CLIMATE CHANGE IMPACTS ON ECO-HYDROLOGY IN MOUNTAIN ENVIRONMENTS; WHY SPATIAL PATTERNS OF SOIL AND SUBSURFACE DRAINAGE MATTER

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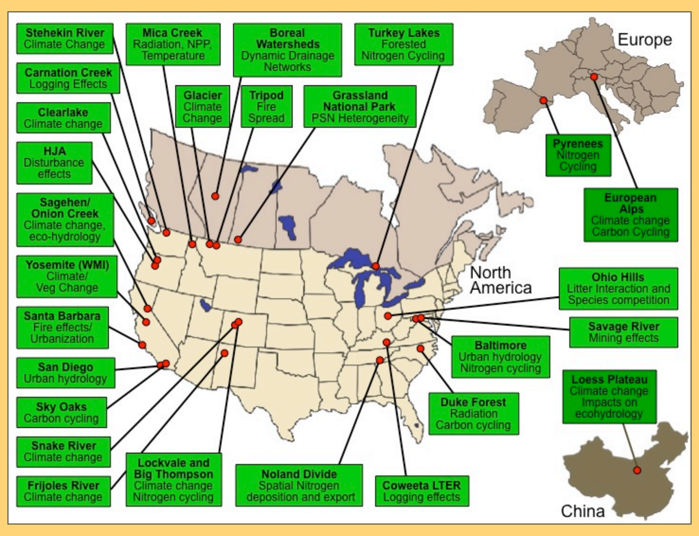
RHESSys Model

RHESSys is a process based, spatially distributed coupled model of hydrologic and vegetation carbon and nutrient cycling processes.

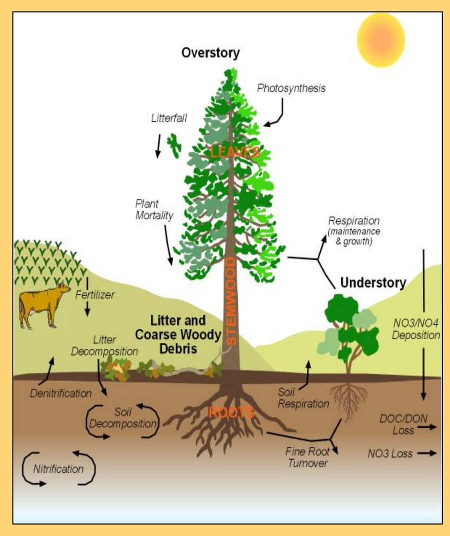
We continue to evolve this model based on interactions with field-based scientists. We use this model to investigate the impact of climate/land use change at 1st to 3rd order watershed scales for sites throughout the US and Europe.

