Importance of sub-watershed spatial heterogeneity in ecohydrological modelling using multi-scale and multi-criteria data in the context of climate variation and change

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Abstract

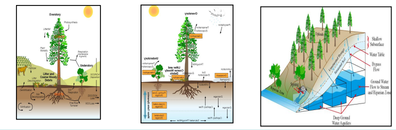
One of the goals of the Southern Sierra Critical Zone Observatory (SSCZO) is to strategically combined field data and spatial models to improve our ability to predict how ecohydrologic variables (snow, soil moisture, ET, photosynthesis and streamflow) will respond to a warming climate. While there have been a variety of modeling studies in the Sierra that have examined how these variables respond to warming, most studies have been done at relatively coarse spatial scales (120m grids). Further calibration and validation of these models often relies solely on streamflow data. The SSCZO provides an opportunity to assess how well models of coupled eco-hydrologic processes captures plot-hillslope scale patterns of ecohydrologic variables, and then to test whether including this level of spatial heterogeneity in a modeling study is important for accurately estimating aggregate watershed responses to climate variability and change. In the Sierra CZO, we have applied Regional Hydro-Ecologic Simulation System (RHESSys), a physically based spatially distributed model of coupled carbon, nutrient cycling and hydrology. We initially implement the model at a 30m spatial resolution and calibrate subsurface drainage parameters using measured streamflow. We also compare model predictions with several existing CZO data sets including co-located snow depth, soil moisture sensor, sapflow and flux tower data. Initial comparisons highlight the importance of microclimate variation and point to inadequacies in current approaches used to upscale point meteorology measurements (or downscale gridded estimates) for ecohydrologic modeling. We then use this baseline model to develop a strategy for further data collection that is explicitly directed at evaluating the model's ability to capture spatial heterogeneity in eco-hydrologic processes including soil moisture and transpiration. We present our initial results from this model-driven data collection and show how it can be used to a) identify weakness in model parameterization and b) develop strategies for improving model estimates. We interpret model results in the context of climate variability and change and show how accounting for both local vegetation-driven heterogeneity in snow accumulation and melt and related processes and hillslope scale topographic-driven heterogeneity can be important in estimating aggregate watershed responses.

Research Questions

○ What are optimal additional soil moisture monitoring locations, given the goal of capturing within catchment spatial patterns of inter-annual (climate driven) variation in soil moisture dynamics?

○ What are optimal sap-flux monitoring locations, given the goal of capturing within catchment spatial patterns of inter-annual (climate driven) variation in vegetation summer water stress?

RHESSys Modeling framework



Hydrologic Similarity Indicators

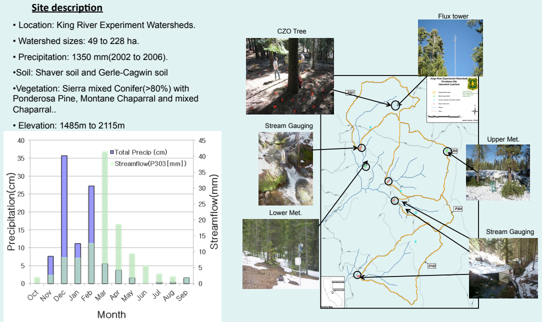
○ mean and inter-annual variation (expressed as coefficient of variation, CV) of five indicators

1) number of days of snow melt
2) day of water year that root-zone soil moisture is fully saturated
3) day of water year that root-zone soil moisture declines to 70% of saturation
4) day of water year that root-zone soil moisture declines to 50% of saturation
5) day of water year that transpiration declines to 50% of its peak growing season value

