Testing conceptual and mechanistic soil hydrology models against observed water fluxes across semi-arid sites in the SW US

Natasha MacBean

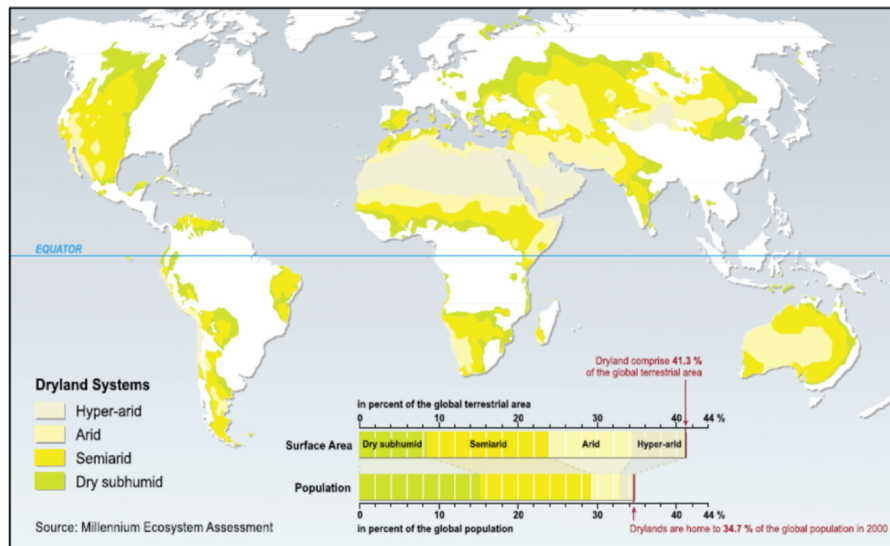*Indiana University*

Russ Scott, Joel Biederman, Tom Kolb, Sabina Dore, Nicolas Vuichard, Agnes Ducharne, and Dave Moore

24th October 2018

Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle

Benjamin Poulter[1,2], David Frank[3,4], Philippe Ciais[2], Ranga B. Myneni[5], Niels Andela[6], Jian Bi[5], Gregoire Broquet[2], Josep G. Canadell[7], Frederic Chevallier[2], Yi Y. Liu[8], Steven W. Running[9], Stephen Sitch[10] & Guido R. van der Werf[6]

Dryland Systems
- Hyper-arid
- Arid
- Semiarid
- Dry subhumid

Dryland comprise 41.3 % of the global terrestrial area

Drylands are home to 34.7 % of the global population in 2000

Source: Millennium Ecosystem Assessment

The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink

Anders Ahlström,[1,2]* Michael R. Raupach,[3]† Guy Schurgers,[4] Benjamin Smith, Almut Arneth,[5] Martin Jung,[6] Markus Reichstein,[6] Josep G. Canadell,[7] Pierre Fried Atul K. Jain,[9] Etsushi Kato,[10] Benjamin Poulter,[11] Stephen Sitch,[12] Benjamin D. Stocker, Nicolas Viovy,[15] Ying Ping Wang,[16] Andy Wiltshire,[17] Sönke Zaehle,[6] Ning Zeng[18]
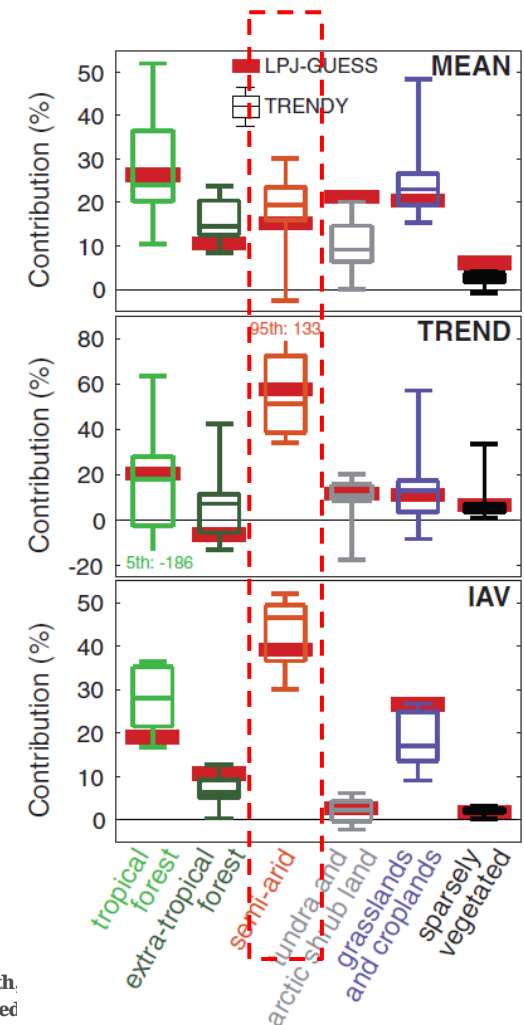
SW US C cycle dynamics

➢ 50% sites switched between functioning as C sinks/sources in wet/dry years.

→ *Moisture availability is clearly important!*
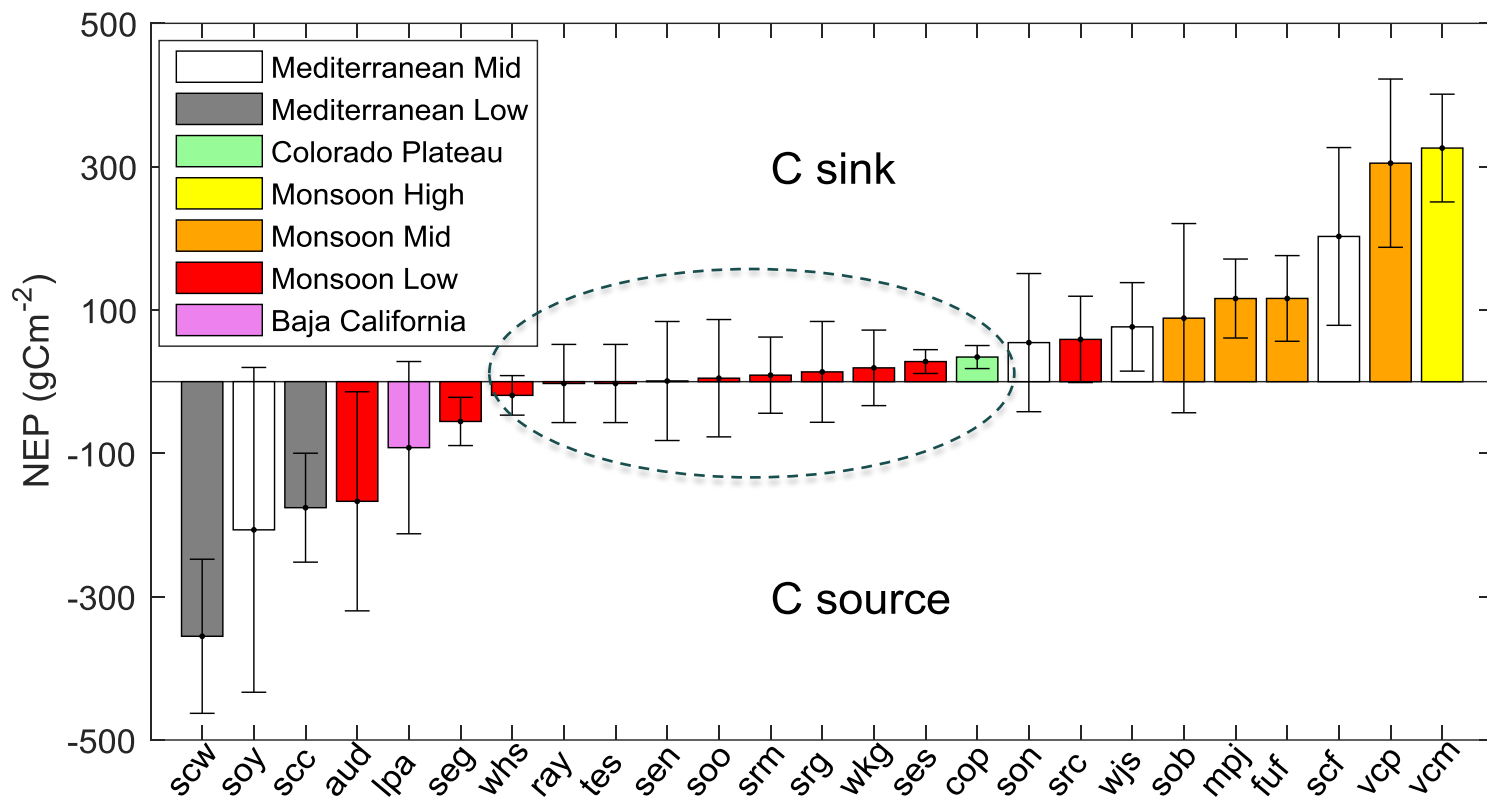
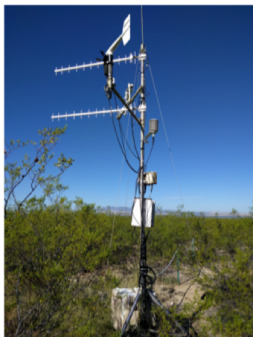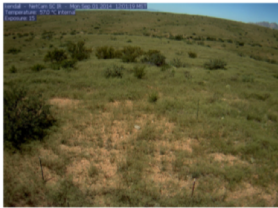*Biederman et al. (2017) (and Scott et al. (2015))*

