Implementing a deep, dynamic root water uptake scheme in Noah-MP

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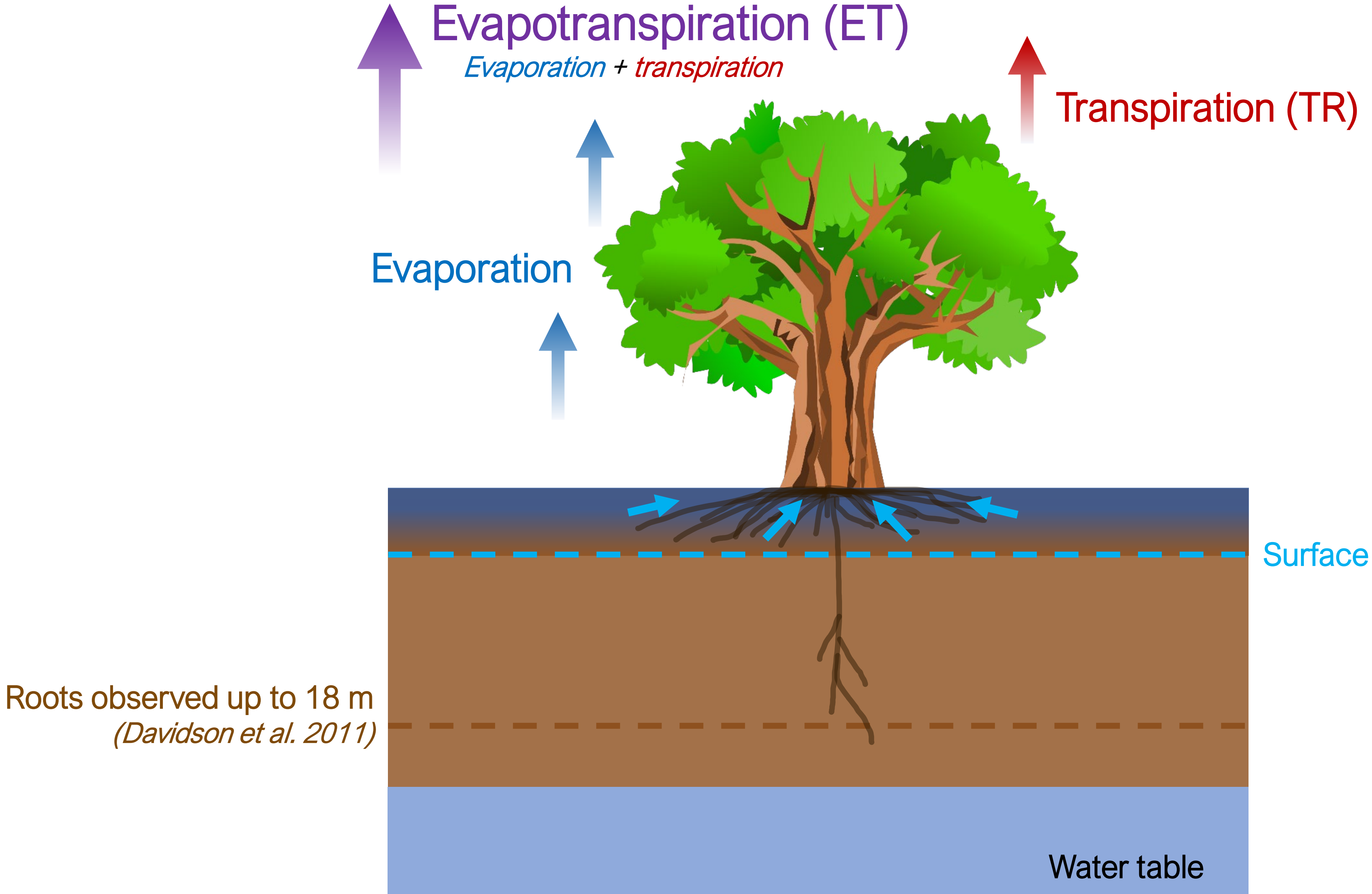
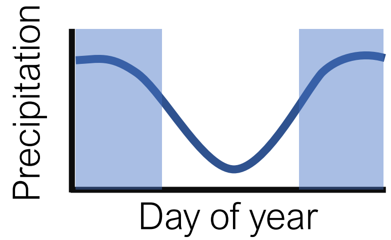
2024 Noah-MP International Workshop

3-4 June 2024

Mature forests in the Amazon rely on deep roots to avoid water stress during the dry season.



October - May



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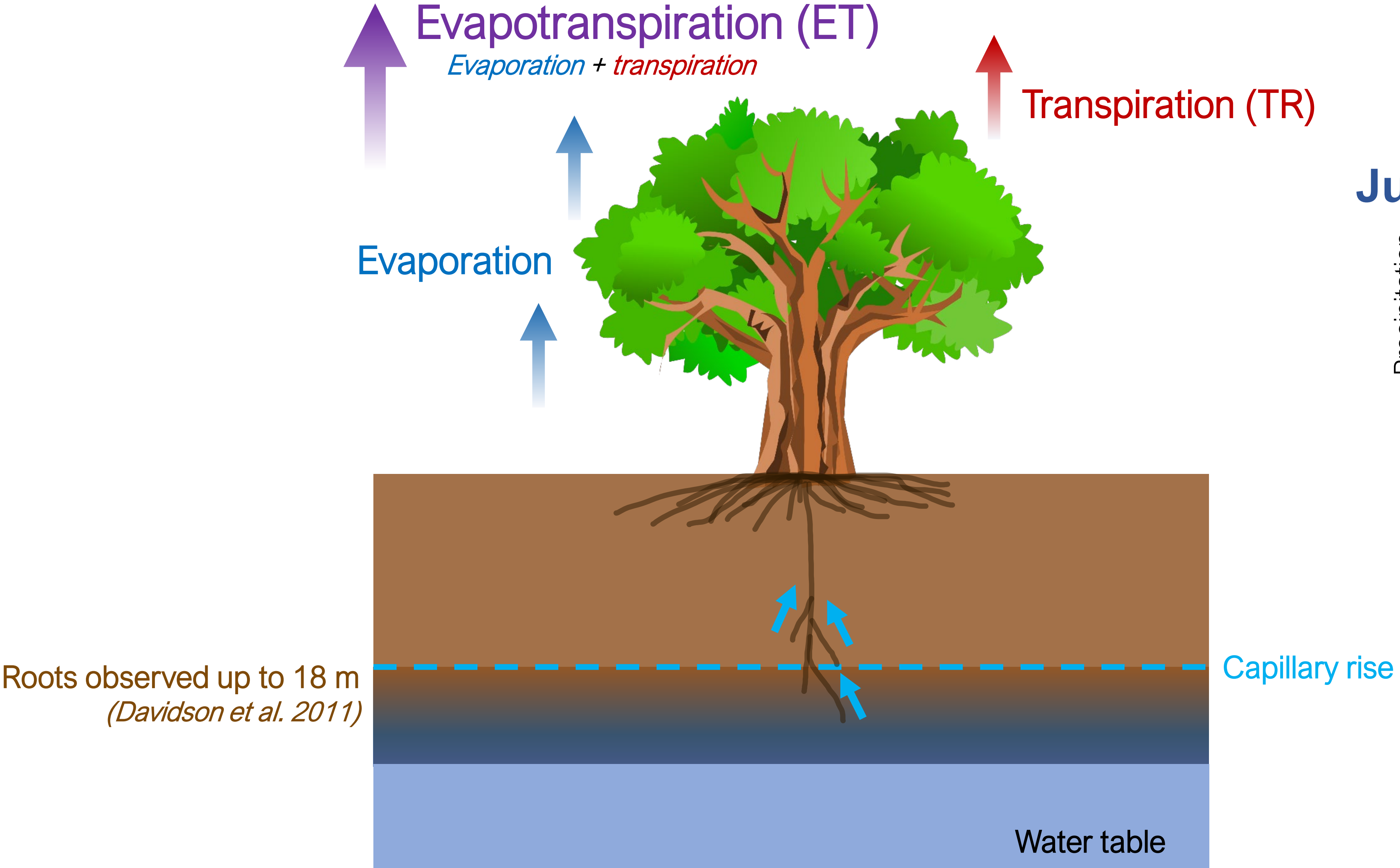
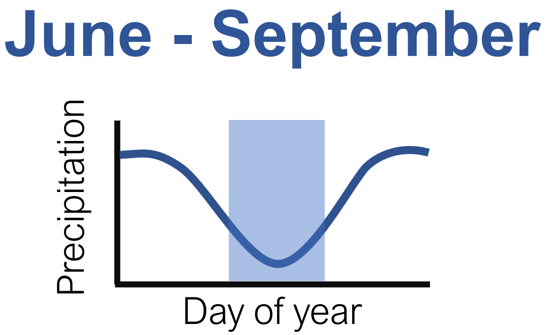




Topographical variations are central to determining the location of the water table & root access to deep moisture.

