Top-down Approach Soil moisture and Sapflux Sampling Design to Capture the Effect of Inter-annual Climate Variability on Ecohydrologic Response in Mountain Catchments

Kyongho Son and Christina Tague, Bren School of Environmental Science and management ,

University of California State university, Santa Barbara (kson@bren.ucsb.edu)

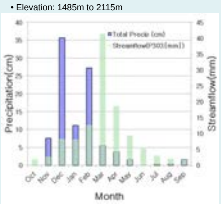
Abstract

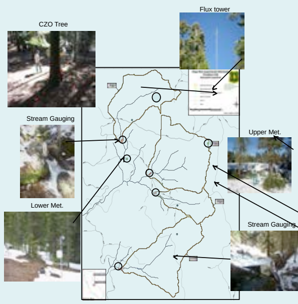
In this study, we demonstrate the use of a top-down approach for sampling design of soil moisture and sapflux measurement based on an ecohydrologic model and clustering analysis. The sampling strategy is explicitly designed to capture the effect of inter-annual climate variability on ecohydrolgy response of mountain catchments located in King River Experiment Watersheds, Sierra National Forest. An ecohydrolgic RHESSys model [Tague and Band, 2004] is calibrated with existing collected data sets including snow depth, soil moisture, sapflux, evapotranspiration from a flux tower and streamflow. The model is used to generate spatial-temporal patterns of snow accumulation and melt, soil moisture and transpiration and compute inter-annual mean and coefficient of variation of five hydrologic similarity indices. Similarity indices are chosen to reflect seasonal trajectories of snowmelt, root-zone soil moisture storage and evapotranspiration. Clustering analysis, using Partitioning Around Medoid (PAM) [Maechler, et al.,2006] is used to partition the watershed based on these similarity indices. For the Kings River Experimental Watersheds, clustering distinguished six clusters and a representative plot per cluster. These results were used to identify additional strategic sampling points within the watershed. For each of these points, we installed soil moisture sensors (5TE) at the two depths (30m and 90m) and at the five soil pits within a 30m plot. A sapflux sensor at the average-size white fir tree per plot was also installed. Initial results from monitoring in summer 2010 are compared with model predictions and used to refine model calibration and uncertainty analysis. Cross-cluster differences in soil moisture and sap-flow trajectories derived from sampling data will be compared with results from initial model to assess the validity of the suggested sampling design.

Southern CZO Watersheds

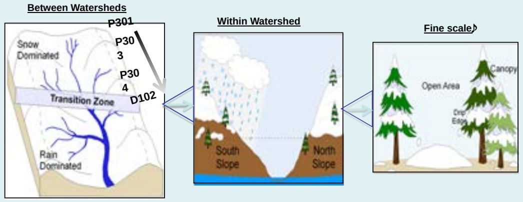
Site description

- 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

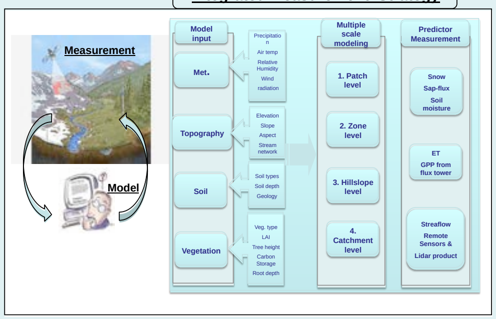




Spatial Heterogeneity at Multiple Scales



Integrated Measurement Strategy

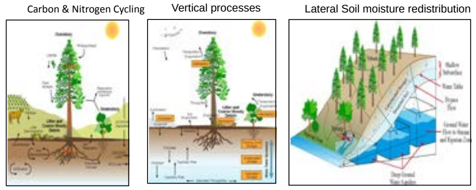


Research Questions

ο 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?

ο 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

ο 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 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

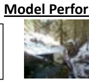
Model Performance

Snow depth:

Lower and upper providence met. station

Calibration Parameters:

Temperature melt Coefficient

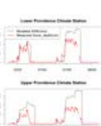


Calibration Parameters:

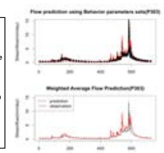
Drainage parameters:

Ksat: saturated conductivity

m : decay of Ksat with depth



- Model captured timing of accumulation of snow.
- Model estimates of melt are several weeks too late in 2004 for upper climate station.
- Potential sources of error in upper met station estimates are: errors in model estimates of albedo and error in interpolating spatial patterns of air temperature .



