

Connections between groundwater flow and transpiration partitioning

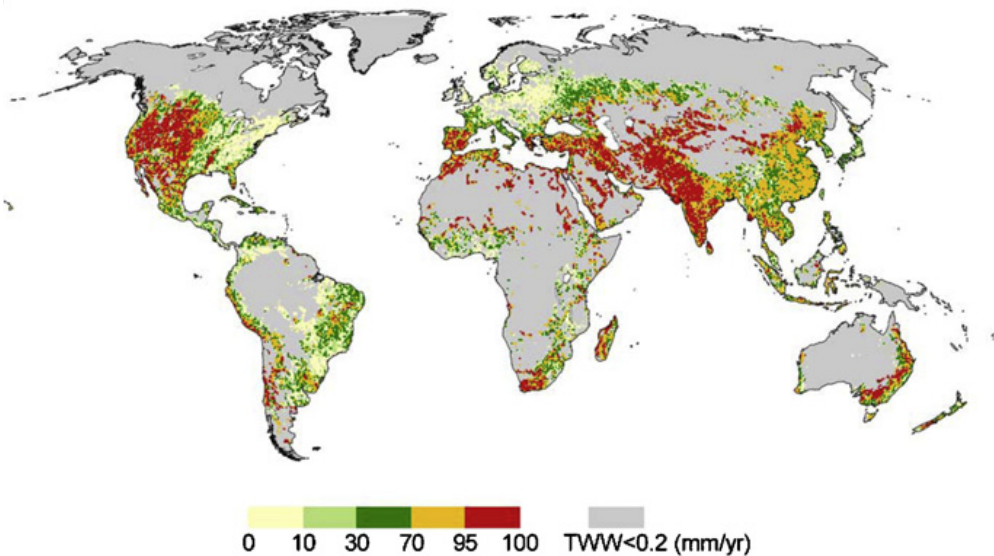
Impact of Groundwater in Earth System Models
Paris, October 2016



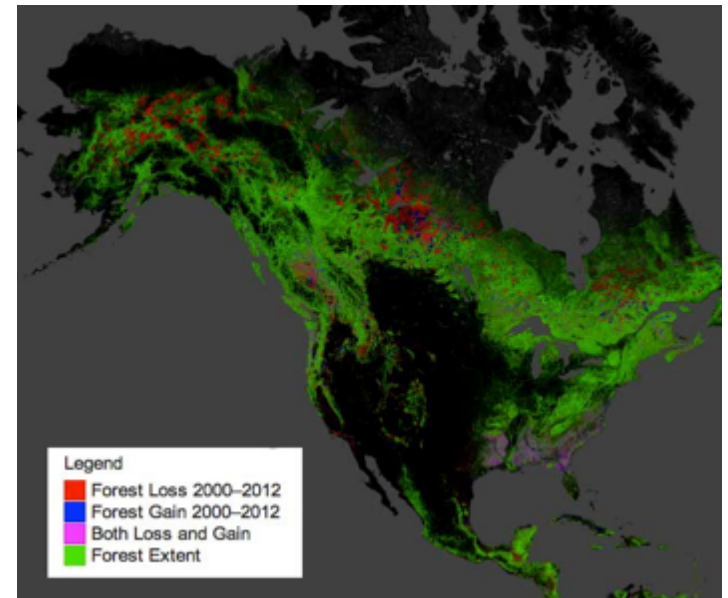
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Colorado School of Mines
Laura Condon
Syracuse University



To address global hydrologic responses to stress we need integrated tools that can evaluate managed and natural systems



Döll *et al* JoG (2012)



Hansen *et al* Science (2013)

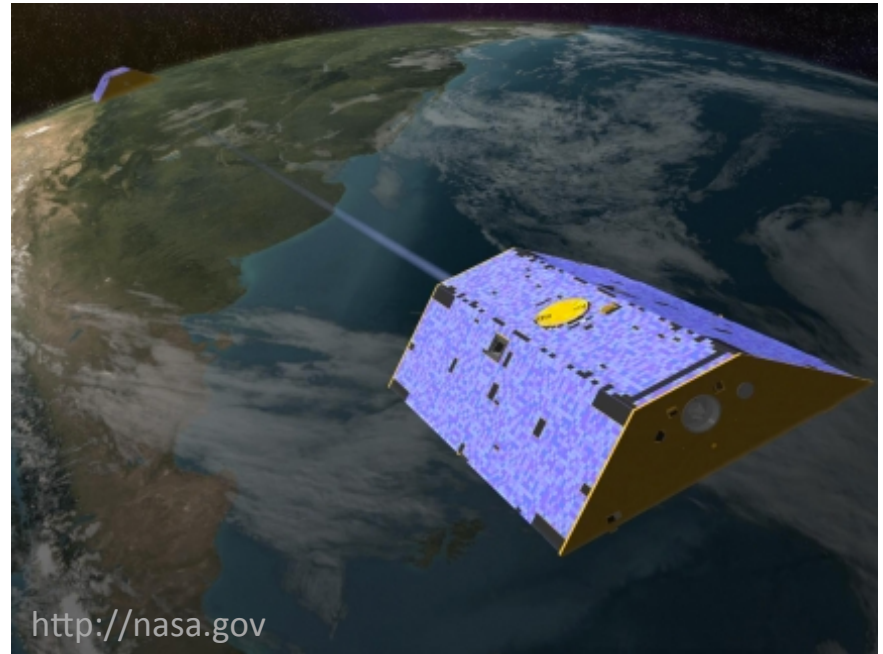
Observations are valuable but don't tell the whole story

Local measurements are difficult to scale



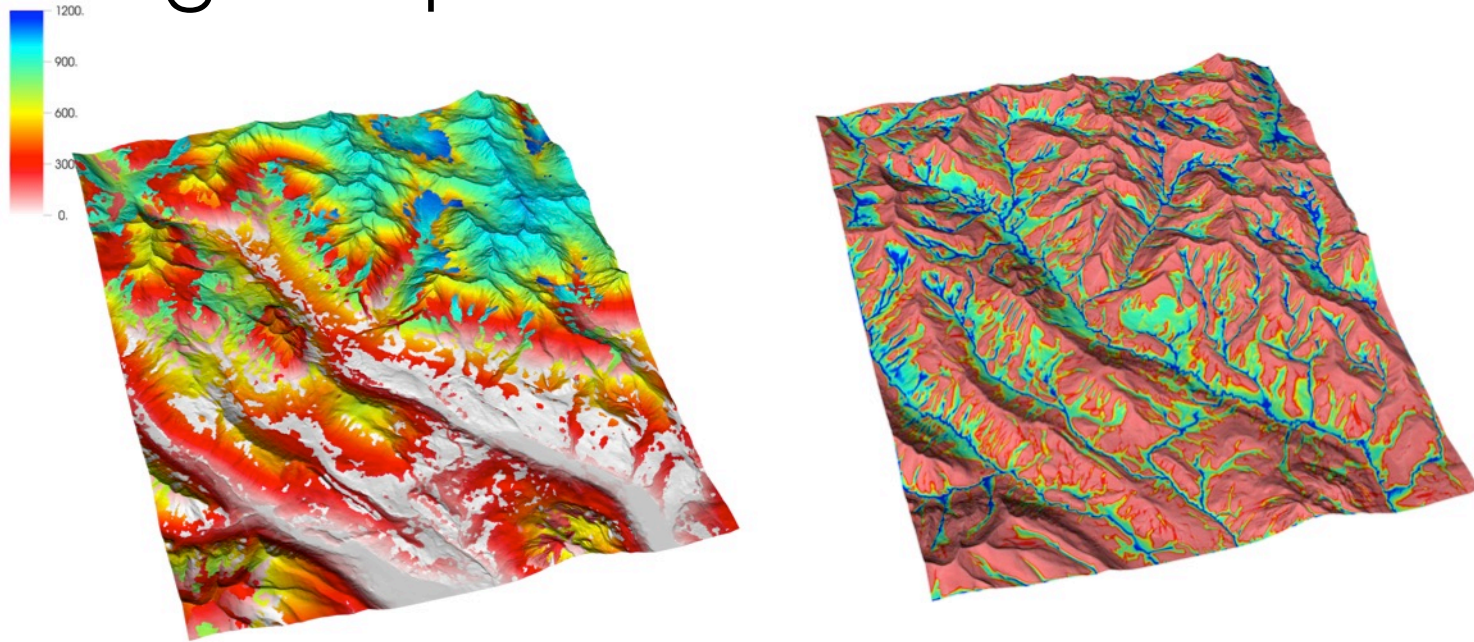
<http://triplelandfarms.com/>

Remote sensing can't see everything



<http://nasa.gov>

High-resolution modeling of groundwater-land surface-atmosphere feedbacks is a **valuable tool** to help understand and predict hydrologic response.

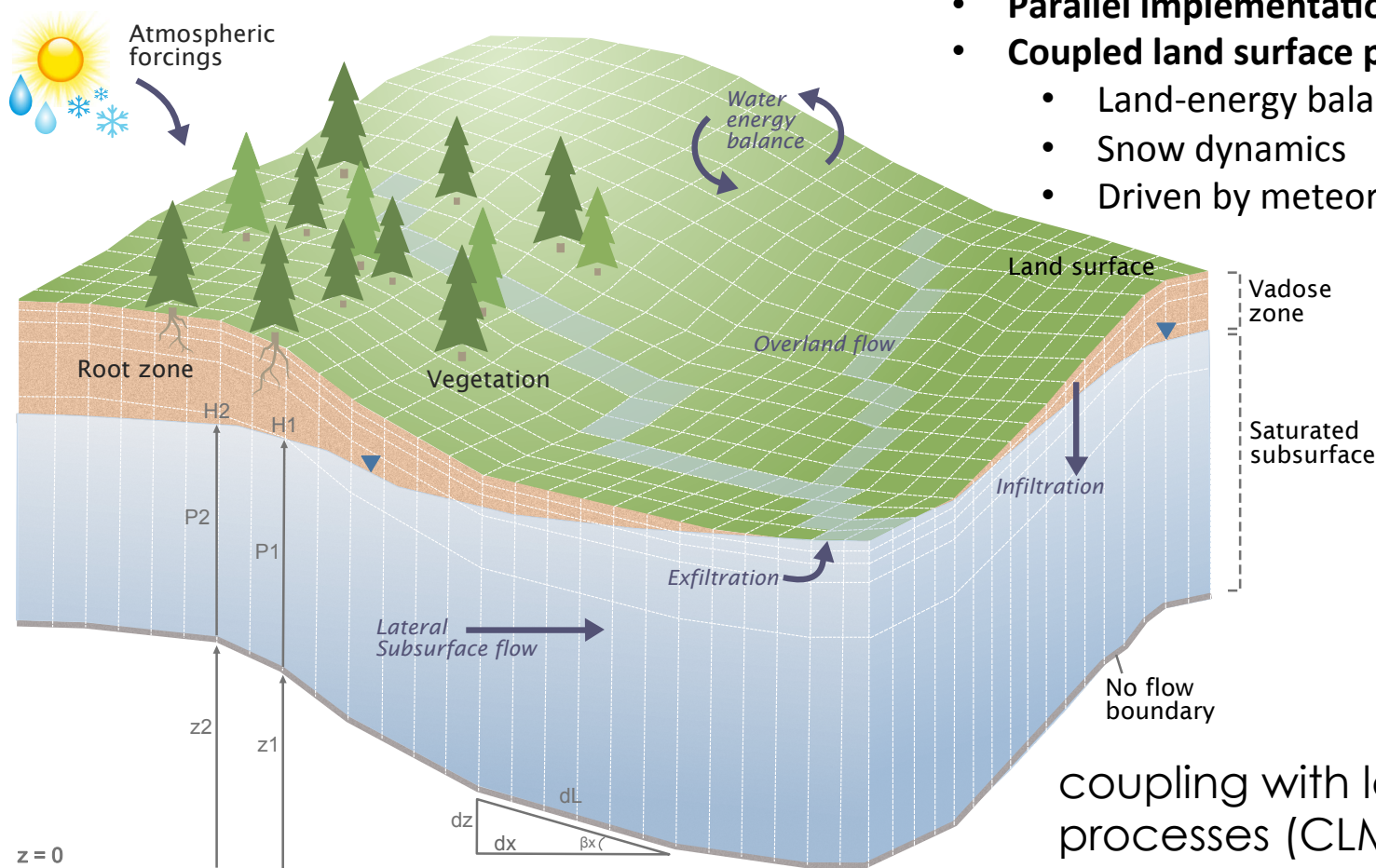


East River CO @10m resolution, SWE and subsurface pressure

Feedbacks between ground- and surface-water dynamics, vegetation processes, and the atmospheric boundary layer significantly affect local and regional climate across a **range of scales** and climatic conditions.