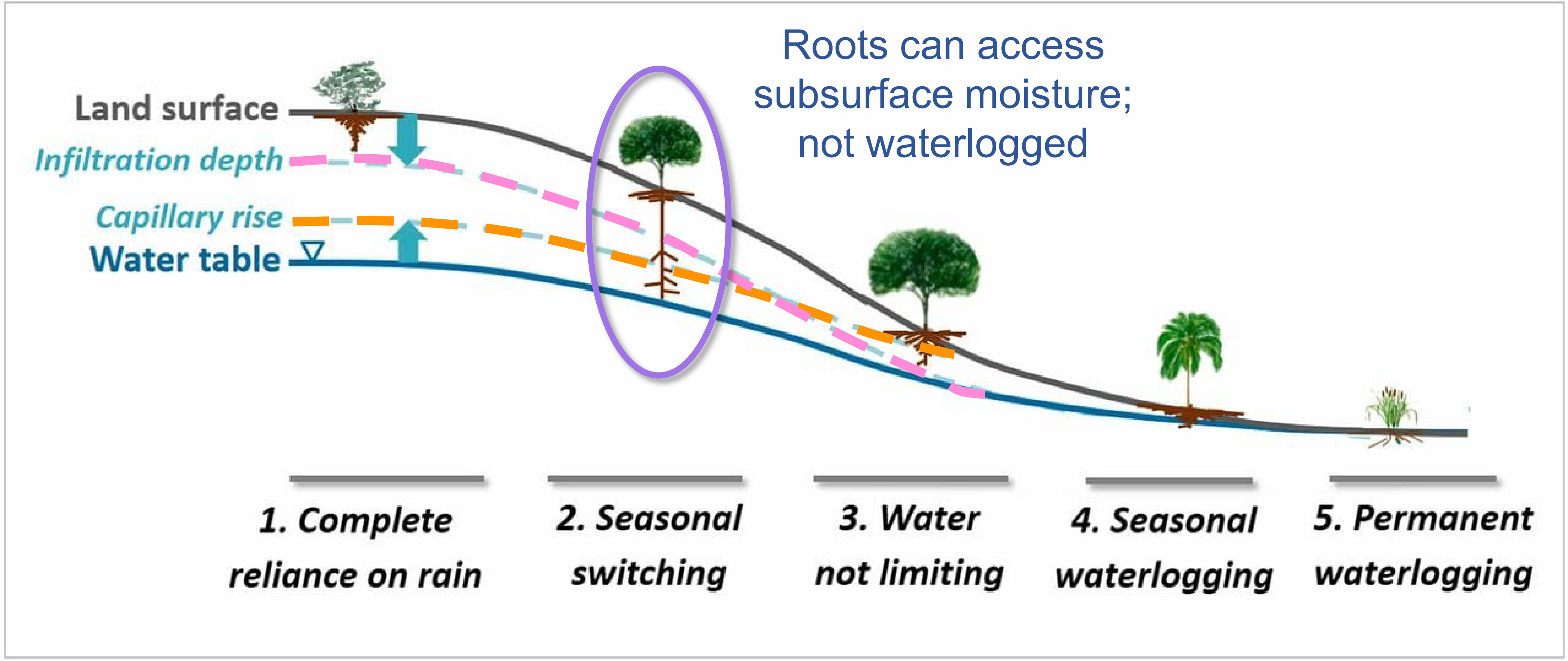
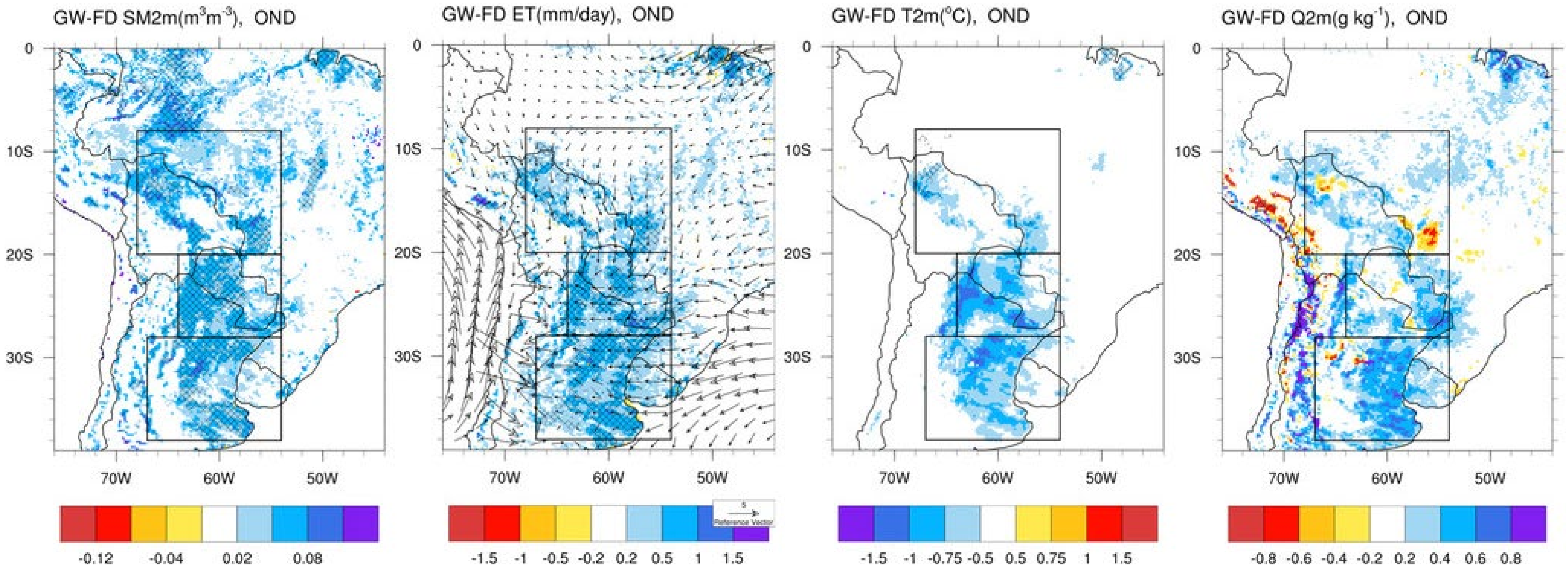


Figure: Fan et al. (2017)

Previous work studied the inclusion of a groundwater (GW) scheme in Noah-MP/WRF and simulated high-resolution water table depth variations in space.



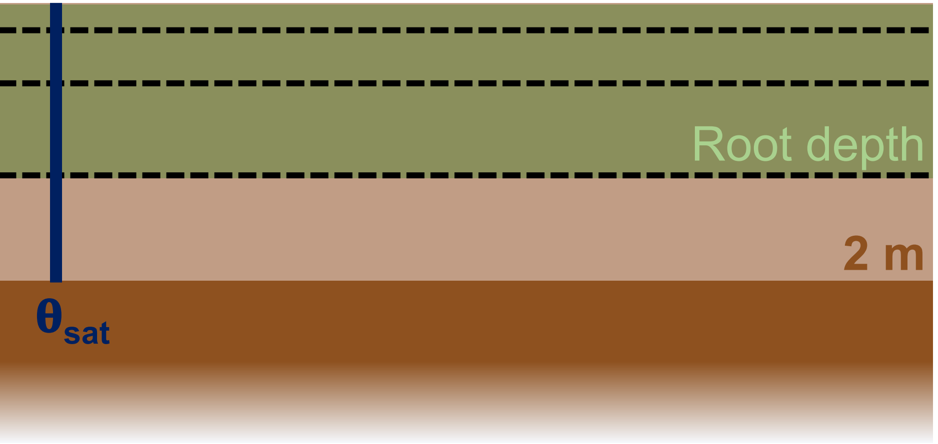
Figures: Martinez et al. (2016)

We build on this work with addition of a deep, dynamic root water uptake (DRWU) scheme in Noah-MP.

We make several changes to Noah-MP, including implementation of a dynamic root water uptake (DRWU) scheme.

Original setup, Noah-MP Version 4.5 (Niu et al. 2011)

4 soil layers to 2 m



$RWU_1 = \beta_1 TR$

⋮

$RWU_N = \beta_N TR$

Rooting depth static in time
Soil props static w/ depth
β used in root water uptake

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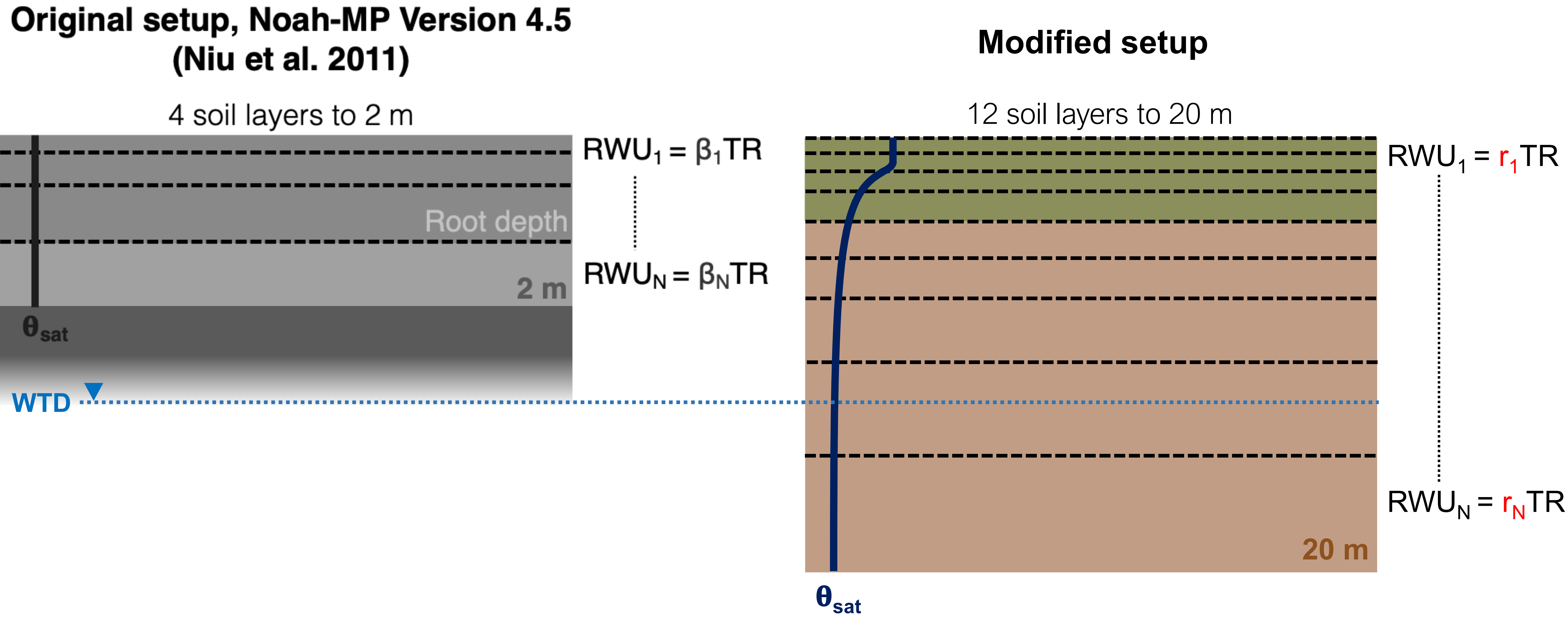

Rooting depth static in time
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Rooting depth varies in time
Use exponential function to vary soil props w/ depth
r used in root water uptake

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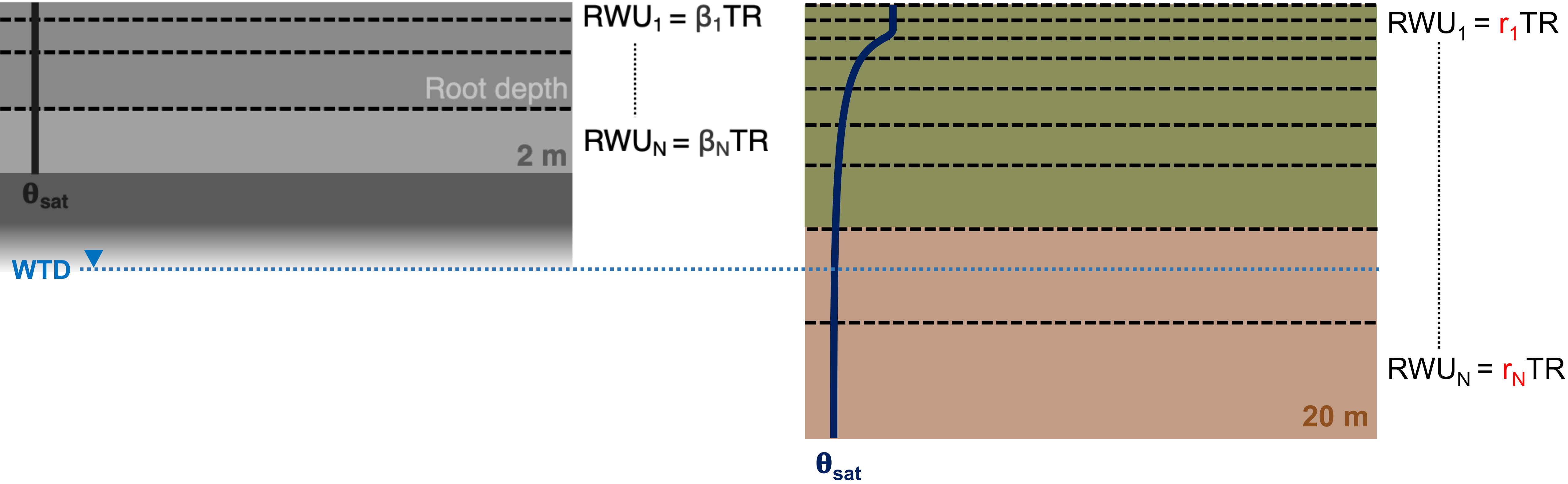
Original setup, Noah-MP Version 4.5 (Niu et al. 2011)

Modified setup

4 soil layers to 2 m

12 soil layers to 20 m



Rooting depth static in time
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Rooting depth varies in time
Use exponential function to vary soil props w/ depth
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The DRWU scheme is simple, scalable, and based on the soil water profile.

