the coastal oceans (Diaz and Rosenberg, 2008). River deltas are increasingly vulnerable to coastal hazards as declining sediment supply and climate change alter their sediment budgets (Nienhuis et al., 2020).

Even though access to recent in situ observational data of rivers is known to be globally declining (The Ad Hoc Group et al., 2001) due to lack of sharing, operational expense, and political instability (Fekete et al., 2015), some critical data sets are available (The Global Runoff Data Centre, 2023). In addition to in situ measurements, river systems can also be observed using spaceborne remote sensing and existing technology allows for measurements of water quantity (Smith, 1997) and water quality (Swain and Sahoo, 2017). Space agencies around the world have recognized the importance of Earth's rivers and lakes, and myriad current and upcoming satellites are either specifically designed to observe rivers or are capable of doing so. Radar nadir altimetry missions, such as the Topography Experiment (TOPEX)/Poseidon, Jason-1, Jason-2, Jason-3, and Sentinel 6 series or the European Remote-Sensing Satellite (ERS)-1, ERS-2, Envisat, Satellite with ARGOS and ALTIKA (SARAL), and Sentinel 3 series, initially designed to measure ocean levels, have shown their usefulness in monitoring inland waters globally (Crétaux et al., 2011; Schwatke et al., 2015). Optical satellites like Landsat and Sentinel 2 and synthetic aperture radars like Sentinel 1 and the National Aeronautics and Space Administration (NASA)-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR) are also being combined to provide surface water extents (Bato et al., 2022). The Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, is the first satellite mission specifically designed to observe global inland water dynamics (Durand et al., 2023). The unprecedented type, extent, and amount of data being acquired by SWOT could become a gamechanger in modern surface water sciences.

Multiple existing river models applicable at continental to global scales have been developed in the past two decades. The current generation of models includes–among others–Catchment-Based Macroscale Floodplain (CaMa-Flood; Yamazaki et al., 2011), Centre National de Recherches Météorologiques (CNRM) Total Runoff Integrating Pathways (CTRIP; Munier and Decharme, 2022), Hillslope River Routing (HRR; Beighley et al., 2009), Hydrological Modeling and Analysis Platform (HyMAP; Getirana et al., 2012), LISFLOOD-FP (Bates and Roo, 2000), Modelo de Grandes Bacias (MGB; Pontes et al., 2017), Organizing Carbon and Hydrology In Dynamic Ecosystems (ORCHIDEE; Polcher et al., 2011), and Routing Application for Parallel computatIon of Discharge (RAPID; David et al., 2011). Despite the demonstrated existing strengths of these numerical models, the state of global river modeling is currently insufficient to leverage existing global observations, particularly with respect to a comprehensive evaluation of how human interventions (e.g., dam building, reservoir operation, flood control structures, and water withdrawal) alter the spatiotemporal variability of surface waters (Harding et al., 2015). In addition, and although progress has been made on the integration of satellite data at the regional scale (Emery et al., 2020a; Revel et al., 2019; Pedinotti et al., 2014; Emery et al., 2020b; Paiva et al., 2013; Getirana et al., 2013; Wongchuig et al., 2024), ingesting spaceborne river data at the global scale, especially with the deluge of SWOT data, is still a challenge.

While intercomparison and benchmarking of land surface and climate models have been well-established in the past three decades (Henderson-Sellers et al., 1993; Boone et al., 2004; Meehl et al., 1997; Meehl et al., 2007), river models and their evaluation are still in drastic need of standardization. Recent river modeling efforts have been made to quantify streamflow accuracy as a function of total runoff boundary condition uncertainties (Getirana et al., 2014; Getirana et al., 2017; David et al., 2019), parameterization uncertainties (Yamazaki et al., 2011; Getirana et al., 2013; Decharme et al., 2012) , and anthropogenic effects (Hanasaki et al., 2006; Hanazaki et al., 2022; Tavakoly et al., 2023; Getirana et al., 2023; Dalcin et al., 2023; Sadki et al., 2023). However, due to conceptual and structural differences such as model discretization and numerical representation of natural and anthropogenic processes, the scientific community still lacks standardizations allowing for the objective comparison of river models, hence hindering their adoption into decision support activities.

