Consequences of warming temperatures and shifts in precipitation regimes for snow-dominated mountain systems.

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RHESSys
Regional Hydro-Ecologic Simulation System

An Eco-hydrologic "take" on the question

ET
Water for forests

Q
Water for us and for fish

How does the partitioning of Precipitation (P) into Streamflow (Q) and Evapotranspiration (ET) change with warming?

What is the role of timing of recharge - as it shifts from snow to rain and earlier melt?

The “tools” for the job

Empirical Analysis
(What Ross Did)

Assessment of broad scale patterns in observations

Spatially-distributed, dynamic models of coupled eco-met-geo-hydro processes
(What I’m going to do)

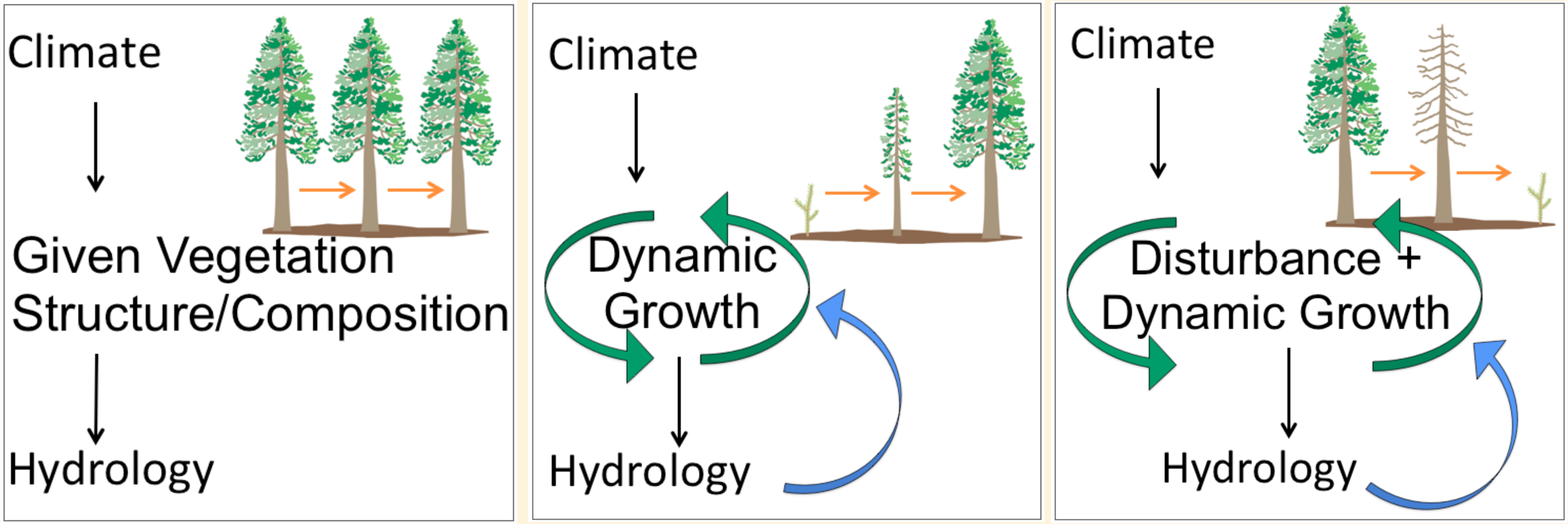
Place-based understanding

Able to isolate the impact of specific mechanisms

Vulnerable in weakness in model assumptions

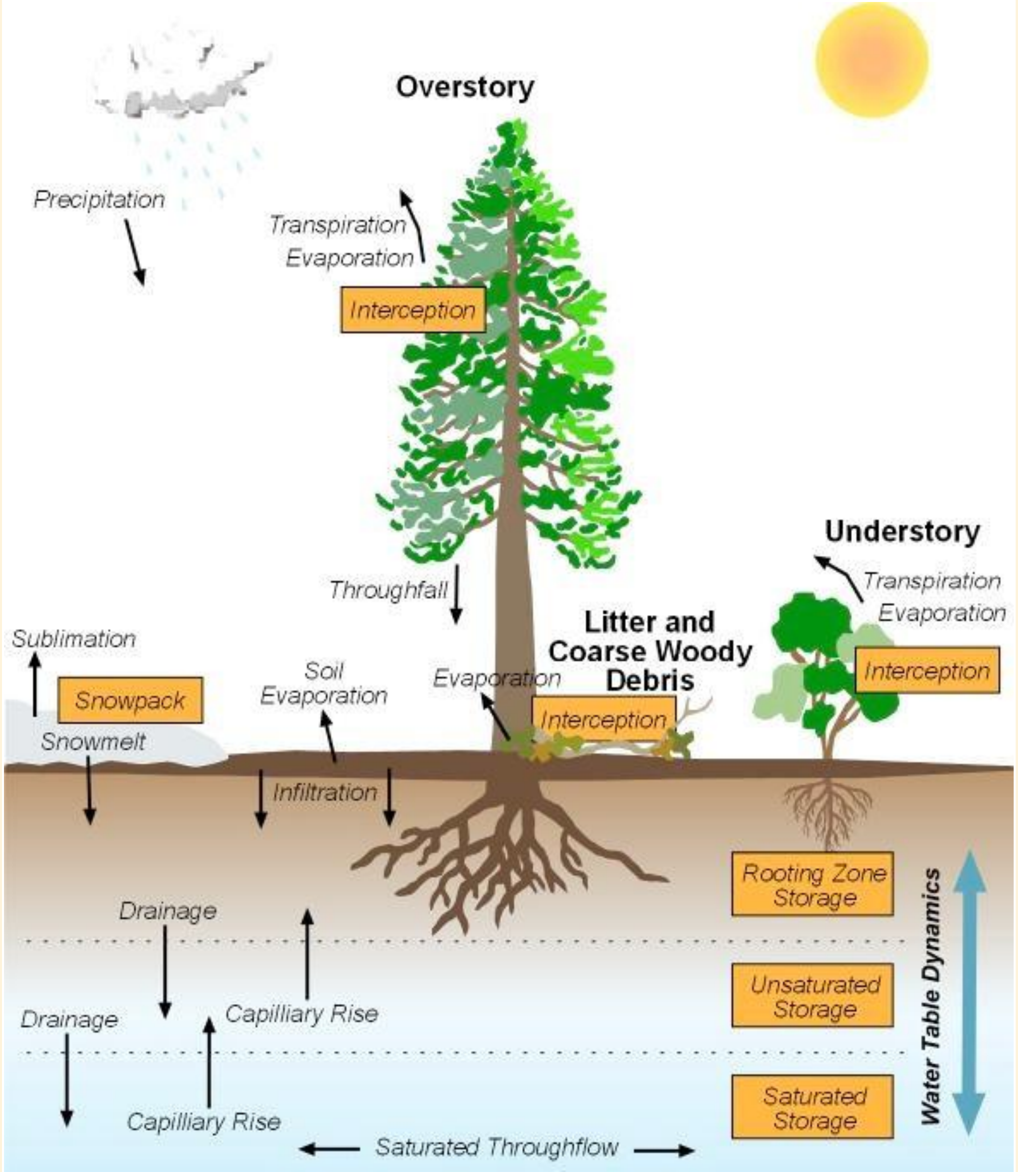
NOTE that both use observations

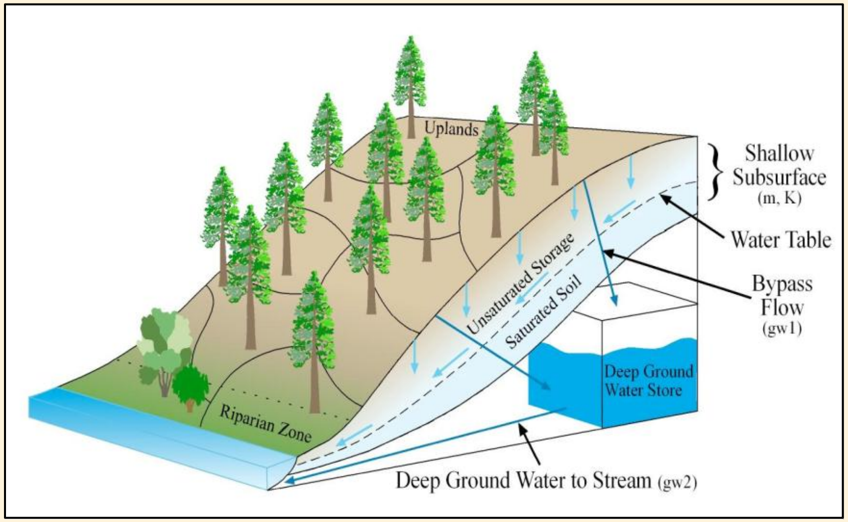
Behavioral modelling (Schaefli et al., 2013, HESS) approach to model evaluation and application



Progression of model representation of behaviors relevant to eco-hydrology responses to warmer temperatures

Hydrologic processes in RHESSys





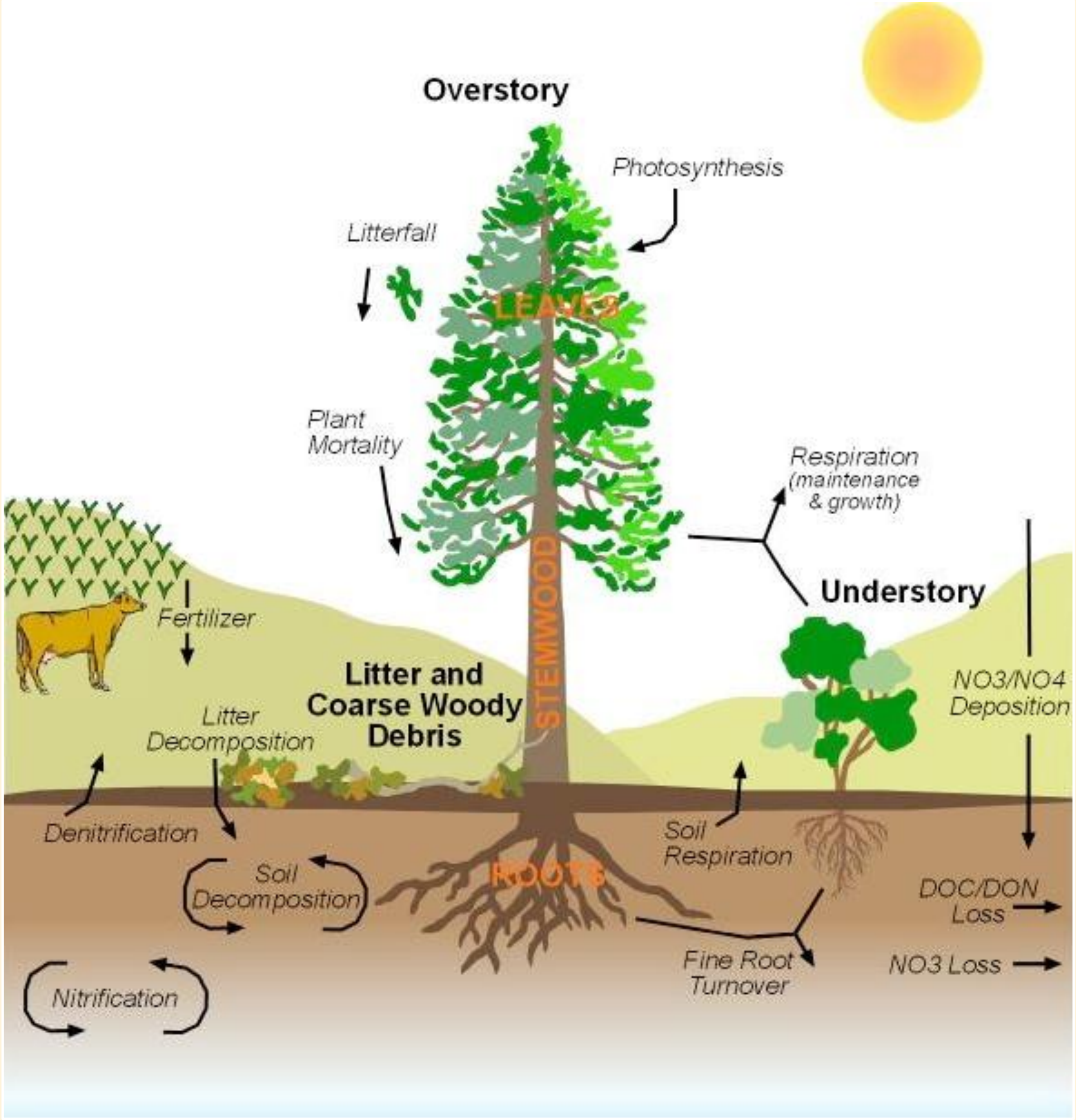
Tague, C. and Band, L. (2004) RHESSys: Regional Hydro-ecologic simulation system: An object-oriented approach to spatially distributed modeling of carbon, water and nutrient cycling. *Earth Interactions* 8:19, 1-42.

Substantial updates have been made to the model since that publication:
www.fiesta.bren.ucsb.edu/~rhessys
https://github.com/RHESSys/RHESSys

Carbon and Nitrogen cycling in RHESSys

Key point is that the model maintains energy, moisture, and carbon balance

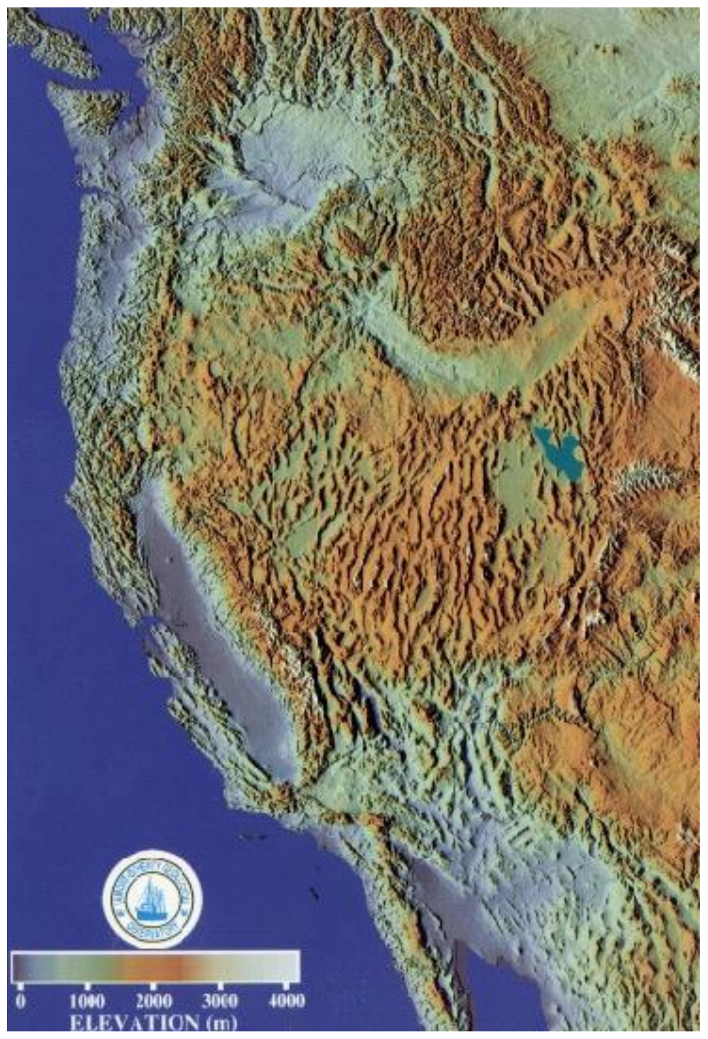
So we can tease out at least a 1st order approximation of some of these dynamics