Model code is open source and hosted at http://fiesta.bren.ucsb.edu/~rhessys/

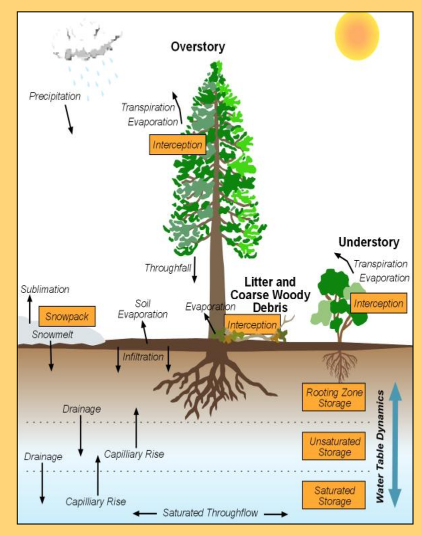
RHESSys Project Locations



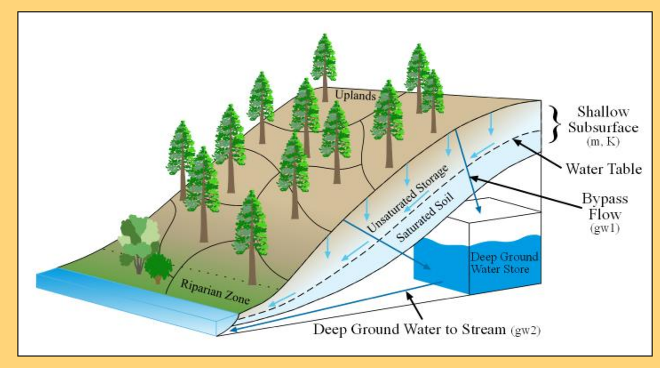
Carbon & Nitrogen Cycling



Vertical hydrologic processes

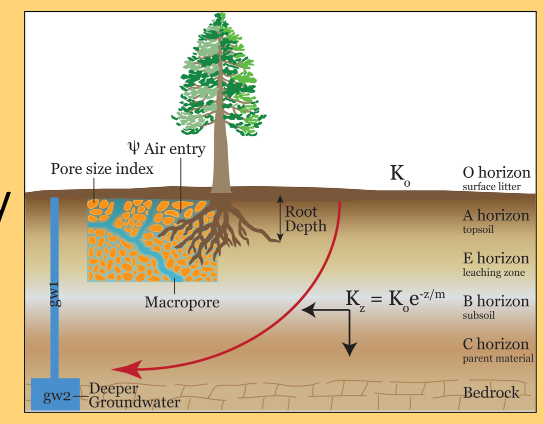


Lateral moisture redistribution



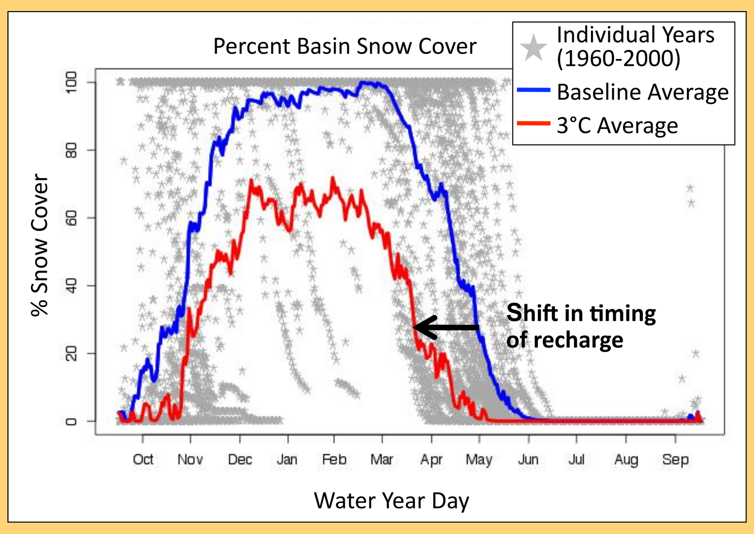
RHESSys algorithms and processes are described in: *Tague, C. and Band, L. 2004. RHESSys: Regional Hydro-ecologic simulation system: An object-oriented approach to spatially distributed modeling of carbon, water and nutrient cycling. Earth Interactions, 8:19, 1-42.*

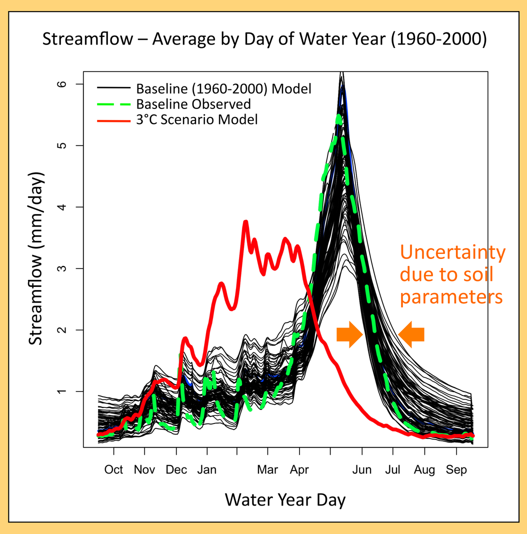
Soil Parameters



As in all eco-hydrology models, drainage and storage parameters are highly uncertain.

