Ecohydrology modeling - example

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Forest in Mediterranean Type Ecosystems (MTEs) (winter wet, summer dry) are changing

https://www.climateassessment.ca.gov/

*Increased fire severity

*Increased forest mortality

*Changes in forest growth, health, carbon sequestration

*Changes in hydrology: floods and droughts

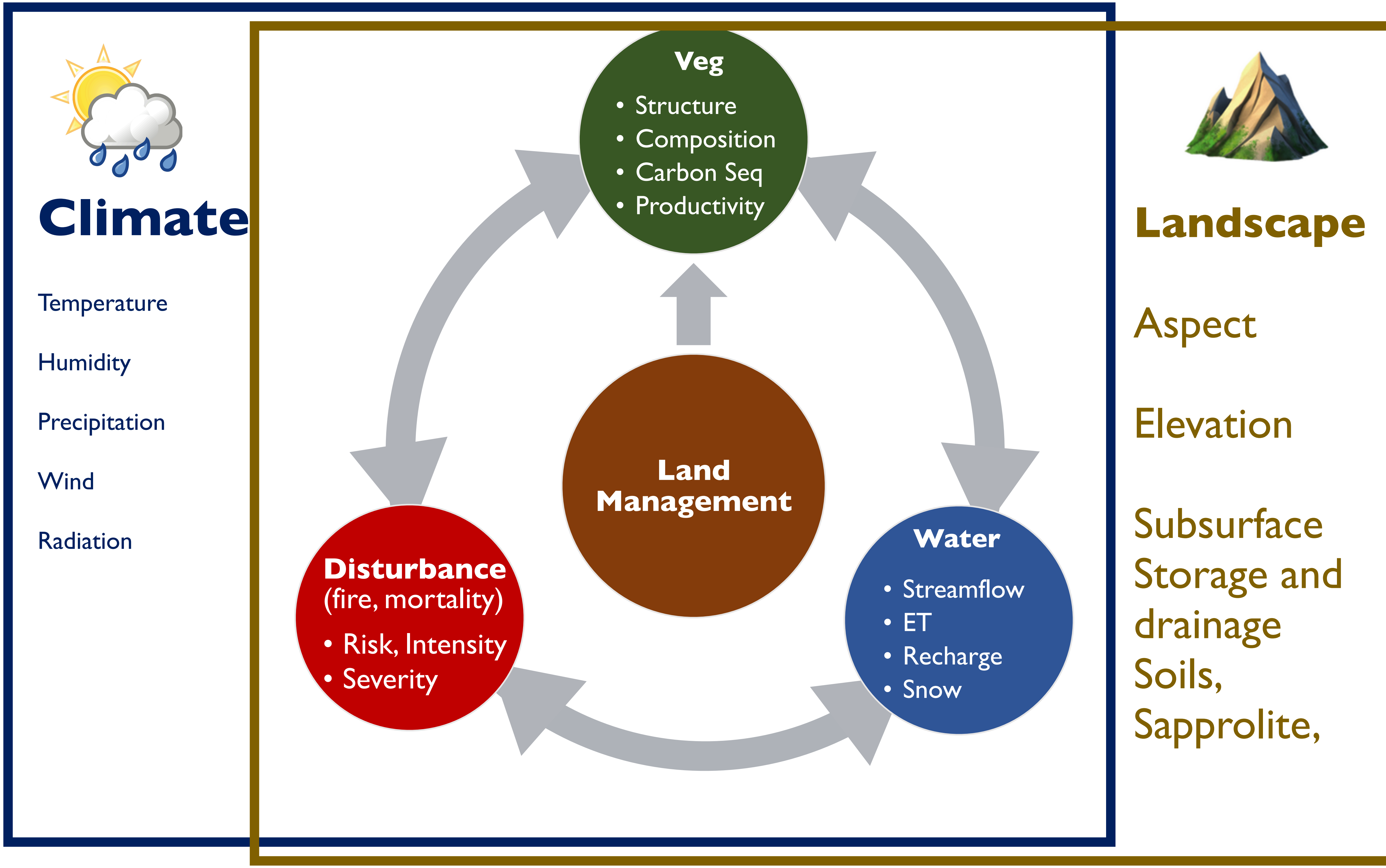
Key Questions

*What will future forests, water resources look like? Next decade..beyond

* What role can management, mitigation play?

Less carbon sequestration, summer water

Answers are challenging because…



Processes are tightly coupled…highly heterogeneous in space and vary in time (seasons…years)

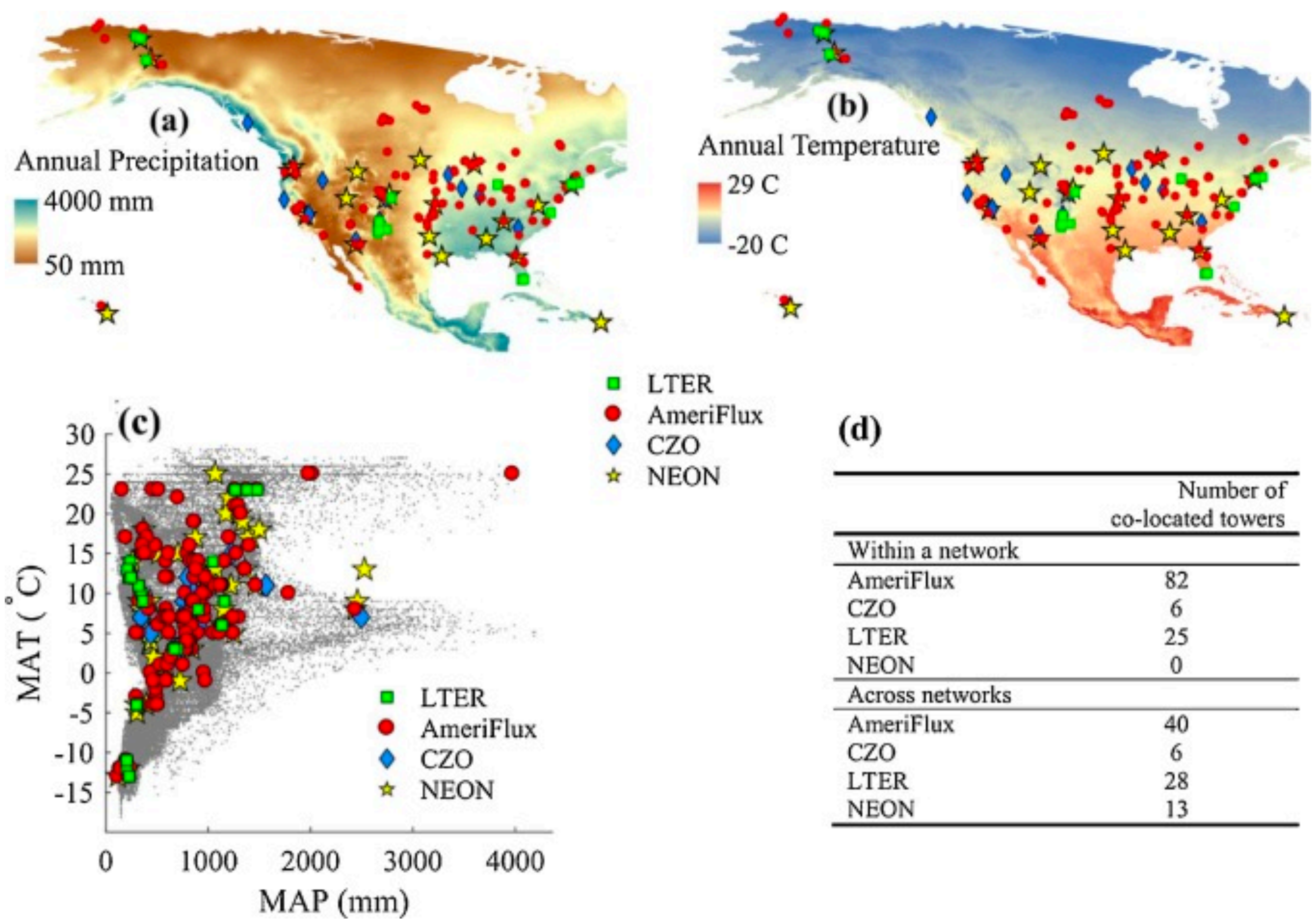
The "tools" for the job

Intensive Experiments and Field Study

Data mining of broad scale patterns in observations (often remote sensing, synthesis data products)

Process-based models of coupled eco-hydro processes

Networks of collaboration…site scale measurements (Example: Carbon flux towers)



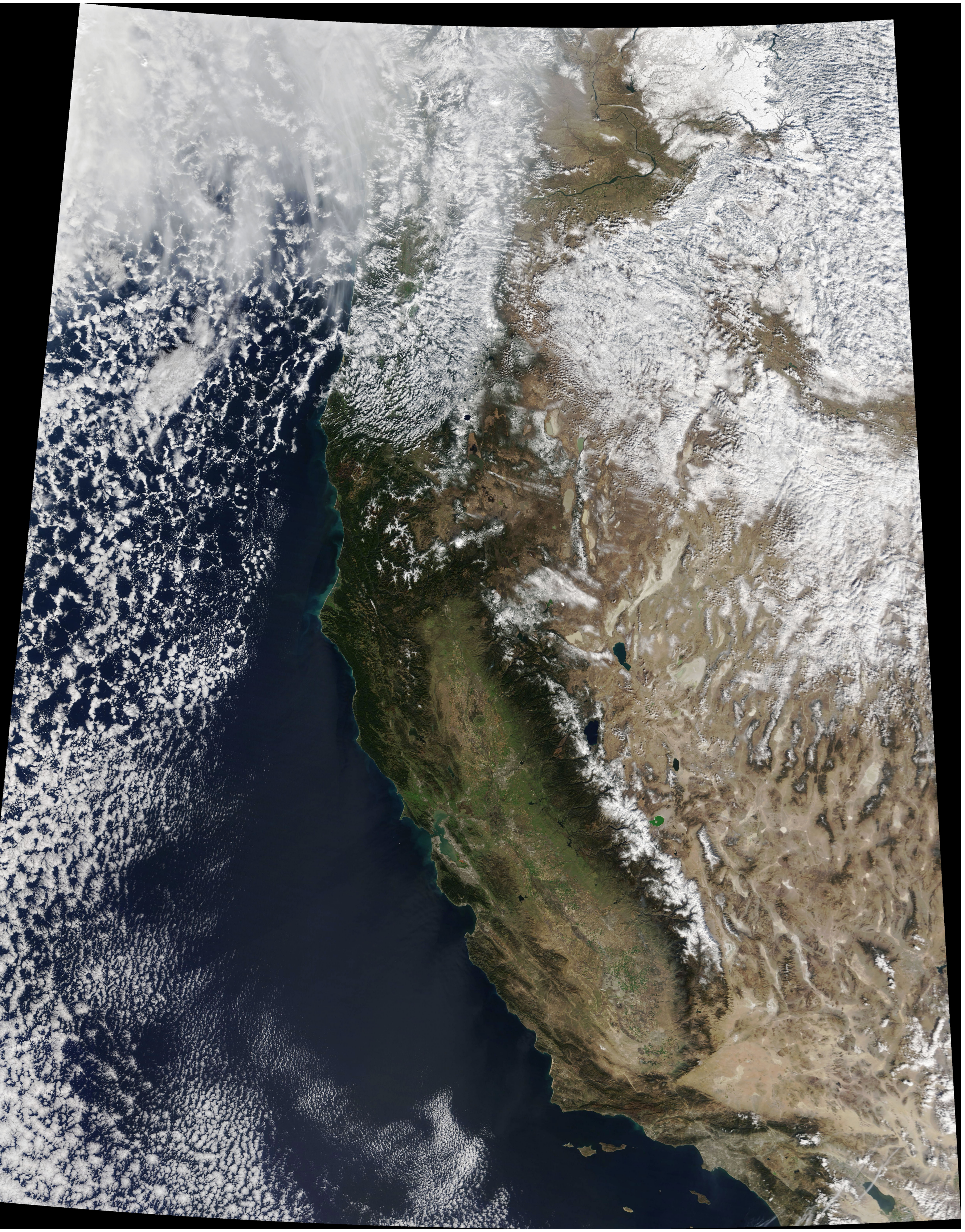
	Number of co-located towers
Within a network	
AmeriFlux	82
CZO	6
LTER	25
NEON	0
Across networks	
AmeriFlux	40
CZO	6
LTER	28
NEON	13

NSF Observatory Networks

LTER - long term ecological research
CZO - critical zone observatory
NEON - national ecological observatory network
AmeriFlux

Novik et al., 2018, The AmeriFlux network: A coalition of the willing

https://www.sciencedirect.com/science/article/pii/S0168192317303295#fig0005



Remote sensing….snow, veg….

NASA

Emerging sources…

USGS and other LiDar sources (https://prd-tnm.s3.amazonaws.com/LidarExplorer/inde

Planet (https://www.planet.com/)

California Observatory (https://salo.ai/projects/california-forest-observatory

https://eoimages.gsfc.nasa.gov/i

What is a "process-based" model

Encodes theories about ecohydrologic function mechanisms of "how stuff works"

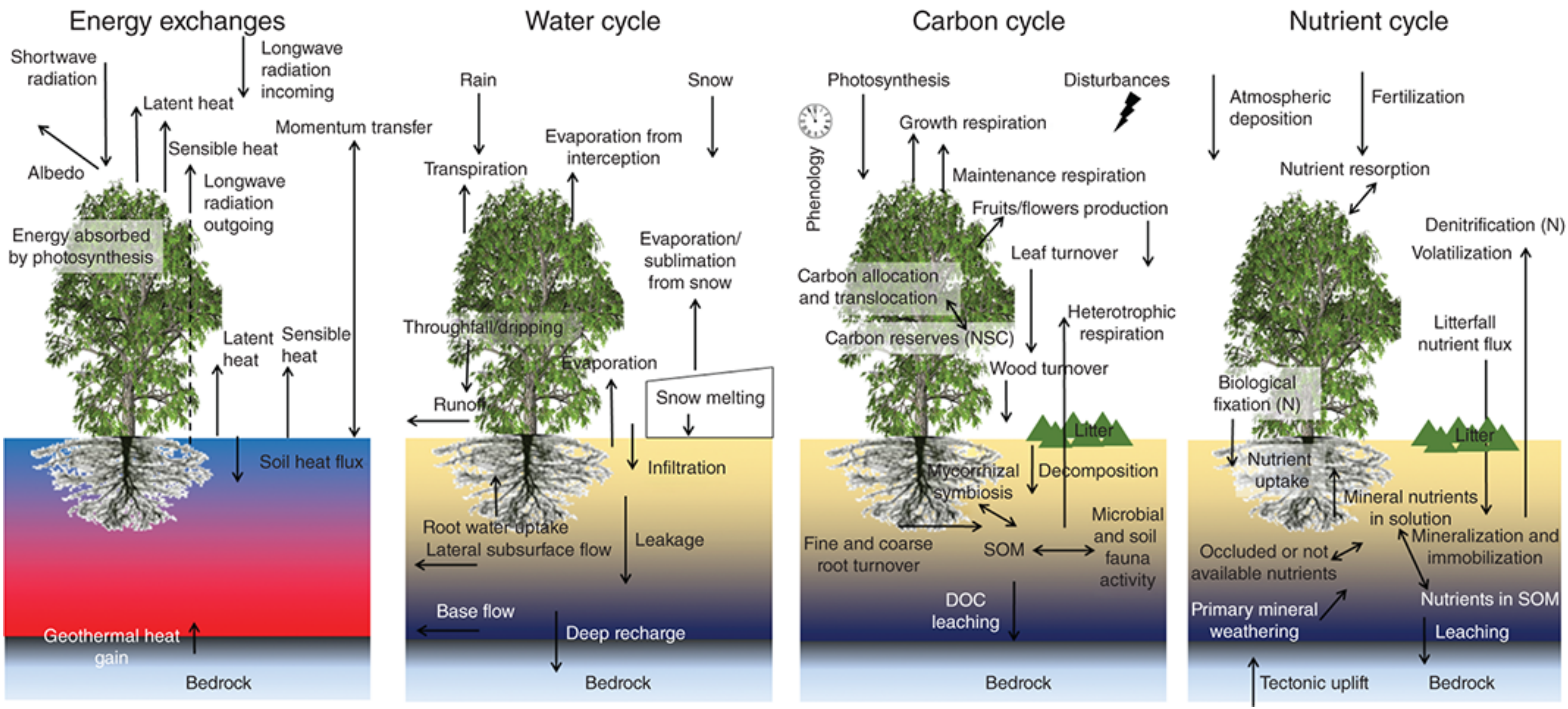
Example - process based model of leaf-scale transpiration combines

- Radiation absorption - leaf area
- Aerodynamic properties - vegetation height, wind, VPD
- Stomatal Function - active regulating water loss