Ease function

$$e_j = \left(\frac{\psi_{lmin} - \psi_j}{\frac{2}{3} h_{veg} + d_j} \right)$$

Ψ_j matric potential at soil layer j
Ψ_{lmin} minimum leaf water potential (-2 MPa)
h_{veg} canopy height
d_j layer depth

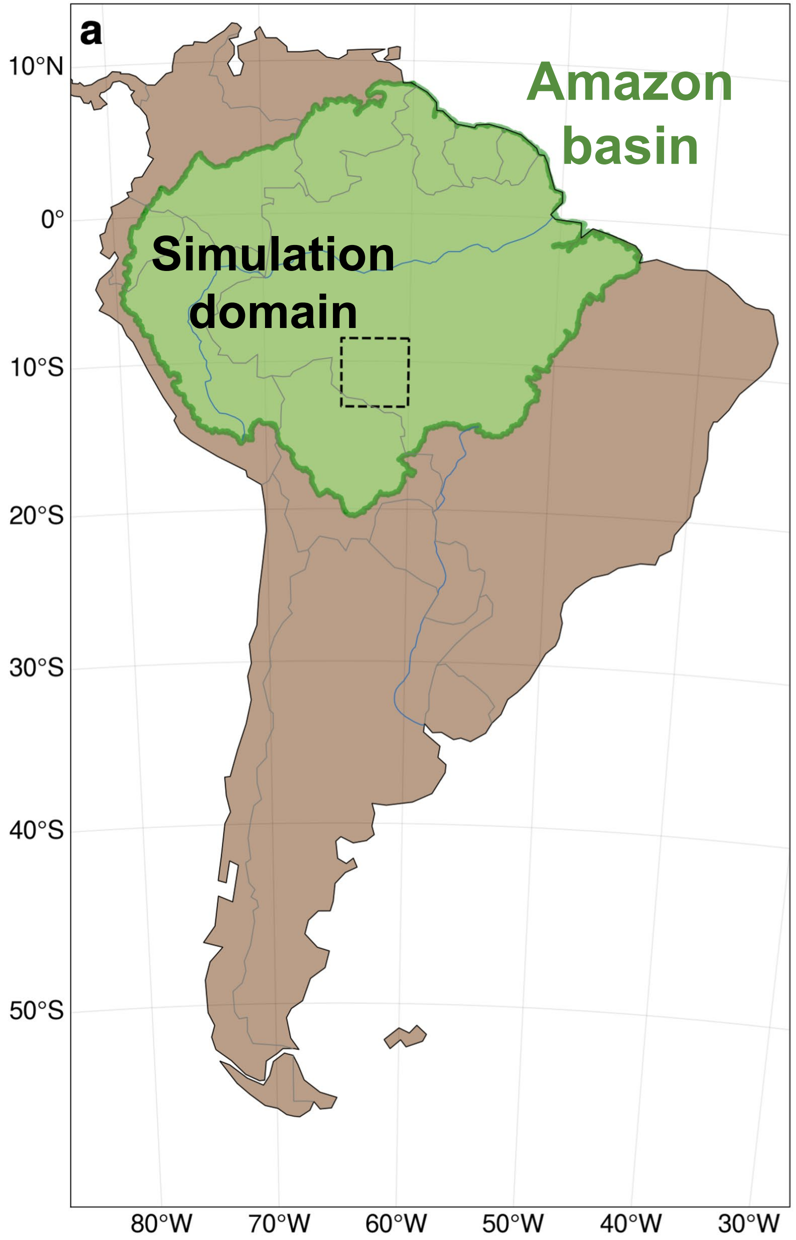
less effort for wetter and shallower layers

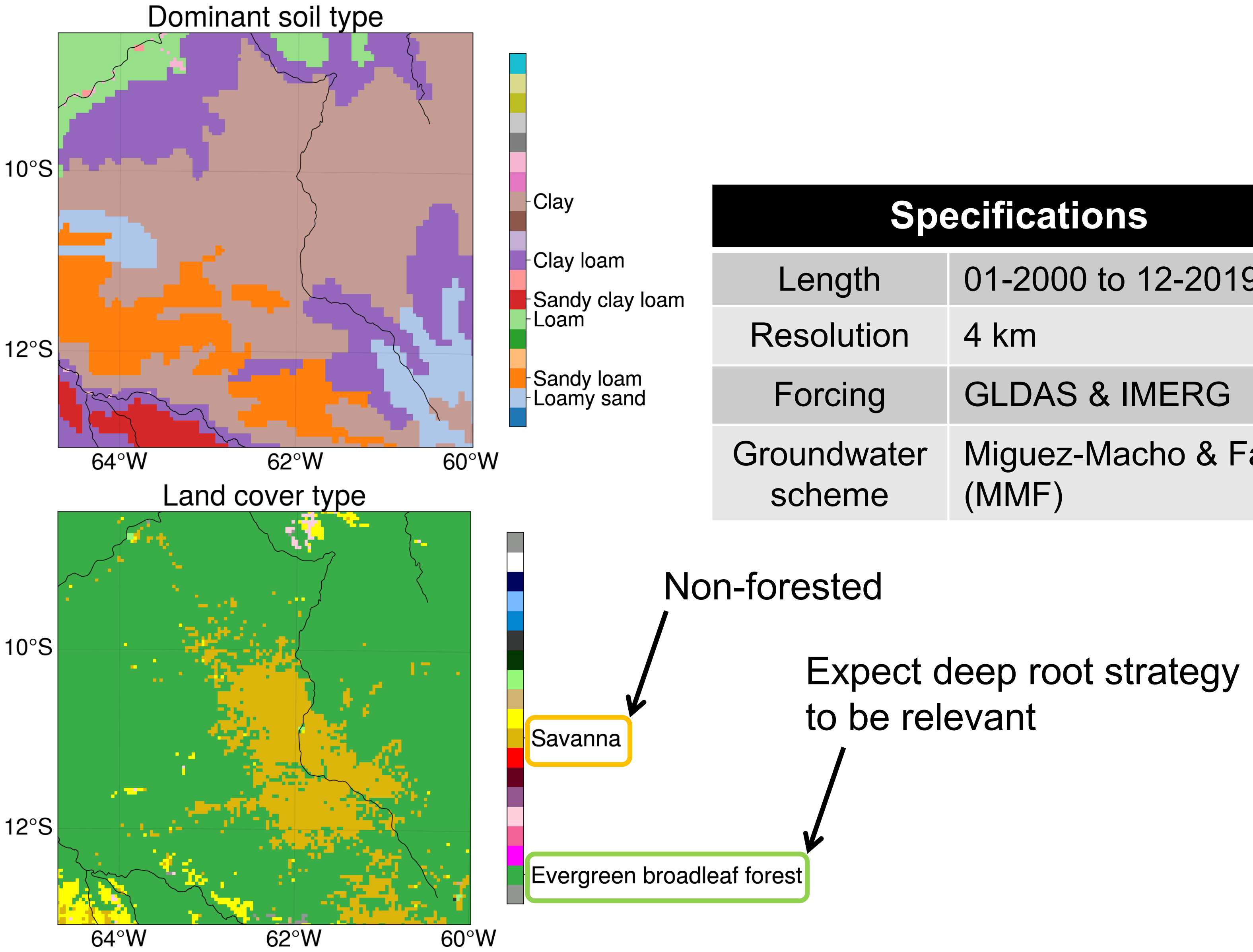
more effort for drier, deeper layers and taller vegetation

quantifies where & when it is advantageous for vegetation to take up deep moisture

For more details, see Fan et al. (2017), PNAS: *Hydrologic regulation of plant rooting depth*

We carry out uncoupled Noah-MP simulations for a domain in the southern Amazon.





Specifications	
Length	01-2000 to 12-2019
Resolution	4 km
Forcing	GLDAS & IMERG
Groundwater scheme	Miguez-Macho & Fan (MMF)

We carry out uncoupled Noah-MP simulations for a domain in the southern Amazon.