Forest water use and recharge timing





In the Western US, a key question is "How will shifts in the timing of recharge (due to shifts from snow to rain and earlier melt) influence forest water use, and consequently, streamflow and forest health?"

Example: Sagehen Creek

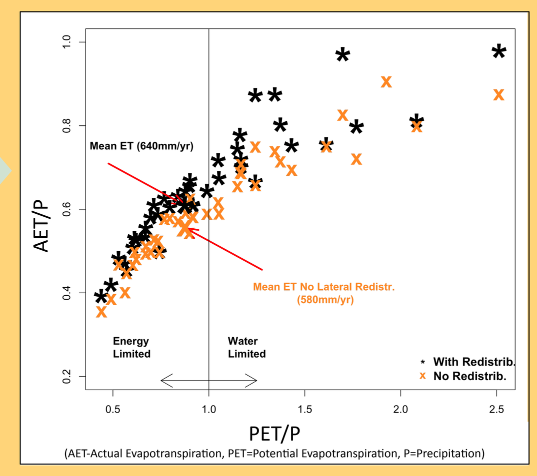
- Forested experimental watershed in the California Sierras
- Elevation range 1800m-2650m
- Mean annual precipitation 880mm/year.

Evapotranspiration (AET) sensitivity to climate drivers

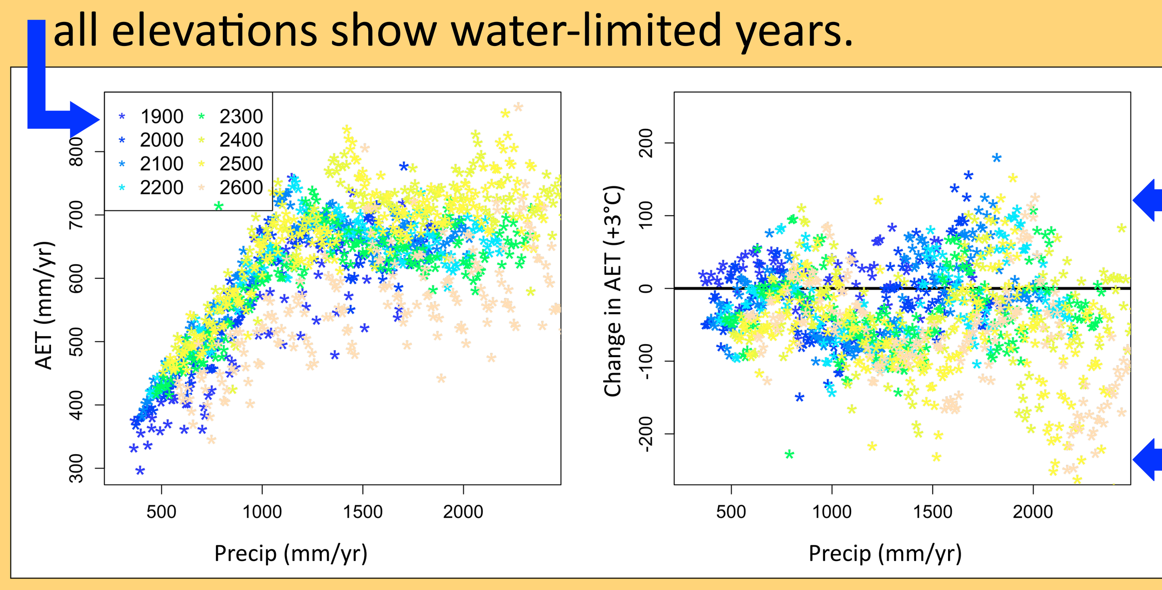
Basin shifts between water limited and energy limited, but timing accounts for shifts away from the curve.

