The Development of Quantitative Hydrologic Storylines to Understand Uncertainty in Climate

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1. Introduction

- Future climate projections are inherently uncertain, and quantifying and managing this uncertainty is one of the key tasks in any climate application.
- Previous research assessing climate change impacts on hydrologic systems has revealed a clear need to better understand how uncertainty in hydrologic projections propagates through traditional modeling chains.
- This uncertainty stems from chaotic variability in the climate system as well as uncertainty due to the methods we use (either from lack of understanding of the system or intentional simplifications in our models).
- We are particularly interested in the uncertainty that comes from methodological choices related to emissions scenarios, climate models, downscaling methods, and hydrology models and parameters (see Figure 1).

2. Hydrologic Storylines

- We aim to develop a set of representative hydrologic projections or "storylines" while specifically addressing the leading contributors of uncertainty.
- The first step is to characterize the uncertainties in the "full" ensemble in order to understand where and how much each component of the model chain contributes to the full ensemble's uncertainty.
- The second phase of the project will focus on reducing uncertainties by refining methodologies and eliminating unlikely ensemble members.
- Finally, distinct hydrologic storylines will be developed using data-driven and bottom-upsampling methods.

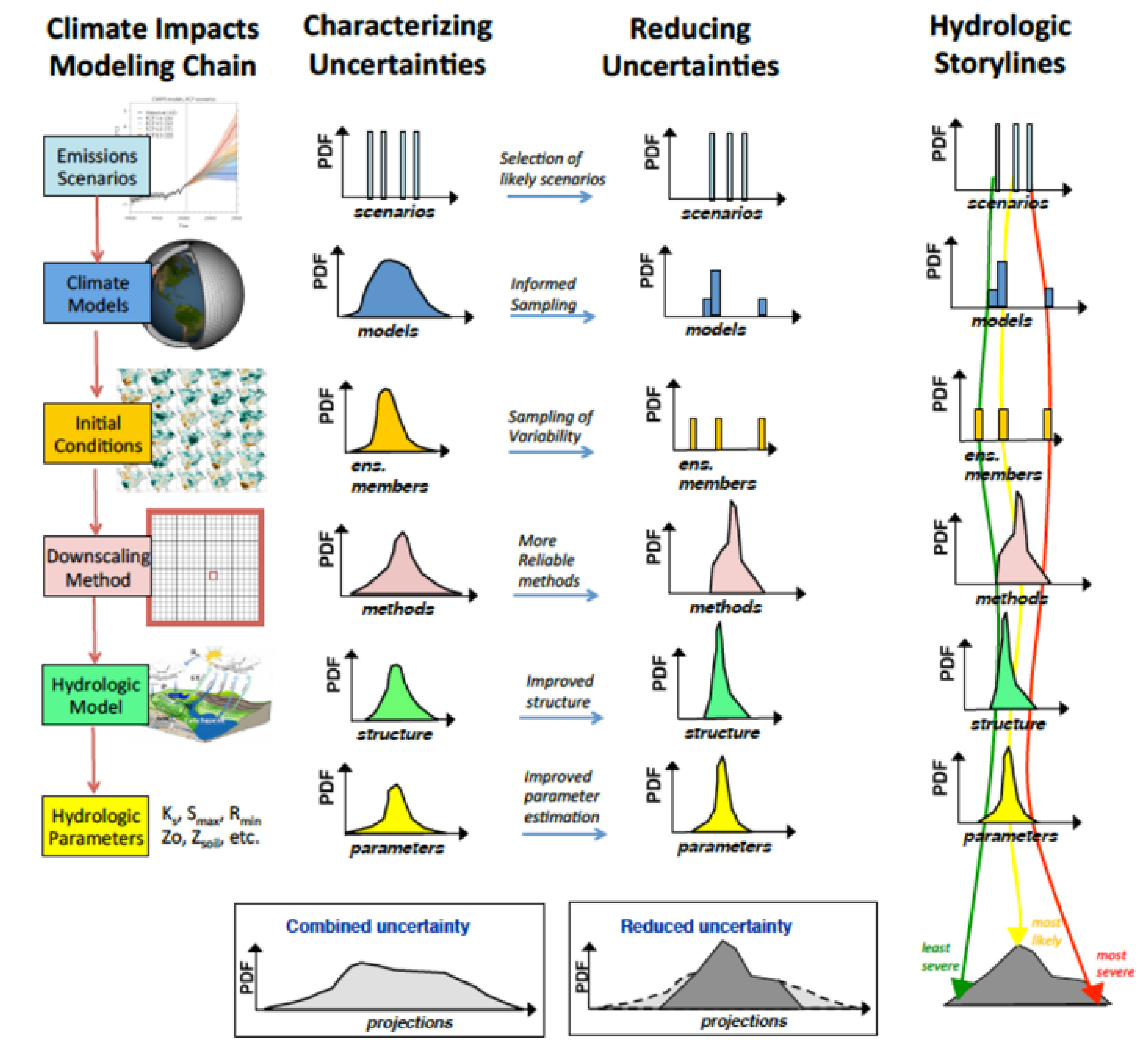

Figure 1: Schematic on approaches to explicitly characterize and reduce the myriad uncertainties in assessments of the hydrologic impacts of climate change and the development of representative quantitative hydrologic storylines for specific applications. Caption and figure from (Clark et al., 2016).