Accuracy measures

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

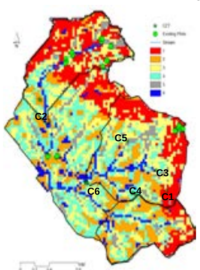
$$\log(R_{eff}) = 1 - \frac{\sum_i (\log(Q_{obs,i}) - \log(Q_{sim,i}))^2}{\sum_i (\log(Q_{sim,i}) - \log(\overline{Q_{obs}}))^2}$$

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

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

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

Soil moisture and Transpiration Clusters



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

Topographic and vegetation characteristics at six clusters

	1	2	3	4	5	6
Elev	1967	1892	1921	1861	1876	1750
Slope	9.9	16.6	17.2	12.1	13.7	9.9
aspect	NW	SE	WS	WS	S	NW
LAI	2.3	1.9	4.6	3.9	2.6	3.3

Soil Properties (Ksat (cm/h)) at six clusters

	1	2	3	4	5	6
30cm	22.73	3.44	13.05	5.38	7.73	5.60
90cm	30.70	5.10	2.89	2.63	0.22	33.66

- Ksat varies vertically and horizontally.
- Cluster 1 has high Ksat compared with cluster 2 and 4
- Cluster 3, 5 and 6 have distinctive difference of Ksat with depth

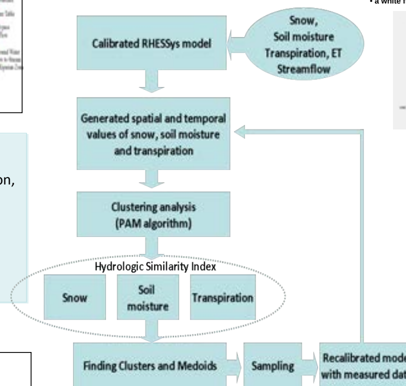
Number of existing plots in each cluster

	1	2	3	4	5	6
Number of existing plots	23	3	11	3	3	6
	47%	6%	22%	6%	6%	12%

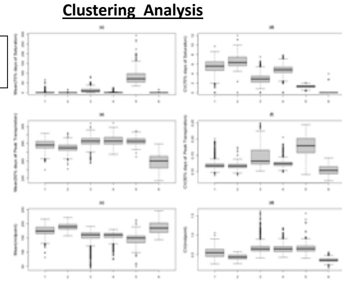
- Cluster 1 has the largest number of existing plots
- Collected soil moisture data at existing plots

Will be compared with model clustering analysis

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



Clustering Analysis



- Using PAM to cluster five hydrologic similarity indicators
- Six clusters are chosen
- Cluster 5 is the wettest area and Cluster1, 2 and 6 are dry area.
- Cluster 3, 4 and 5 has high transpiration and Cluster 6 has the lowest transpiration.

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.

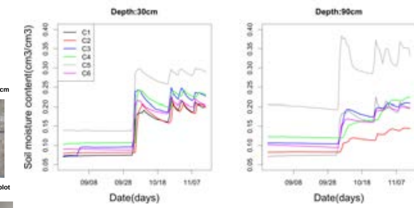
Tague, C. and Band, L. 2004. RHESSys: Regional Hydro-ecologic simulation system: An object-oriented approach to spatially distributed modeling of carbon, water and nutrient cycling. *Earth Interactions*, 8:19, 1-42

Soil Moisture

- using 5TE Sensor

- Install sensors at 30cm and 90cm

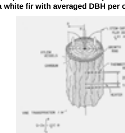
- Five soil pits per cluster plot



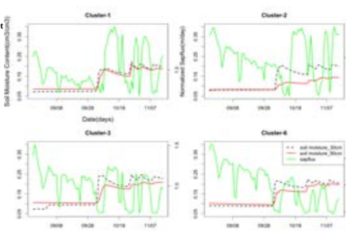
- In the summer, deep soil(90cm) is wetter than shallow soil (30cm).
- After Oct., shallow soil become wetter than deep soil.
- Temporal variation of soil moisture is similar between sampling sites.
- Cluster 5 has highest soil moisture content, while cluster 2 has lowest soil moisture content.
- Spatial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

Sapflow

- using heat pulse method (Green,et al., 2003)
- a sapflux sensor per cluster plot
- a white fir with averaged DBH per cluster plot

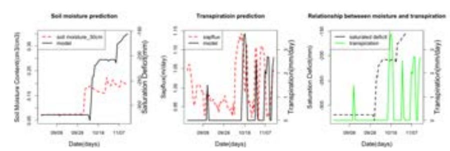


Relationship between soil moisture and Sapflux



- This study focuses on temporal trends and spatial variation of vegetation water use rather than actual amount of transpiration.
- Sapflux data is normalized by averaged value of each time series since the value is uncalibrated.
- During summer, sapflux declines at all sites
- After Oct., sapflux maintained or increased except for cluster-6 site
- Sapflux recovery in Oct. related to increased soil moisture

Future work



- Using sapflux data and soil moisture will constrain the model parameters and reduce the predictive uncertainty
- Revised model (based on additional measurements from cluster based sampling) will be used to examine the relationship among soil moisture, transpiration and climate for existing and projected future climate scenarios

Summary

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

ο Transpiration and soil moisture patterns reflected by model clusters are similar to measured soil moisture patterns.

ο The additional sampling data will be used to constrain model parameter spaces and reduce the model uncertainty.

This Project is funded by grants from the National Science Foundation – California Sierra Critical Zone Observatory and Kearney Foundation of Soil Science