We use the integrated hydrologic model ParFlow which is a tool for computational hydrology

- Variably saturated groundwater flow
- Fully integrated surface water
- **Parallel implementation**
- **Coupled land surface processes**
 - Land-energy balance
 - Snow dynamics
 - Driven by meteorology

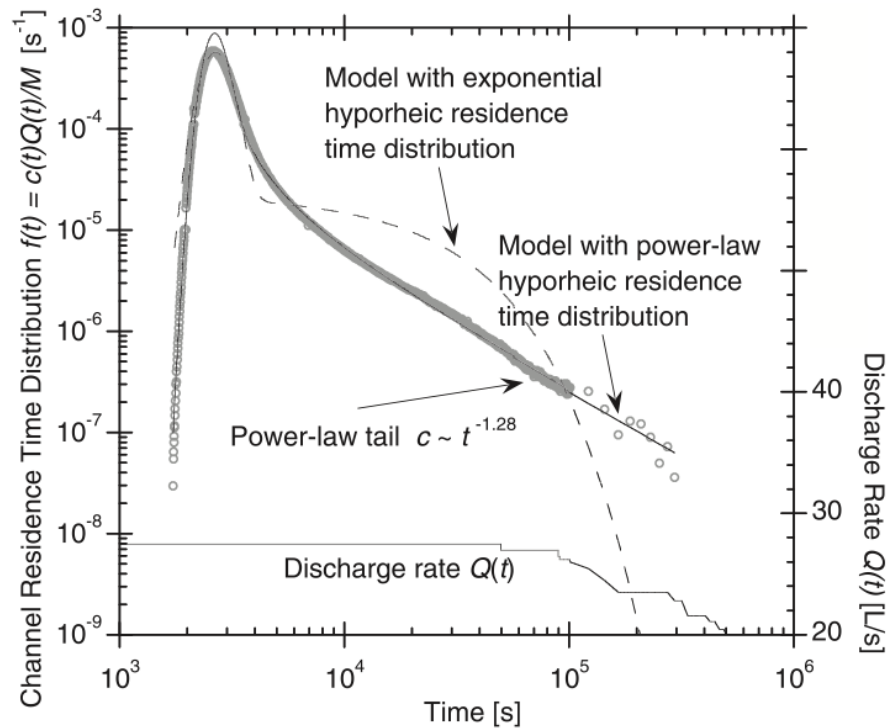


coupling with land surface processes (CLM) allows for simulation of interactions and connections

Maxwell (2013); Kollet and Maxwell (2008); Kollet and Maxwell (2006); Maxwell and Miller (2005); Dai et al. (2003); Jones and Woodward (2001); Ashby and Falgout (1996)

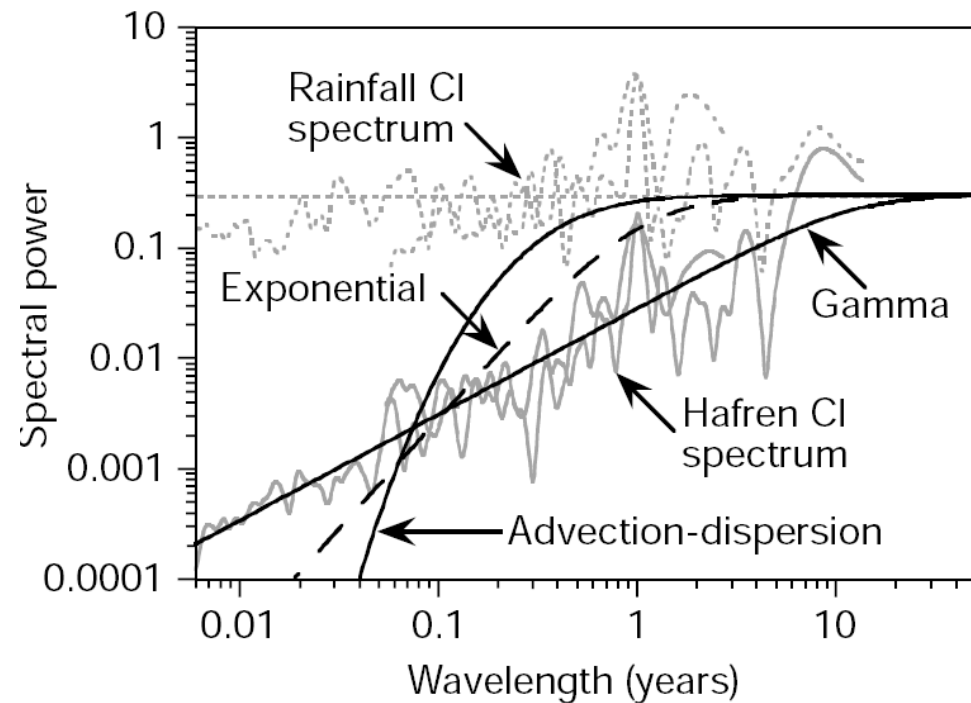
Groundwater's complications often underappreciated

- Range of paths and scales in groundwater
- Water moves as $K/\theta \sim 10^{-4}$ - 10^{-5} m/s
- Pressure propagates as $Kb/S_s \sim 10^0$ - 10^1 m/s
- System responds over a **wide range of scales** (e.g. Kirchner et al 2000, 2001; Alley et al 2002; Haggerty et al 2002; Wörman et al 2007; Cardenas 2007; Kollet and Maxwell 2008; Maxwell et al 2016)
- Topography and land surface processes have strong influence



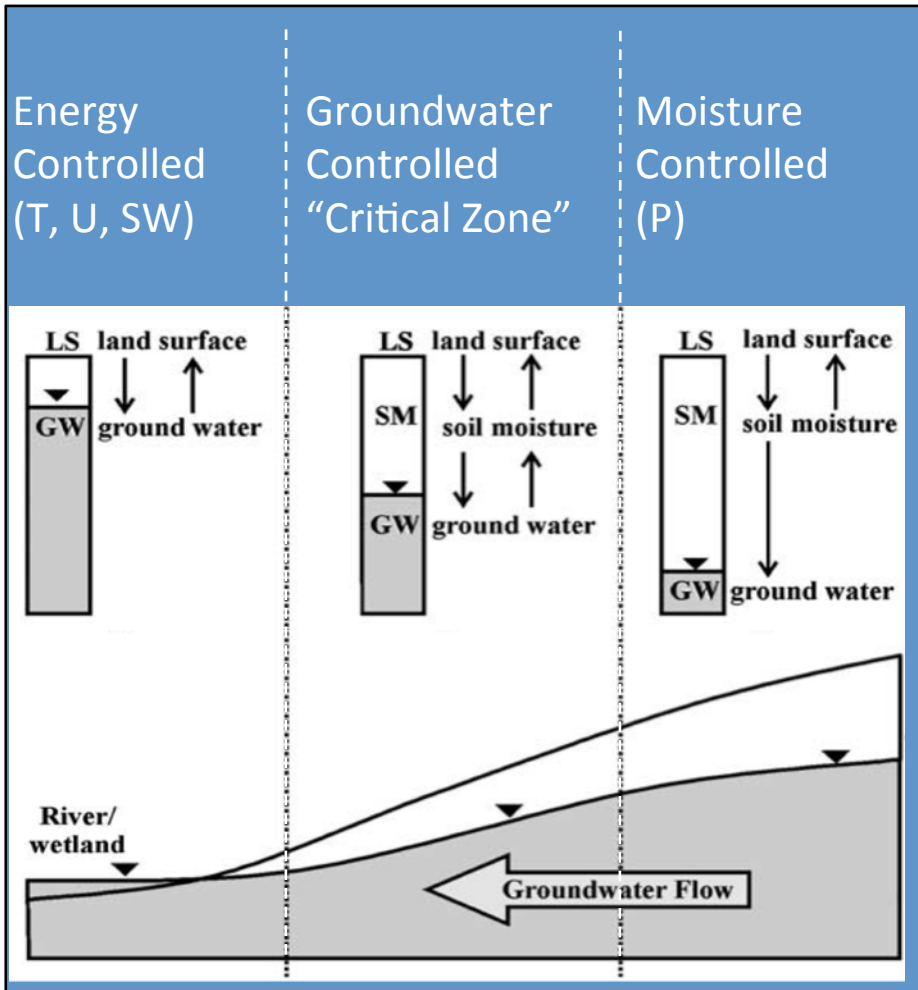
Haggerty et al (2002)

Observations

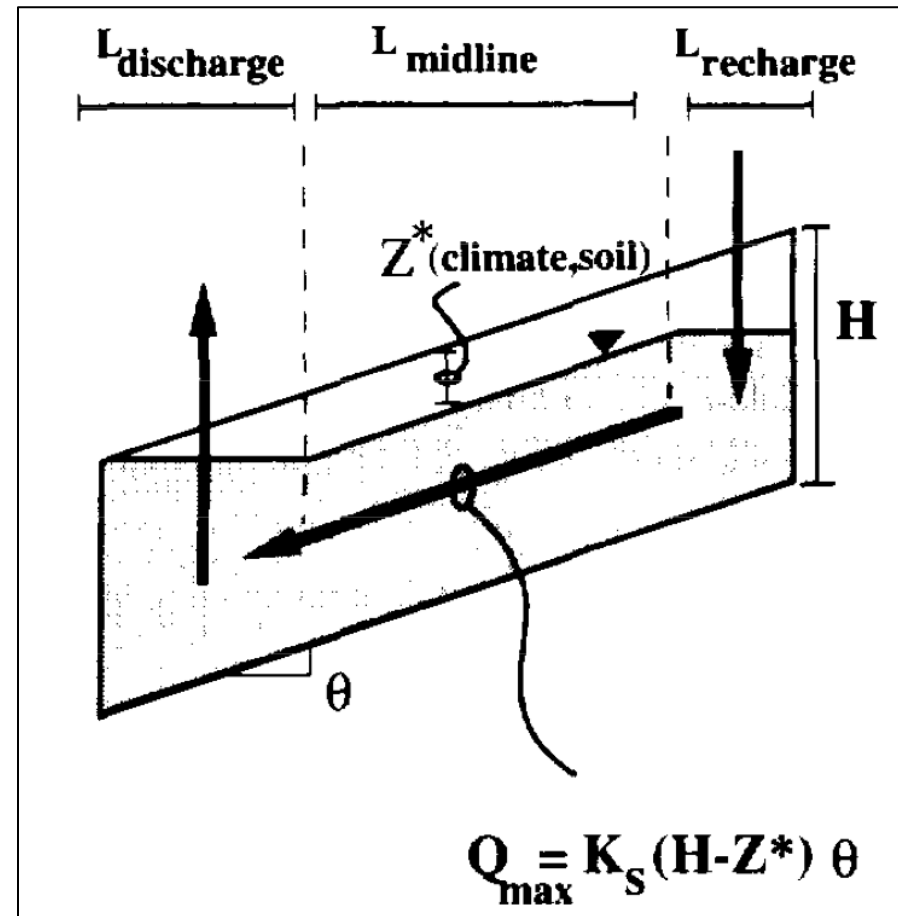


Kirchner et al (2000)

There is theory on how groundwater depth affects land energy fluxes

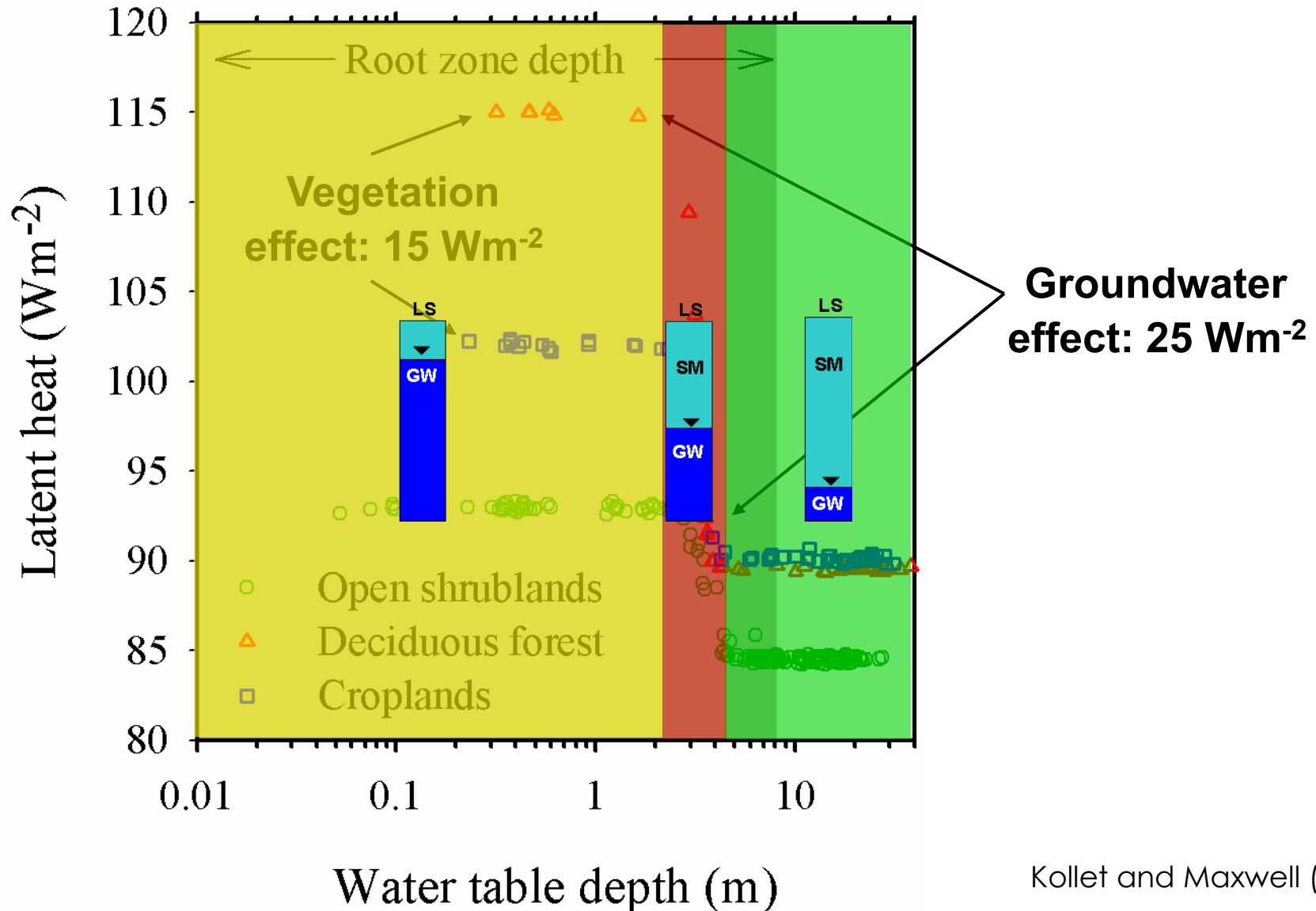


Kollet and Maxwell WRR (2008)

