Building Resilience to a Changing Climate:

A Technical Training in Water Sector Utility Decision Support

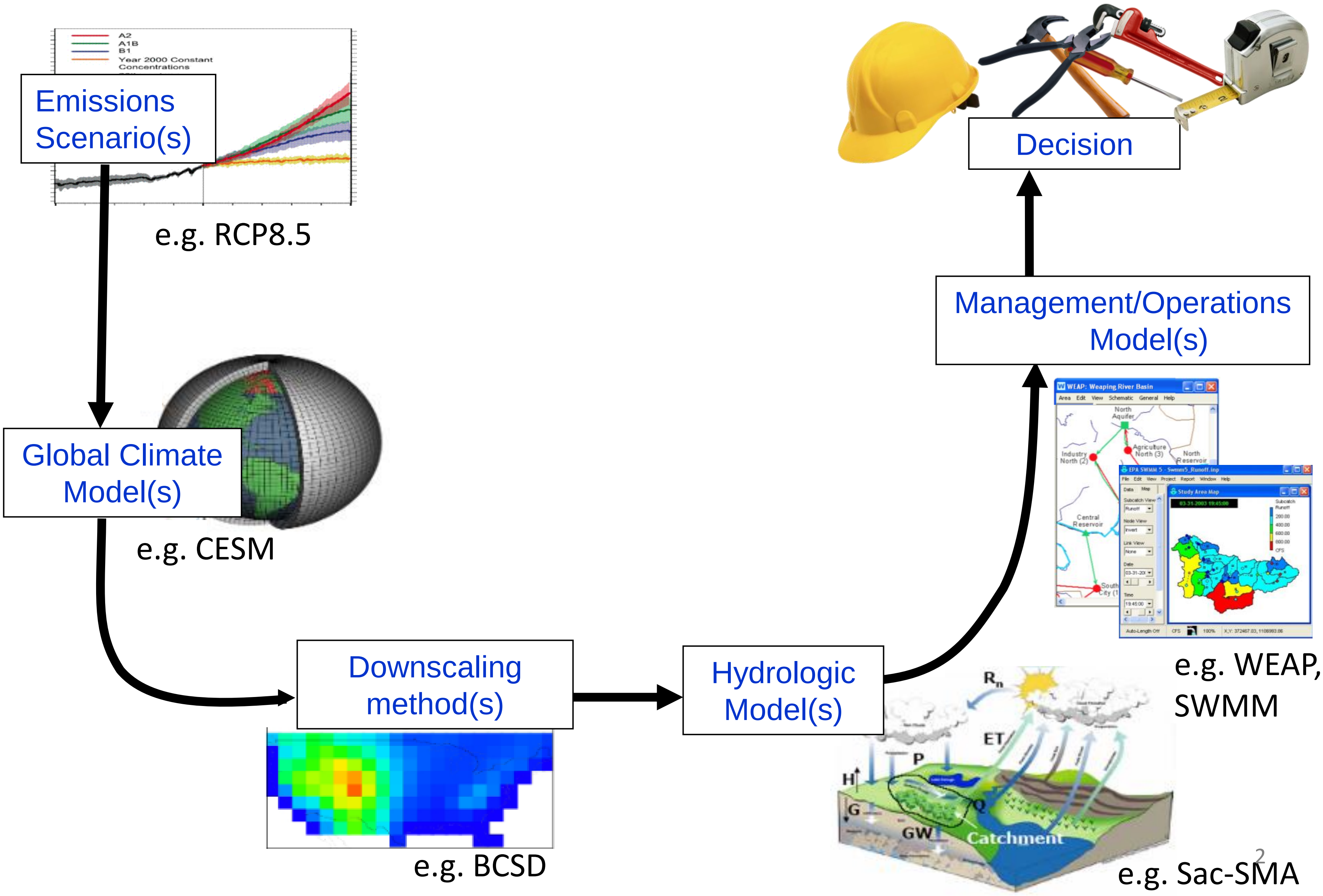
WUCA

Water Utility Climate Alliance

A Practical Look at Downscaling, Bias Correction, and Translating Climate Science into Hydrology

Julie Vano, National Center for Atmospheric Research

Classic "Top-down" Impacts Modeling Chain



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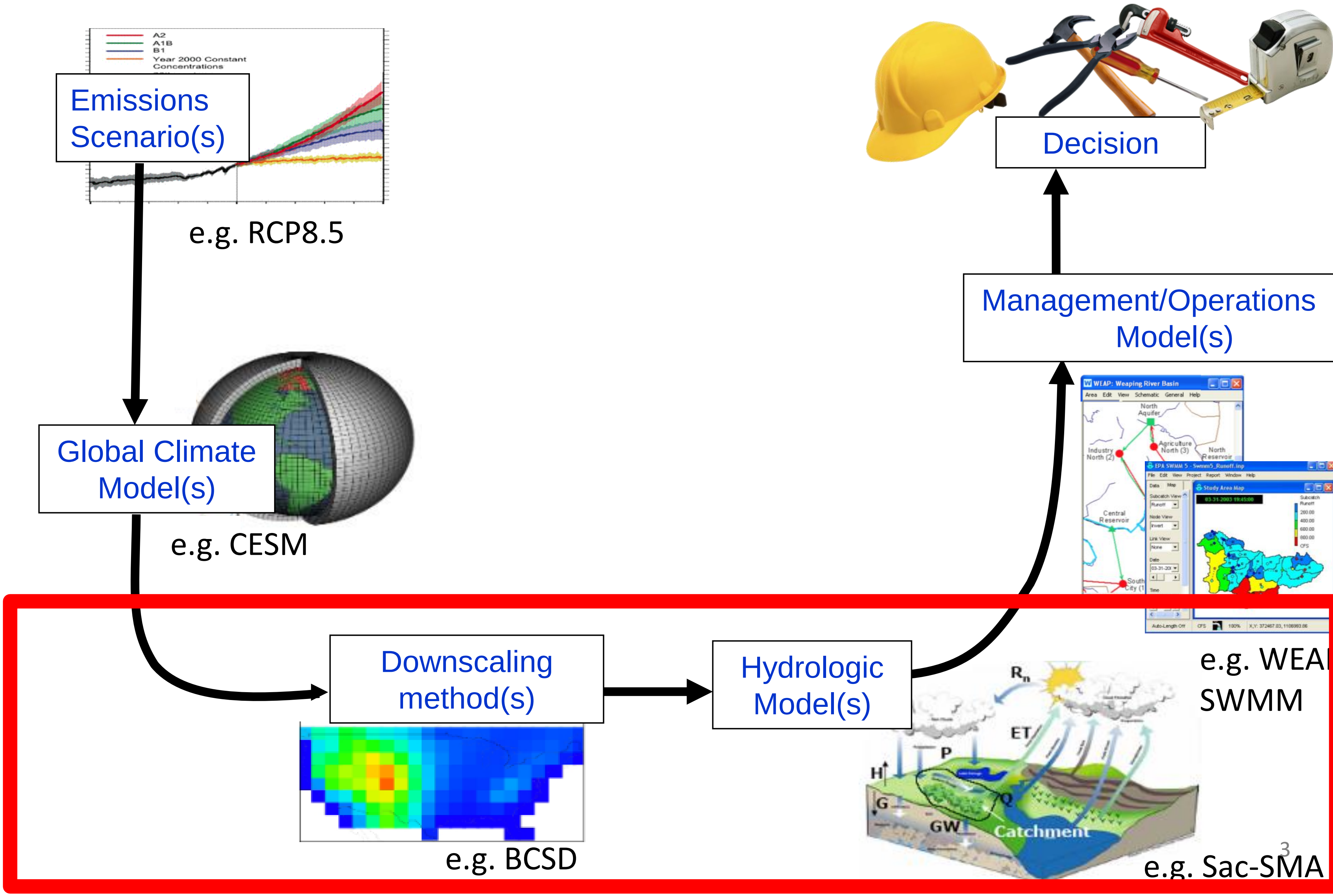

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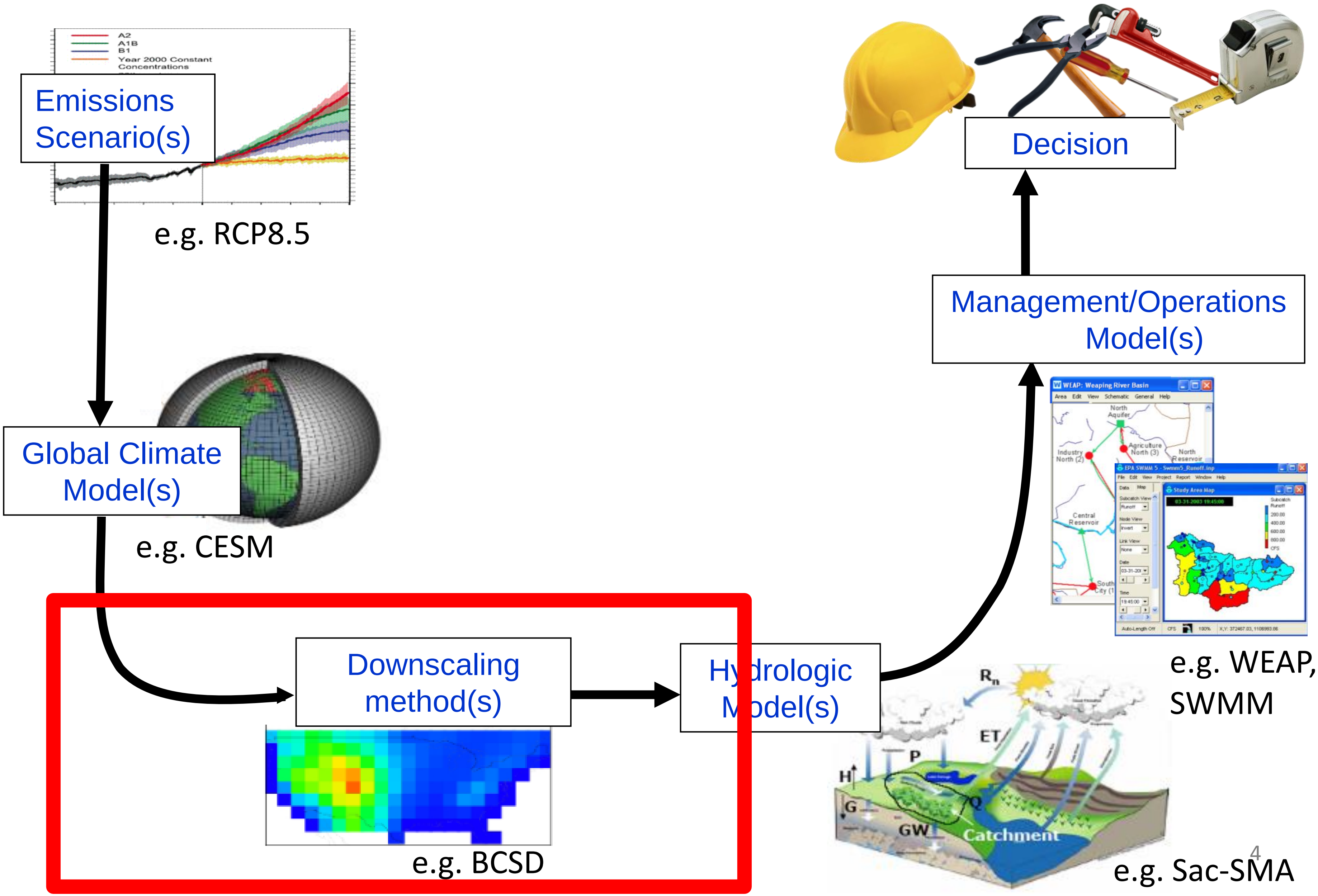

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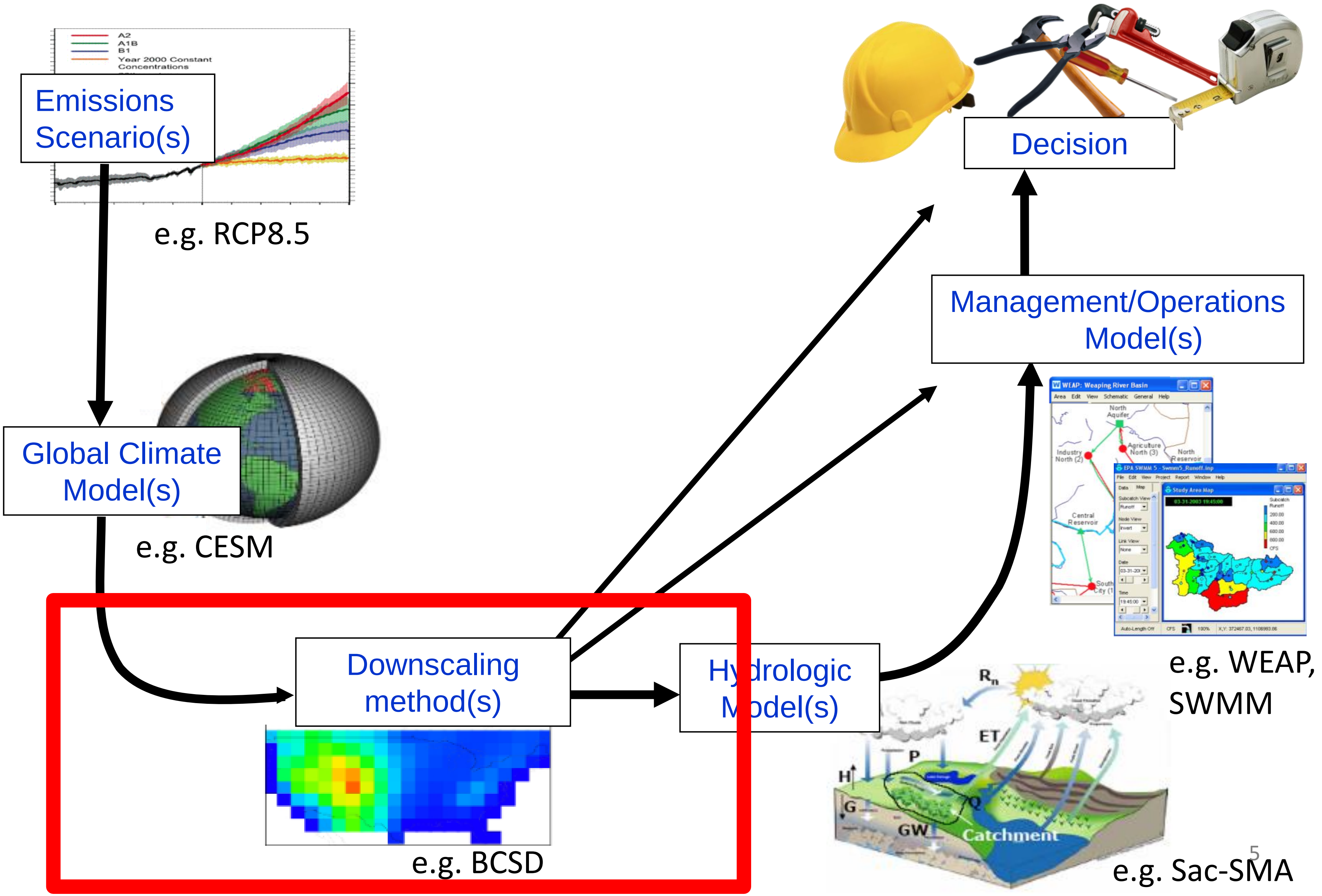


