Evaluation of three climate downscaling techniques in forcing a coupled hydrological model in a snow-dominated watershed in the Lake Tahoe basin

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The problem, the solution?

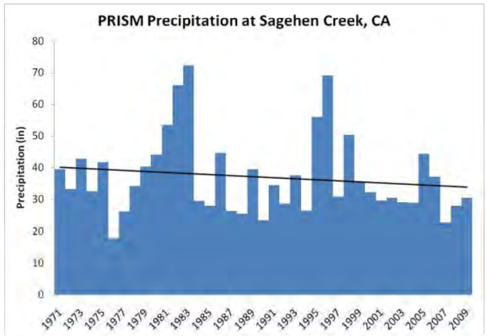
- Hydrological models require fine-scale resolutions data (10m -1km)
- What is the contribution from coarse-scale GCM resolution (~100km) for hydrological impact assessment?
- Appropriate downscaled climate predictions is an important step.

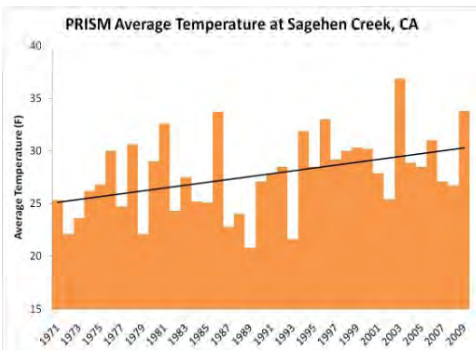
Introduction

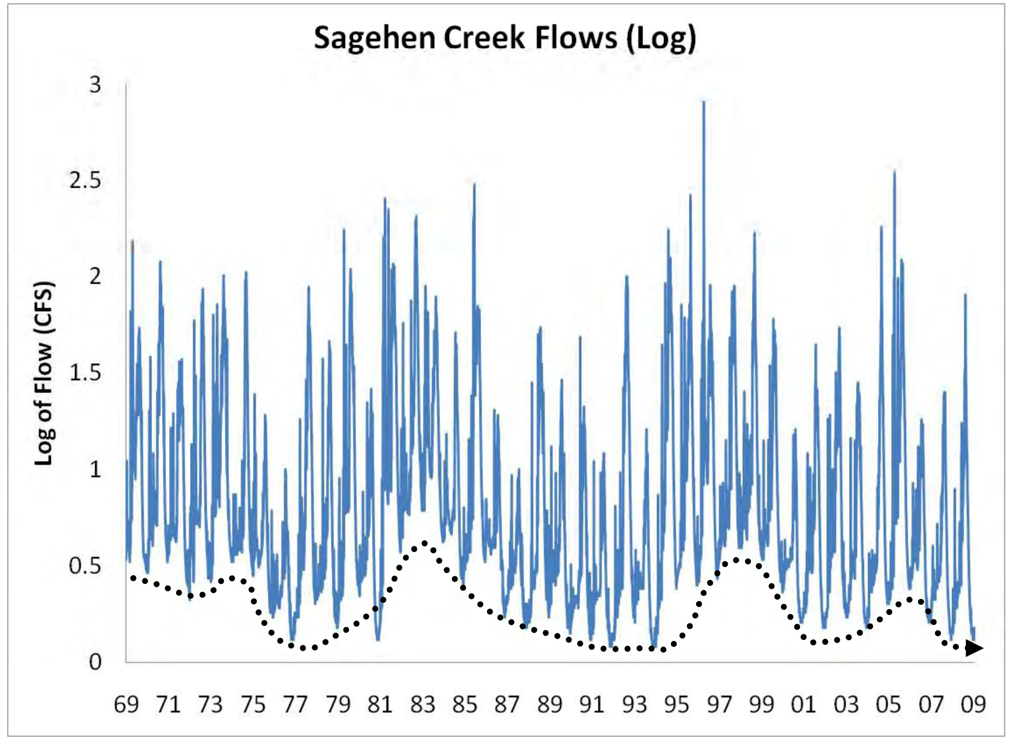
- Current climate change projections are unanimous in predicting warming across the arid southwestern US, with most ranging from about ~3-6^{o}C over the next 50-100yrs

- Projected precipitation changes are more complicated, and mountain regions of the Sierra Nevada region falls in the zone of increasing or decreasing precipitation

Temporal Variations of Temperature and Precipitation

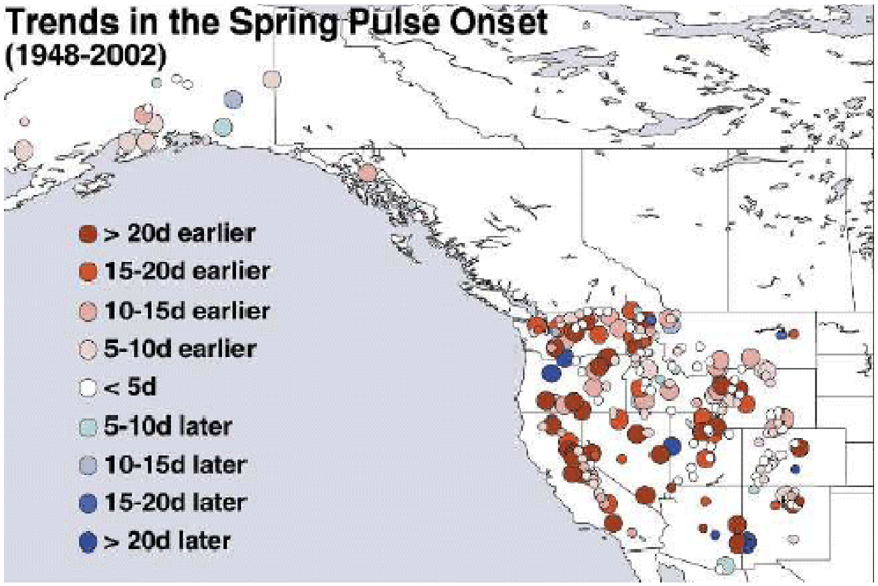


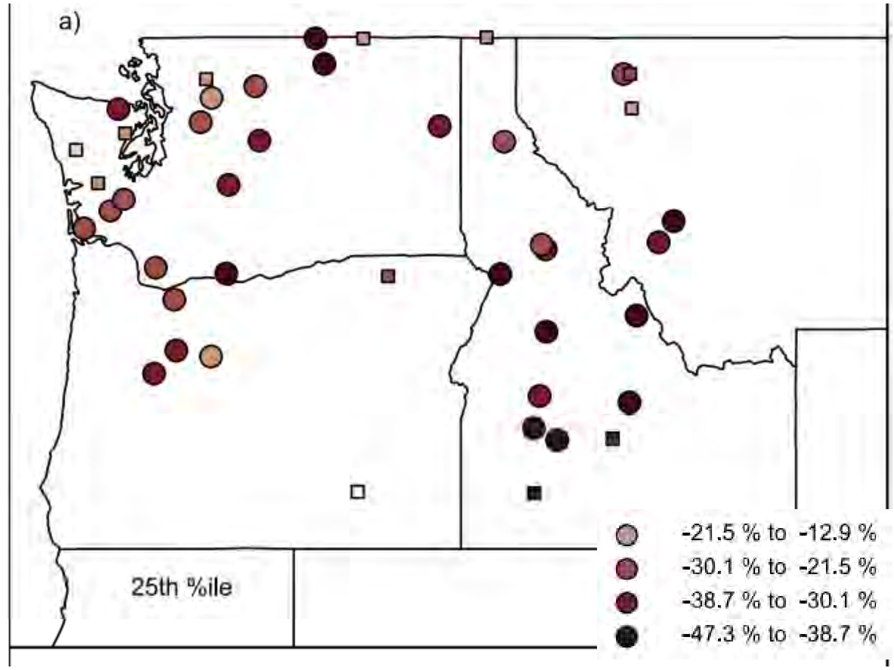




- Natural climate variability will be an important component of future climate conditions, and a good representation of these cycles in the future will lead to more realistic projections of water availabilty and the severity of climate-change extremes
- 1.5 to 2 degree C increase in the average Temp since 1969 at Sagehen Creek, CA
- Low flows are decreasing

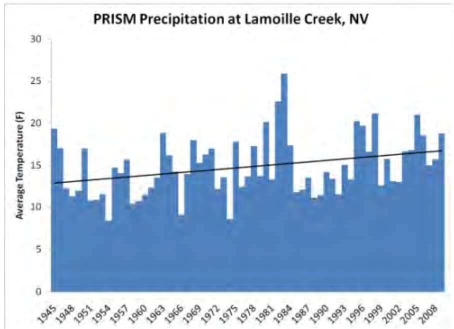
Introduction

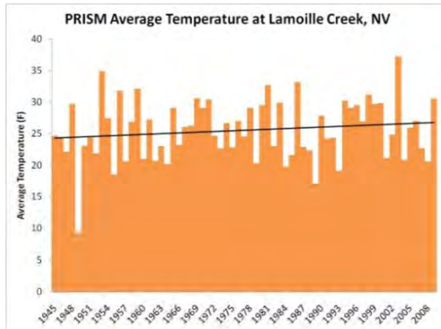


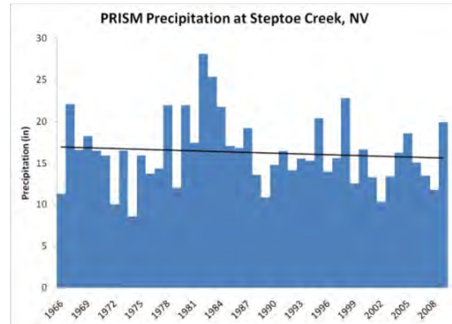


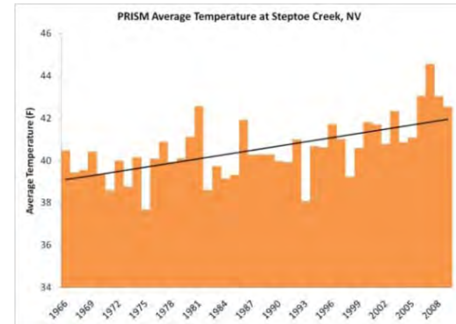
- We know current warming has impacted hydrology
  - Earlier spring runoff (Stewart et al., 2005)
  - Flows decreasing, especially dry year flows (Luce and Holden, 2009)
- What are the mechanisms for the decreases in flows, specifically low flows?