Beyond Carbon!
Testing terrestrial biosphere model *hydrology* at semi-arid sites

➤ Can TBMs capture soil moisture and ET dynamics at semi-arid sites (case study SW US)?

    ➤ *What do we care about?*

- Seasonal dry moisture limited periods

- Is moisture replenished after rain event (esp. monsoon)

- "Flashiness" of rain events

- (Long-term trends)

➤ Does the complexity of the soil hydrology scheme impact modeled soil moisture and ET?
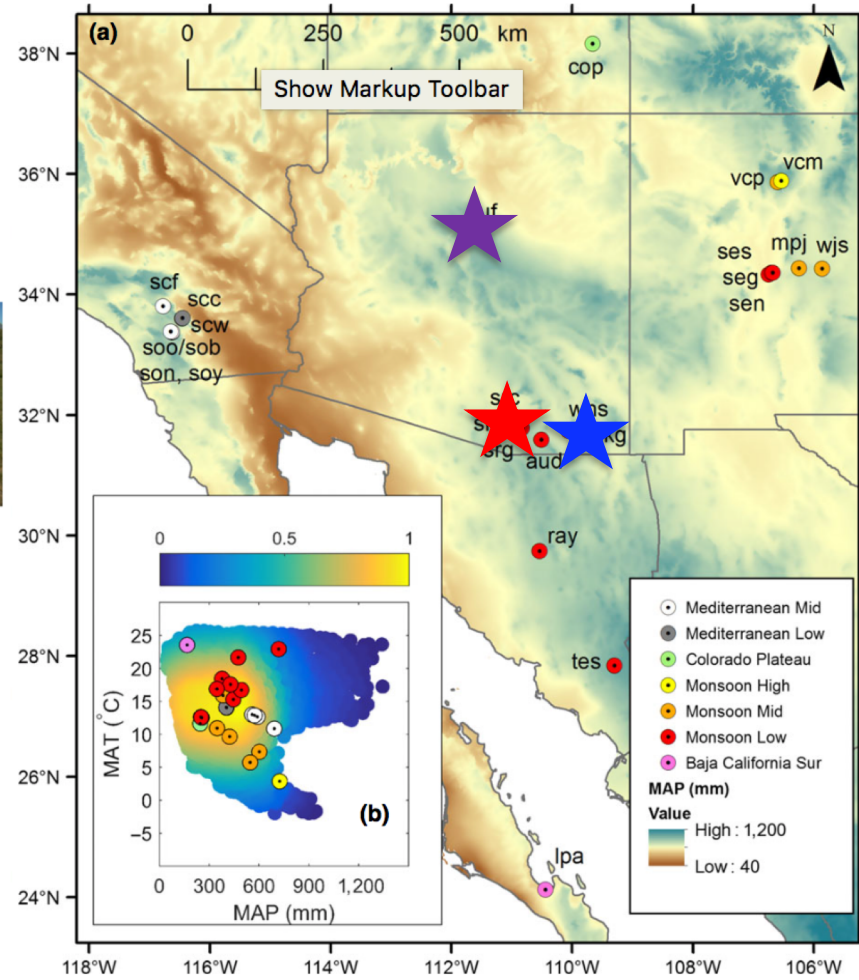
SW semi-arid sites

Walnut Gulch Shrubland (Whs) and Lucky Hills Grassland (Wkg)
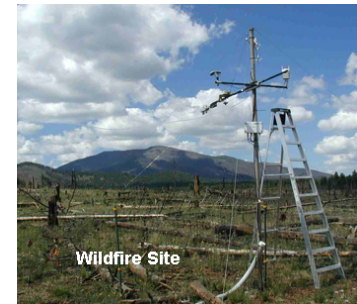
Santa Rita Mesquite (SRM) and grassland (SRG) sites

Flagstaff Unmanaged Forest (Fuf),

Managed Forest (Fmf) and wildfire affected forest site (Fmf)

Biederman et al. (2017)

Model experiments

- ➢ 7 monsoon dominated sites in Arizona

- ➢ Gradient in elevation and vegetation type (grass, shrub and evergreen tree dominated)

- ➢ Site climate forcing, vegetation and soil characteristics

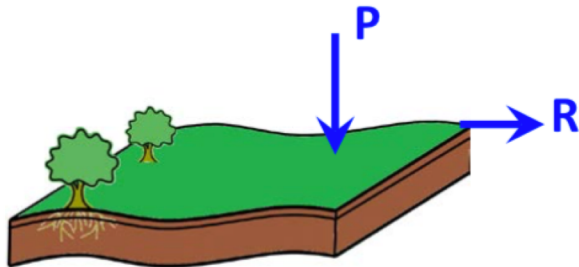- ➢ Gap-filled using Vuichard and Papale (2015) using downscaled ERA-I climate reanalyses
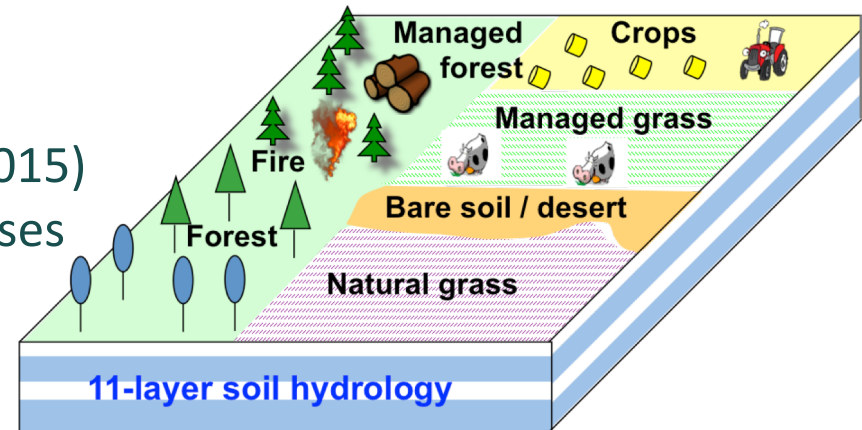
- ➢ ORCHIDEE TBM