Case 1
CONTROL

Default Noah-MP

Case 2
GW

Default Noah-MP
+
GW scheme

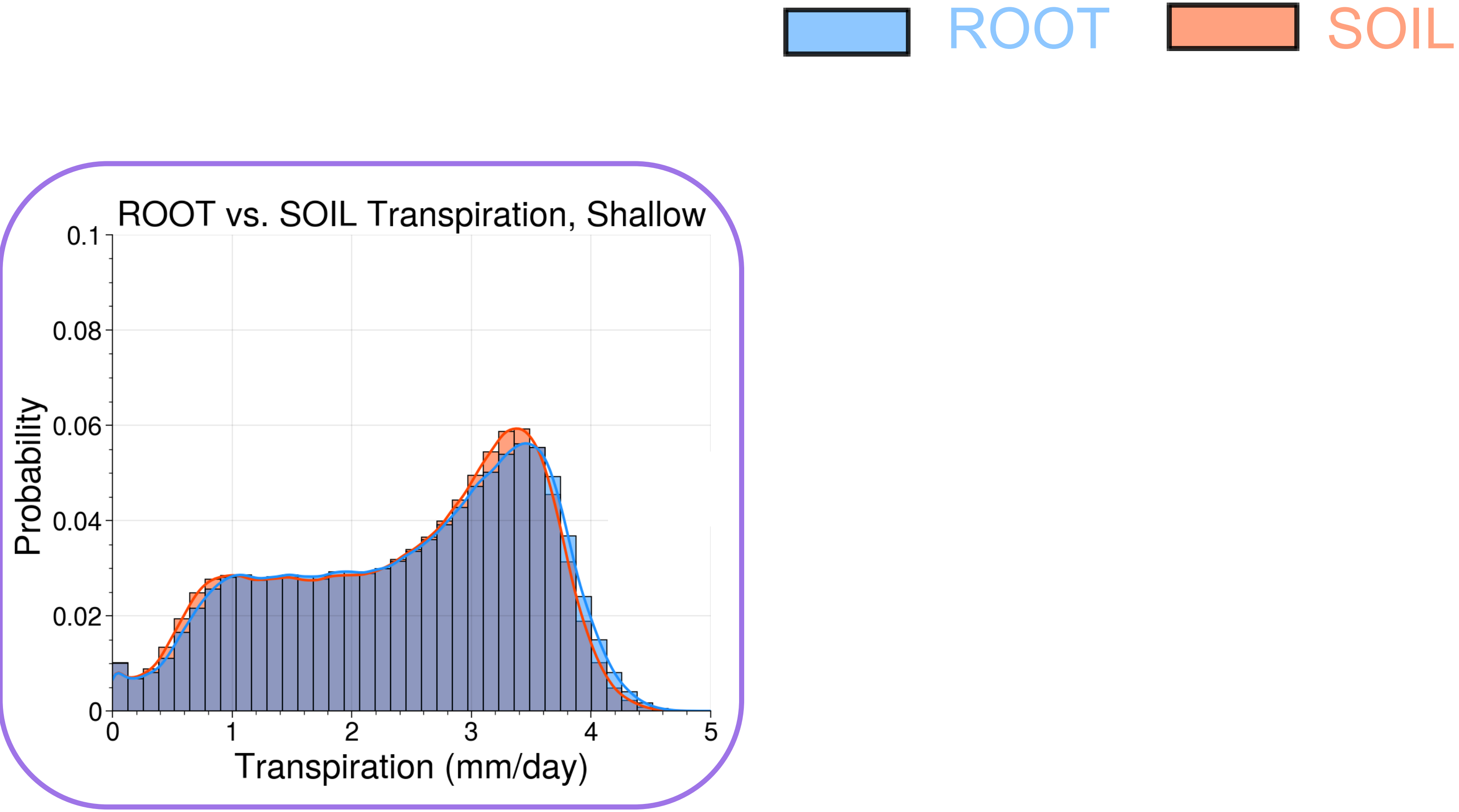
Case 3
SOIL

Default Noah-MP
+
GW scheme
+
Added soil layers

Case 4
ROOT

Default Noah-MP
+
GW scheme
+
Added soil layers
+
DRWU scheme

We see a clear shift in the distribution of mean dry season TR for grid points without waterlogging & with accessible deep moisture.



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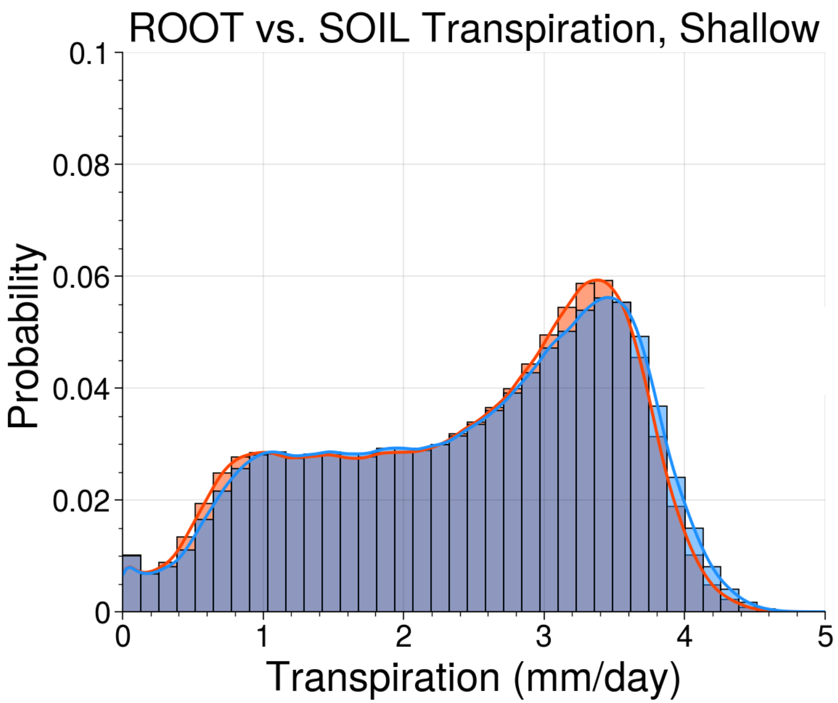
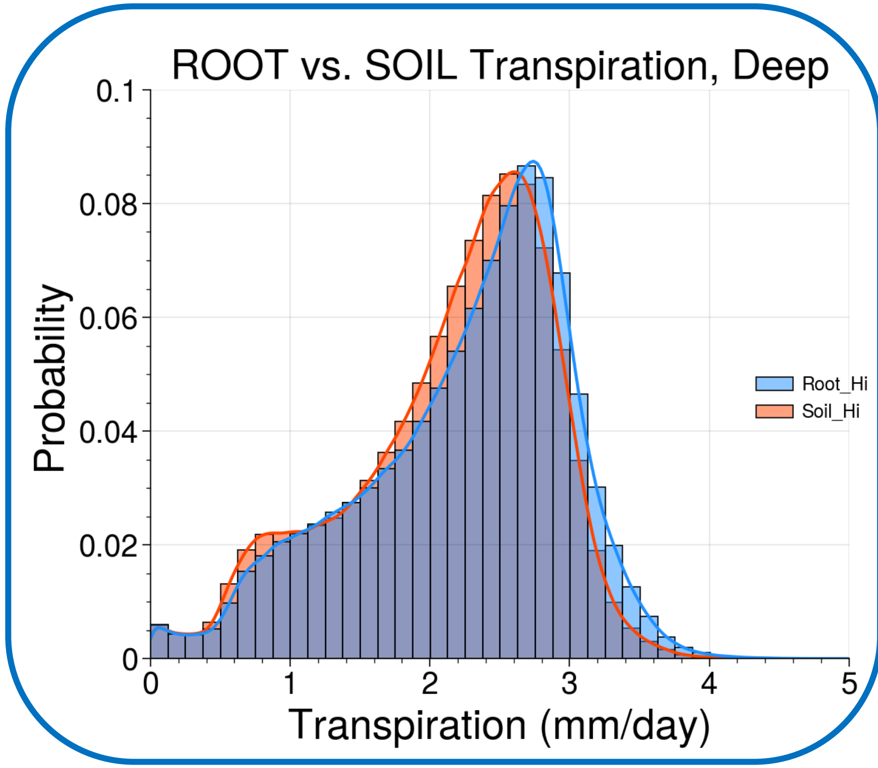
ROOT SOIL





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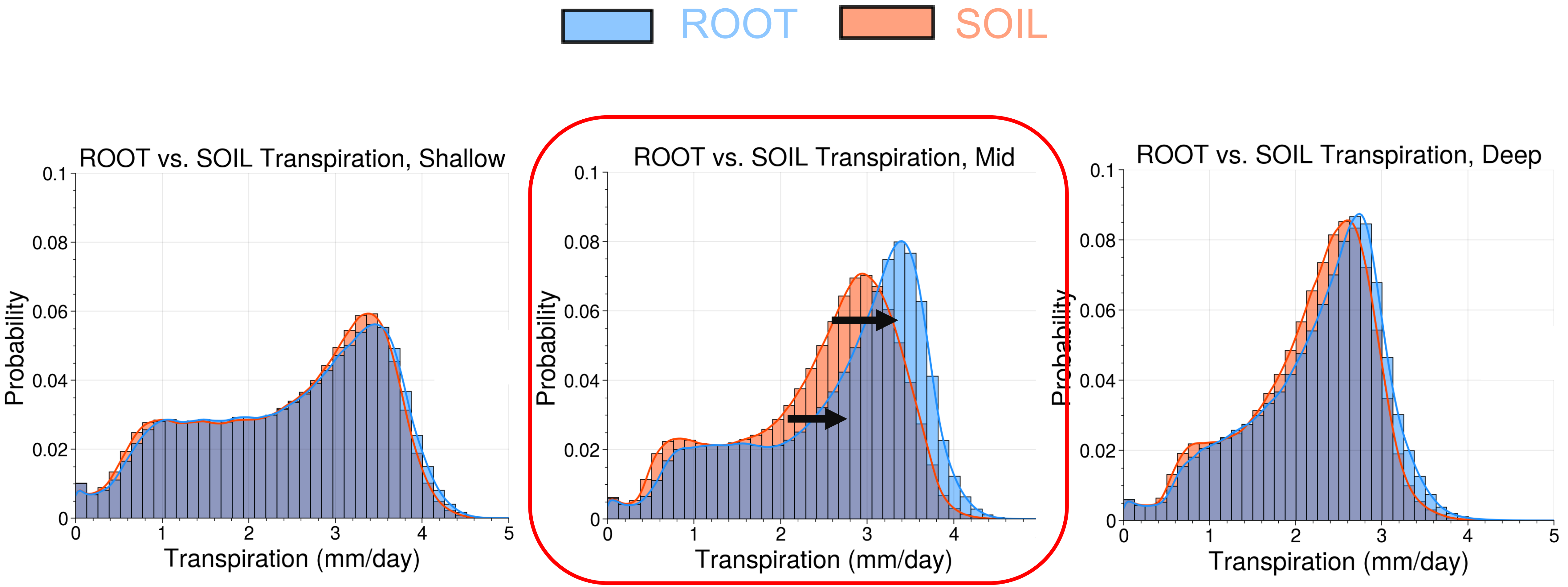