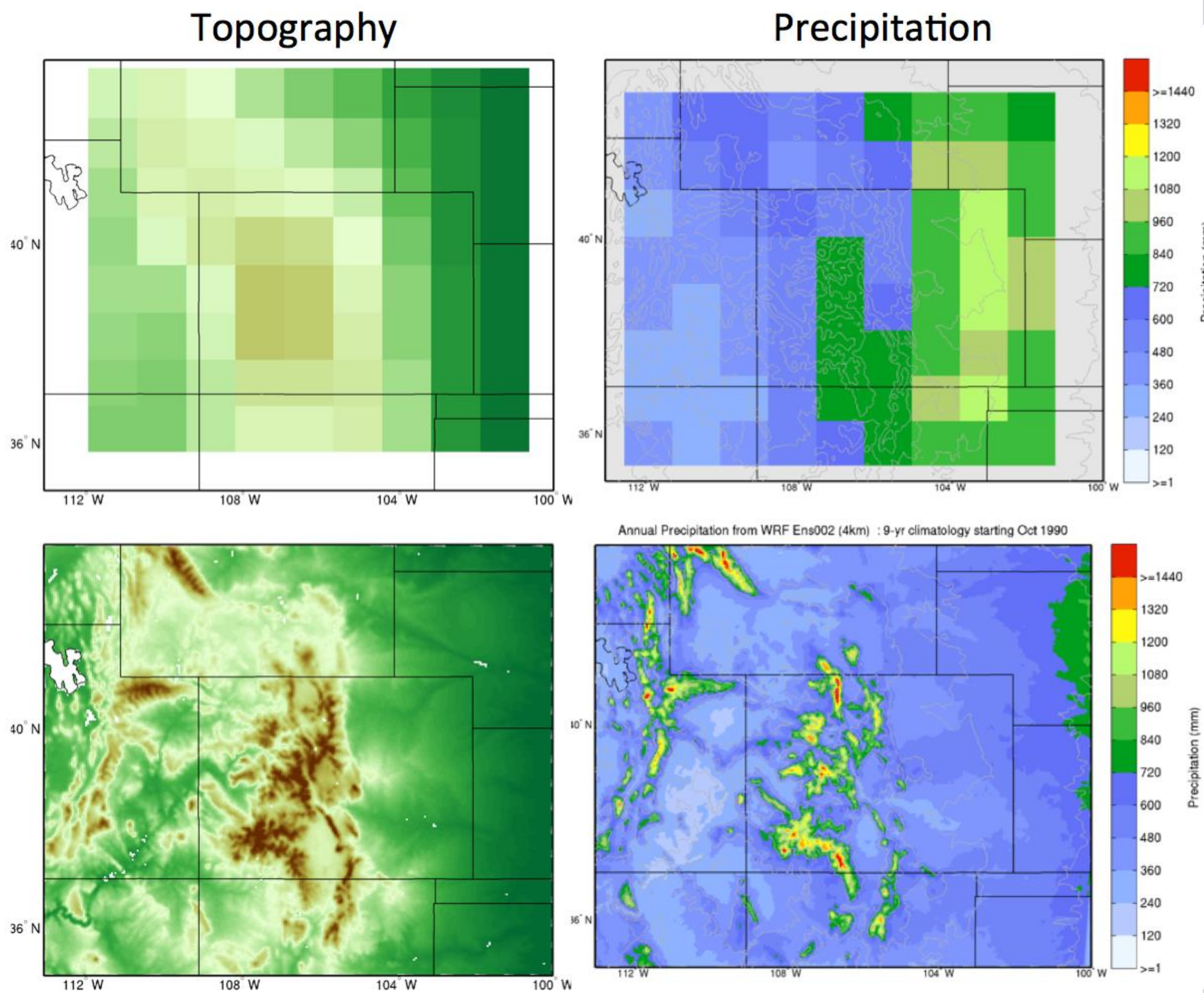
Why Do We Need to Downscale?

Global climate models:

- Coarse resolution of topography
- Inaccurate simulation of orographic precipitation, temperature gradients, cloud, snow, etc.

Regional climate models:

- High resolution of topography
- More accurate simulation of local physics and dynamics

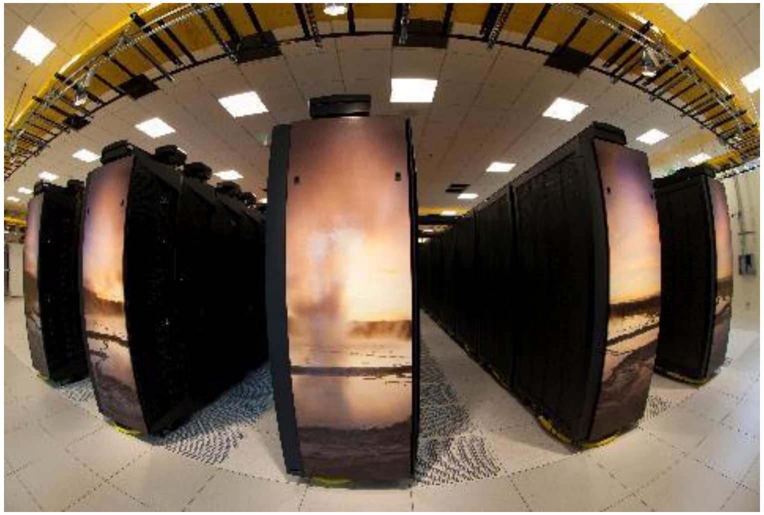


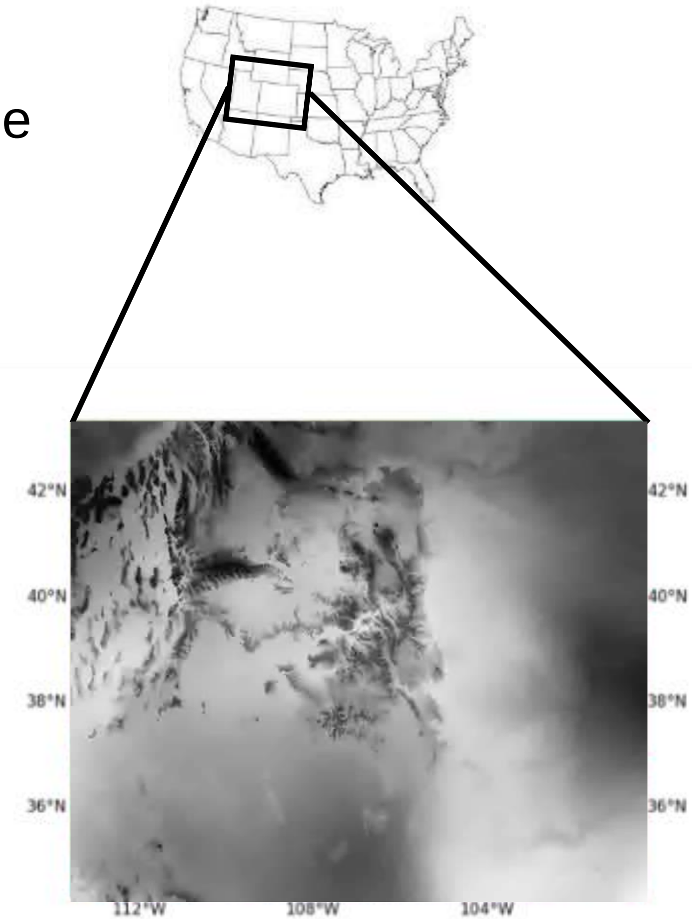
Benefits of Downscaling

- Downscaling provides **local-scale insight**
- Impacts models need **fine-scale and high-temporal resolution climate inputs** (e.g., precipitation, temperature, winds, radiation, moisture)
- Downscaling can **correct for certain biases** of global climate models

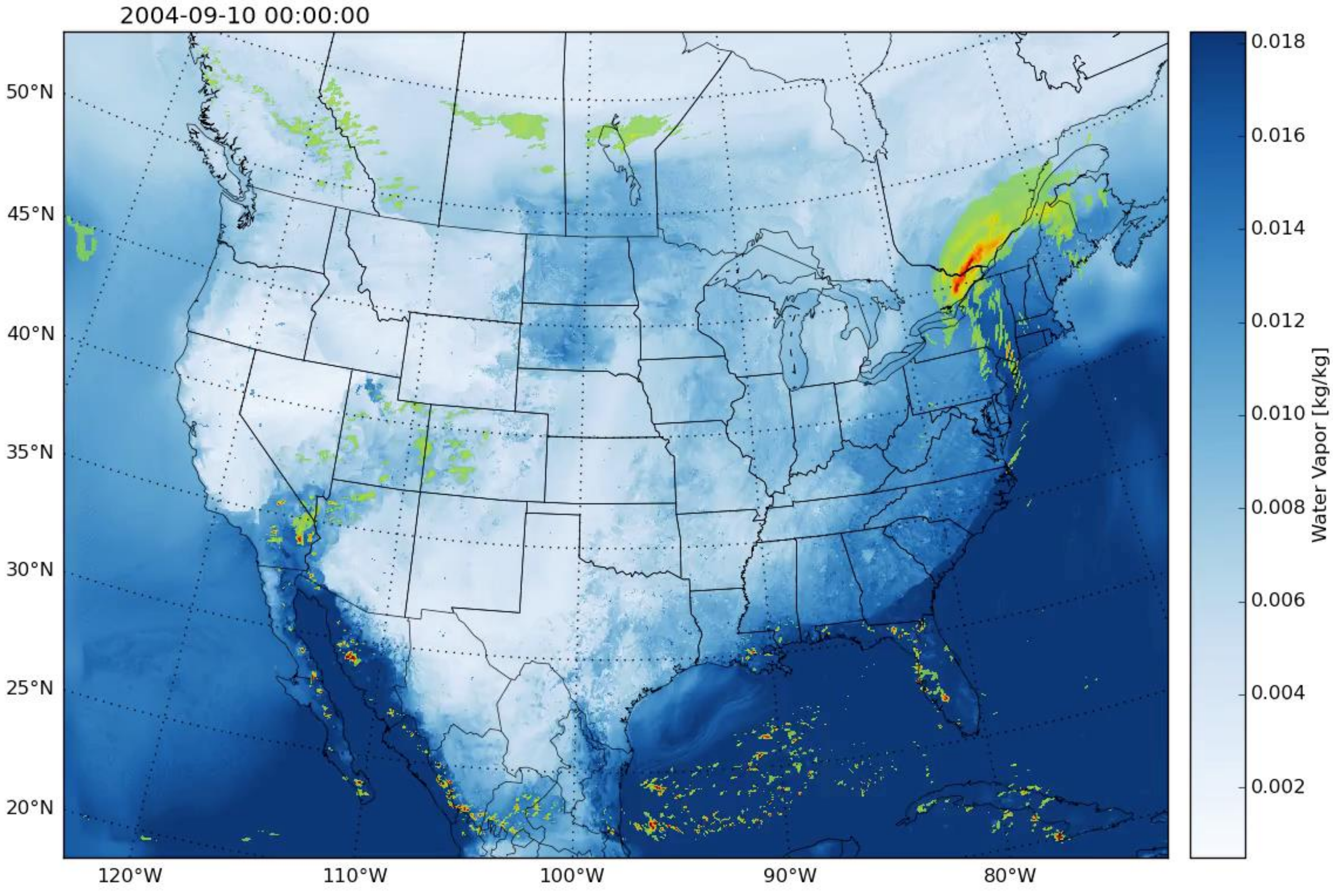
Types of Downscaling: Dynamical

- Uses a high-resolution regional climate model (e.g., WRF) to simulate local dynamics over the area of interest
- Global model output is applied along the boundaries and as initial conditions
- Computationally expensive, time and supercomputers (usually) required

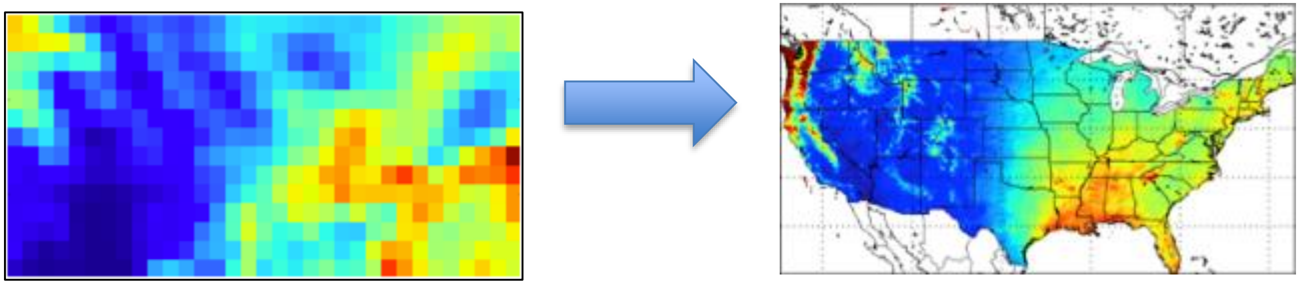




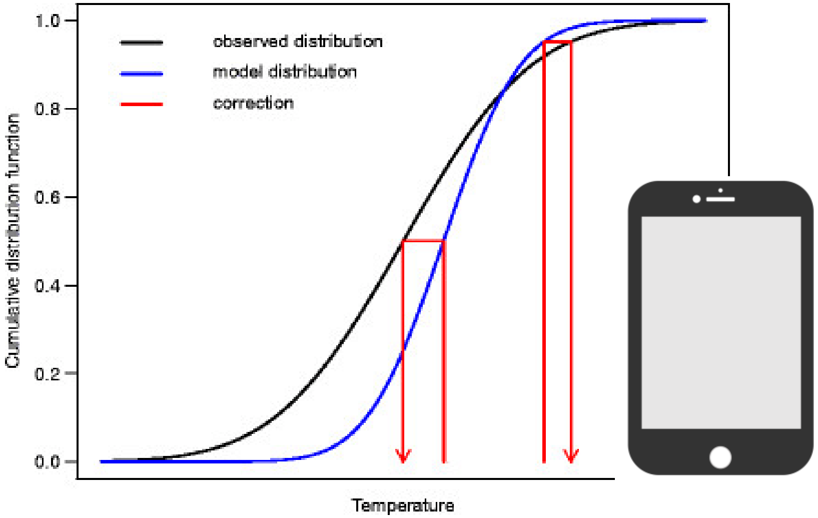
Dynamical Downscaling Output



Types of Downscaling: Statistical



- Uses statistical relationships that relate coarse to fine resolution from historical record
- Stationary statistical relationships then applied to future global model output
- Output usually for subset variables (temperature, precipitation)
- Computationally cheap, quick and can be done anywhere
- Statistical relationships do an excellent job reproducing historical data



Example: Bias correction with spatial disaggregation (BCSD)

Tradeoffs Between Dynamical and Statistical Downscaling

Dynamical

Pros

- **Represents physical processes**
- No stationarity assumptions
- Physically consistent across variables

Cons

- **Computationally expensive**
- Data set availability is limited
- Introduces need for additional ensembles
- Produces climate change signals that still must analyzed for credibility

Statistical

Pros

- **Computationally tractable for large GCM ensembles**
- Large high-resolution data sets publicly available
- Consistent with observations

Cons

- **May not represent climate change signal correctly** (often is effectively just interpolated GCM signal)
- Statistical nature often introduces artifacts

A Continuum of Downscaling Options

increasing physical representation ↑

- Dynamical downscaling using state-of-the-art RCMs
  e.g., Water Research and Forecasting model

- ”Hybrid” (dynamical + statistical) downscaling
  e.g., build statistical emulator using limited set of dynamical runs