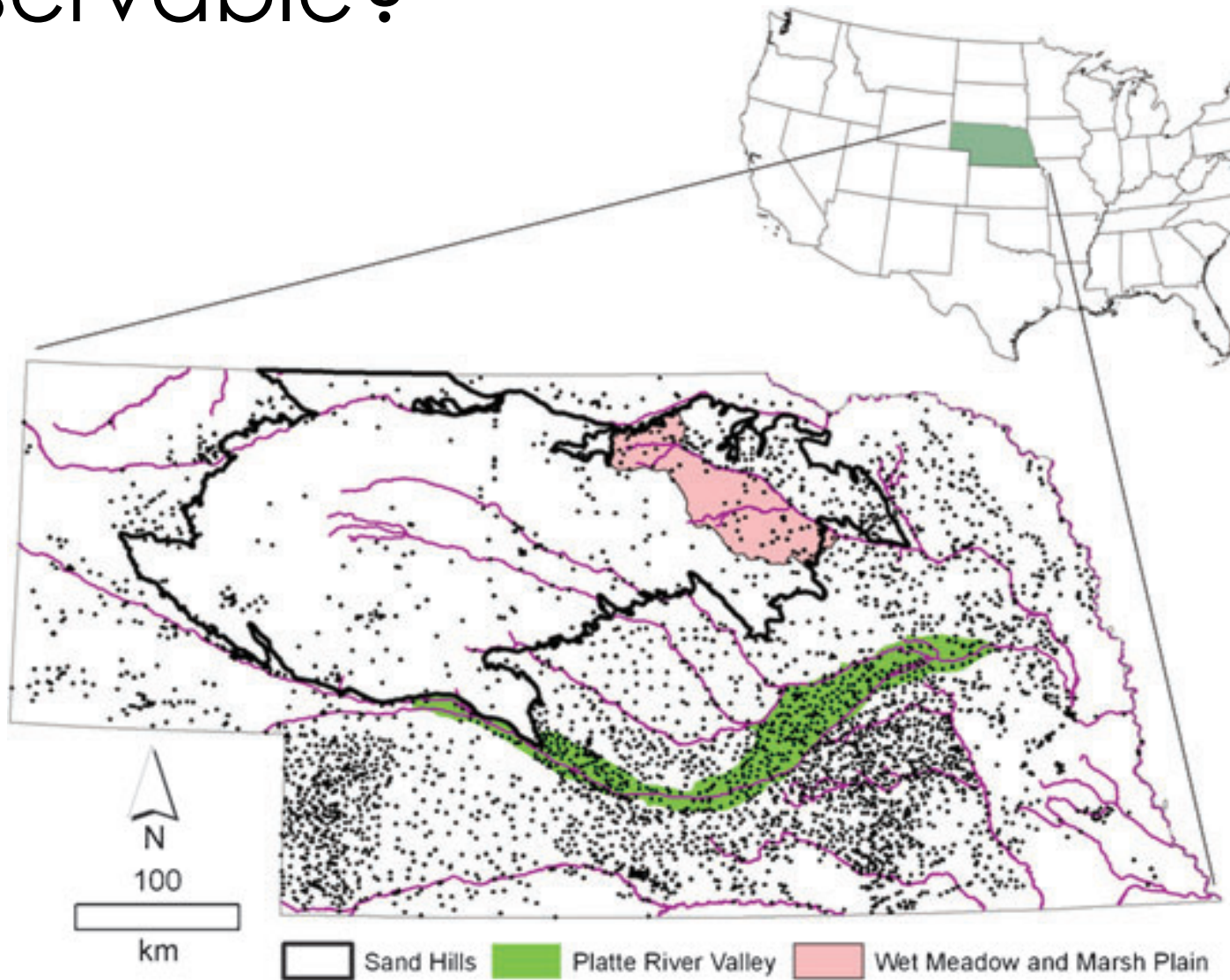


Salvucci and Entekhabi (1995)

Water table depth may influence land energy fluxes over three distinct regions



Are these relationships observable?



Observations of critical depth range agree with models

Szilagyi et al *Groundwater* 2013

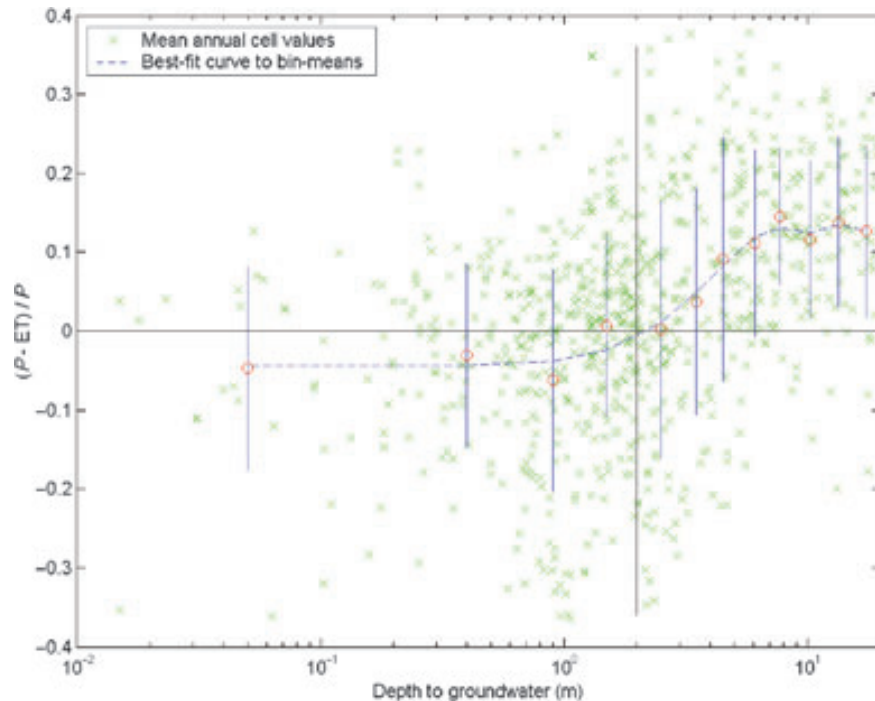
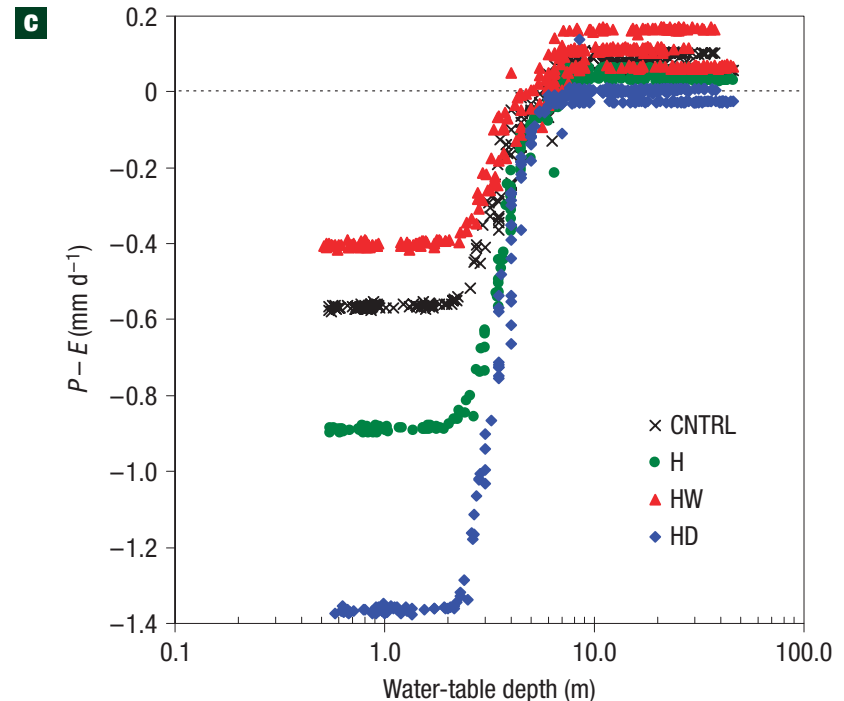


Figure 6. Mean annual $(P - ET)/P$ ratios vs. depth to groundwater (from Figure 5c) for the Platte River Valley in Nebraska. The length of each whisker denotes the standard deviation of the binned data around the bin mean (circle). Total number of data points is 1169. See Table 1 for the coefficients of the fifth-order best-fit polynomial to bin means.

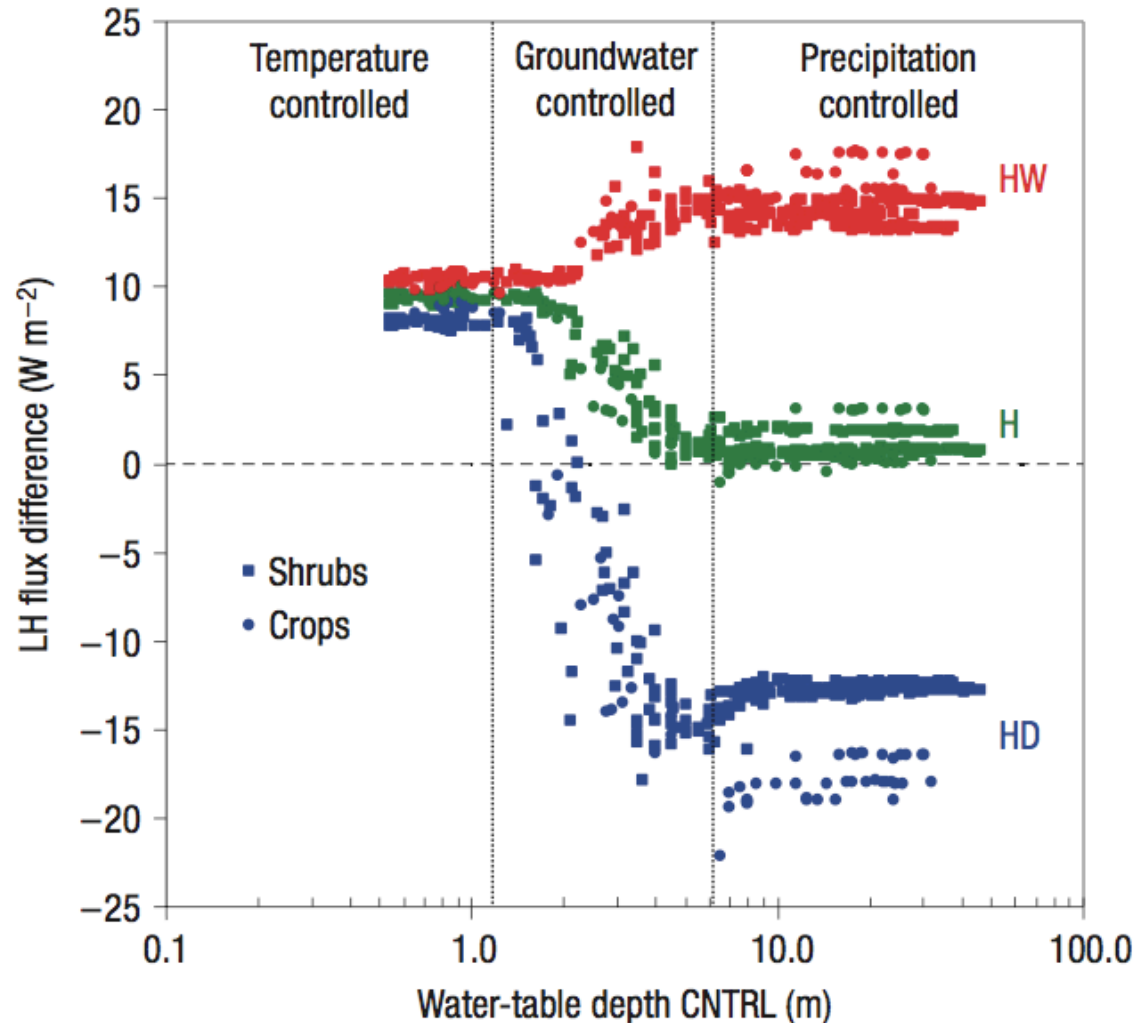
Maxwell and Kollet *NatGeo* 2012



“Two saturation depth values (above or below net recharge becomes independent of the depth to the groundwater) were obtained, 1 (± 1) m and 7 to 8 (± 1) m, the latter saturation depth being almost identical to the modeled value of Maxwell and Kollet (2008)”

We see that groundwater depth affects energy fluxes and moderates climate change impacts