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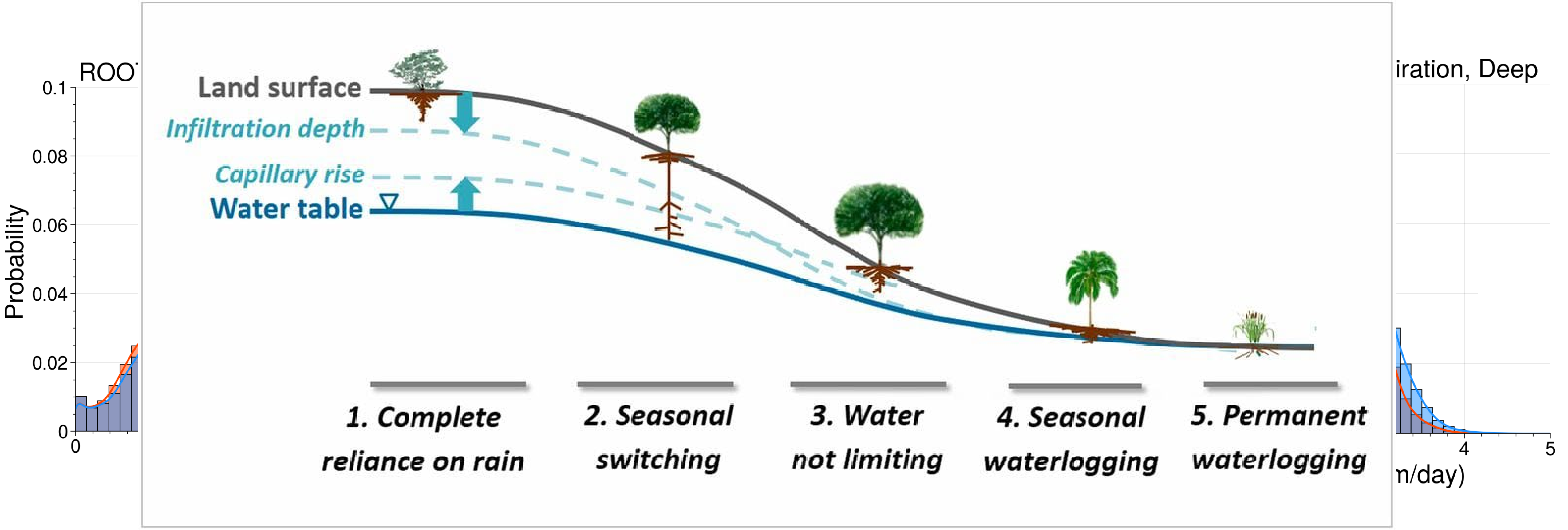
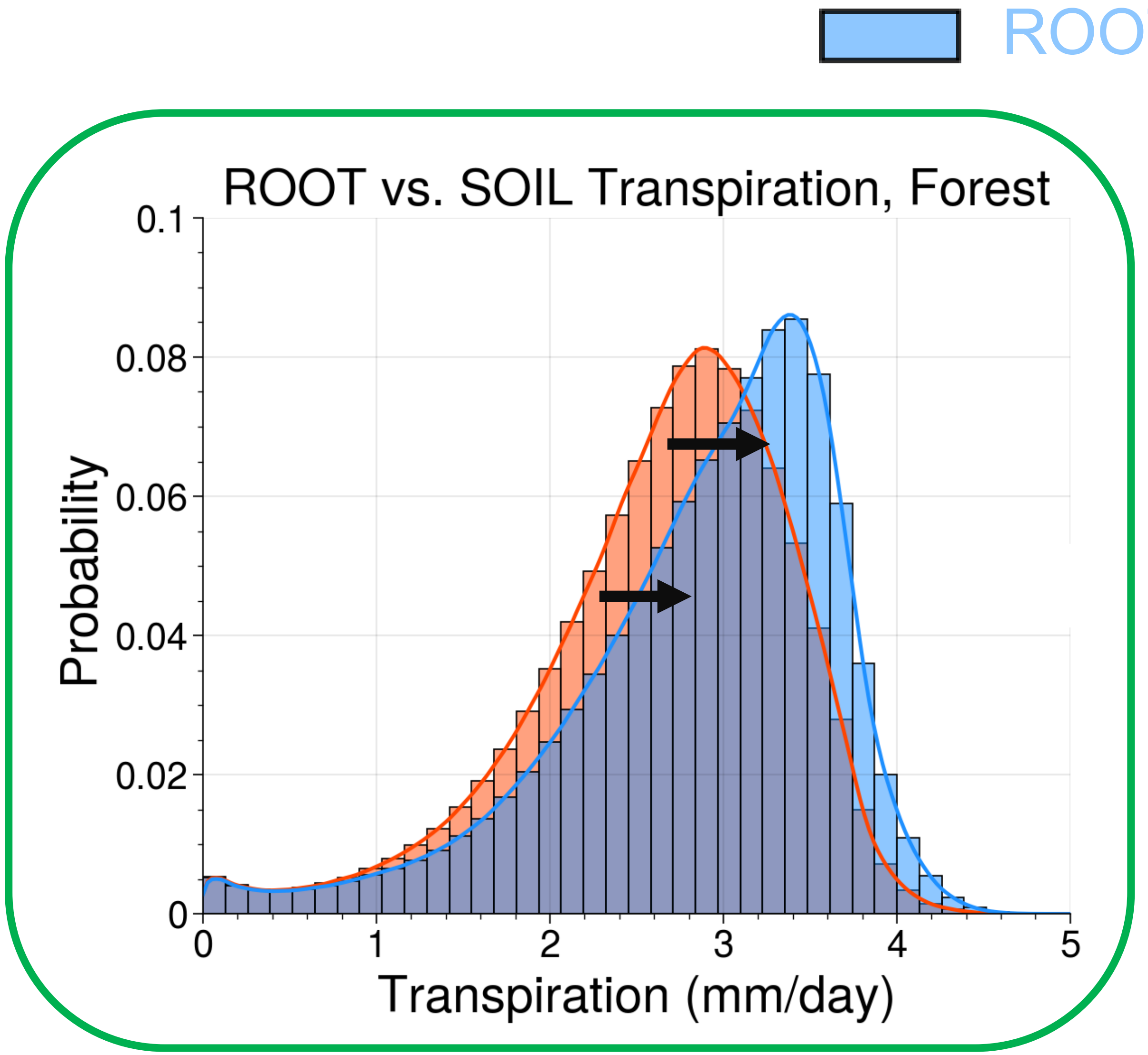


We see a clearer shift in the distribution towards higher values of dry season TR at forested grid points.



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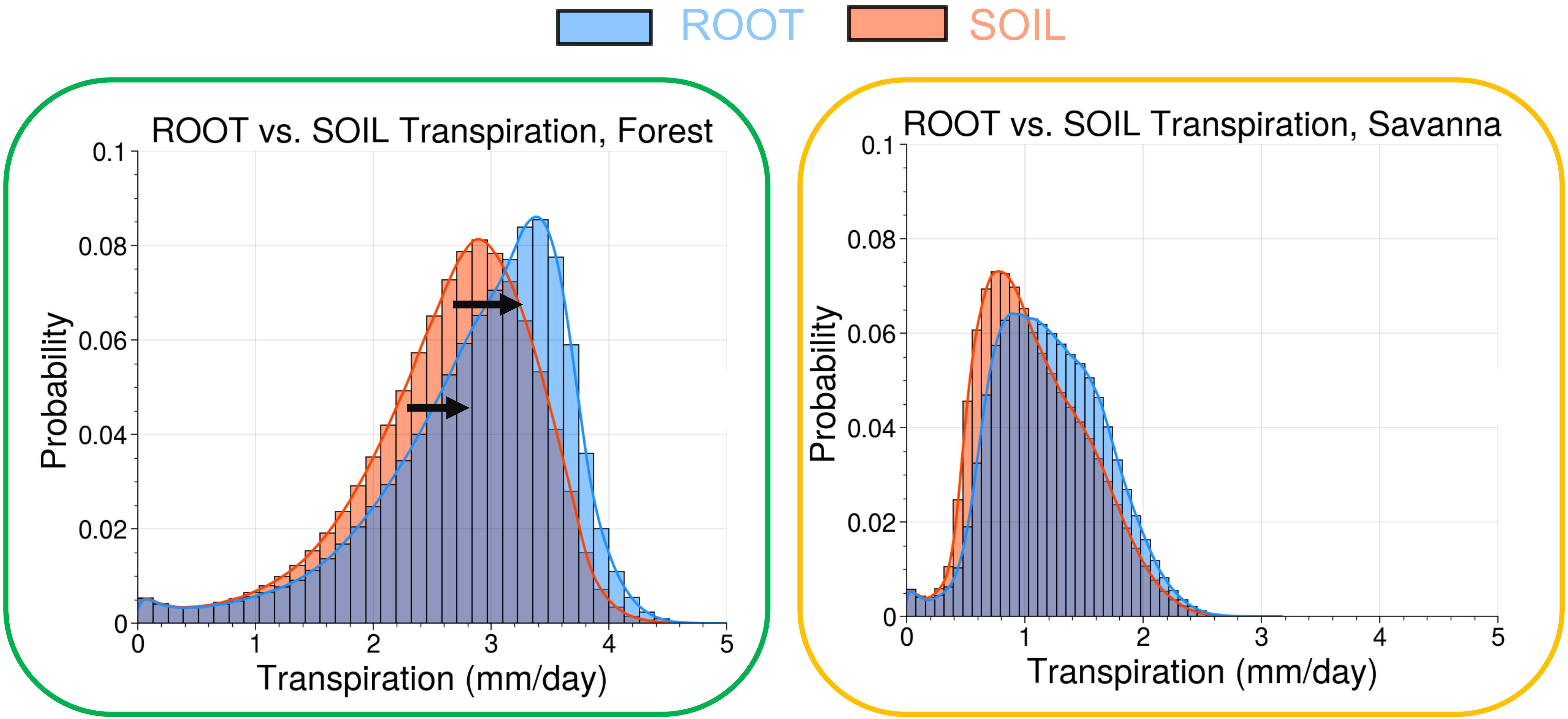
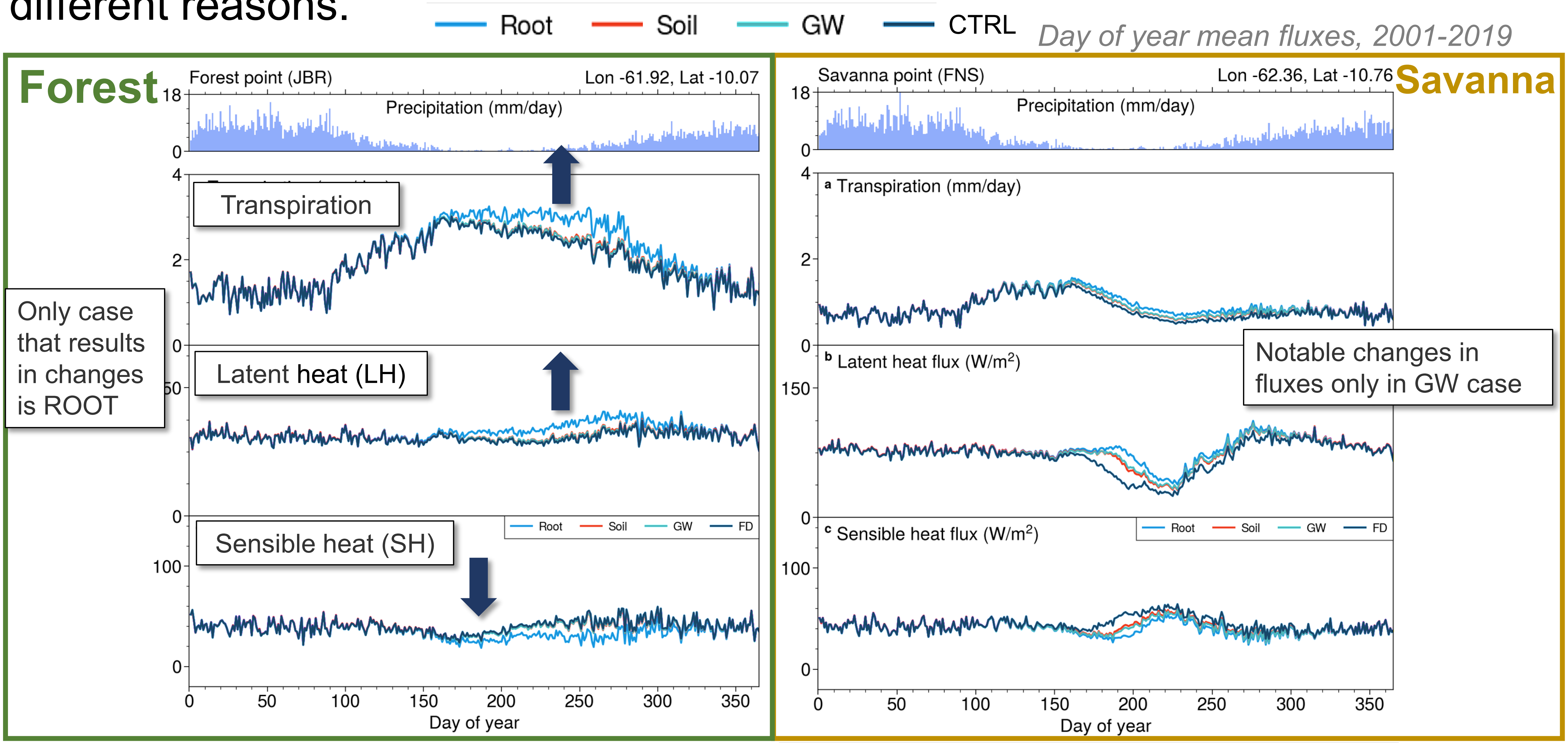