Accounting for lateral redistribution of water significantly increases AET estimates. Simply accounting for spatial variation in energy & recharge is not enough!

Budyko curve estimates for Sagehen



If we look at all 90m patches within the watershed, all elevations show water-limited years.



With 3°C temp. increase we see two counter-balancing effects:

high vapor pressure deficits and longer growing seasons leading to increased AET

\- versus -

earlier recharge leading to greater summer moisture stress and AET declines.

Do soil parameters matter?

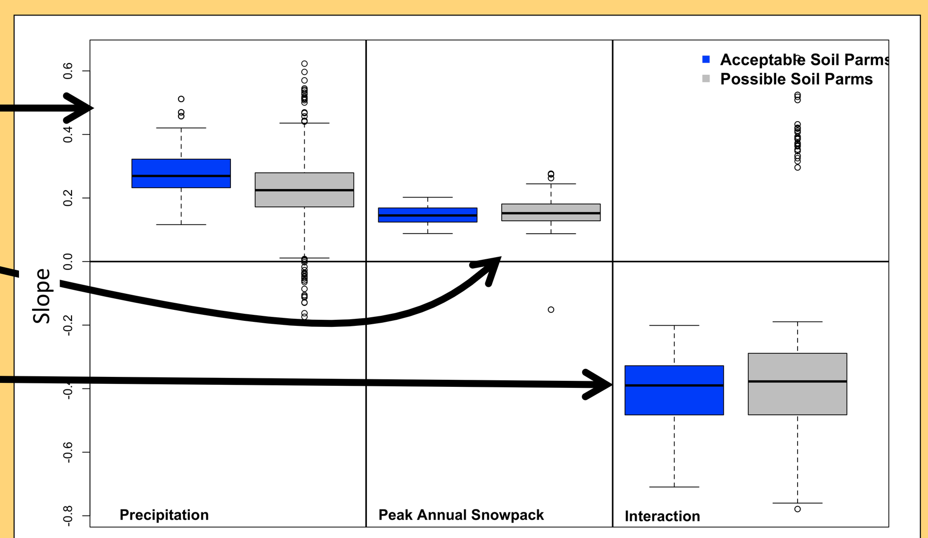
Precipitation is the dominant driver of historic inter-annual variation in AET estimates.

The timing of recharge (using peak annual snow pack) is a significant second order control.

Although less so in wetter years (interaction term is significant and negative).

Slopes of these relationships vary across soil parameter uncertainty - but signs do not change. How sensitive forest water use is to timing of recharge (or how much of the precipitation is snow) depends on soil parameters.

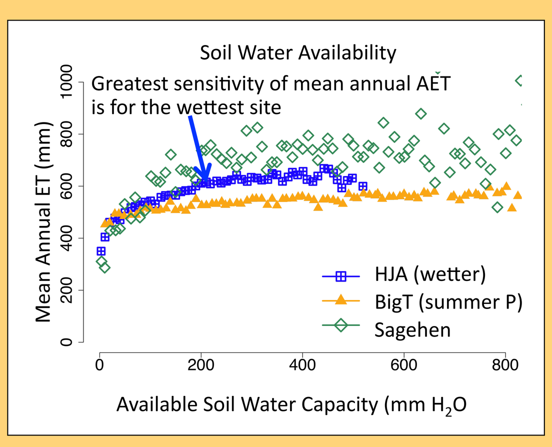
Regressions of inter-annual variation in basin scale AET for Sagehen Creek



all variables are normalized deviations from the mean

Tague and Peng (in review)The sensitivity of forest water use to the timing of precipitation and snow melt recharge in the California Sierra: Implications for a warming climate, JGR.

