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 shows a need to understand the sources of this uncertainty so that future work can reduce uncertainty, and so that the most realistic assessment of uncertainty can be presented.
- This uncertainty stems from chaotic variability in the climate system (Deser et al., 2014) and from the uncertain nature of the methods we use (Gutmann et al., 2012; Mendoza et al., 2016; Mizukami et al., 2016; Clark et al., 2016) (either from lack of understanding of the system or intentional simplifications in our models.)
- We focus on quantifying 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 to represent the range of likely outcomes with a minimum number of ensemble members.

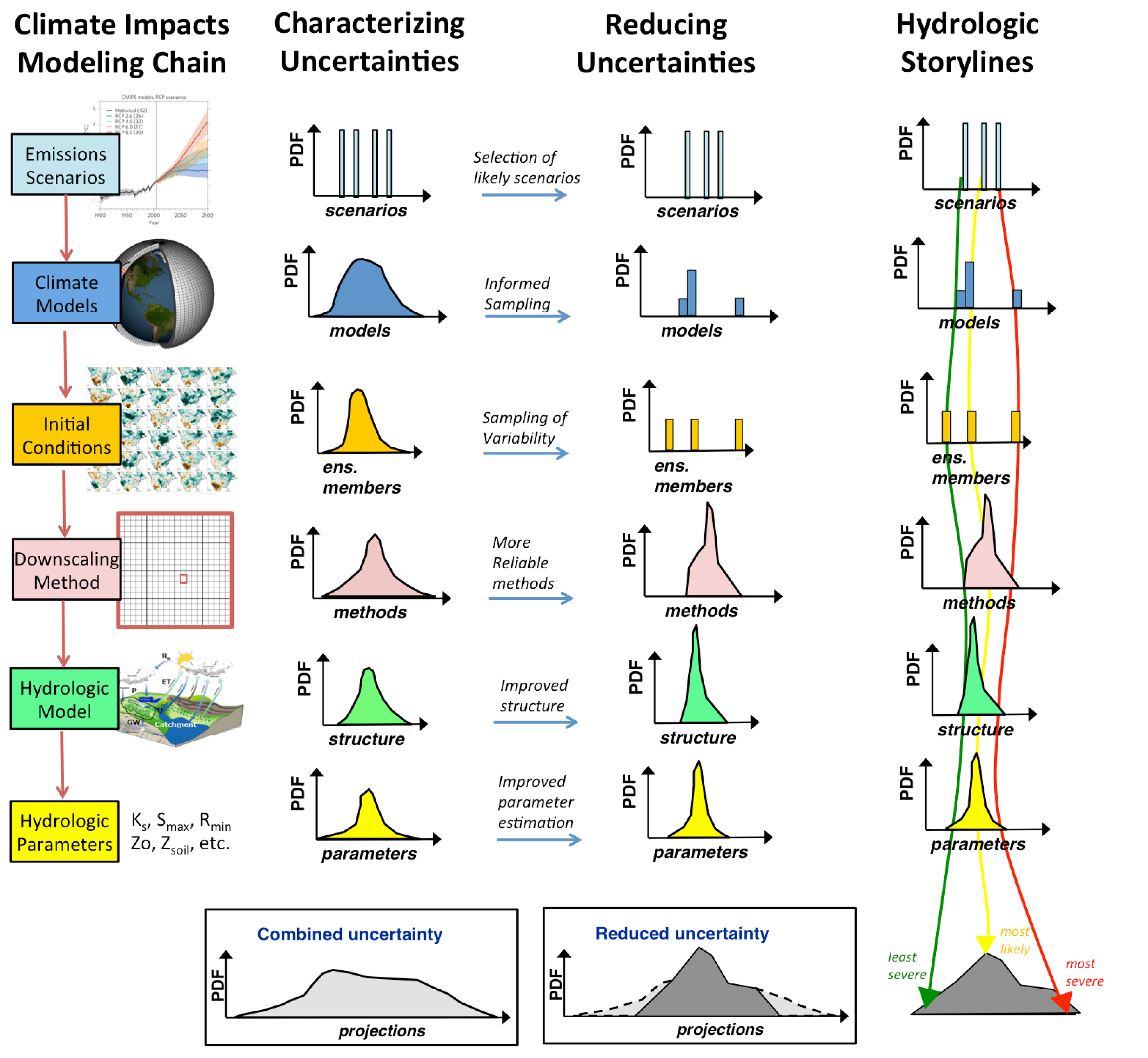

Figure 1: Schematic on approaches to explicitly characterize and reduce the myriad uncertainties in assessments of the hydrologic impacts of climate change and the development of representative quantitative hydrologic storylines for specific applications. Caption and figure from (Clark et al., 2016).

3. Downscaling

The complexity continuum of climate downscaling methodologies

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