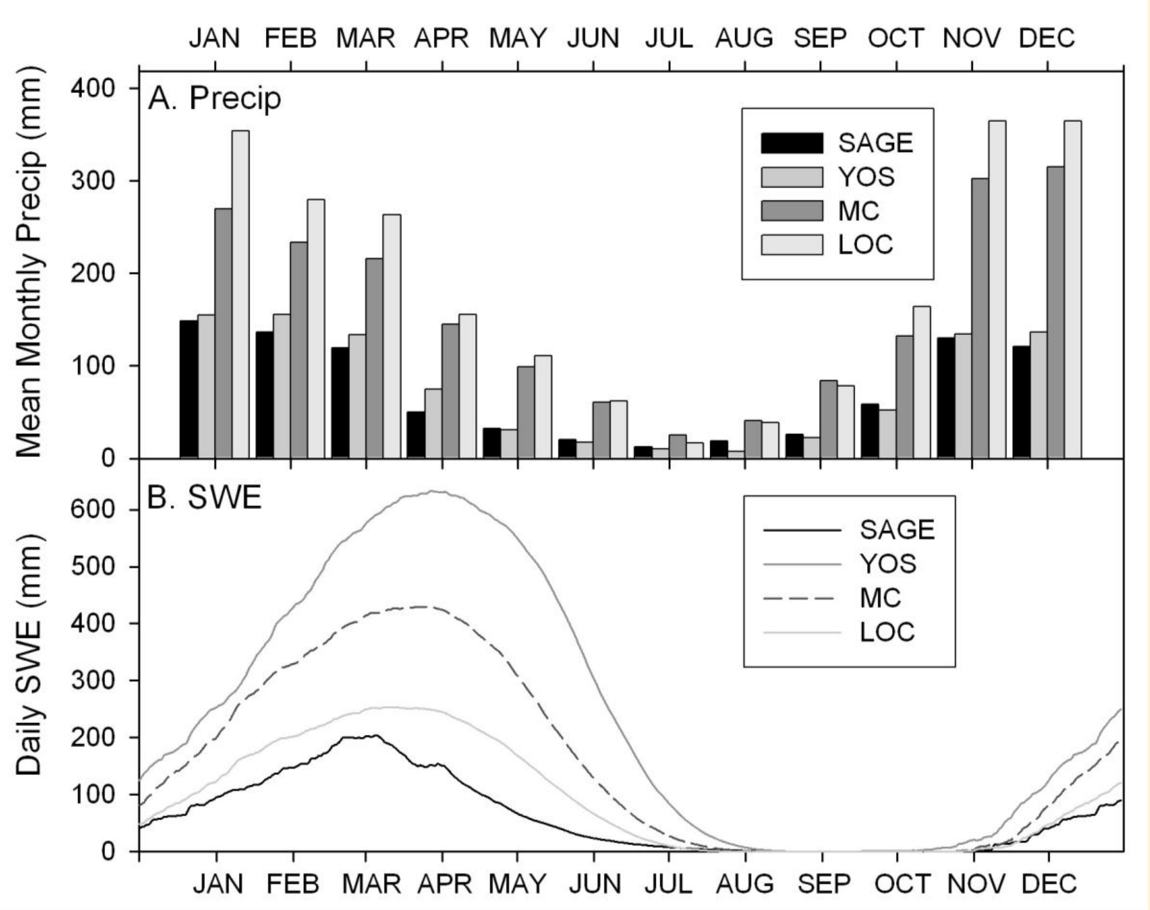


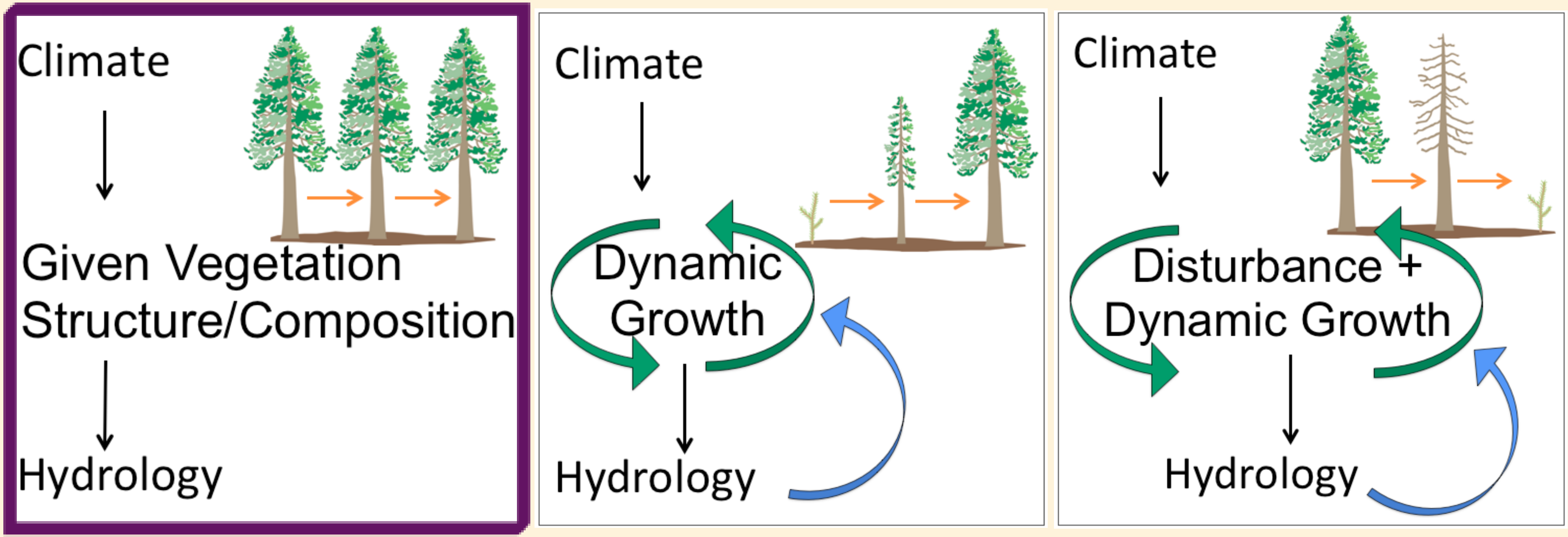
Mediterranean Climate

(most precipitation falls during the winter months,
rain at low elevations, snow at higher elevations (> 4000m))

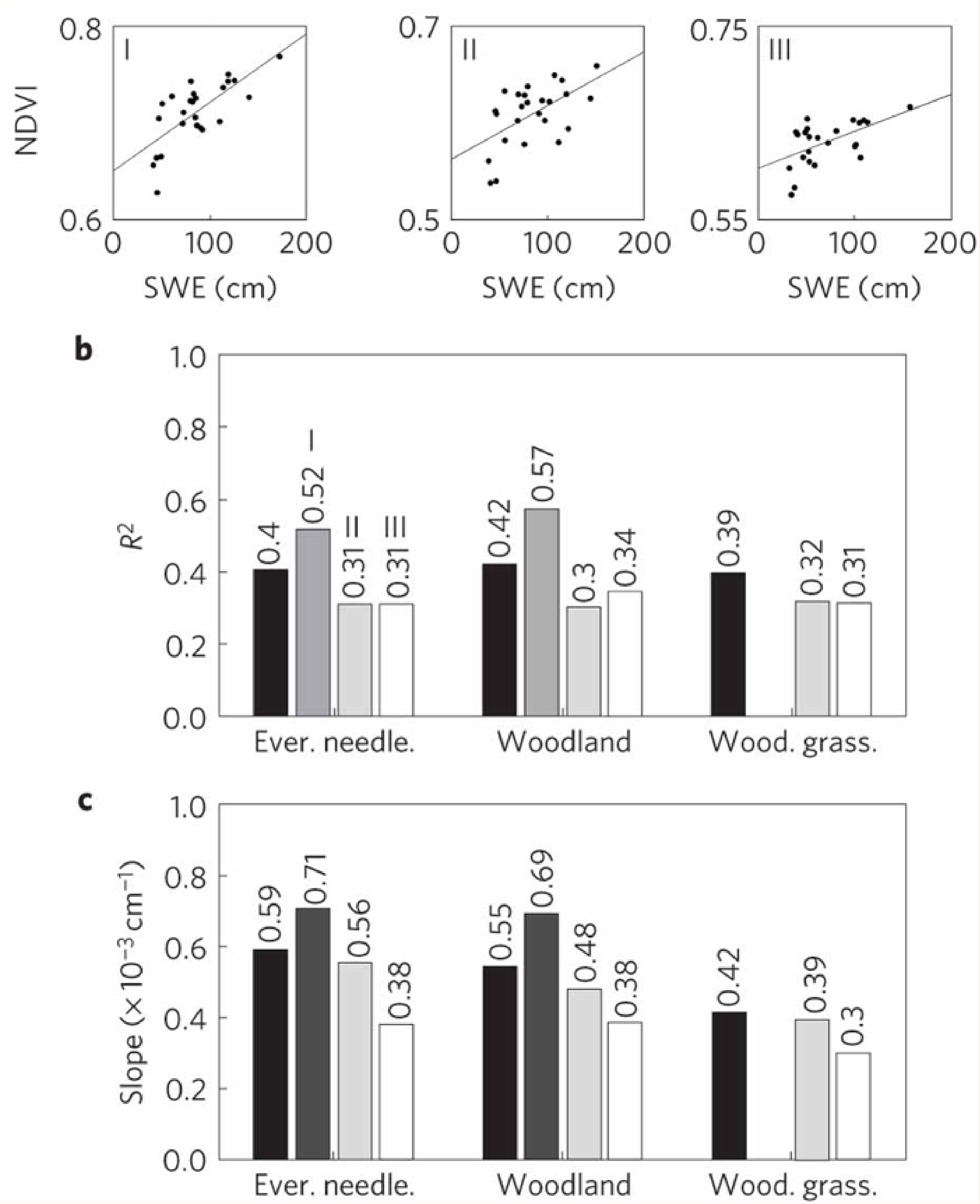
Example Western US, Pyrenees







Progression of model representation of behaviors relevant to eco-hydrology climate variation and change

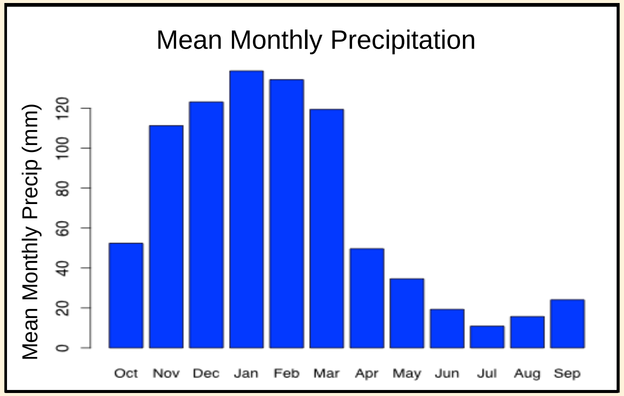


Relationships between forest greenness and maximum snow accumulation for large region (California Sierra – elevations 2000m – 2600m

More productive (more ET) in more snow?

But is that just more P?

Trujillo, E., Molotch, N.P., Goulden, M.L., Kelly, A.E., Bales, R.C. (2012) Elevation-dependent influence of snow accumulation on forest greening. *Nature Geoscience* 5: 705-709



Study sites

Sagehen Experimental Watershed (UC Berkley Field Station)

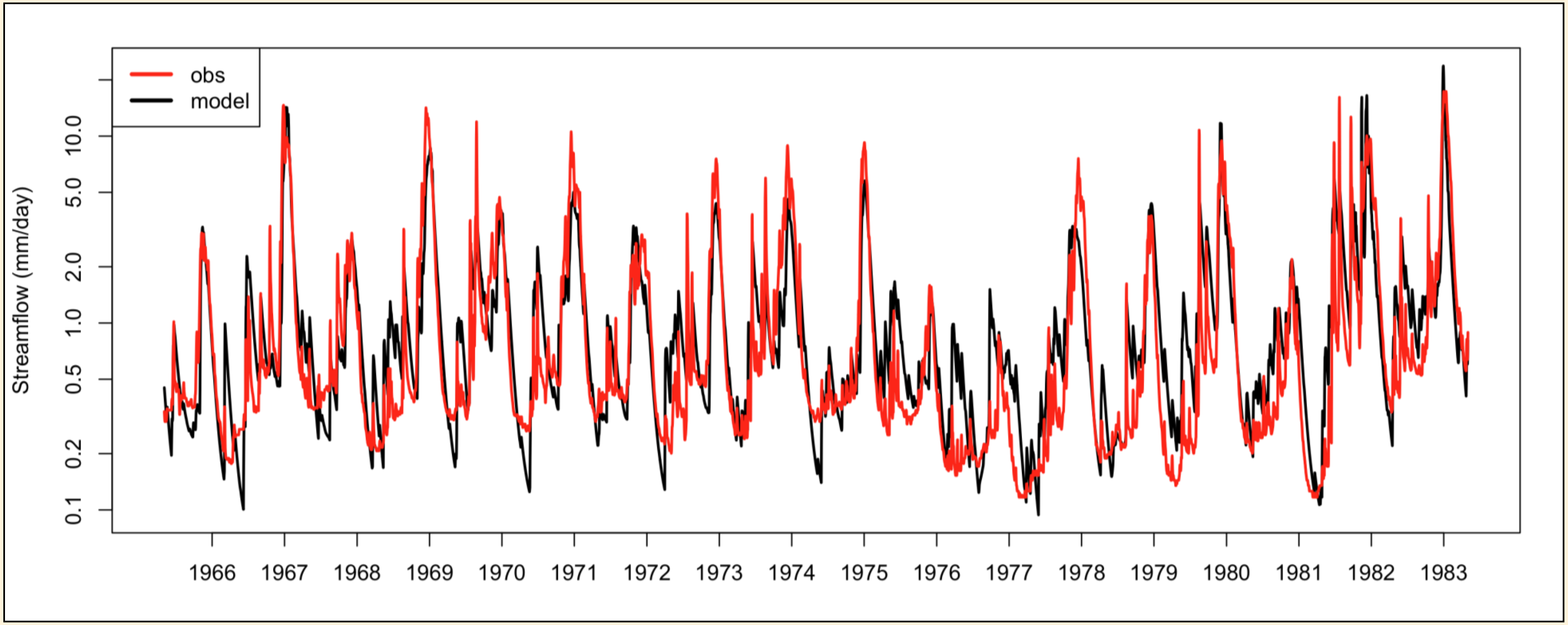
Sierra Nevada Mountain watershed (183ha)
Elevation range *1800-2700m*
Vegetation: conifer (Jeffrey and Lodgepole pine and fir with substantial meadows)