Similar analysis for other Western US sites, shows that climate patterns alter the sensitivity of AET estimates to soil parameters.

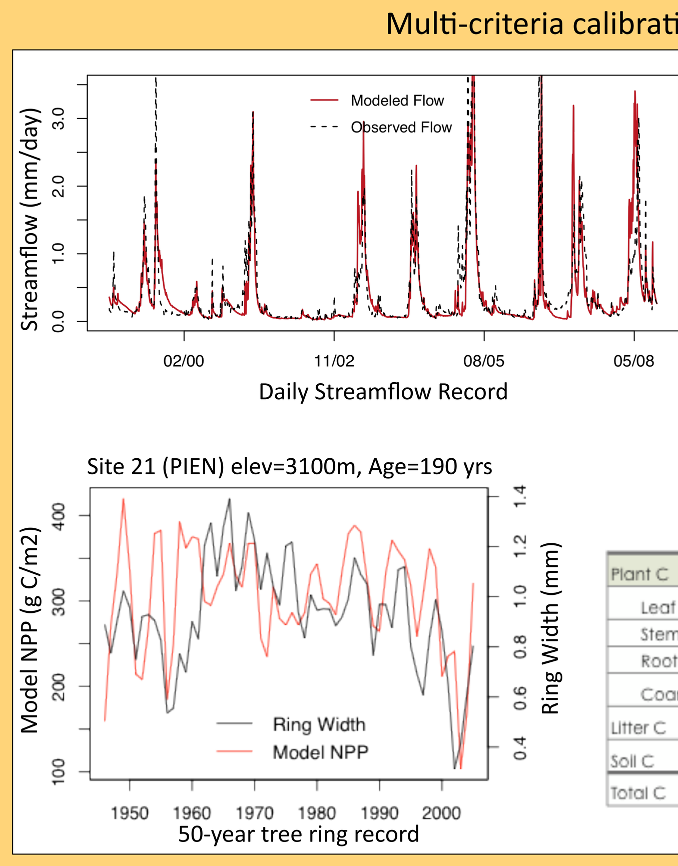


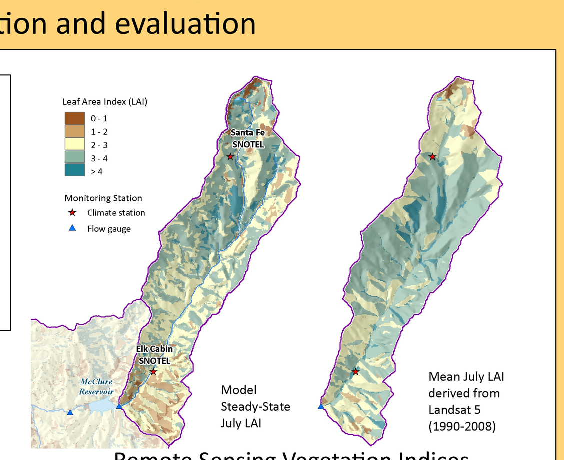
Western Mountain Initiative
http://westernmountains.org/

Streamflow sensitivity to links between forest biomass, climate, and landscape characteristics in Western mountain watersheds, Garcia, E., Tague, C (in prep).

How do we constrain those parameters?