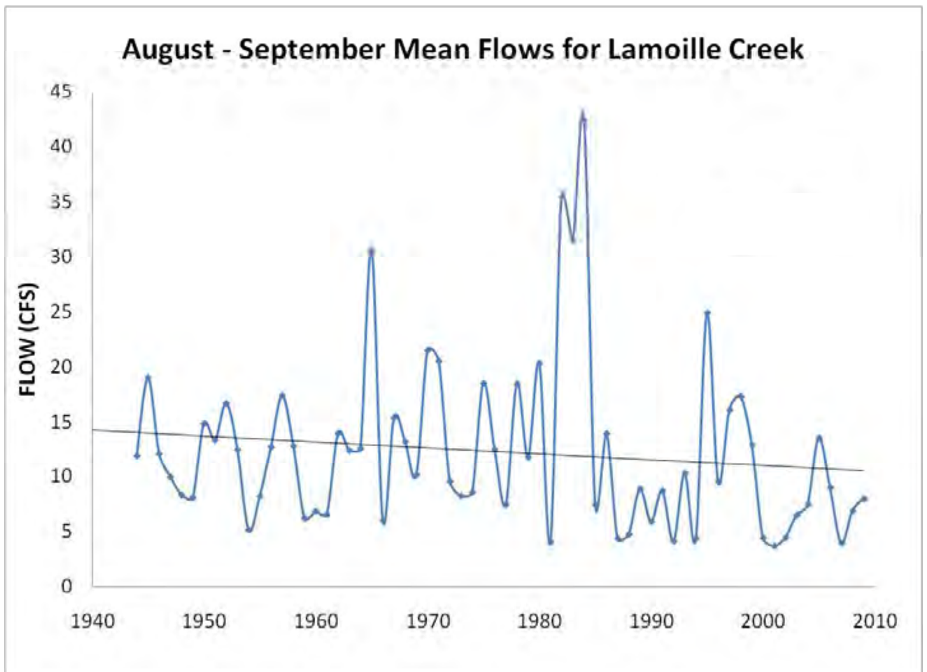
Historical Low Flows

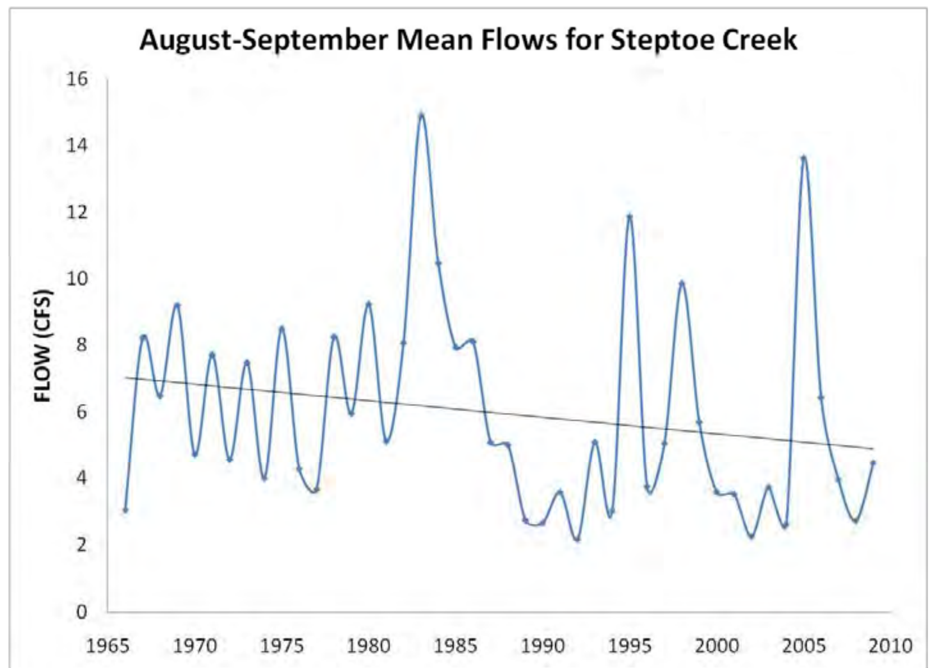












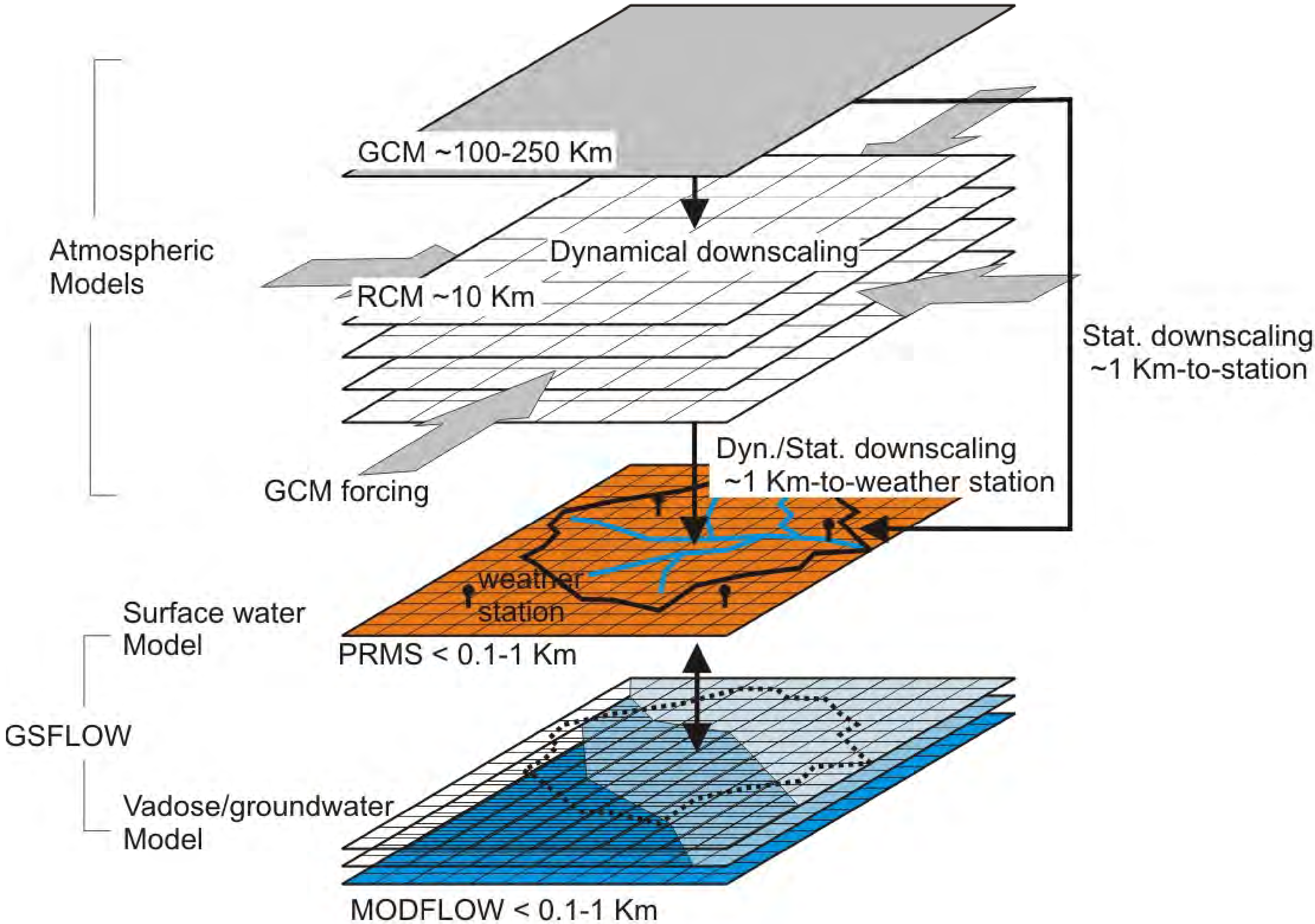
- Near Elko, NV
- Near Ely, NV

Climate Change And Hydrologic Modeling

- Hydrologic processes co-vary with time and space
  - Difficult to analyze effects of climate change for any one hydrologic process
  - Need a modeling framework to analyze these integrated processes

- Decoupled compartmental models have difficulty simulating the effects of climate change on water resources in many settings
  - The unsaturated zone is represented as a stagnant column of soil where water flows independent of the underlying water table
  - Recharge is calculated independent of groundwater levels
  - Simulating runoff to, and recharge from stream channels is especially problematic for decoupled models because these processes are strongly coupled

Integrated Systems Model Framework



Hydrology Approach

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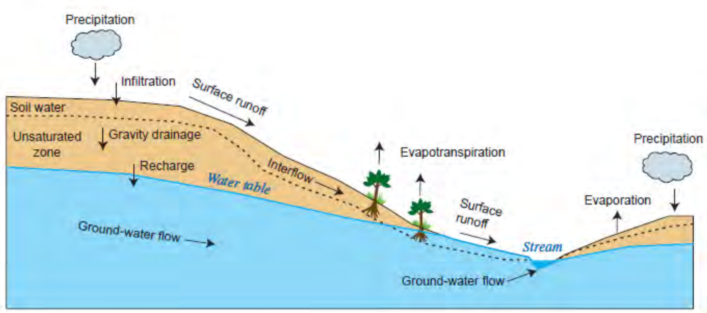
GSFLOW—Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005)

Chapter 1 of
Section D, Ground-Water/Surface-Water
Book 6, Modeling Techniques



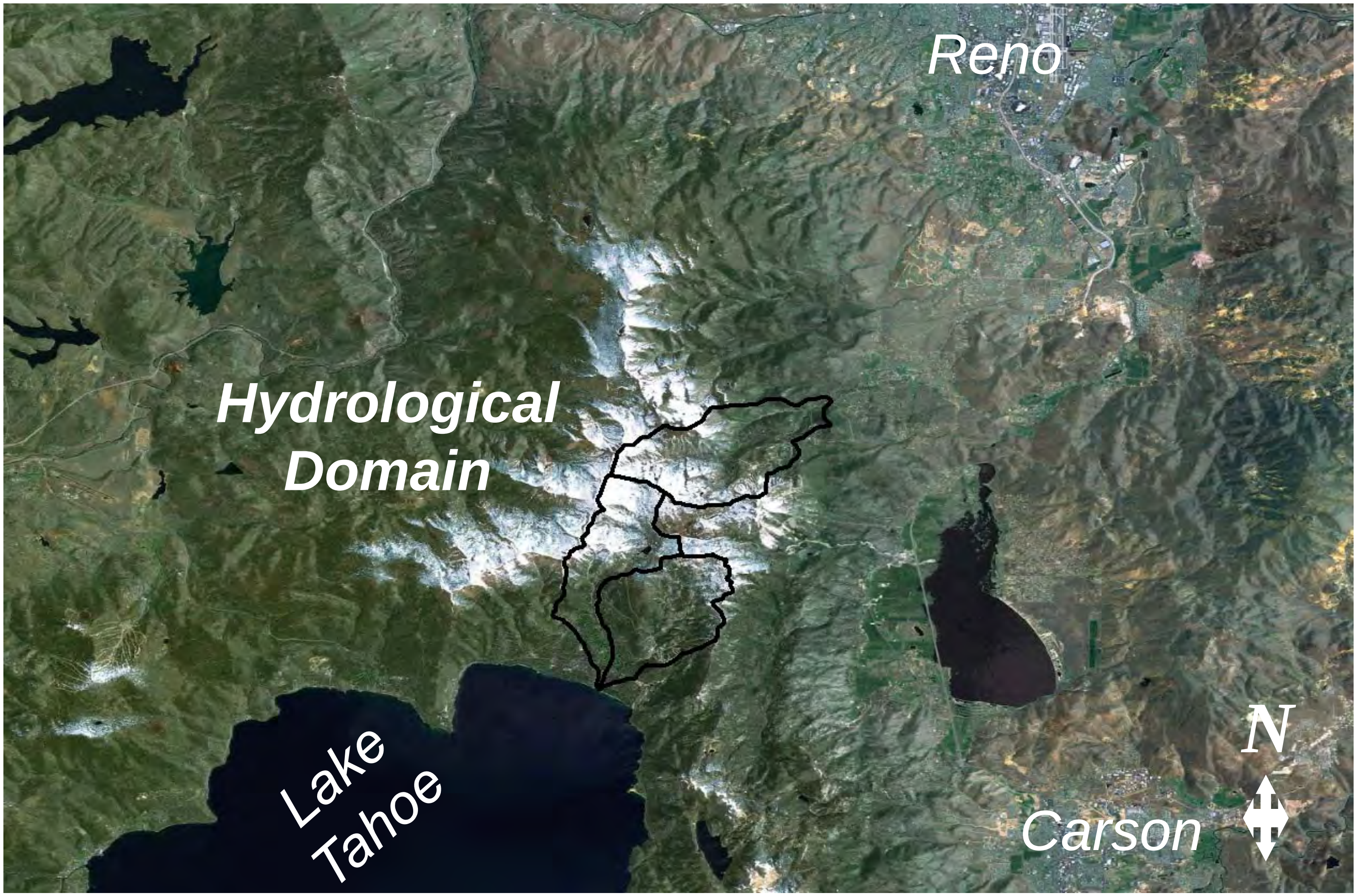
Techniques and Methods 6–D1

U.S. Department of the Interior
U.S. Geological Survey

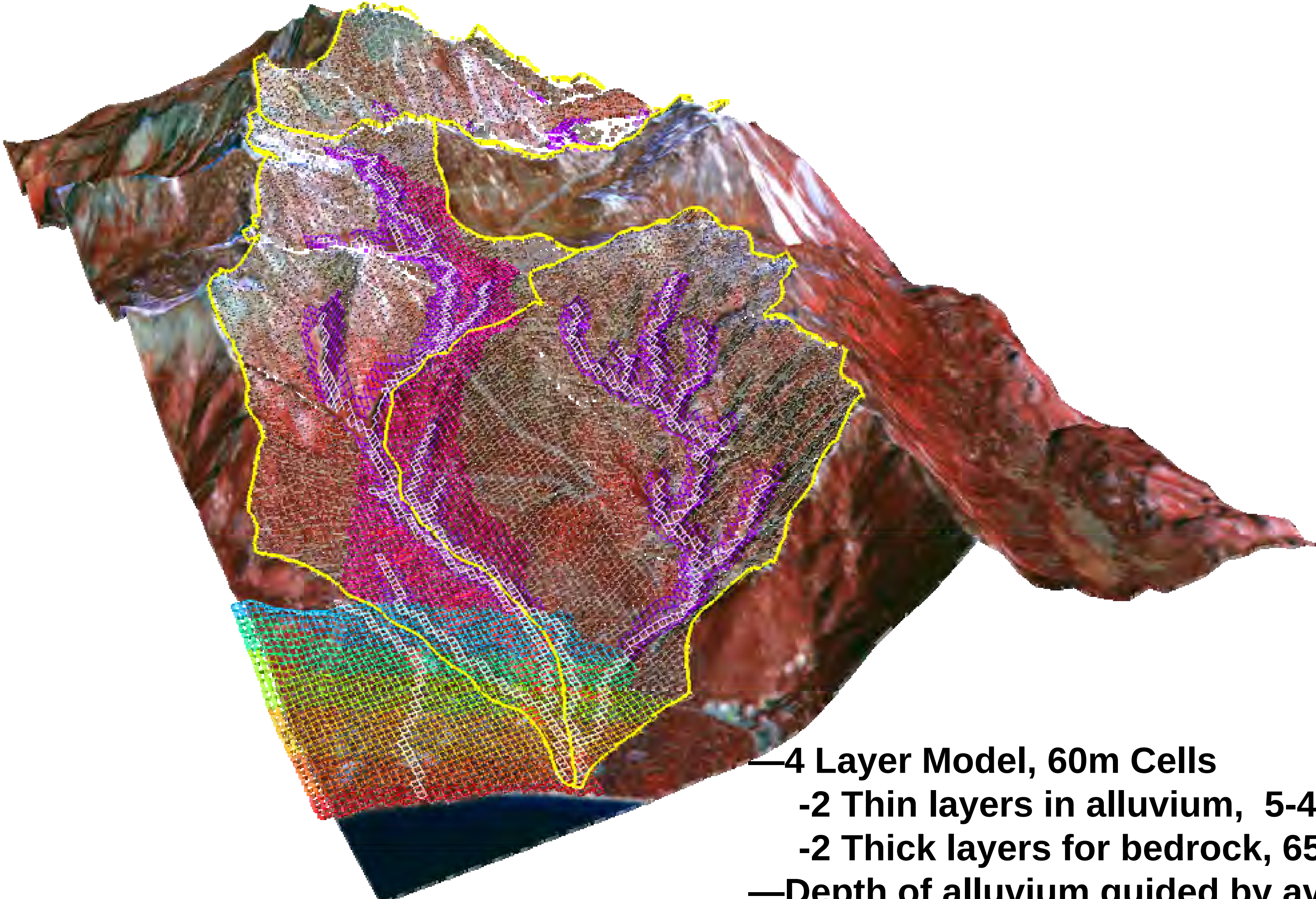
- We rely on an integrated hydrologic model GSFLOW constructed for three watersheds in the Carson Range of the eastern Sierra
- Benefit: Instead of applying recharge, ET, and water surface elevations as boundary conditions in the model they are simulated at a daily time step
- GSFLOW is the integration of PRMS and MODFLOW and most of the capabilities of these individual models, in addition to capabilities provided by the integration of these models (Springs, saturation excess runoff)