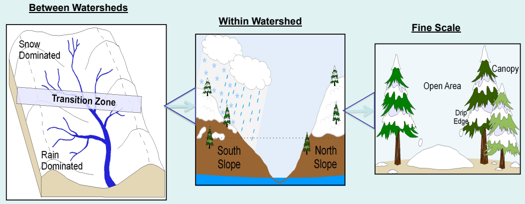
Southern CZO Watersheds

Site description

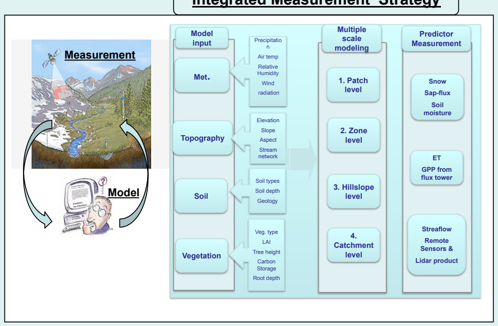
- Location: King River Experiment Watersheds.
- Watershed sizes: 49 to 228 ha.
- Precipitation: 1350 mm(2002 to 2006).
- Soil: Shaver soil and Gerle-Cagwin soil
- Vegetation: Sierra mixed Conifer(>80%) with Ponderosa Pine, Montane Chaparral and mixed Chaparral..
- Elevation: 1485m to 2115m



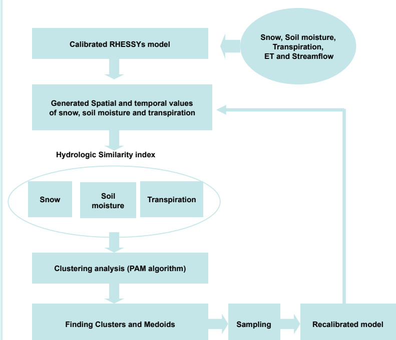
Spatial Heterogeneity at Multiple Scales



Integrated Measurement Strategy



Conceptual framework of top-down sampling design approach for soil moisture and vegetation water use



Model Performance

- Using GLUE approach to assemble the behavior simulation results
- Accuracy of behavior parameter sets >0.4

$$R_{eff} = 1 - \frac{\sum_i (Q_{obs,i} - Q_{sim,i})^2}{\sum_i (Q_{sim,i} - \overline{Q_{obs}})^2}$$

$$\log(R_{eff}) = 1 - \frac{\sum_i (\log(Q_{obs,i}) - \log(Q_{sim,i}))^2}{\sum_i (\log(Q_{sim,i}) - \log(\overline{Q_{obs}}))^2}$$

$$PerErr = \frac{(\overline{Q_{sim}} - \overline{Q_{obs}})}{\overline{Q_{obs}}} \times 100$$

$$Accuracy = R_{eff} \times \log(R_{eff}) \times (1 - \frac{PerErr}{100})$$

Calibration Soil Parameters:

Drainage parameters:

Ksat: saturated conductivity

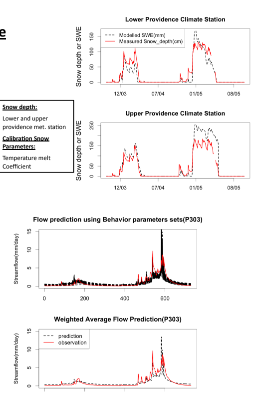
m : decay of Ksat with depth

Snow depth:

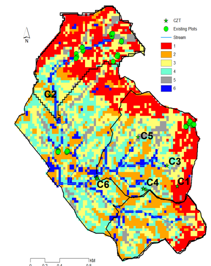
Lower and upper providence met. station

Calibration Snow Parameters:

Temperature melt Coefficient

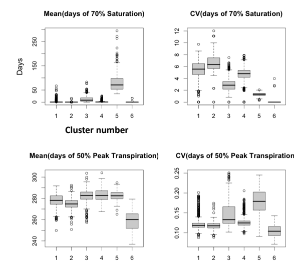


RHESSys Soil moisture and Transpiration Clusters



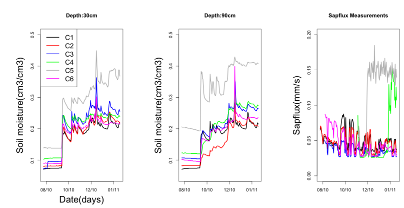
- Clustering distinguished six clusters
- A representative plot per cluster
- A plot size is 30m*30m