3. Downscaling

The complexity continuum of climate downscaling methodologies

Raw GCM → BCSD → Multivariate Regression → Reduced Physics RCM → High-res RCM

- A wide array of downscaling and bias correction methodologies have been proposed.
- Not all downscaling methods are created equal. Some methods should not be used for hydrologic modeling. See Gutmann et al. (2014).
- We are developing the Generalized Analog Regression Downscaling (GARD) tool to provide a simple statistical downscaling method relying on regressions and statistical transformations from various inputs (e.g. precipitation, humidity, wind, PCA, etc.) to various outputs (e.g. precipitation, temperature, etc.). See http://gard.readthedocs.io/.
- Simple / existing downscaling methods (e.g. BCSD) are being compared to progressively more complex methods like GARD, ICAR, and WRF to better understand how methodological complexity is related to fidelity and sensitivity.

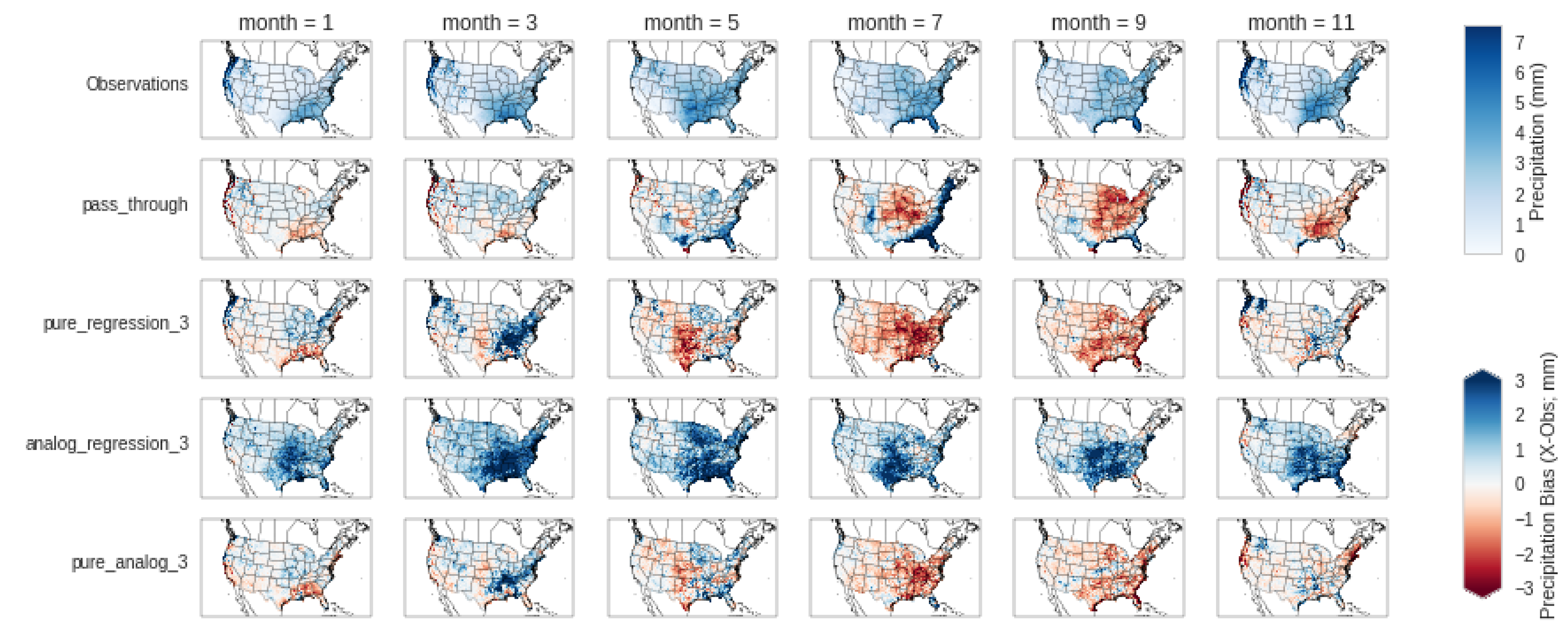

Figure 2: Comparison of precipitation predicted using 4 different downscaling approaches in GARD. Row 1: Gridded (1/8 deg) observed precipitation from Maurer et al (2001), Row 2: 50-km WRF precipitation interpolated to observations grid, Row 3-5: precipitation derived from multi-variate linear regression, analog, and analog regression techniques using predictor variables of precipitation, 500mb U/V winds, and SLP.