Study Area – 3 watersheds in eastern Sierra

- Incline, Third, and Galena Creeks – 20 mi^2



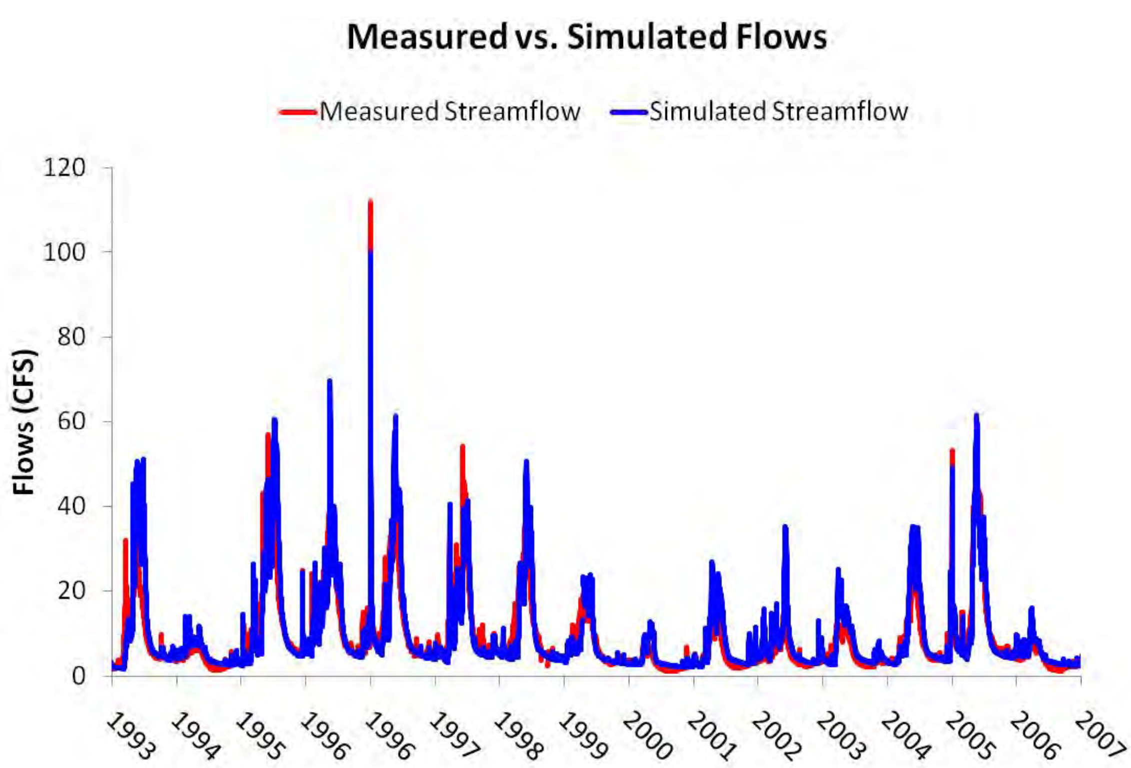
Model Construction

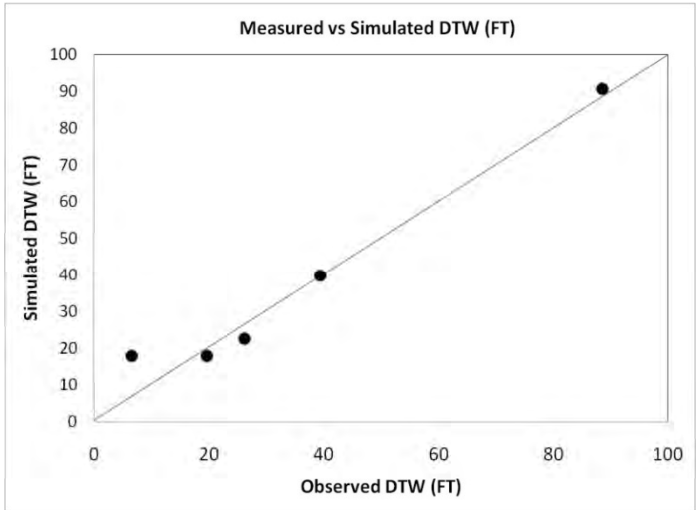


—4 Layer Model, 60m Cells
  -2 Thin layers in alluvium, 5-40m
  -2 Thick layers for bedrock, 65-125m
—Depth of alluvium guided by available geology, well logs, and geophysics

Calibration

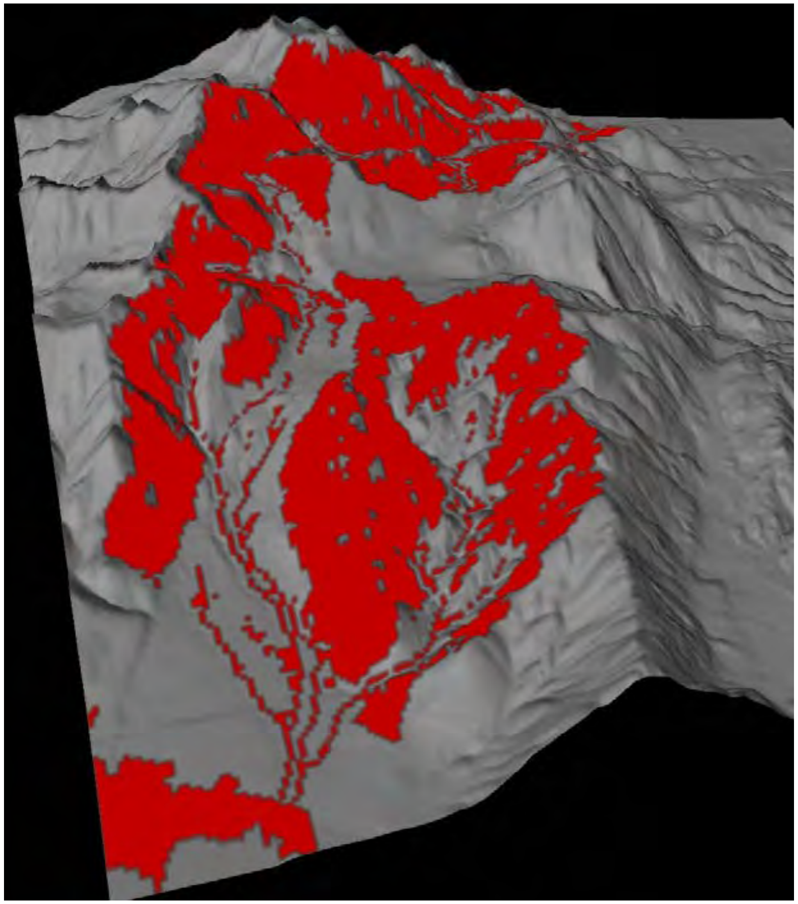
- Steady-State MODFLOW is calibrated independently of PRMS
- PRMS is calibrated independent of MODFLOW
- Transient model is calibrated using integrated model
- Saturated hydraulic K calibrated to topographic intersections with shallow groundwater around known discharge, stream areas, water levels, and runoff