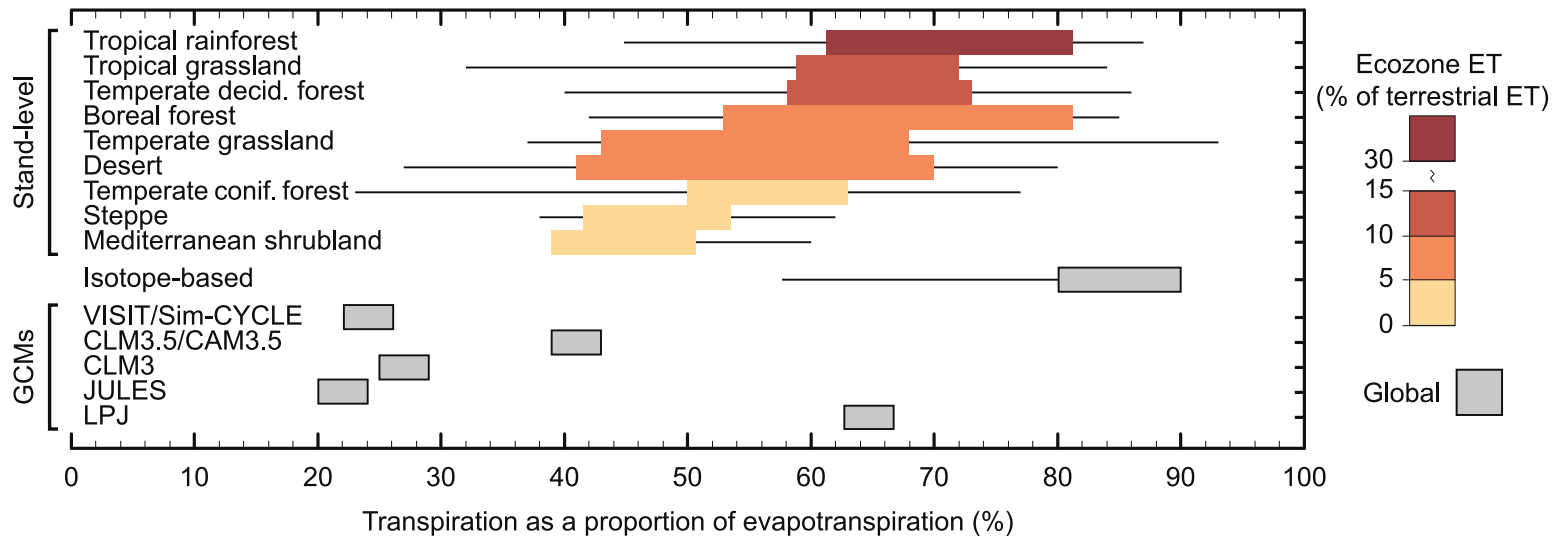
- Same increase in ET in convergent zones
- When WT disconnects precipitation runs the show



Maxwell and Kollet *NatureGeo* (2008)

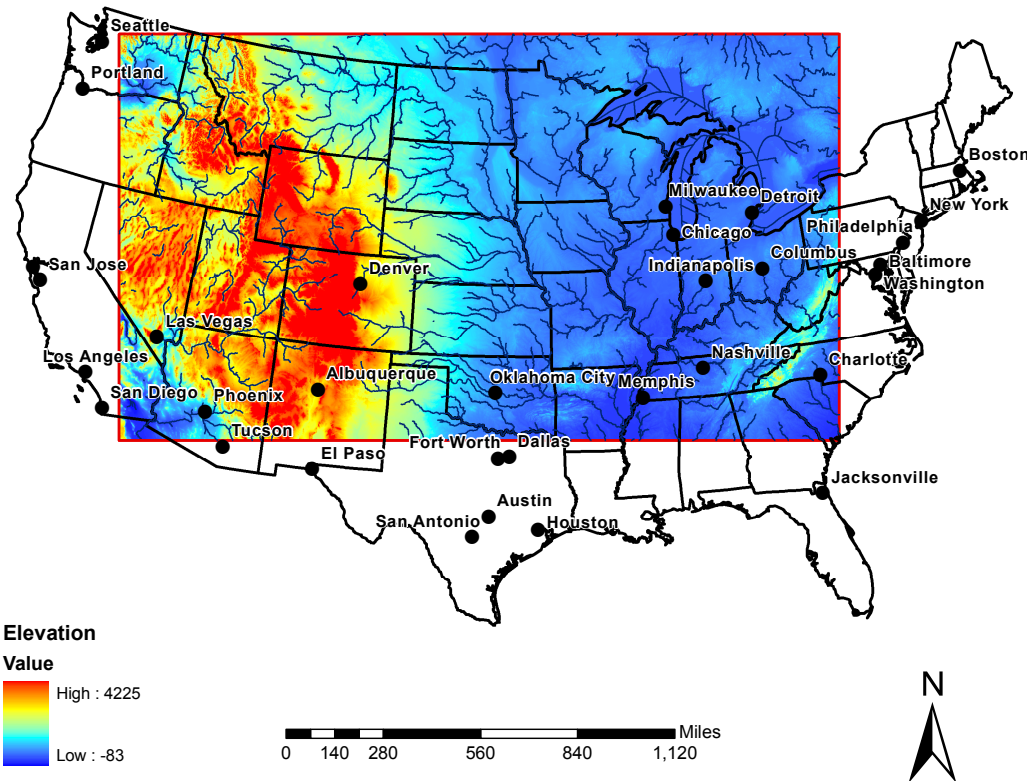
Estimating transpiration partitioning globally is an important challenge

- ET is largest terrestrial water flux
- Estimates of T/ET range around 62% (Good *et al* 2015; Coenders-Gerrits *et al* 2014; Jasechko *et al* 2013) yet models are challenged by representing this



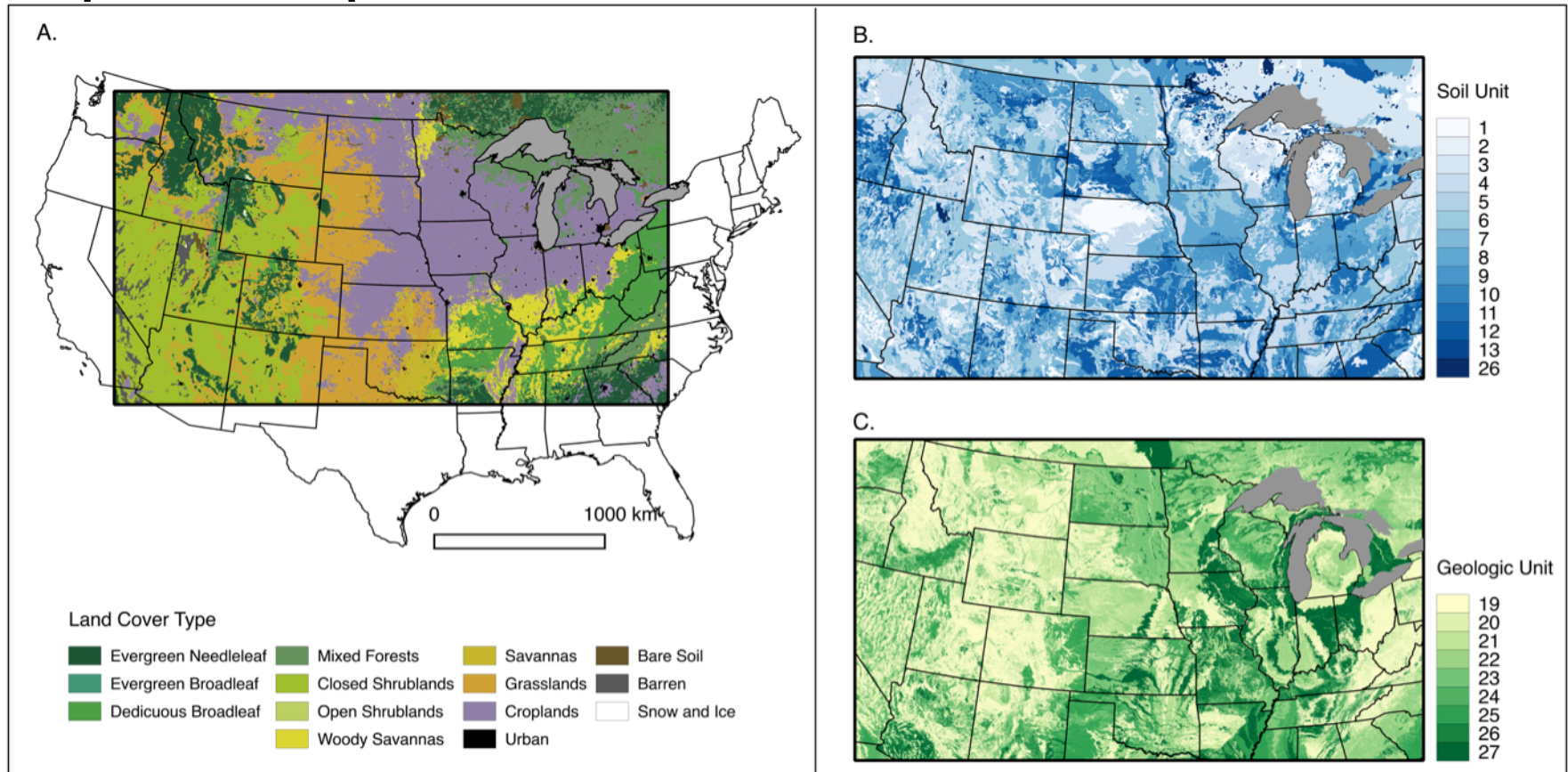
Schlesinger and Jasechko (2014)

We have built a *proof-of-concept*, 6.3M km² domain covering much of the CONUS



- 1 km lateral resolution
- .1 – 100m vertical resolution over 102m depth
- ~32M unknowns
- The Miss and CO watersheds
- *Fully integrated, 3D Richards' EQ, Shallow Water Equations, Land Surface Processes*

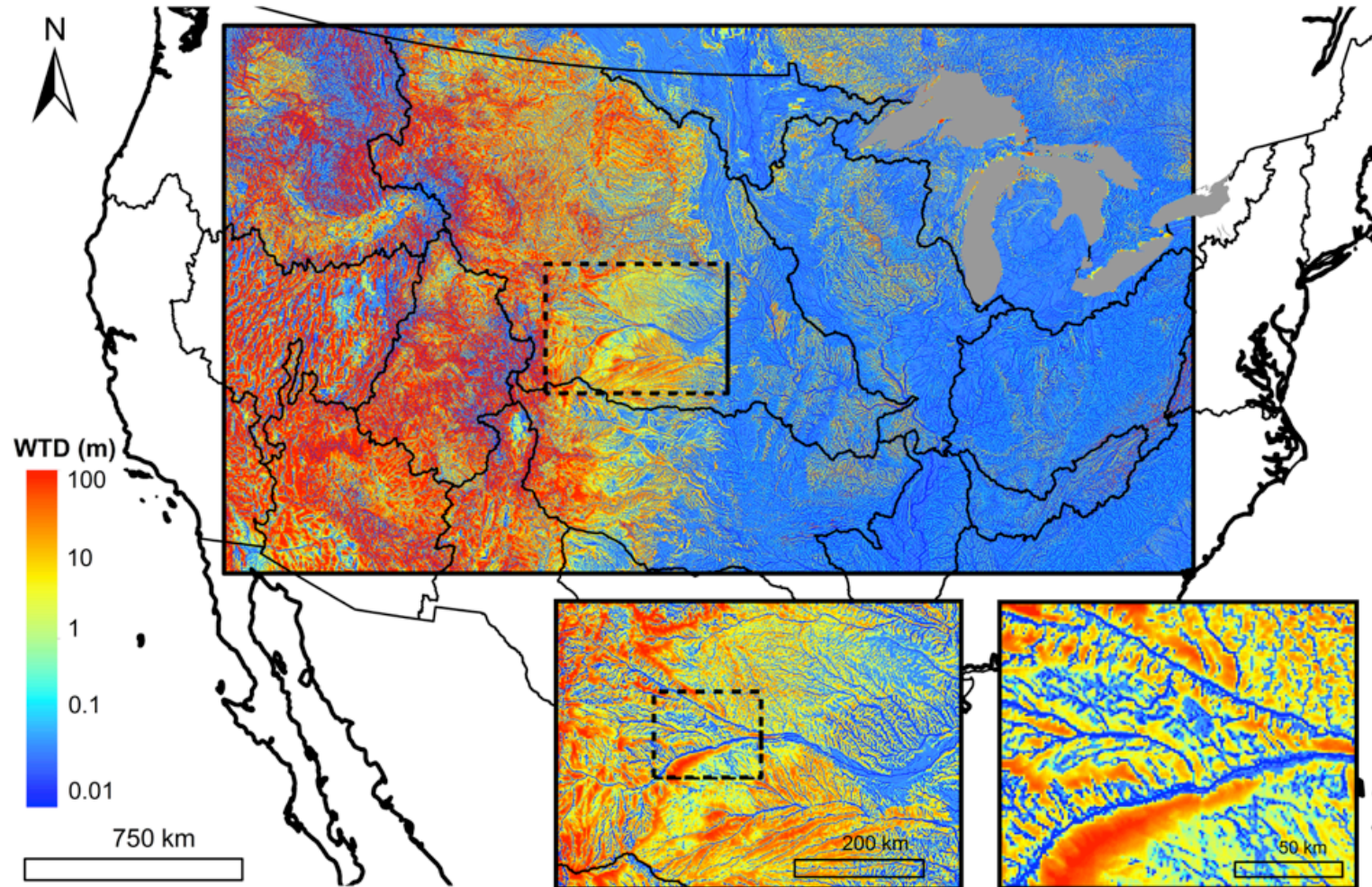
The domain is constructed and spun up from available datasets



- Topography, soil properties and hydraulic conductivity from USGS HydroShed, Gleeson *et al.* (GRL 2011) and Statsgo
- **Steady-state and represents pre-development conditions**

A steady-state solution was used to initialize a fully-transient, fully-coupled integrated simulation

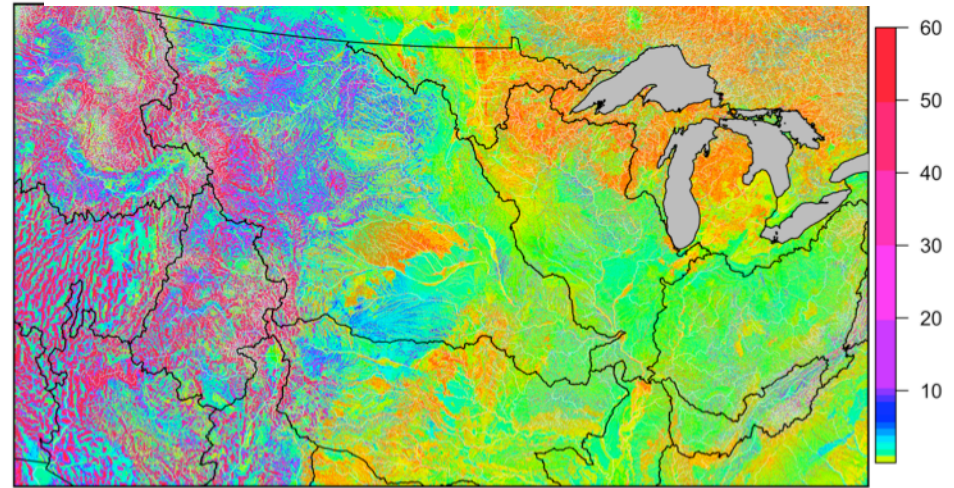
We used the results from Maxwell et al **GMD** (2015) to initialize a fully transient simulation.