http://sagehen.ucnrs.org/Photos/scenics/index.html

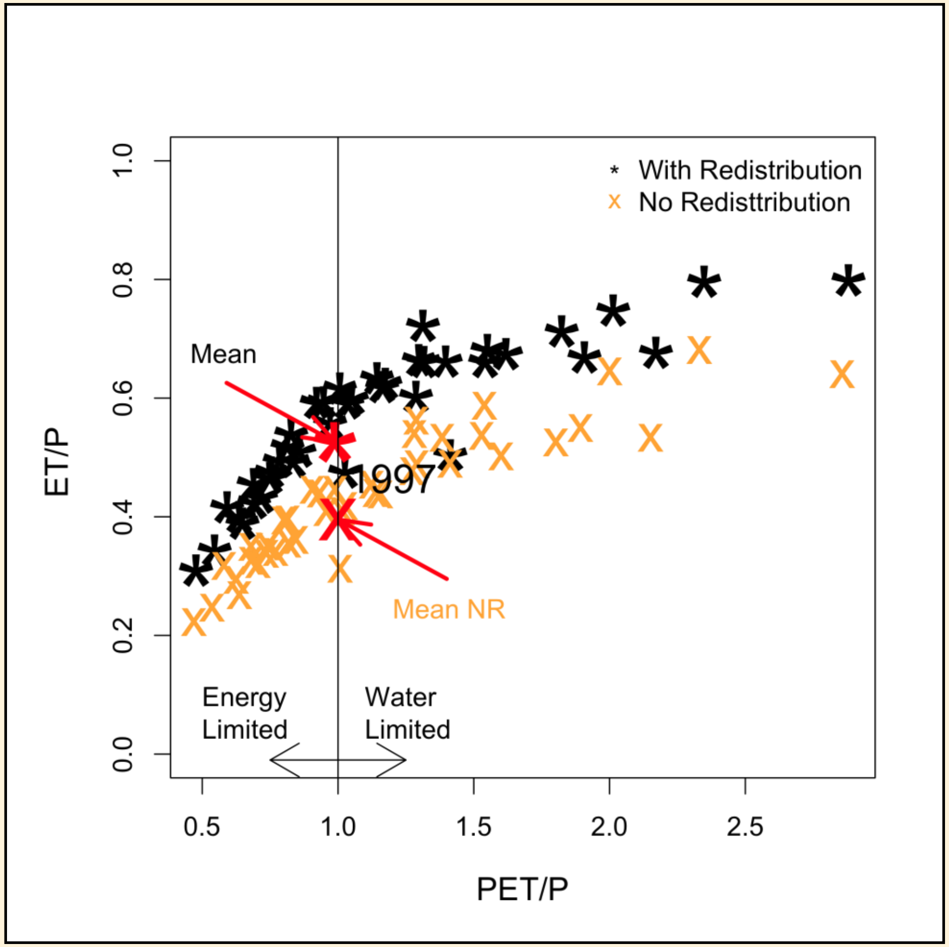
Classic hydrology parameterization-evaluation
RHESSys hydrologic model performance – post calibration
Streamflow (1960-2000)

- NSE (daily) 0.6
- NSE (log transformed daily) 0.6
- Bias < 10%
- Monthly R2 > 0.9

about 10% of parameter sets give reasonable results



Scatter in ET/P relationship is due to the timing of when that precipitation became recharge – and the synchronicity of the recharge with forest water demand



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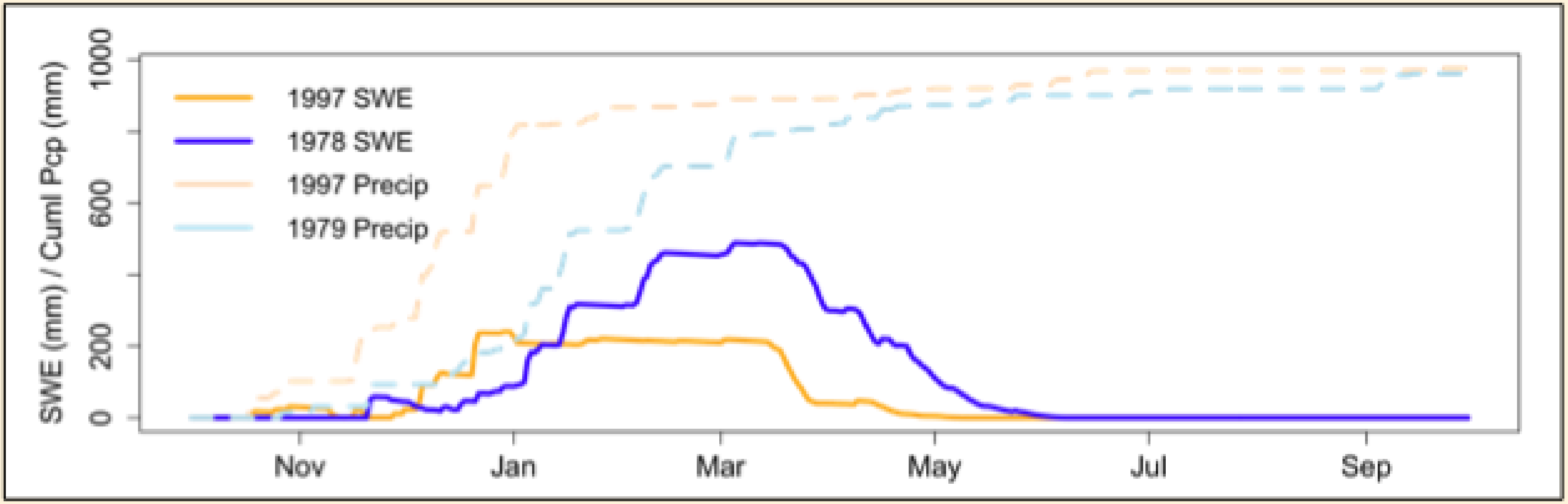
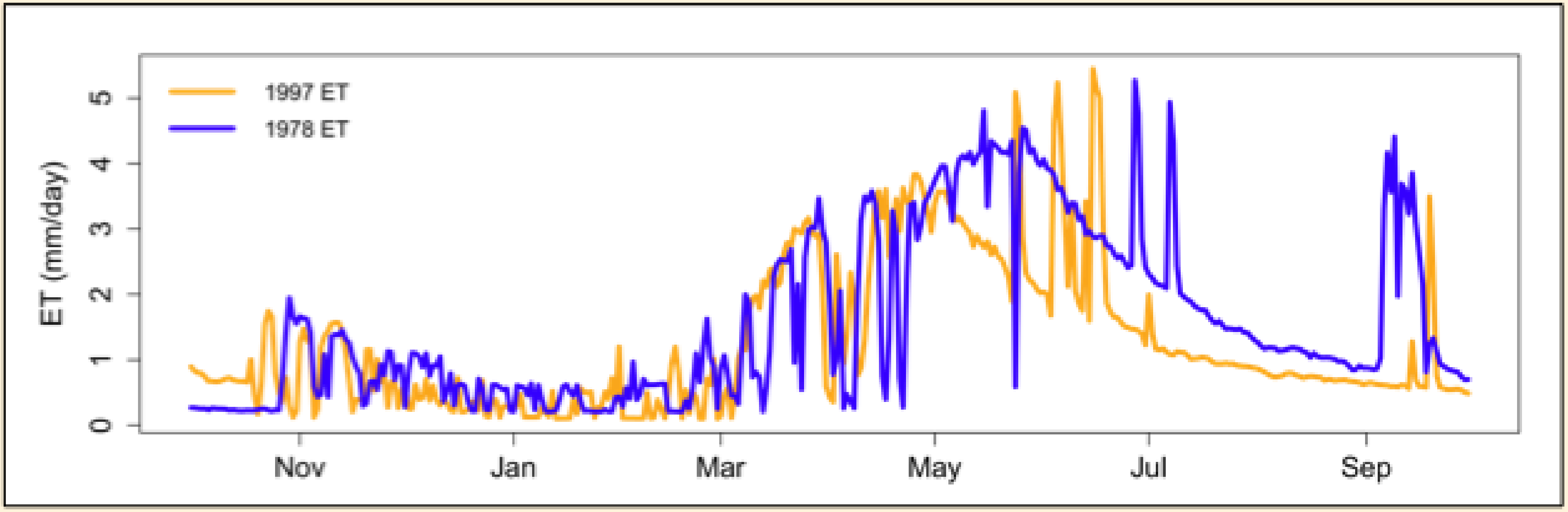
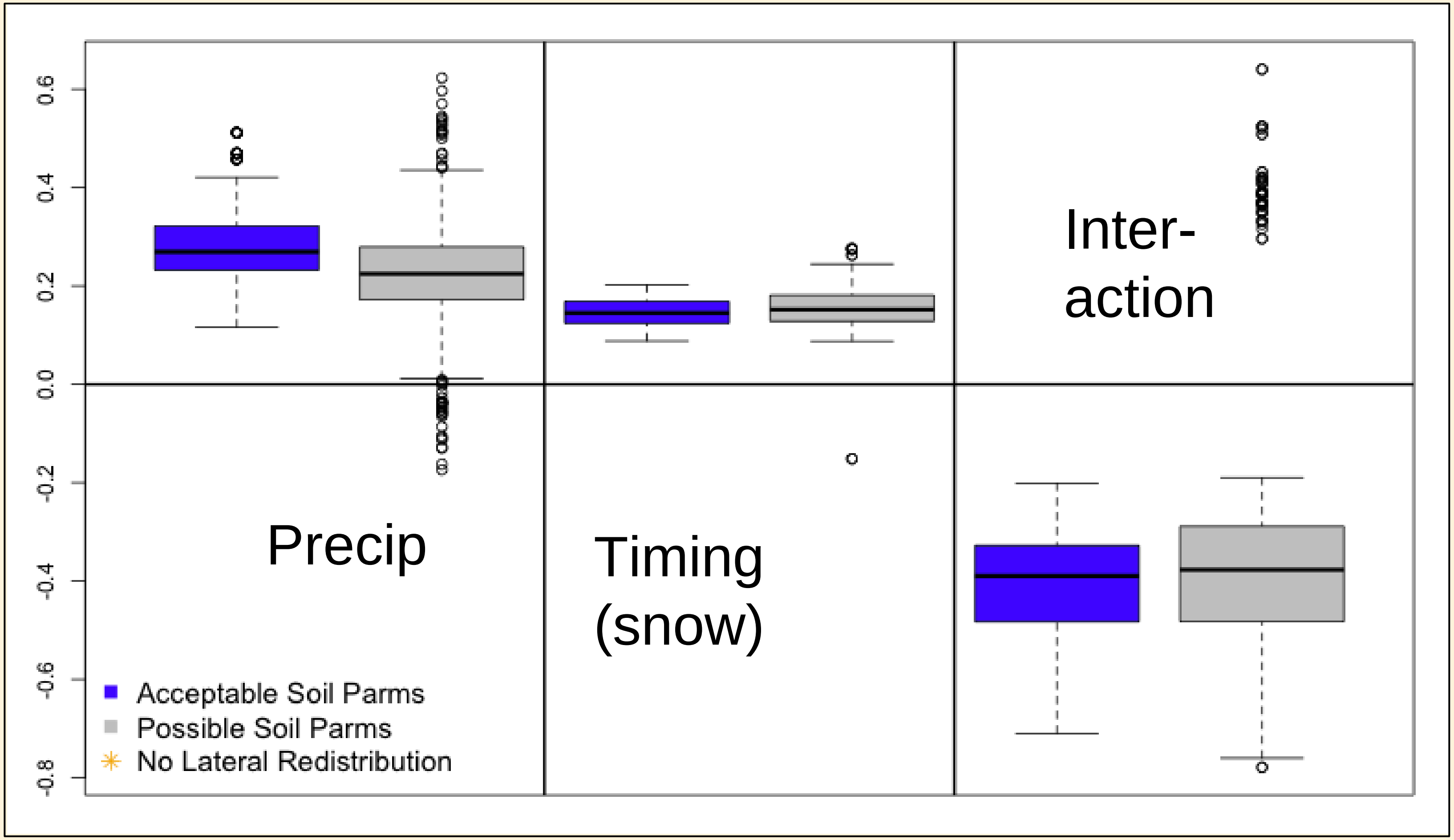