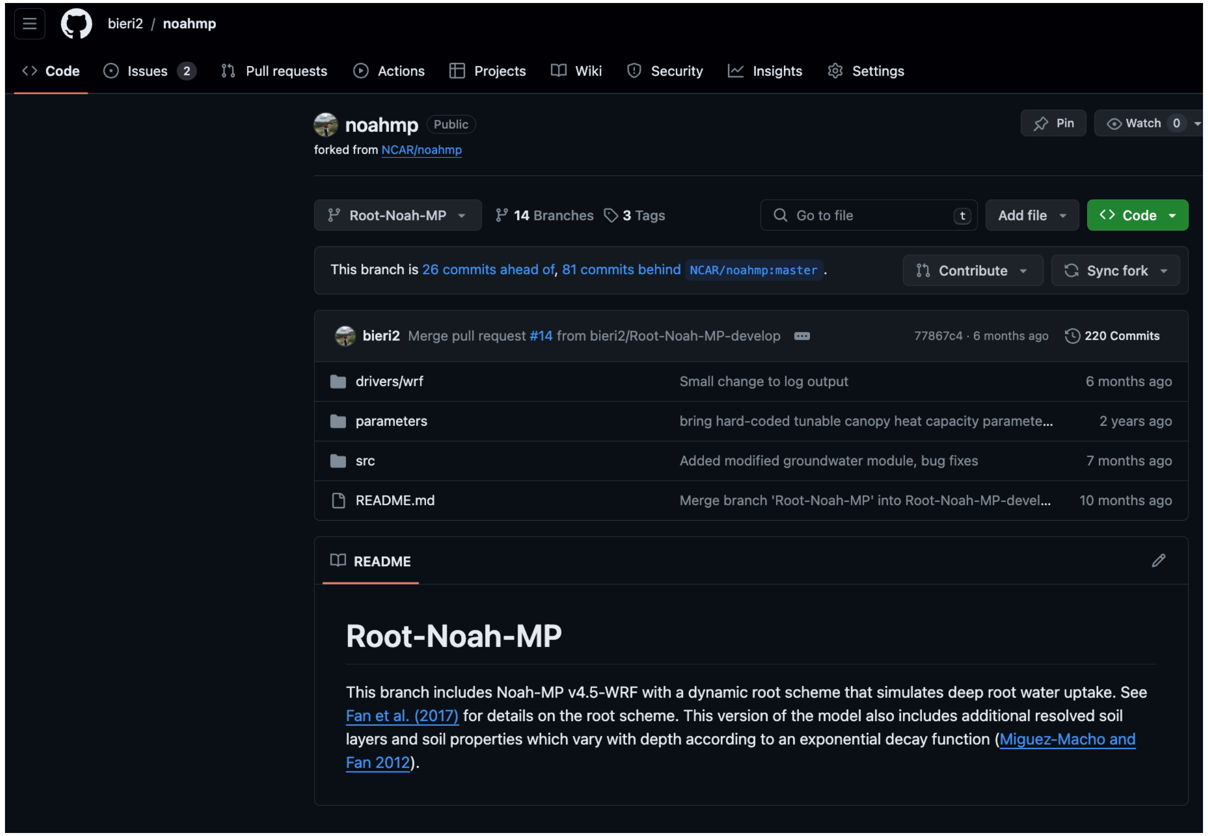
Mean annual cycles of fluxes indicate + LH and – SH at both points, but for different reasons.



Paper soon to be submitted to AMS Journal of Hydrometeorology

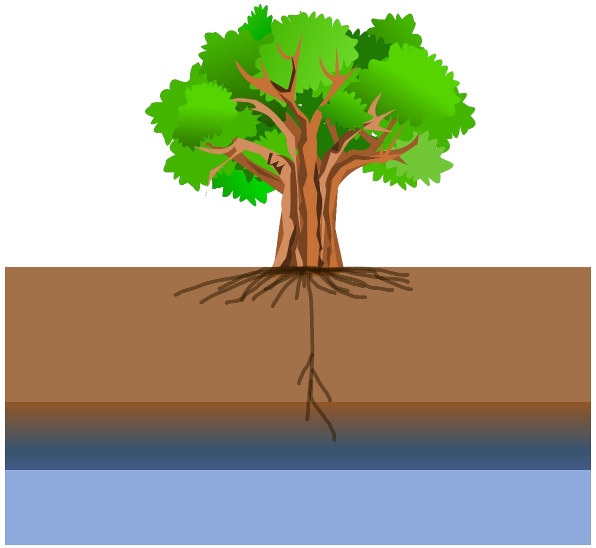
Working with Tim Lahmers @ NASA Goddard to implement root scheme in LIS Noah-MP

Code will be available for others to view on GitHub

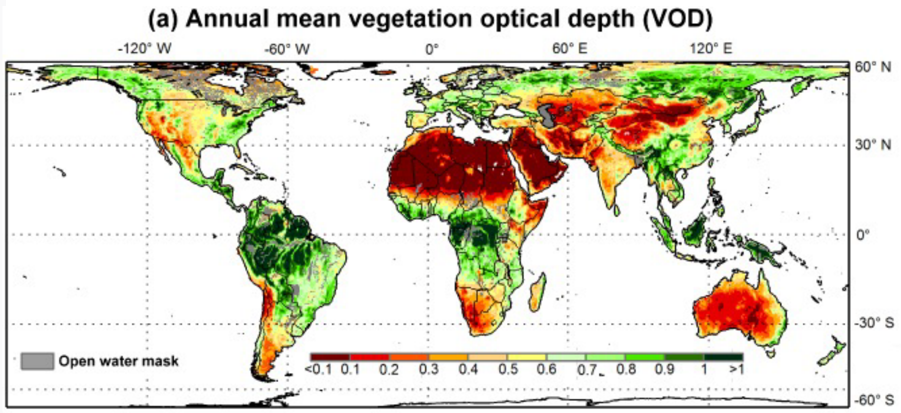


Conclusions

We implemented a deep, dynamic root water uptake scheme in Noah-MP and enhanced representation of the deep soil column.



A step forward for representation of soil moisture, RWU, and land surface fluxes in Noah-MP



Future work will focus on validation of results using vegetation optical depth data.
We also hope to study the effects of the scheme in a coupled framework.

Thank you!

Mature forests in the Amazon rely on deep roots to avoid water stress during the dry season.

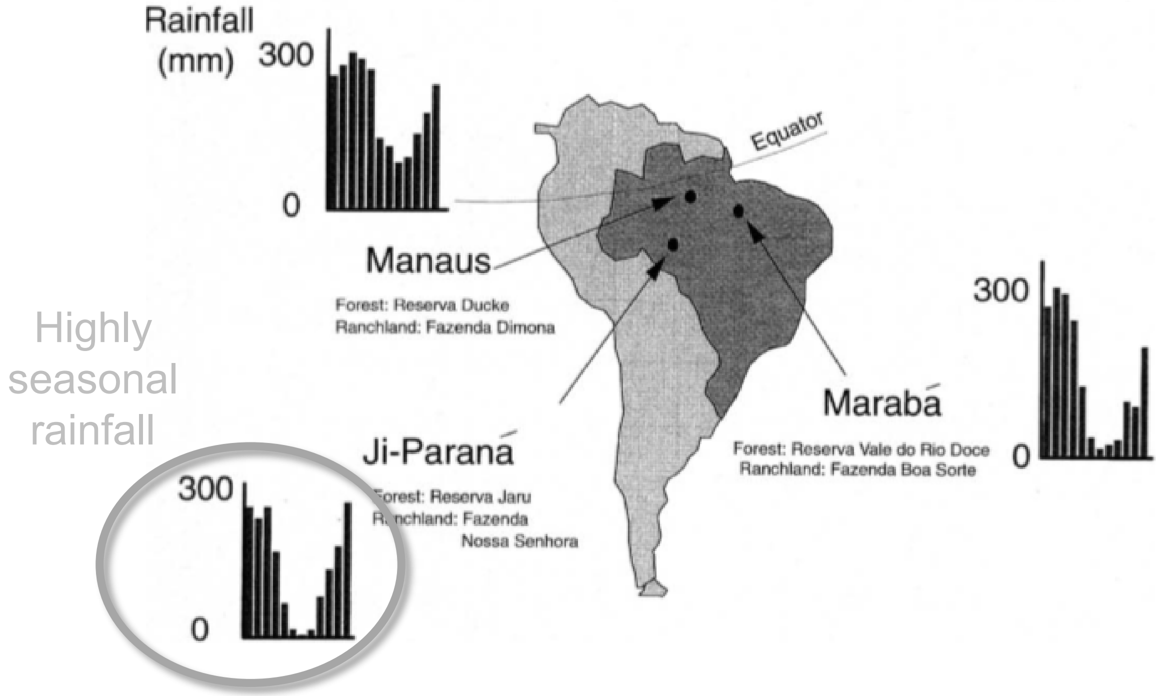


Figure: Gash and Nobre (1997)