Penman-Monteith

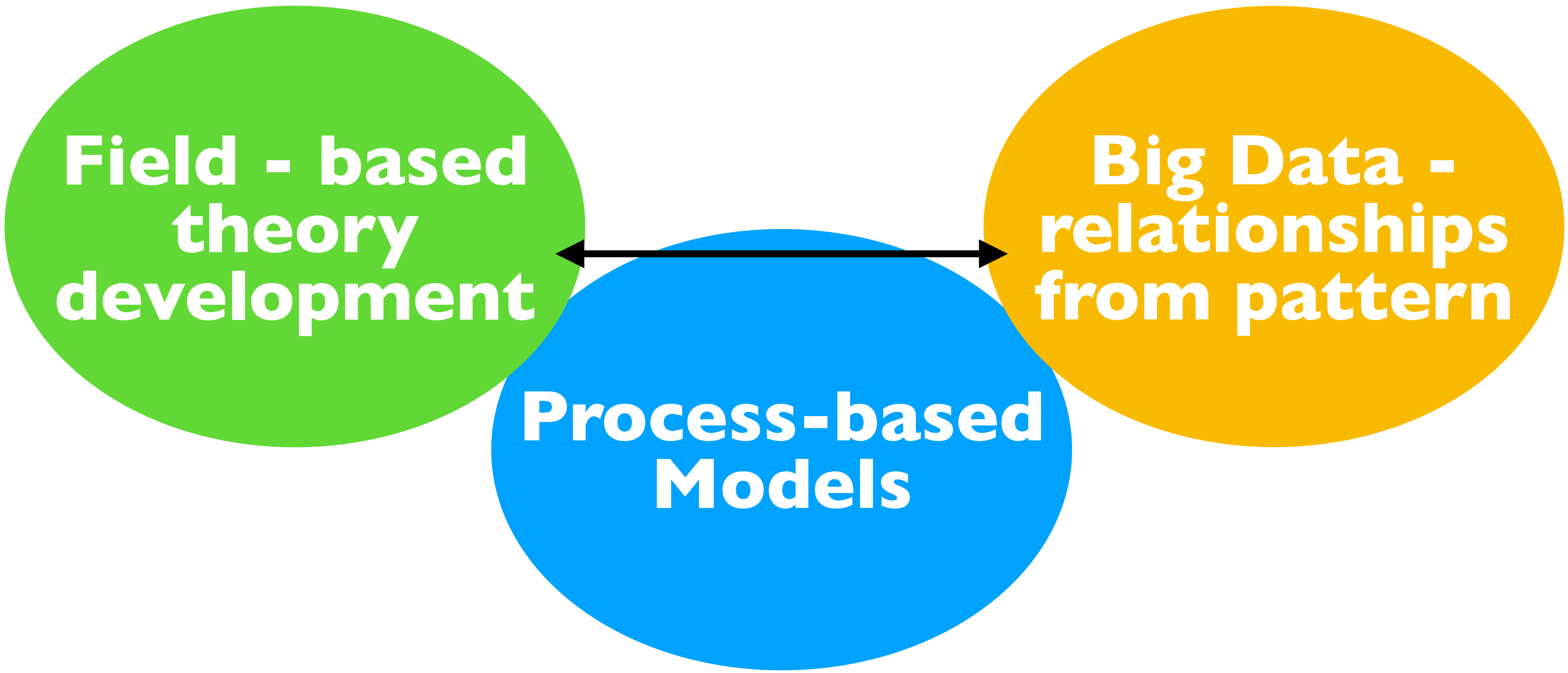
$$E = \frac{s\,R_N + \rho_a\, c_p\, Cat\; u\,[e_s(T_a)-e_a]}{[s + \gamma(1+Cat/Ccan)]\,\lambda_v}$$

Review of flow and grow models



Wiley Interdisciplinary Reviews: Water
Volume 3, Issue 3, pages 327-368, 19 NOV 2015 DOI: 10.1002/wat2.1125
http://onlinelibrary.wiley.com/doi/10.1002/wat2.1125/full#wat21125-fig-0006

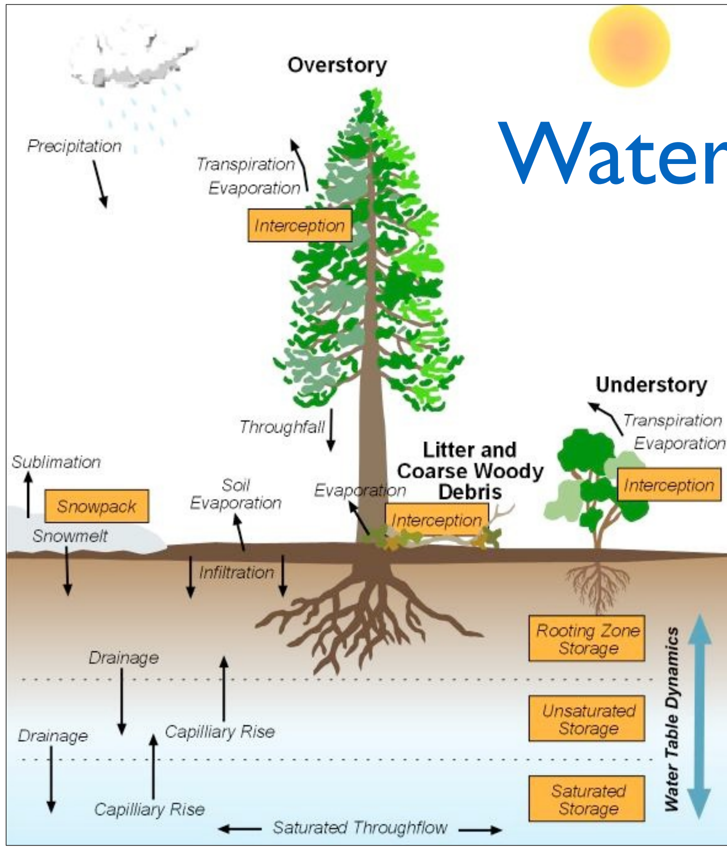
Advances in ecohydrolgy require integrating…

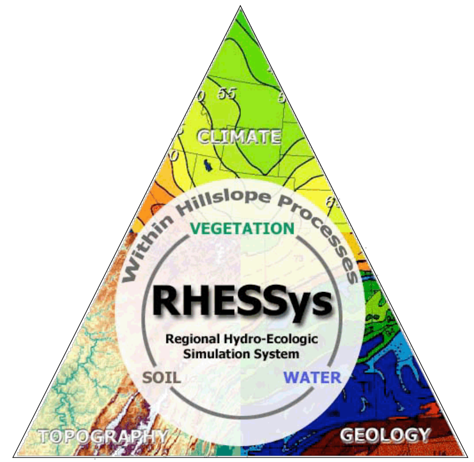


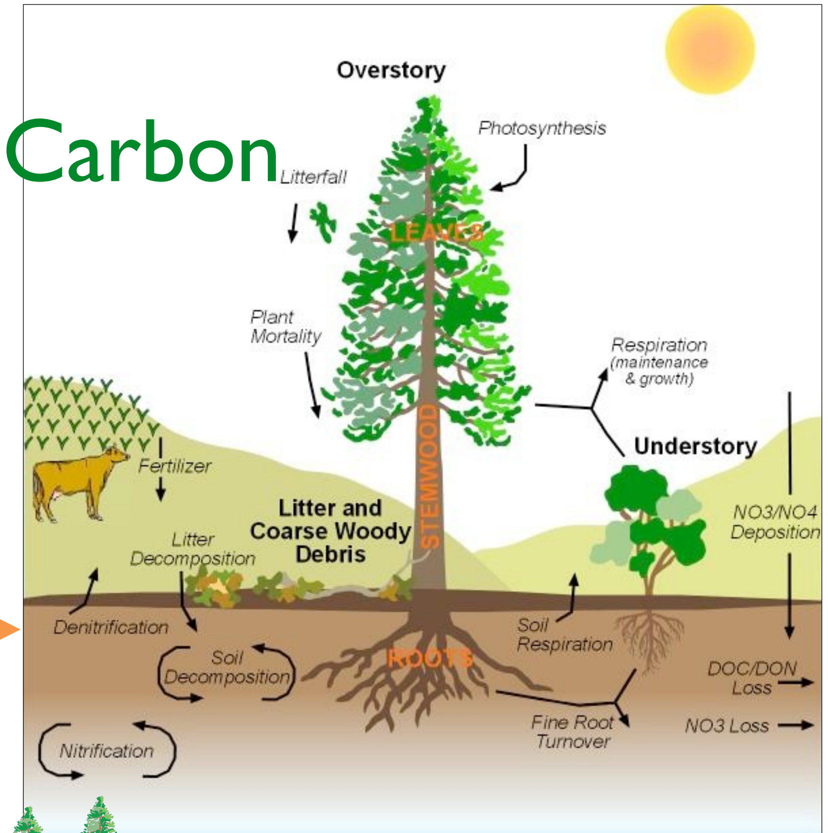
- what we are learning from field-investigations
- what we learn from patterns from big data

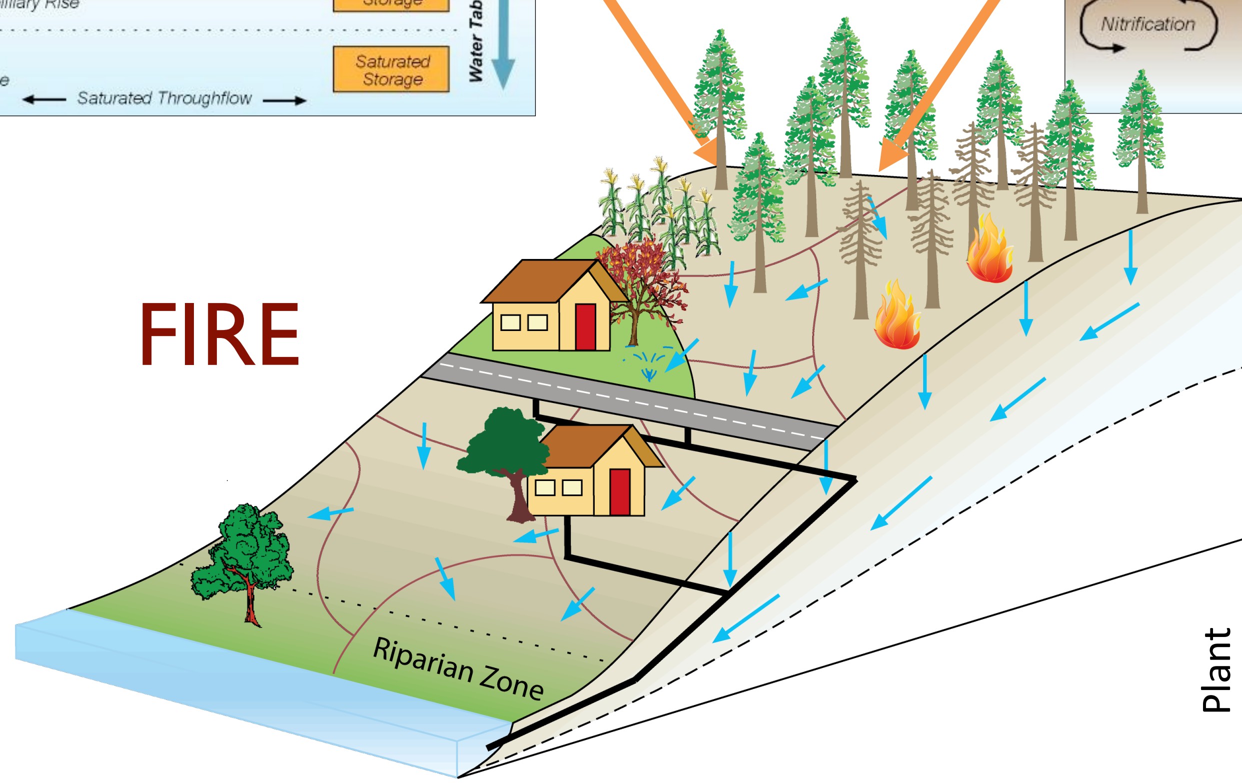
Process-based models can help us to do that

RHESSys process model does both space-time

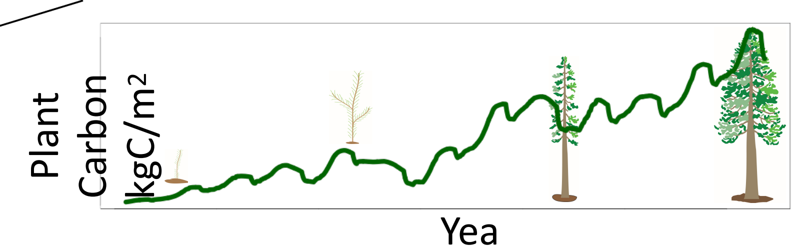








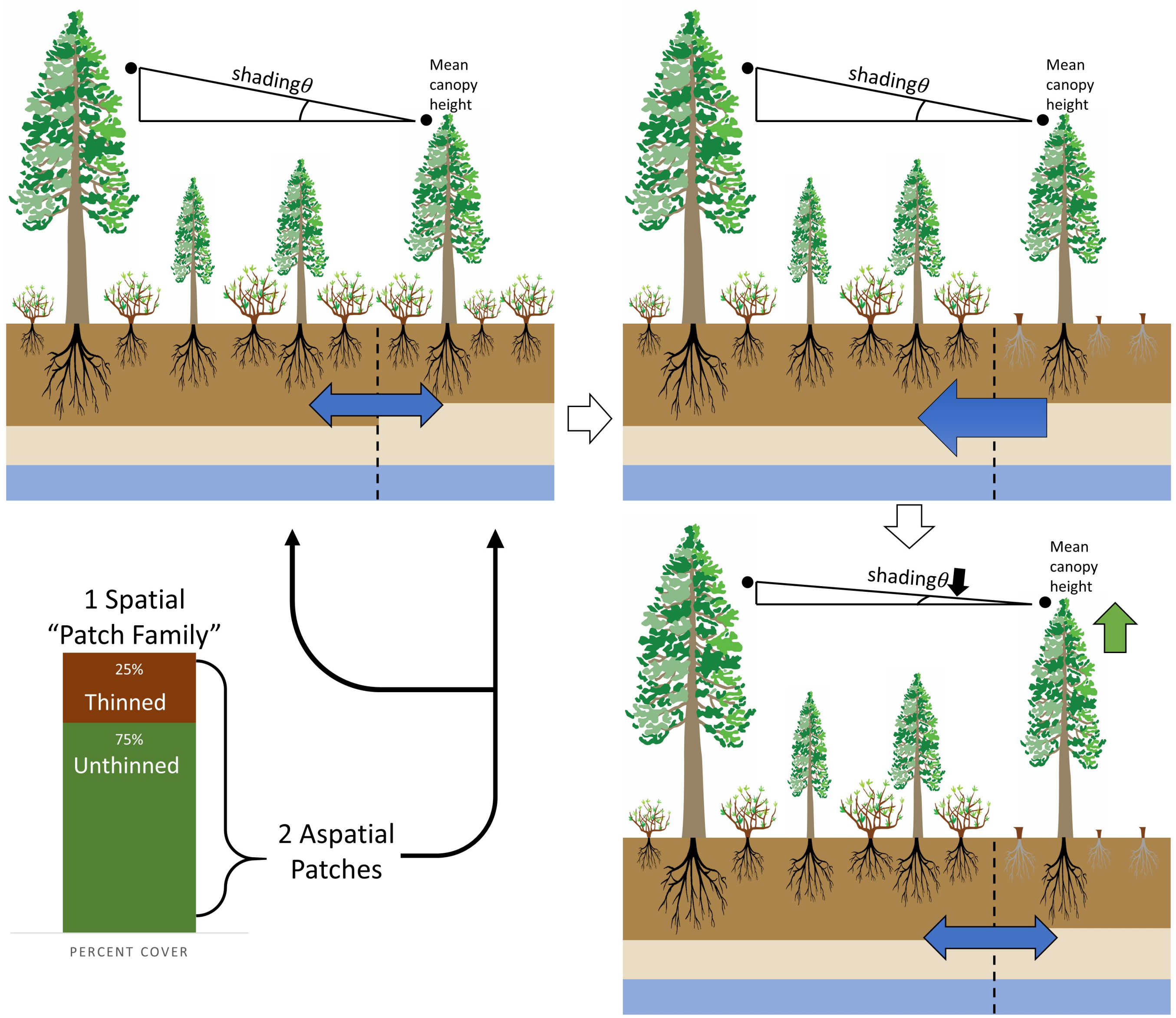
https://github.com/RHESSys/RHESSys/wiki



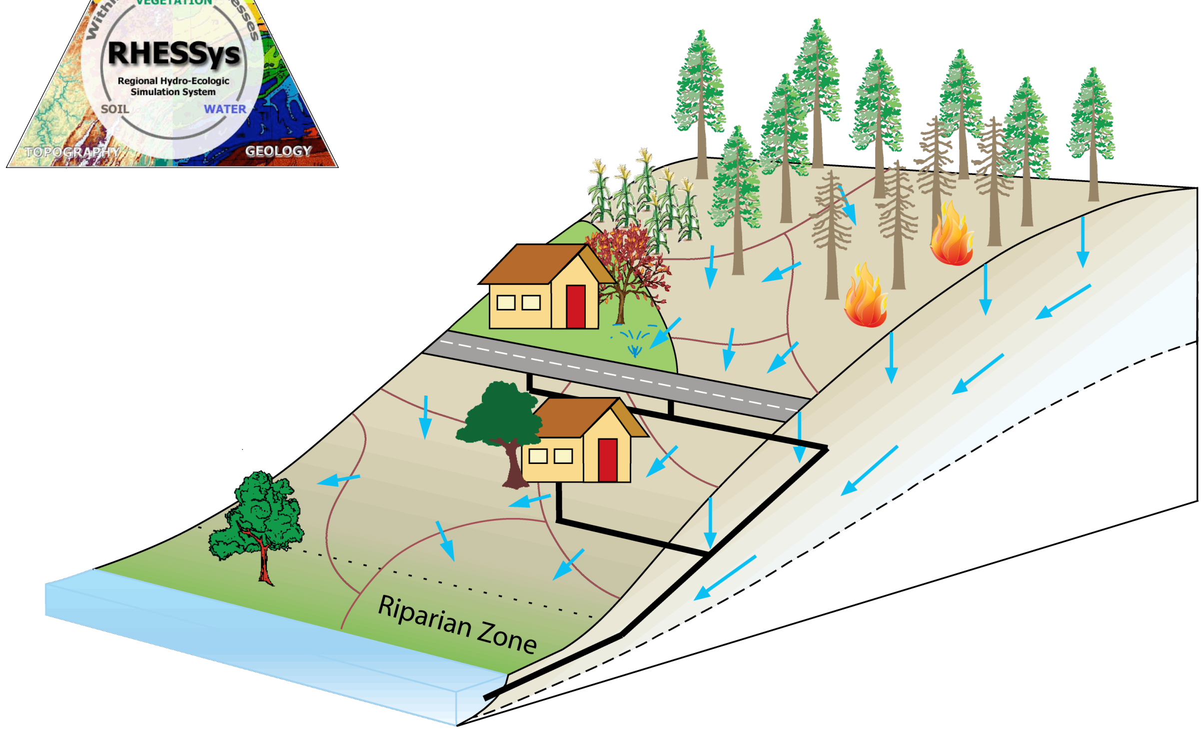
Models help to synthesize these data sets…and create ‘best guess’ and ‘plausible’ scenarios of where things are going;