Regression: Inter-annual variation in ET



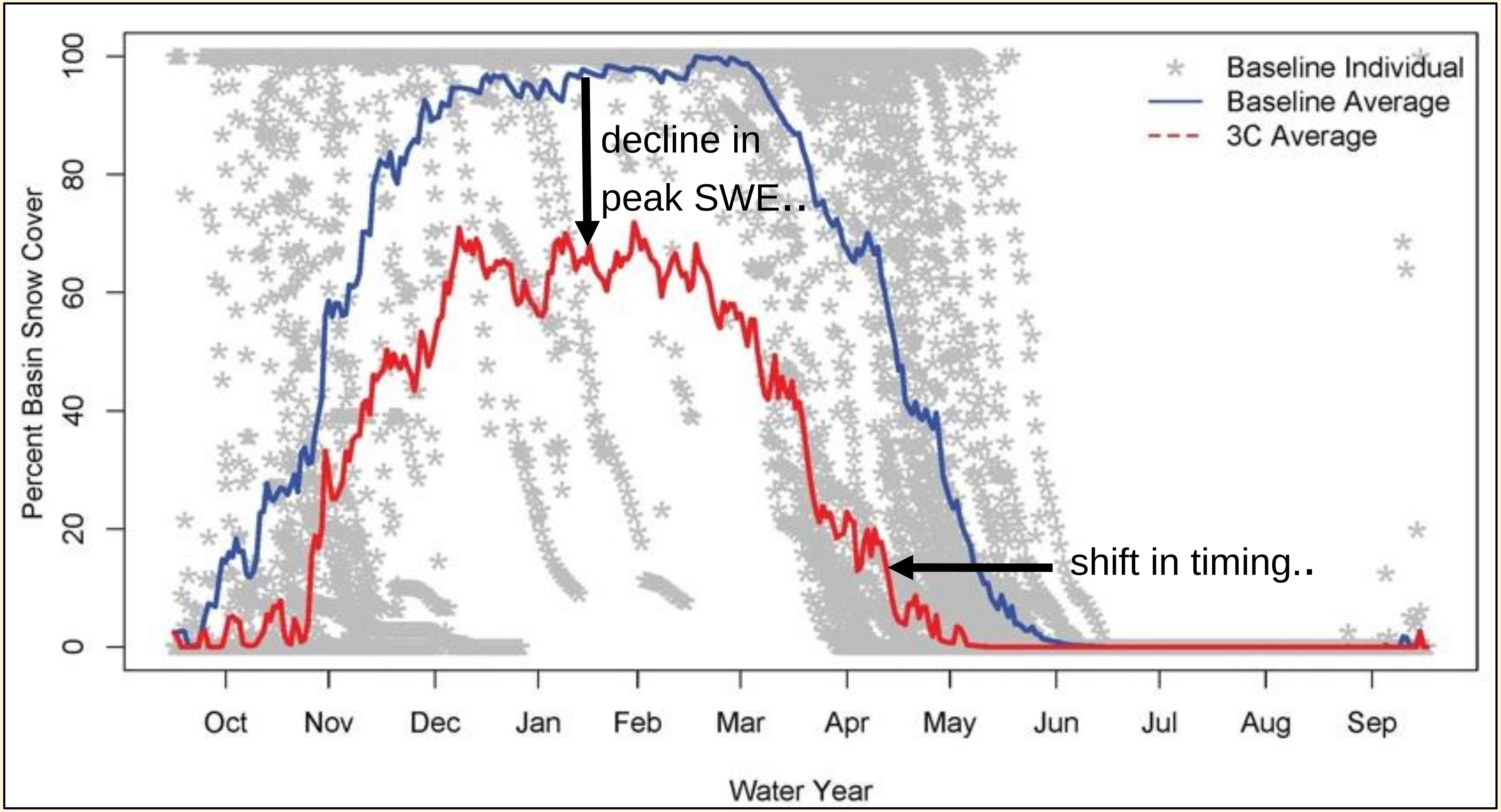
First-order control is magnitude

- but timing matters, particularly in dry years

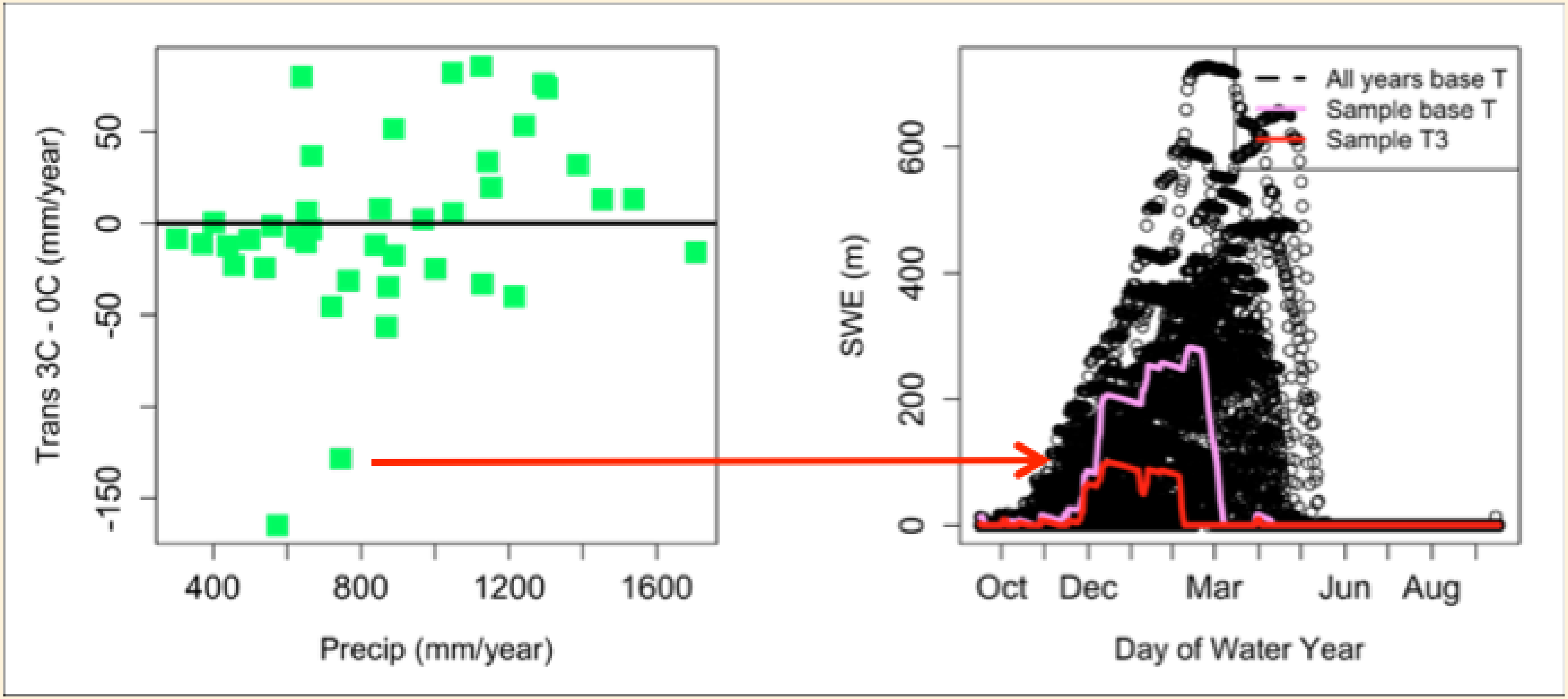
Tague, C.L. and Peng, H. (2013) The sensitivity of forest water use to the timing of precipitation and snowmelt recharge in the California Sierra: Implications for a warming climate, *JGR* 118(2): 875-887

Spatial patterns of snow – changes in % basin cover and depletion trajectories

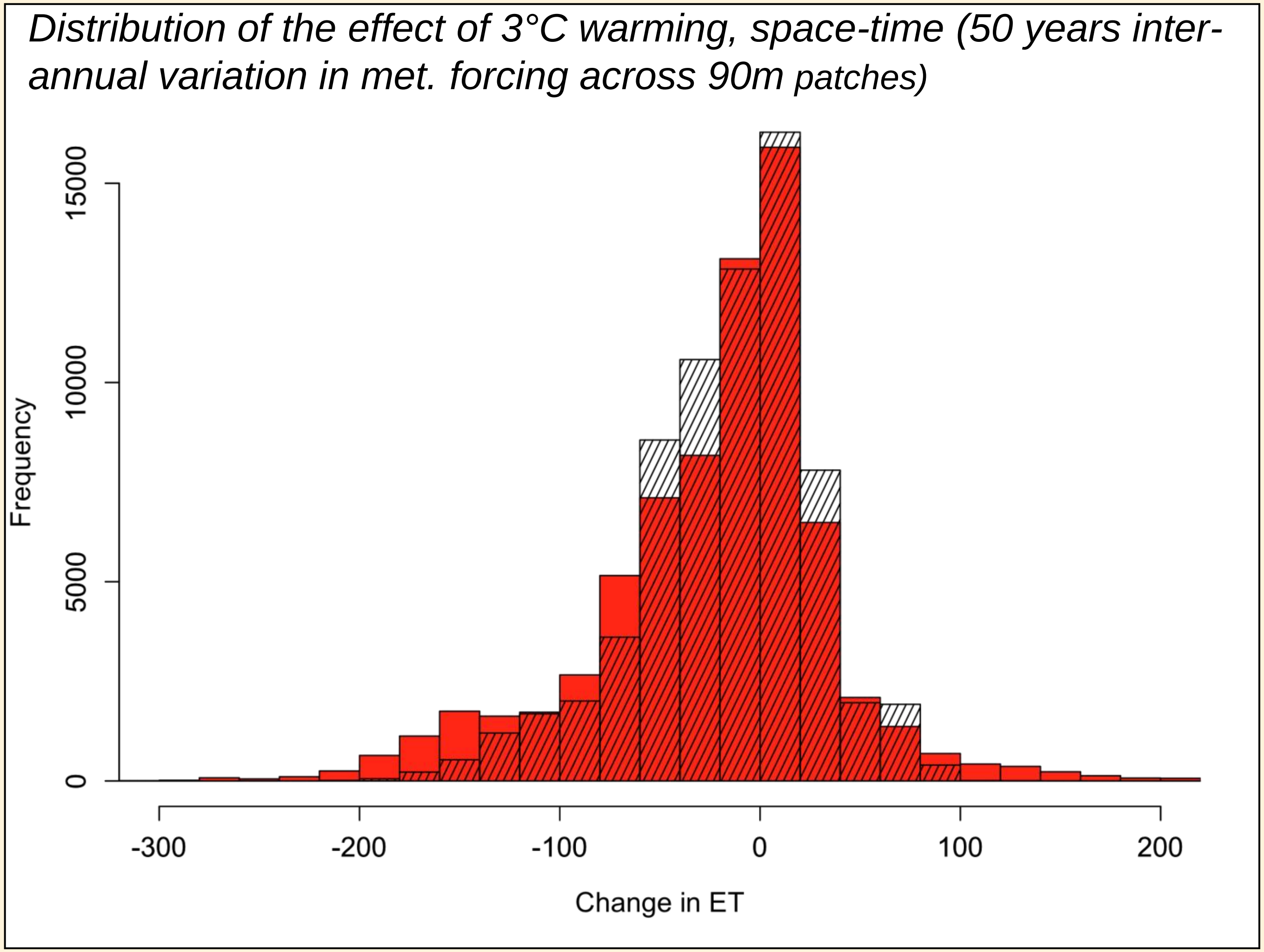
0.4℃/decade since the 1970's but no change in annual precipitation



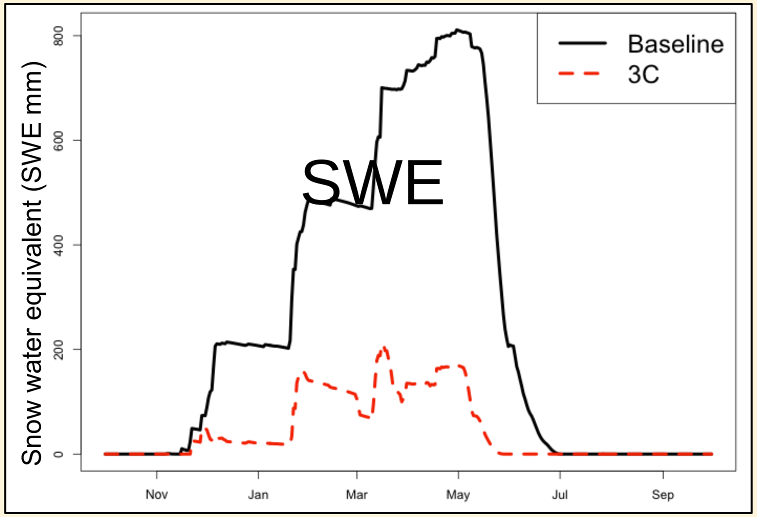
Mean watershed change is small (< 1% increases balance decreases; individual years show declines ~15%)



Change in ET for all 90m patches for 50 years

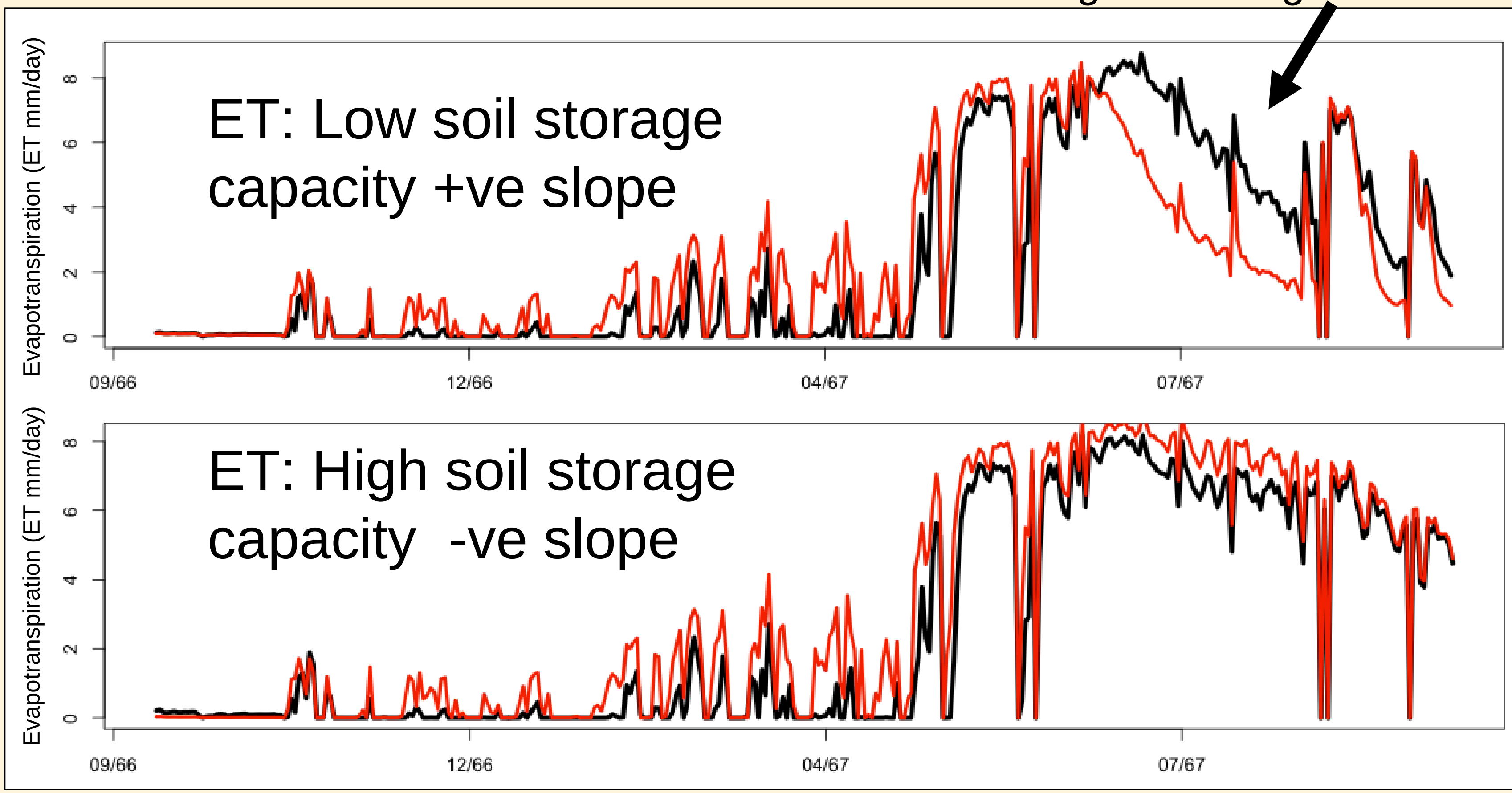


Left skewed distribution – for some patches, some years show quite large declines in ET (and NPP estimates), more but smaller increases