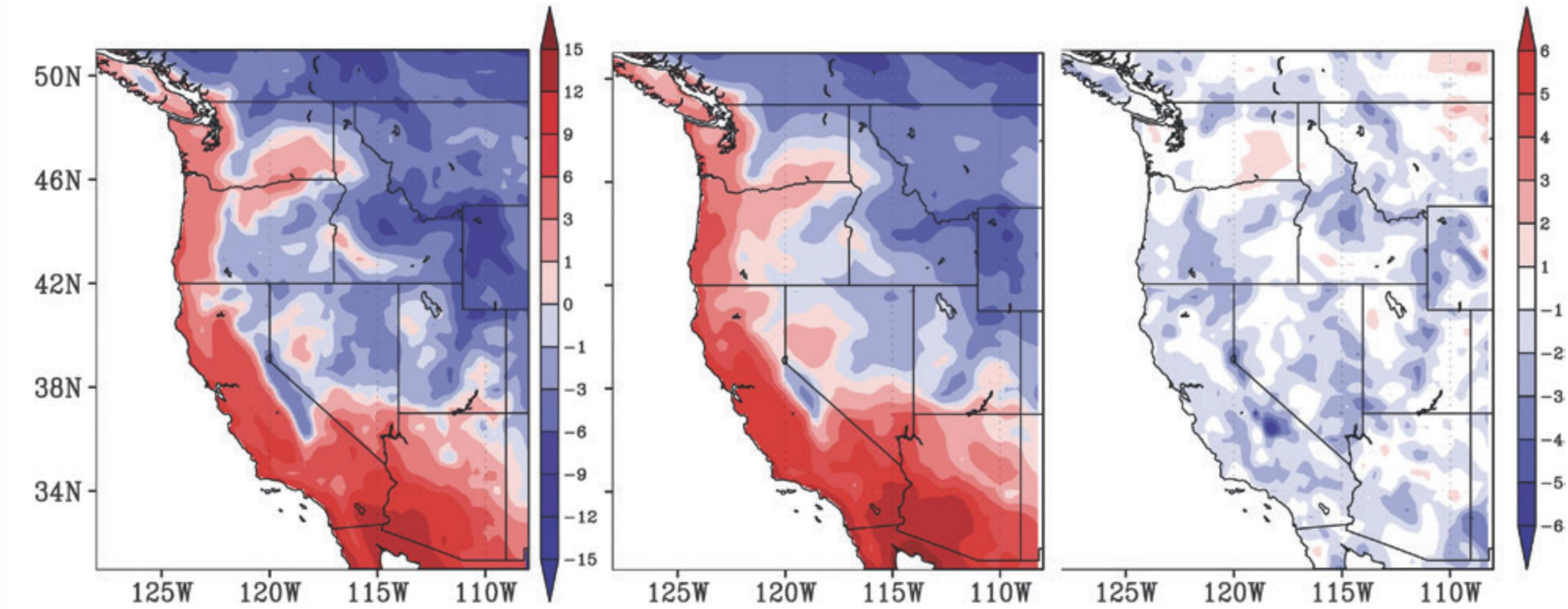
- Physically-based intermediate-complexity atmospheric models
  e.g., Linear Orographic Precipitation model

- Statistical downscaling based on GCM dynamics (water vapor, wind, convective potential, etc.)
  e.g., regression-based, analog, pattern scaling

- Methods to relate downscaled fields to synoptic scale atmospheric predictors
  e.g., self-organized maps, weather typing

- Statistical downscaling based on rescaling GCM outputs
  e.g., BCSD, LOCA, BCCA, linear regression, and more

Simulations in the Northwest



HadRM3P NARR Differences

Winter temperatures

from OSU’s Weather@home project, 1979-2009

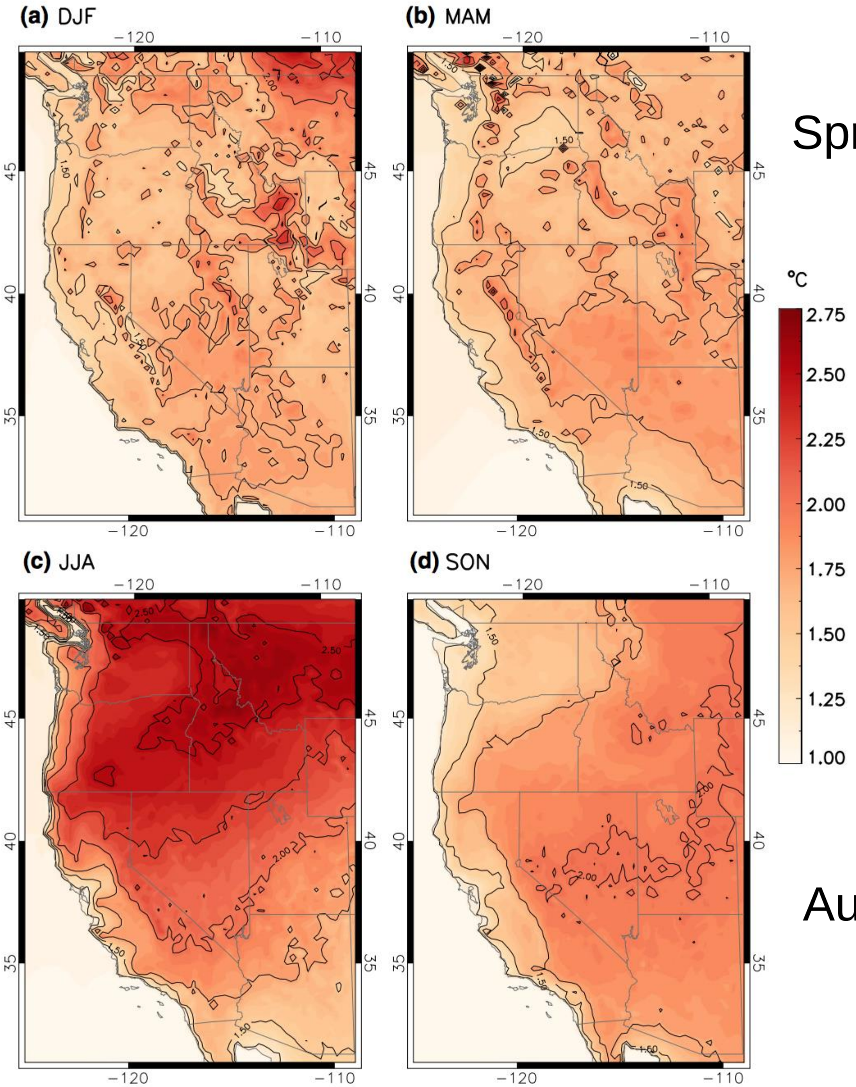
Regional Climate Simulations with Crowdsourced Computing, Mote et al. BAMS 2015

NARR = North American Regional Reanalysis; HadRM3P= high-resolution, regional configuration of HadAM3

Simulations in the Northwest

Winter

Spring



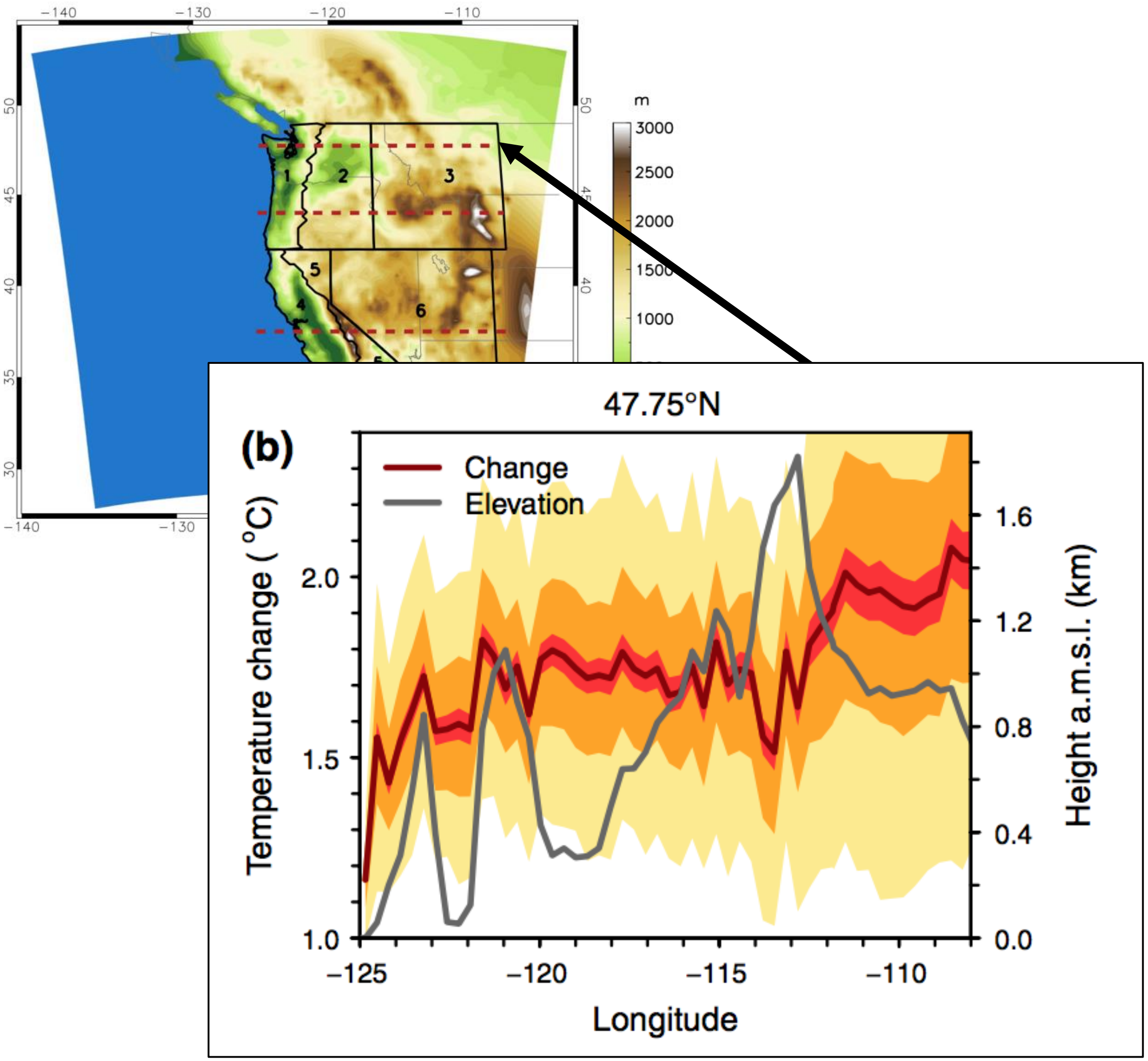
Summer

Autumn

Change in ensemble mean temperature, 1985-2014 to 2030-59 for RCP 4.5

Rupp et al., HESS, 2016

Simulations in the Northwest



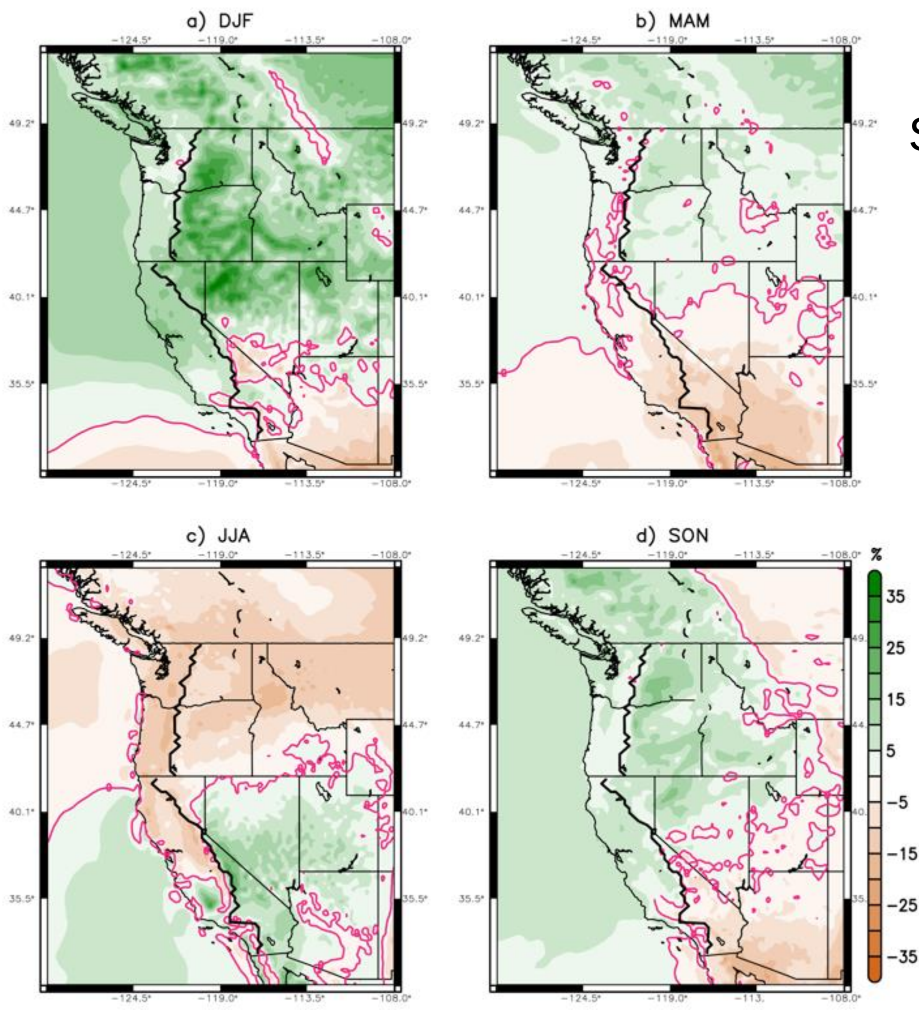
Rupp et al., HESS, 2016

Temperature changes at 47.75ºN, 1985-2014 to 2030-59 for RCP 4.5

Simulations in the Northwest

Winter

Spring



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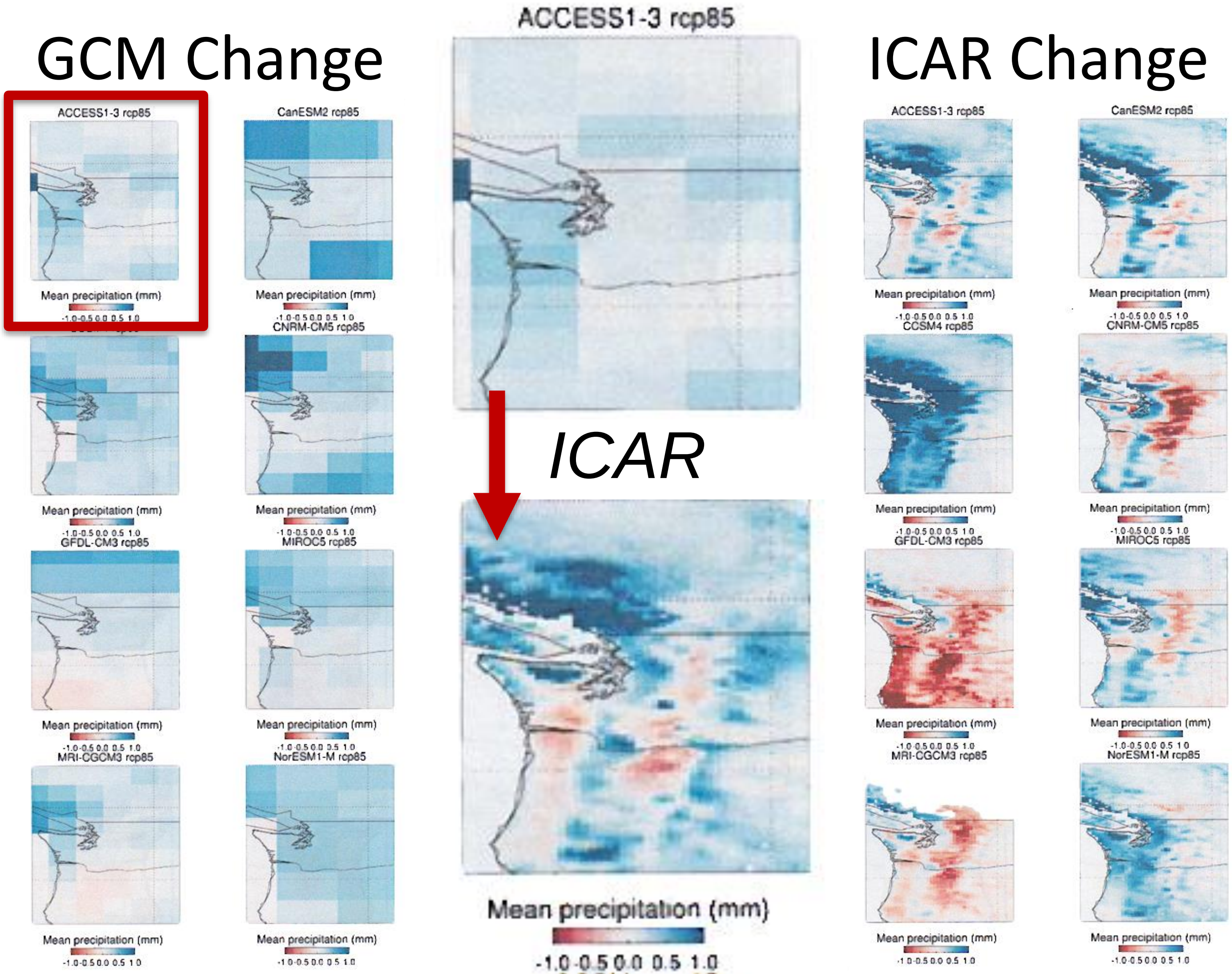
Change in ensemble mean precipitation, 1985-2014 to 2030-59 for RCP 4.5