4. Hydrologic Modeling

- Typical hydrologic climate impacts studies do not explore how hydrologic model structure or model parameters influence the inferences derived from the modeling activity.
- We will use the Structure for Unifying Multiple Modeling Alternatives (SUMMA) model (Clark et al., 2015) to generate large a series of different modeling approaches using the same structural core (see Figure 3). Using SUMMA allows for the controlled and systematic analysis of modeling options and complexities.
- Model parameters will be derived using the Multi-scale Parameter Regionalization (MPR) method of Samaniego et al. (2010). Using MPR allows for the generation of ensembles of parameters, derived from calibrations performed using an array of objective functions.

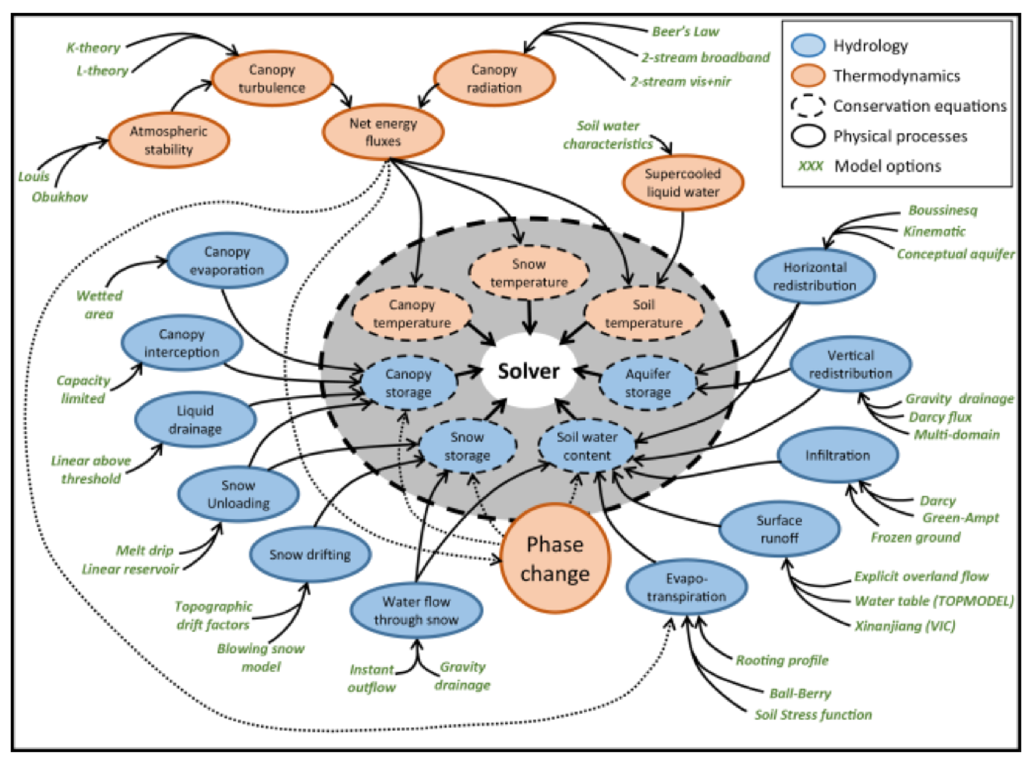

Figure 3: Conceptual diagram illustrating the SUMMA framework for supporting multiple alternative model options for a range of physical processes, integrated as part of a common numerical solver. Figure and caption adapted from Clark et al. (2015).

5. Outlook: Production of large ensembles of hydrologic projections

- We are developing a large ensemble of hydrologic projections over the CONUS domain.
- Our controlled evaluation of both the climate forcing and hydrologic modeling will allow for increased understanding of uncertainty derived from each component of the climate impacts modeling chain.