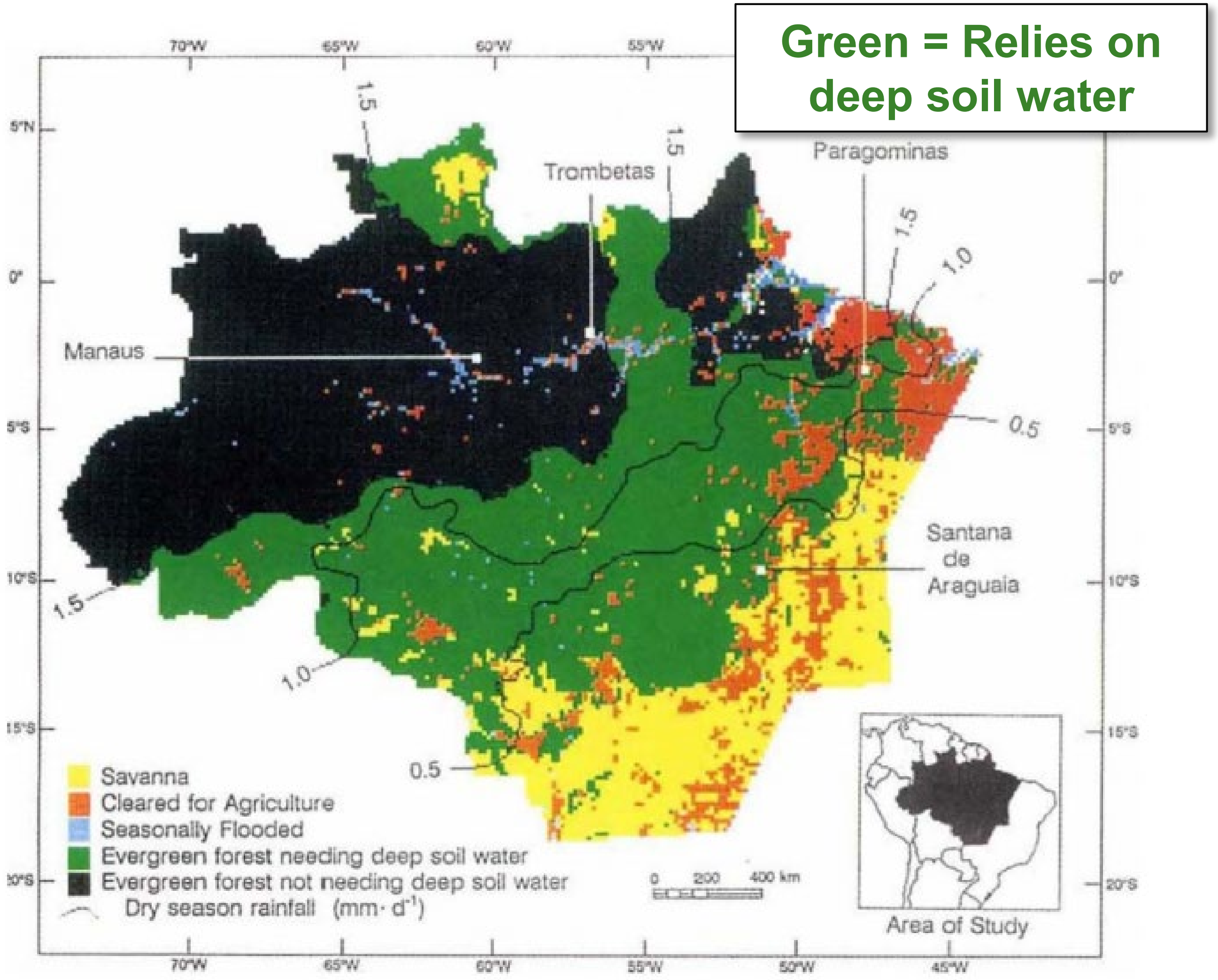


Figure: Nepstad et al. (1994)

The DRWU scheme is simple, scalable, and based on the soil water profile.

Ease function

$$e_j = \left(\frac{\psi_{lmin} - \psi_j}{\frac{2}{3} h_{veg} + d_j} \right)$$

Ψ_j matric potential at soil layer j
Ψ_{lmin} minimum leaf water potential (-2 MPa)
h_{veg} canopy height
d_j layer depth

Root activity

$$r_j = \frac{e_j \Delta z_j}{\sum e_j \Delta z_j}$$

Contribution from each soil layer

Ease function weighed by layer thickness (soil water store)

Δz_j thickness of soil layer j

For more details, see Fan et al. (2017), PNAS: *Hydrologic regulation of plant rooting depth*

We calculate varying soil properties with depth based on exponential decay functions.

κ_{sat}, θ_{sat}, θ_{wilt}, ψ_{sat}, D_{sat}
vary exponentially with depth on kilometer scales

$$K_{sat_i} = K_{o_{sat}} exp(\frac{-z}{f})$$

$$\psi_{sat_i} = -\psi_{o_{sat}} exp(\frac{z}{f})$$

$$\theta_{sat_i} = \theta_{o_{sat}} exp(\frac{-z}{f})$$

$$\theta_{wilt_i} = \theta_{o_{wilt}} exp(\frac{-z}{f})$$

$$D_{sat_i} = \frac{-K_{sat_i} \psi_{sat_i} B_i}{\theta_{sat_i}}$$

z → layer depth from surface
f → controls how fast permeability decreases with depth (input data for MMF)
$K_o, \psi_o, \theta_o, etc.$ → known value at top of column (table parameter; dependent on soil type)

Sources: Miguez-Macho & Fan (2012), Beven & Kirkby (1979)

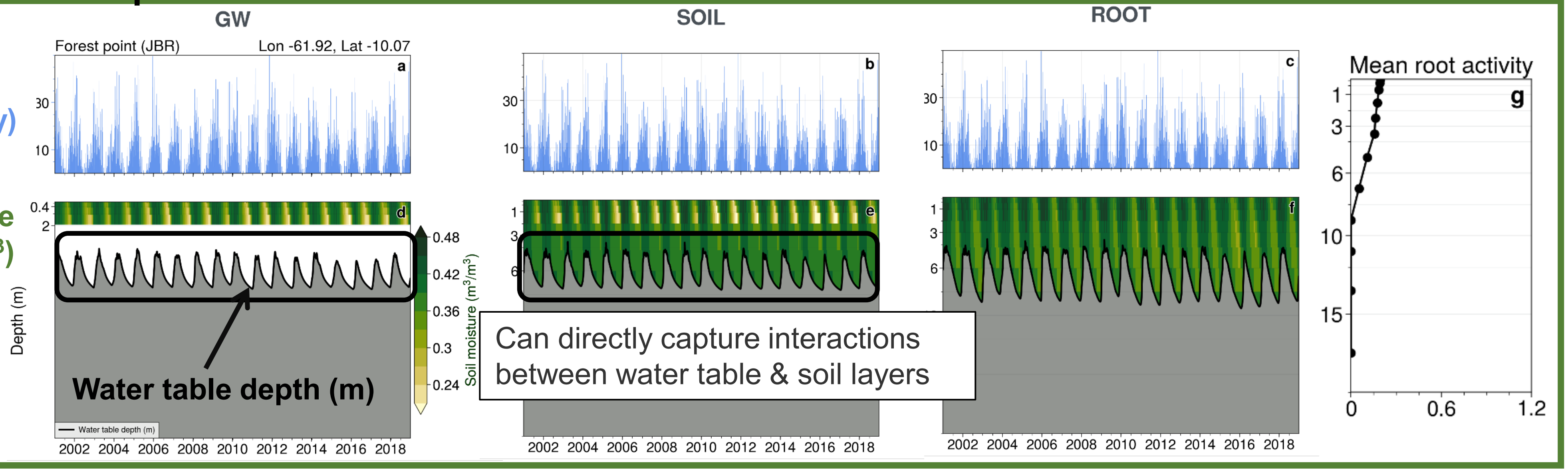
Time series at forest & savanna points reflect additional layers and seasonal dependence on deep RWU.

Daily mean time series, 2001-2019

Forest

Precipitation (mm/day)

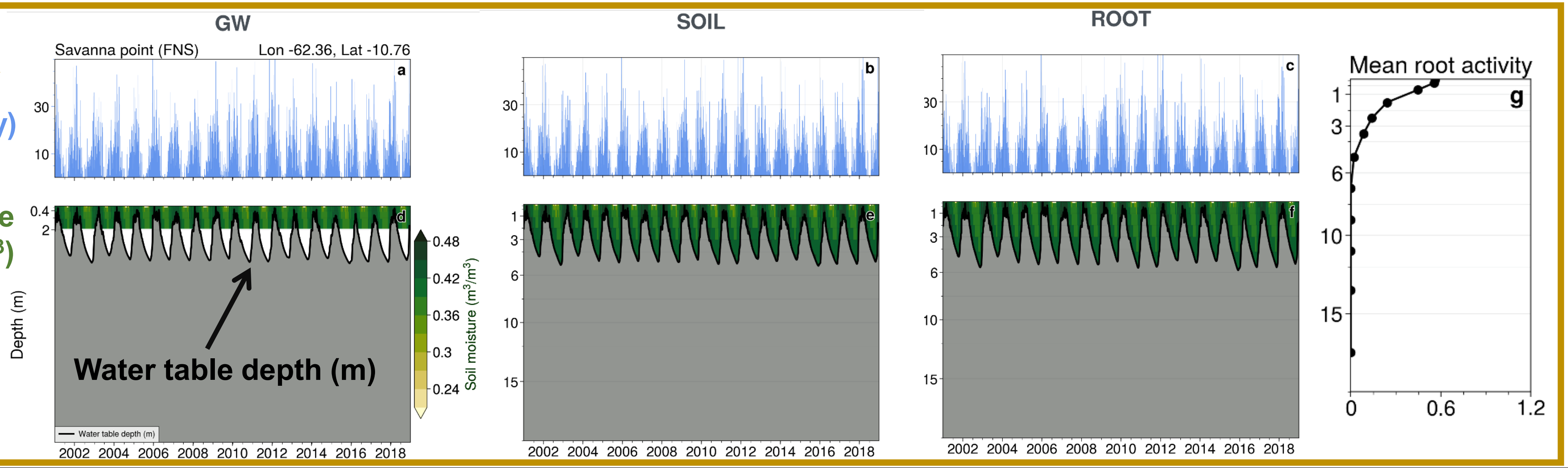
Soil moisture (m^3/m^3)



Savanna

Precipitation (mm/day)

Soil moisture (m^3/m^3)