Li et al., in prep, figure courtesy of Phil Mote

Simulations in the Northwest

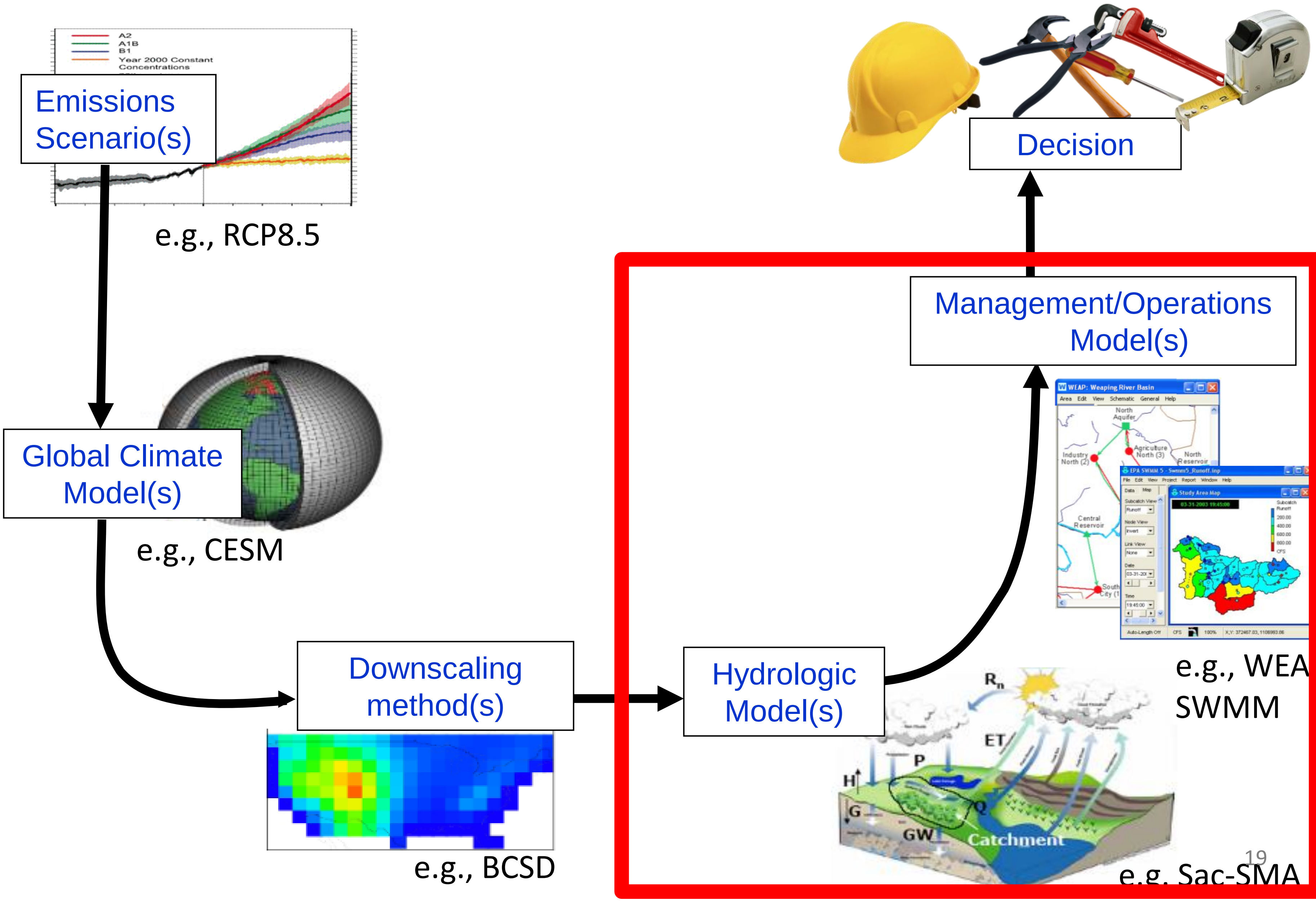


from NCAR's Intermediate Complexity Atmospheric Research Model, Gutmann et al. 2016
More at: https://ncar.github.io/hydrology/models/

Questions to Help Determine an Appropriate Downscaling Technique

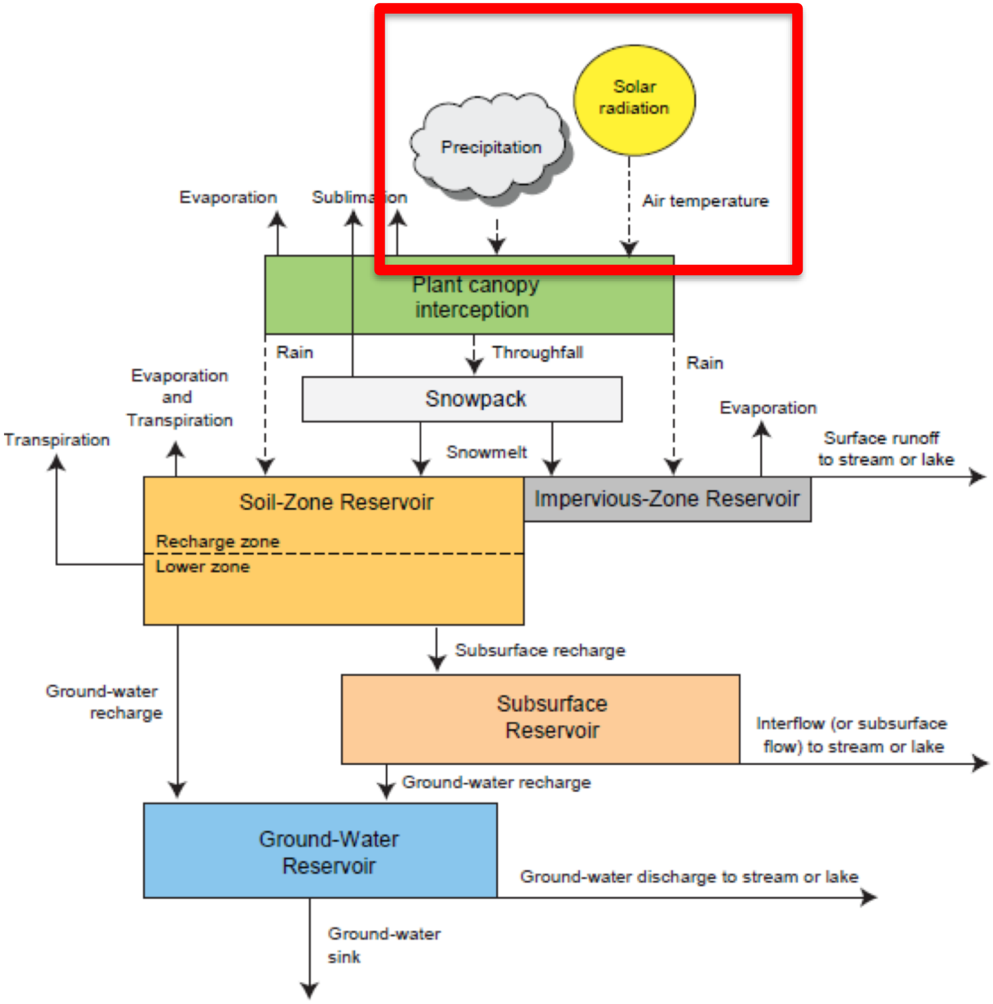
- How large is the area of interest?
- Where is it?
- What is the impact of interest?
- When in the future?
- Does the sequencing of events matter?
- What type of climate change uncertainty is important?
- What is available?

Classic "Top-down" Impacts Modeling Chain



What type of models do you use to track water in your system?

Why Do We Need Hydrology Models?



What we have: precipitation, temperature, other atmospheric values

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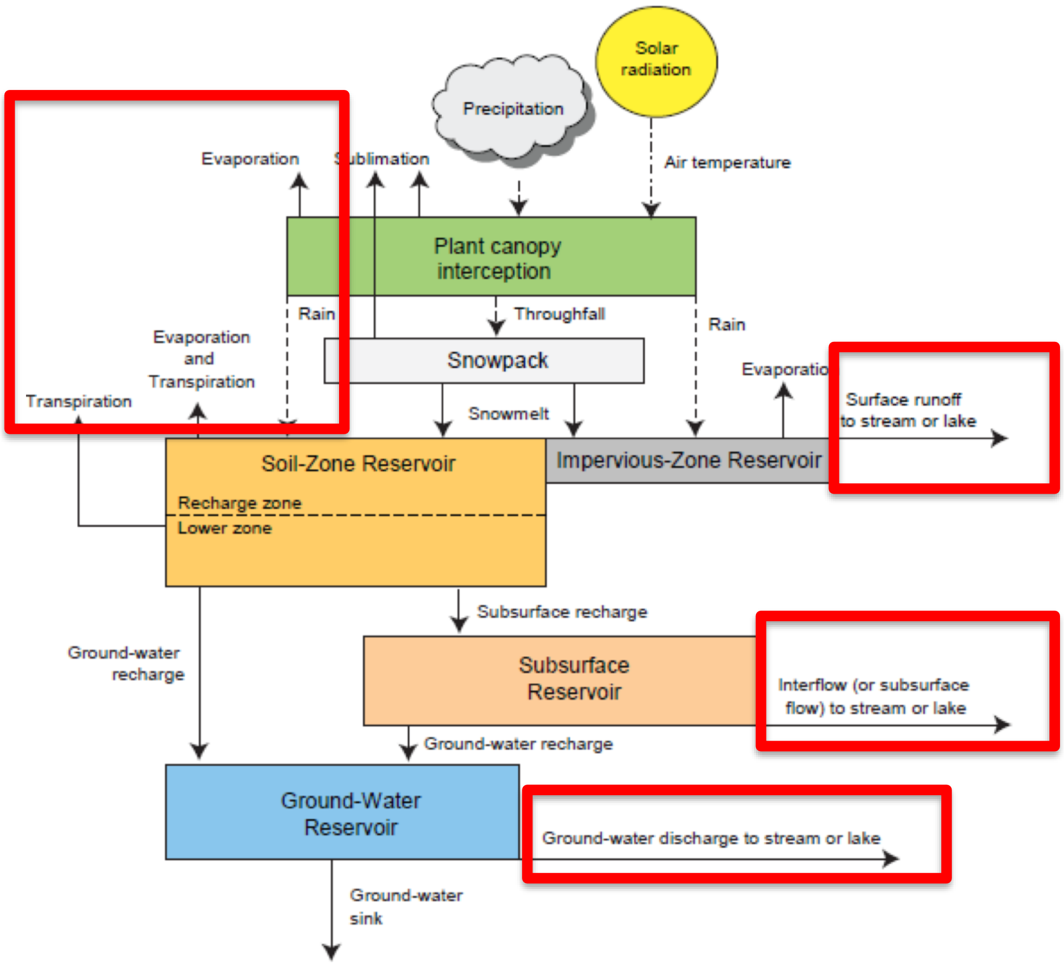

What we have: precipitation, temperature, other atmospheric values

What we would like: streamflow (highs, lows), water demand from vegetation, water temperature

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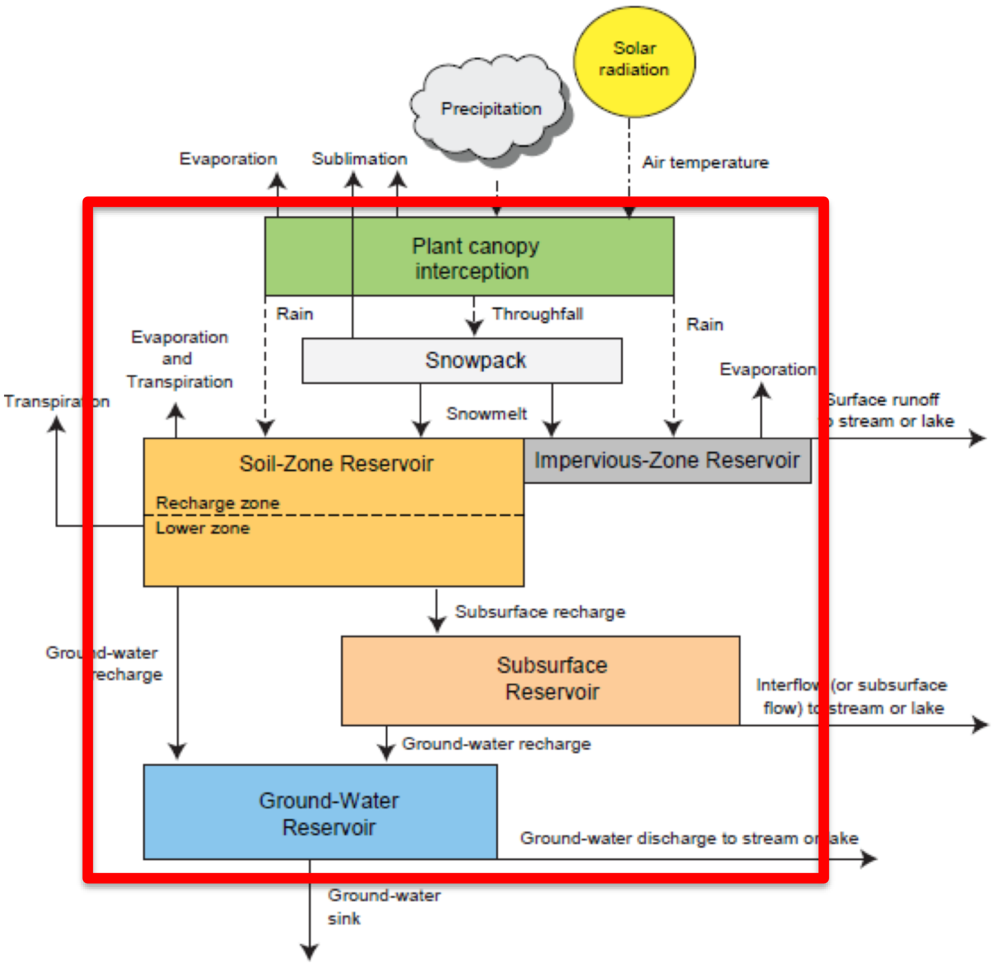


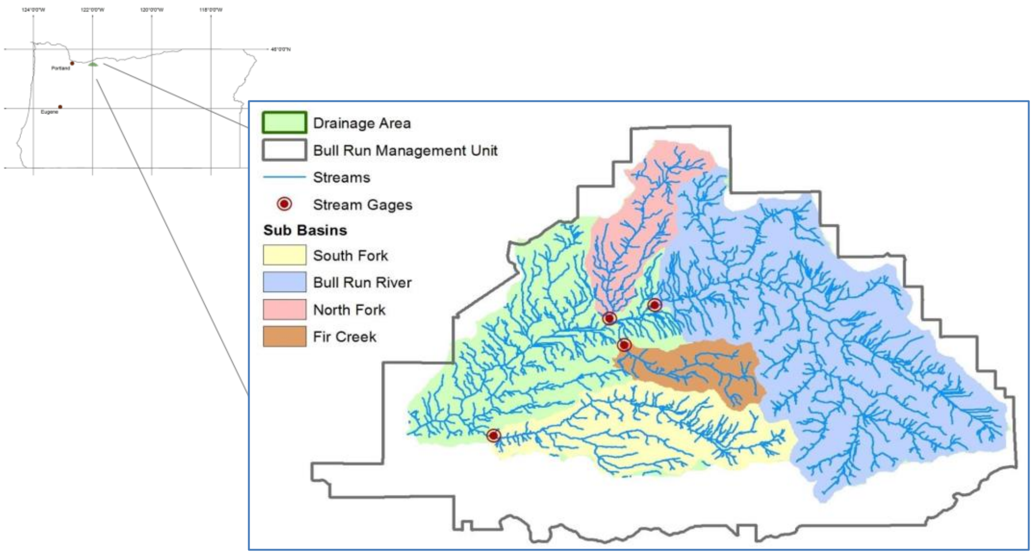
What we have: precipitation, temperature, other atmospheric values

What we would like: streamflow (highs, lows), water demand from vegetation, water temperature

Hydrology models represent energy and water fluxes in watersheds, combine measurements and physical processes to encapsulate our understanding.