- ➢ Test conceptual 2-layer soil hydrology model vs mechanistic 11-layer model
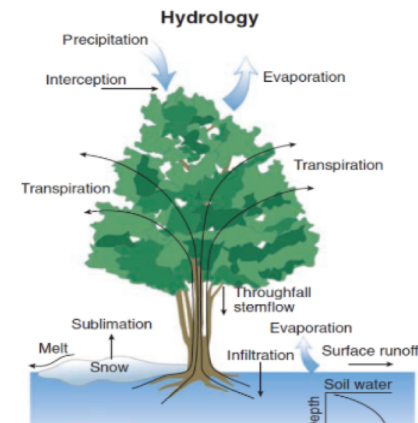
# Two hydrology versions

Two-layer = Choisnel = ORC2

Ducoudré et al., 1993; Ducharne et al., 1998; de Rosnay et al. 1998

- **Conceptual description of soil moisture storage**
- **4-m soil and 2-layers**
- Top layer can vanish
- Constant available water holding capacity (between FC and WP)
- Runoff when saturation
- No drainage from the soil
  We just diagnose a drainage as 95% of runoff for the routing scheme

Multi-layer = CWRR = ORC11

*de Rosnay et al., 2002; d'Orgeval et al., 2008; Campoy et al., 2013*
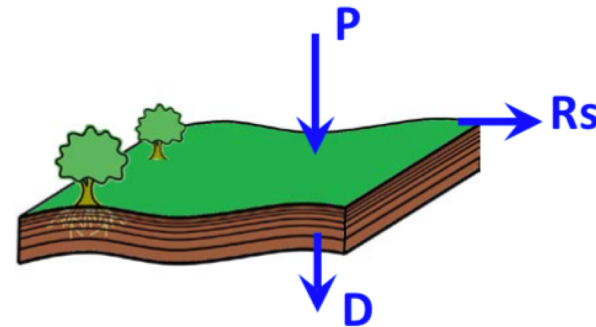
- **Physically-based description of soil water fluxes using Richards equation**
- **2-m soil and 11-layers**
- Formulation of Fokker-Planck
- Hydraulic properties based on van Genuchten-Mualem formulation
- Related parameter based on texture
- Surface runoff = P – Esol – Infiltration
- Free drainage at the bottom

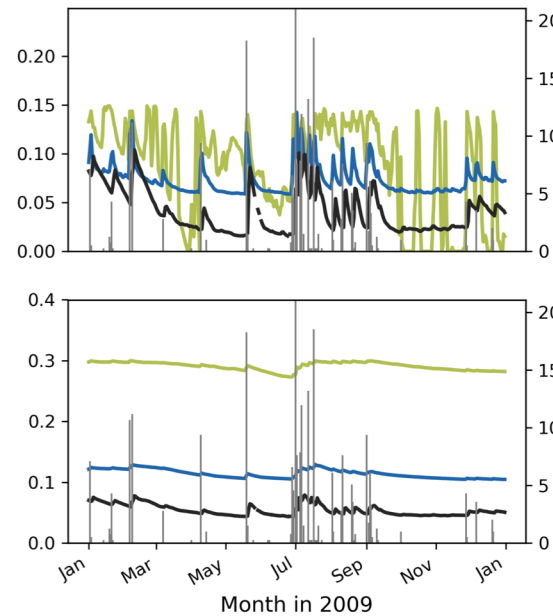# Does a mechanistic hydrology model improve soil moisture simulations?