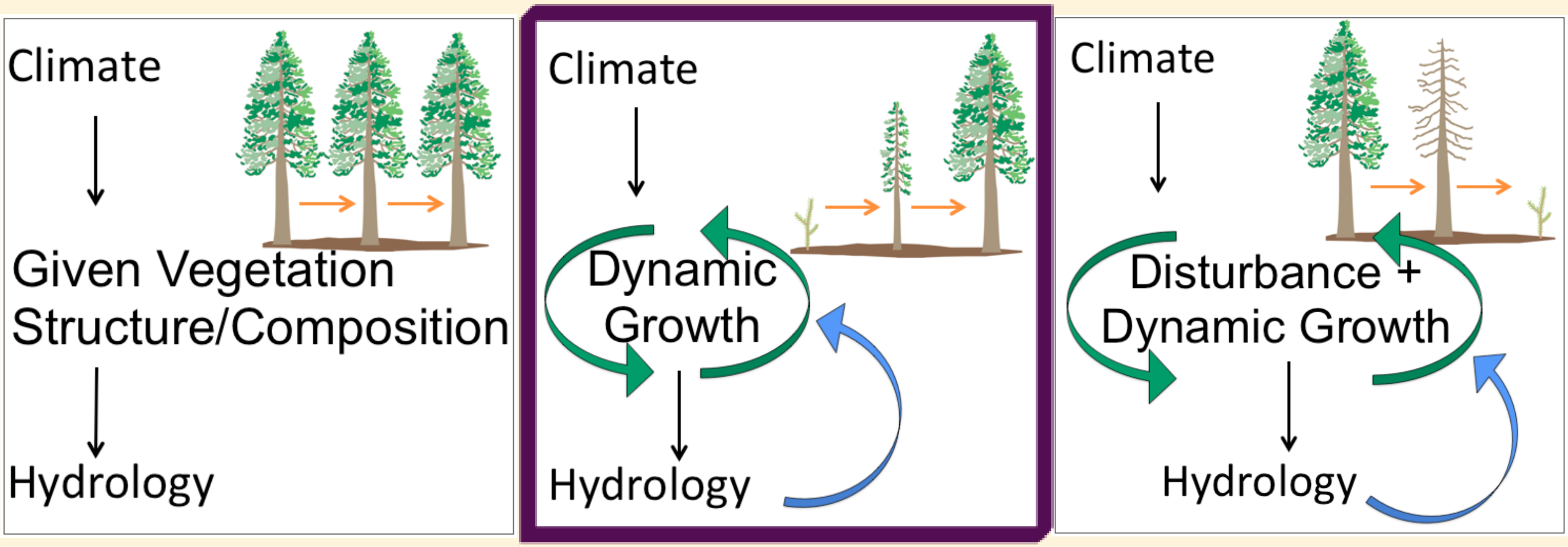


Example water year (1967): Change in snow with 3°C warming

Decline in ET due to shift in timing of recharge

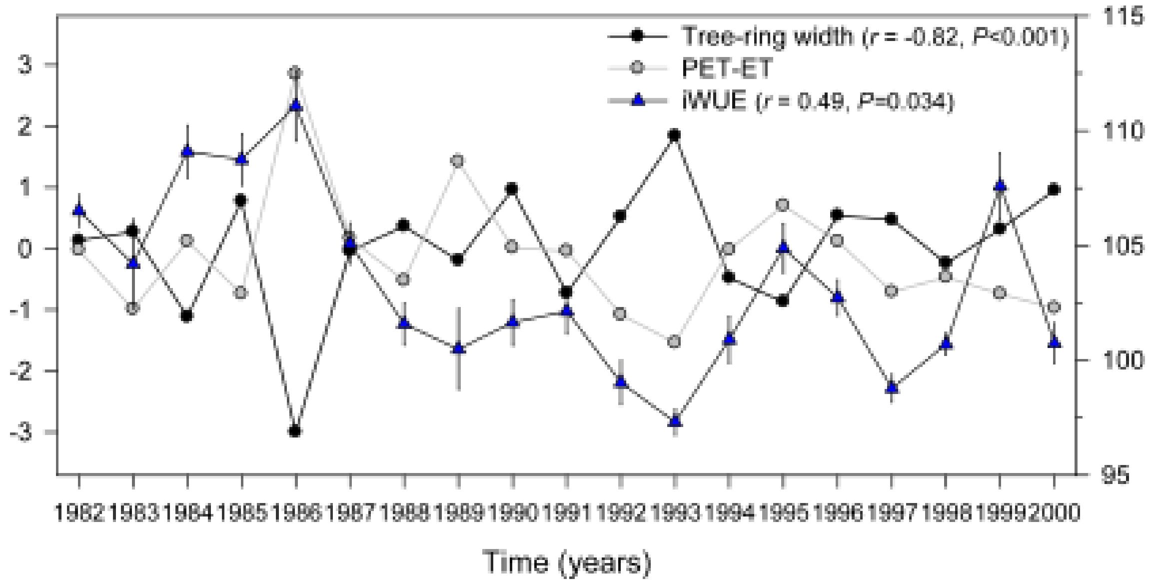


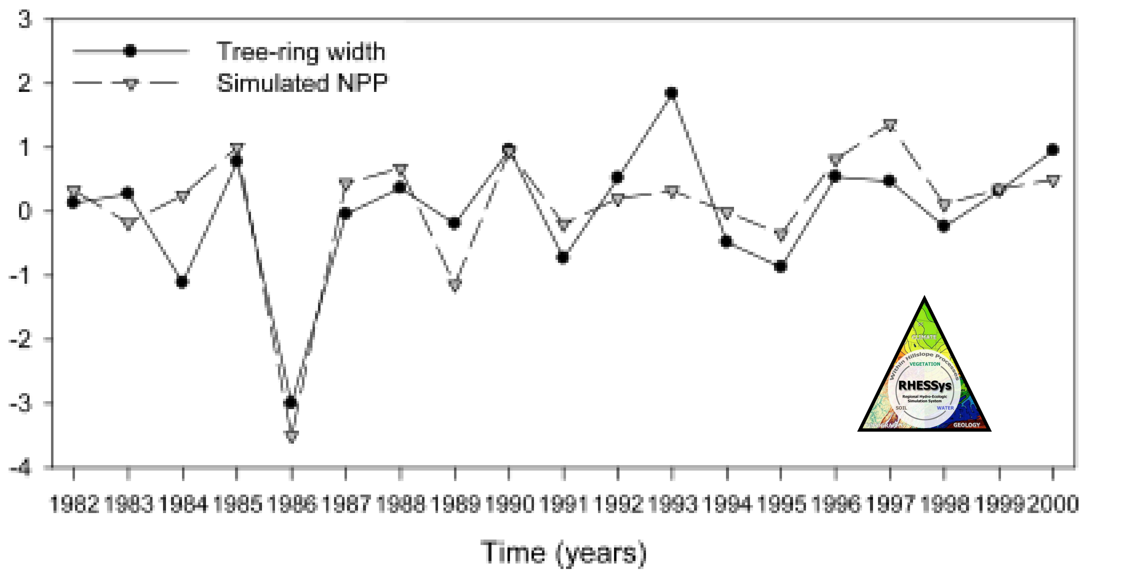
Behavioral modeling approach to model evaluation and application



Progression of model representation of behaviors relevant to eco-hydrology climate variation and change

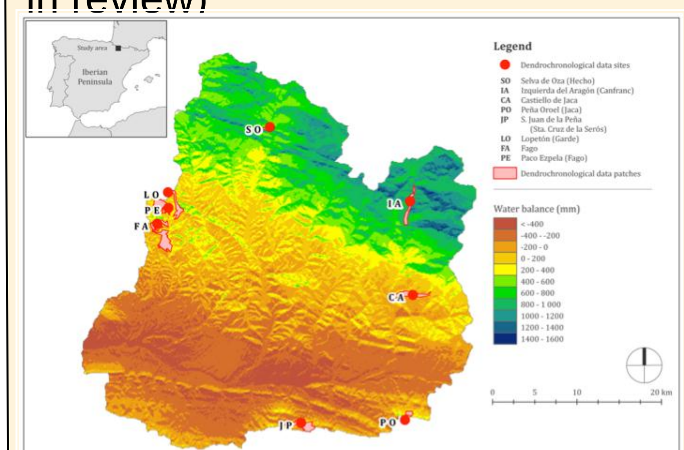
Tree Ring analysis:



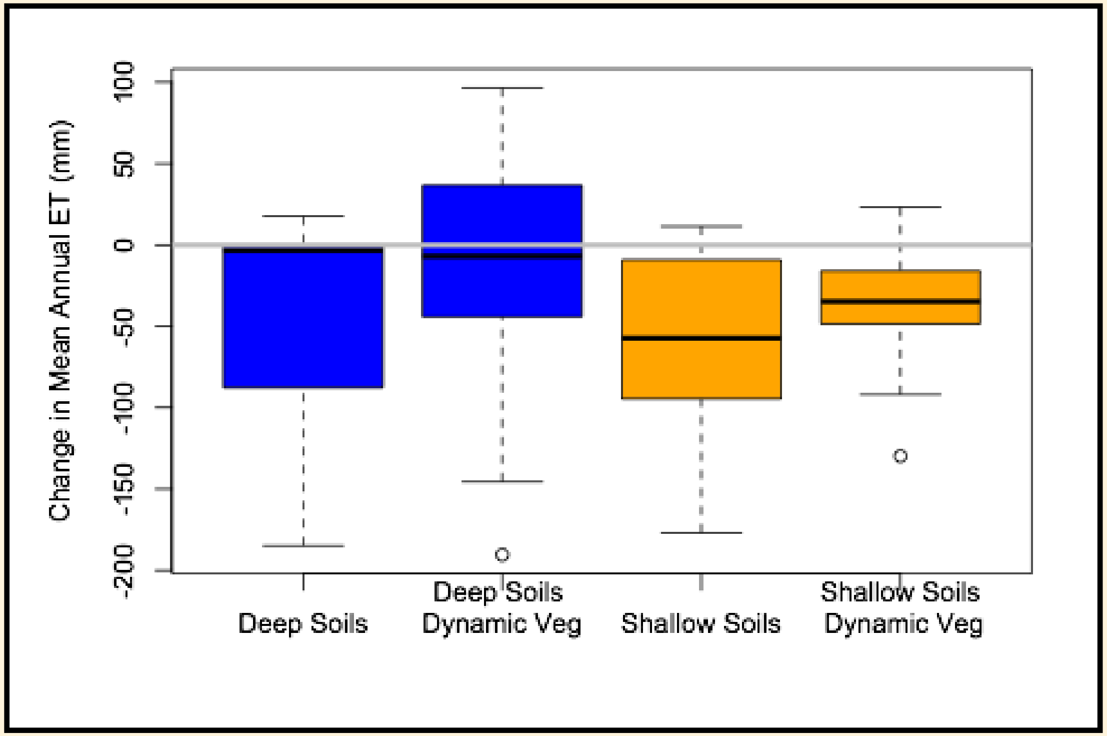


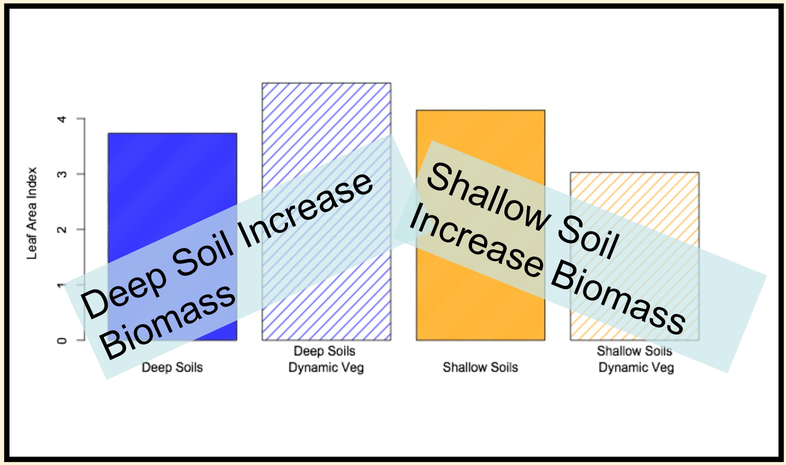
Evapotranspiration deficit controls growth and net primary production: implications for Pyrenean silver fir growth under warmer and drier conditions

(Vicente-Serrano et al., in review)



Growth implications for a forest plot in Sierra (less water limited than New-Mexico)





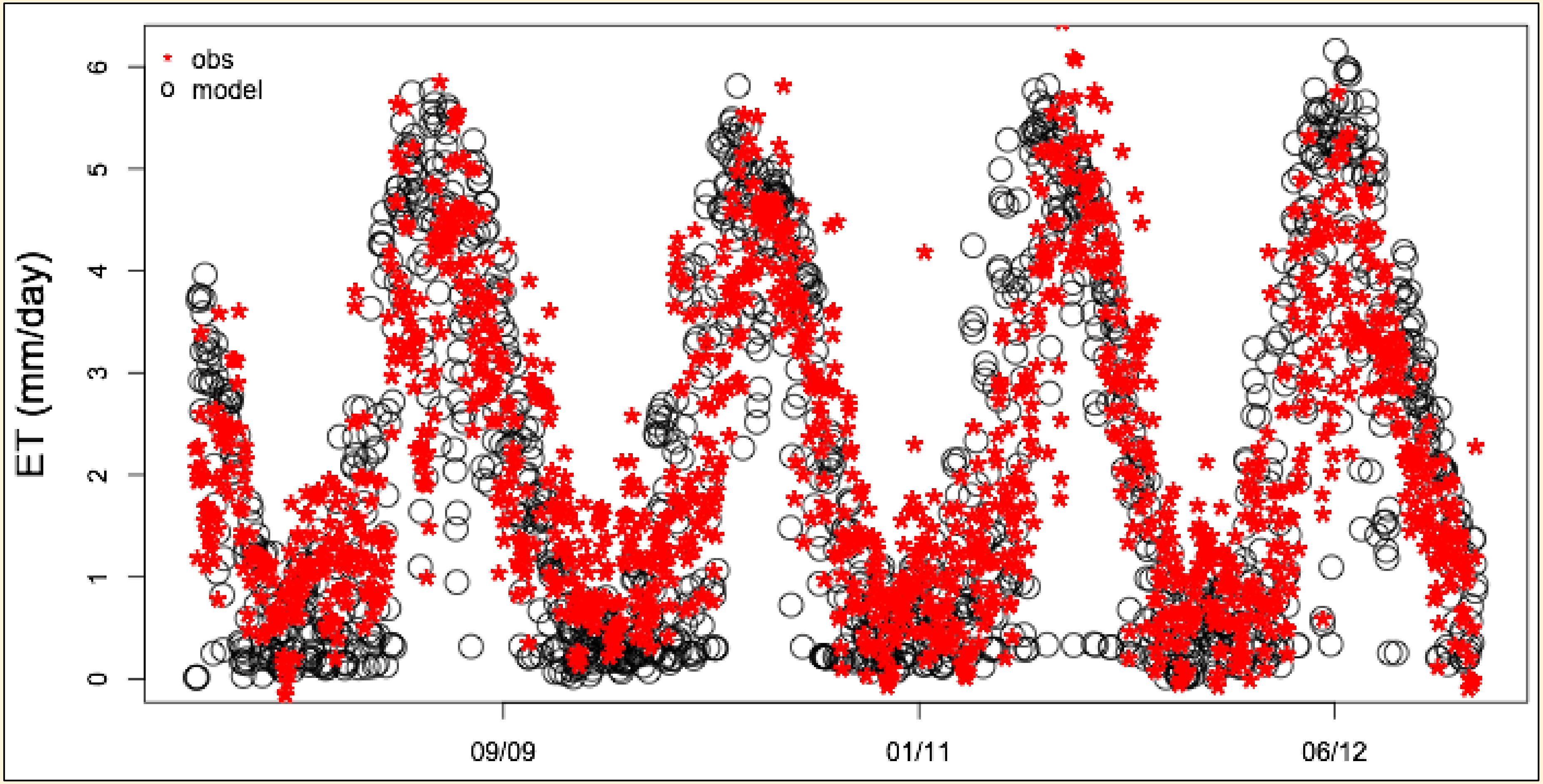
if we assume deep soils, accounting for increased productivity, increases ET with 3C warming

CZO Flux Tower: Mid Elevation Sierra Site

Goulden, M. L., R. G. Anderson, R. C. Bales, A. E. Kelly, M. Meadows, and G. C. Winston (2012), Evapotranspiration along an elevation gradient in California's Sierra Nevada, J. Geophys. Res., 117, G03028, doi:10.1029/2012JG002027.