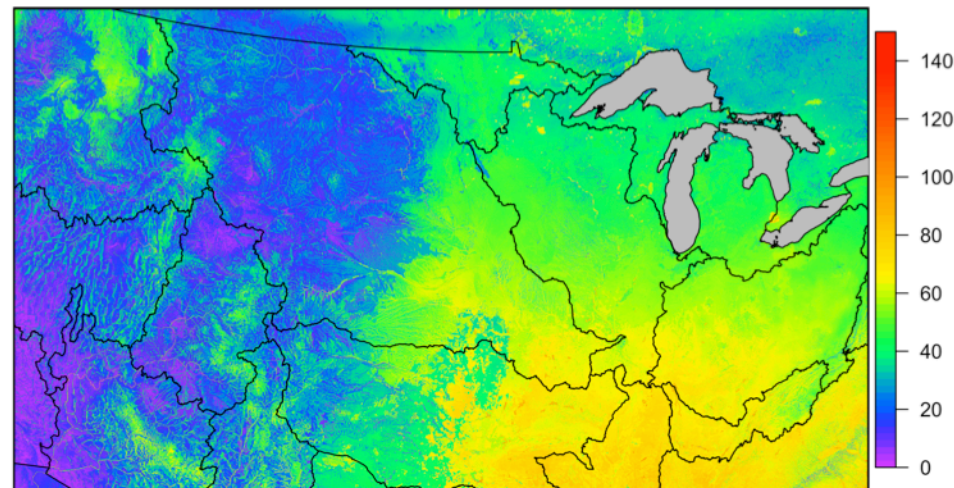
A transient, PF-CLM simulation is first of it's kind, proof of concept

- Driven by hourly forcing (NLDAS-II)
- WY1985 (Oct 1, 84 – Sep 30, 85)
- 450K core hours on Yellowstone
- 1 week of wall clock on 2,304 processors
- 12TB of model output, 3TB of input
- **>1.3 trillion outputs**
- **Represents pre-development conditions, no model calibration**

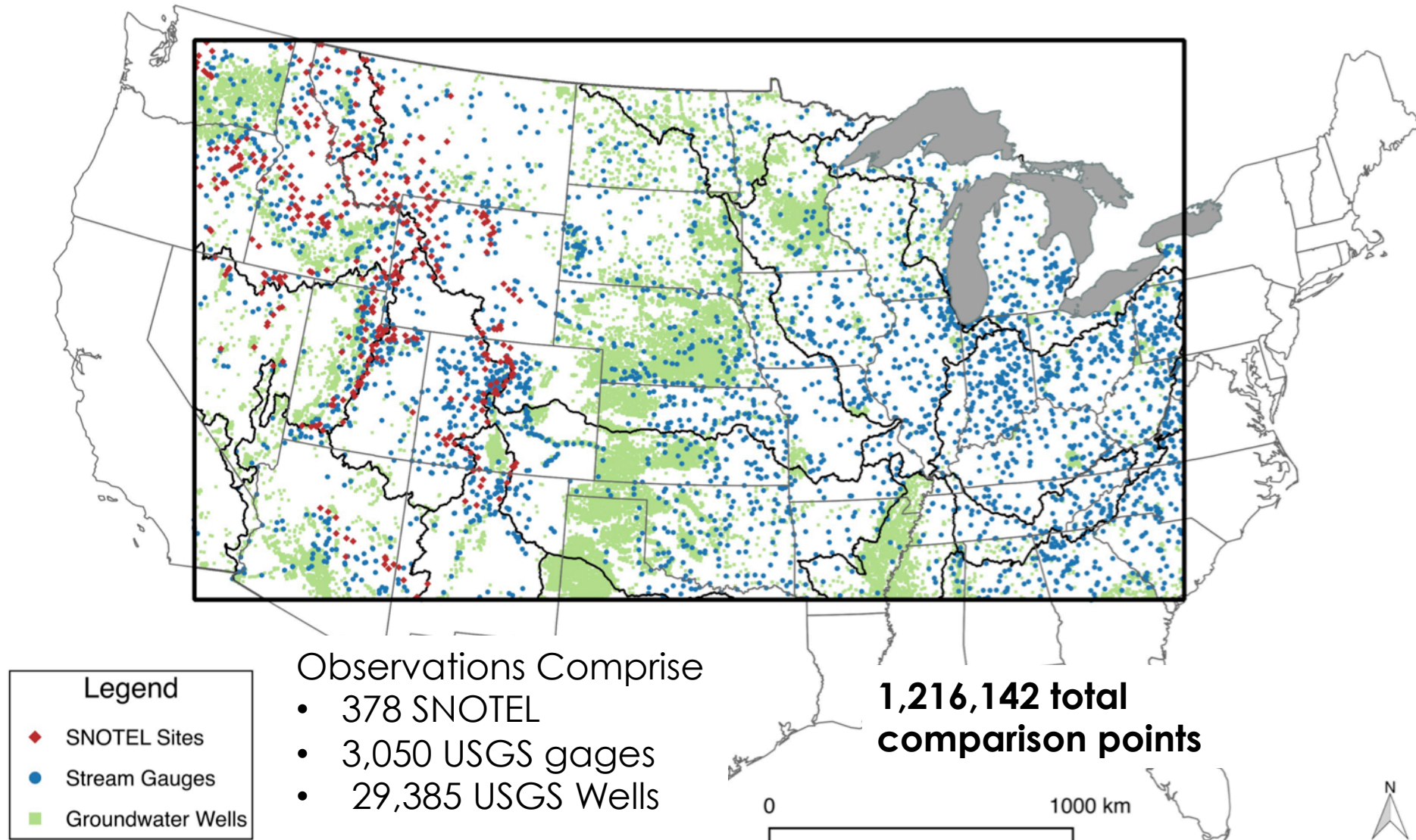
Annually-averaged WT depth [m]



Annually-averaged LH Flux [W/m^2]



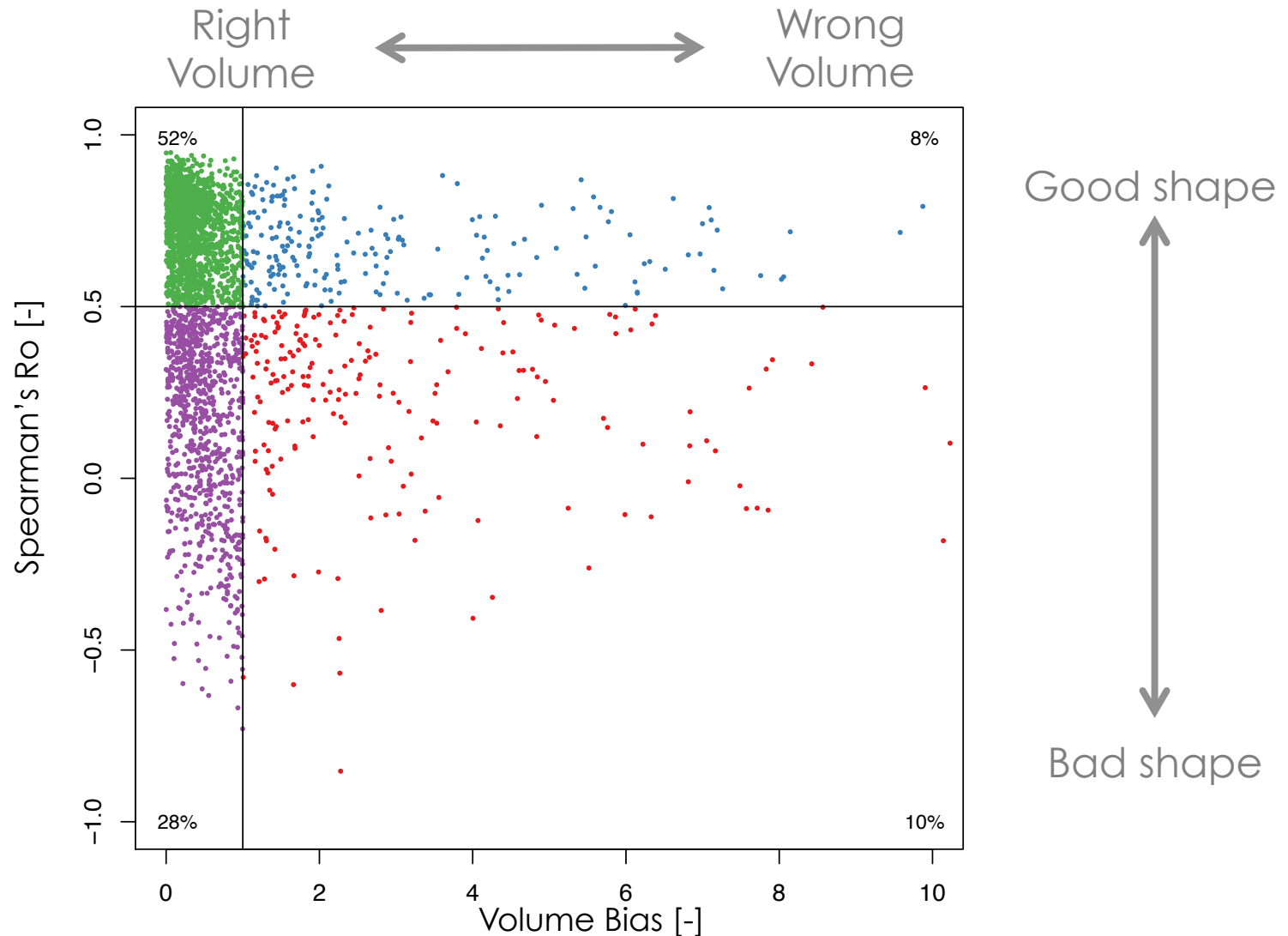
Validation of huge simulations is a challenge and attribution of bias and error is important



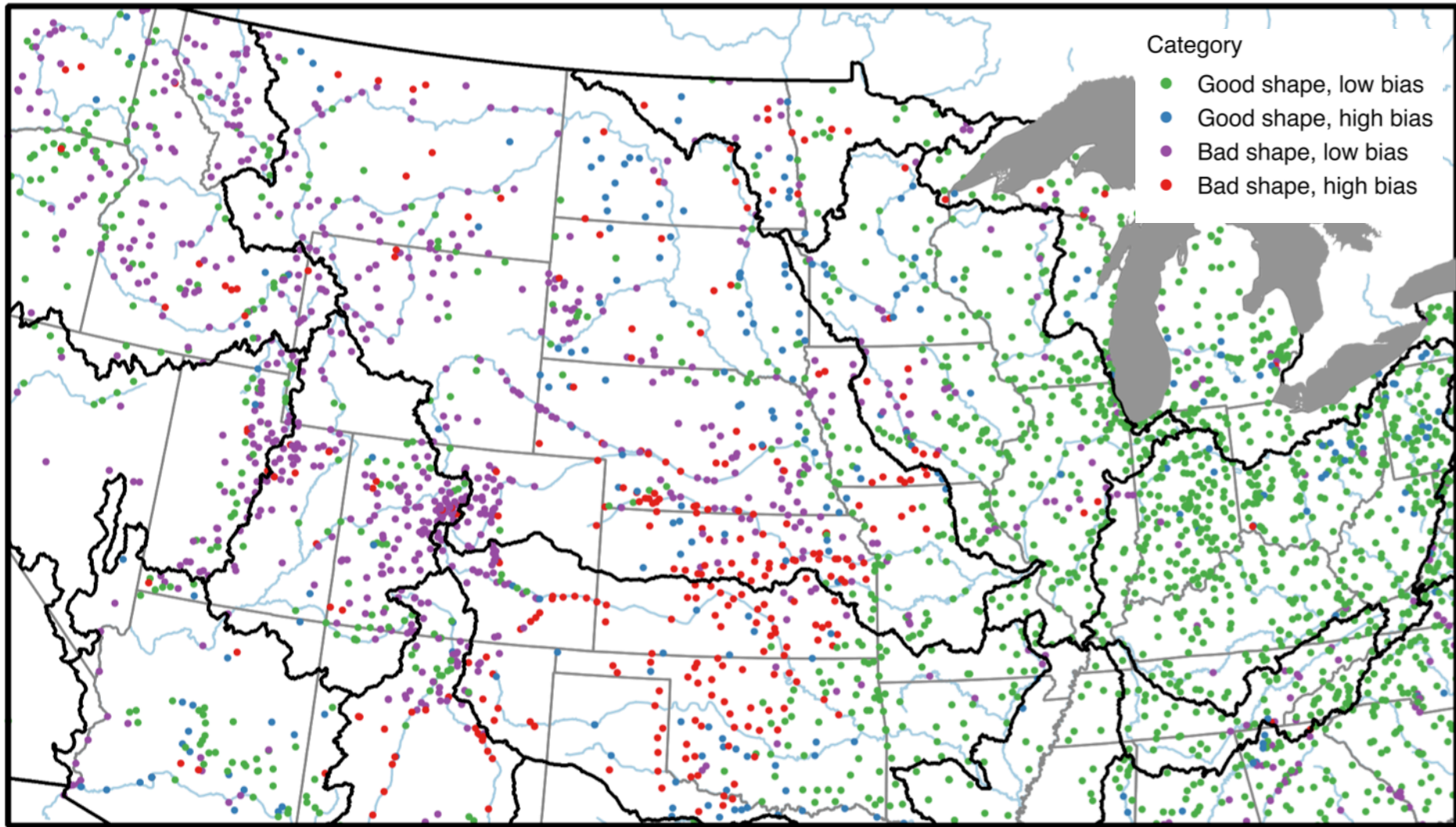
In addition to model physics there are many sources of bias