➢ Overall: YES! Mechanistic hydrology improves soil moisture temporal dynamics and magnitude across all sites/vegetation types
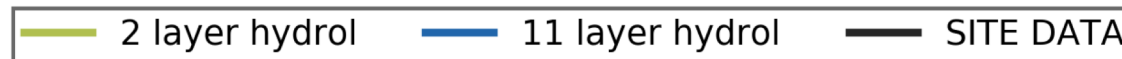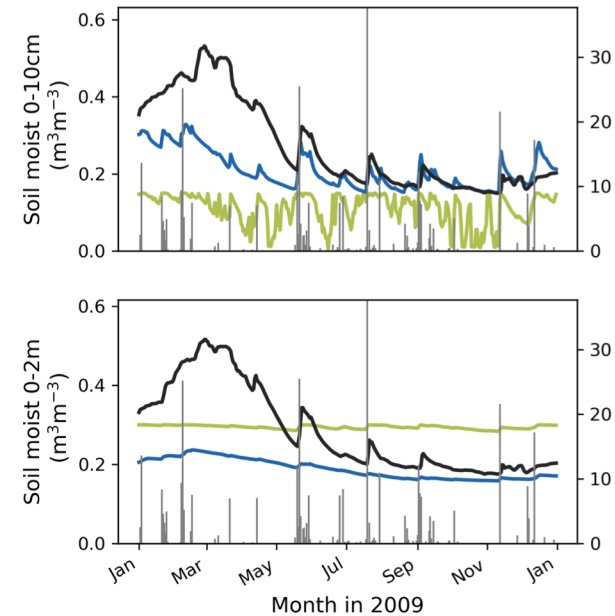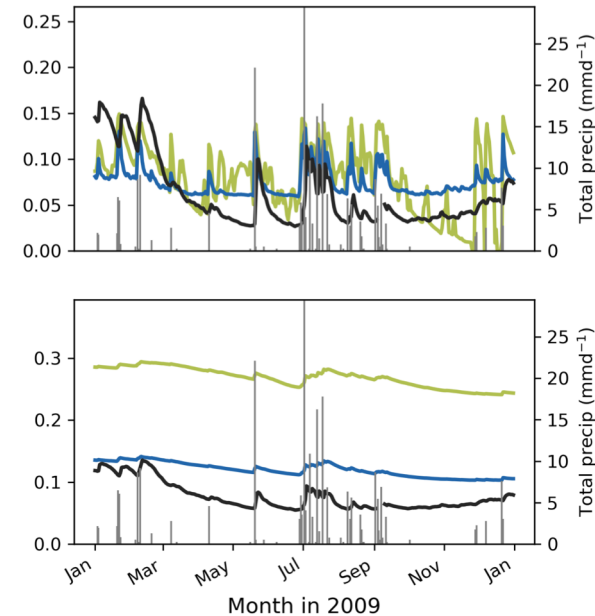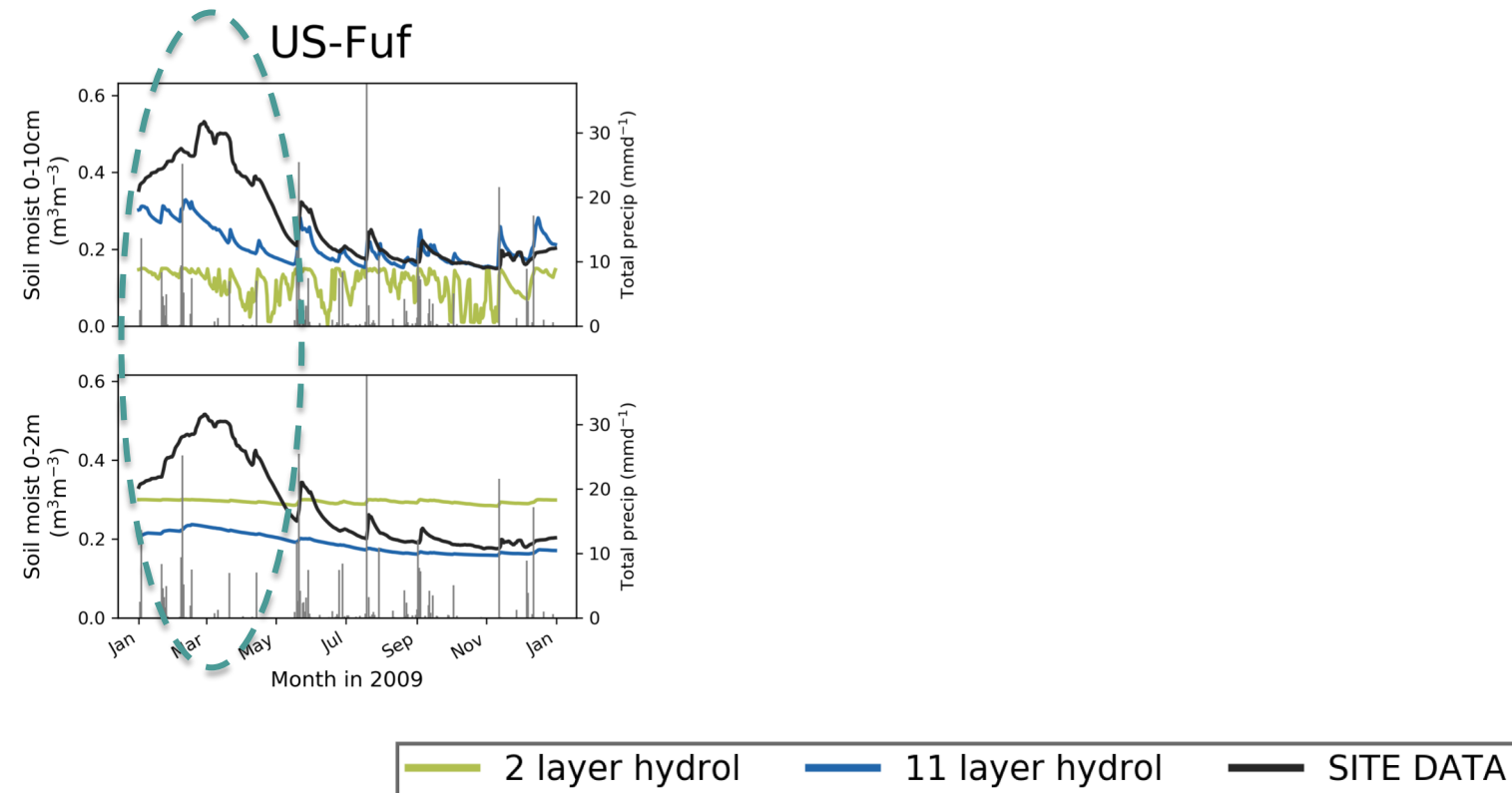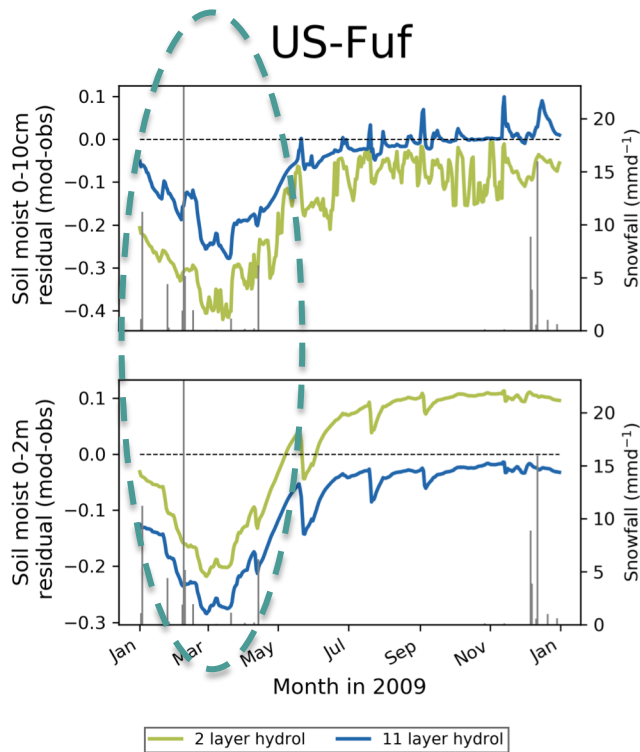
Does a mechanistic hydrology model improve soil moisture simulations?

➢ Overall: YES!
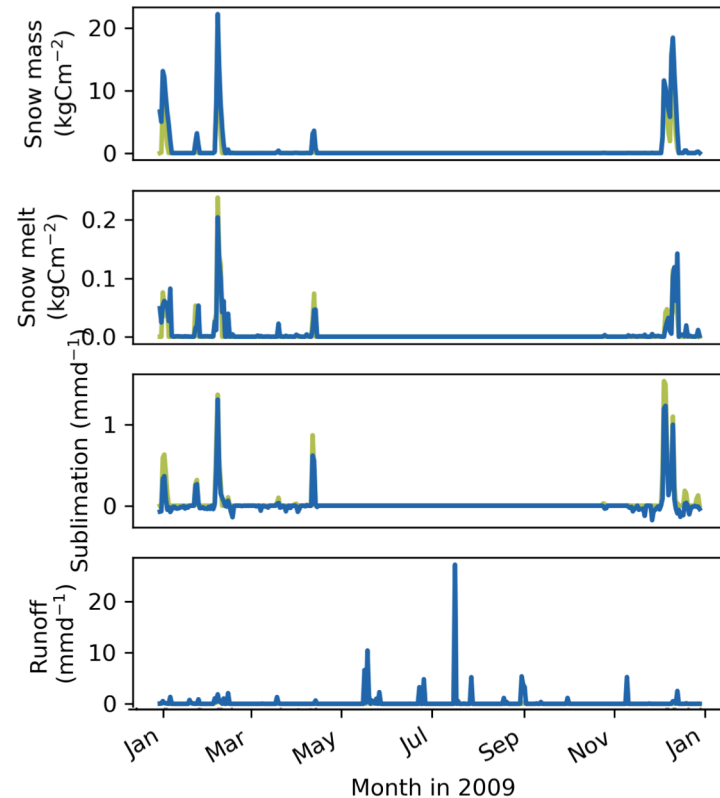➢ But still some model–data discrepancies…

Does a mechanistic hydrology model improve soil moisture simulations?