Within patch patch family - Storage is "shared"

Multi-Scale RHESSys -
allows us to resolve the impact of vegetation removal on neighboring vegetation

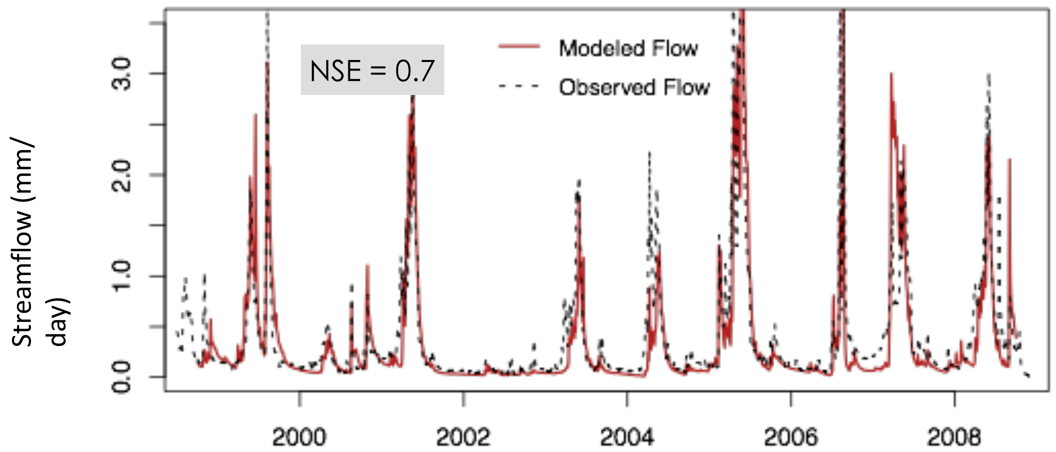


Within Plot/Stand

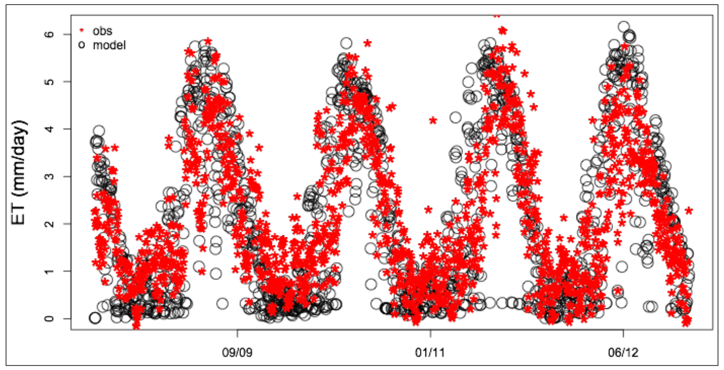


Between Plot/Stands

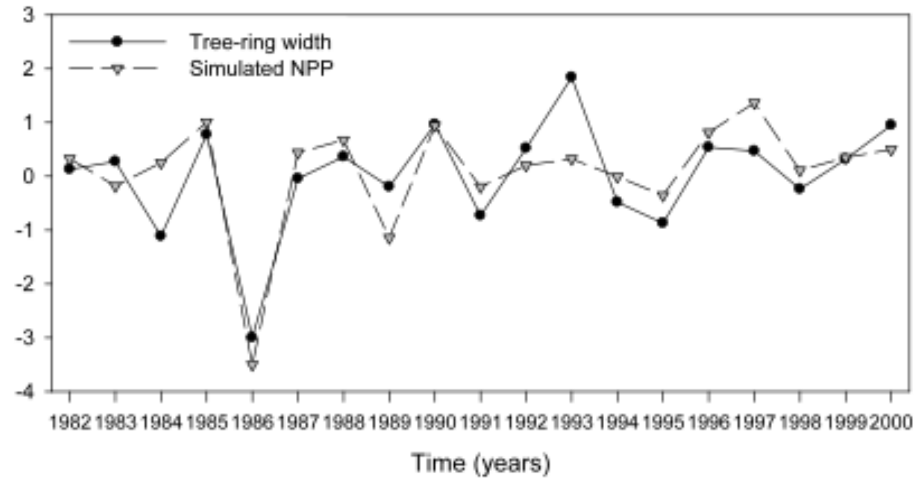
Multiple dataset used for model validation over times - General Model Evaluation - Why?



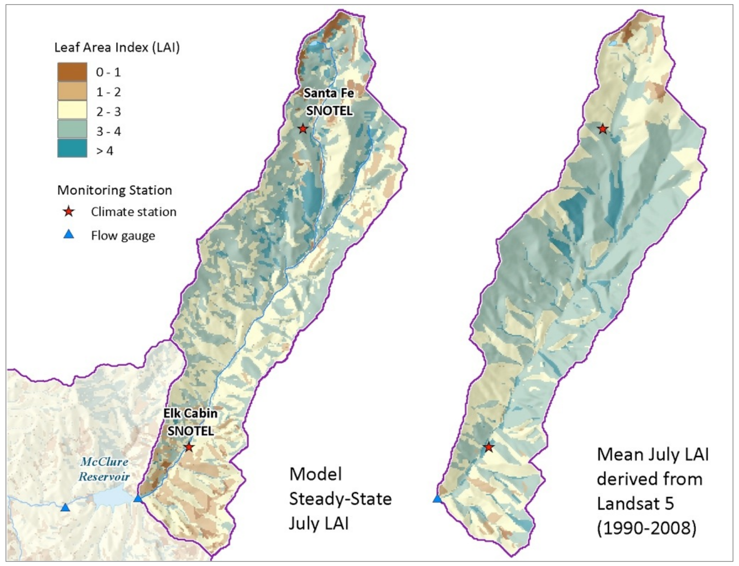
Daily Streamflow Record Tgue and Peng (2013) Journal of Geophysical Research: Biogeosciences 118(2): 875-887. doi: 10.1002/jgrg.20073



Carbon - flux Bart et al., (2017)PLoS ONE 11(8): e0161805. doi:10.1371/journal.pone.0161805



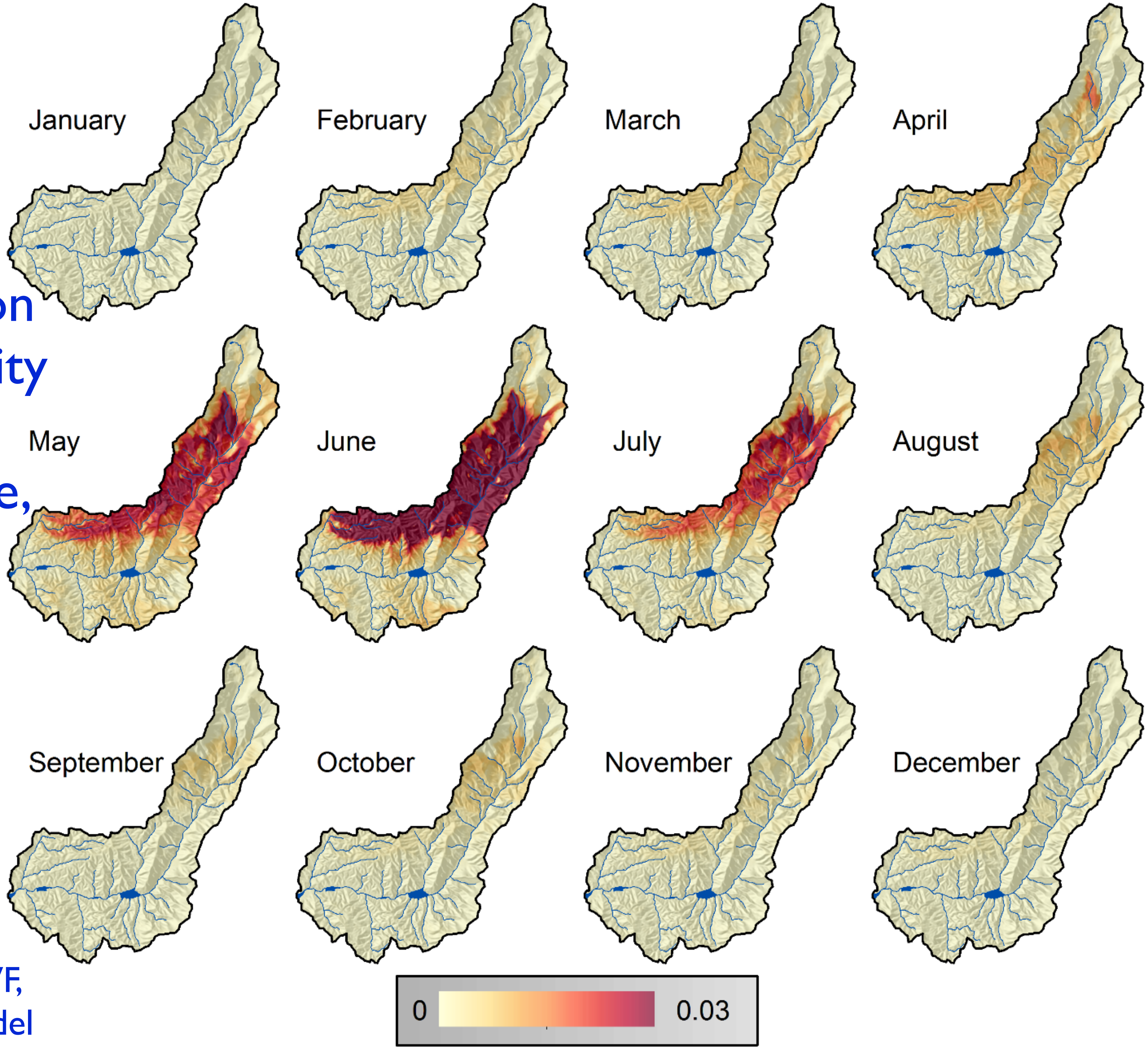
Tree Rings Vicente-Serrano et al., (2015), Agricultural and Forest Meteorology 206: 45-54. doi:10.1016/j.agrformet.2015.02.017



Remote Sensing Vegetation Indices

turbance…RHESSys-Fire

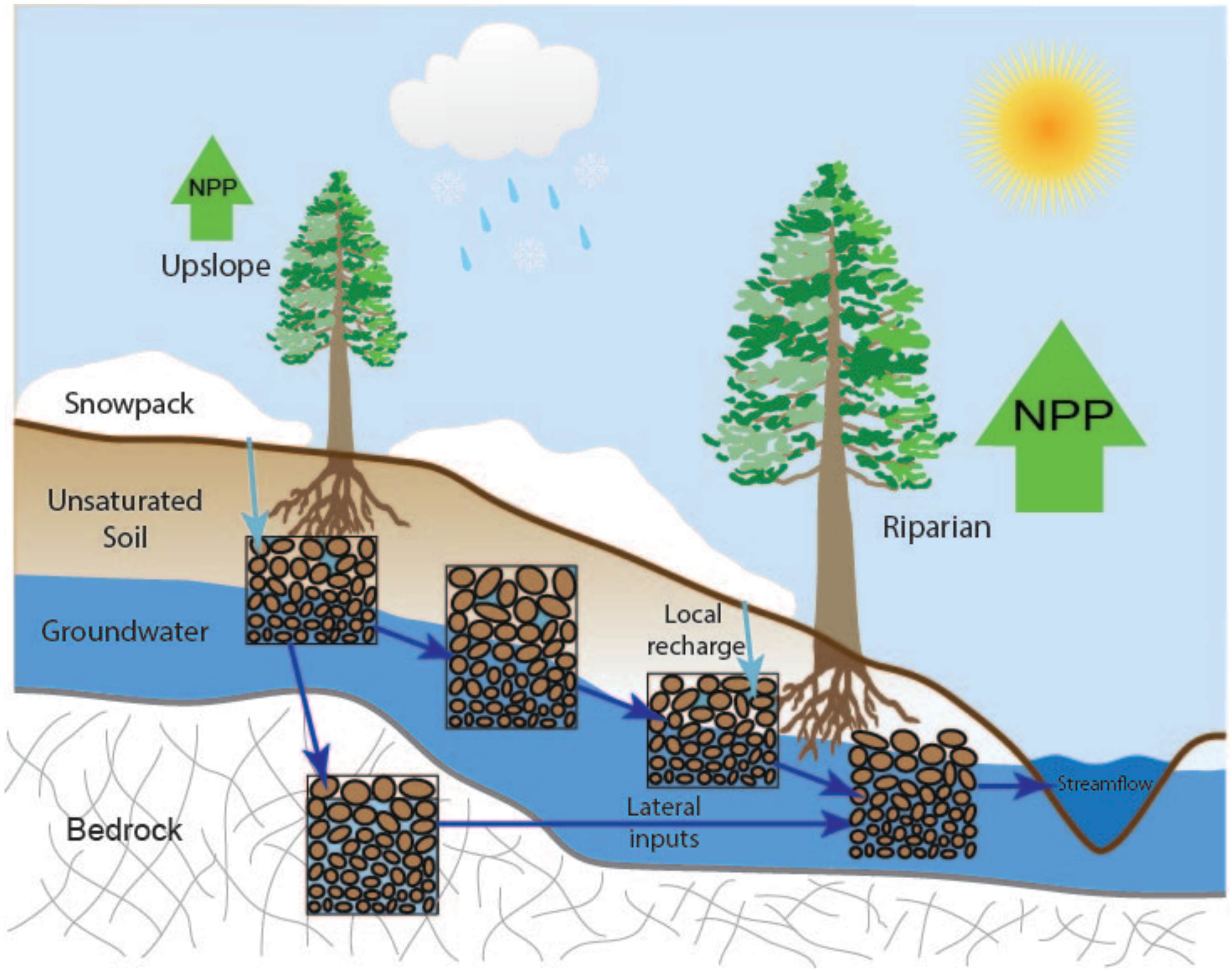
Spatial estimation of burn probability under historic climate: Santa Fe, New Mexico

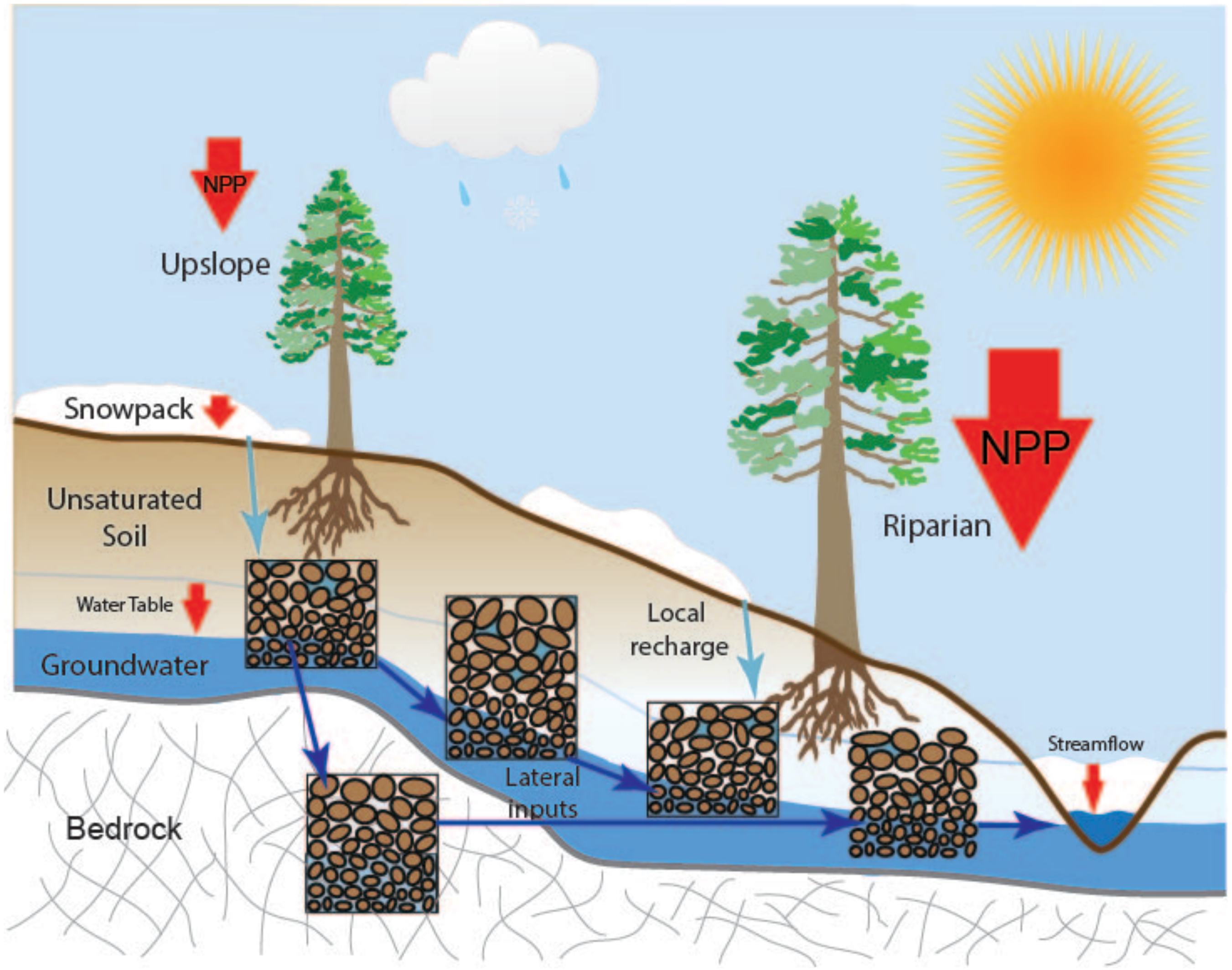


Kennedy et al. (2017) IJWF, Bart et al., (2019) Eco Model

Conceptual Model

(Subsurface Lateral Flows Buffer Riparian Water Stress Against Snow Drought, JGR, Graup et al., in 2022)