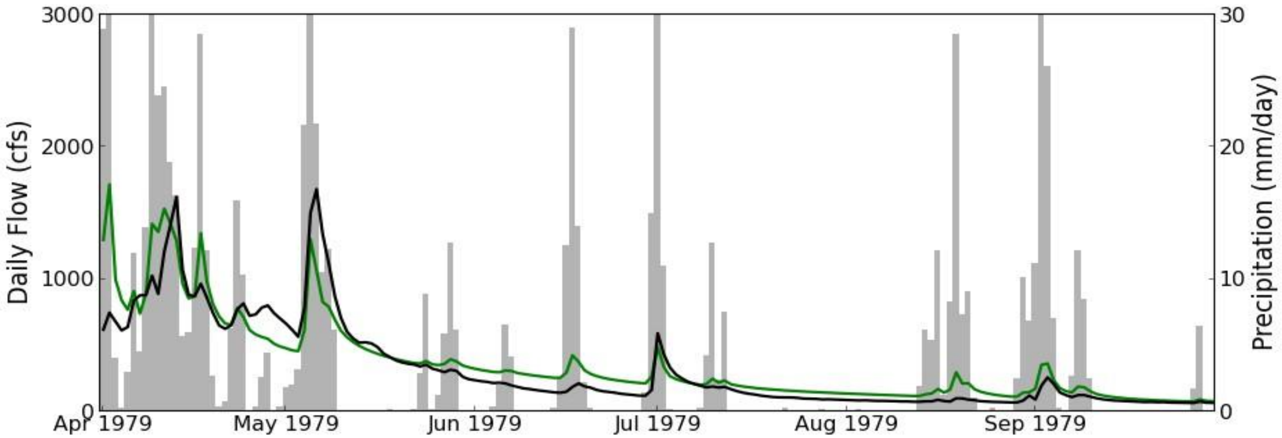
Important in filling gaps since measurements are not available in most places.

Modeling Benefits



Portland Water Bureau

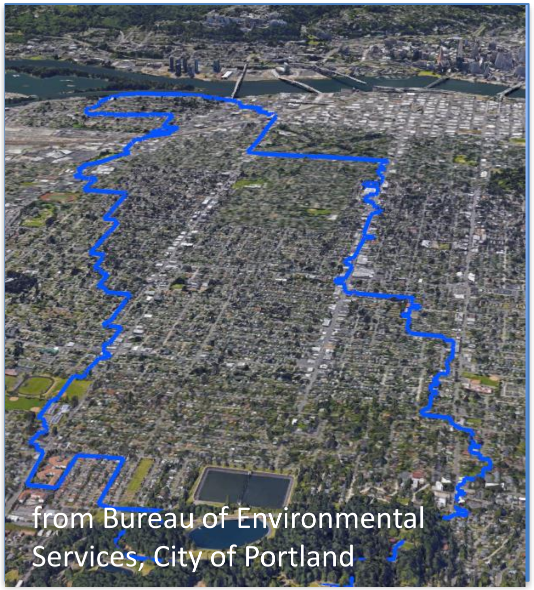
- Land surface values from GCMs measures not helpful
- Worked with University of Washington to select and set up in-house hydrologic model
- Model allows PWB to understand how changes in streamflow affect future supply conditions
- Included in Supply System Master Plan



Modeling Cautions

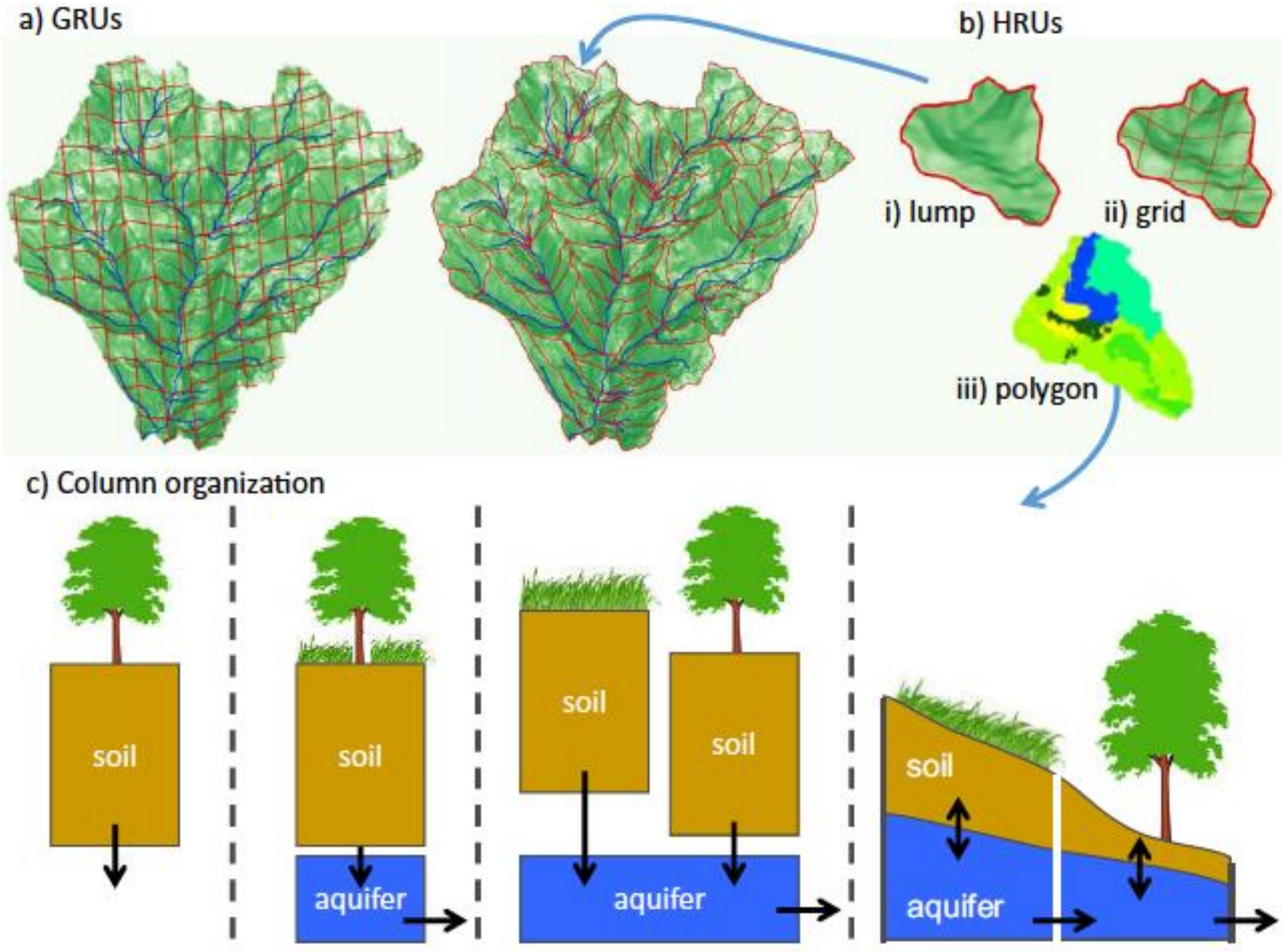
- Models built to represent many landscapes, processes, spatial configurations+
- May miss key elements
  - Snow redistribution
  - Groundwater interactions
- Important to be a savvy user

from Cedar River Watershed Education Center

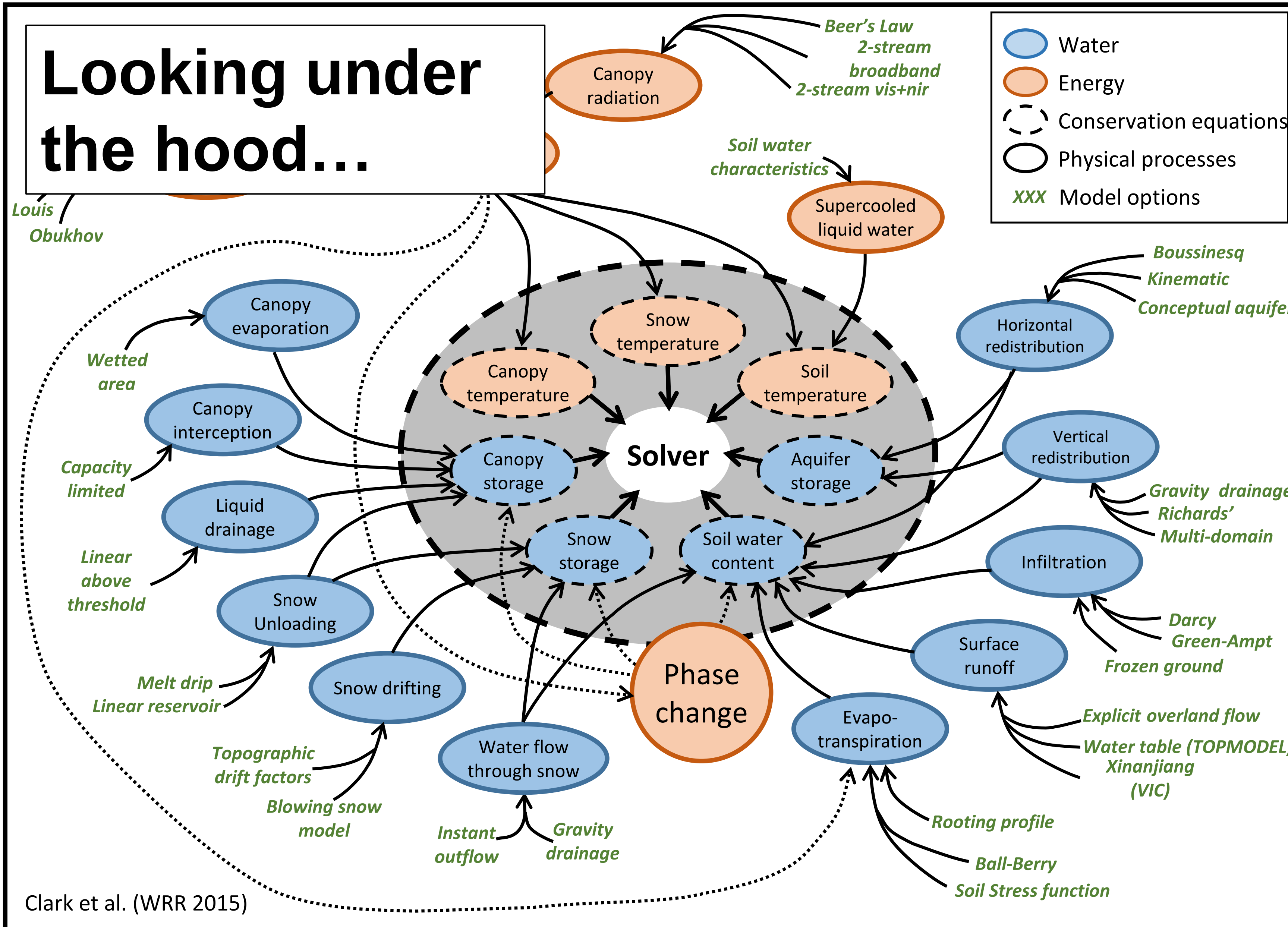


from Bureau of Environmental Services, City of Portland

Hydrologic Model Spatial Structures

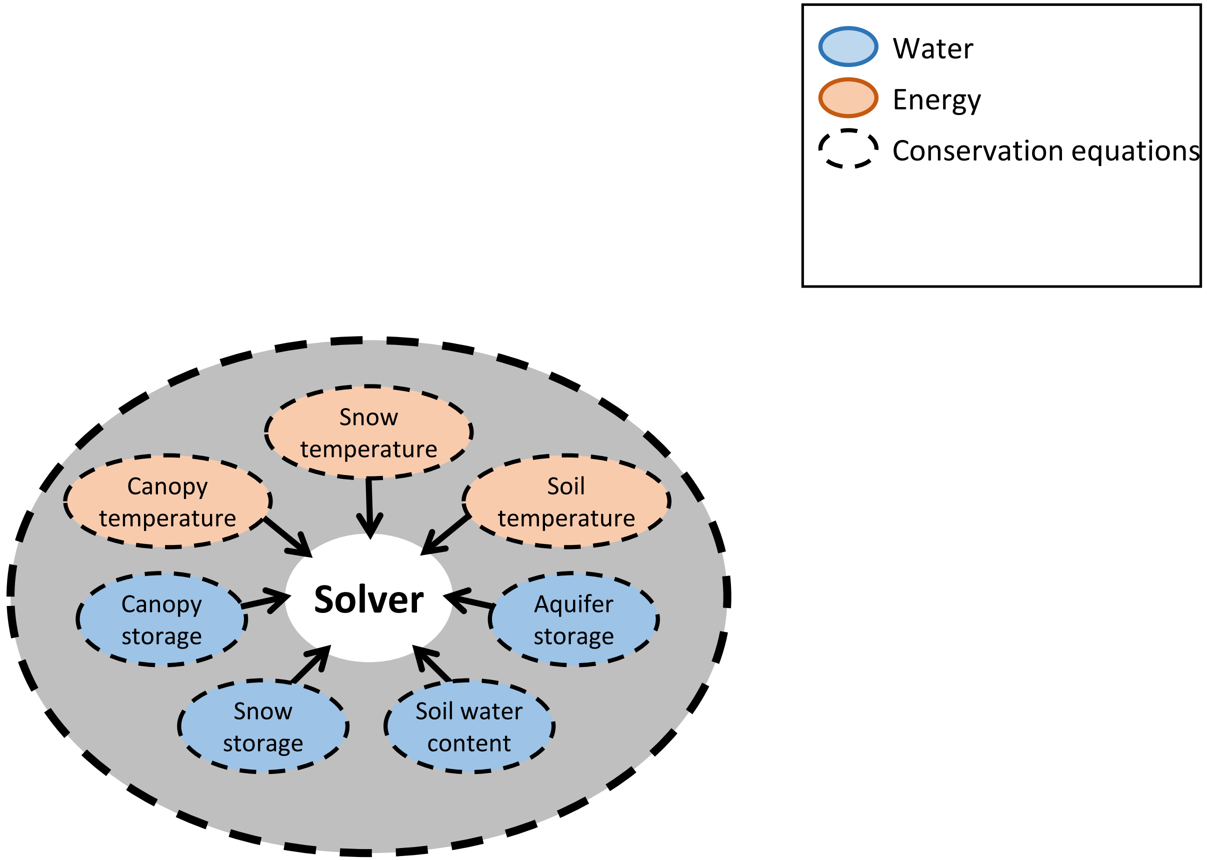


Hydrologic Model Process Structure



Clark et al. (WRR 2015)