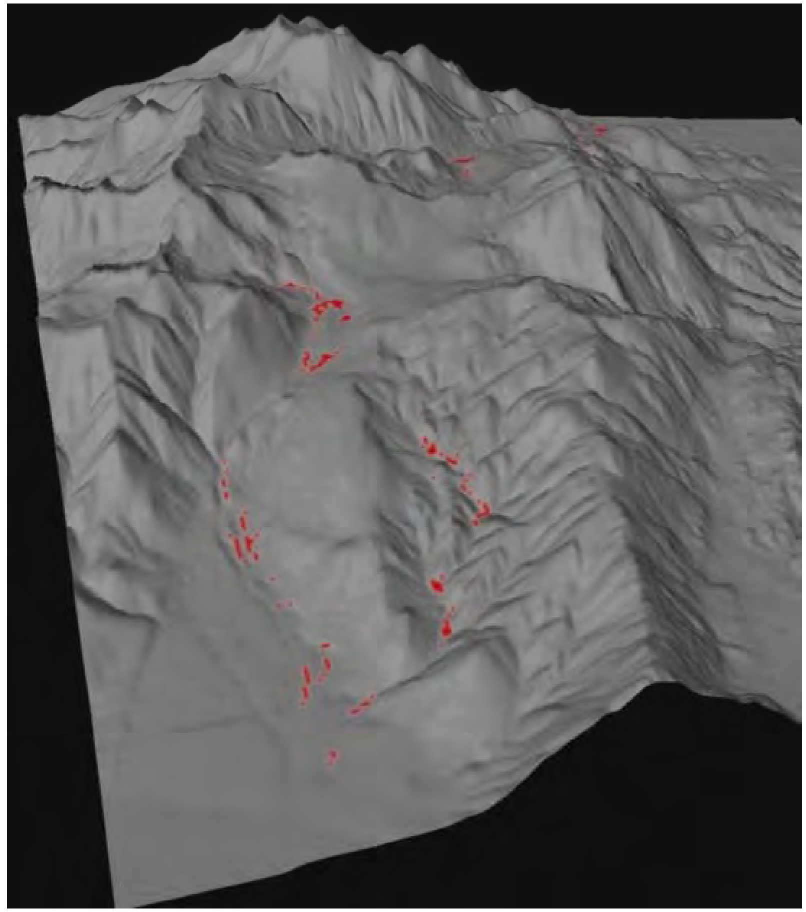


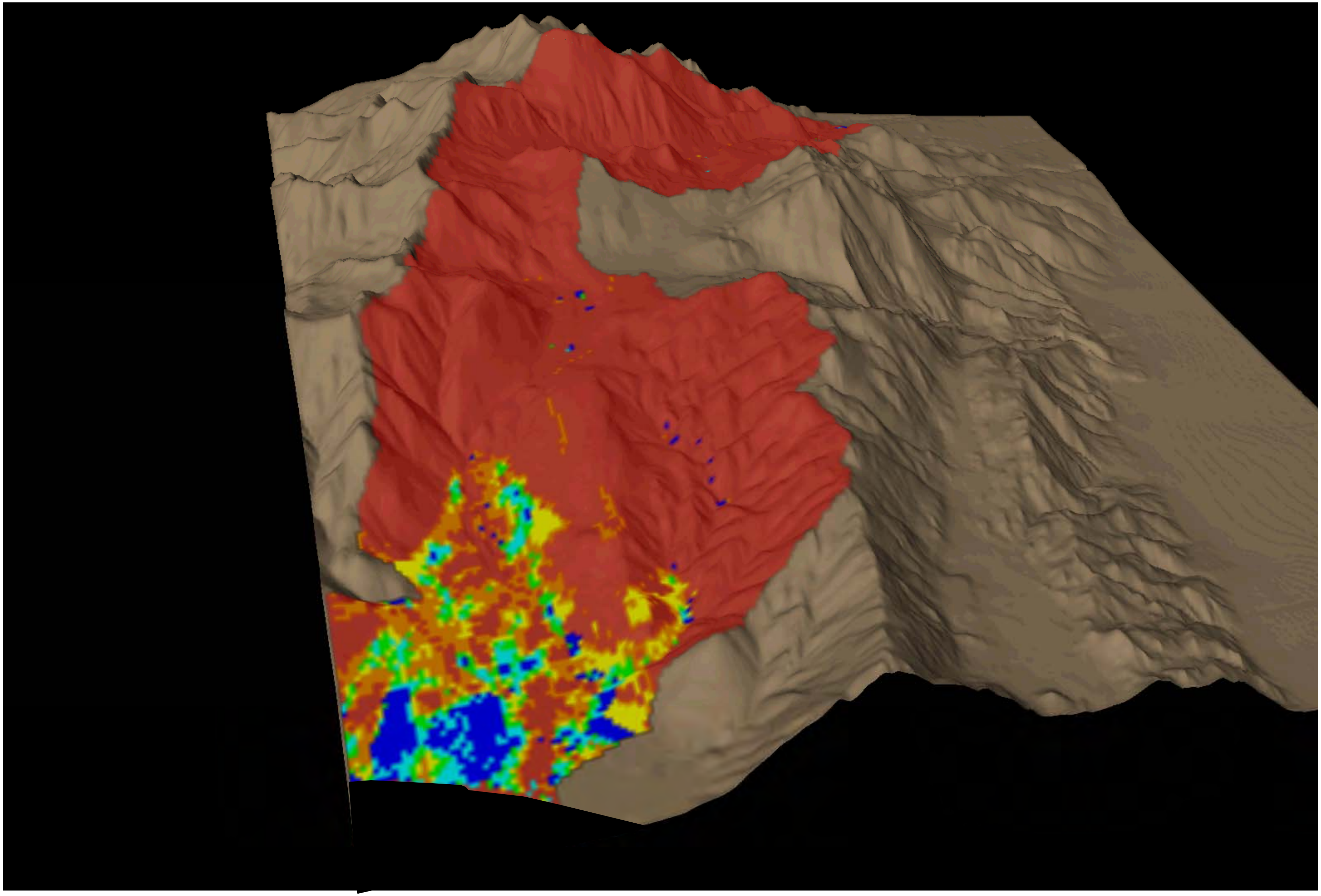


—Ksat lay1&2 =
2.3-1.8m/d – T=10~1000m2/d
SY = 0.25, SS = 1.0E-6
—Ksat lay2&4 =
0.01-0.006m/d – T=0.3-0.7m2/d
SY = 0.005, SS = 1.0E-6

Red Color Shows Intersection of Land Surface and Water Table

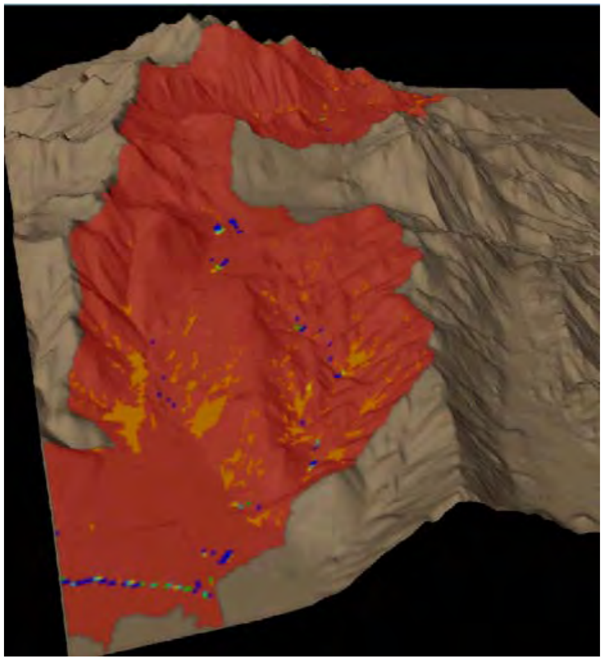




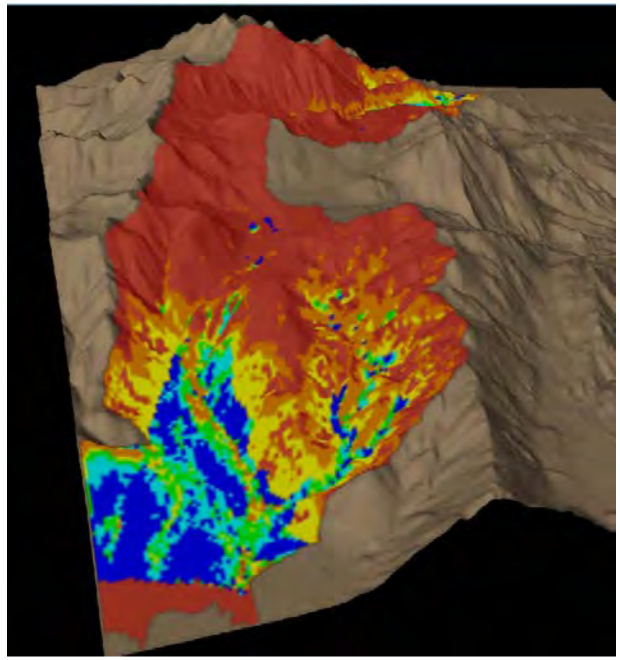


Variations in Recharge

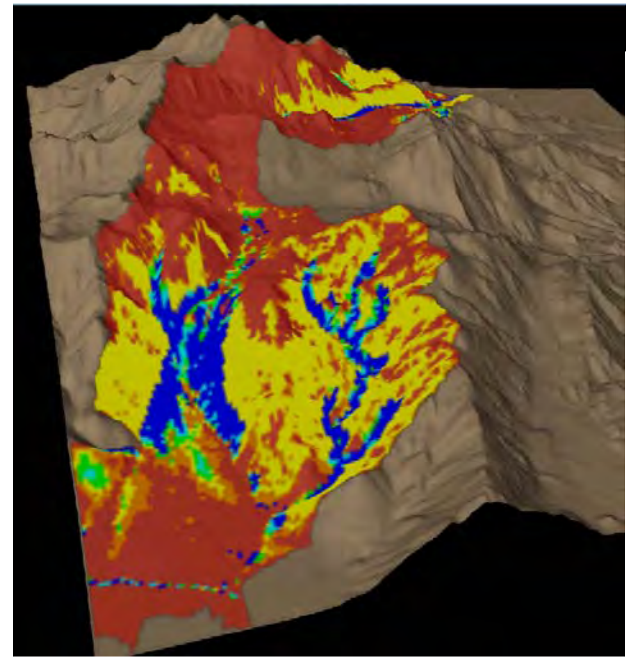
Late Fall Recharge (consistent spring areas)



Early Spring Recharge (more at low elevations)

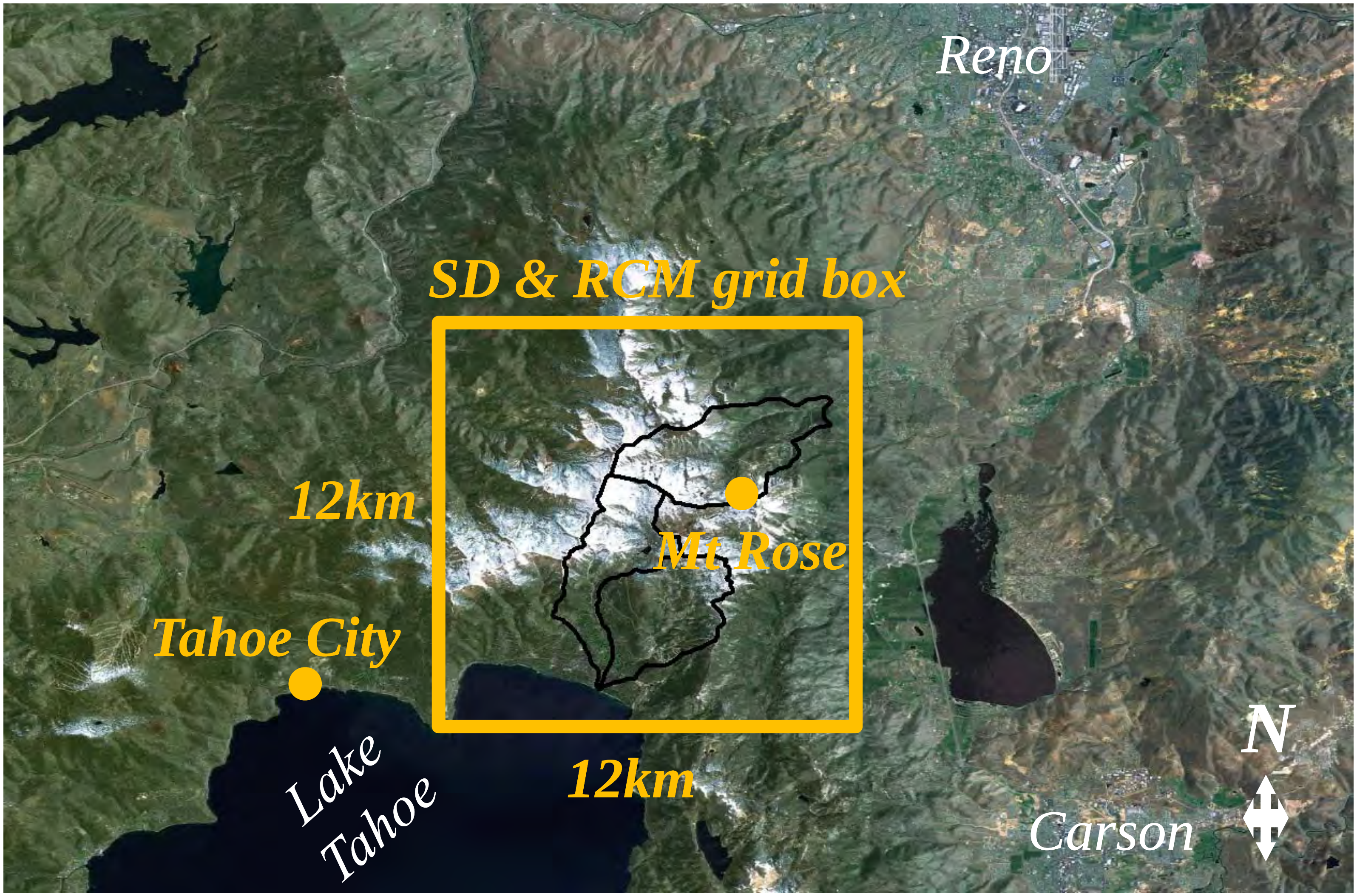


Mid Spring Recharge (more at high elevations)



- Recharge fields illustrates the dominant flow paths within the watershed.
- Most recharge over the river canyons and valleys, likely associated with shallow and outcropping granite.