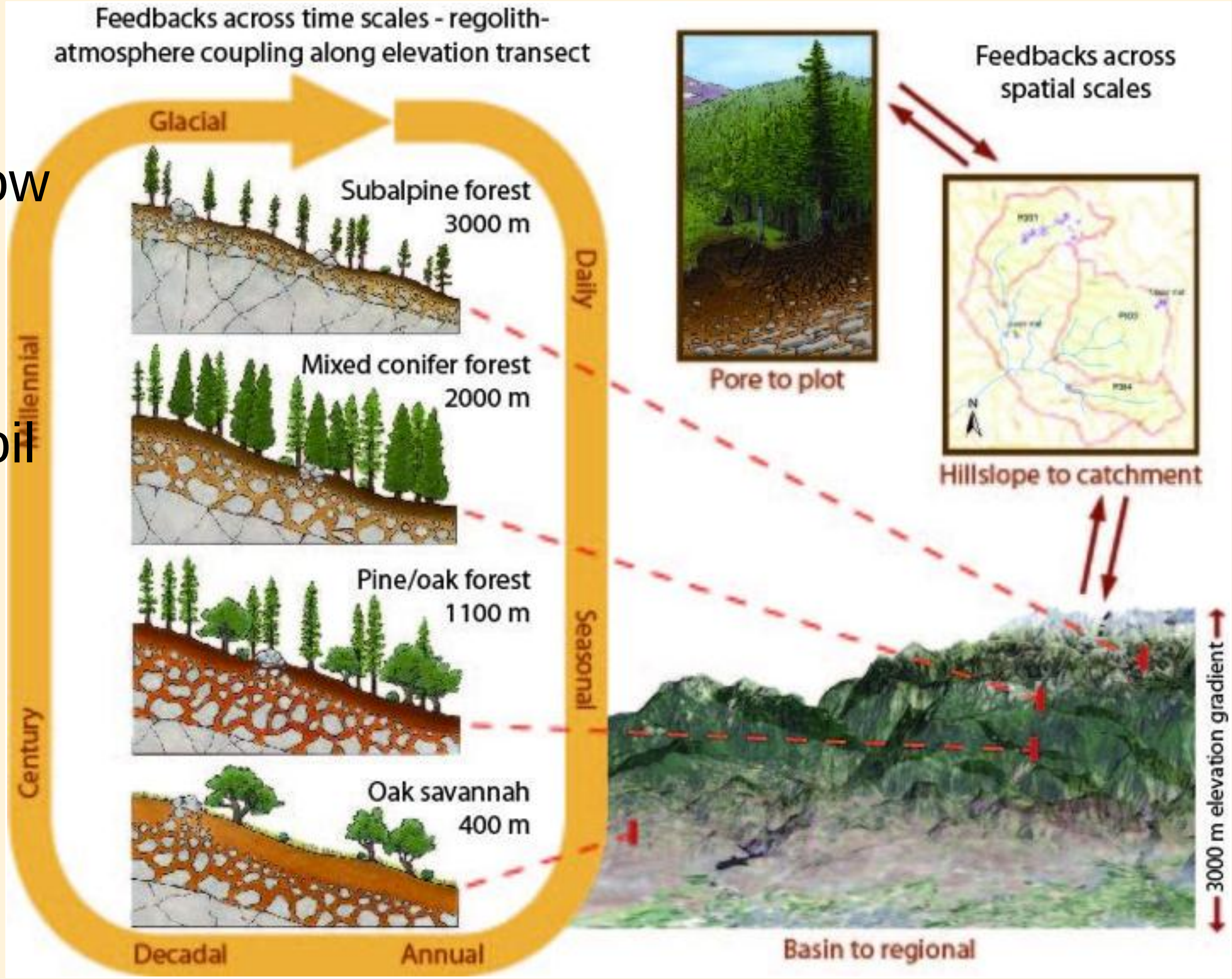
Goulden et al., (2013) Evapotranspiration along an Elevational Gradient in California Sierra. Journal of Geophysical Research

RHESSys and Observed ET - from CZO Mid Elevation Flux Tower (Calibrated soil depth of 4m! Deep Soil)



Shallow Soil

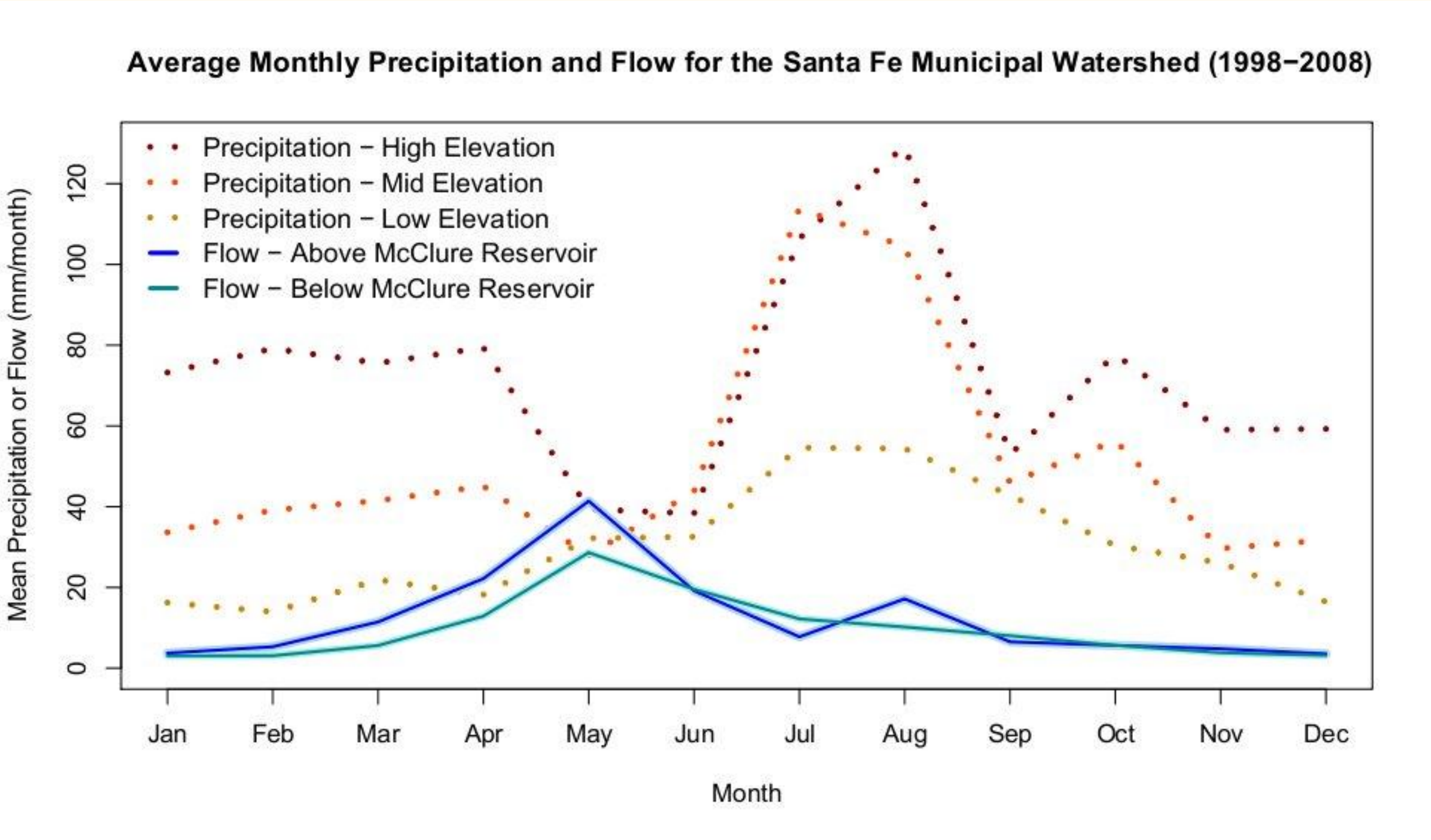
Deep Soil



Sierra Critical Zone Observatory:

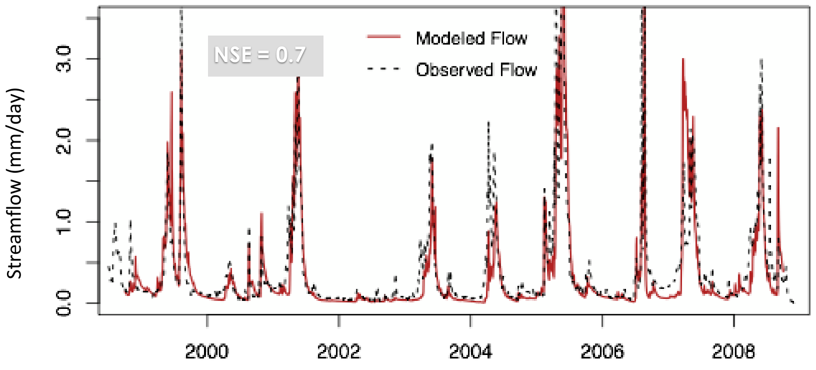
Higher elevations have shallower soils; expected increases in growth (and ET) with warming is likely to be limited soil water storage capacity (Goulden et al., 2013)

Santa Fe Municipal Watershed: More water-limited; summer precip, still strongly snowmelt dominated



Dugger, A.L., Tague, C., and Margolis, E.Q. (working paper) A three-pronged approach to coupled carbon and water-cycling model validation in a semi-arid mountain watershed.

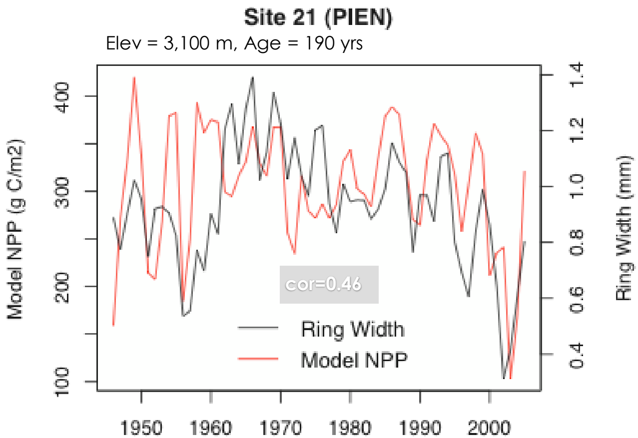
Model ♥ Data: Multi-criteria Calibration/Validation



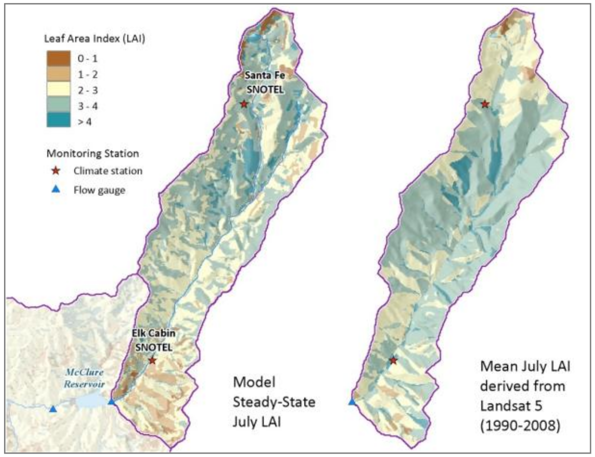
Daily Streamflow Record

	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



50-Year Tree Ring Record



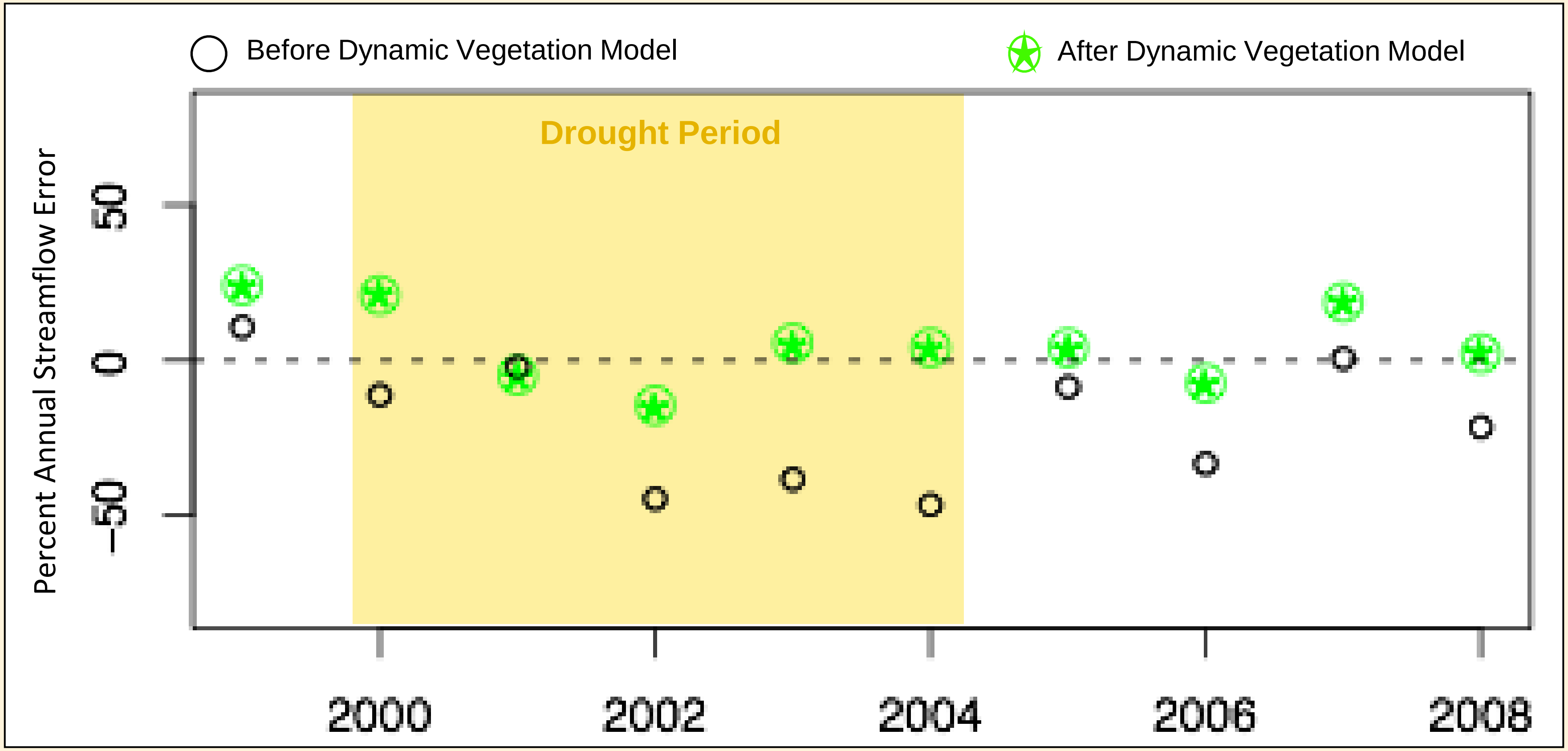
Remote Sensing Vegetation Indices

Dugger, A.L., Tague, C., and Margolis, E.Q. (working paper) A three-pronged approach to coupled carbon and water-cycling model validation in a semi-arid mountain watershed.

Model ♥ Data: Multi-criteria Calibration/Validation

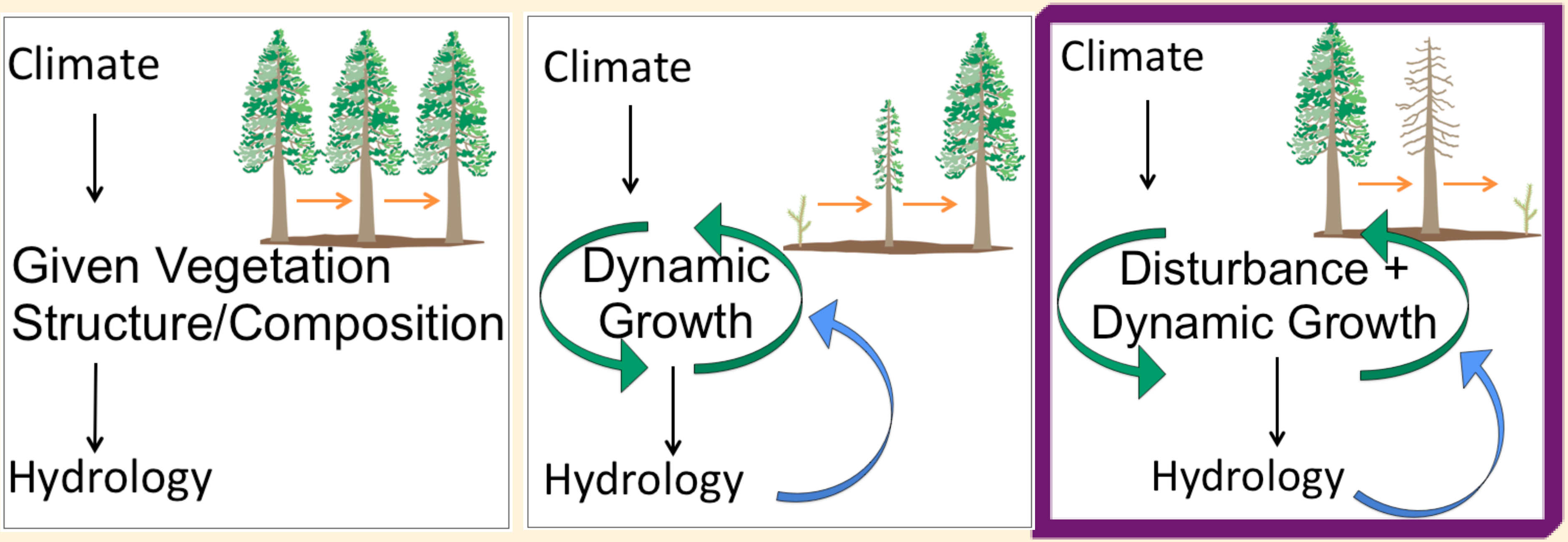
Improvement in annual streamflow prediction:

The dynamic vegetation model improved streamflow predictions during drought years, shifting the mean annual streamflow percent error from 20% to 10%.