Here, we propose establishing a common strategy for comparing river models called the GEWEX Hydroclimatology Panel (GHP) River Experiment (RivEx) Crosscutting initiative to strengthen our modeling systems and eventually facilitate their integration into local and regional decision-support activities, hence capitalizing on observational investments–both in situ and remote–and their impact on scientific discovery and societal applications. Specifically, we plan for the initiation of a dedicated data gathering and model comparison campaign that leverages the past two decades of progress in surface water modeling and remote sensing to provide physical constraints on the joint monitoring, understanding, and prediction of Earth's surface water cycle. Anthropogenic pressures on global surface water and their associated climate feedback have the potential to be better resolved through these activities, promoting linkage between modern water science and contemporary human societal needs.

We raise the following questions to receive the highest priorities as part of RivEx activities:

1. What is the current state of surface water modeling capabilities? When, where, and why do models perform well or fail to perform?
2. What are the hotspots of anthropogenic influences on global surface water, and can their footprint be accounted for in models?
3. How can global hydrological models be enhanced to ingest an increasing number of observations for more accurate reproduction of surface water stores and fluxes with relevancy at local and regional levels?

We anticipate that the initial RivEx activities will span over 36 months in two consecutive phases. Phase A (18 months) would produce a common and consistent data set of model inputs, model parameters, and hydrographic descriptions of the land surface, as well as a set of common metrics for model evaluation. Phase B (18 months) would follow with the implementation of multiple models and their joint evaluation.

Figure 1 (see cover) presents a schematic view of the RivEx initiative, highlighting its integration of in situ and remote observations across global to local scales to improve its process understanding and spatiotemporal characterization, aiming to eventually better serve local decision support.

The proposed activity directly aligns with two of the three GEWEX Science Goals (GEWEX, 2021). For Goal 1 (G1), "Determining the extent to which Earth's water cycle can be predicted", we aim for quantifiable progress at fine spatiotemporal scales on two of the subgoals: G1.1 ("Stores") and G1.2 ("Fluxes"), focusing on continental surface waters. For Goal 3 (G3), "Quantify anthropogenic influences on the water cycle and our ability to understand and predict changes to Earth's water cycle", our efforts align with subgoals G3.1 ("Anthropogenic forcing of continental scale water availability"), G3.2 ("Water management influences"), and G3.3 ("Variability and trends of water availability"). As the terrestrial hydrological cycle undergoes perturbations from human activities such as water withdrawals and irrigation, anthropogenic construction (e.g., dams, dikes), and floodplain urbanization, the magnitude, timing, and statistical distribution of surface water quantities are being modified. The accurate prediction of stores and fluxes at fine spatiotemporal scales is becoming an increasing challenge when using traditional modeling approaches without fusion of observations. By proposing community activities to ingest novel river, lake, and reservoir observations into numerical models at unprecedented spatiotemporal coverage and resolution, we aim to improve the quantification of the rate of change in global surface water networks. Our activities would directly contribute to understanding the space-time characteristics along natural and anthropogenic drivers. Such new approaches are essential for making substantial progress toward improving the predictability of such changes. In addition, the proposed activity also involves producing a consistent set of new data and metrics, which will be instrumental in evaluating to what extent anthropogenic activities changed surface waters from local to continental scales. Although indirectly related, the proposed activity may also impact GEWEX Science Goal 2, "Quantify the inter-relationships between Earth's energy, water, and carbon cycles to advance our understanding of the system and our ability to predict it across scales". For example, evapotranspiration is the most uncertain flux connecting energy, water, and carbon cycling, but it is not a directly observable quantity at macroscale. Likewise, runoff is not observable at continental to global scales. An accurate depiction of global surface water across scales can be used to constrain evapotranspiration and runoff more widely than before, and hence constrain both water-energy and water-carbon cycling processes.

We aim to promote an inclusive environment. Within the general scope envisioned, we welcome inclusion of all ideas, individuals, and communities that have not (yet) been involved.

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