➤ Looking at residuals → Considerable underestimate of soil moisture in both schemes during winter at the Flagstaff forested site…
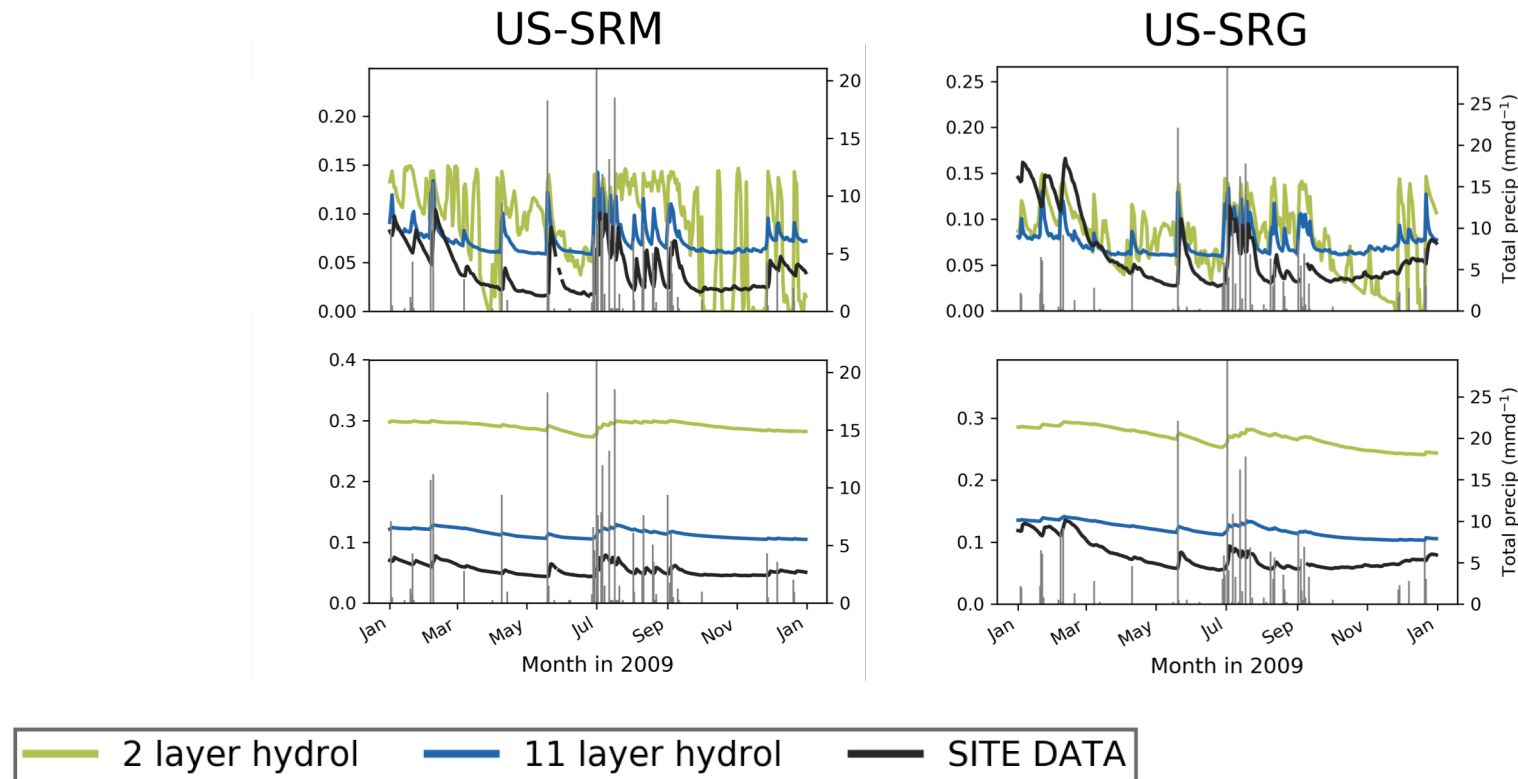
➤ Probably due to issues with snow mass, snow melt or sublimation

Does a mechanistic hydrology model improve soil moisture simulations?

- ➤ Overall: YES!
- ➤ But model still overestimates soil moisture at low elevation shrub and grass dominated sites
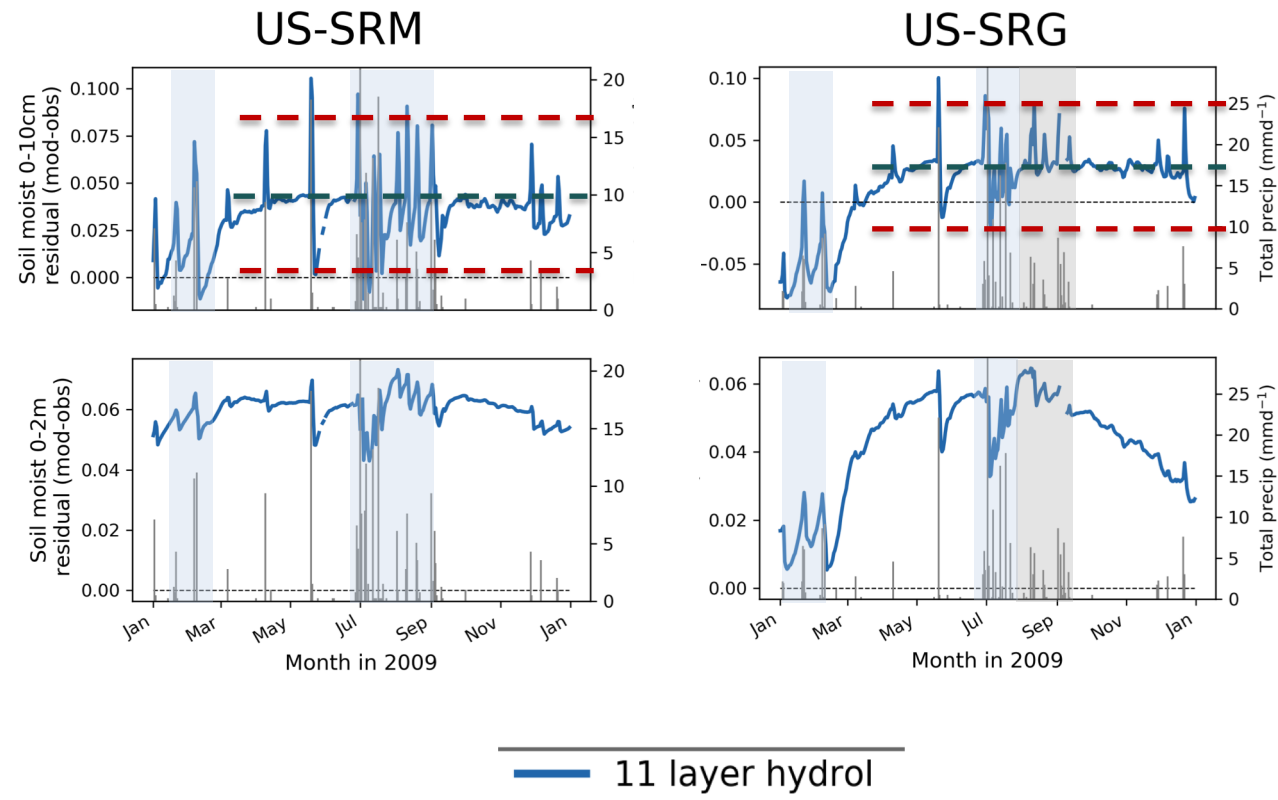
Does a mechanistic hydrology model improve soil moisture simulations?