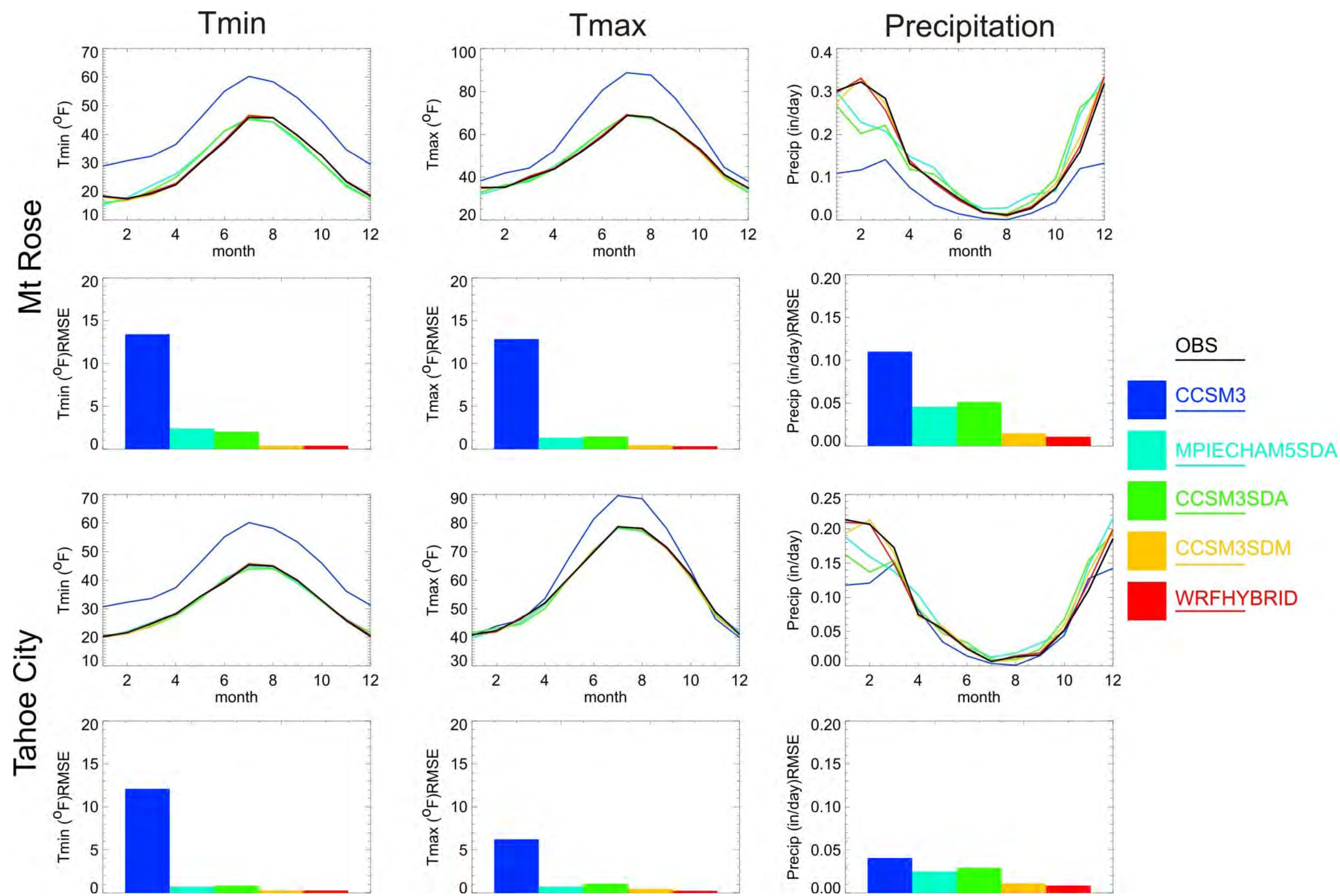
Atmospheric Forcing Approach

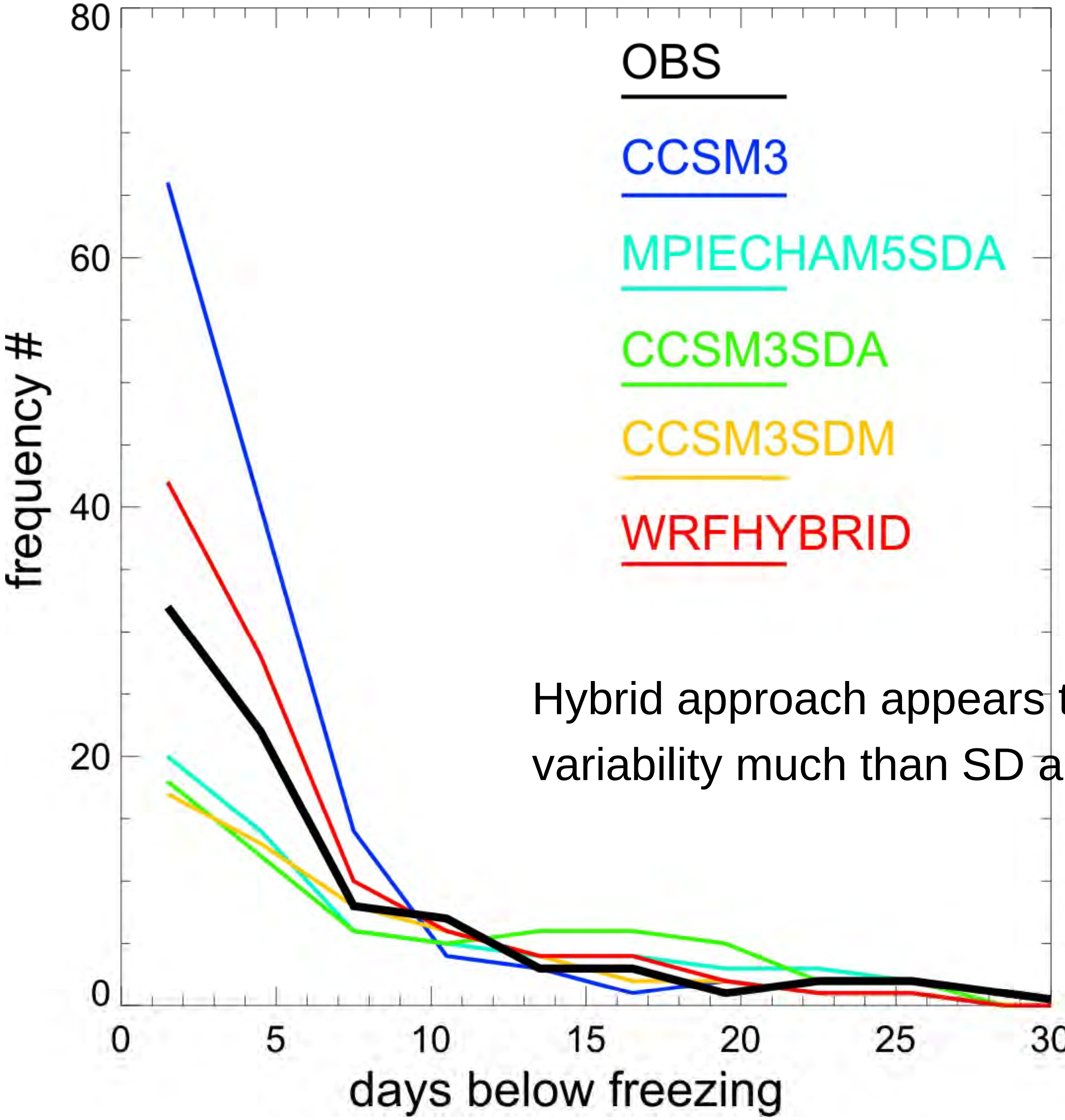


Forcing Data: Tmin, Tmax, and Precip !Downscaling into station-based data!

Forcing	Downscaling approach	Grid size	Temporal resolution	Naming convention
GCMs monthly	Bias Correction Spatial Disaggregation (BoR) “YEARLY”	1.125 deg	From Monthly into daily “Analog approach”	GCM##SDA
GCMs 6 hourly	Q-Q bias correction mapping “MONTHLY”	1.125 deg	From 6-houly into daily	GCM##SDM
NCEP/NCAR reanalysis, GCMs	RCM-WRF + Q-Q bias correction mapping	36 and 12 km	Hourly into daily	WRFHYBRID

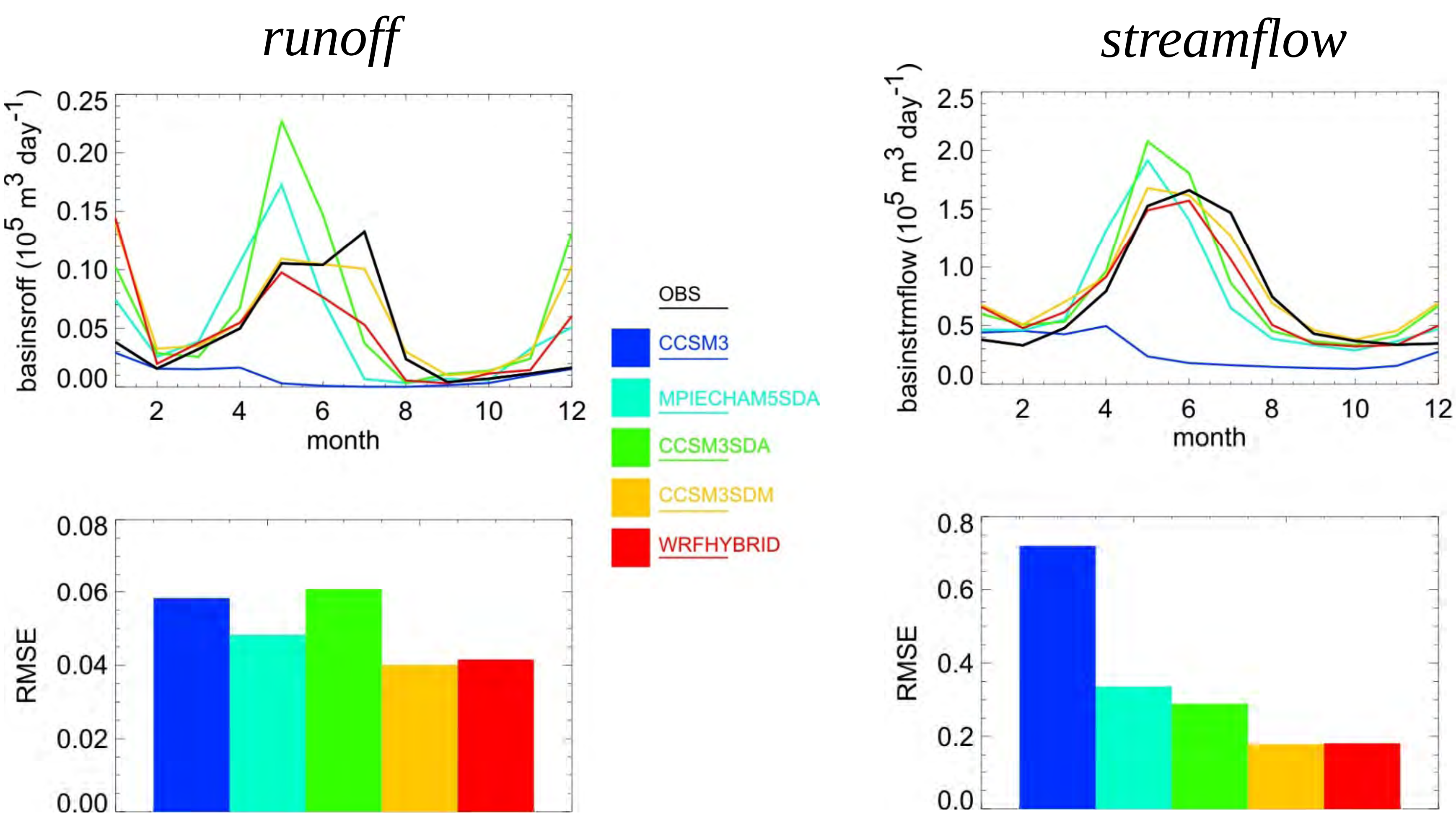
Evaluation period: 1982-2007





Hybrid approach appears to simulate day-to-day variability much than SD approaches.