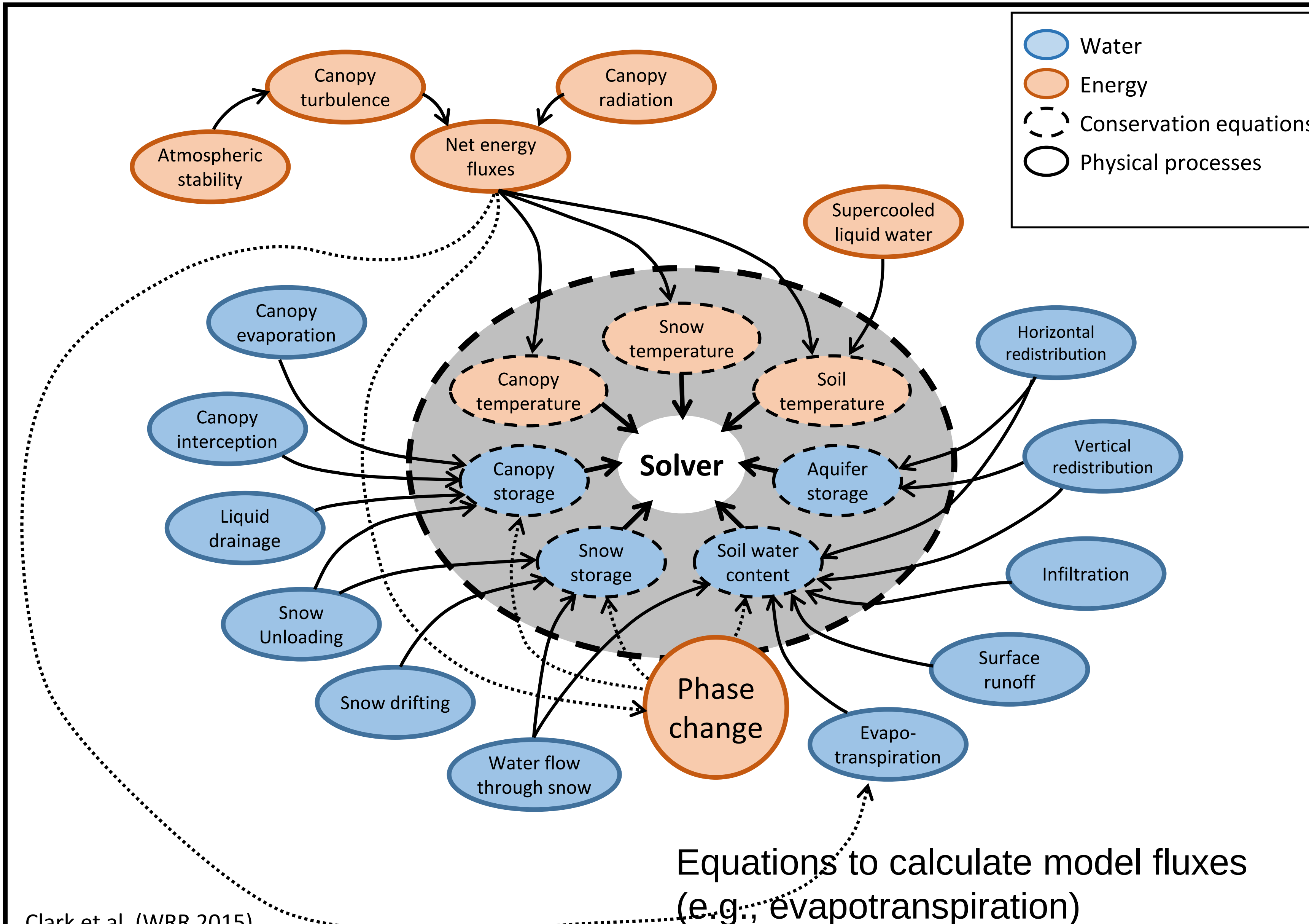
Hydrologic Model Construction



Conservation equations, the order they are solved and time step matter

Clark et al. (WRR 2015)

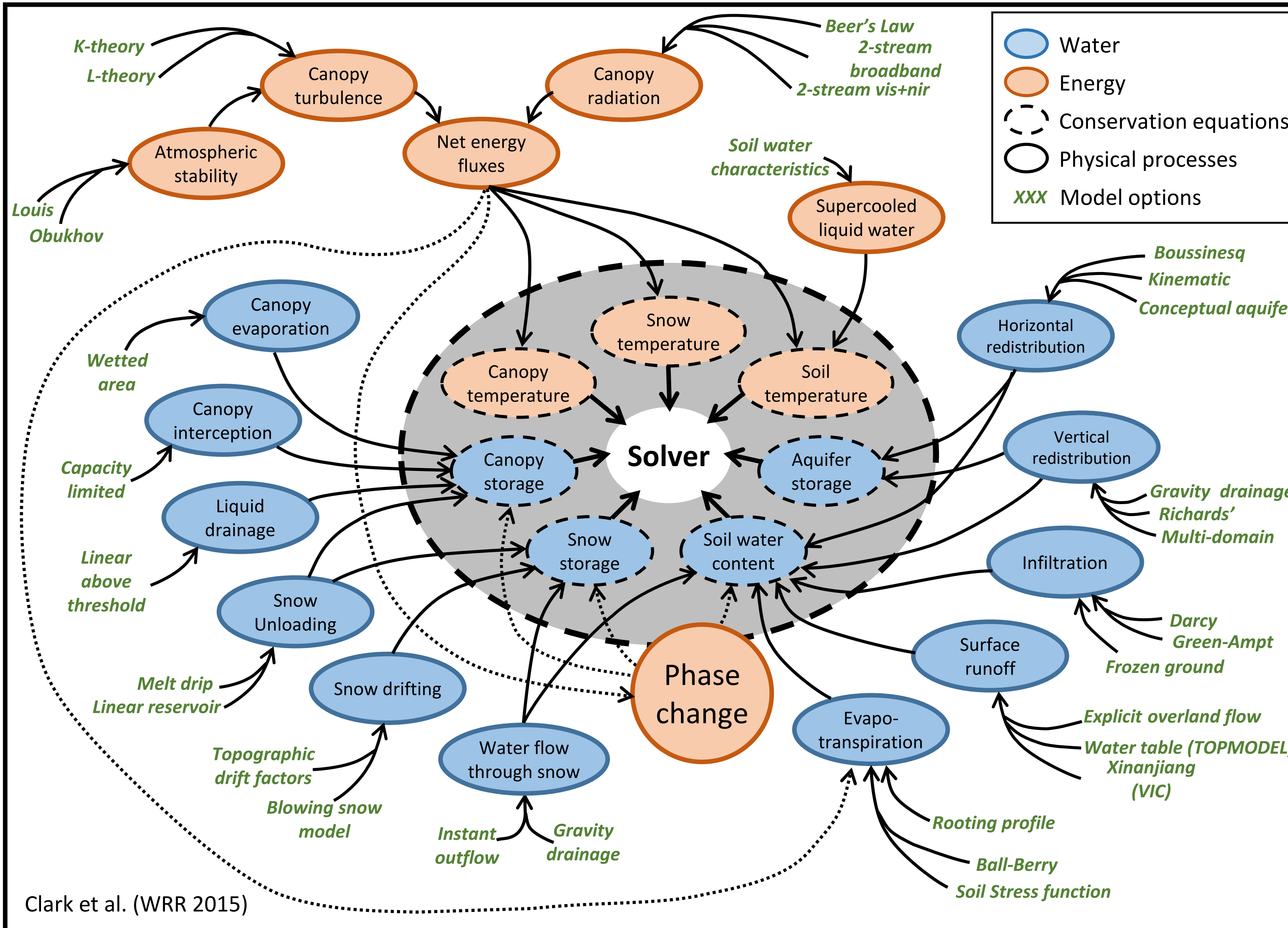
Hydrologic Model Construction



Equations to calculate model fluxes (e.g., evapotranspiration)

Clark et al. (WRR 2015)

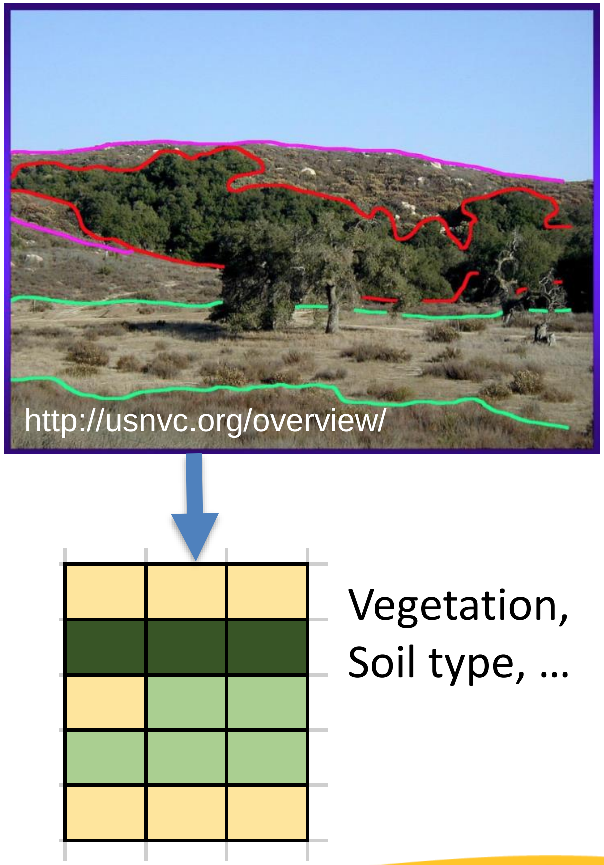
Hydrologic Process Flexibility



Clark et al. (WRR 2015)

Model Parameters

- Parameters can represent real-world vegetation, soil type
- Calibrated parameters can compensate for other errors
- Compensating errors can respond differently to climate change
- Check robustness by exploring multiple parameter sets



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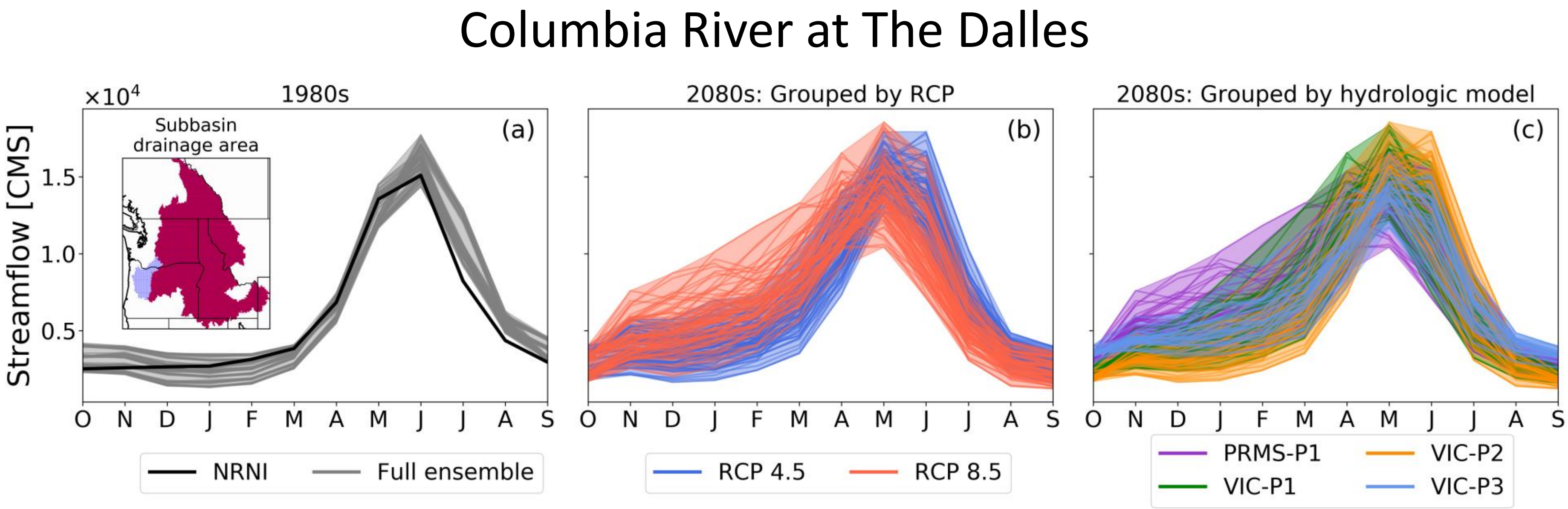
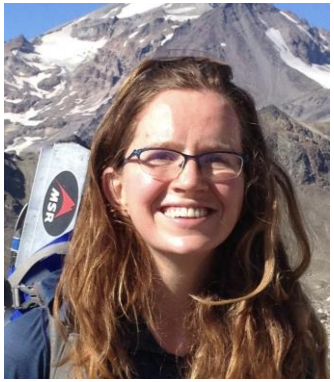


RMJOC-II: Predicting the Hydrologic Response of the Columbia River to Climate Change