➢ **11-layer: Decrease in residuals during heavy rainfall events at low elevation monsoon sites (shrub or grass dominated)…**
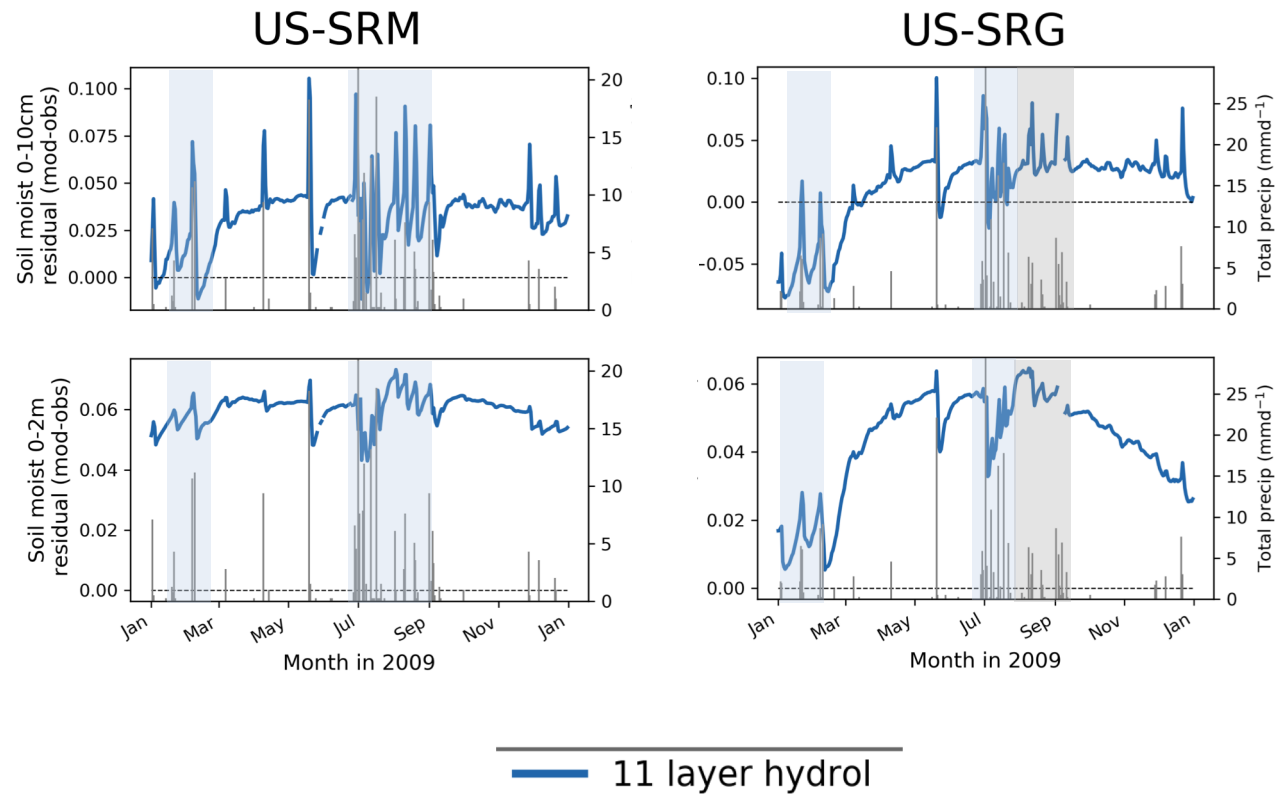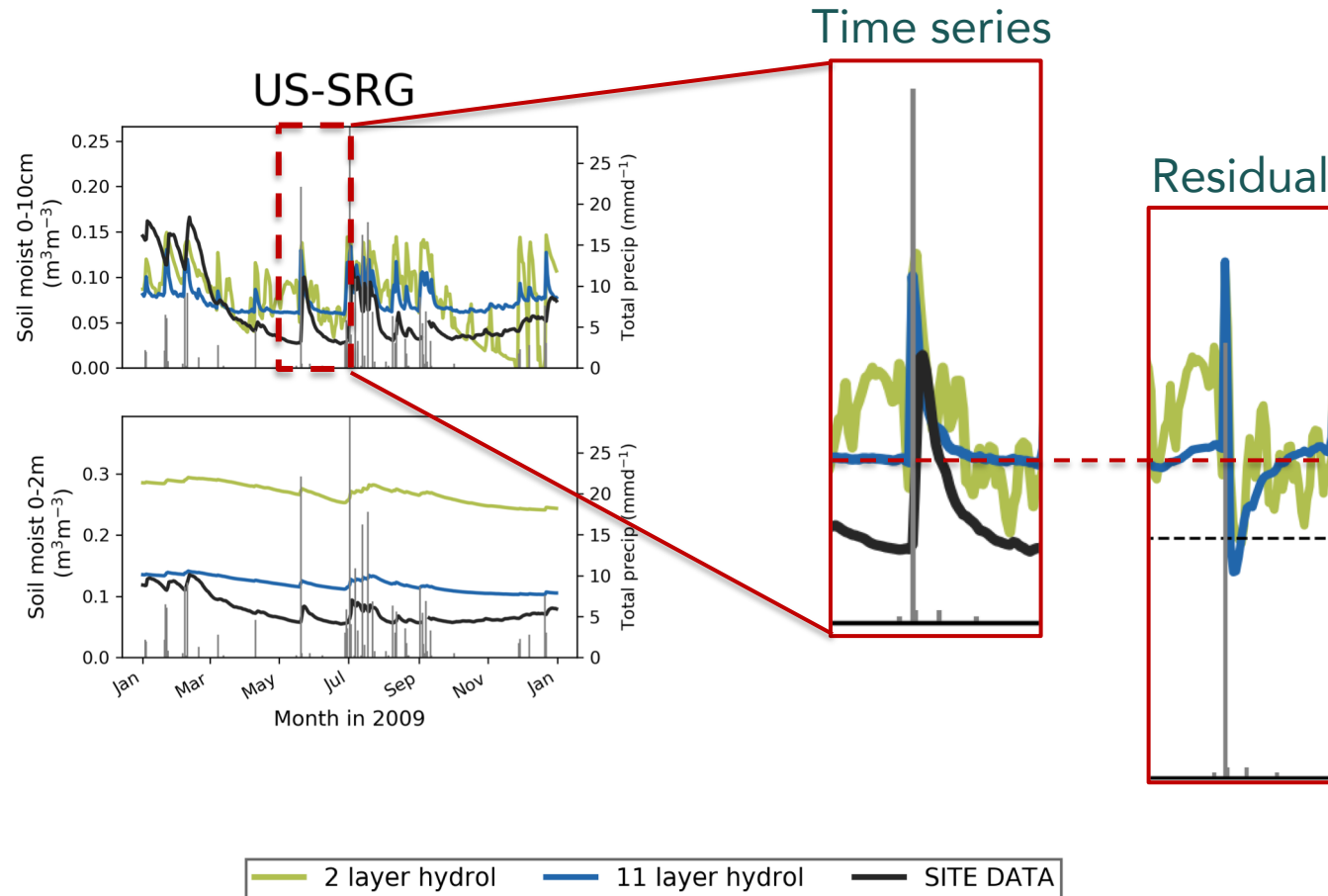
Does a mechanistic hydrology model improve soil moisture simulations?