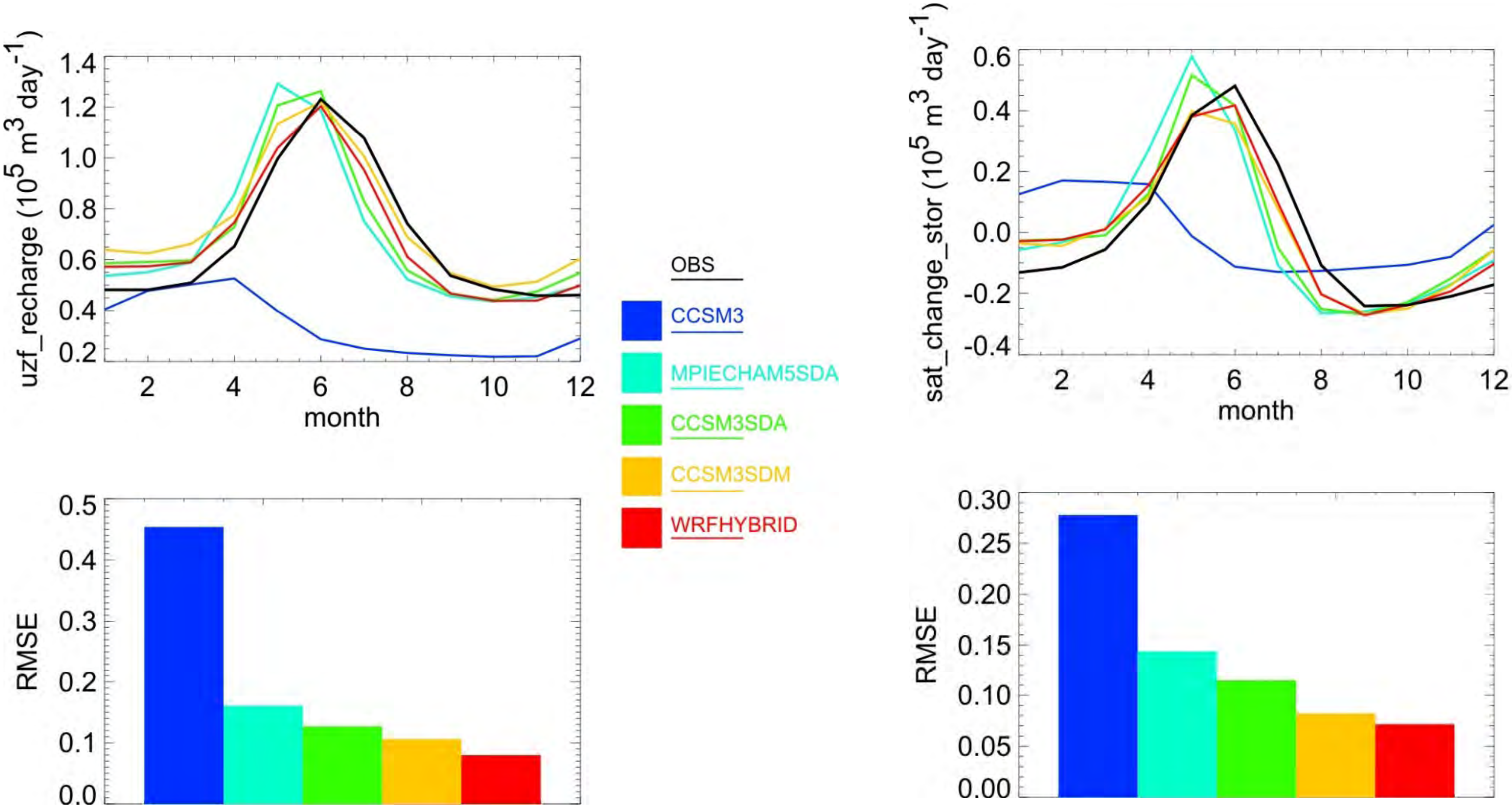
Evaluation Runs: 1982-2007



Evaluation Runs:*1982-2007*

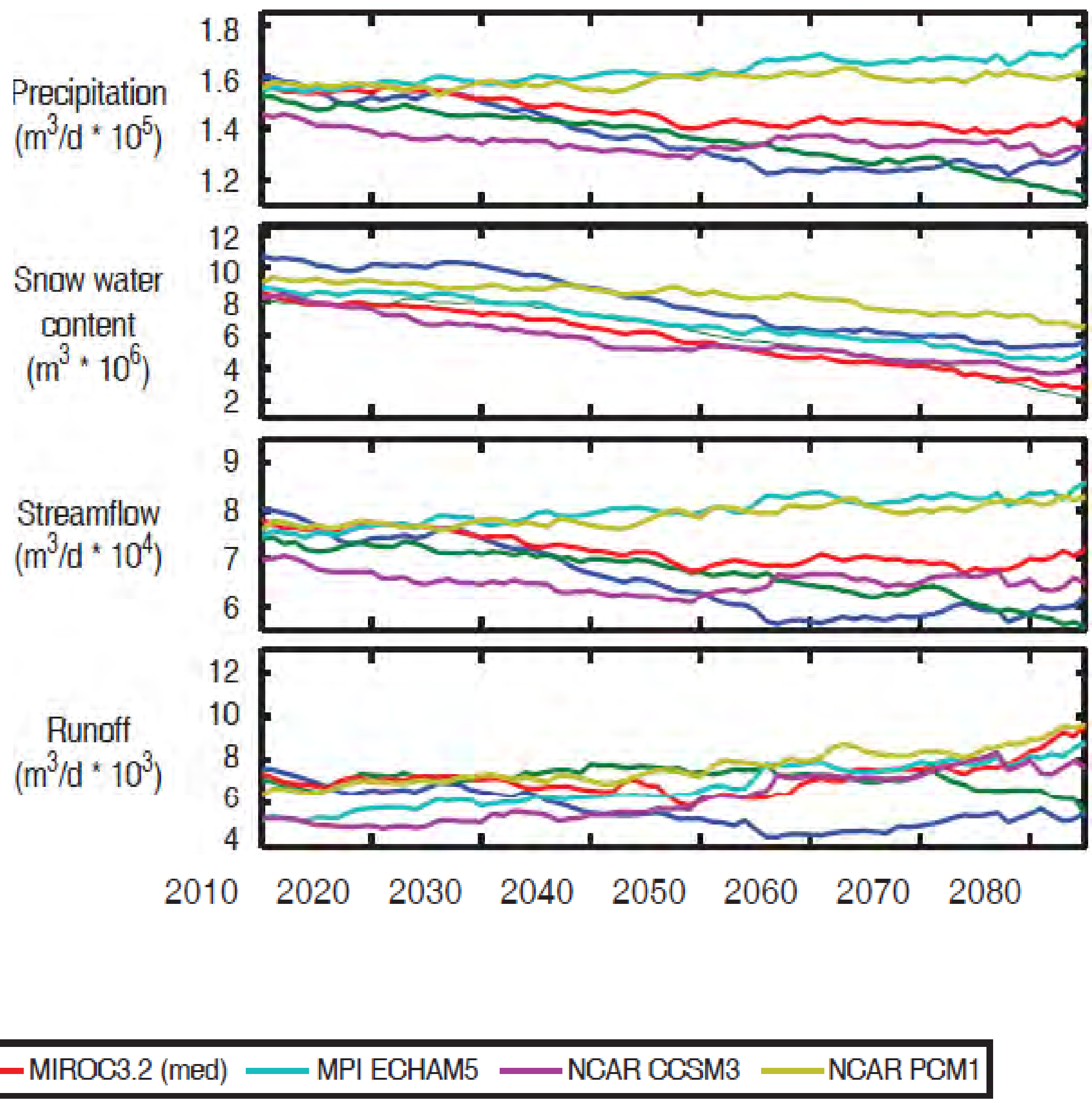
Recharge

Change in Storage



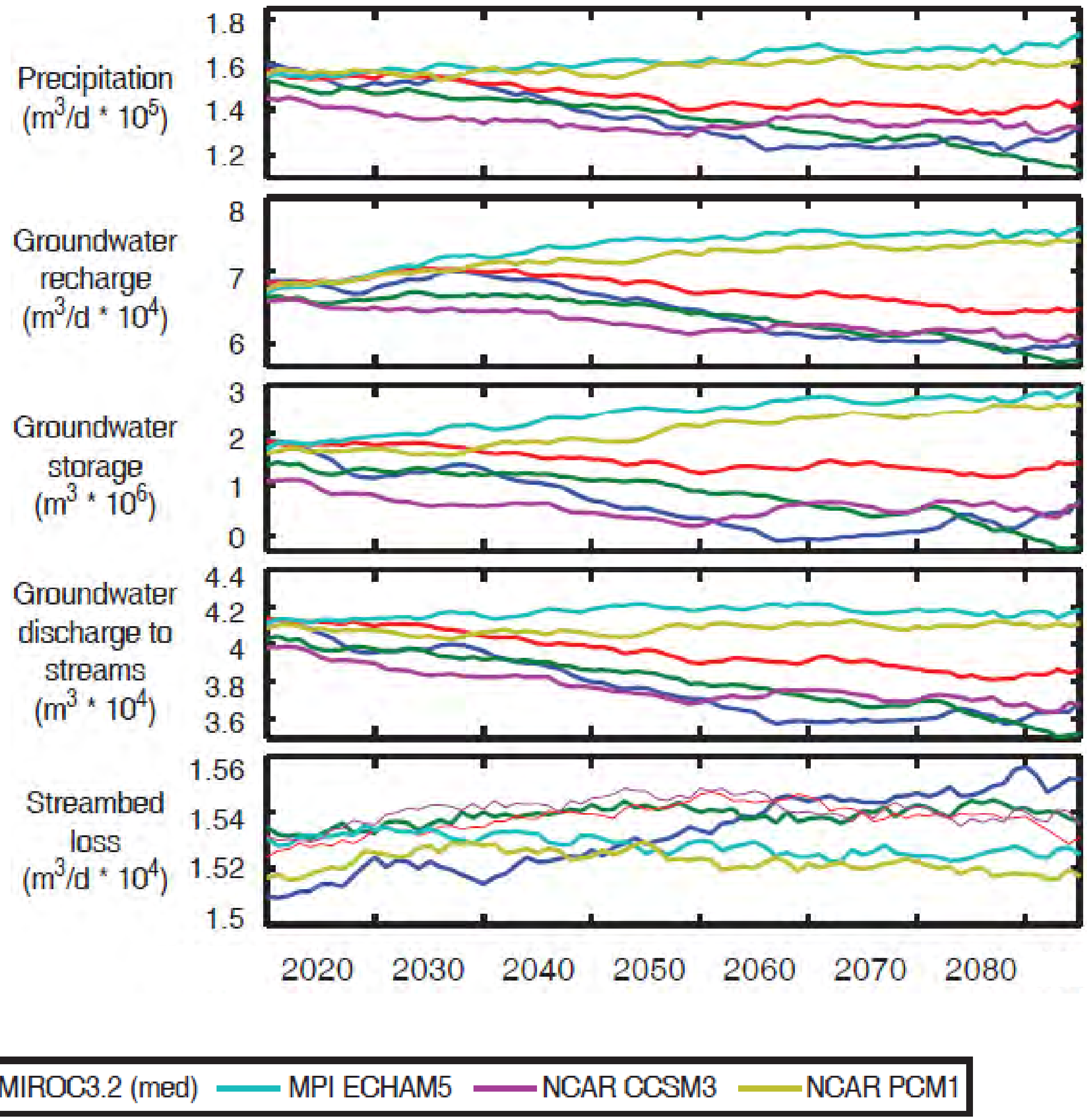
Annual Surface Water Results (A2)

- Annual Precipitation decreasing in all 4 of 6 GCMs
- Snow water content decreases due to increased temps
- Annual streamflow mimics the precipitation, little to no change in annual ET
- Annual runoff (overland) generally increases

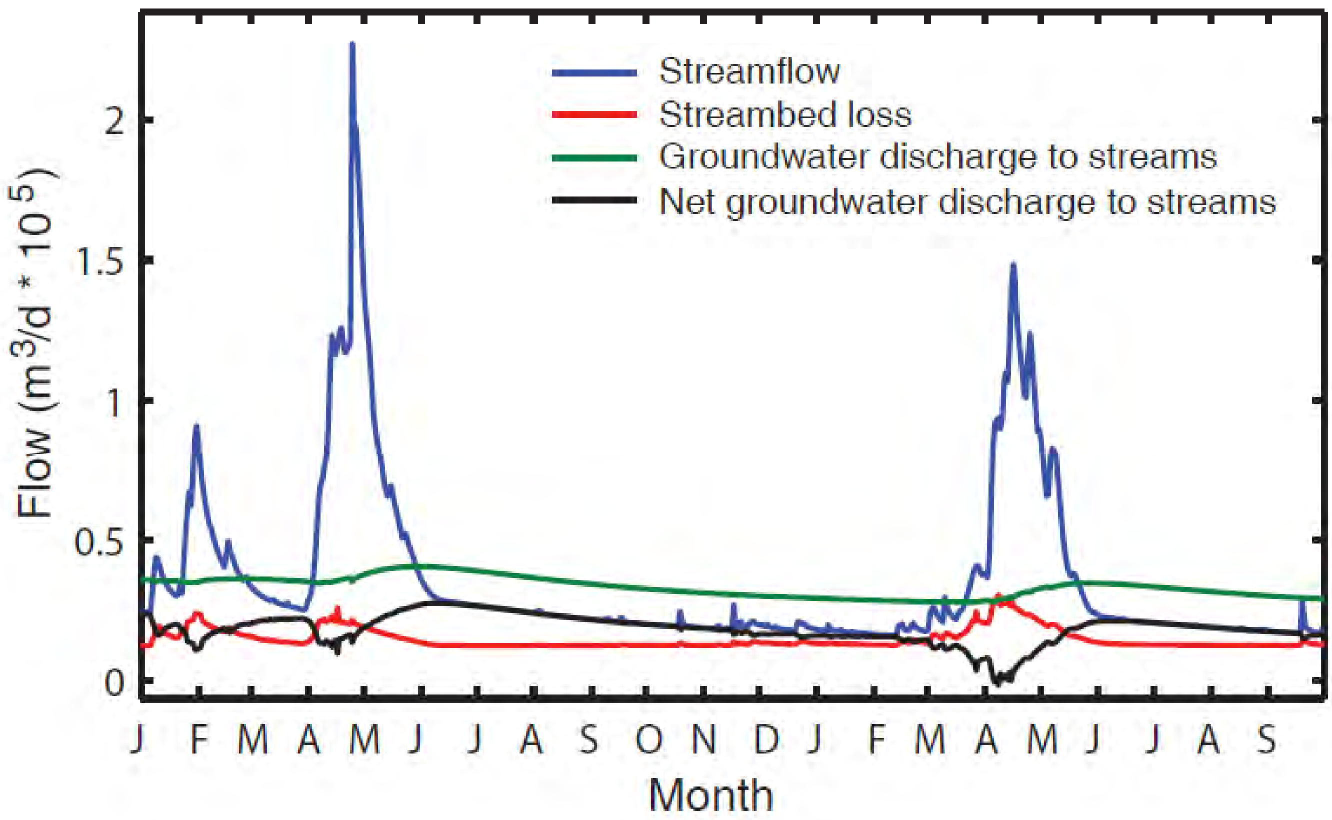


Annual Groundwater Results

- Annual groundwater recharge and storage mimic precipitation but changes are enhanced
- Groundwater discharge to streams decreases, as recharge and storage decrease
- Streambed losses increase, as recharge and storage decrease
- Result illustrates the important interplay between SW and GW and underscores the need to run long-term simulations when making inferences about the effects of climate change on surface and groundwater processes



