NCAR Earth System Laboratory

Investigating the role of Land Surface Hydrology in Land Cover Change in CLM 4

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Terrestrial Science Section

Simulating the Biogeochemical and Biogeophysical Impacts of Transient Land Cover Change and Wood Harvest in the Community Climate System Model (CCSM4) from 1850 to 2100.

Lawrence, P. J., J. J. Feddema, G. B. Bonan, G. A. Meehl, B. C. O'Neill, S. Levis, D. M. Lawrence, K. W. Oleson, E. Kluzek, K. Lindsay, and P. E. Thornton (2012) *Journal of Climate*, In Press

The National Center for Atmospheric Research sponsored by NSF

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1. Investigate CLM4 under extreme land cover change

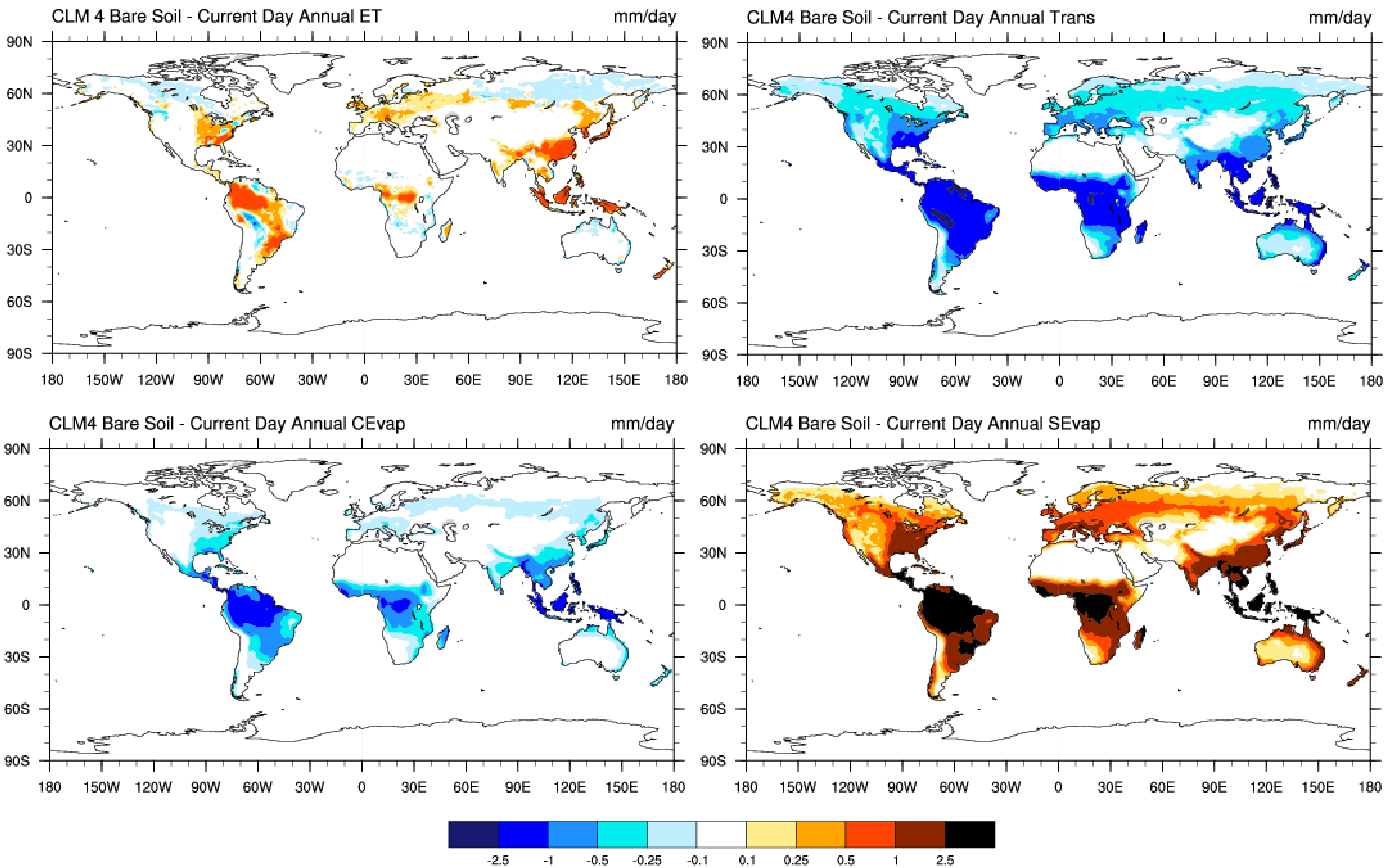
1. Investigate changes in land surface climate of CLM4 with land cover change. All experiments are forced with Qian meteorology for 1970 – 1999 and have monthly satellite phenology (SP) Leaf Area Index.