➢ …but higher variability in residuals during rainfall events

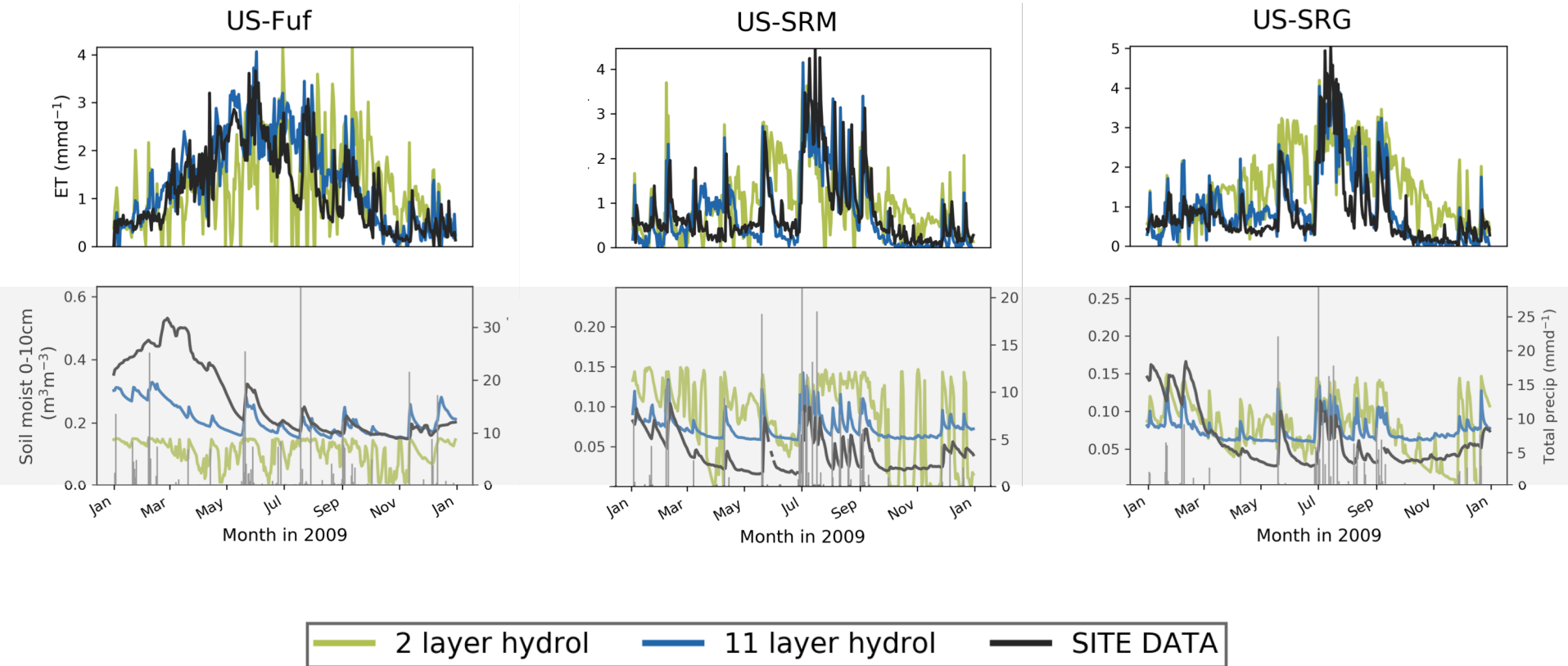# Does a mechanistic hydrology model improve soil moisture simulations?

➤ 11-layer model *too quick* to respond to "flashy" events…

Time series

Residual

US-SRG

2 layer hydrol   11 layer hydrol   SITE DATA
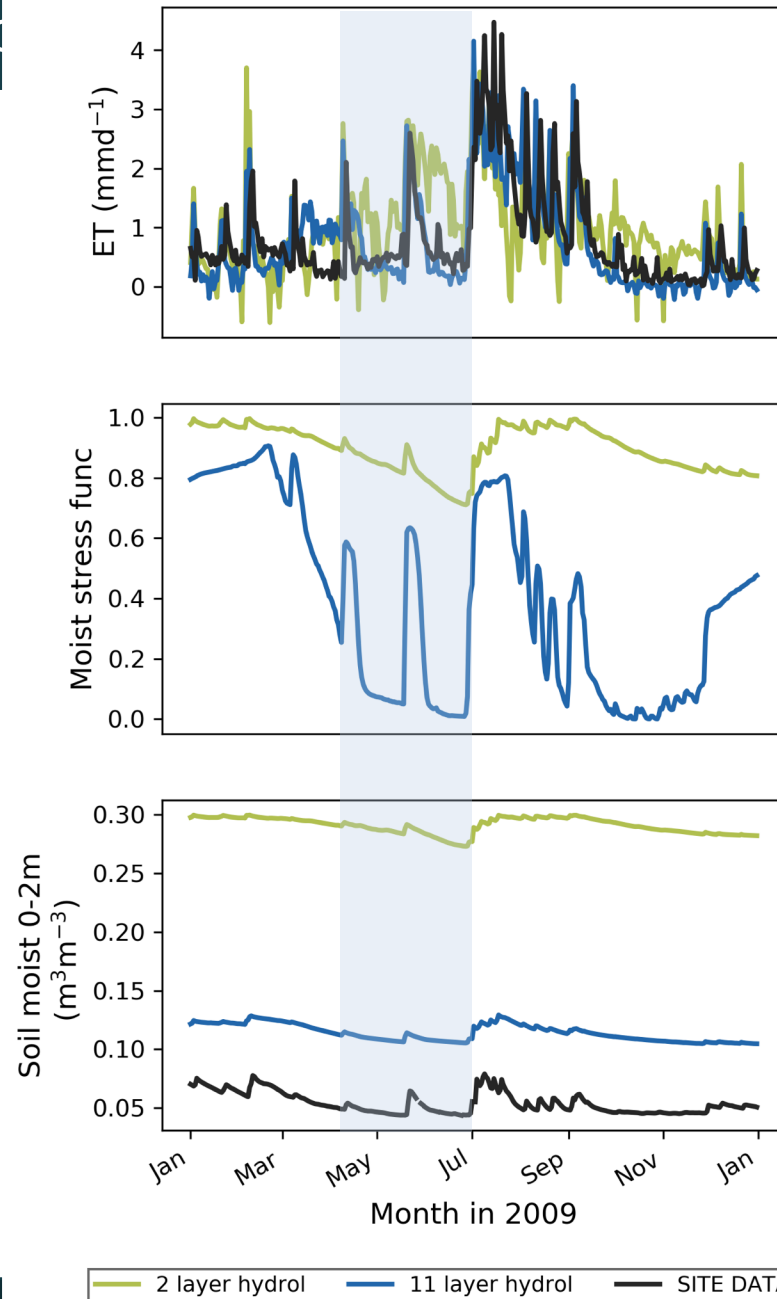
Does a mechanistic hydrology model improve evapotranspiration (ET) simulations?

➤ **Mechanistic hydrology improves soil moisture temporal dynamics and magnitude** ➔ *improvement in ET*

US-SRM

> Improvement in synoptic temporal ET dynamics during moisture limited periods…

> Improvement in empirical water stress function

Legend: 2 layer hydrol — 11 layer hydrol — SITE DATA

Does a mechanistic hydrology model improve evapotranspiration (ET) simulations?