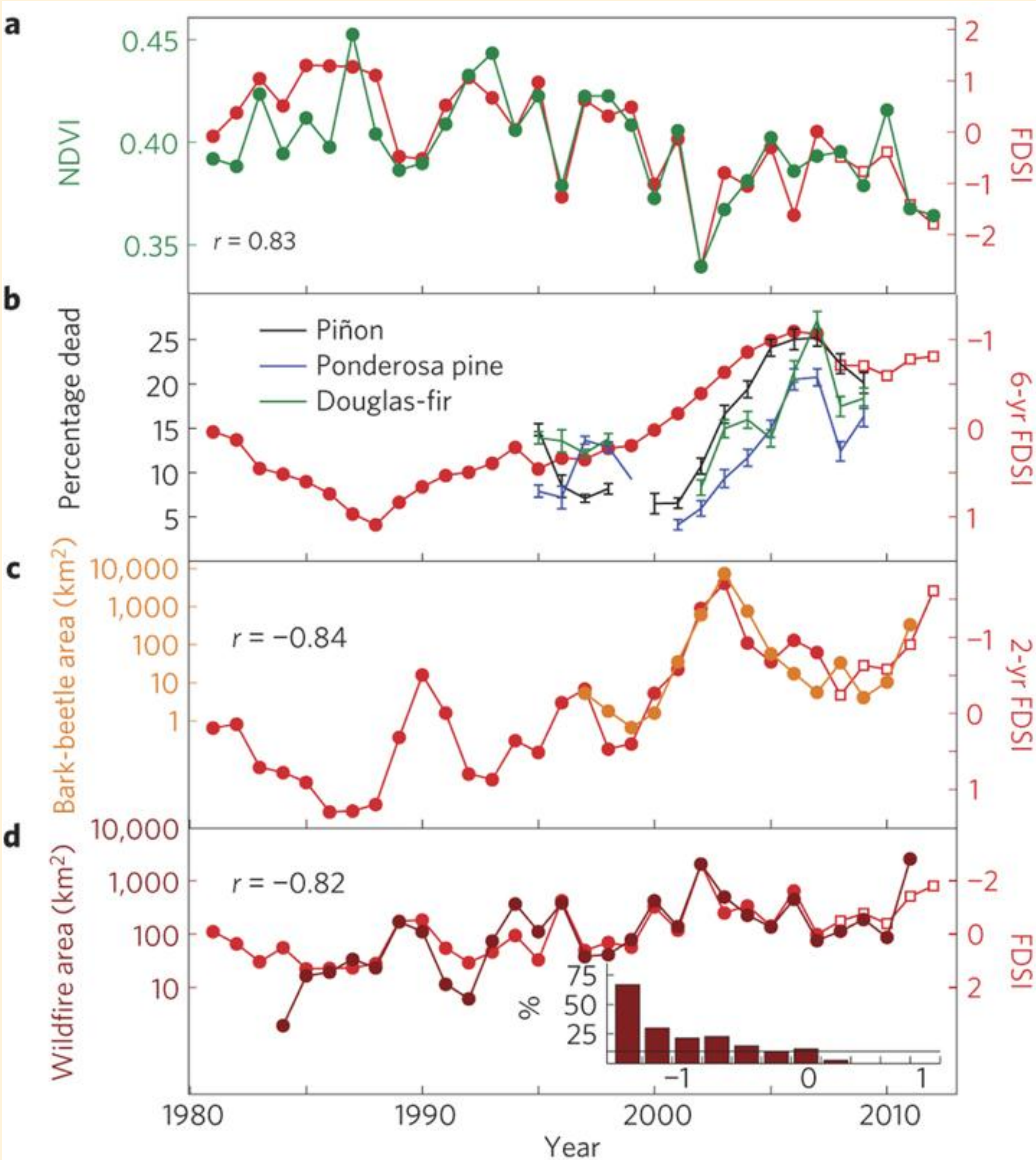
Dugger, A.L., Tague, C., and Margolis, E.Q. (working paper) A three-pronged approach to coupled carbon and water-cycling model validation in a semi-arid mountain watershed.

Behavioral modeling approach to model evaluation and application



Progression of model representation of behaviors relevant to eco-hydrology climate variation and change

Tague C.L., McDowell N.G., Allen C.D. (2013) An Integrated Model of Environmental Effects on Growth, Carbohydrate Balance, and Mortality of *Pinus ponderosa* Forests in the Southern Rocky Mountains. PloS One 8(11): e80286.



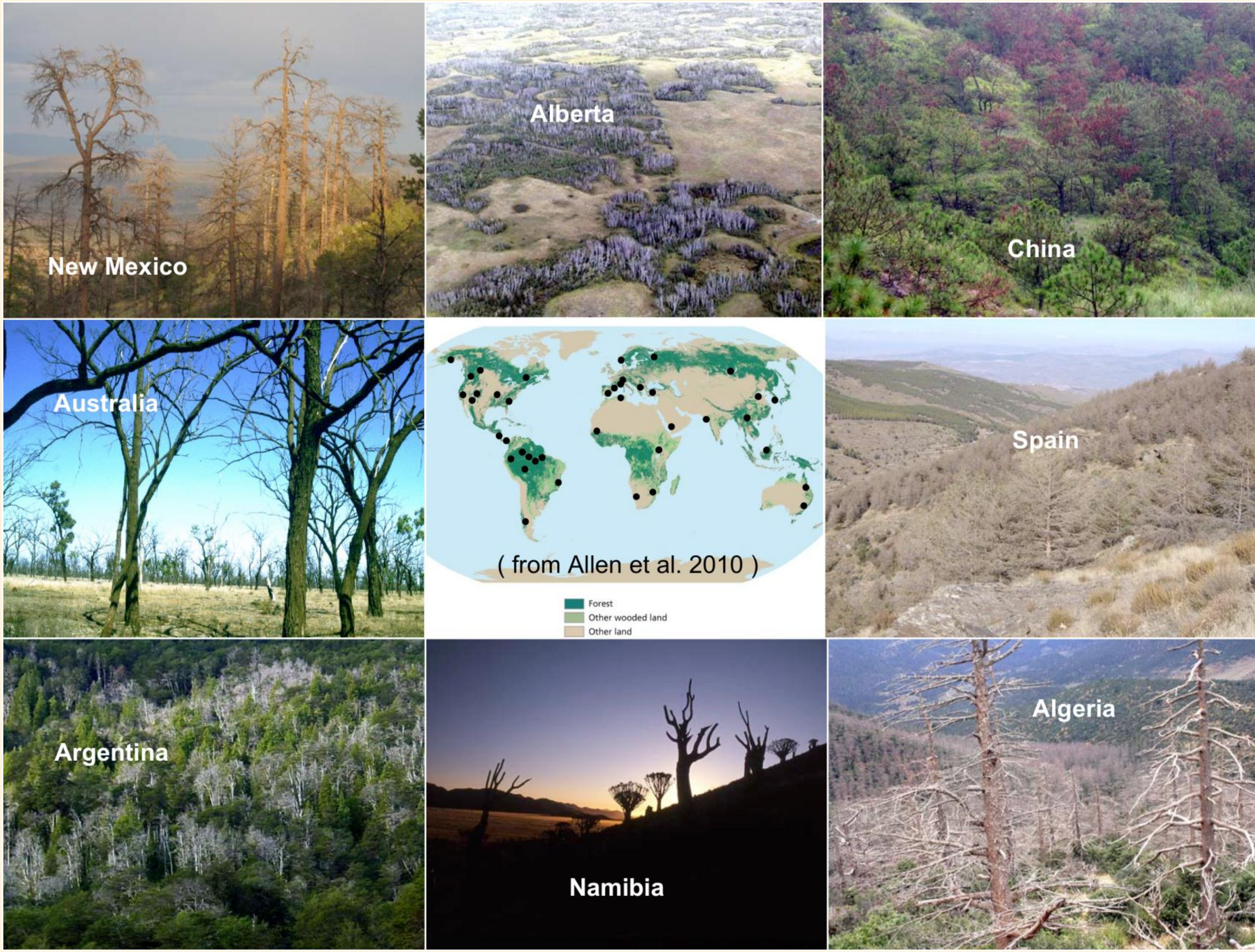
Measurements of forest productivity and mortality overlaid on the FDSI (red, right *y* axis).

but why some places "die" and others "don't" is unclear

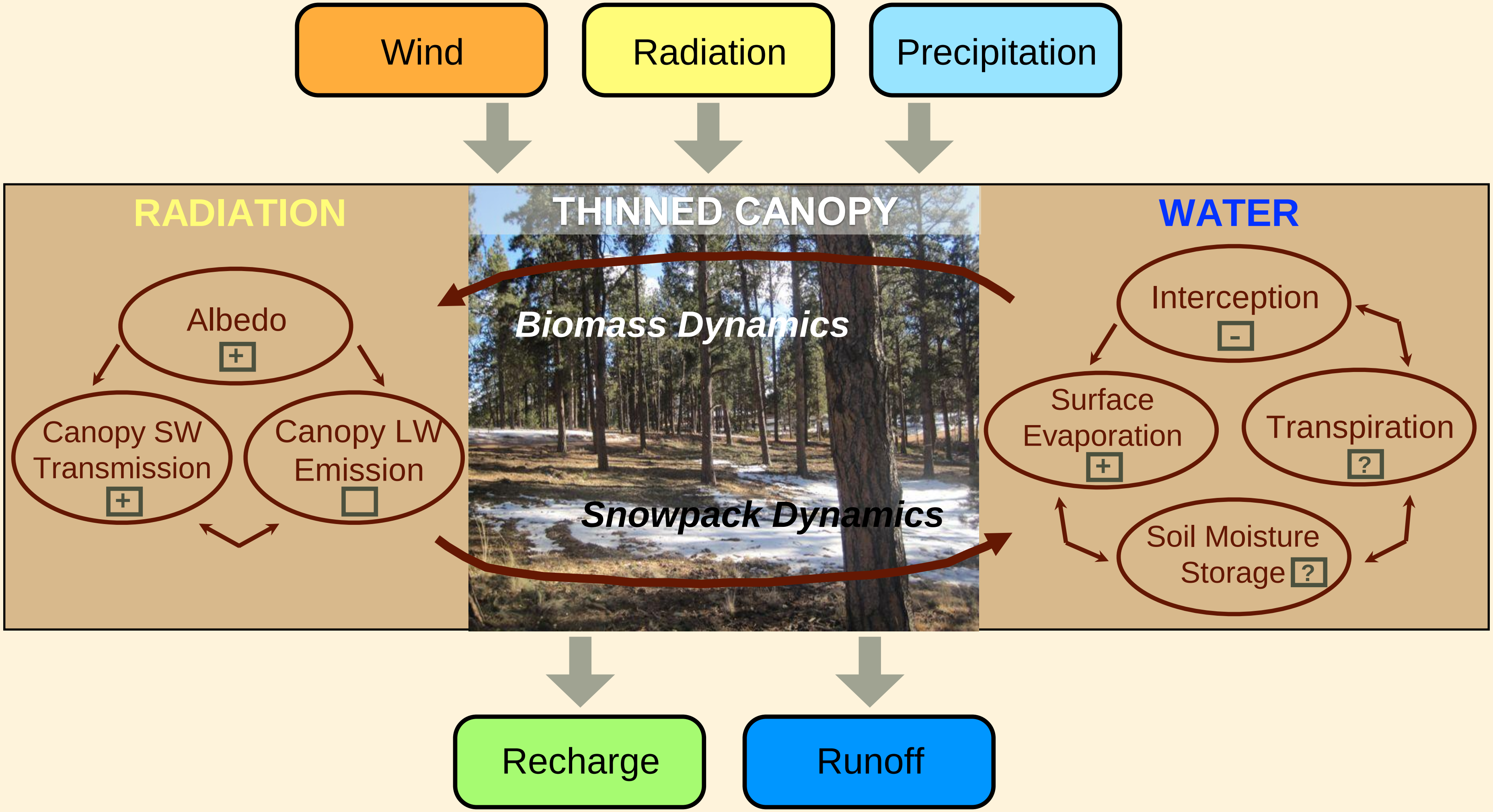
Williams et. al. (2013) Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change* 3: 292-297. doi: 10.1038/nclimate1693

Forest response to warming

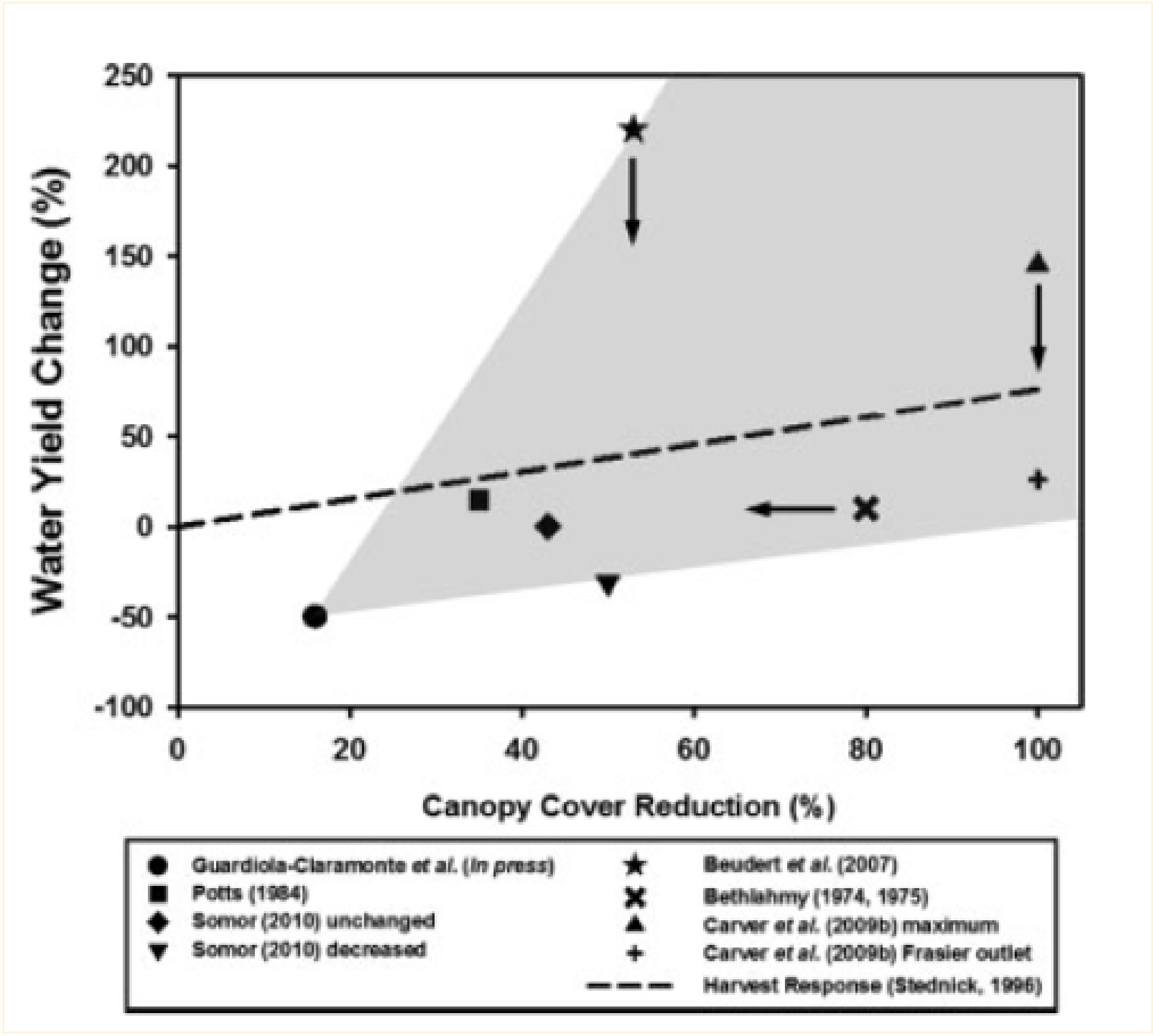
(increasing drought, fire, disease, and forest mortality)