Model Clustering Analysis



- Cluster 5 is the wettest area and Cluster1, 2 and 6 are dry areas.
- Cluster 3, 4 and 5 have high transpiration and Cluster 6 has the lowest transpiration

Measured Soil moisture and Sapflux



- In the summer, deep soil(90cm) is wetter than shallow soil (30cm).
- After Oct., shallow soil become wetter than deep soil.
- Temporal variation of soil moisture is similar between sampling sites.
- Cluster 5 has the highest soil moisture content, while cluster 2 has the lowest soil moisture content.
- Spatial variation of collected soil moisture is similar to model clustering analysis.

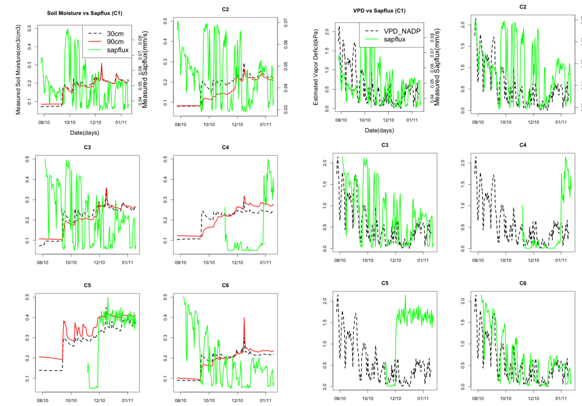
Reference

Green SR, Clothier BE, Jardine B (2003) Theory and practical application of heat-pulse to measure sap flow. Agron J 95:1371–1379

Maechler, M. et al. (2006), Cluster Package, R. Package Version 1.10.5.

Tague, C. and Band, L. 2004. RHESSys: Regional Hydro-ecologic simulation system: An object-oriented approach to spatially distributed modeling of carbon, water and nutrient cycling. *Earth Interactions*, 8:19, 1-42

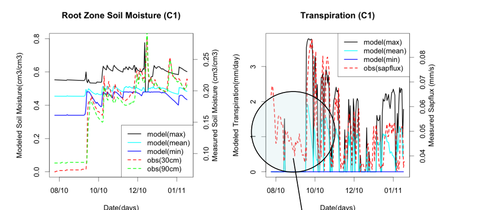
Relationship between VPD, Soil moisture and Sapflux



- During summer, sapflux declines at all sites
- After Oct., temporal fluctuation of sapflux is similar to VPD except for C4 and C5.
- Sapflux recovery in Oct. relates to increased soil moisture
- Temporal trend of sapflux at C6 is highly correlated with VPD.

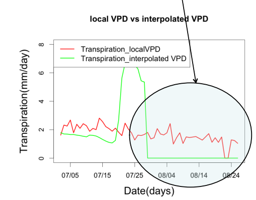
Preliminary Model Simulation Results at Plot Scale

- Plot-scale(30m) modelling at C1 using randomly 100-sampled soil parameters (m, Ksat, pore size index, air entry pressure) to test the sensitivity of soil moisture and transpiration to soil parameter uncertainty.



- Model captured temporal trend of measured soil moisture and sapflux.
- Model underestimated transpiration in the late summer period
- Using local microclimate measurements may improve transpiration predictions in the late summer.

- We hypothesize that underestimation of transpiration in the late summer is due to overestimation of VPD
- Model shows high sensitivity to approach used to estimate VPD for the nearby flux tower site.
- Flux tower measurements also show that tree continuously transpires in the late summer



Summary

○ Strategic clustering of estimates from a physical distributed model are used to guide site selection for soil moisture and sapflux measurements.

○Soil moisture patterns reflected by model clusters are similar to measured soil moisture patterns.

○ Preliminary comparison between observed and modeled eco-hydrologic fluxes suggest a need for improved estimation of micro-climate patterns

○ Additional sampling data will be used to constrain model parameter spaces , reduce the model uncertainty and improve micro-climate estimation.