➤ ET mean seasonal cycle much improved with mechanistic 11-layer hydrology
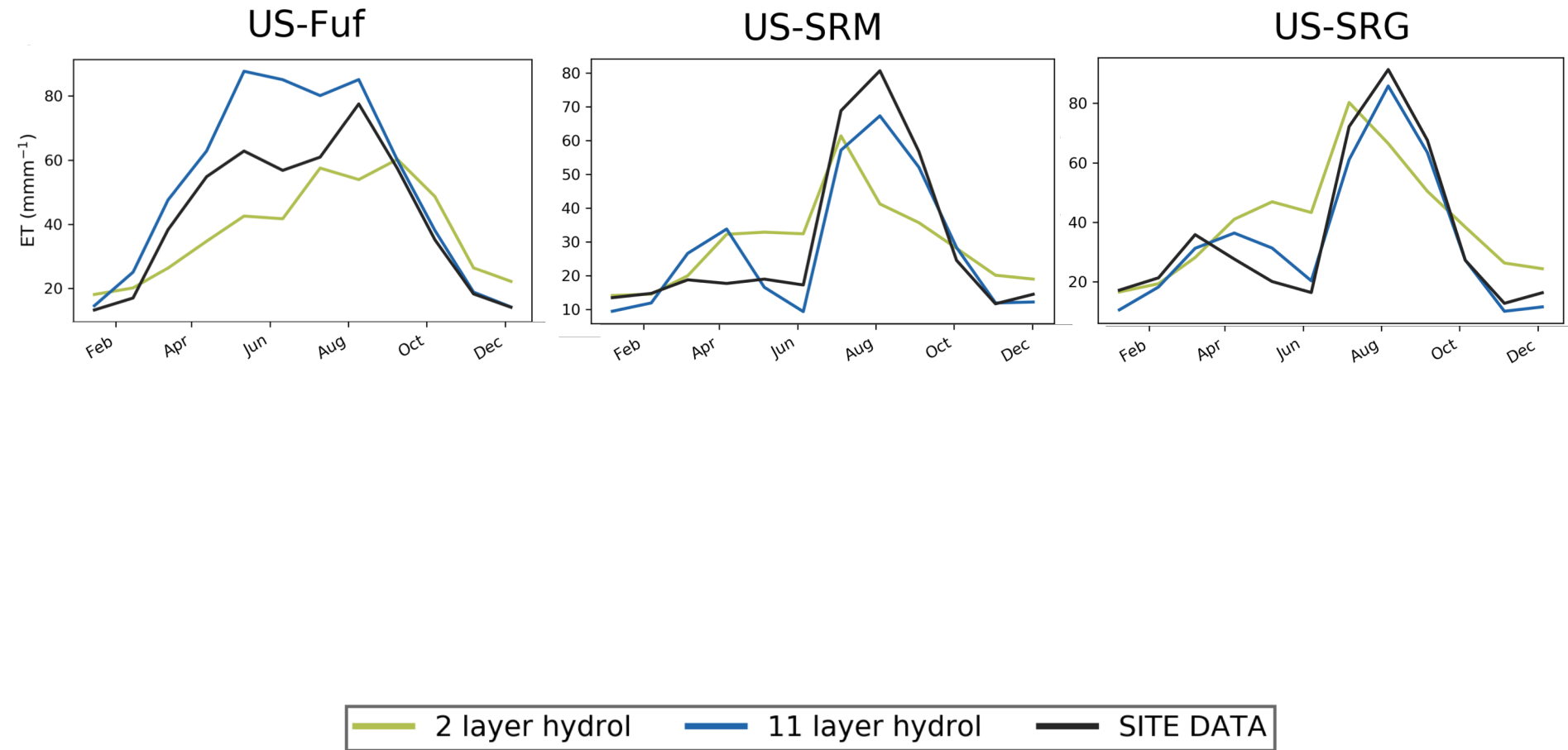
Summary

➢ Mechanistic hydrology does improve temporal dynamics (and magnitude) of soil moisture for SW semi-arid sites (across elevation/vegetation gradient)

➢ Consequent improvement in ET seasonal cycle and magnitude → particularly during periods of moisture limitation

➢ Some issues remain:

    i)   snow at high elevation sites → *consequences for impacts of changing snowpack in moisture/snowmelt driven mountain ecosystems?*

    ii)   LAI / vegetation seasonality of drought deciduous trees/shrubs → impacting transpiration and E:ET ratios?

Perspectives for model-data comparisons at flux sites….

Specific to Ameriflux/FluxNet:

➢ Soil moisture and LAI are very helpful for modelers!

More generally:

➢ Digging into model processes at site level…how best to go about this?

➢ Collaboration between site PIs and modelers is extremely valuable

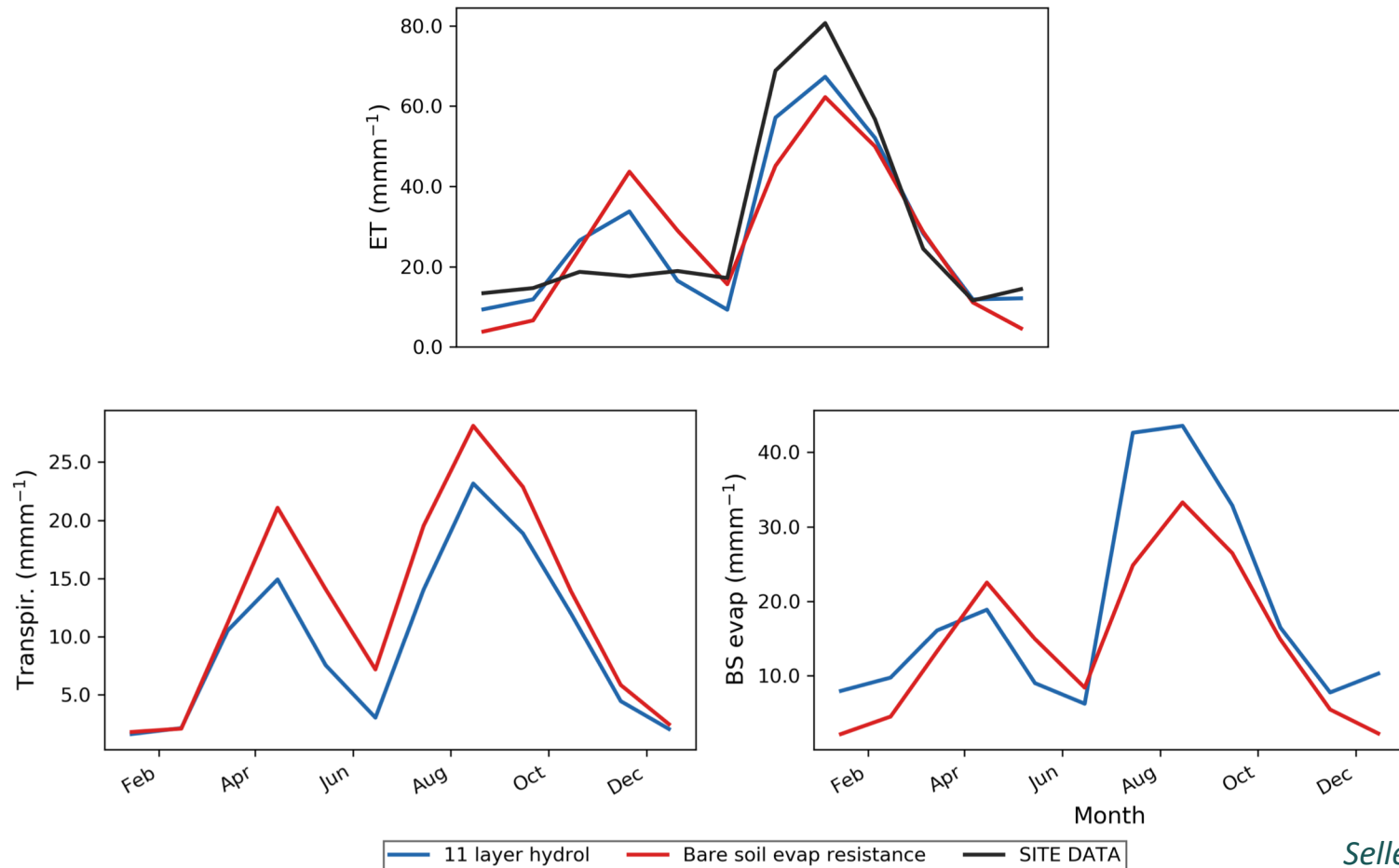*Thank you to the Ameriflux Network and site PIs for providing such valuable datasets!*

Additional slides

US-SRM spring ET issues related to bare soil evaporation : transpiration partitioning?

➢ Tested a resistance term to bare soil evaporation
→ but not solved the problem….

Sellers et al. (1992)

Does a mechanistic hydrology model improve soil moisture simulations?

➢ Looking at residuals ➔ Considerable underestimate of soil moisture in both schemes during winter at the Flagstaff forested site…

   ➢ Probably due to issues with snow melt