	Meteorological Forcings	Scenario / Water Management	Topography/ grid resolution	Model Parameters
<i>Streamflow Timing and Volume</i>	Temperature and precipitation bias	Reservoirs, groundwater development	DEM resolution and stream network differences	Manning's n
<i>Groundwater Depth</i>	Bias in spinup forcings	Groundwater development	DEM resolution and RE at coarse resolution	Conductivity, lack of confining units, lower boundary condition
<i>Snow Water Equivalent</i>	Bias in NLDAS precipitation and temperature	Human disturbance	DEM resolution	Albedo, LAI

We use a range of metrics for streamflow comparison to better attribute sources of bias

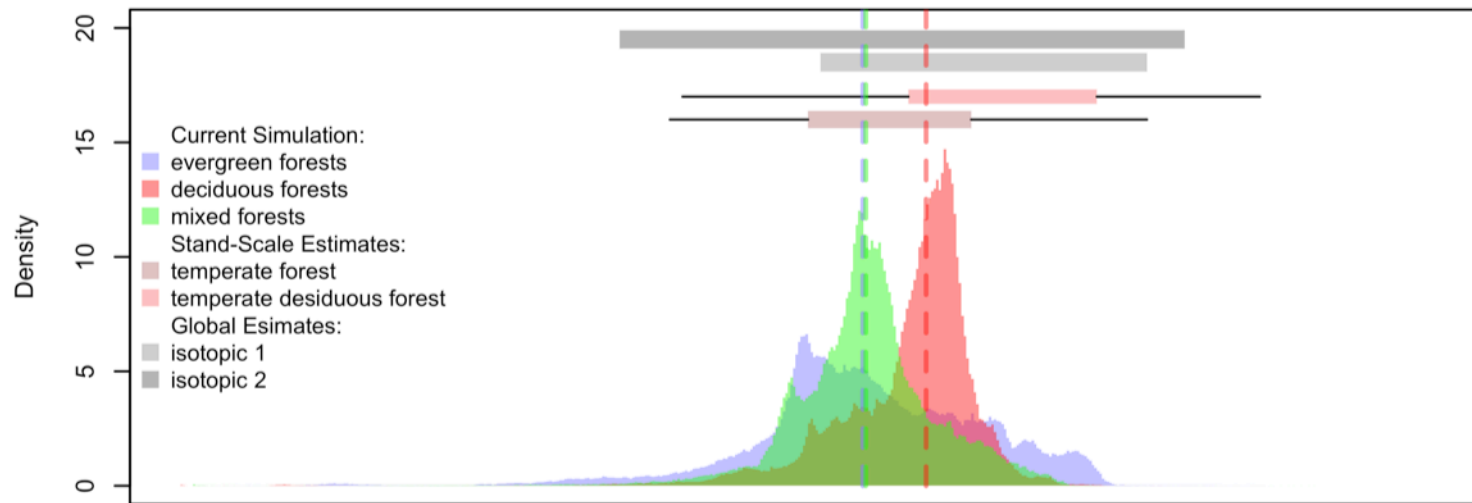


Flow results are incredibly promising

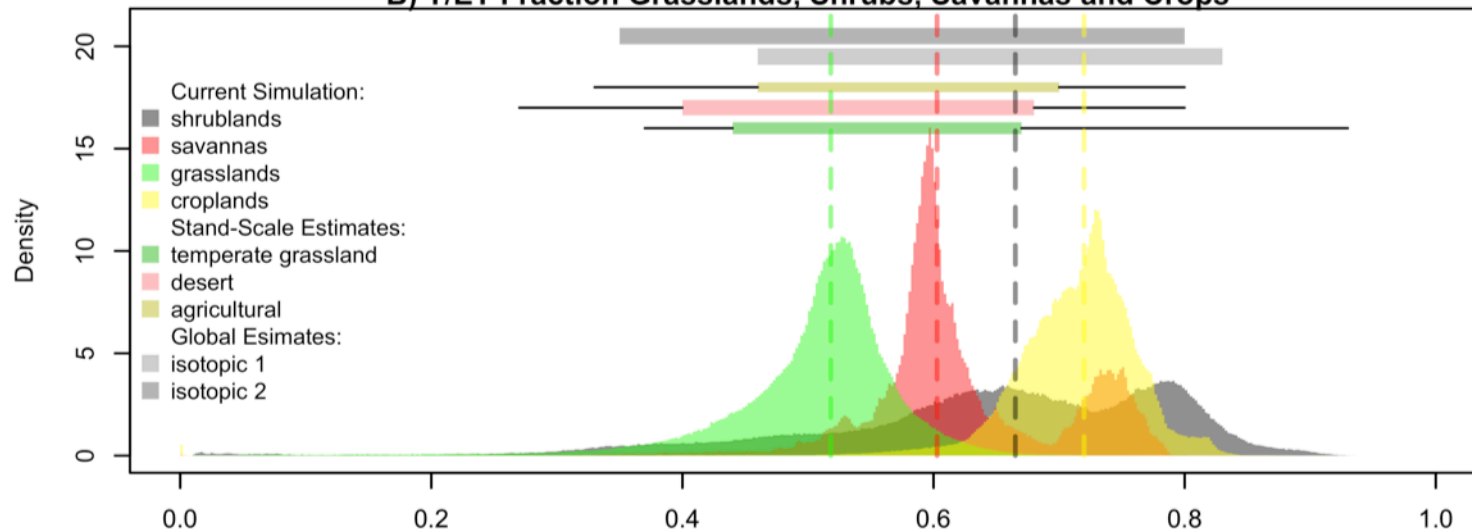


These results reconcile model, stand and global scale ET partitioning

A) T/ET Fraction Forests



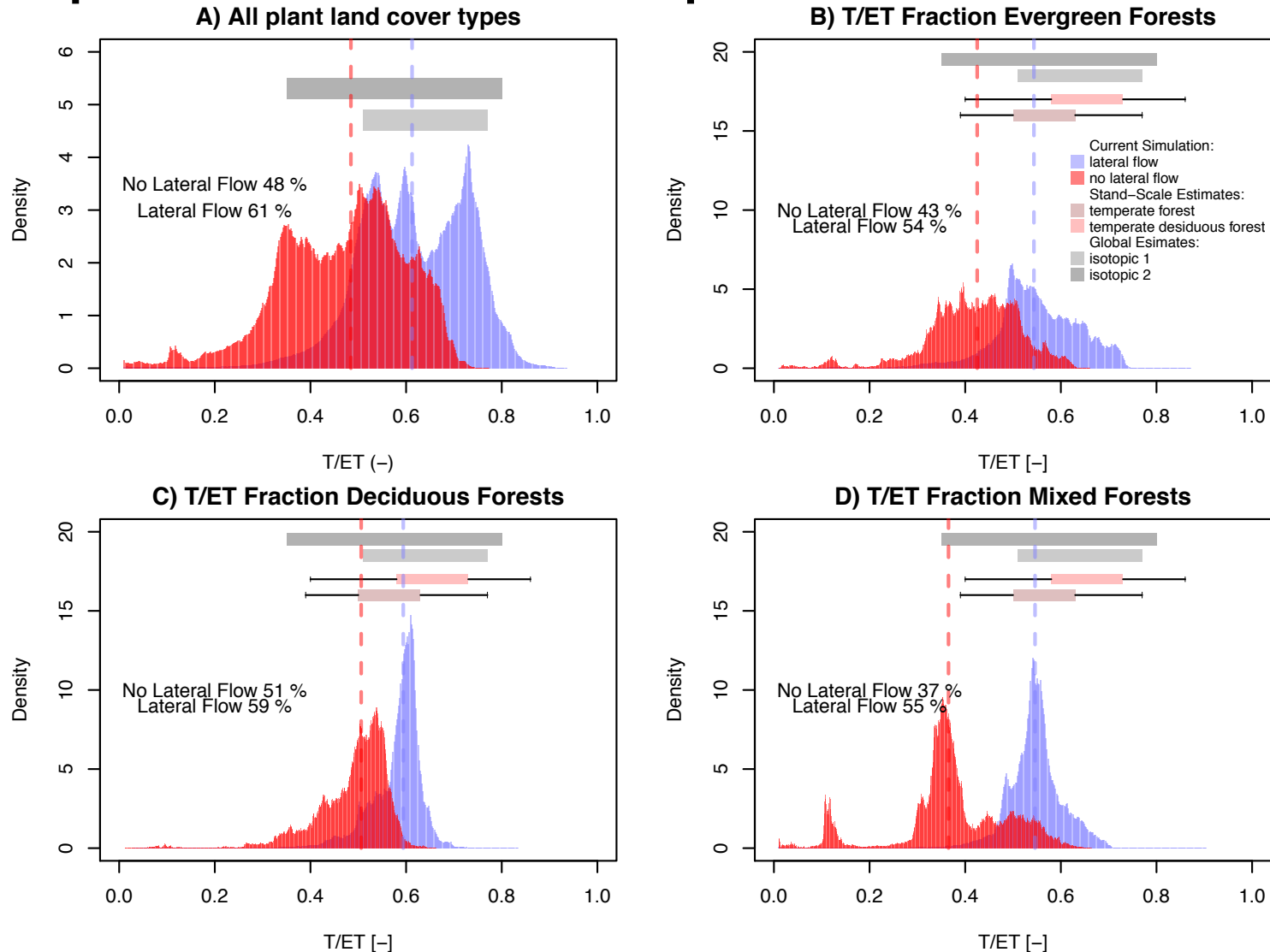
B) T/ET Fraction Grasslands, Shrubs, Savannas and Crops



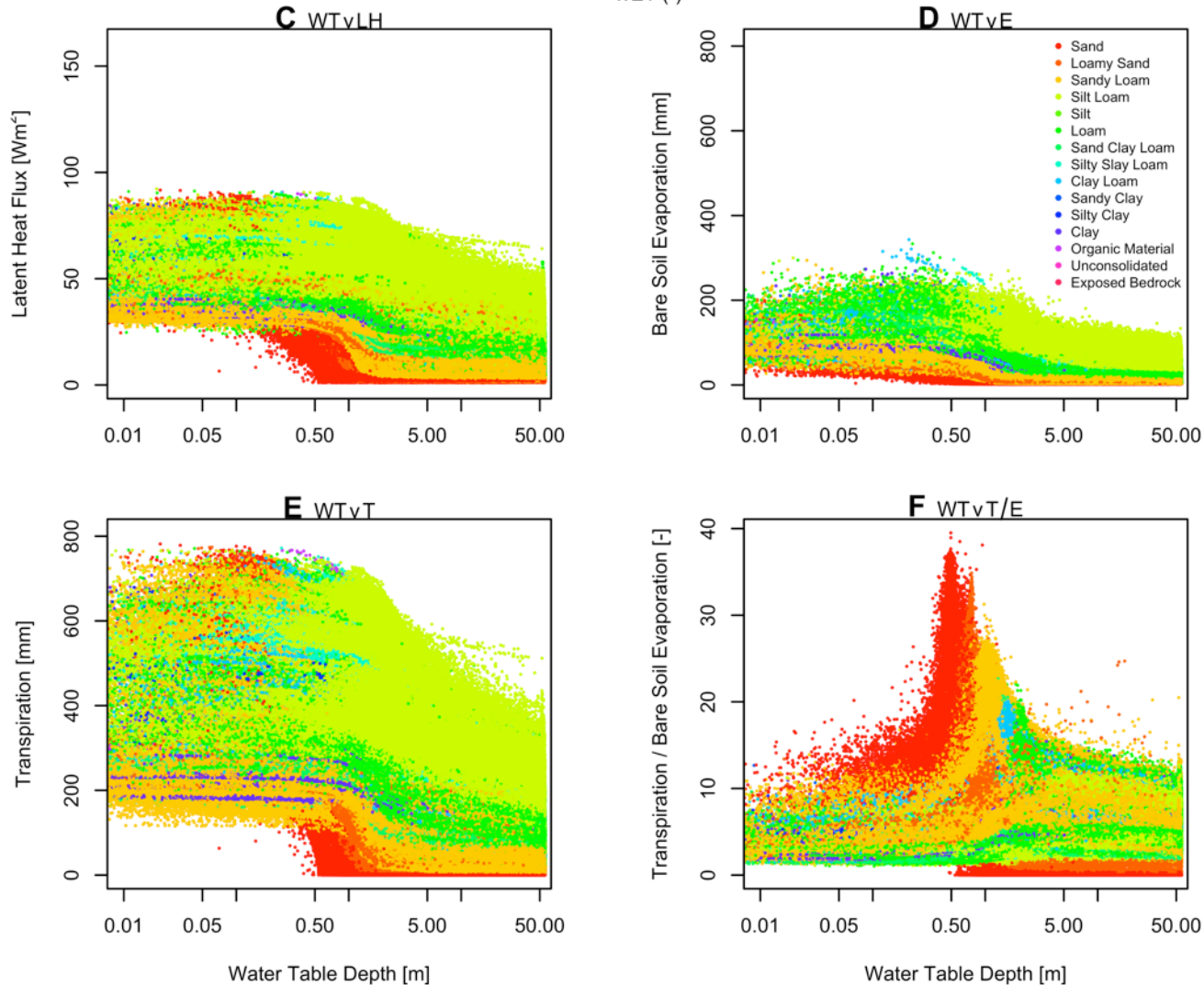
T/ET (-)