Multi-criteria calibration and evaluation



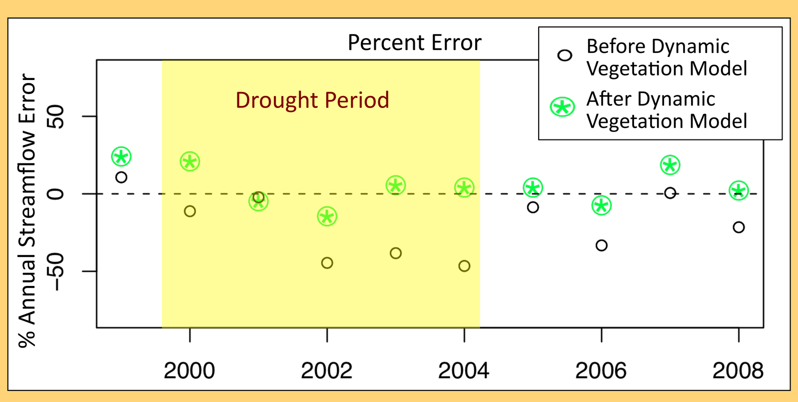


Remote Sensing Vegetation Indices

	Model Steady State kg C / m²	Ponderosa Pine in Oregon kg C / m²	Spruce-Fir in Colorado kg C / m²
Plant C	13.45	12.67	15.1
Leaf C	0.57	0.27	12.4
Stem C	9.49	10.5	
Root C	3.38	1.9	2.7
Coarse Woody Debris	5.24	1.3	7
Litter C	0.55	1.2	6.8
Soil C	6.60	5.3	12.6
Total C	25.84	20.47	41.5

Literature-reported carbon stores

Calibration in landscapes where there is significant co-variation between forest biomass/growth and hydrologic fluxes.



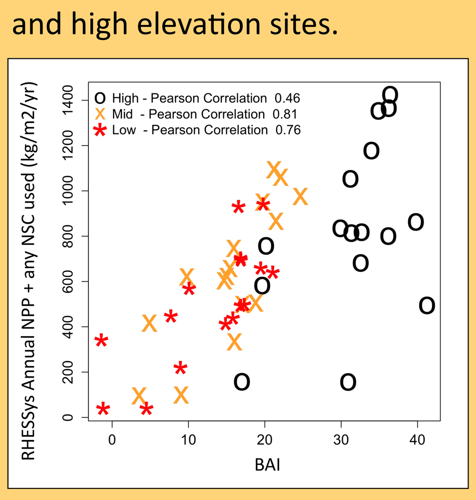
Inclusion of dynamic vegetation also matters in terms of getting streamflow right.

CZO SOUTHERN SIERRA CRITICAL ZONE OBSERVATORY

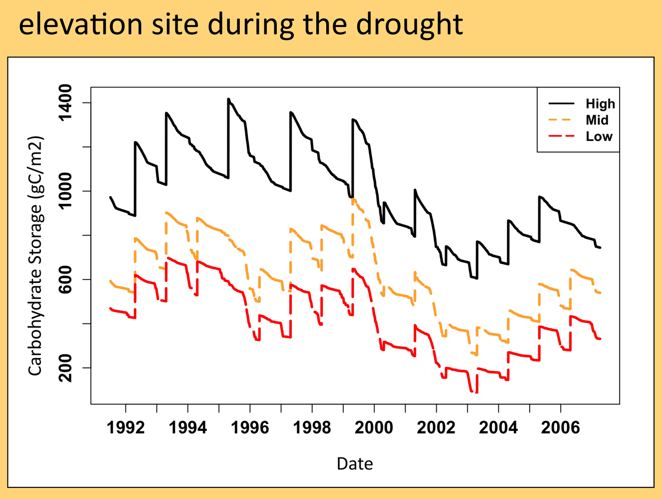
Other sources (sapflow and flux tower measurement) - done as part of the Sierra Critical Zone Observatory. http://criticalzone.org/sierra/

Drought , stress, and mortality

Rough "soft" data comparison – NPP (Net Primary Productivity) with stem width change as Basal Area Increment (BAI) for low, mid and high elevation sites.