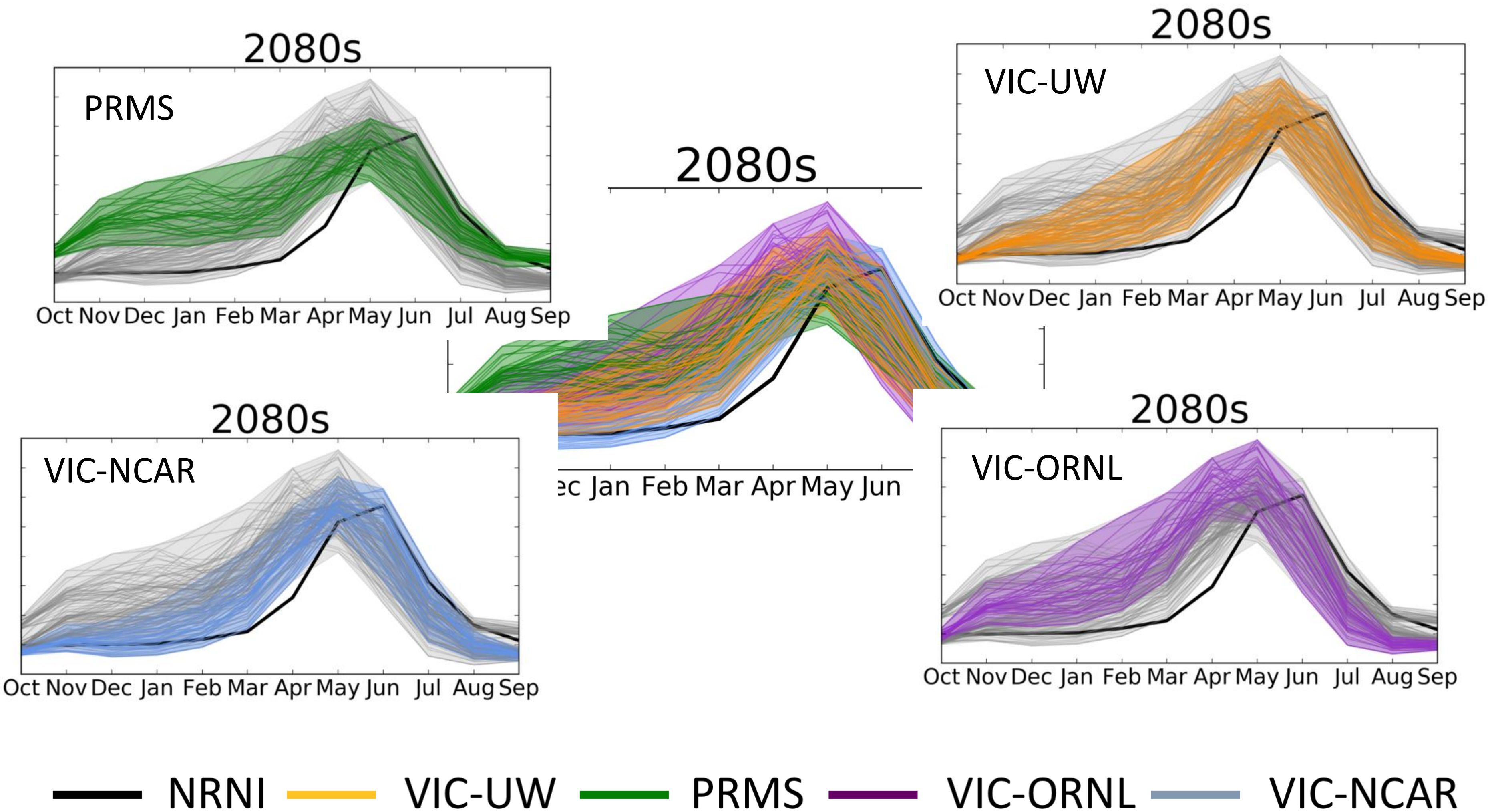
Project at UW and OSU

Data available at:
hydro.washington.edu/CRCC



Simulations in the Northwest

Columbia River at The Dalles

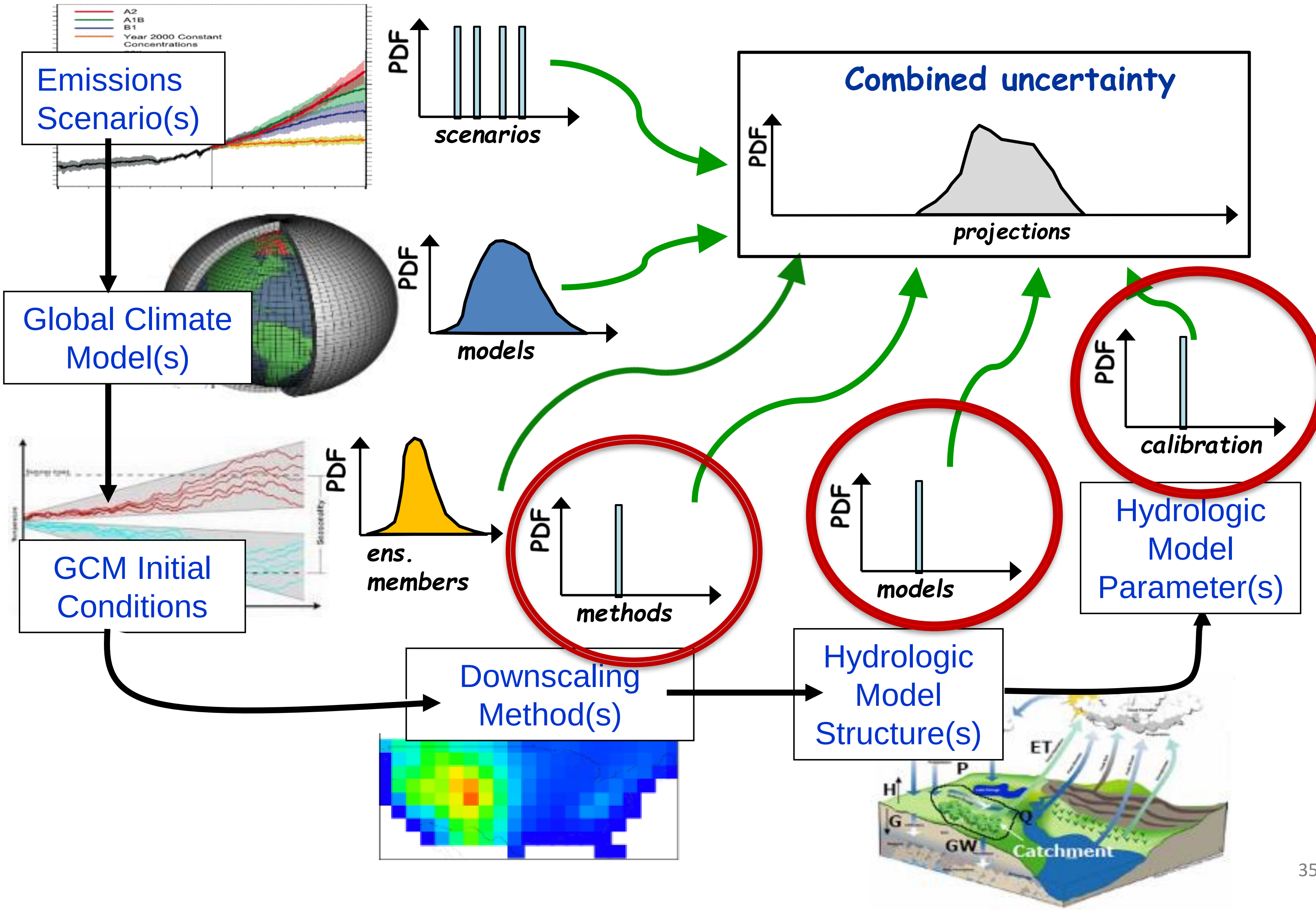


**comparisons made prior to bias correction, pre-released version of dataset for illustration only*

What Do Models Tell Us?

- Many responses to climate change are "obvious" but some are not
- Hydrology-climate interactions not always linear
  - Rain-on-snow events
  - Slower snow melt in a warmer world
- Tipping points can be hard to detect
- Models encapsulate our understanding of the system, but far from perfect

Revealing Uncertainties



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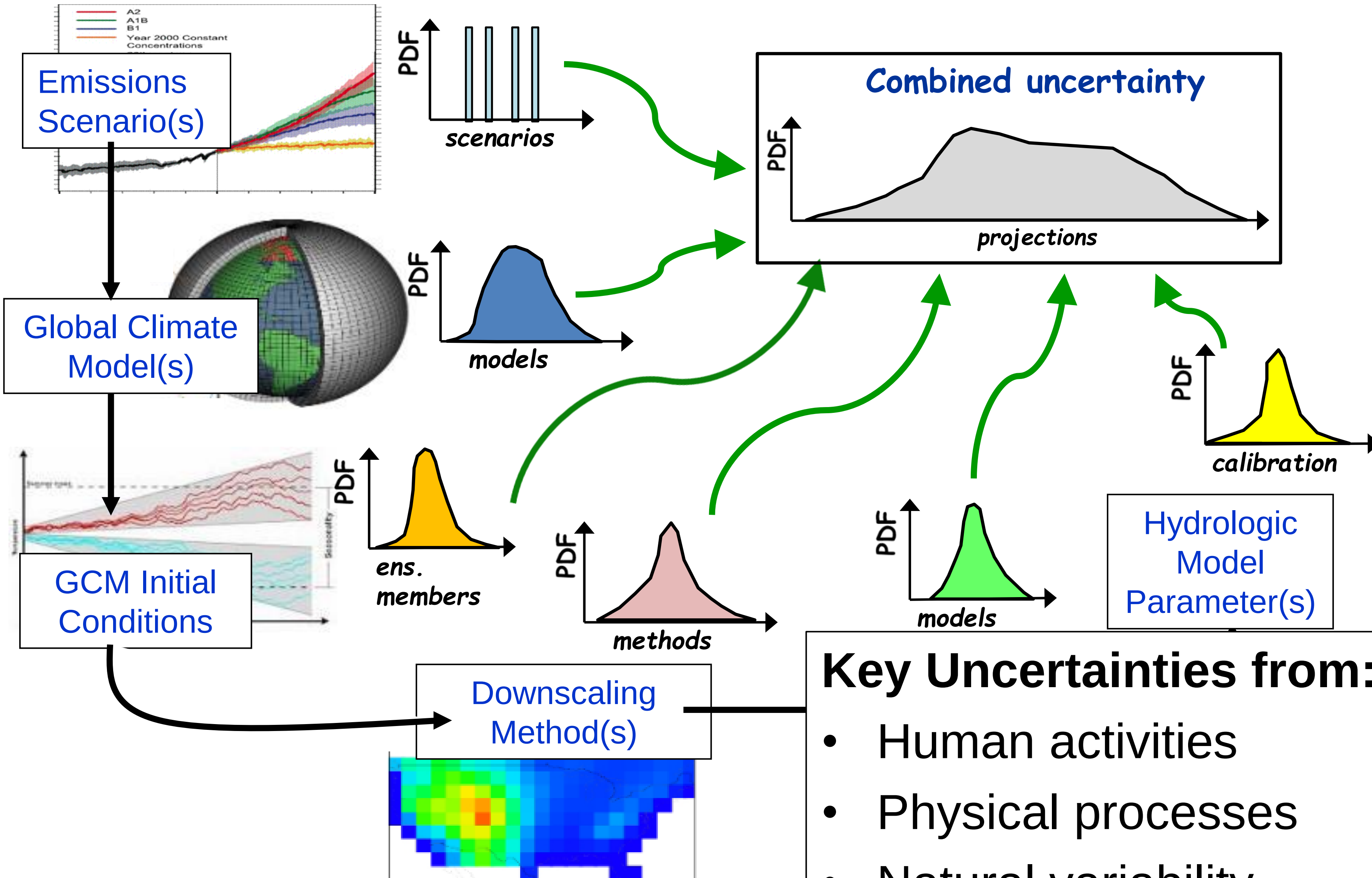
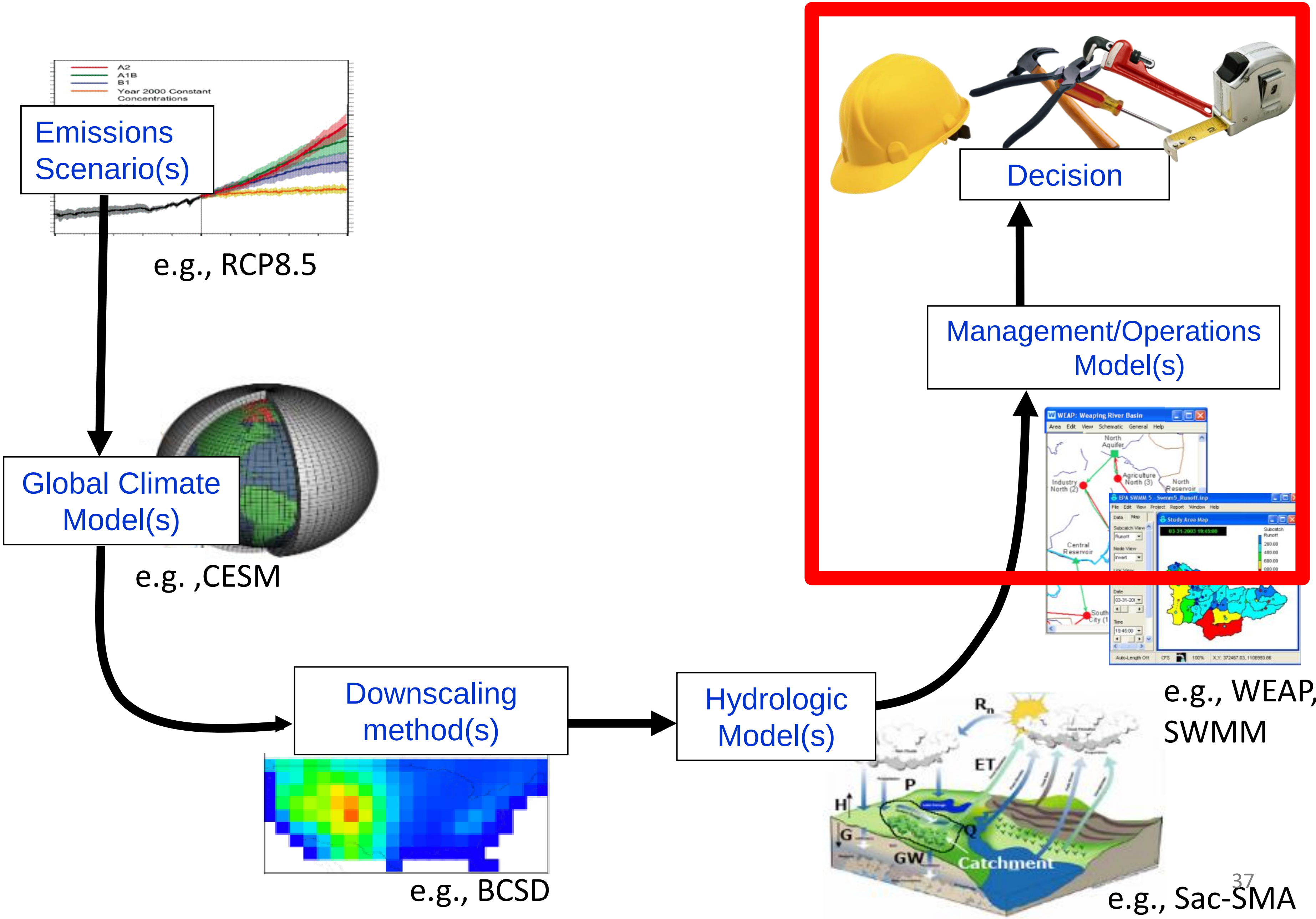


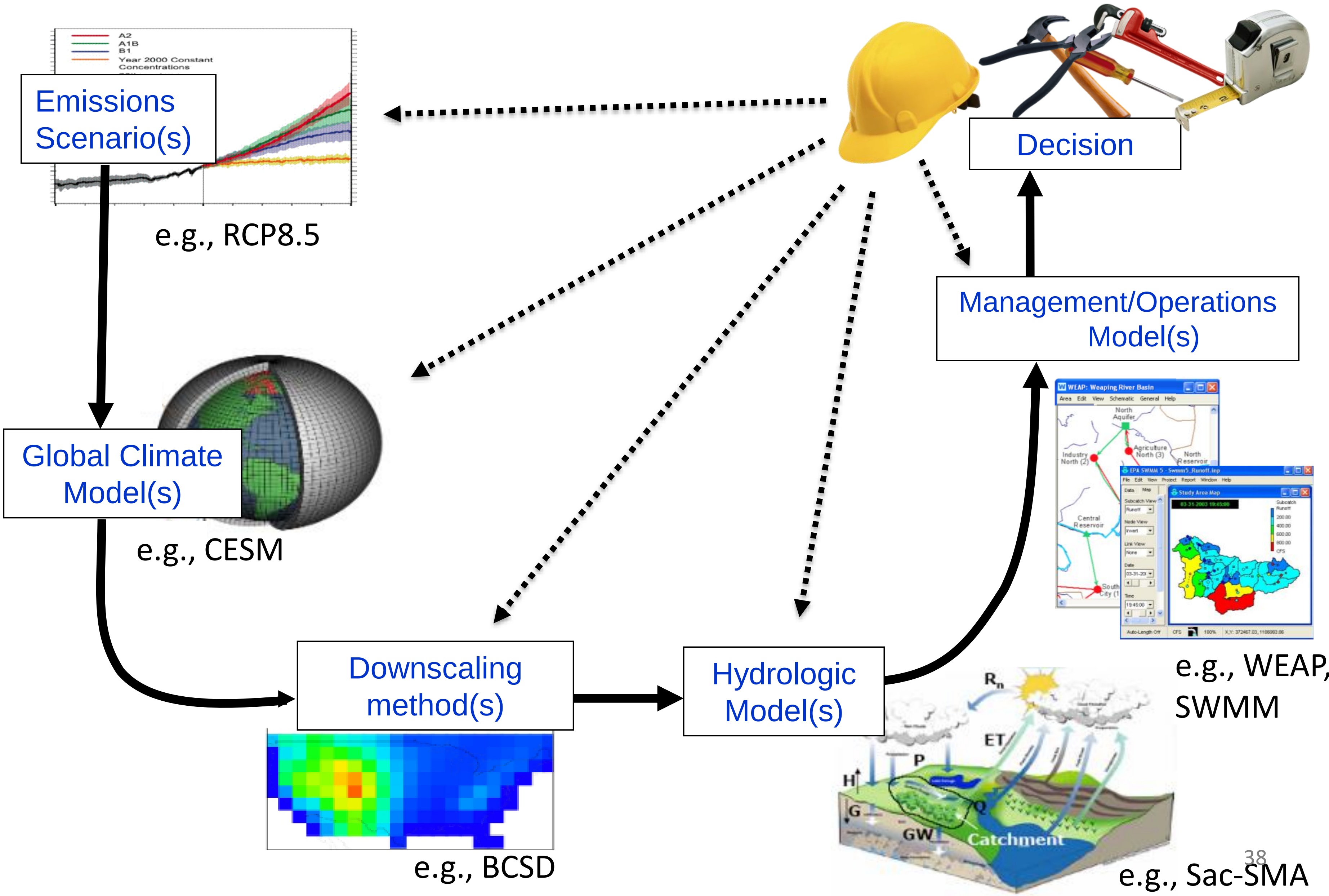
Key Uncertainties from:

- Human activities
- Physical processes
- Natural variability

Classic "Top-down" Impacts Modeling Chain

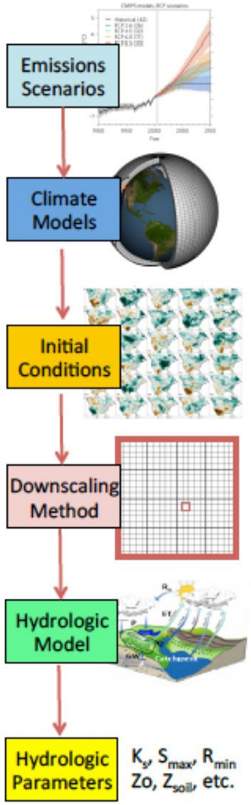


Revised "Top-down" Impacts Modeling Chain



Do Be Aware of Multiple Ways to Evaluate Future Changes

Scenario studies



Clark et al. 2016; connect models in a chain

Stochastic hydrology

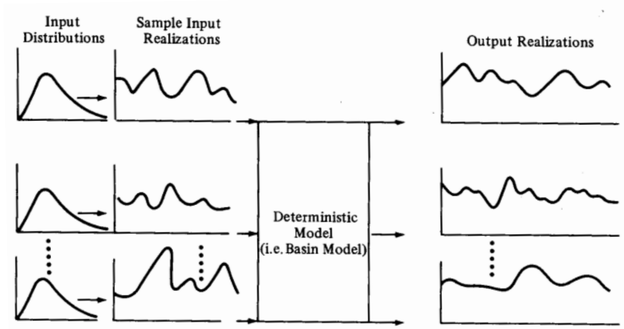
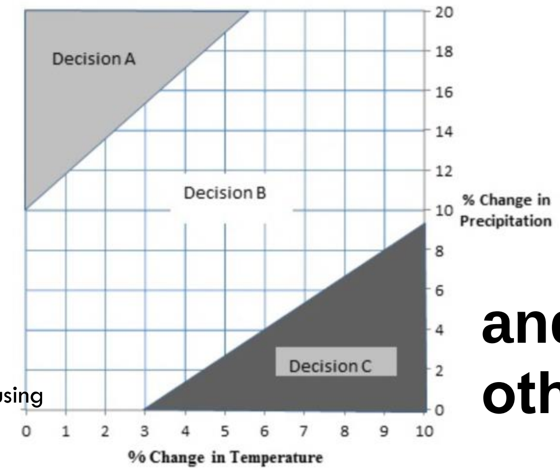


Figure 1.3 Concept of Monte Carlo experiments.

Bras and Rodriguez-Iturbe, 1985; generate synthetic timeseries using statics from the past

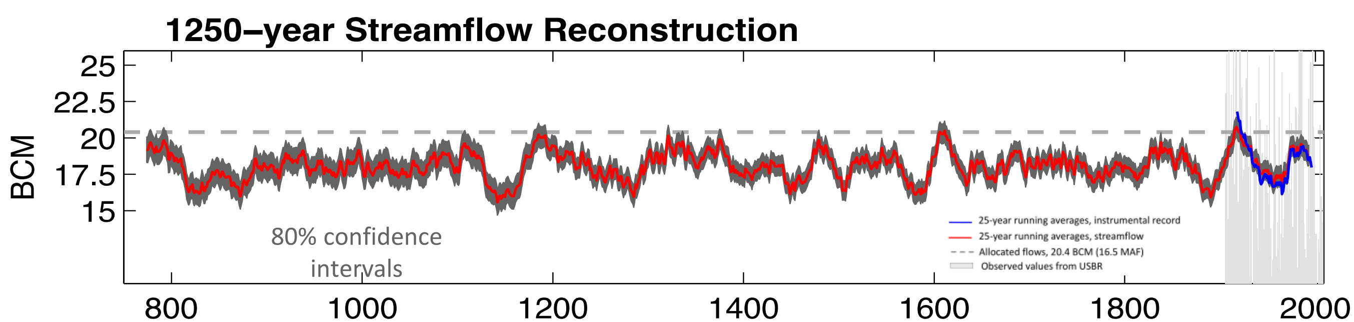
Climate-informed vulnerability analysis



Brown et al., WRR, 2016; explore system vulnerabilities with perturbations

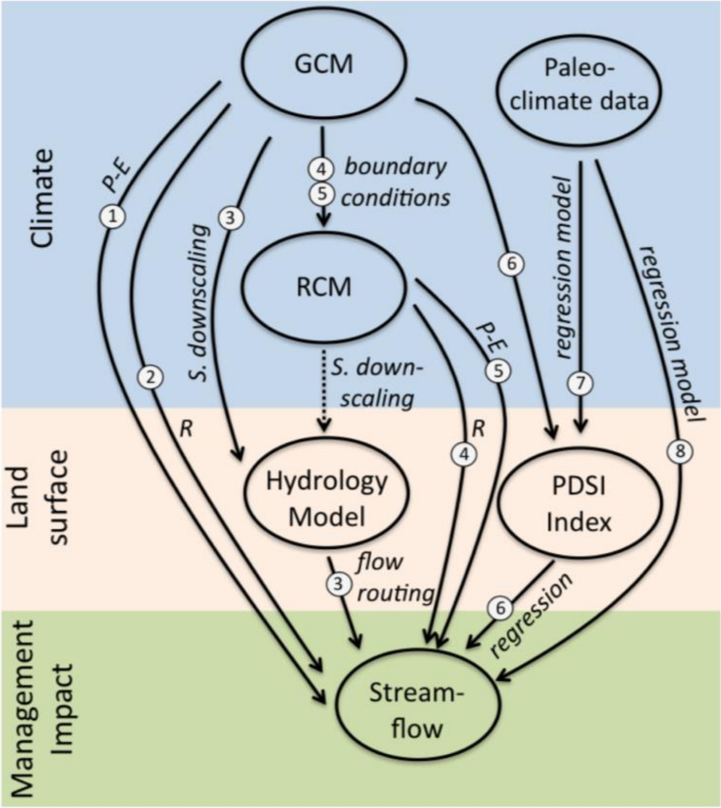
and others…

Paleoclimate studies



Vano et al., BAMS, 2016; generate timeseries using reconstructions of the distant past

Don't Treat All Future Projections or Methods Equally



Different: GCMs, emission scenarios, spatial resolution, hydrology, +

- Certain models and methods are more appropriate
- Certain spatial and temporal scales are more appropriate for certain questions
- Realize some questions may not be possible to answer with current knowledge
- Finer resolution in space and time is not necessarily better
  - Higher Resolution ≠ Higher Accuracy

Be a savvy consumer and remember…

Figure from Vano et al., BAMS, January 2014

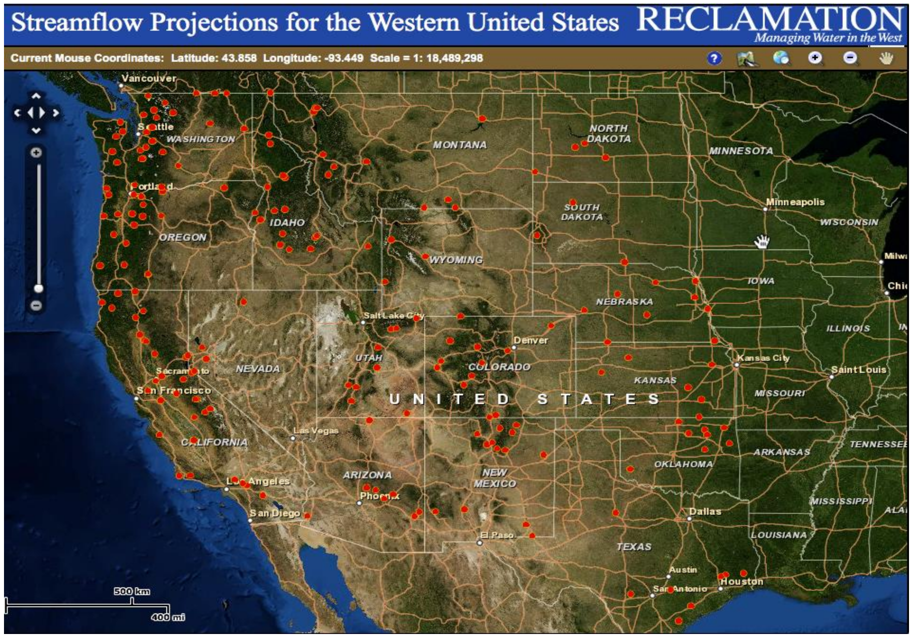
No Model is Perfect

"The accuracy of streamflow simulations in natural catchments will always be limited by simplified model representations of the real world as well as the availability and quality of hydrologic measurements." (Clark et al., WRR, 2008)

- **Don't expect perfect results,**
  - Not prediction, but a tool to test how system responds (what if scenarios)
- **BUT we can make better choices…**
  - Seek simple yet defensible (don't need a Cadillac)
  - Be aware of models shortcomings (know the warts)

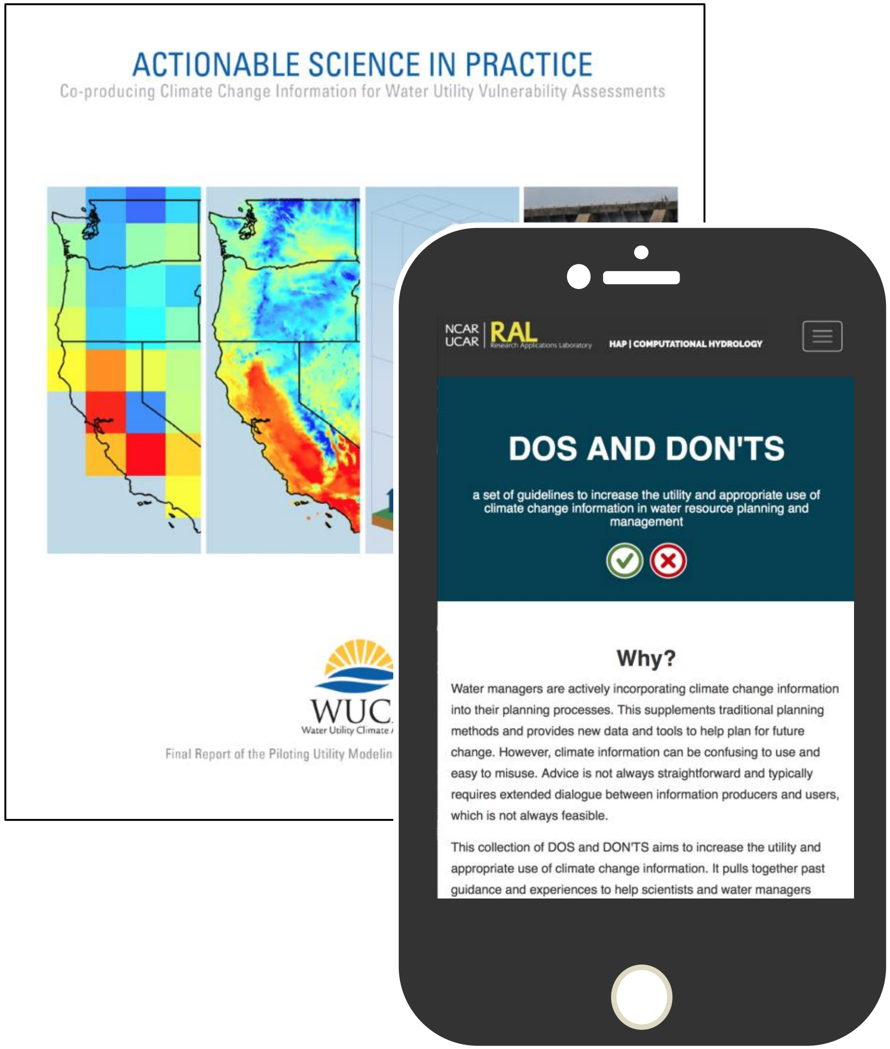
What Data are Available Now?

- Hydrology focused Green Data Oasis (GDO) portal
  - BCSD (12km), LOCA (6km)
  - VIC streamflow
- Dynamical
  - NARCCAP (50km),
  - CORDEX (limited 25km)
  - Others over regional domains or limited time periods
- USGS GeoDataPortal
  - Collection of different archives
- Northwest Knowledge Network
  - MACA (6 km, 4 km)
- RMJOCII, Columbia River Climate Change
  - BCSD, MACA
  - VIC, PRMS streamflow
- Many others (NASA NEX, ARRM)

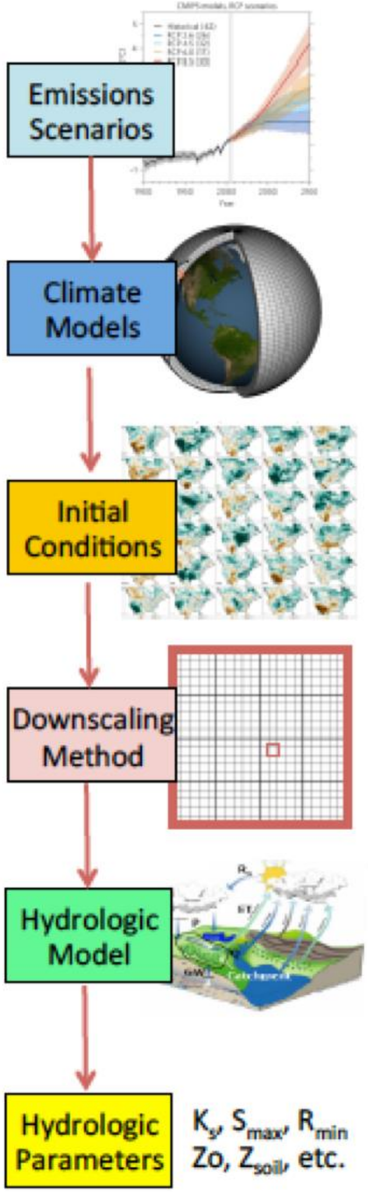


What Resources are Available?

- WUCA products
  - PUMA project examples
  - www.wucaonline.org
- Federal Agency Guidance
  - Bureau of Reclamation
  - U.S. Army Corps of Engineers
  - Environmental Protection Agency
  - U.S. Climate Resilience Toolkit
- Professional Societies
  - American Society of Civil Engineers
- Regional Boundary Organizations
  - Climate Impacts Research Consortium (NOAA RISA) at OSU
  - Climate Impacts Group, UW
- Dos and Don'ts Guidelines from NCAR
  - Reviews other guidance
  - www.ncar.github.io/dos_and_donts
- Many others, including each other



Climate Change Study Choices



Clark et al. 2016

- Approach type (e.g. scenarios, paleo, vulnerability analysis):
- Emission scenarios used:
- GCMs used:
- Number of initial conditions for each GCM used:
- Downscaling methods used:
- Hydrologic models and parameter sets used:
- Time period of interest (transient or delta):
- Project timeline:
- Impacts evaluated:
- Results reported (ensembles, individual simulations):

Key Takeaways

- Downscaling and hydrology modeling provide **local-scale insights** into possibilities projected by GCMs.
- There is a continuum of downscaling approaches that span tradeoffs between computational efficiency and methodological complexity.
- Some change signals are more certain than others.
- Some uncertainty is unavoidable.
  - Representation of uncertainties is hard but necessary.
  - Uncertainties have always been there; just understanding them now.
  - Previous studies may be over-confident.

Key Takeaways

- Research underway to develop ways to select representative set of scenarios useful for water resources planning.
- It is critical to understand important processes and uncertainties in **your** system.
- Models are tools that can be useful, if used appropriately. **Be a savvy consumer.**
- Consult local experts and national resources, e.g., OSU, UW, NCAR https://ncar.github.io/dos_and_donts