Maxwell and Condon Science (2016)

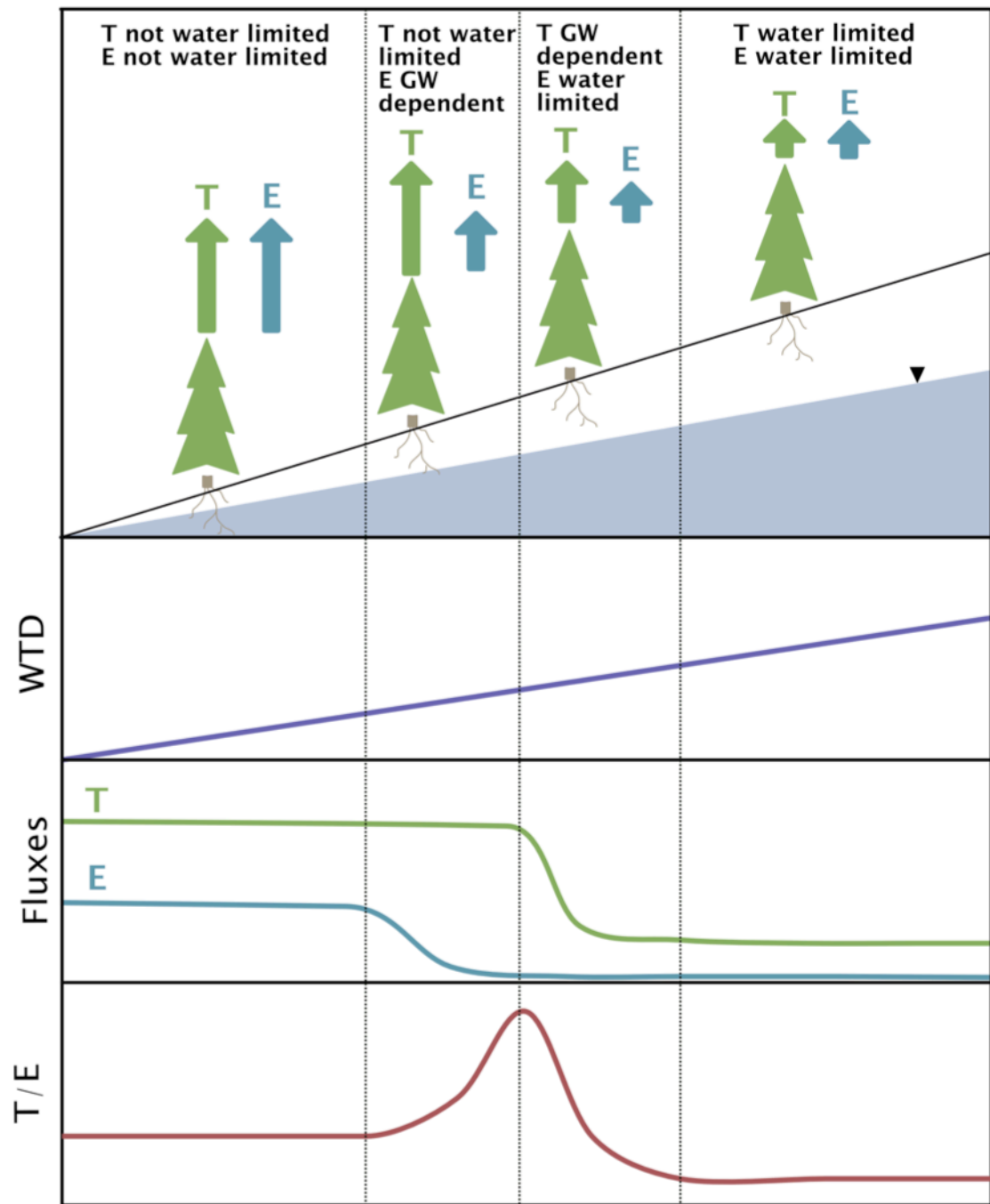
And lateral flow is clearly in important component of T/ET



Model results suggest that connections between hydrology and land-energy fluxes drive this relationship

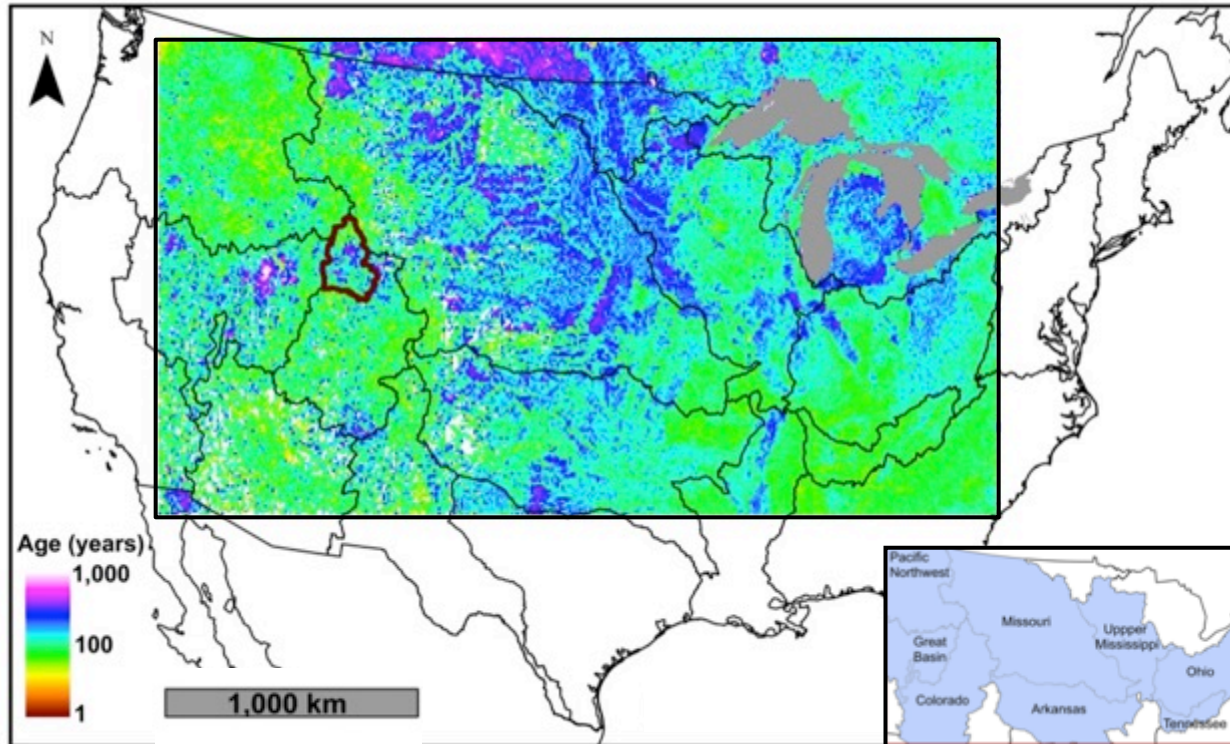


We hypothesize the differences in groundwater depth for T and E contribute to this behavior

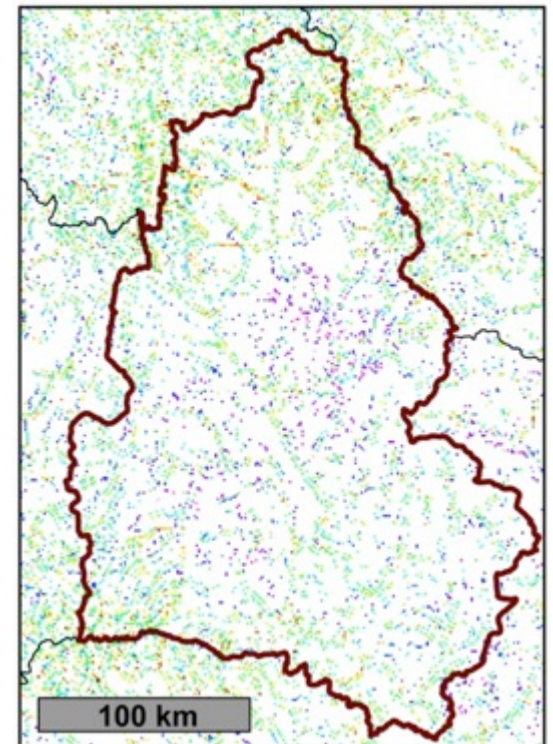


We can use large-scale simulations in conjunction with particle tracking to estimate GW residence time at large scale