- Not all downscaling methods are created equal. Some methods create artifacts even in historical climate (Gutmann et al., 2014), with implications for hydrologic modeling (Mizukami et al., 2016). The sensitivity of the climate change signal to downscaling methodology has not been widely explored.
- We are developing the Generalized Analog Regression Downscaling (GARD) tool to provide a simple statistical downscaling method capable of implementing a variety of 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/.
- We have developed a quasi-dynamical downscaling tool ICAR, the Intermediate Complexity Atmospheric Research model (Gutmann et al., 2016) to provide a downscaling option in between a full physics RCM and a statistically based tool.
- 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.

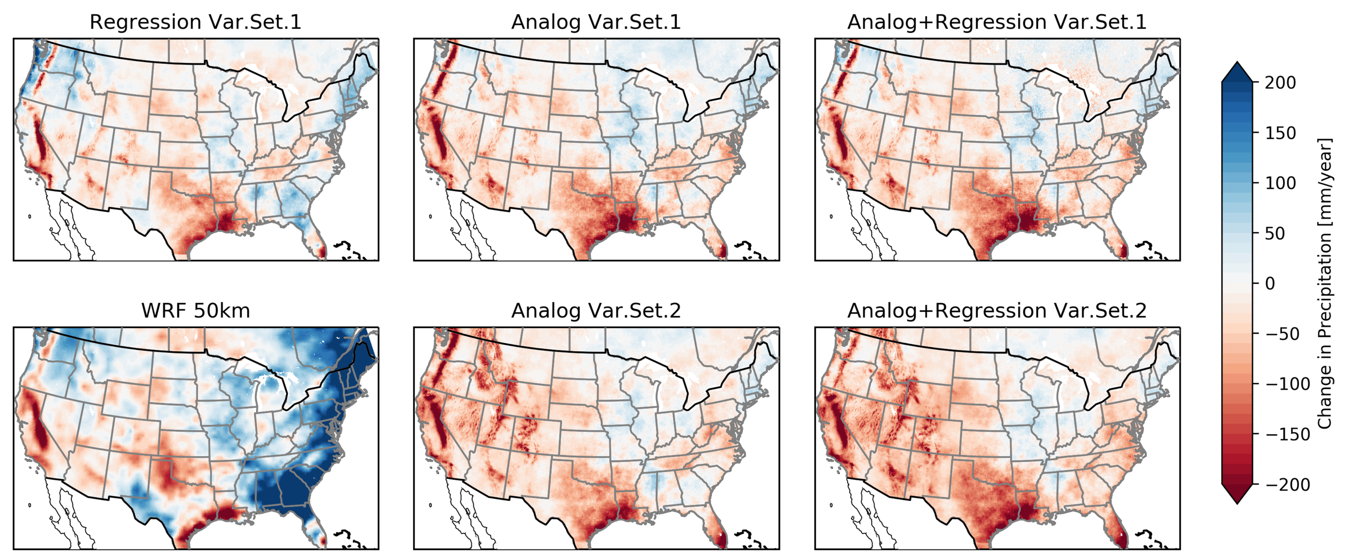

Figure 2: Changes in precipitation over CONUS from 6 downscaling approaches applied to an RCM. Top-left: linear-regression scheme precipitation as input, bottom-left: raw 50km RCM, middle: analog scheme, and right: analog regression scheme. "Var.Set.1" refers to schemes that used only precipitation as input and "Var.Set.2" refers to schemes that used a combination of precipitation and upper-air circulation.