2. Control: Current day vegetation

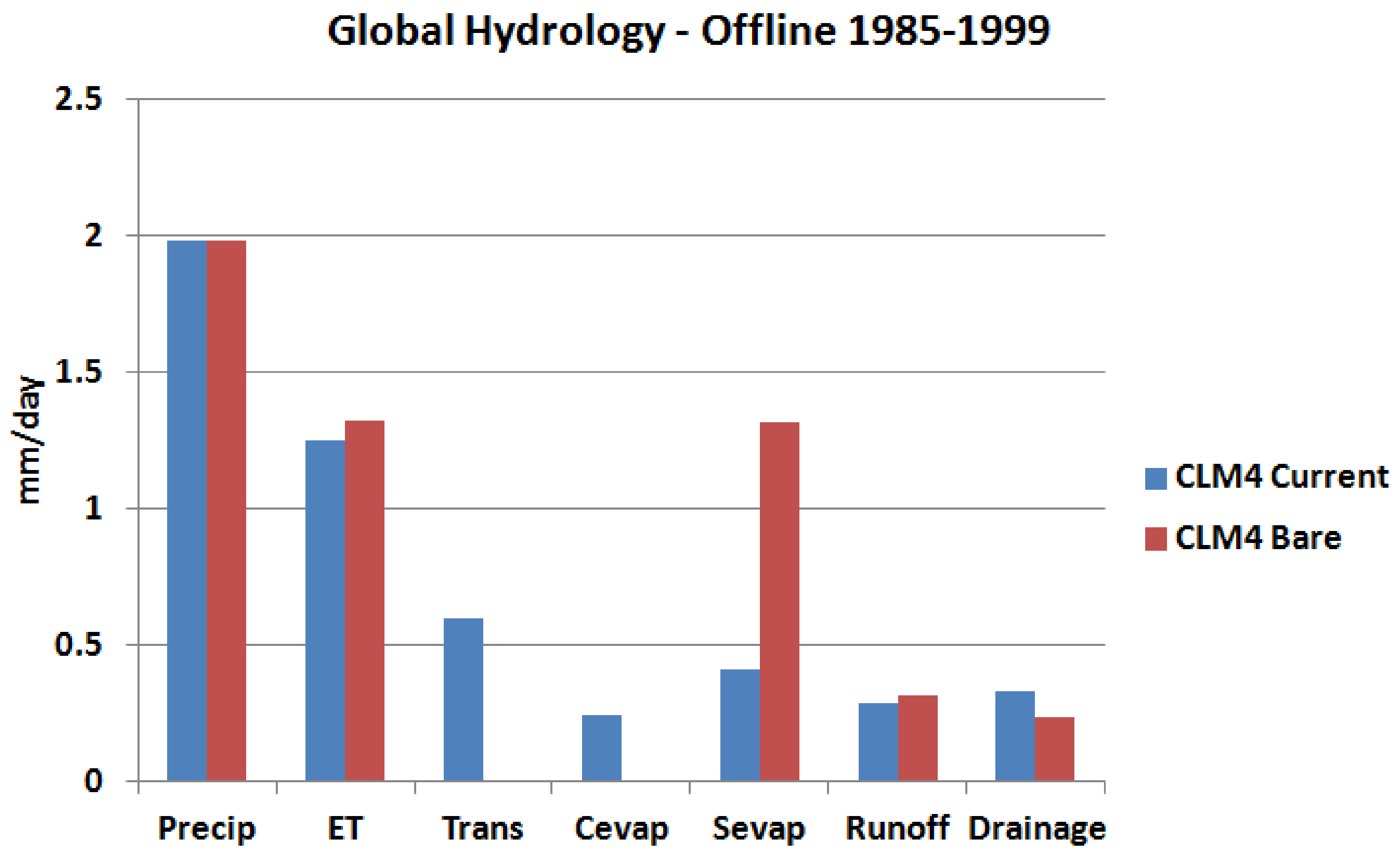
3. Vegetation Removal: Global bare soils

4. All Grass: All current day vegetation replaced with climate appropriate grass PFTs (Bare soil stays at Current Day values)

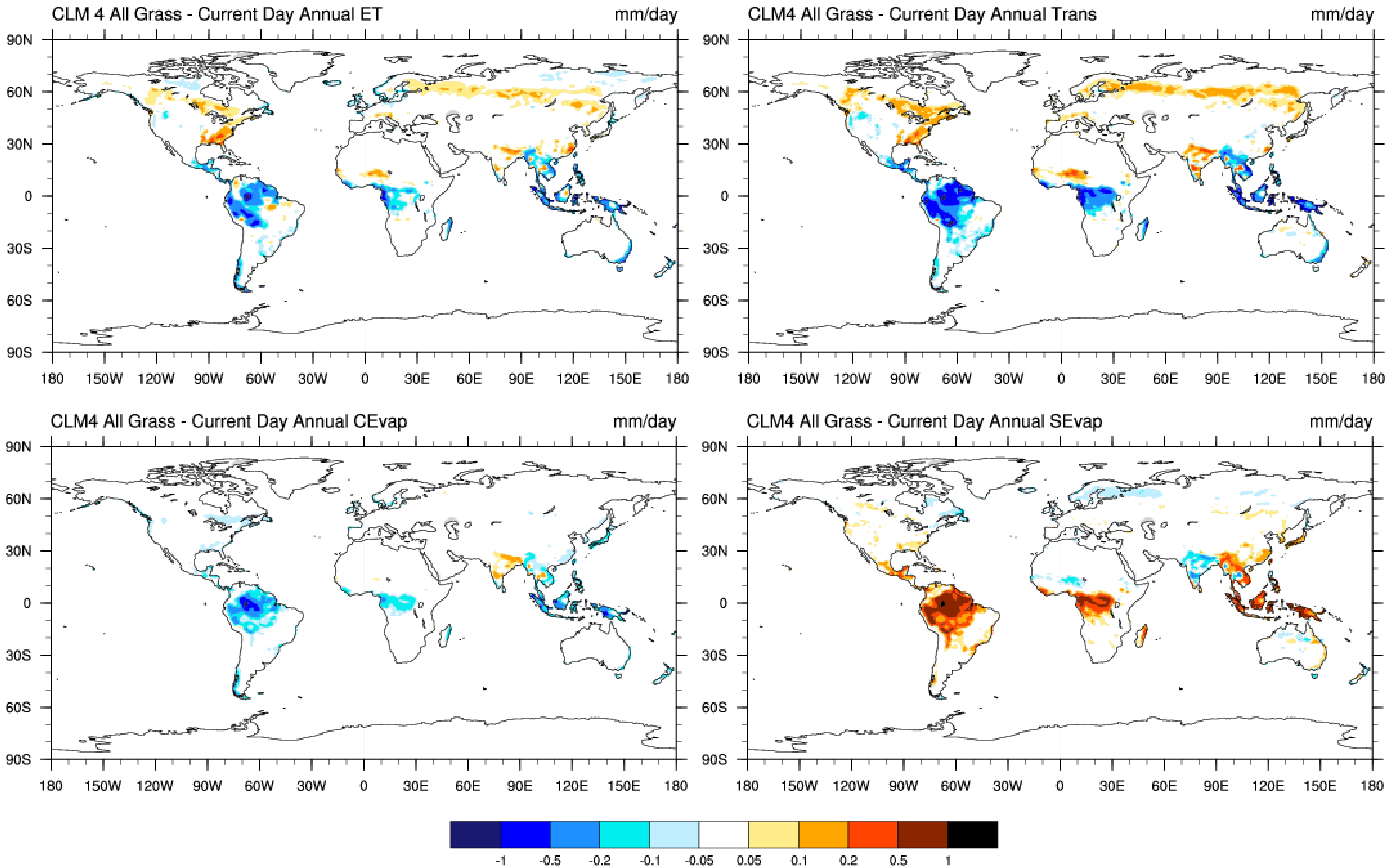
1. Offline CLM4 – Vegetation Removal – Annual ET