Thinning & Streamflow: Key Processes

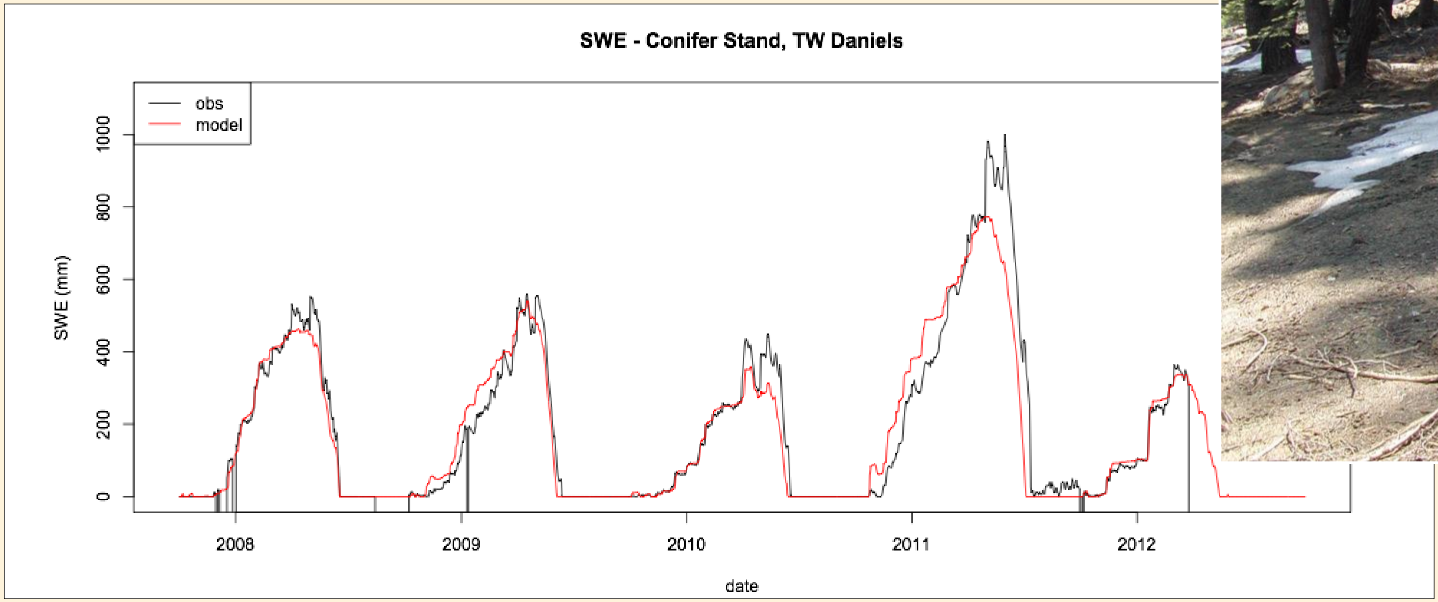


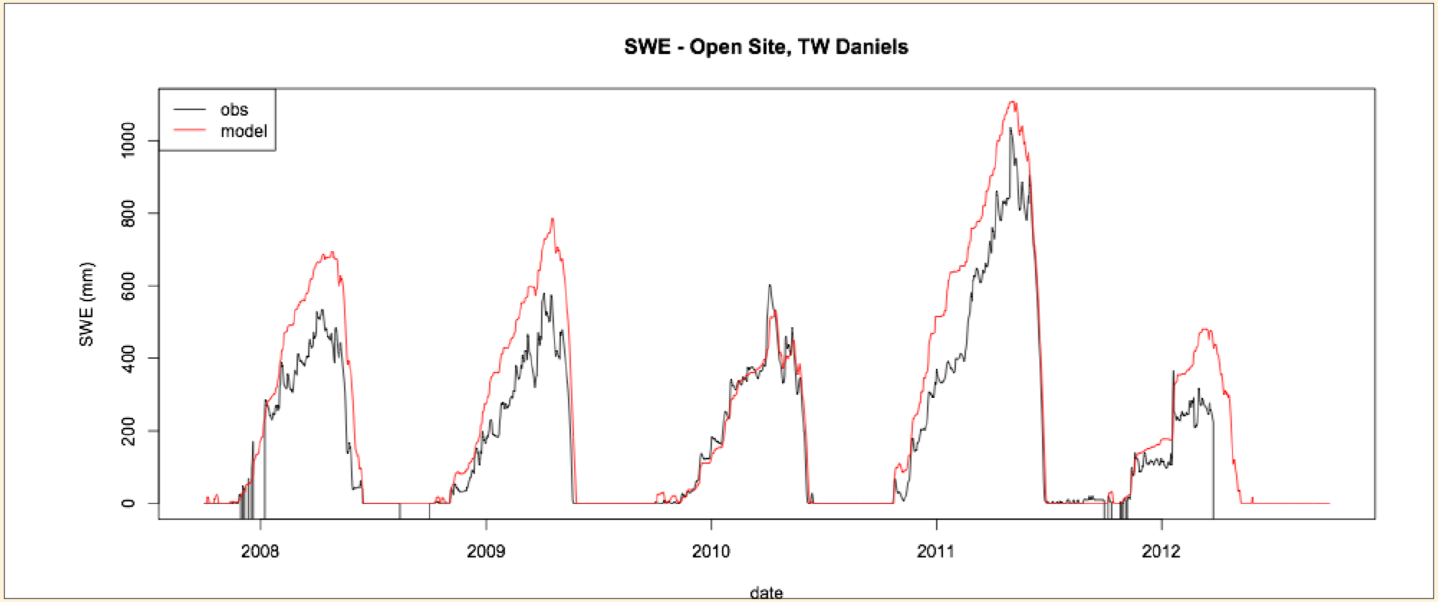
Range of responses to changes in canopy cover (thinning/mortality)



Adams et al. (2011) Fig. 2

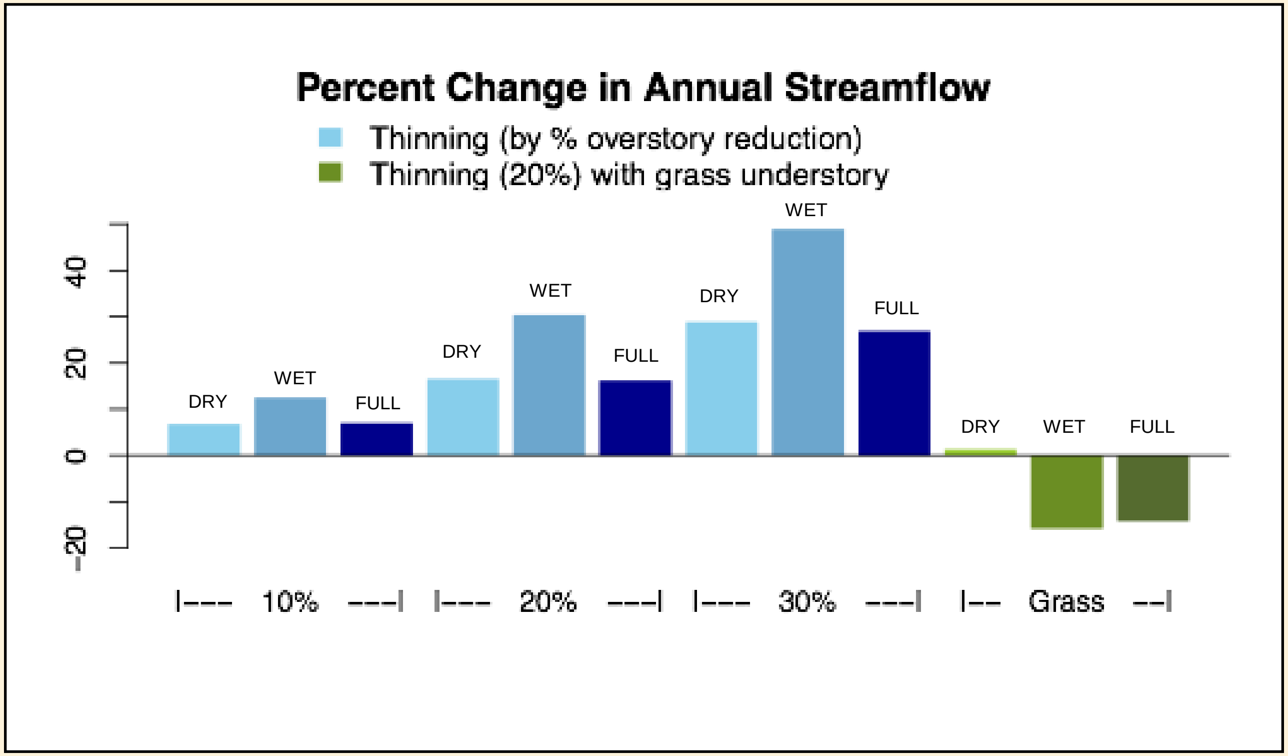
Evaluation of thinning impacts on snow accumulation and melt





Understory implications of “thinning”

Herbaceous understory growth beneath thinned canopies has the potential to shift the streamflow response from gaining to losing flow.



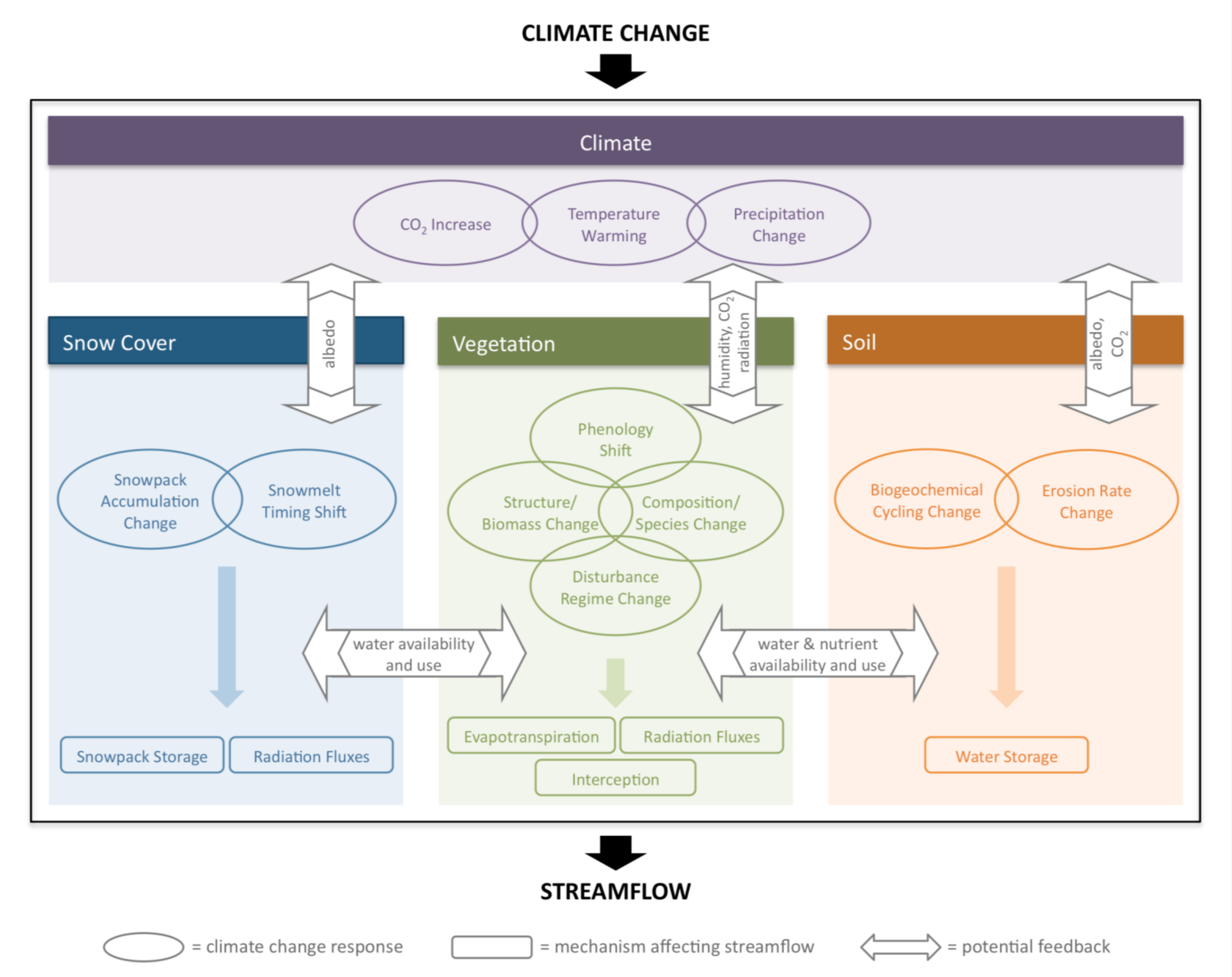
Eco-hydrology of warming, snow-dominated mountain systems (in MTE): The behavioral modeling perspective

Ecosystem dynamics + geophysical setting will modulate the effect of changing precip-snow on partitioning of P to ET versus Q

“Surprises” re: conditions under which ecosystem water use (ET) decreases even though it is warmer

1) snowmelt provides more “useable” water for forest (soil / rooting zone storage is a first order control)

2) declines in productivity/mortality -> reduce ET (or moderate increases) or increase (understory, soil E, impacts on snowmelt)



Tague and Dugger (2010) Ecohydrology and Climate Change in the Mountains of the Western USA – A Review of Research and Opportunities. *Geography Compass* 4(11): 1648-1663

Acknowledgements:

UCSB students:

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USGS Western Mountain Initiative
http://westernmountains.org/

BioEarth
Biosphere-relevant earth system model

http://www.cereo.wsu.edu/bioearth/

http://criticalzone.org/sierra/