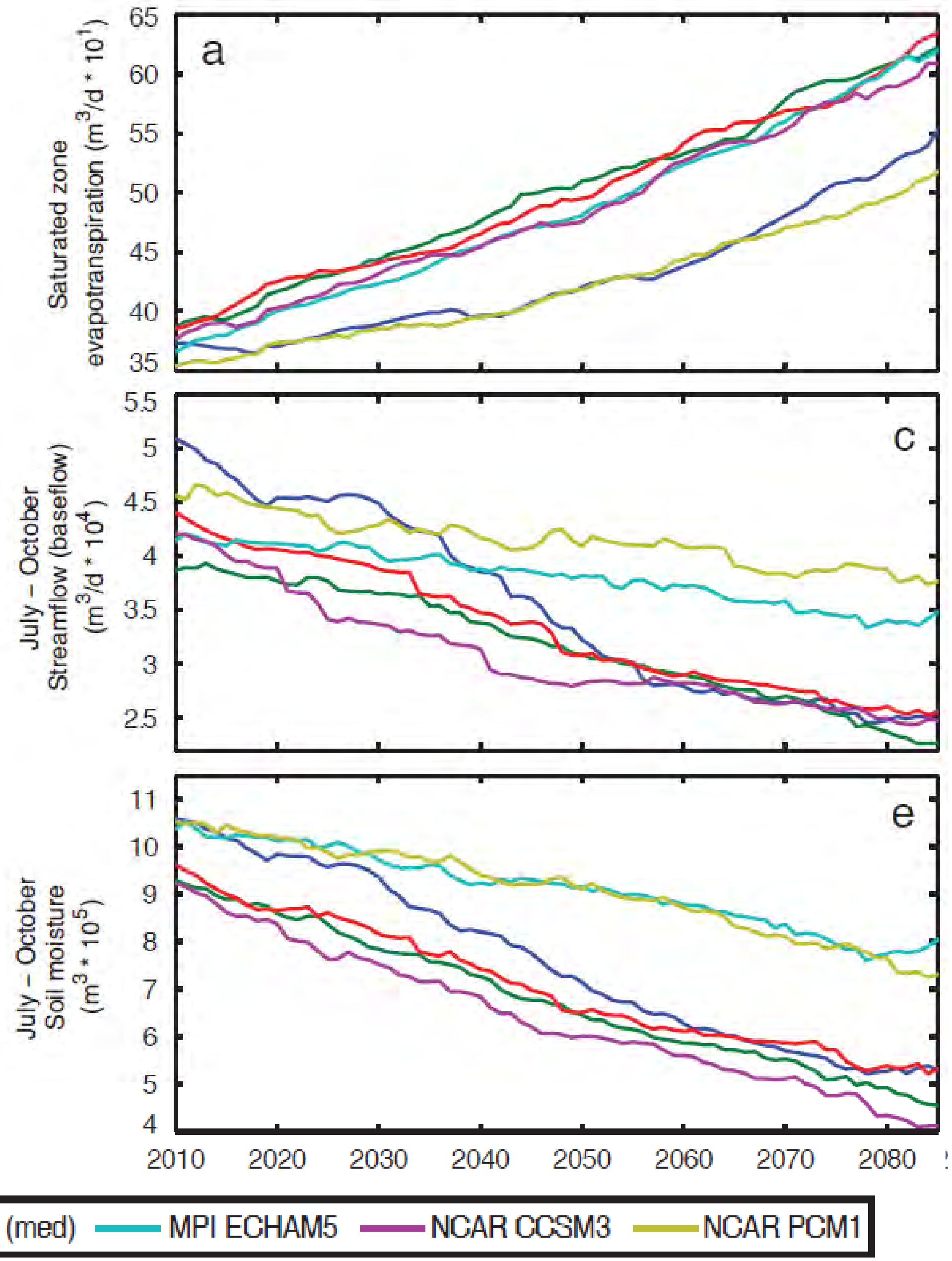
Seasonal SW GW Interactions



- As stream stage increases, it suppresses groundwater discharge to the stream from reduced vertical hydraulic gradients beneath the streambed
- Causes the maximum groundwater discharge to follow the spring snowmelt and streamflow
- Losses to the groundwater reach a maximum as streamflow increases (depleted from summer and fall drainage)
- During the low flow period, streamflow becomes 100% comprised of net groundwater discharge
- As the streamflow timing shifts, so does the groundwater discharge, leaving less groundwater to discharge in the summer

Summer Changes

- Increasing saturated zone ET (ETsat) from riparian areas around streams
- Combination of shifts in groundwater discharge and increasing ETsat (minor volume increase), reduce the streamflow during the hottest part of the year even though 2 of the GCM predict increasing PPT
- Average summertime soil moisture decreases significantly as a result of earlier snowmelt and runoff



Conclusions

- Believe!!! This integrated modeling effort can help with addressing questions on climate change impacts on water resources!

- A combination of Dynamical and Statistical downscaling “Hybrid Approach” offers the best meteorological input.

- The “Hybrid Approach” appears to impact hydrological results positively.

Conclusions

- Temp and Precip projected by 6 different GCMs under two emissions scenarios cause significant changes to the timing and magnitude of important hydrologic budgets in 3 watershed in the Sierra Nevada.

- Global Warming>>Regional Warming>>Peak discharge occurs earlier in the spring, and a greater than 30% reduction in baseflow during the summer.

- Thus, summertime aridity of these watersheds increases due to climate change.

- Our “Integrated Model Framework” (GCM to GWM) provides Hydro-Climate Variability and Change impact information on low flows, spring flows, and long-term groundwater resources.

Acknowledgements

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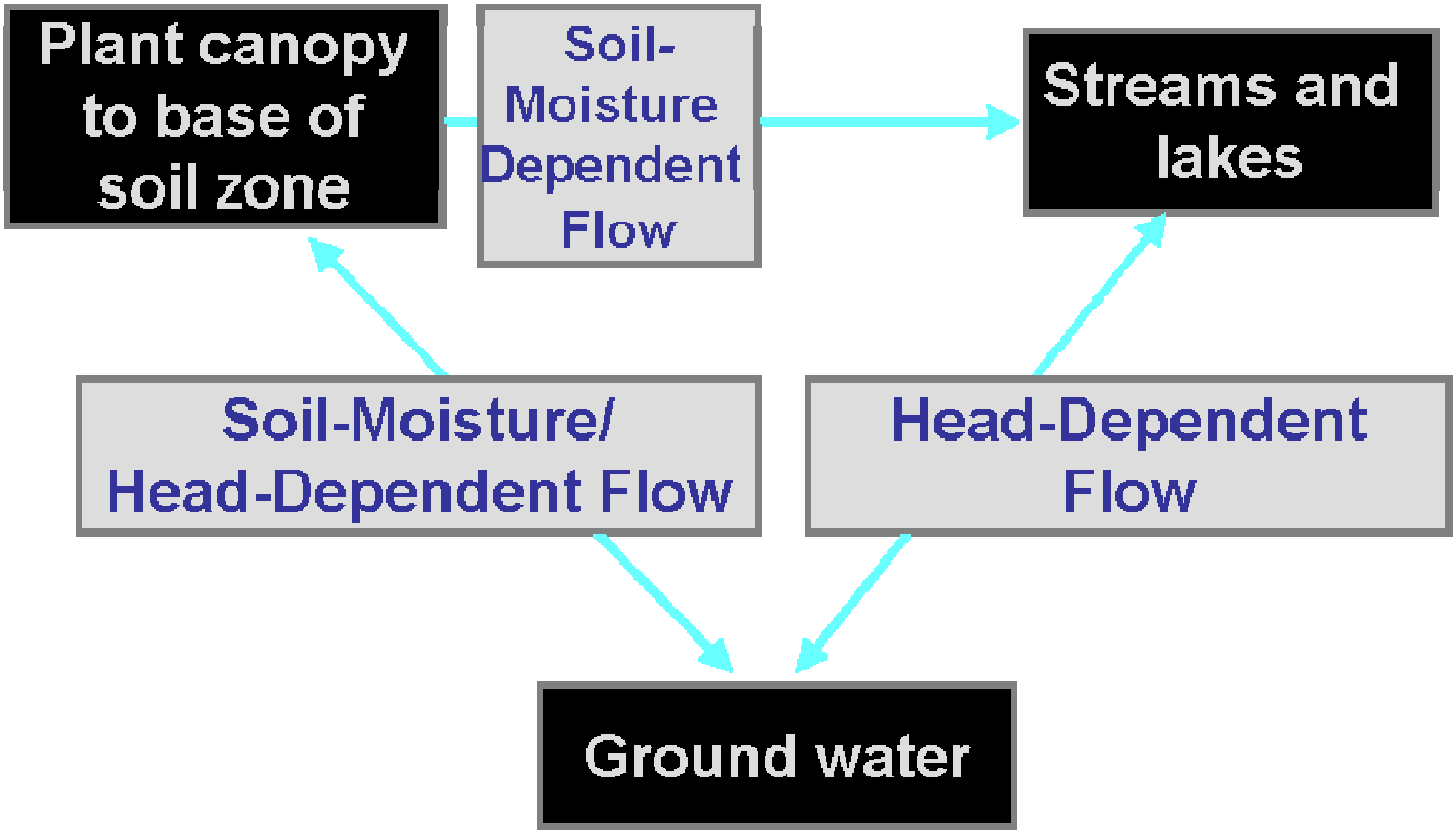
- PCMDI & WCRP CMIP3 for distributing the GCM multi-model dataset.

GSFLOW
Model Connections



GCM Bias Correction and Statistical Downscaling

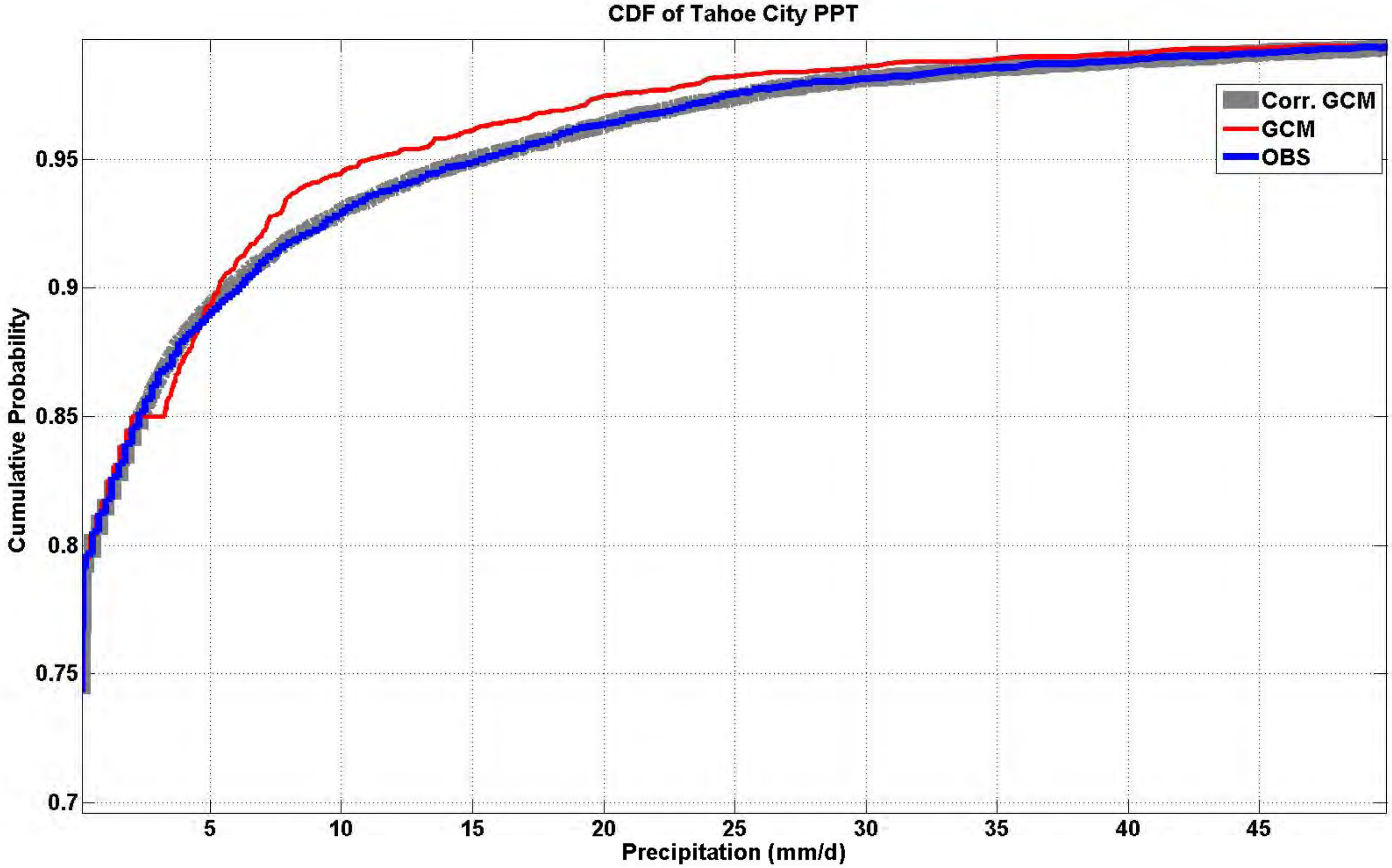
Pros

- – Retains observed spatial-temporal relationships
- – Shifts in variability and extremes at monthly and longer timescales are carried into downscaled fields