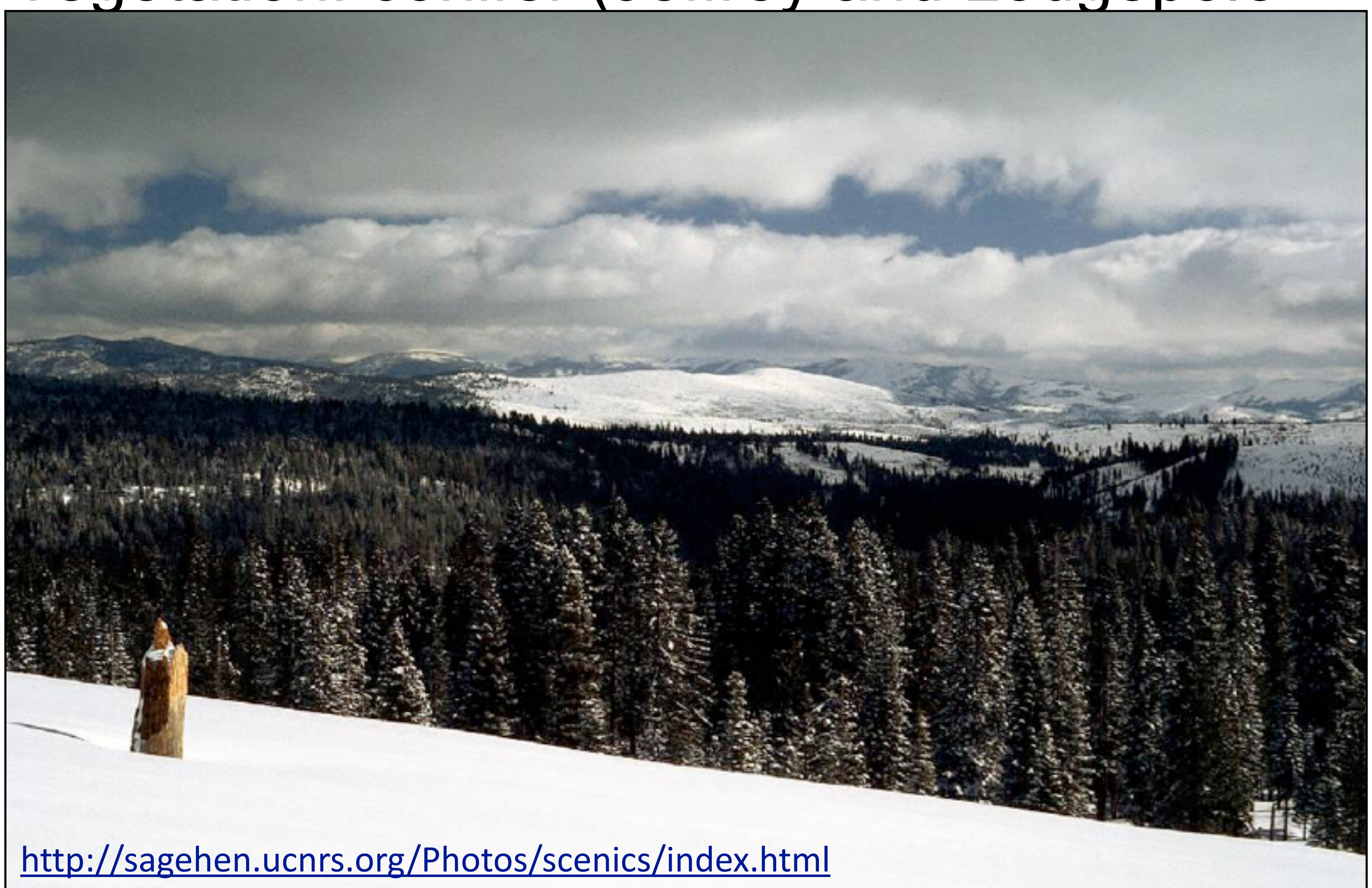


Focus Site

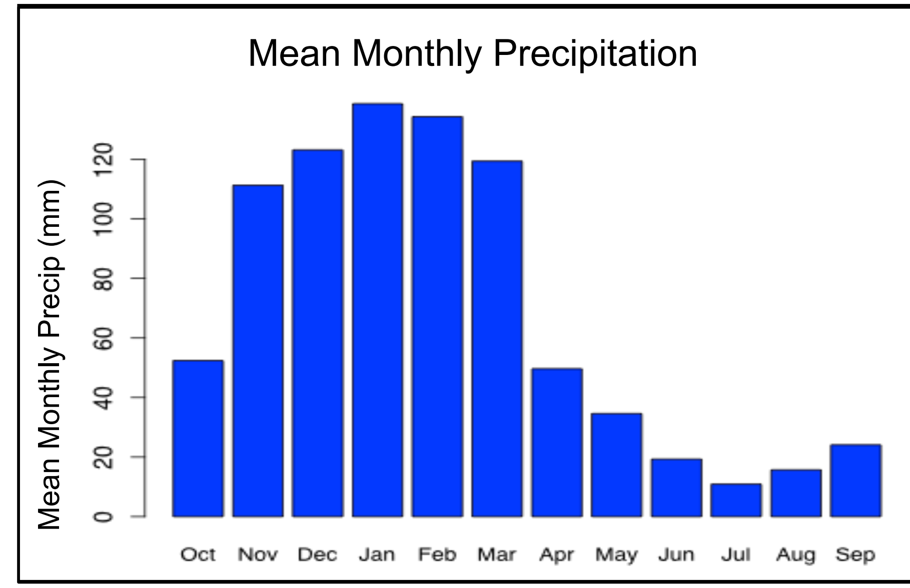
Sagehen Experimental Watershed (UC Berkley Field Station)

Sierra Nevada Mountain watershed (183ha) Elevation range *1800-2700m*

Vegetation: conifer (Jeffrey and Lodgepole

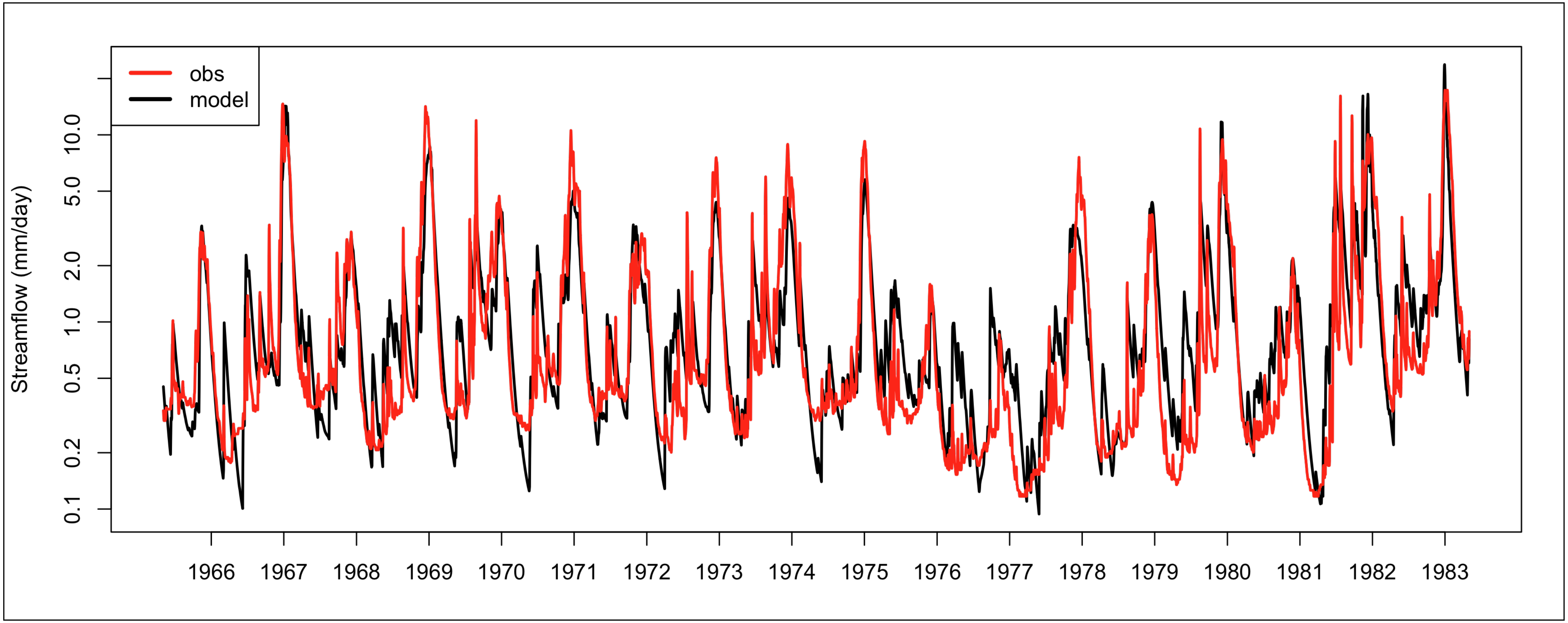


http://sagehen.ucnrs.org/Photos/scenics/index.html

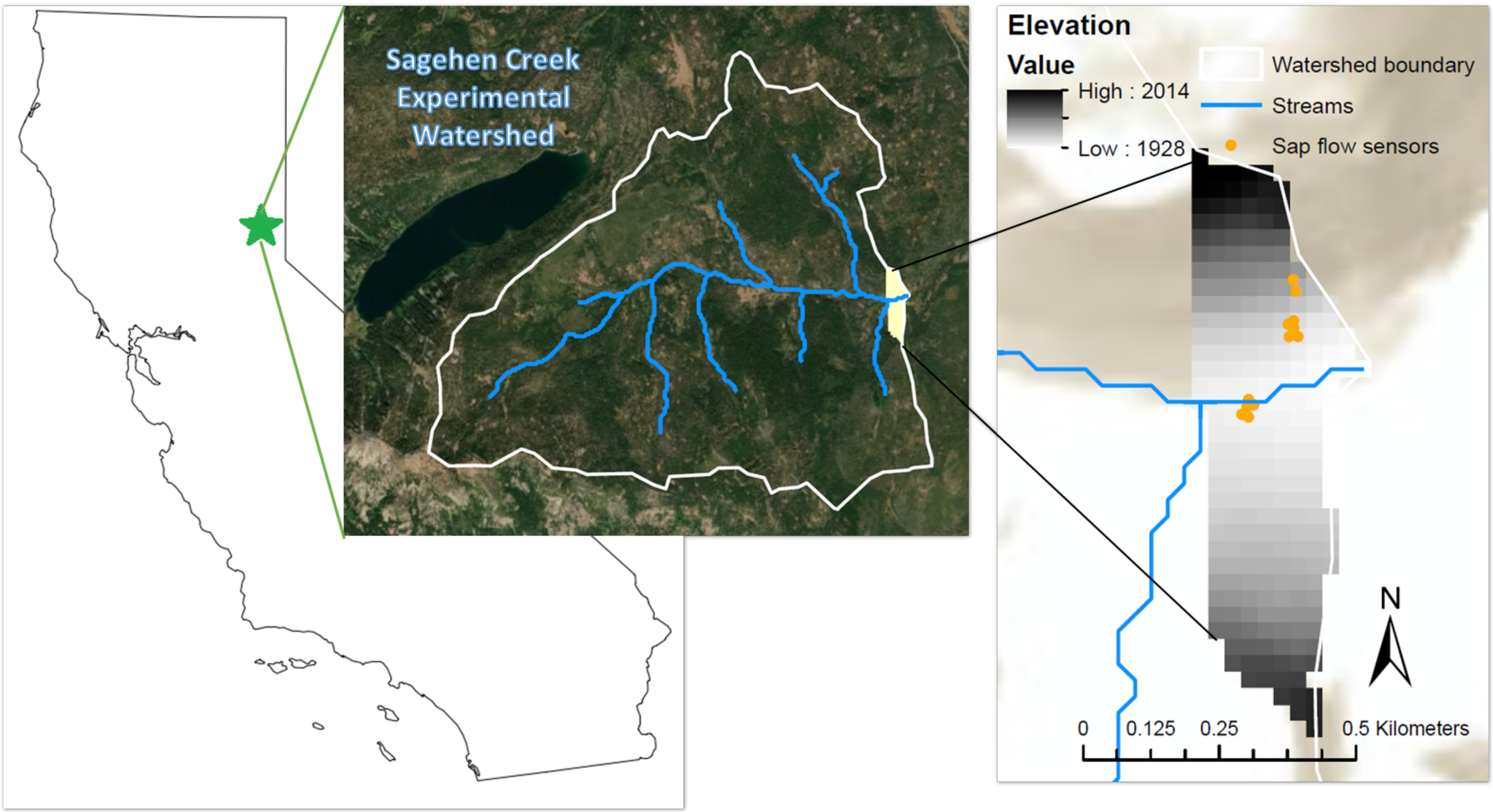


RHESSys hydrologic model performance – post calibration Streamflow (1960-2000)

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



RHESSys application - Sagehen Creek - Hillslope scale redistribution and drought



RHESSys application - Sagehen Creek - Diversity of observations for model evaluation

Growth Metric	Observed Range	Source	Modeled Mean (St. Dev.)
Tree Height (m)	3 - 32	Xu et al. (2018)	17.7 (4.7)
ΔHeight (m)	0 - 5	Xu et al. (2018)	1.3 (0.4)
LAI (m^2/m^2)	1 - 8	Garcia et al. (2016)	2.5 (0.5)
Leaf Carbon ($g\ C\ /\ m^2$)	60 - 363	Law et al. (2001)	244 (45)
Stem Carbon ($g\ C\ /\ m^2$)	1,656 - 13,542	Law et al. (2001)	1,692 (351)
Coarse Root Carbon ($g\ C\ /\ m^2$)	1,500	Law et al. (2001)	836 (209)
	806 ± 142	Chatterjee et al. (2009)	
Fine Root Carbon ($g\ C\ /\ m^2$)	423 ± 95	Law et al. (2001)	188 (51)
	151 ± 7	Chatterjee et al. (2009)	
Plant Carbon ($g\ C\ /\ m^2$)	3,640 ± 770	Johnson et al. (2008)	2,959 (610)
	2,520 ± 199	Chatterjee et al. (2009)	