1. Offline CLM4 – Vegetation Removal – Global Hydro



1. Offline CLM4 – Vegetation to All Grass– Annual ET



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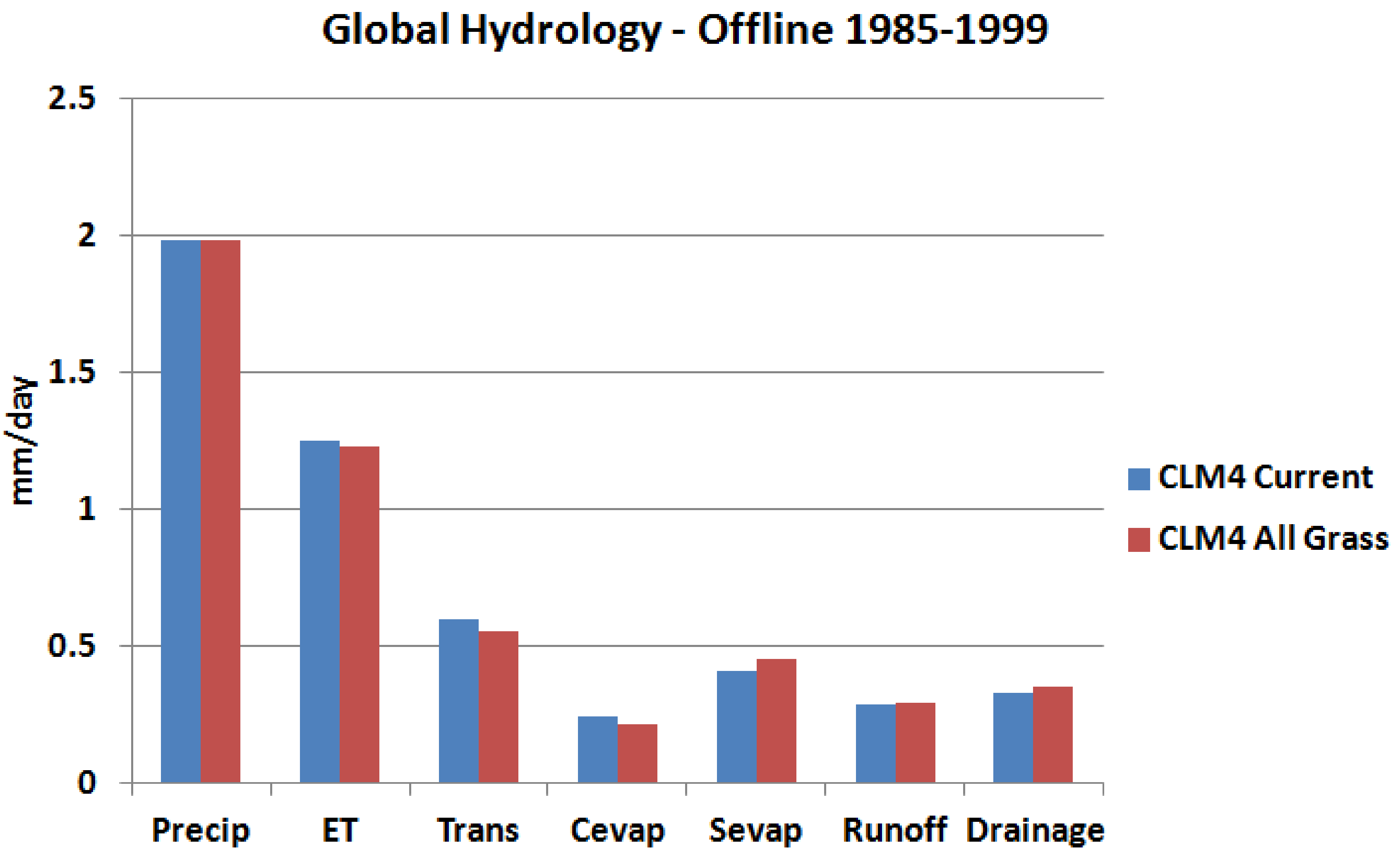


2. Human Land Cover Change and CLM4

Flux Tower studies such as the Large-scale Biosphere-Atmosphere Experiment in the Amazon (LBA) (*von Randow, et al.*, 2004), found that tropical deforestation resulted in reduced evapo-transpiration with increased sensible heat flux:

- Forested areas had 20% higher evapo-transpiration and 45% lower sensible heat flux than nearby pastures in the wet season

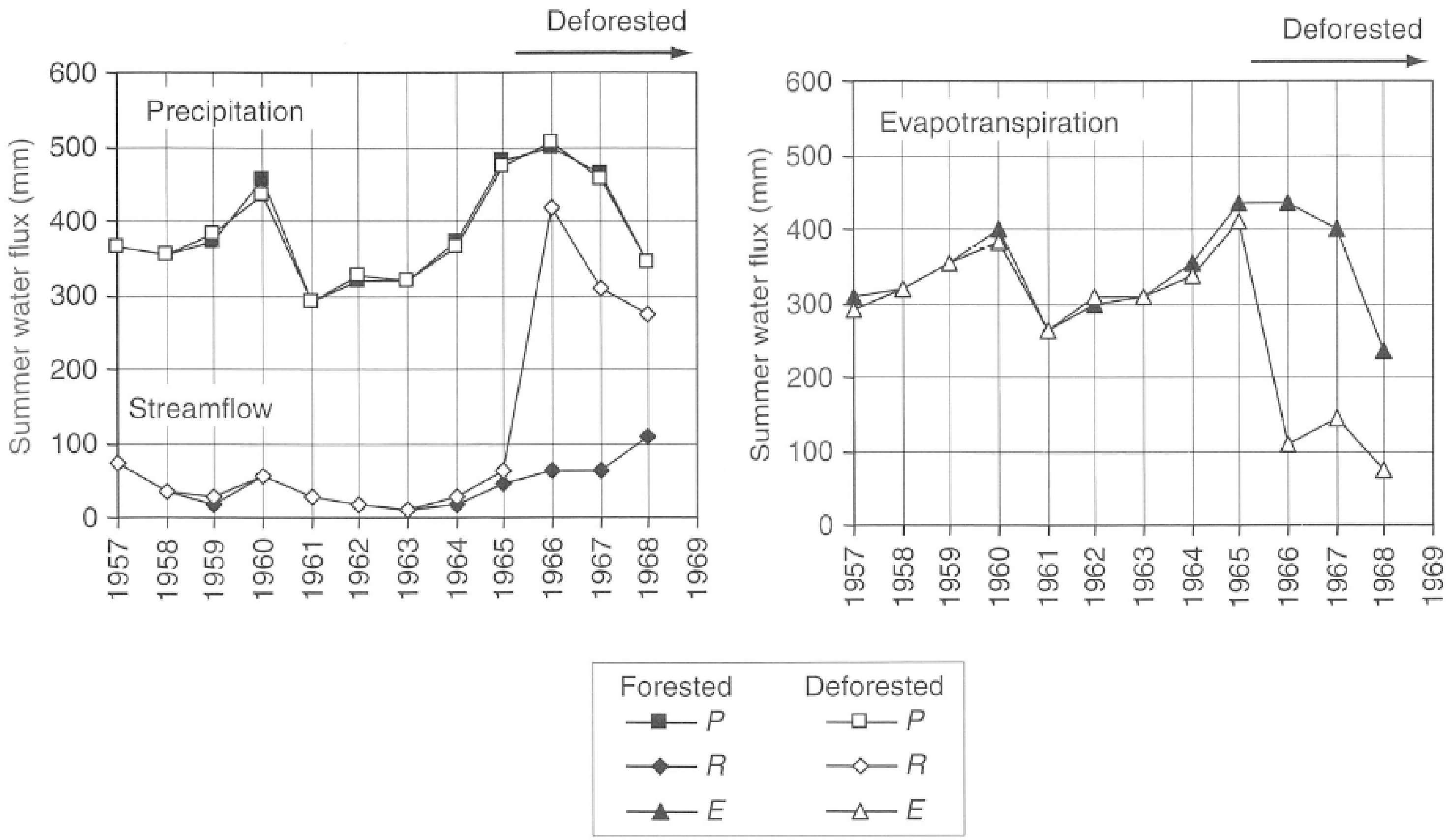
- Forested areas also had 41% higher evapo-transpiration and 28% lower sensible heat flux in the dry season.

- Trees were able to access soil water from deep in the soil profile while the pasture vegetation could only access water from the upper soil layers.

2. Human Land Cover Change and CLM4

Paired Catchment Hydrology Studies also show Temperate Deforestation can result in reduced Evapo-Transpiration and increased Runoff

Hubbard Brook Experimental Forest, New Hampshire Study (*Likens* 2004)



2. Human Land Cover Change and CLM4

Based on the relationship between Deforestation and Agriculture in 171 catchments, *Zhang et al.* (2001) developed a simplistic vegetation based relationship between Annual Precipitation and Evapo-Transpiration:

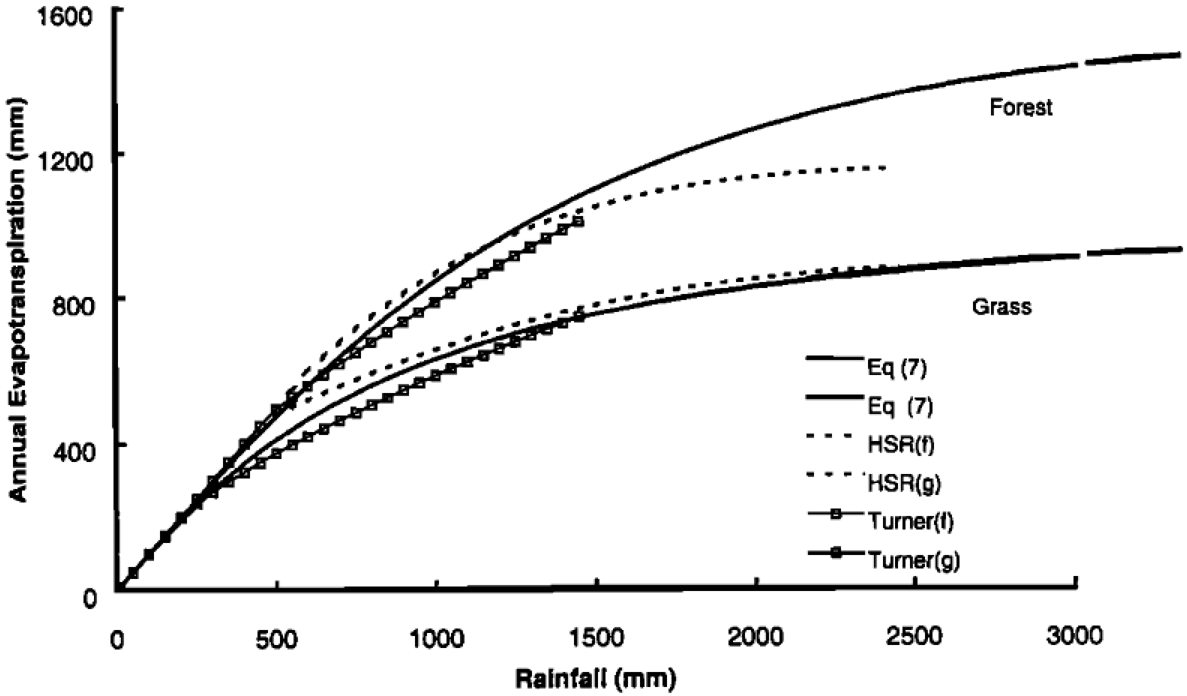
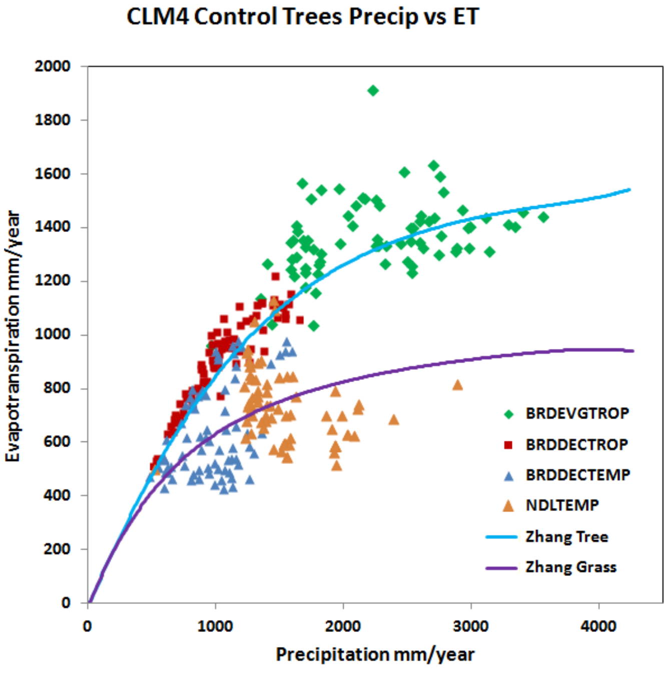
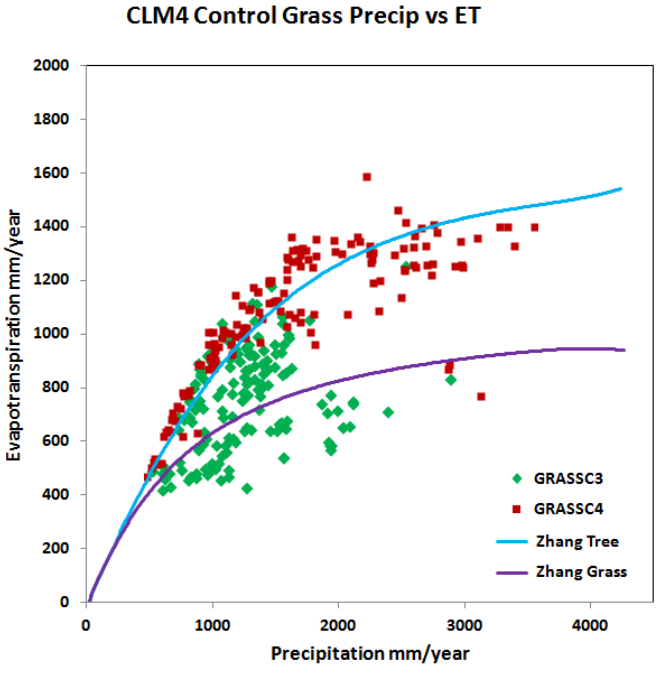


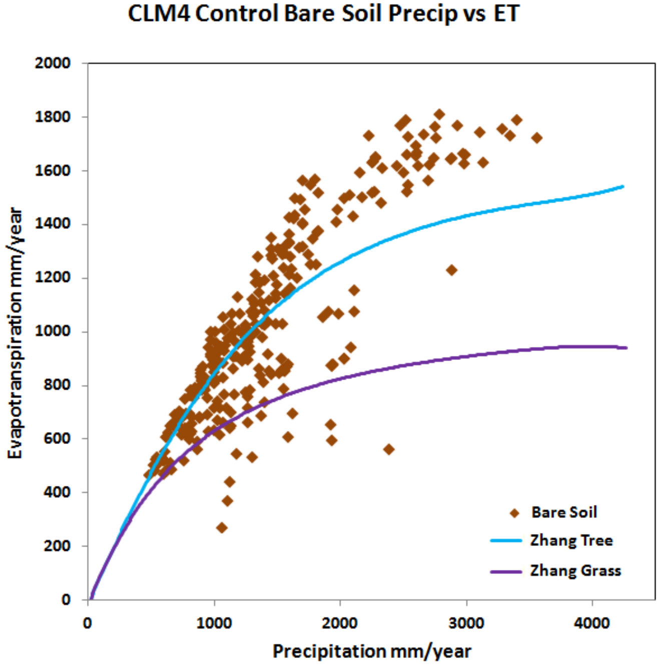
Figure 8. Comparison of equation (8) with the empirical relationships developed by *Holmes and Sinclair* [1986] and *Turner* [1991] for forested and grassed catchments.