Cons

- – Use of CDF or Z-score (quantiles) is important decision in representing tails of distribution
- Predictor-predictand relationship is assumed stationary
- Coefficients of statistical models may be different in the future

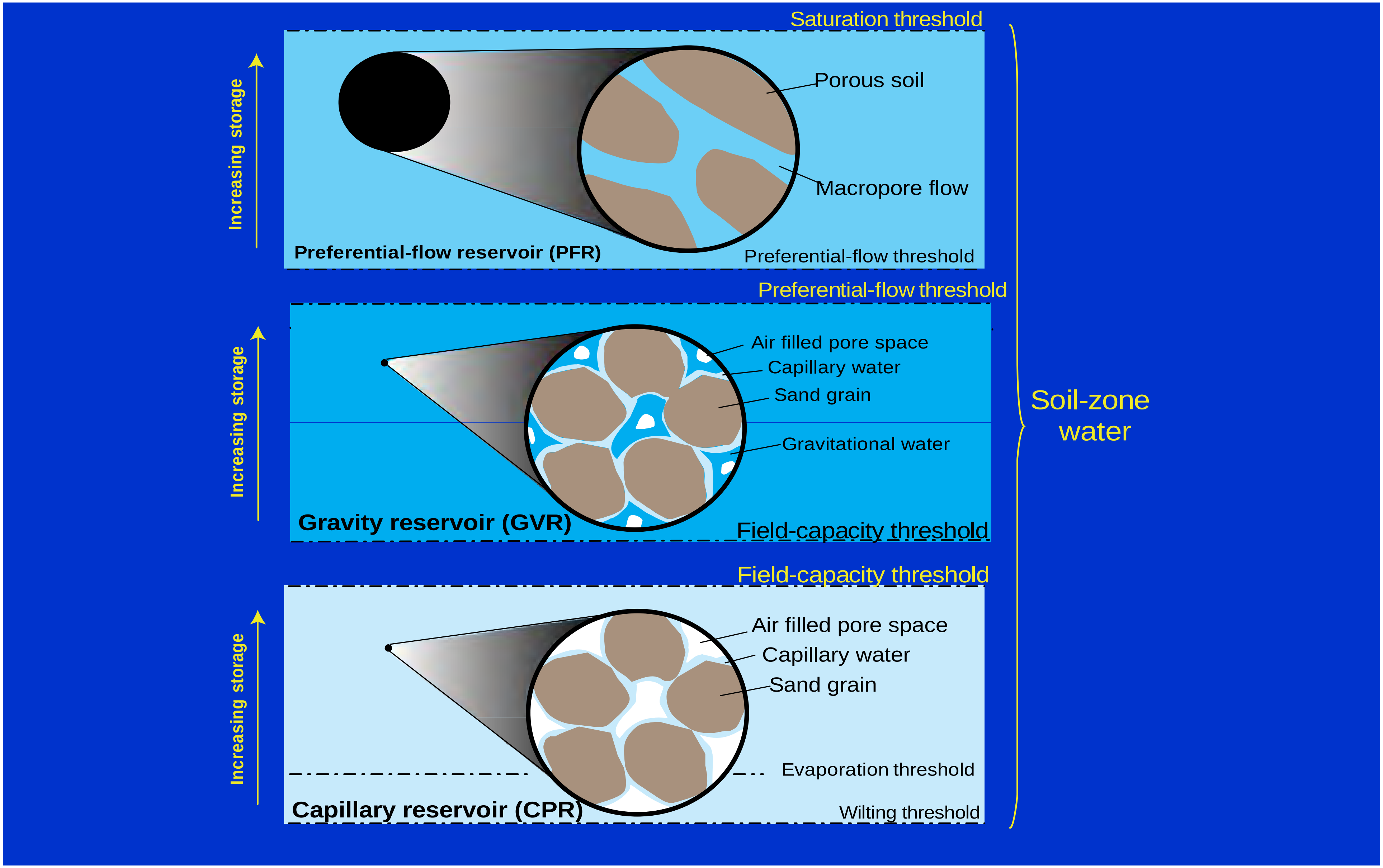
Precipitation Bias Correction



Changes to PRMS and MODFLOW for GSFLOW

- Enhanced soil zone dynamics.
- Enhanced ability to simulate 3-D unconfined ground-water flow.
- Vertical unsaturated flow in thick unsaturated zones.
- Distributed streamflow routing.
- Integrated lake simulation

Enhanced Soil-Zone Dynamics



UZF1 Package for MODFLOW-2005

- Kinematic-wave Equation for vertical unsaturated flow provides a solution for **gravity flow with internal drainage.**

- The method of characteristics solution of the kinematic-wave equation makes it easy to couple 1-D unsaturated flow to the water table (MODFLOW).

Difficulties with Applying Numerical Solution of Richards' Equation for Regional Studies

- Richards' Equation relies on constitutive parametric process models to represent $K(\Psi)$ and $\theta(\Psi)$. These models are measured at the laboratory scale and they don't apply for large cells typically used in regional models.
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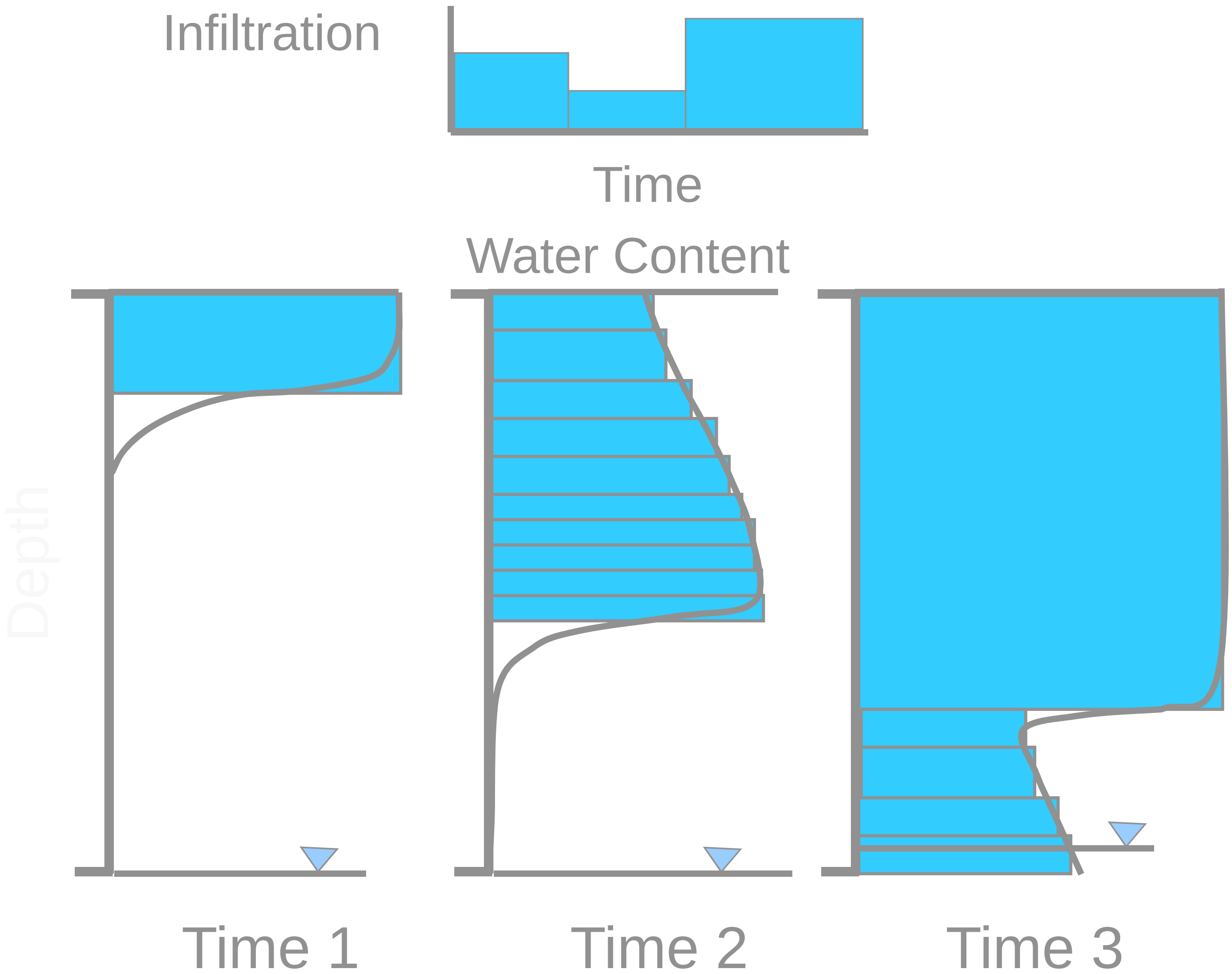
-

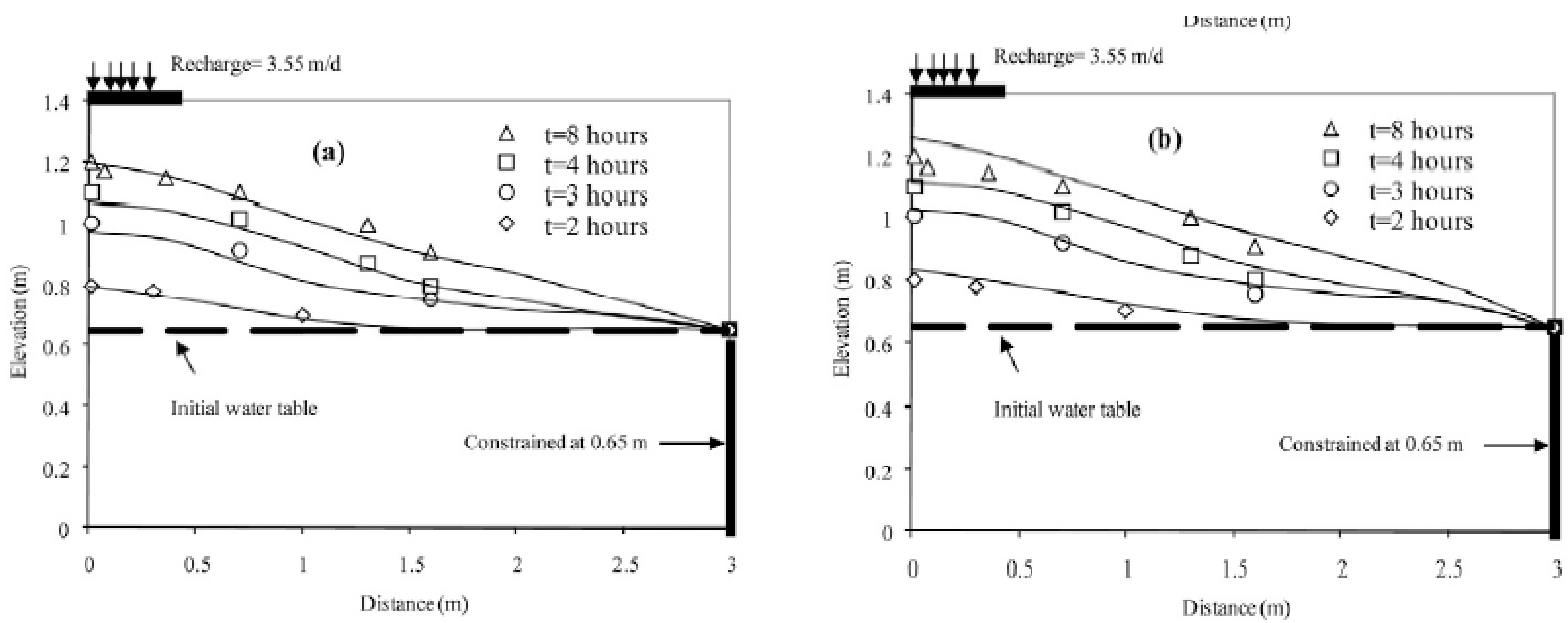
What Have We Learned from Stochastic Modeling:

"With respect to regional-scale flow processes, the solutions showed that at sufficiently large scales and in the absence of interflow, the average lateral flow component is negligible, so that the large-scale Richards' equation becomes one-dimensional"

Method of Characteristics



Comparison to Vauclin et al. (1979) Laboratory Experiment



Saturated or Unsaturated flow Beneath Channels