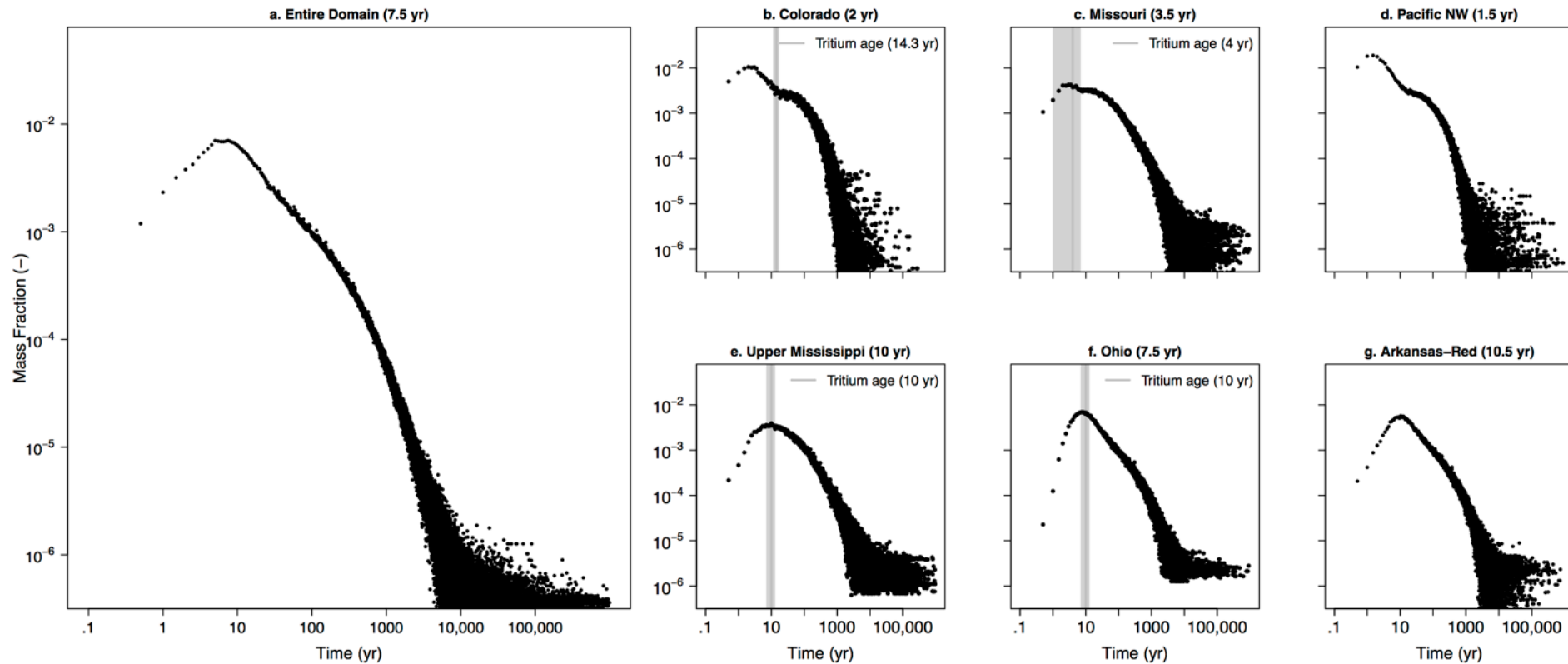
a. 10km average age



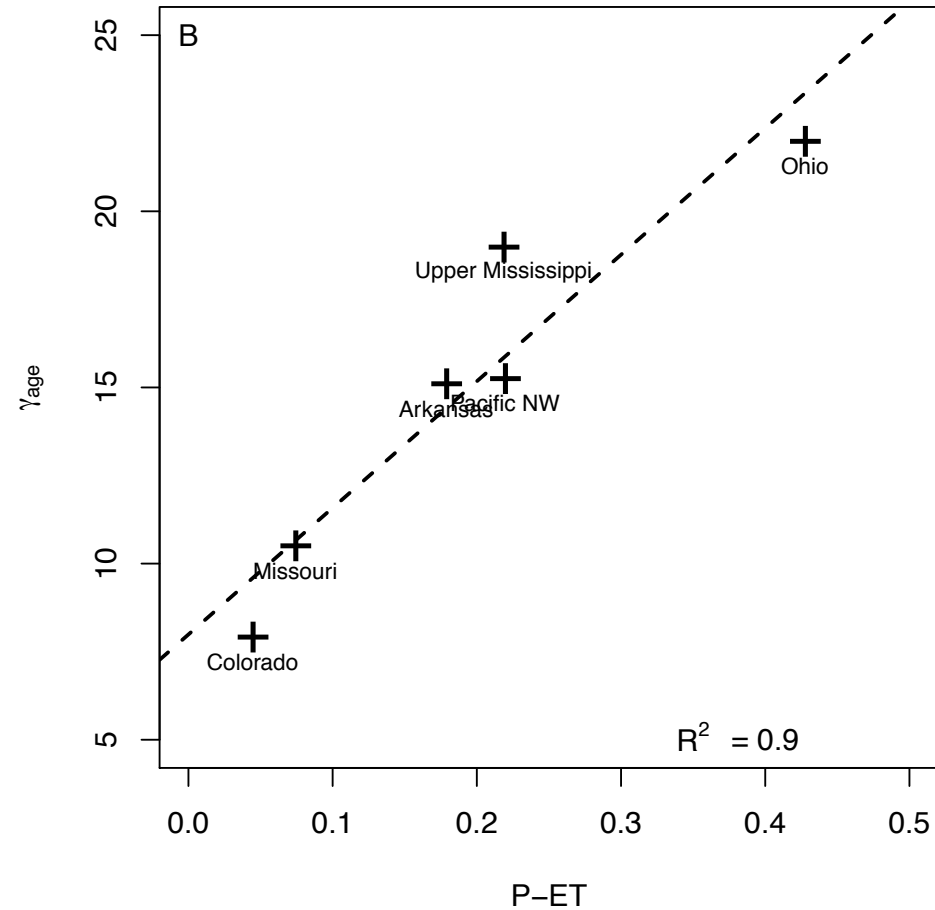
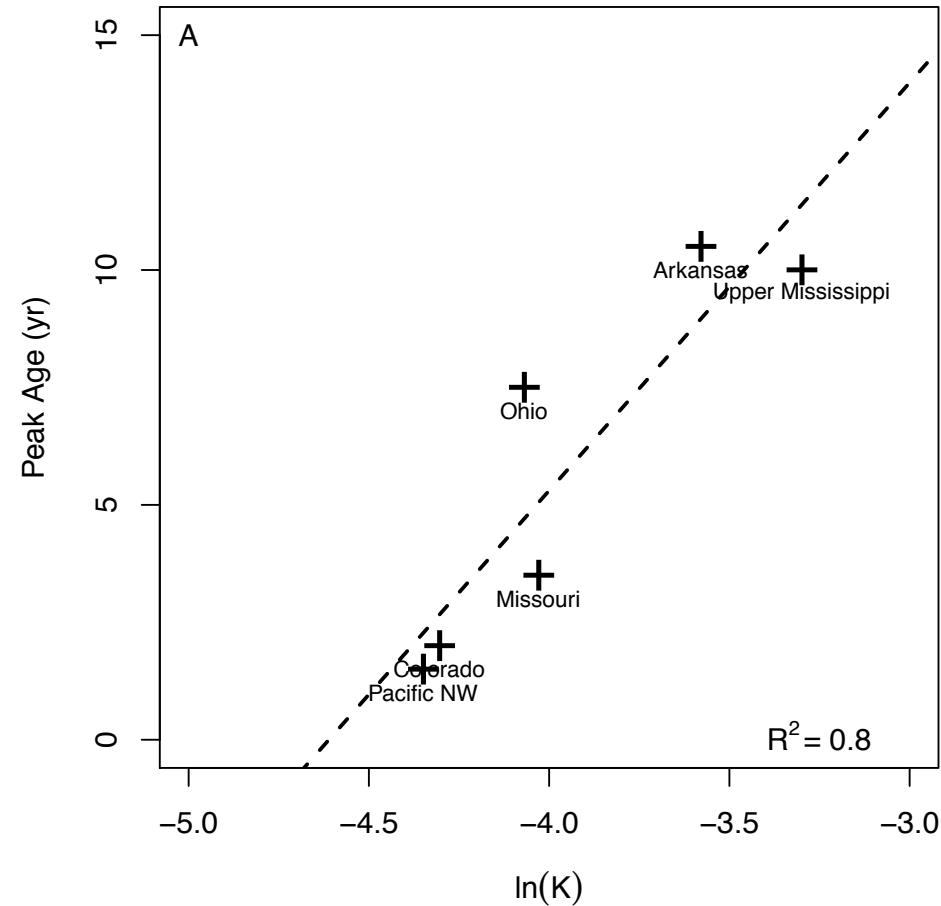
b. 1km average age



Residence time distributions agree with observations but show a range of water age



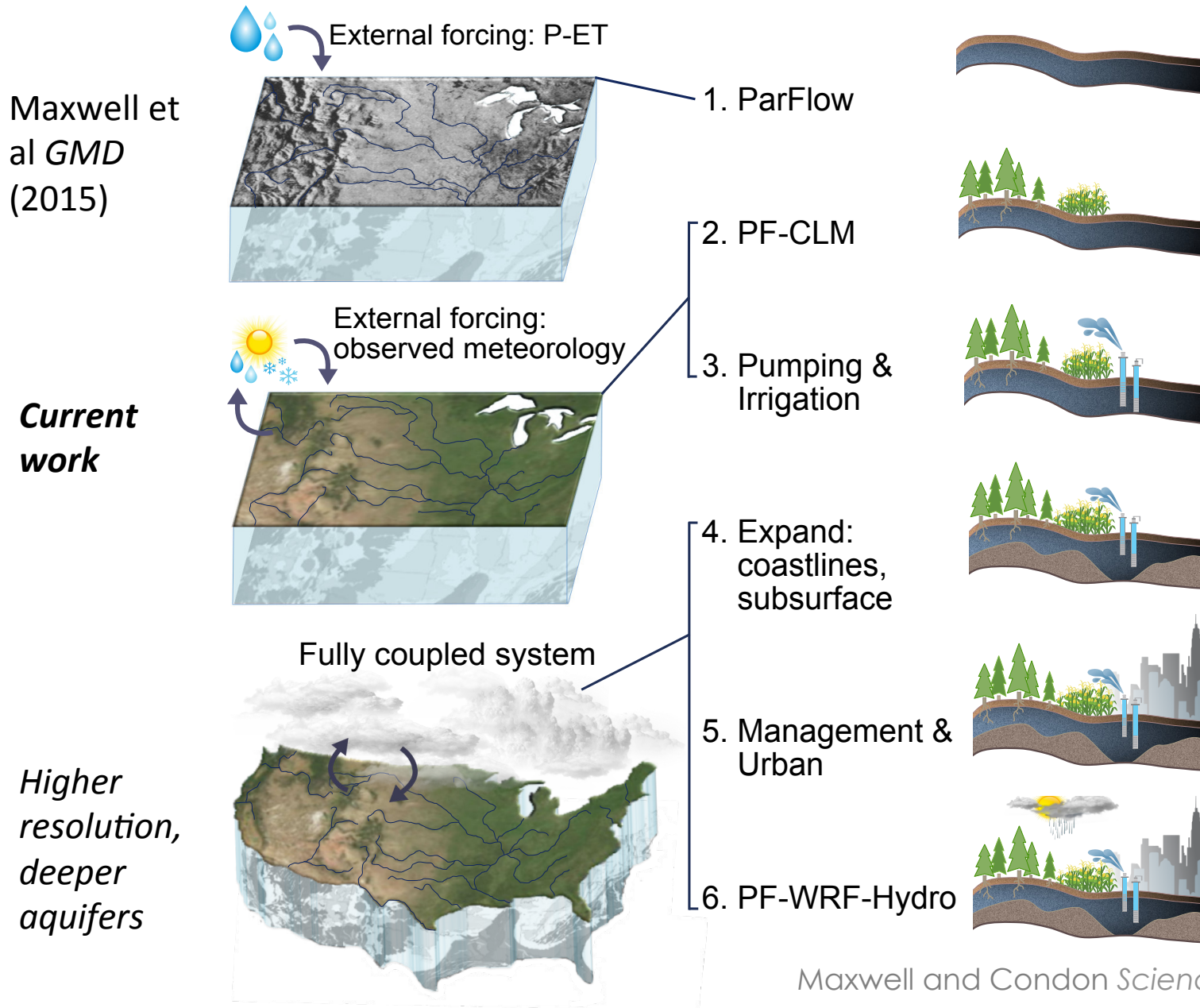
We can use the model to attribute the age distributions: peak age to geology, spread to aridity



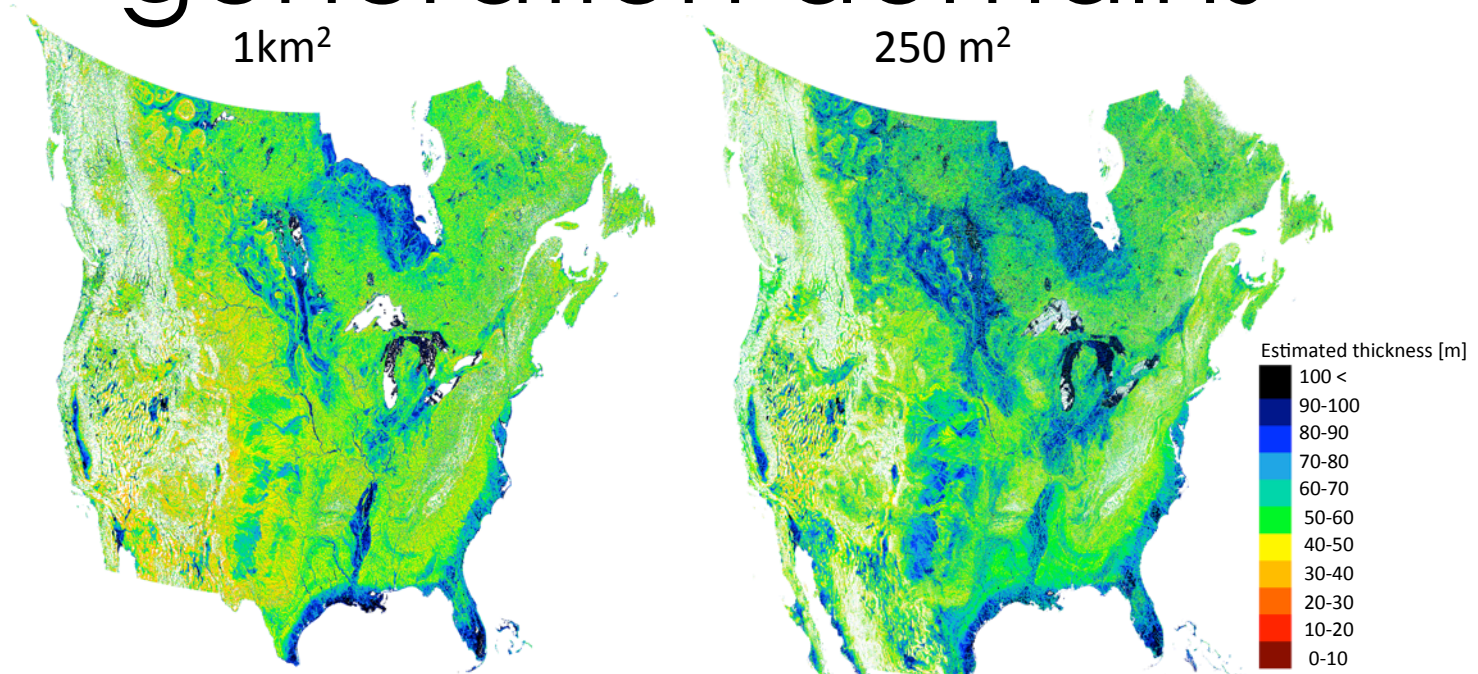
We present a step in the process towards understanding groundwater's influence on ET

- We see **connections** between **hydrology** and **land energy** fluxes and **lateral flow** is very important
- It is important to think about how we use **large-scale, high resolution model** outputs in tandem with **observations** and **theory** to understand **underlying processes in hydrology**.
- Moving forward we want to **engage the community** providing full **access to results**

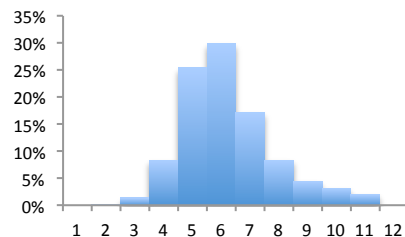
We see an exiting path forward where model, scenario and observations evolve merging into the National Water Model



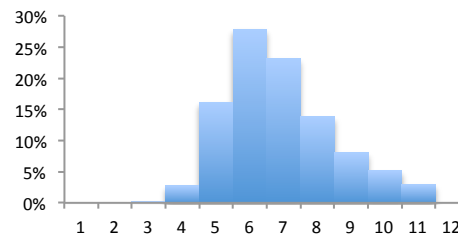
We are developing next-generation domains



1km histo estimated thick. first layer



250m histo estimated thick. first layer



And see differences with resolution