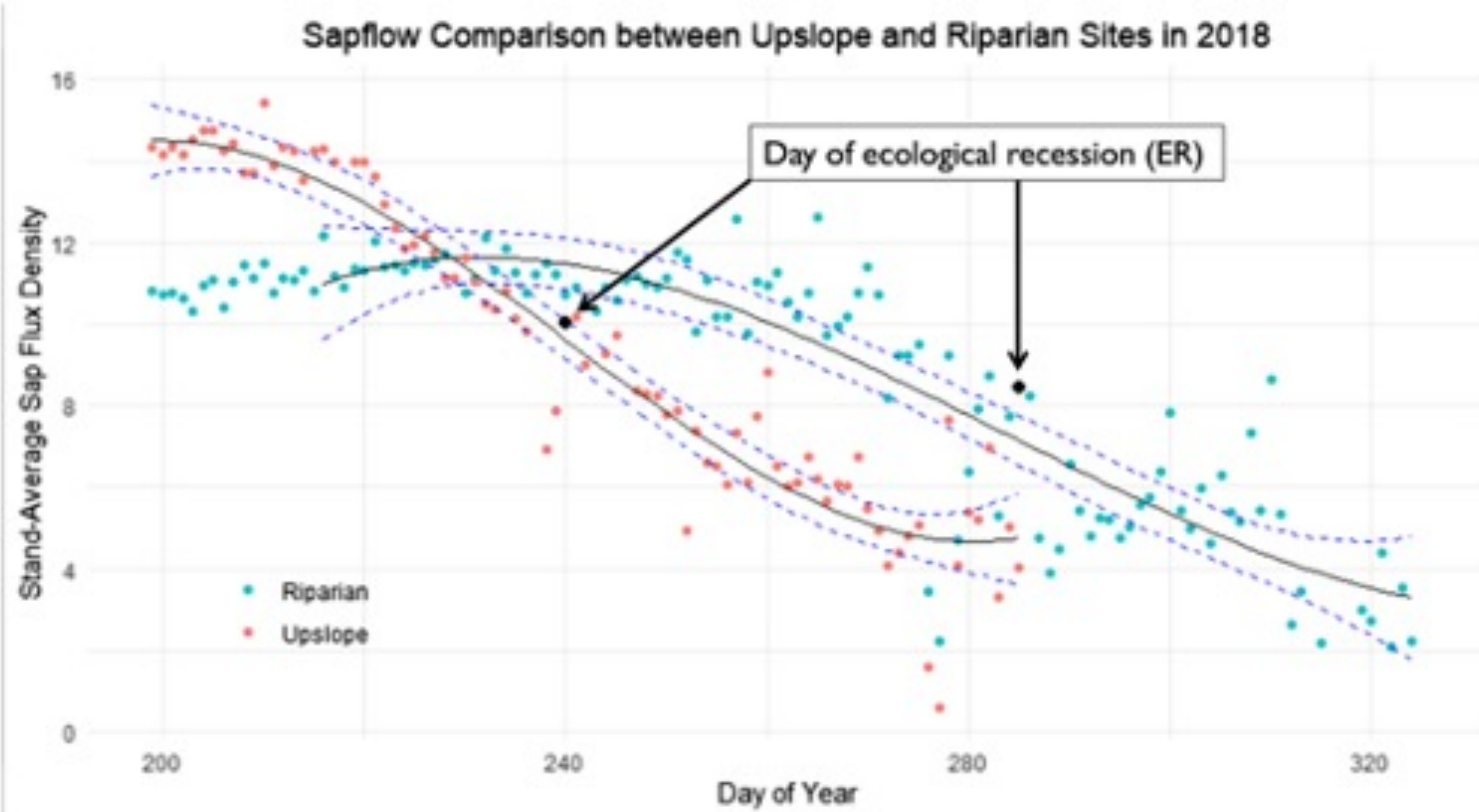
Table S3. Growth metrics derived from literature and Lidar data

Figure S2: Tree height comparison of RHESSys model outputs against Lidar data in Sagehen

First step - only parameters that RHESSys estimates of vegetation biomass (from carbon cycling model) have “reasonable” ranges

* fit with literature values for these species in Sierra region
* Fit with local estimates from Lidar

RHESSys application - Sagehen Creek - Calibration with Observed Sapflow



Second step (drainage parameters)

* fit with a metric derived from comparing upland and riparian sap flow

RHESSys application - Sagehen Creek - Find most sensitive parameters

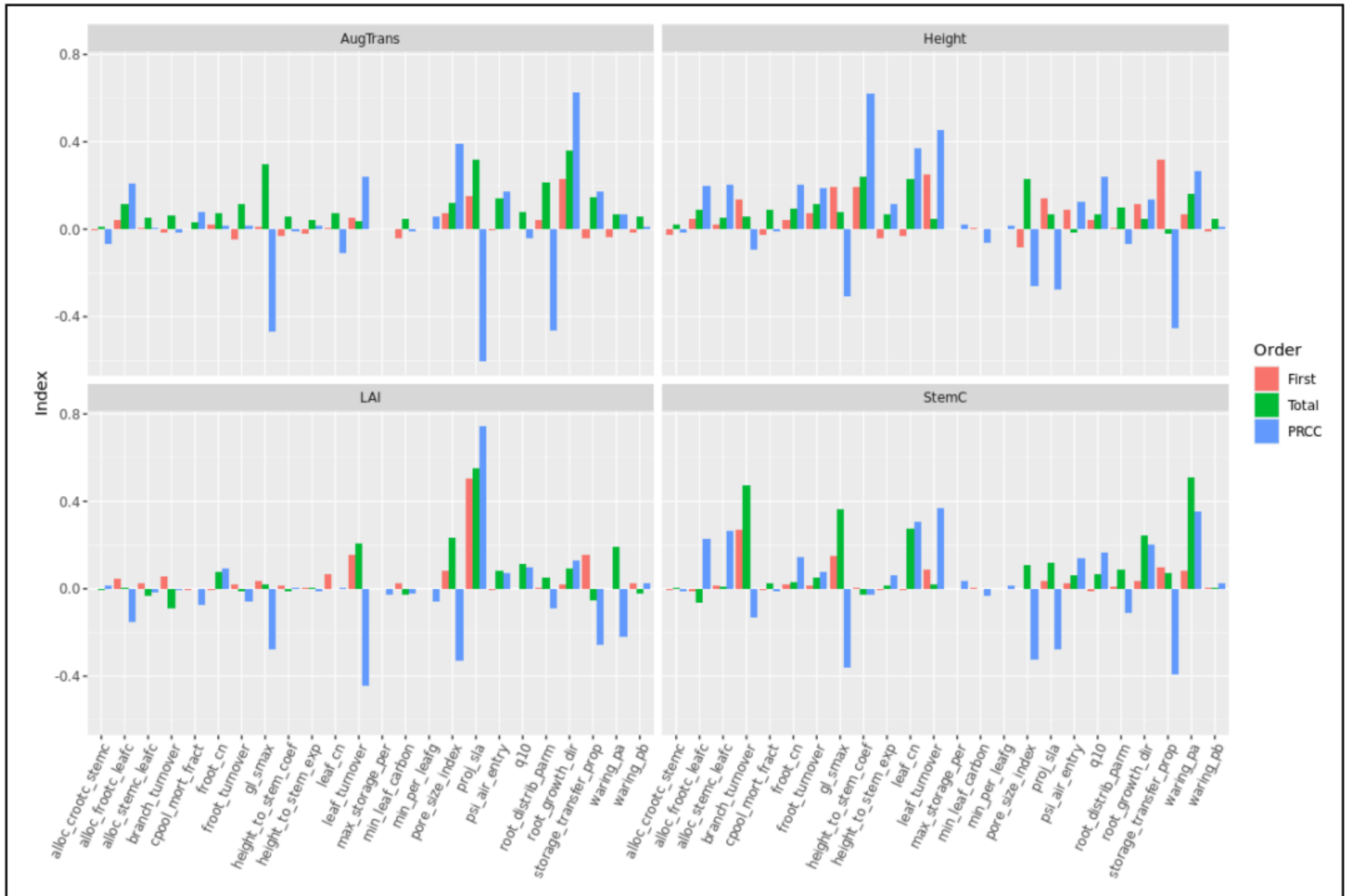


Figure S3: Ecophysiological parameter sensitivity analysis results by metric comparing first- and total-order Sobol indices against Partial Rank Correlation Coefficients (PRCC)

RHESSys application - Sagehen Creek - Maintaining parameter uncertainty "Behavioral Parameters"

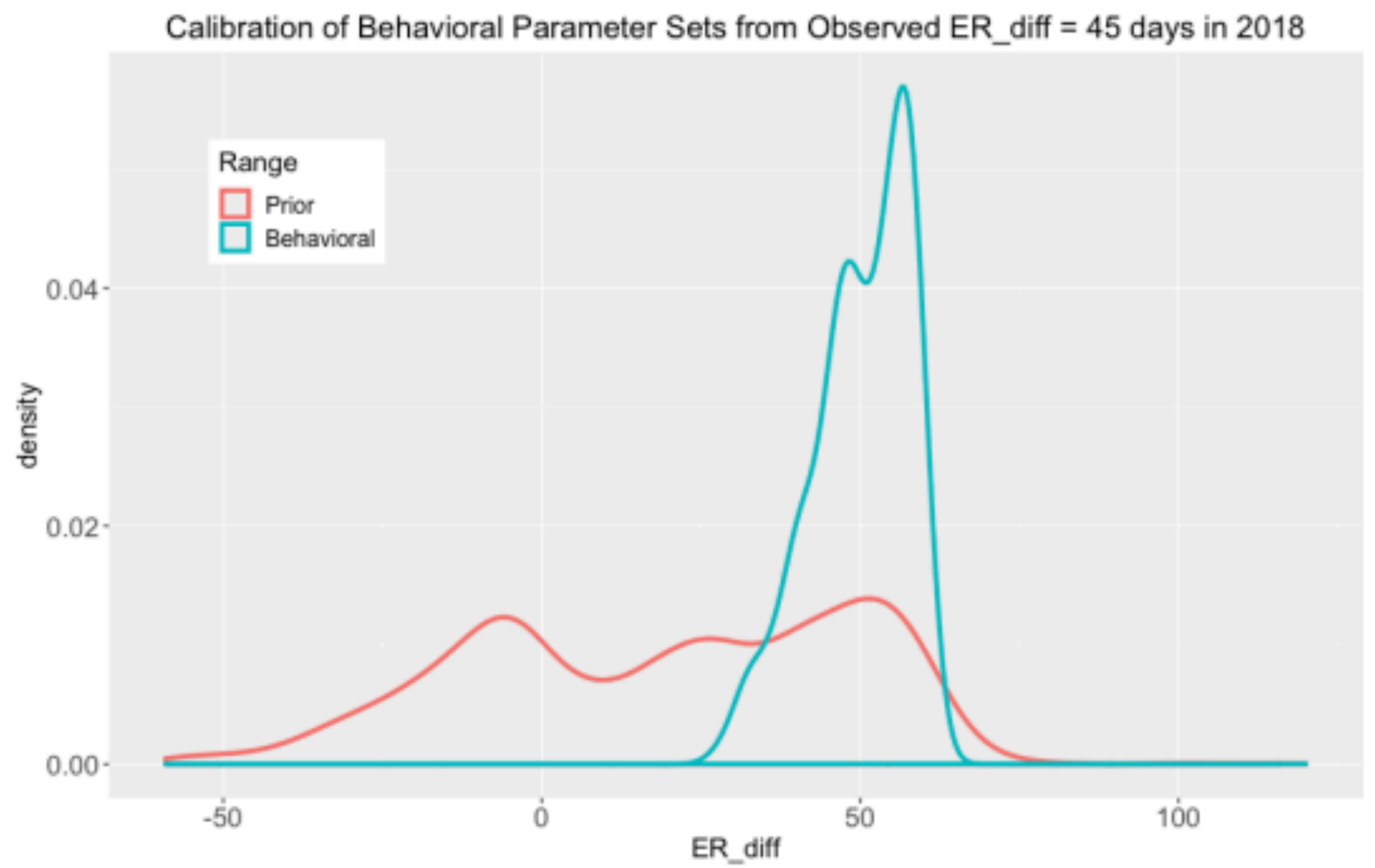


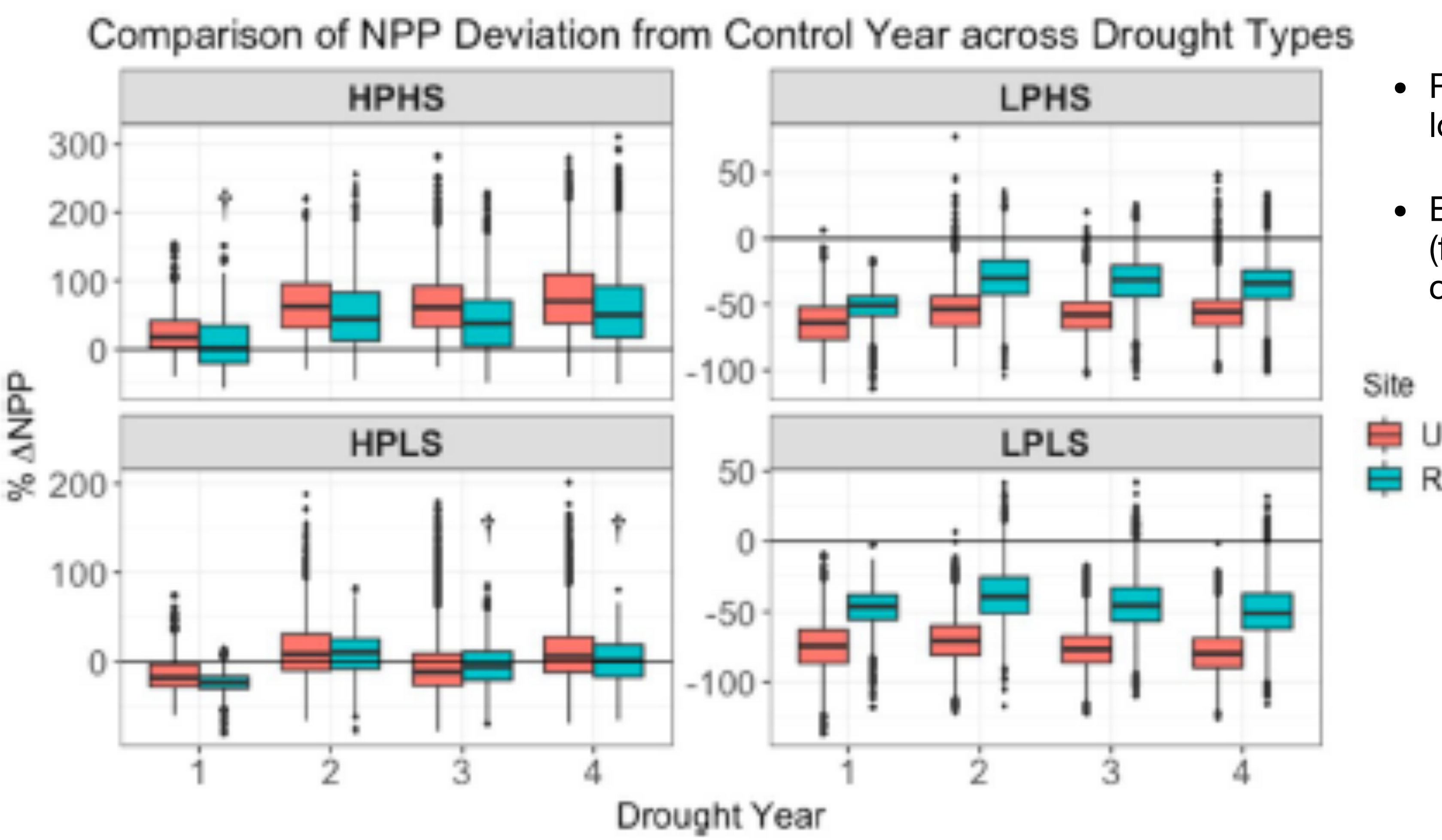
Figure S4: Calibration of RHESSys hillslope drainage parameters to observed ER_diff demonstrating behavioral parameter uncertainty

Multi-year drought how does NPP (water use by plant) change

Table 1
Drought Type Classification

SWE \ P	> Mean (677 mm)	< Mean
> Mean (128 mm)	HPHS	LPHS
< Mean	HPLS	LPLS

Note. P and SWE are accumulated annual precipitation and snow water equivalent, respectively, on April 1st. H is high, L is low, S is SWE—HPHS is high P, high SWE; LPLS is low P, low SWE (i.e., dry snow drought); HPLS is high P, low SWE (i.e., warm snow drought), etc.