- Does not capture physiological differences between tree PFTs or grass PFTs
- Does not account for catchment topography, soils and drainage
- Does not account for net radiation and other climate variables
- But does provide a framework to assess the behavior of trees and grasses in CLM4
- This study is also cited 275 times in the literature

2. Offline CLM4 – Tree – Grass – Bare Soil Precip v ET

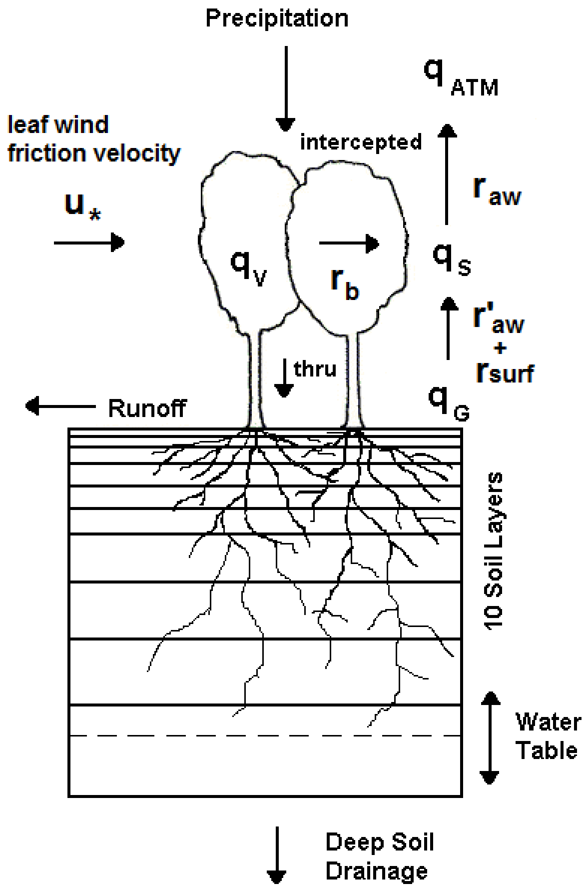






3. Why Does CLM4 Have Higher Bare Soil Evaporation?

Soil Evaporation



$$r'_{aw} = \frac{1}{C_s\, u_*}$$ Zeng et al. (2005)

$$q_G = \exp\left(\frac{\Psi_1 g}{1\times10^3 R_{wv} T_G}\right) qsat(T_G)$$ Philip (1957)

CLM4:

$$E_g = -\rho_{ATM}\beta_{soi}\frac{q_S - q_G}{r'_{aw} + r_{litter}}$$

$$r_{litter} = \frac{1}{0.004\, u_*}\left(1 - e^{-L_{litter}^{eff}}\right) \qquad L_{litter}^{eff} = 0.5 \quad Vegetated \qquad L_{litter}^{eff} = 0.0 \quad Bare\ Soil$$

Sakaguchi and Zeng (2009)

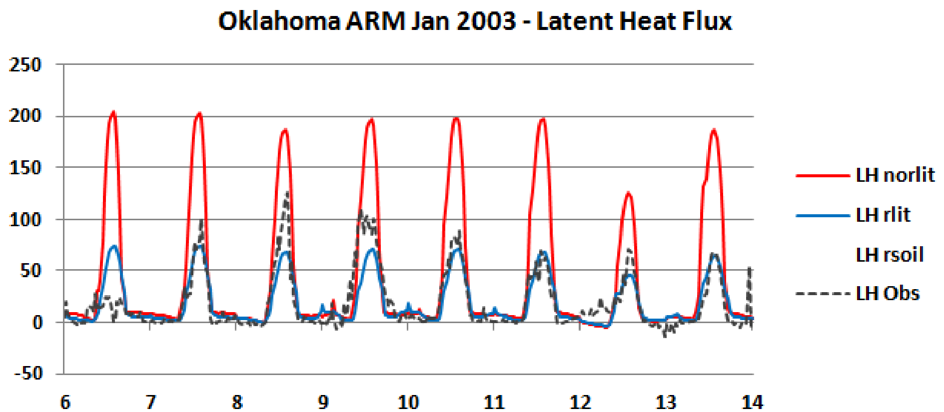
CLM3.5:

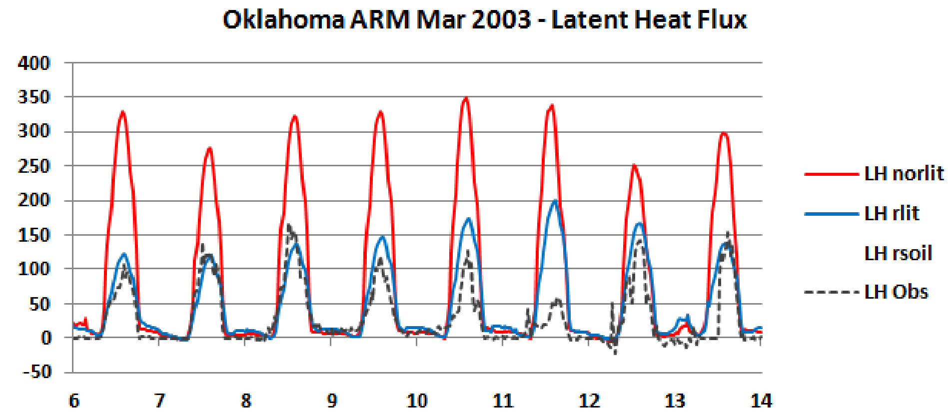
$$E_g = -\rho_{ATM}\frac{q_S - q_G}{r'_{aw} + r_{surf}}$$

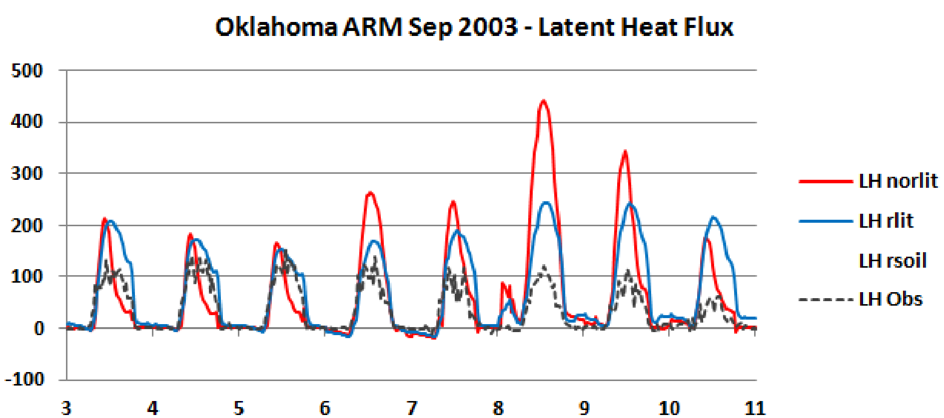
$$r_{surf} = \exp\left(8.206 - 4.255\frac{\theta_1}{\theta_{sat,1}}\right)$$

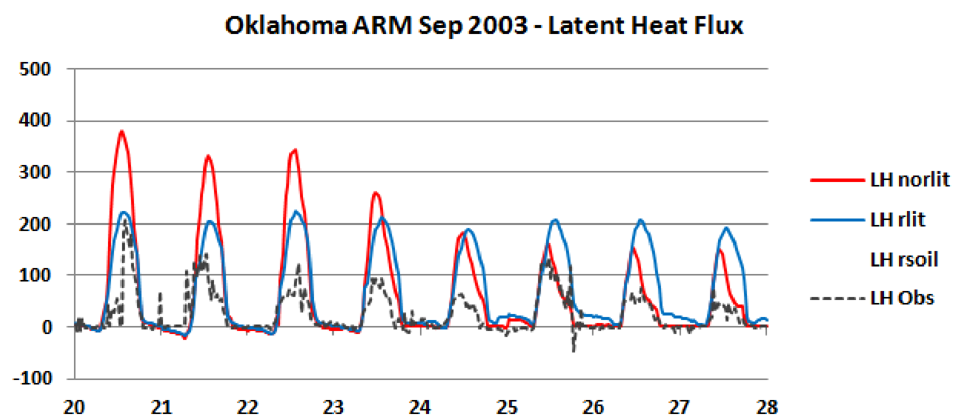
Sellers et al. (1996)