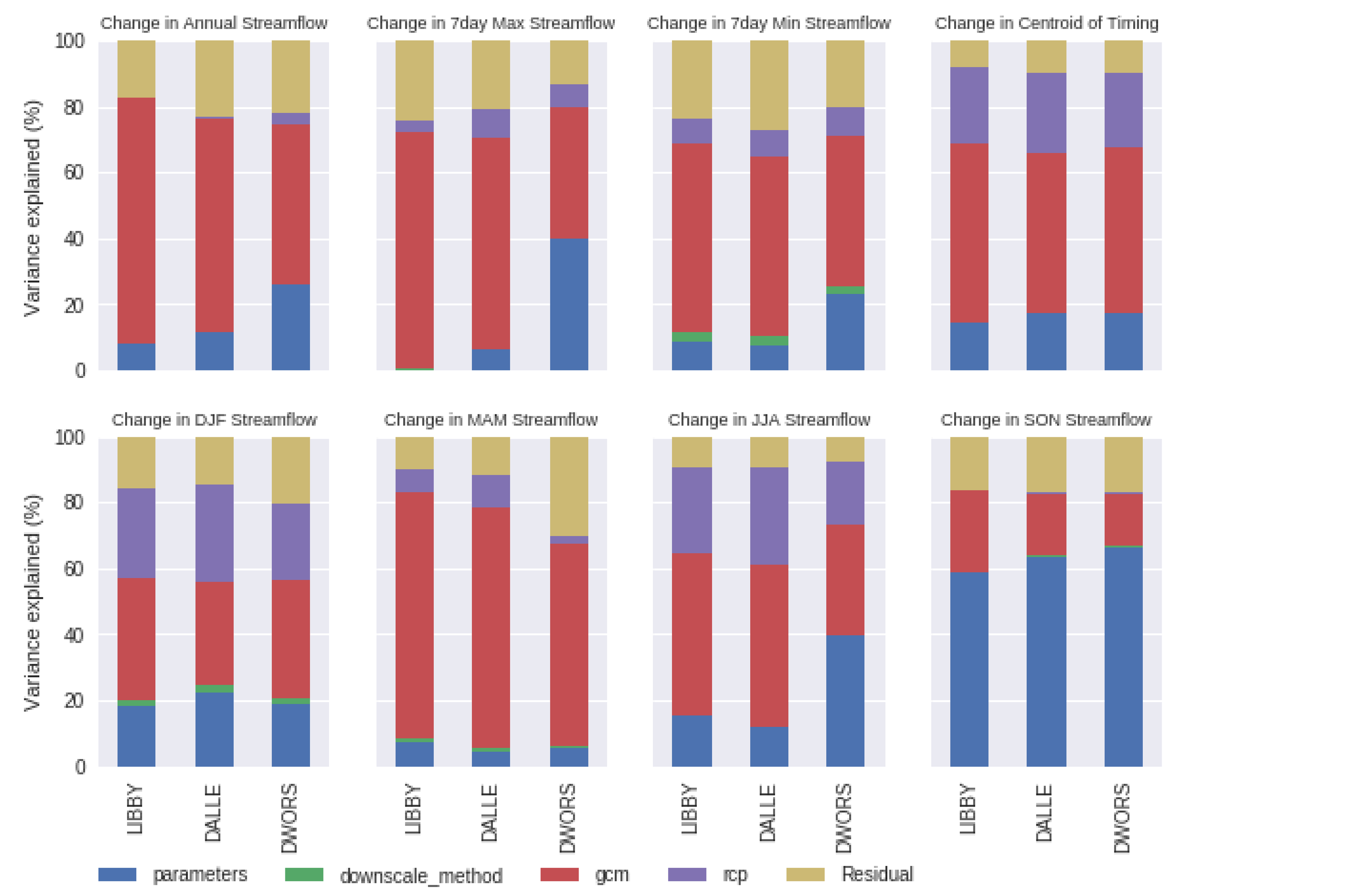

Figure 4: Example of an ANOVA analysis performed using a combination of existing data from the University of Washington RMJOC dataset and the NCAR BCSD dataset. The total dataset includes 2 RCPs, 31 GCMs, 3 downscaling Methods, 1 hydrologic model (VIC), and 4 hydrologic model parameter sets. Each subplot represents a different analysis metric. Each column is a different watershed in the Columbia River Basin.

- Figure 4 provides an example, using existing datasets, of how uncertainty (variance) can be partitioned.
- Key point: the variance explained by each variable is differs between analysis metrics.

6. Conclusions

- Hydrologic climate projections have uncertainty from the climate forcing (emissions scenarios, climate models, initial conditions) and from the hydrologic modeling application (model structure and parameters). We are systematically characterizing these uncertainties.
- We are developing new climate downscaling tools (e.g. GARD, ICAR) to fill in the complexity continuum. These tools will facilitate the generation of large ensembles of climate forcings and new analysis approaches that target the relationship between complexity, fidelity, and sensitivity.
- New data-driven and bottom-up sampling methods are being developed to enable the selection of smaller sets of representative hydrologic projections (storylines) while addressing the leading contributors of uncertainty.

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