- Riparian tress are buffered 28% of annual NPP loss during drought versus 45% for upslope trees
- But there were exceptions - particular parameters (fast draining soil, especially deep rooted, low conductance)

Multi-year drought how does ET(water use by plant) change

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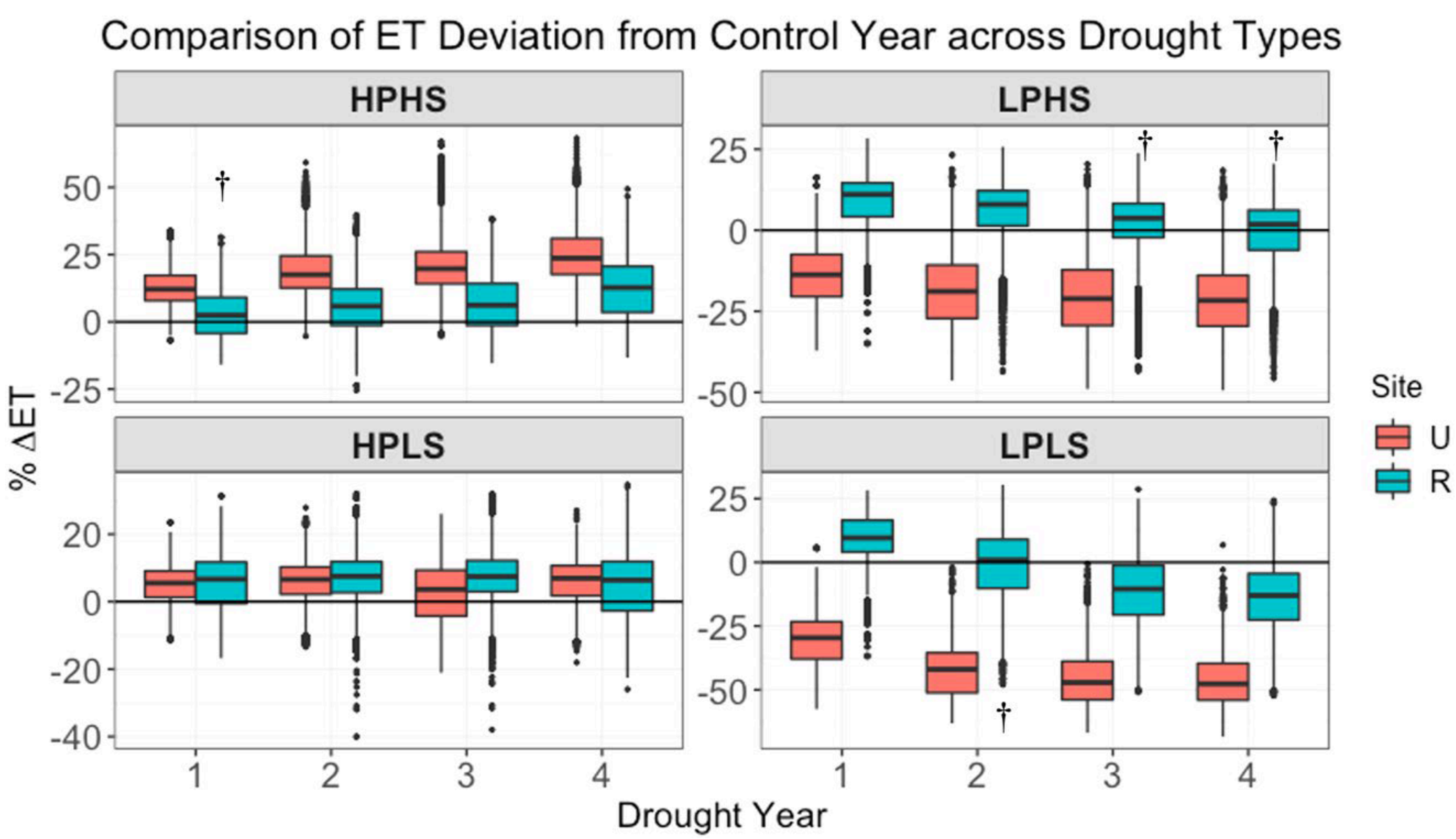
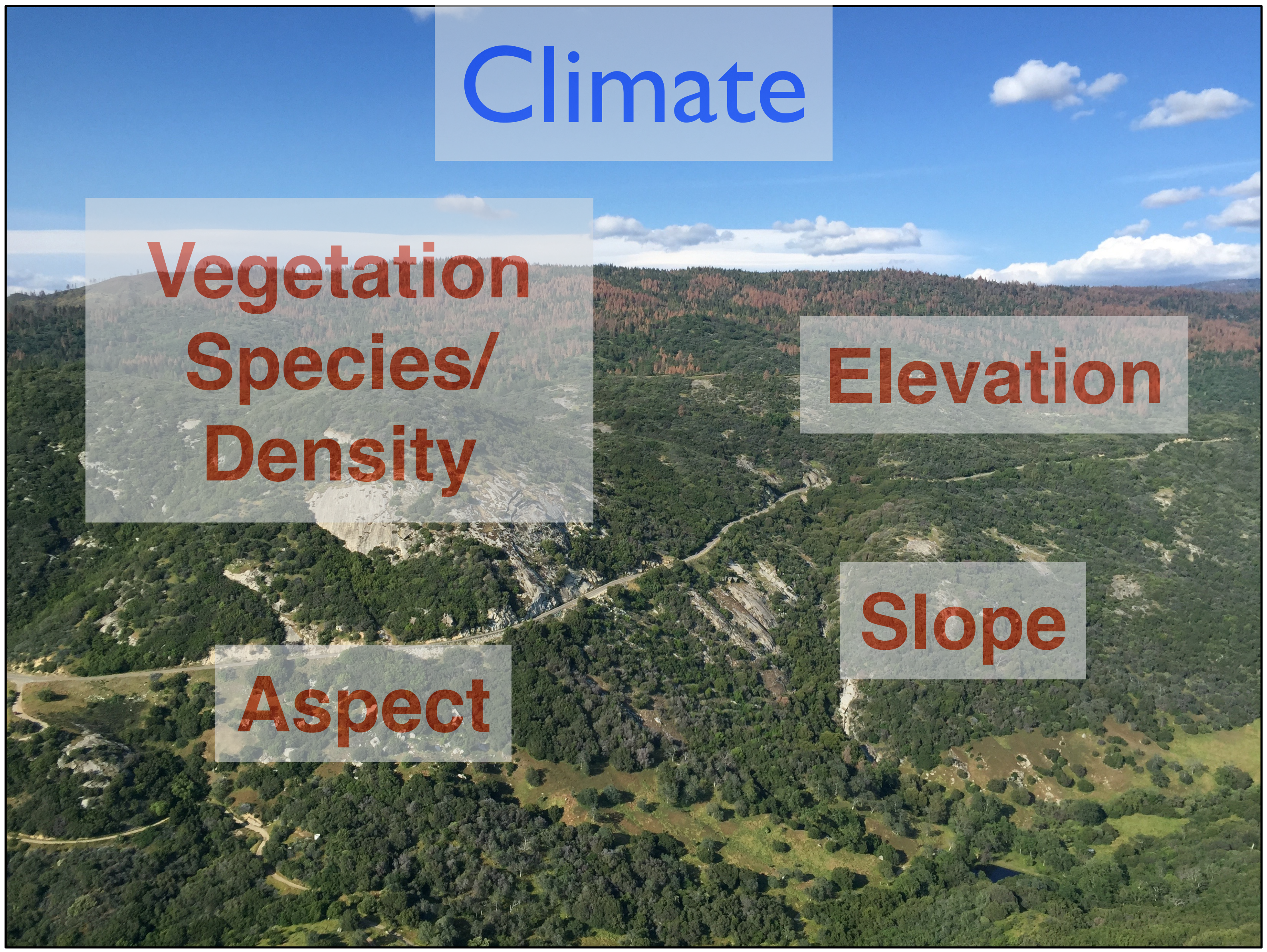


- Low P, riparian trees initially benefit until 4th year of drought, and snow buffers this

Fuel treatment impacts - over time on water, carbon, and fire - what matters? (Burke et al., 2021)



Southern Sierra Watershed

Type of treatment - biomass removal, rotation…

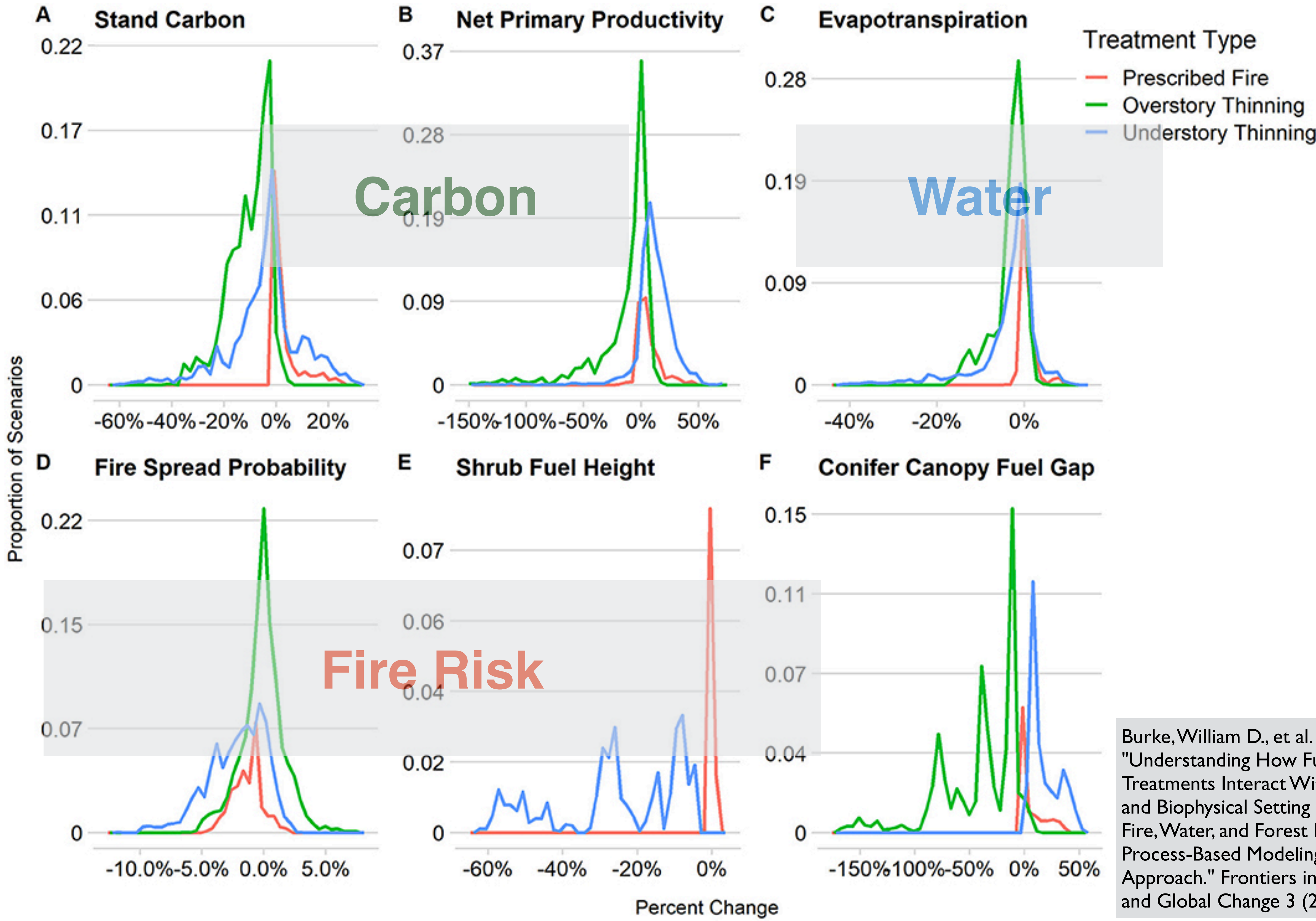
RHESSys-Fire: Context dependence of fuel treatment effectiveness - even within the same watershed

TABLE 1 | Summary of fuel treatment scenario parameters.

Fuel treatment scenarios	
Treatment method and intensity	**10**
Understory thinning + prescribed fire: high, med, low	3
Overstory thinning, with/without slash: high, med, and low	6
Prescribed fire	1
Treatment Frequency: 5, 10, and 30 years	**3**
No treatment	**1**
Site characteristics	**540**
Vegetation: shrub, conifer, and shrub/conifer mix	3
Aspect: north, south	2
Plant accessible water storage capacity: low, med, and high	3
Aridity: dry, variable, and wet	3
Climate warming: baseline, + 2°C	2
Root sharing coefficients: 0, 0.25, 0.5, 0.75, and 1	5
Total (incompatible combinations removed)	**13,500**

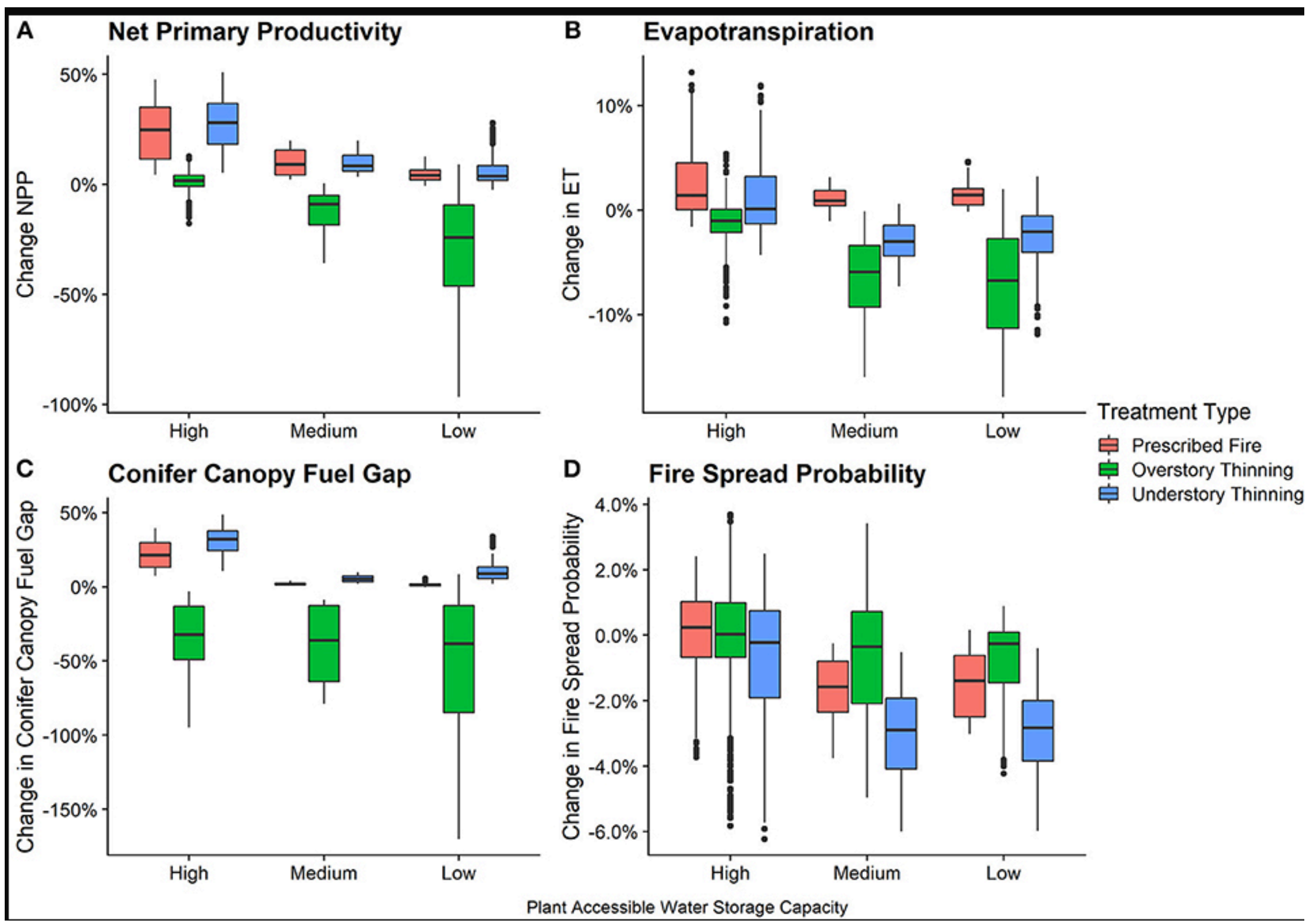
Bold values highlight the major subcategories of scenario variation.

Variation in fuel treatment impacts across site parameters, climate, treatments



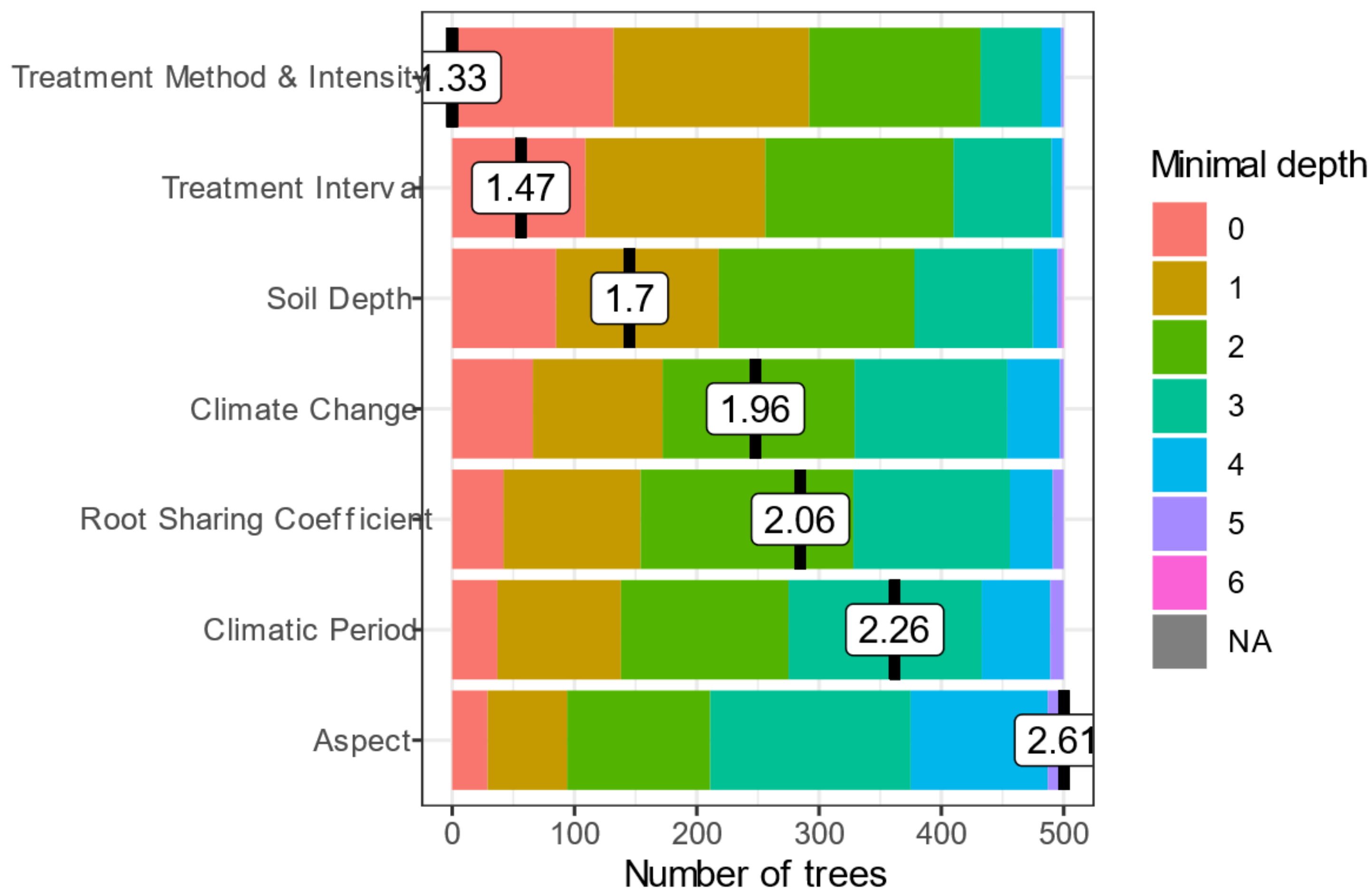
Burke, William D., et al. "Understanding How Fuel Treatments Interact With Cli and Biophysical Setting to Affe Fire, Water, and Forest Health Process-Based Modeling Approach." Frontiers in Fores and Global Change 3 (2021):