Non-structural carbohydrate trajectories - demonstrate "critically" low NSC for low elevation site during the drought

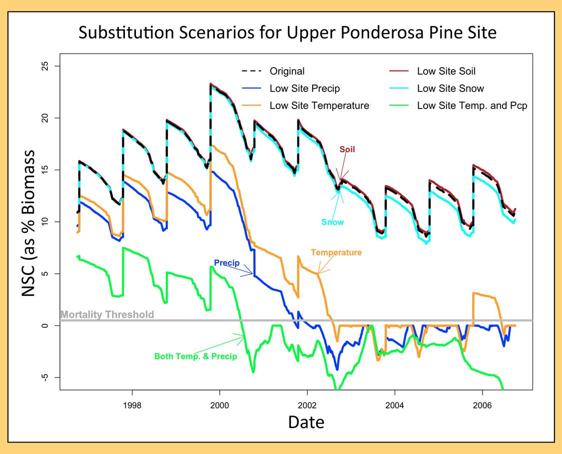


RHESSys estimates the likelihood of forest dieback by including a semi-mechanistic representation of tree death - by using non-structural carbohydrate (NSC) storage estimates as an indicator.

Estimates of ponderosa pine growth and mortality along an elevation gradient where trees are monitored at 3 different elevations.

During a drought in the early 2000's, ALL ponderosa pines at the low elevation sites died (C13 isotope data, tree ring, and visual inspection suggested death due to drought (rather than obvious insects or disease) *McDowell et al., 2010*

Can the model capture this?

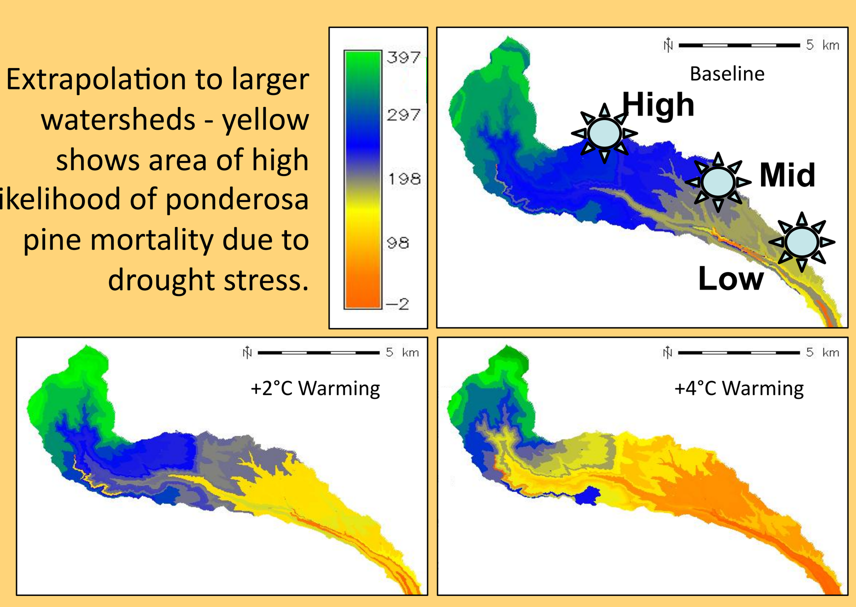


Model sensitivity analysis to estimate "why" trees died only at low site

Substituting upper site soils with lower site soils DOES NOT kill upper site trees

Substituting either temperature (T) or precipitation (P) or both (T&P) DOES kill site trees

Extrapolation to larger watersheds - yellow shows area of high likelihood of ponderosa pine mortality due to drought stress.



Tague, C., McDowell, N. Allen, C., (in final revision) Modeling growth, carbohydrate balance, and mortality of Pinus ponderosa forests in the Southern Rocky Mountains, PLOS ONE.

Next Steps

Evaluation of RHESSys estimation of the impact of thinning on forest water use and NPP - summarizing sensitivity to litter, vegetation structure and soil parameters

Comparison with observations at Sierra Critical Zone Observatory.

recommendations for additional sites with detailed measurements welcome.

Developing a conceptual model of forest thinning-climate interactions.

Integration of RHESSys into fully coupled atmospheric-N-deposition model BIOEARTH http://www.cereo.wsu.edu/bioearth/

BioEarth Biosphere-relevant earth system model