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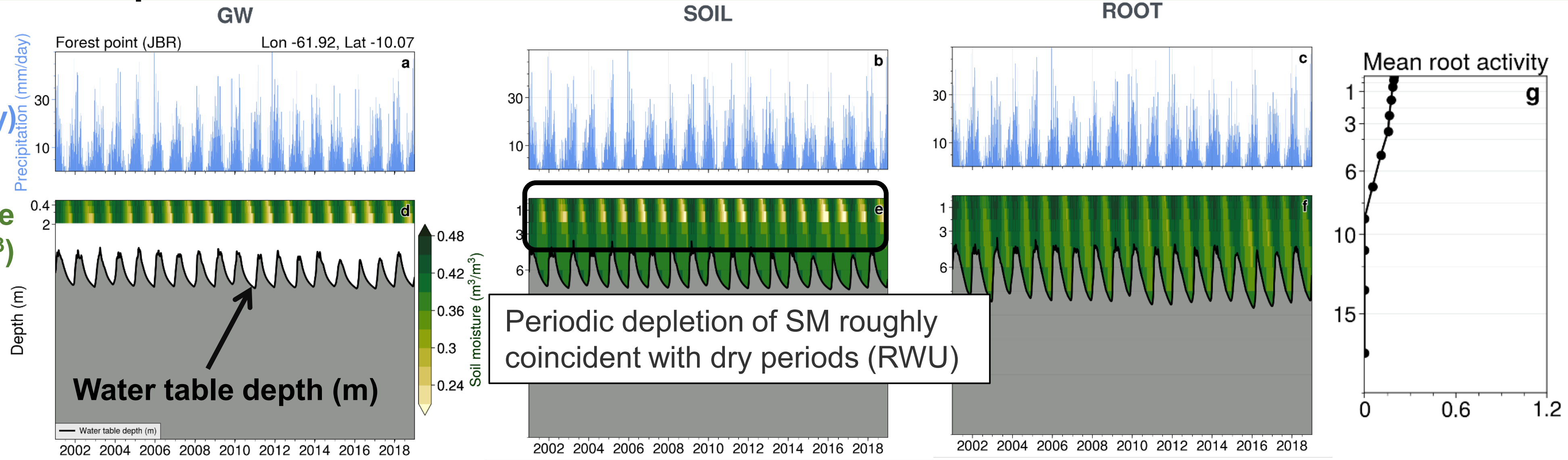
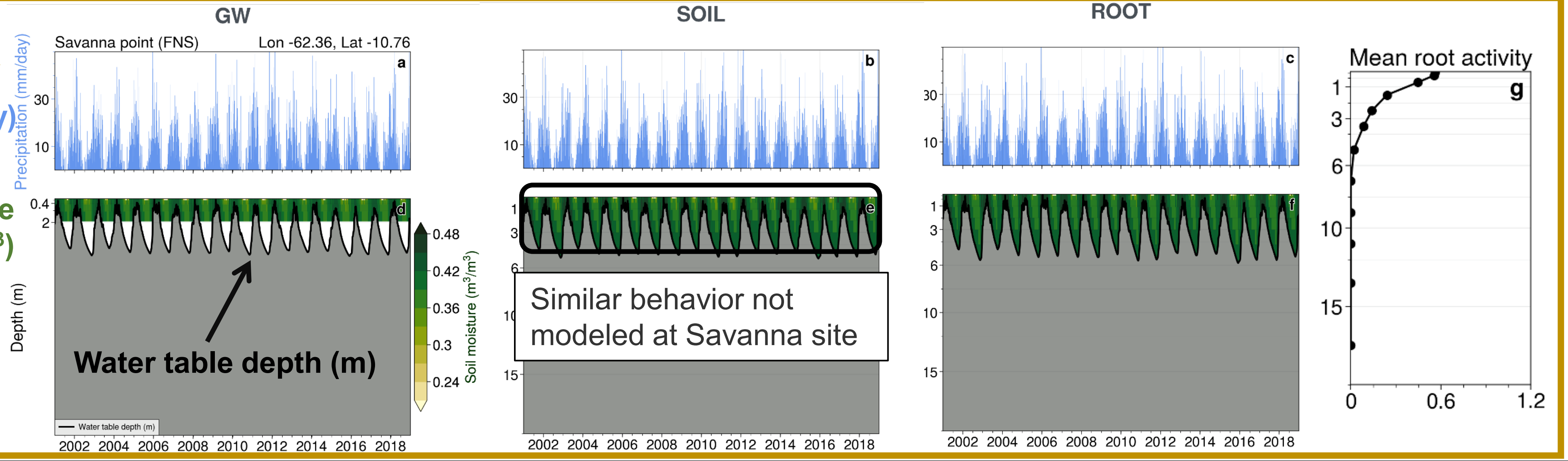


Savanna



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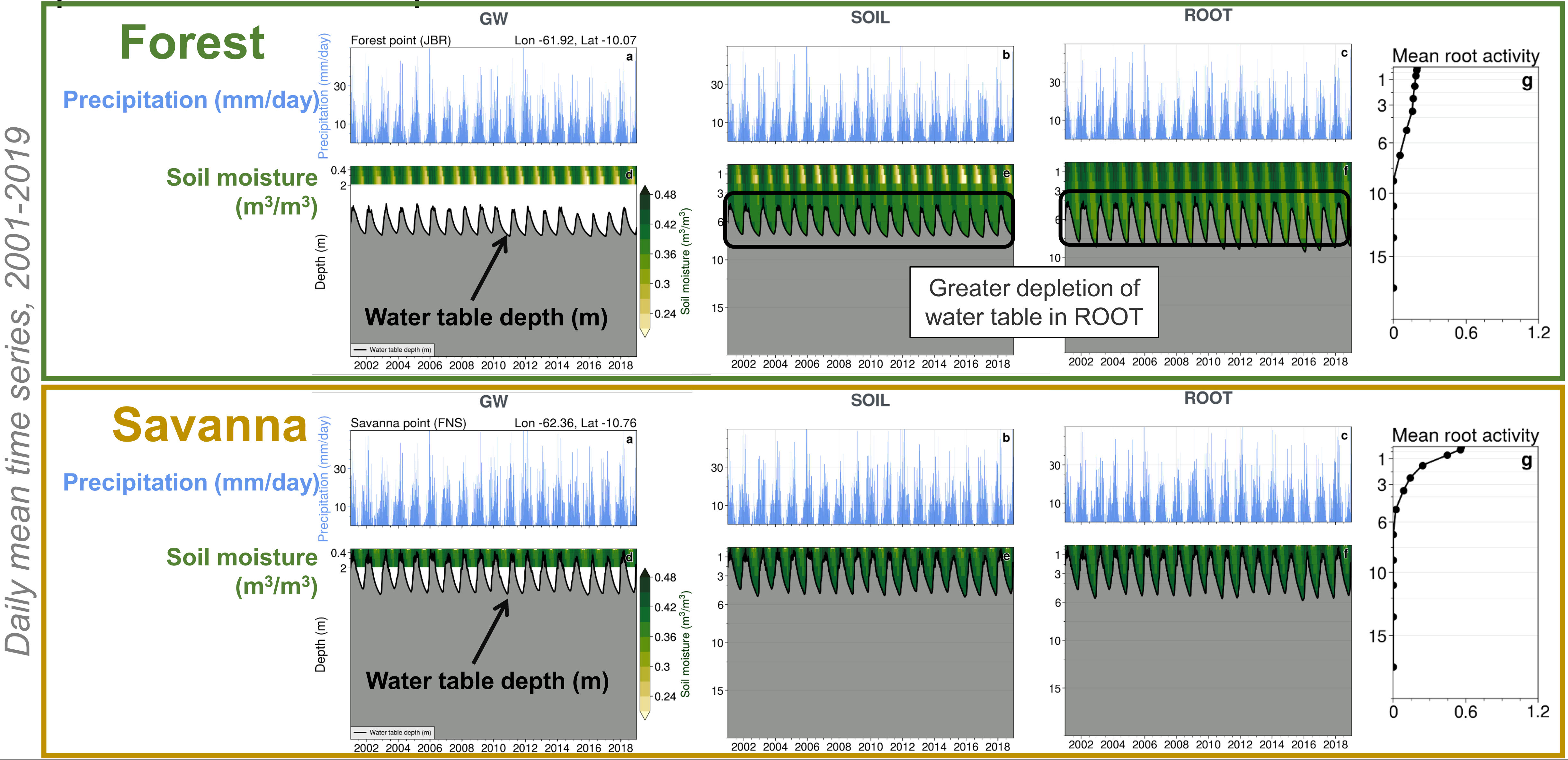

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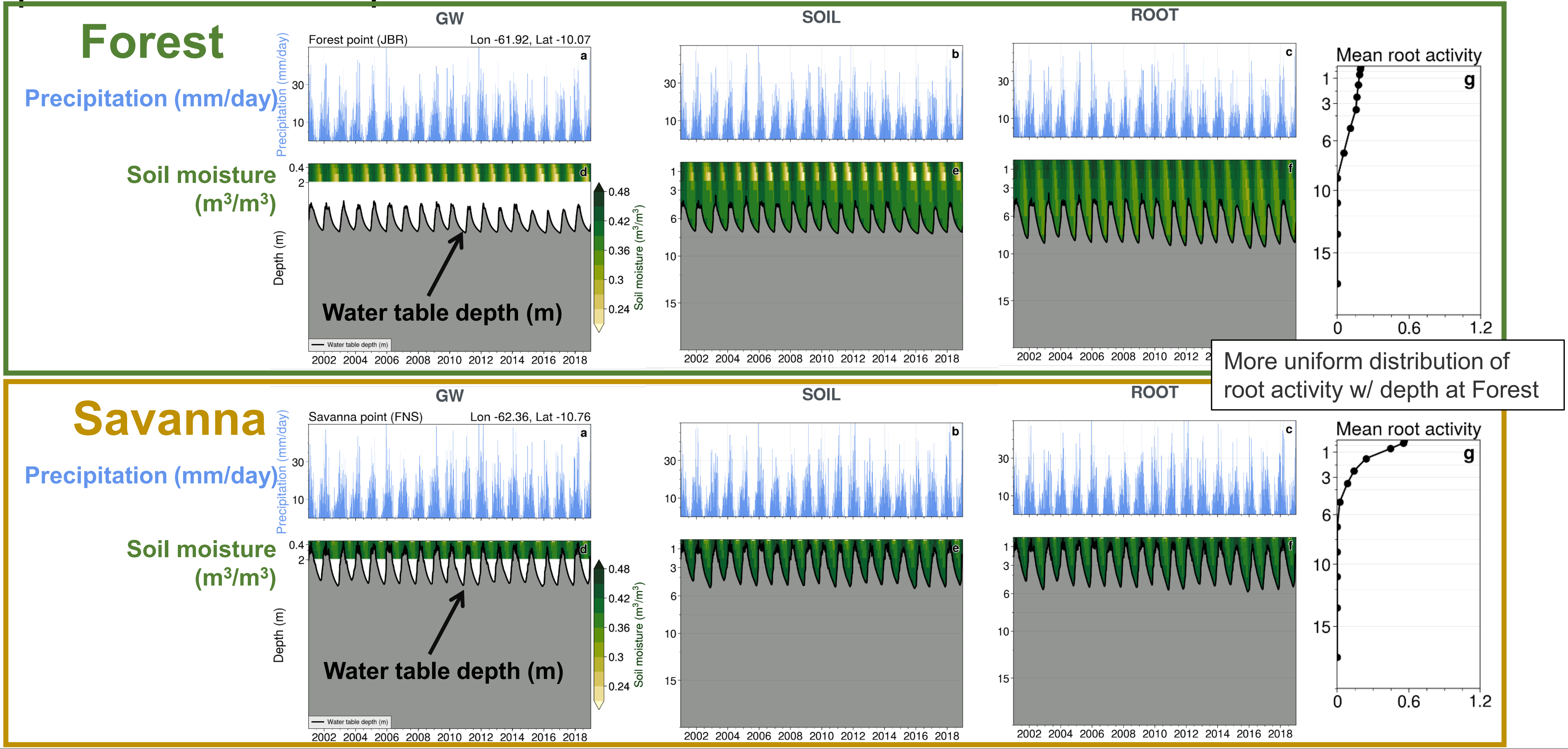

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