Forest growth, water use and fire indicators as responses to fuel treatment



Note parameter interactions - impact of treatment type depends on subsurface water storage

Fire Severity Risk



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Total (incompatible combinations removed)

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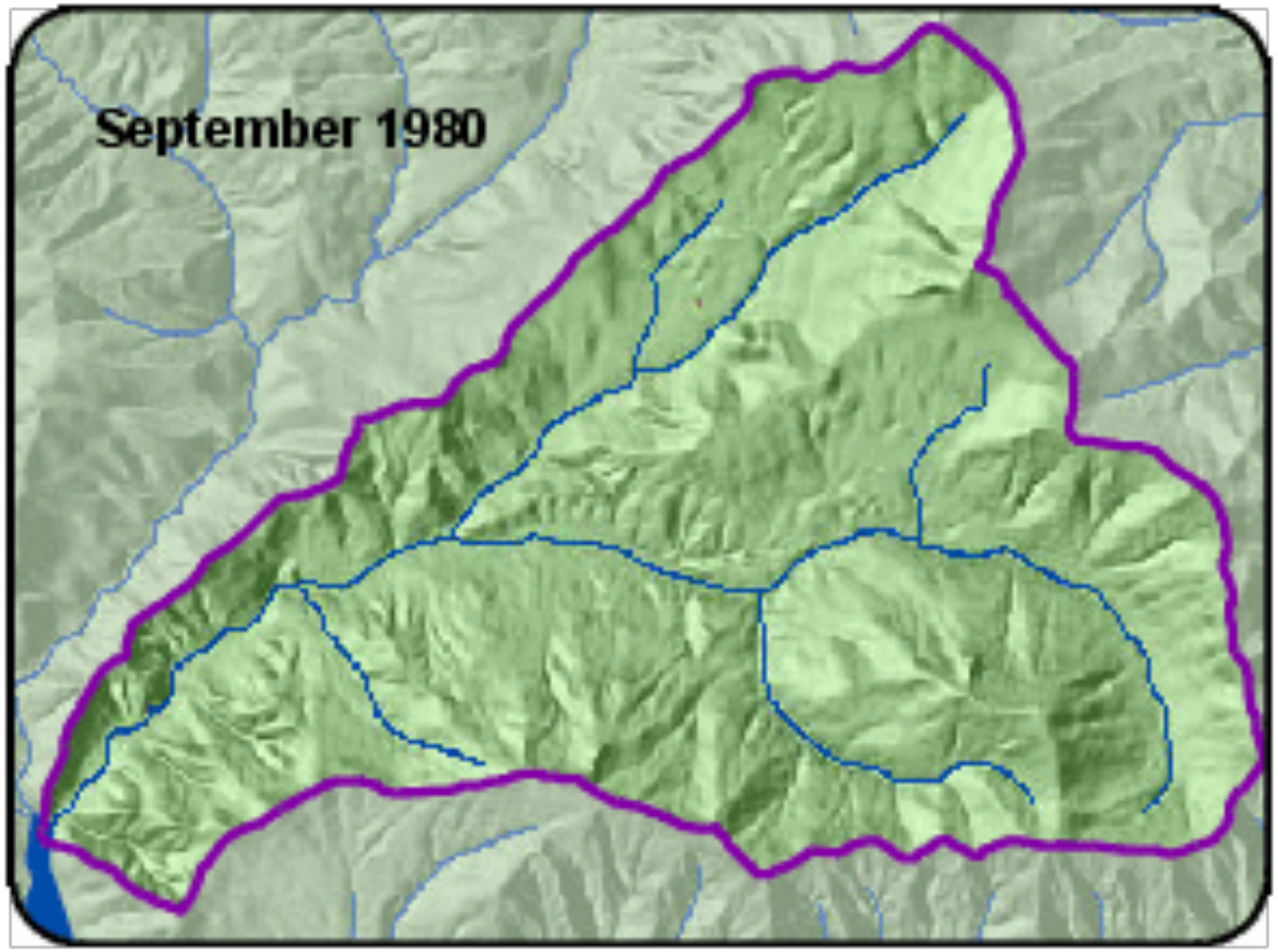
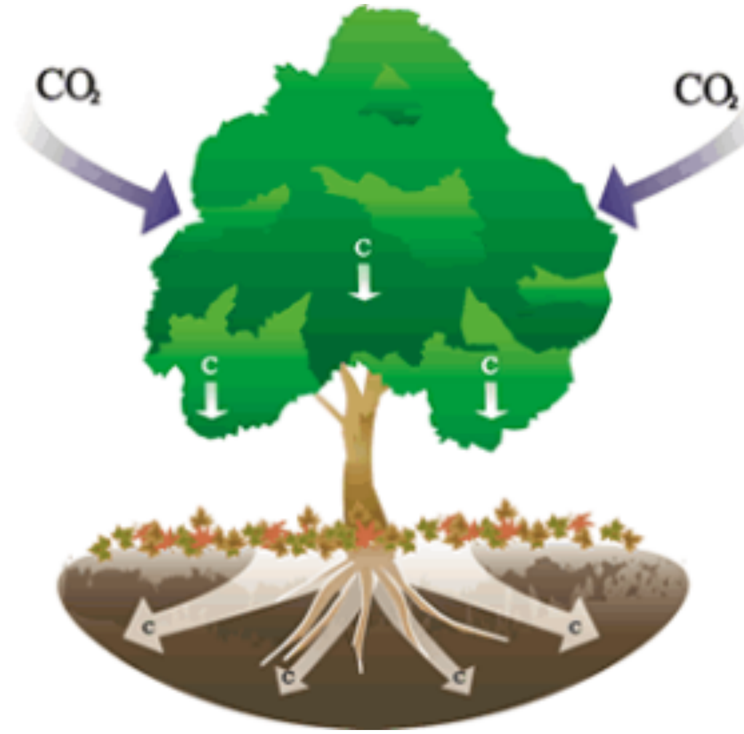
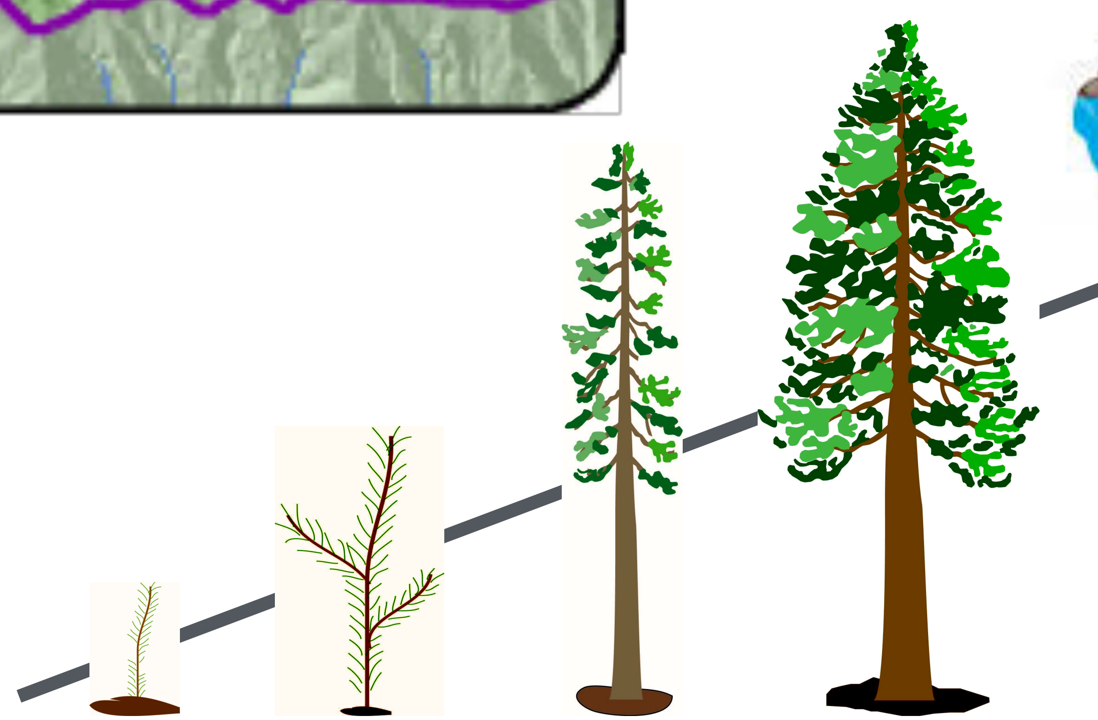
What about fire…..RHESSys-Fire

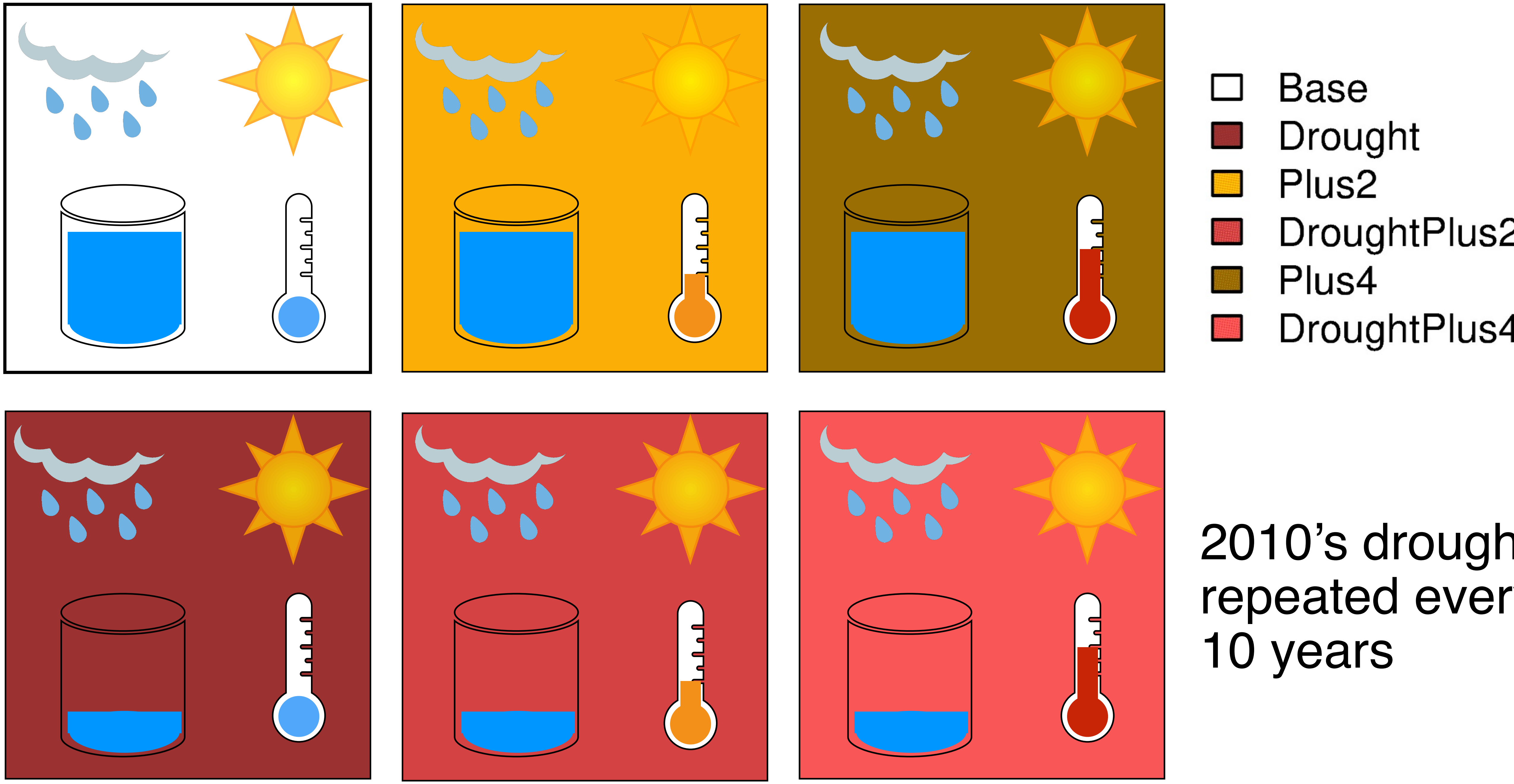


Kennedy et al. (2017)
International Journal of Wildland Fire



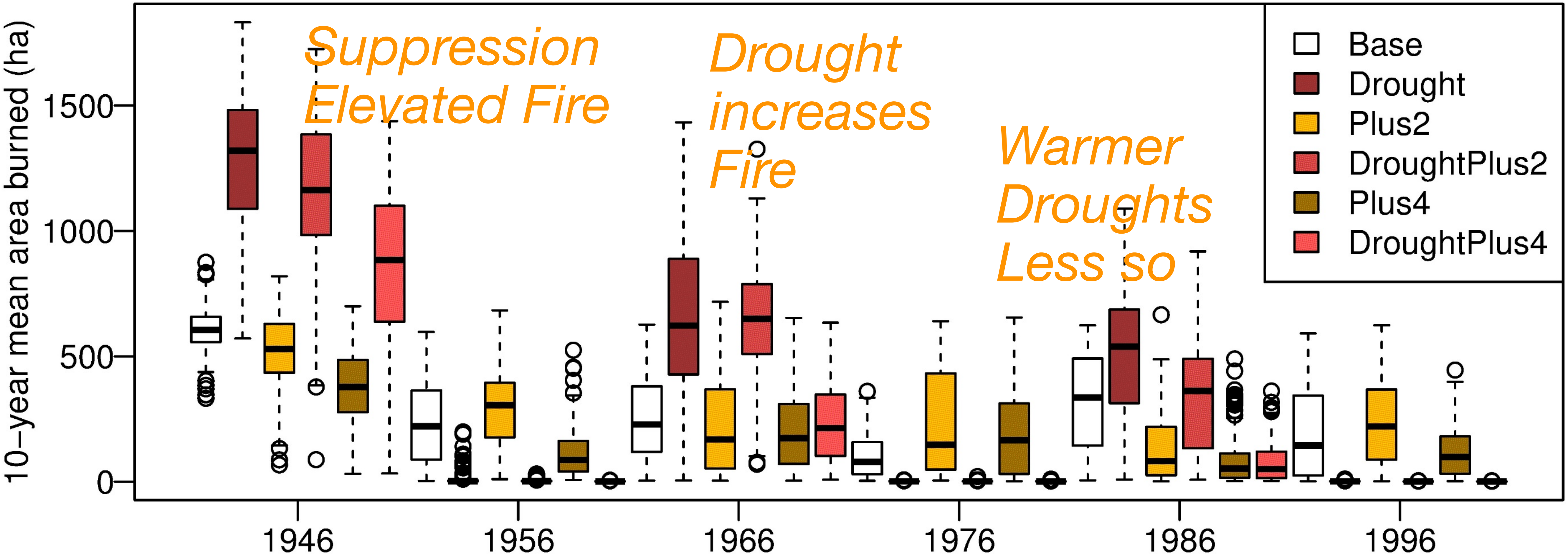


What happens to fire regimes if droughts are more frequent? If droughts are warmer?