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 compare climate signals from traditional models such as VIC, and an ensemble of different modeling approaches using the new multi-physics Structure for Unifying Multiple Modeling Alternatives (SUMMA) model (Clark et al., 2015) (see Figure 3). Using SUMMA allows for the controlled and systematic analysis of modeling options and complexities.
- In addition, an ensemble of model parameters will be tested, including parameters 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.

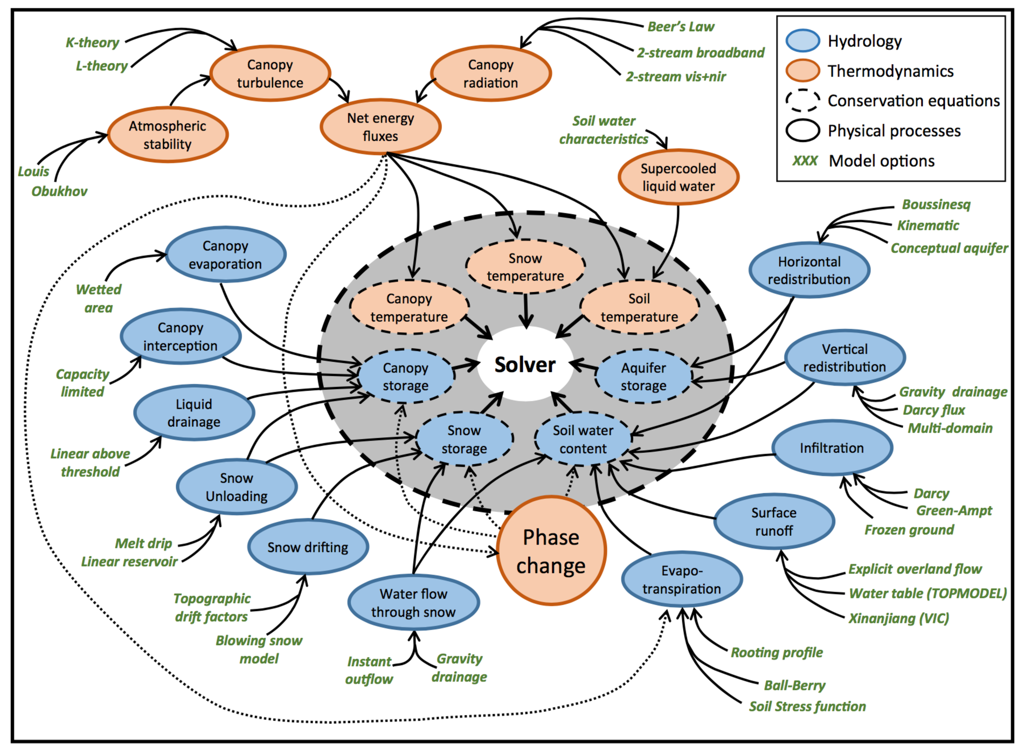

Figure 3: The SUMMA framework for supporting multiple alternative model options for a range of physical processes, integrated with a common numerical solver. Figure from Clark et al. (2015).

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.

