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Modular modelling frameworks for continental-scale hydroclimatic risk assessment

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Climate change is transforming hydroclimatic extremes, such as floods and droughts. Traditionally, hydroclimatic changes are explored by forcing a handful of hydrological models using projections from climate models. While this approach has enabled significant advances over the last decade, it also presents several limitations. In particular, the lack of structural flexibility of current hydrological models typically prevents us from understanding why different models disagree; model selection is often driven by legacy rather than adequacy, leading to subjectivity in risk assessments; there is a lack of coordinated effort to feed forward improvements in one model to the wider community.

In this presentation, we demonstrate the value of an alternative methodology to assess hydroclimatic risks, which overcomes the limitations outlined above. This novel approach relies on modular modelling frameworks (MMFs). MMFs are master templates for hydrological model generation; they rely on “modules” that can be combined in a multitude of ways to create new ensembles of hydrological models. Each module encapsulates the parameterisation of a key hydrological process, such as evaporation or infiltration. Several competing modules are available for the same process, which enables controlled experiments for understanding modelled hydrology at the process level. In contrast to traditional approaches, MMFs can highlight specific reasons for model deficiencies and sample the model space in a systematic way. Additionally, they enable the community to contribute modules, greatly facilitating and accelerating model improvement. All these properties are key to producing reliable risk assessments.

To demonstrate the value of MMFs for hydroclimatic risk assessments, we compared two ensembles of hydrological projections: a traditional ensemble made of simulations from three fixed-structure hydrological models (HBV, VIC and Sacramento) and an MMF ensemble made of three hydrological models produced using the MMF FUSE (Framework for Understanding Structural Uncertainties). We forced both ensembles using the same set of CMIP5 bias-corrected projections and ran them from 1980 to 2100 in 600 US catchments covering a wide range of hydro-climatic conditions. We evaluated the simulations of low and high flows and their projected changes. We show that i) the streamflow simulations from the FUSE models match or outperform simulations from the traditional models, ii) the FUSE models span a wide range of possible future hydroclimatic outcomes, even though they stem from the same framework, iii) FUSE is extremely computationally efficient and robust, which makes it ideally suited for risk assessments requiring long simulations to produce a large sample of extreme events.