2010's drought repeated every 10 years

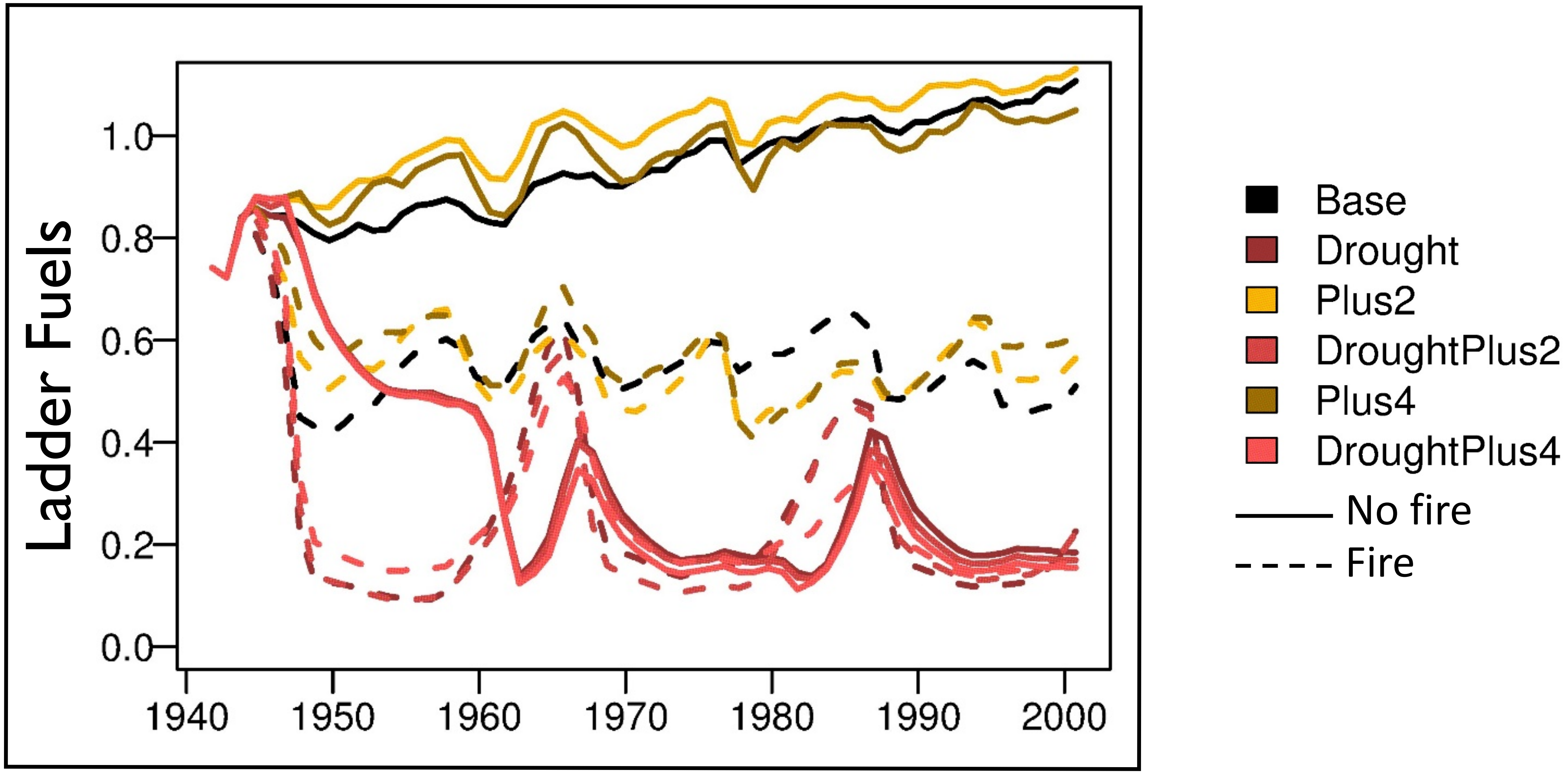
Results of the model experiment



Baseline Climate Time Period

Kennedy et al., (2021) Does hot and dry equal more wildfire? Contrasting short and long-term climate effects on fire in the Sierra Nevada, CA, *Ecosphere* 12(7): e03657

Fire vegetation over time



- Warm droughts:
  reduce vegetation productivity and regrowth - leading to fuel limitation - less fire
- Regular drought:
  increase in fire - weather dominates
- Varies WITHIN watersheds

Related studies in Idaho - suppression vs. climate change for last decades

RHESSys-Fire scenarios - spatial patterns of burn probably with/without historic fire exclusion and climate change (since 1980)

Burn probability and impacts suppression and recent climate change vary with location's aridity

Hanan EJ, Ren J, Tague CL, Kolden C, Bart R, Kennedy M, Abatzoglou J, Adam J (2020) How climate change and fire exclusion drive wildfire regimes at actionable scales. Environ.l Res Lett. https://doi.org/10.1088/1748-9326/abd78e

Our answers always are ‘it depends’……on

- the weather you get
- the soil
- when the fire occurs
- what species come back

How do we communicate this complexity?

Eco-hydrology Modeling for Integration

Many have advocated for using models for:

- eco-hydrology hypothesis testing
- behavioral modeling
- dialog between experimentalist and modelers
- placing new conceptual models into context

(Clark, et al., 2011, *WRR*; Schaefli, 2011, *HESS,*)

But we don't do this very often…
And when we do we mistrust results…
Why?

Barriers: Making use of Eco-hydrology Modeling for Integration

Black Box Model → **Deep dive into papers or model code** →

Is just to hard to know what complex models do

Review of models used to estimate how intentional changes in forest structure impact water cycle

\- model complexity +

Factor	No Recovery	Statistical Recovery	Physical-constant Recovery	Physical-dynamic Recovery
time: stand recovers through time	No	Yes	Yes	Yes
resources: availability of light, water, nutrients changes through time	No	No	No	Yes
canopy structure: stem density, age class	No	No	No	Yes
species composition: evolution through time	No	No	Yes	Yes
fire regime: change in fire regime through time	No	No	No	Yes
mortality risk: change in mortality risk through time	No	No	Yes	Yes
example	Statistical-Dynamical Ecohydrology Model	FVS	Biome-BGC	NA

Conclusion:
Diversity is HIGH;
Transparency LOW

Challenging to integrate new science (particularly on forest adaptation to climate change) into these tools

Niemeyer et al., in prep

Eco-hydrology Models: Revealing what is hidden

Example: Future Mountain interface for RHESSys
Ethan Turpin, David Gordon, & human-computer interface researchers.

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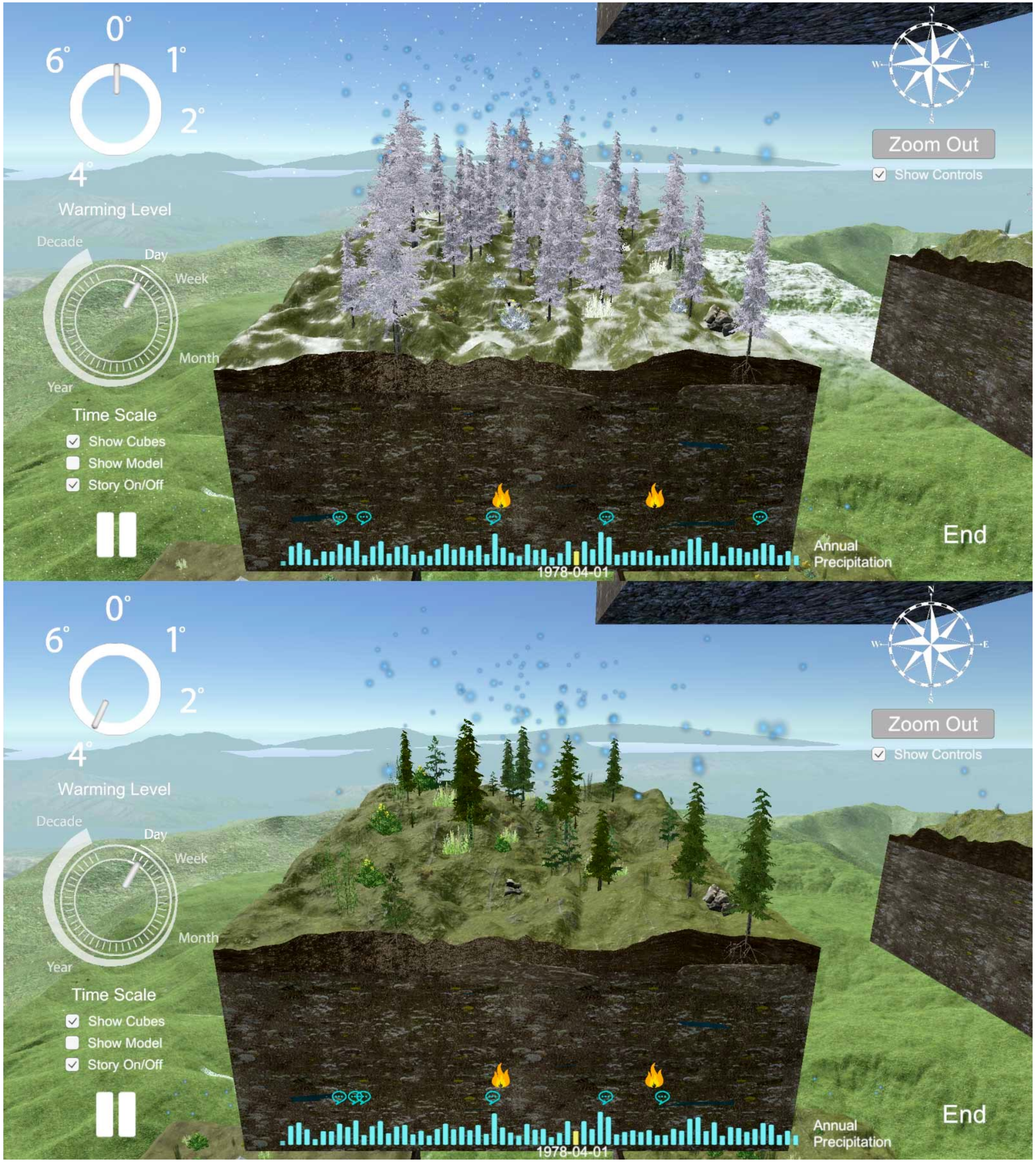


Cube Comparisons:

Simple warming impacts:
less snow

Wildland Art Show- Ethan Turpin

Search

WESTMONT RIDLEY-TREE MUSEUM *of* ART | VISIT | PROGRAMMING | GET INVOLVED | PEOPLE | STORE | PERMANENT COLLECTION | WESTMONT HOME

WILDLAND: Ethan Turpin's Collaborations on Fire and Water

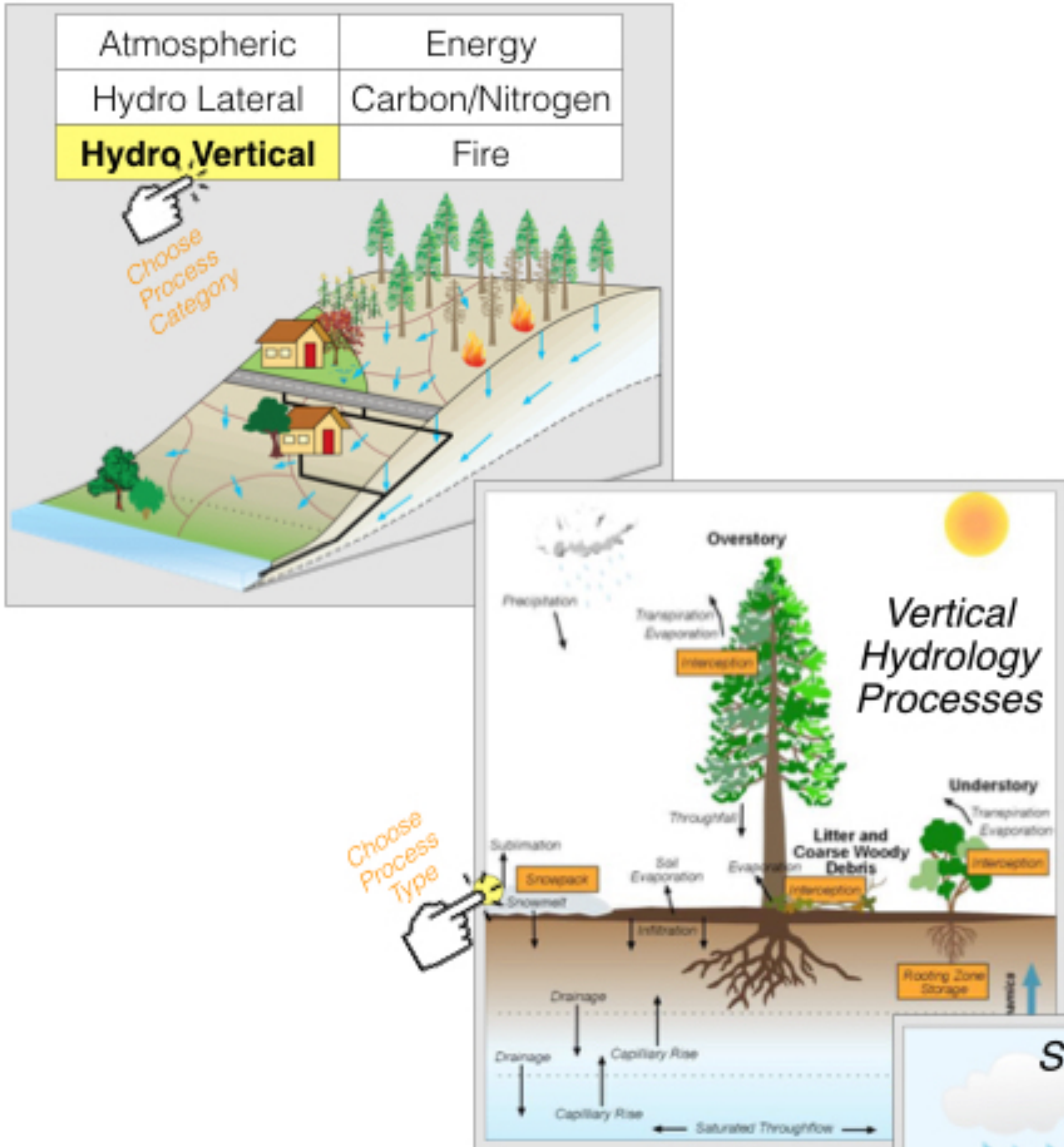
Artist & Collaborator Lecture

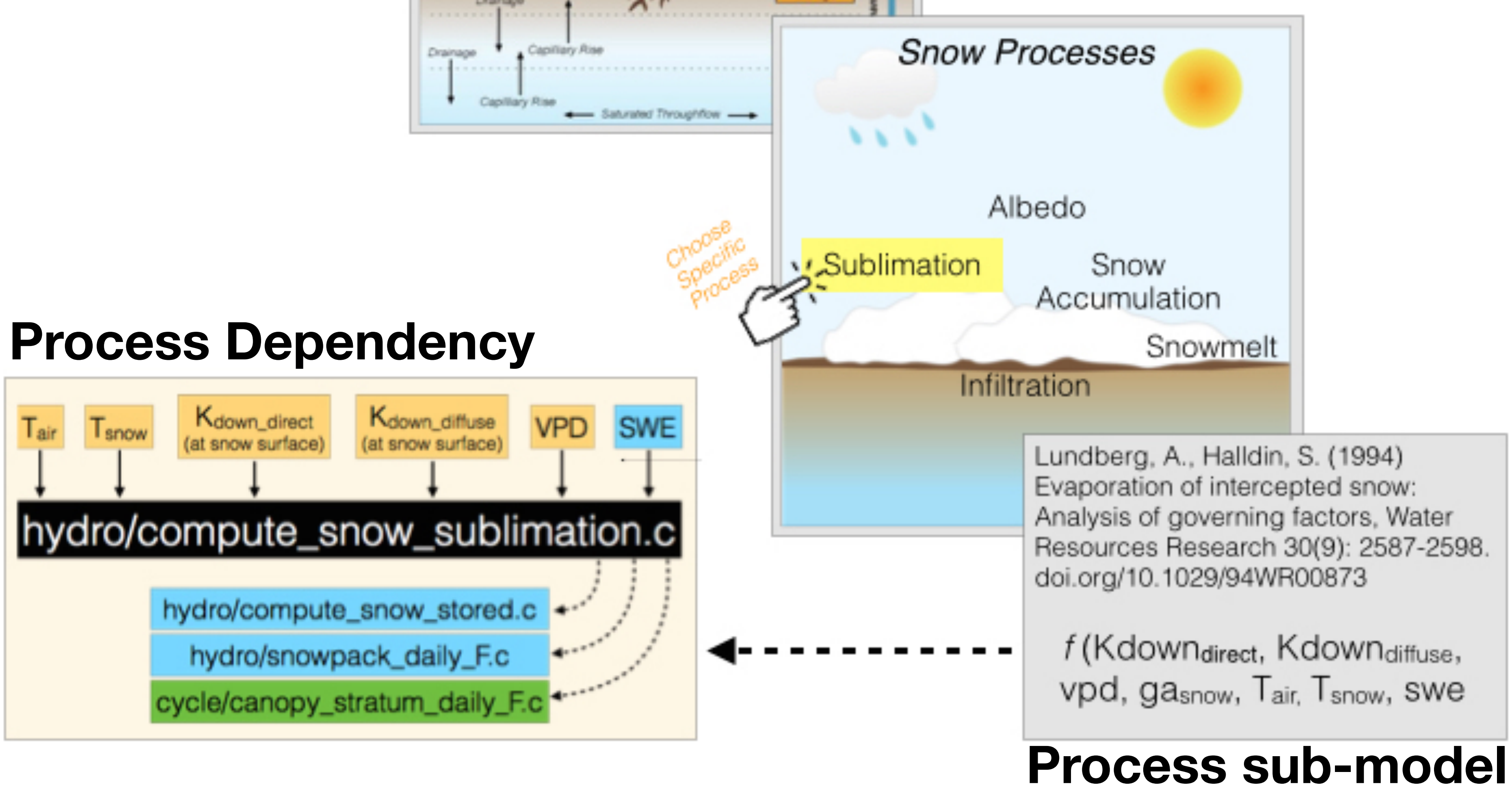
When: January 30, 2025 at 5:30pm
Where: Porter Theatre, Westmont College

Ethan Turpin and Naomi Tague will present a lecture on their collaborations for *WILDLAND*. Naomi Tague is a researcher and professor of ecology at the University of California, Santa Barbara's Bren School of Environmental Science & Management. Join us for "Beyond Data Visualization: Art-Science Collaboration in an Era of Global Environmental Change."

Model Documentation that is:

- Searchable
- Graphical
- Automatically Generated
- Explorable..





the tague team lab
ECOHYDROLOGY+INFORMATICS

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NSF

CZNet
Critical Zone Network

National Science Foundation: US-Israel Binational Science Foundation