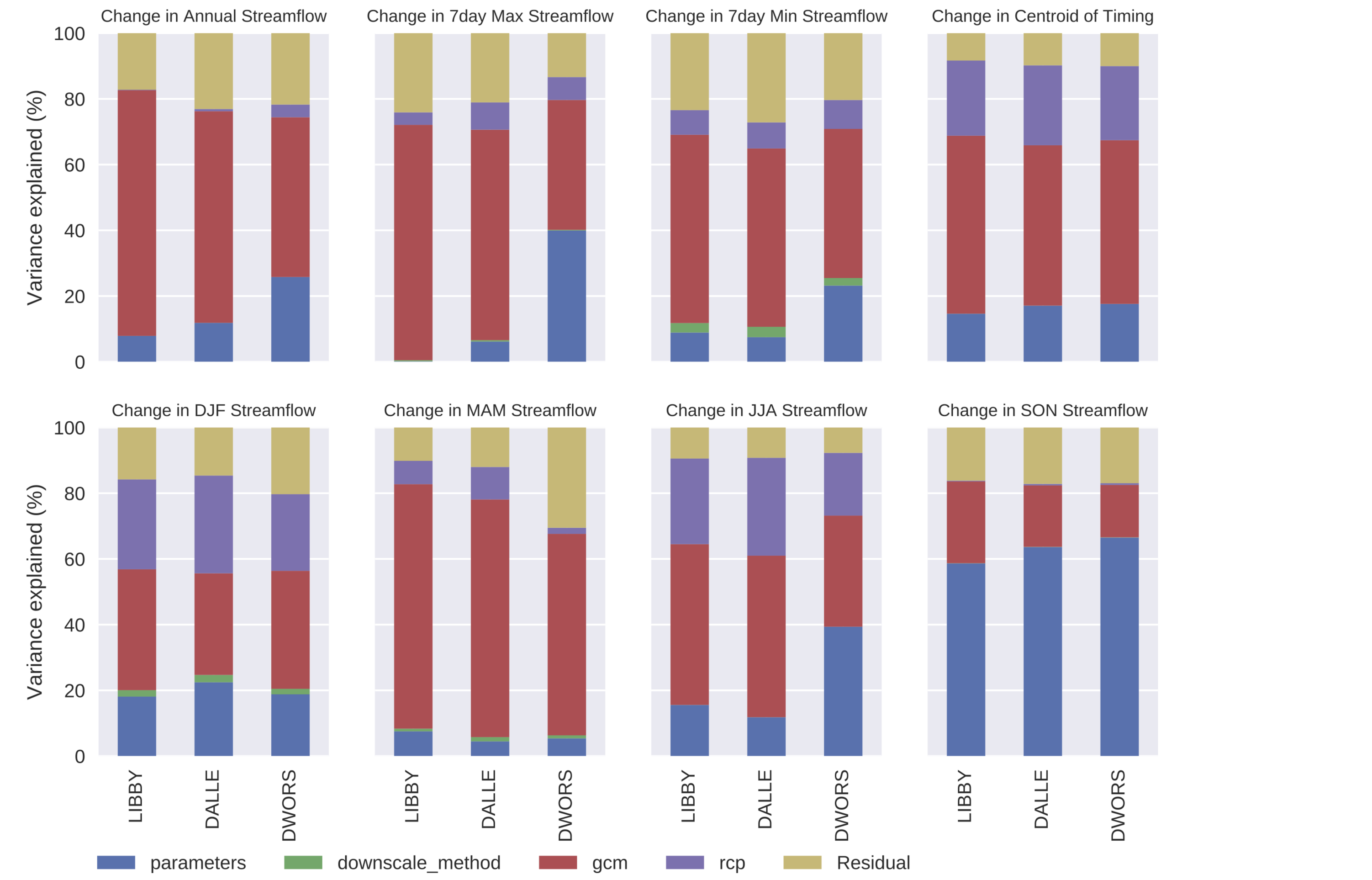

Figure 4: Example of an ANOVA analysis performed using a combination of existing data from the University of Washington RMJOC dataset and the NCAR BCSD dataset. The total dataset includes 2 RCPs, 31 GCMs, 2 simple downscaling methods, 1 hydrologic model (VIC), and 4 hydrologic model parameter sets. Each 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 model diversity, 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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