3. CLM4 Single Point Flux Tower Simulations

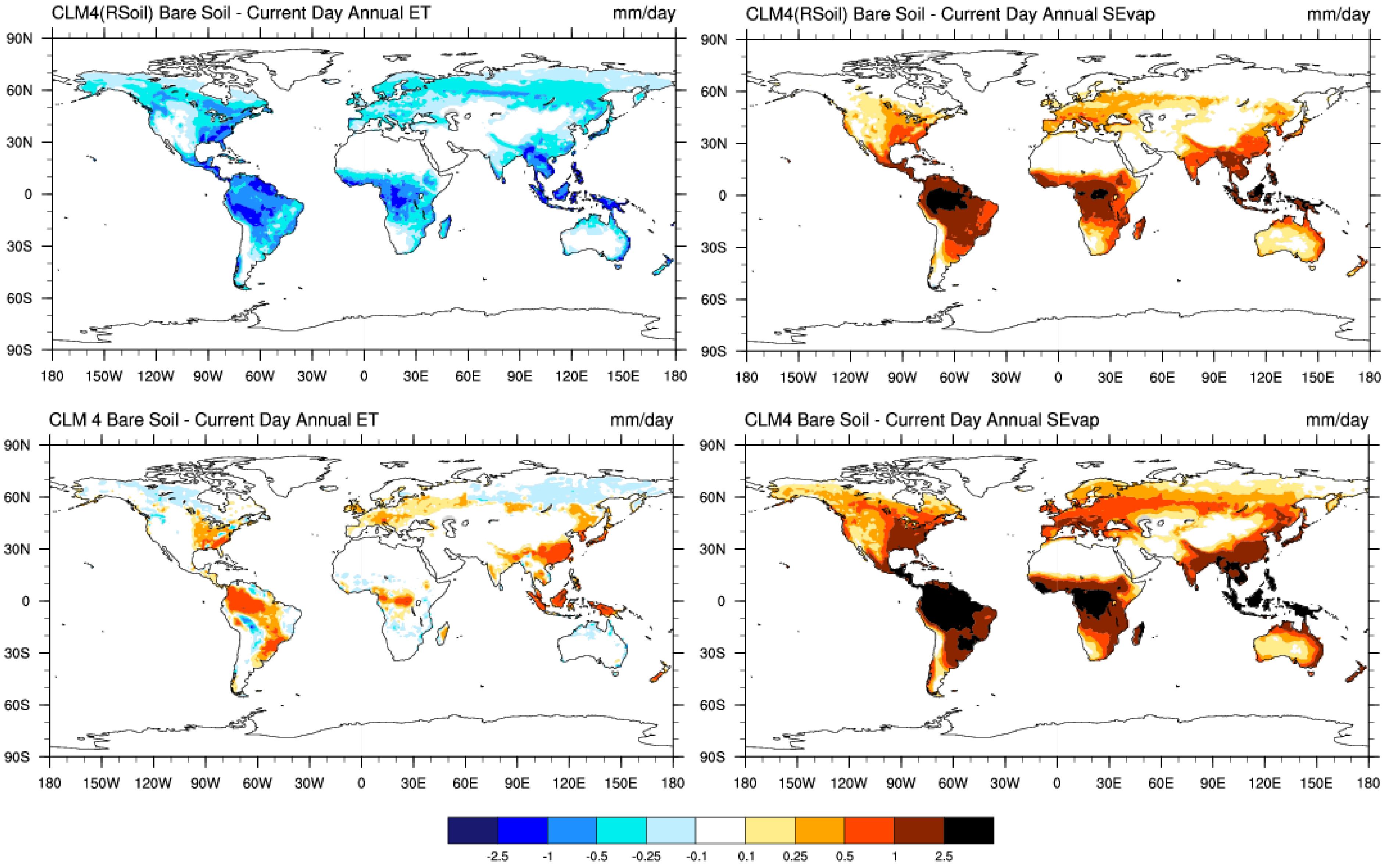




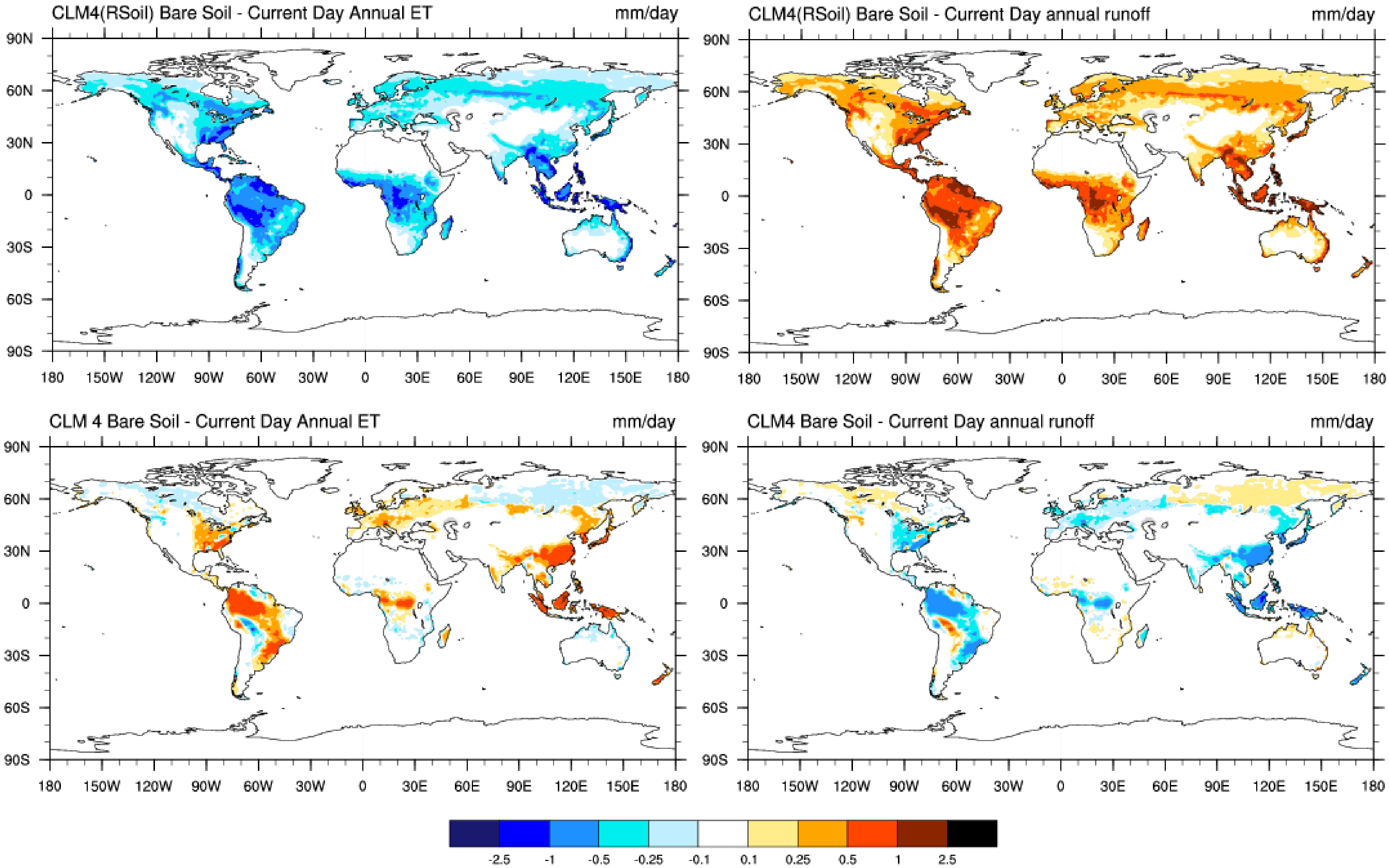




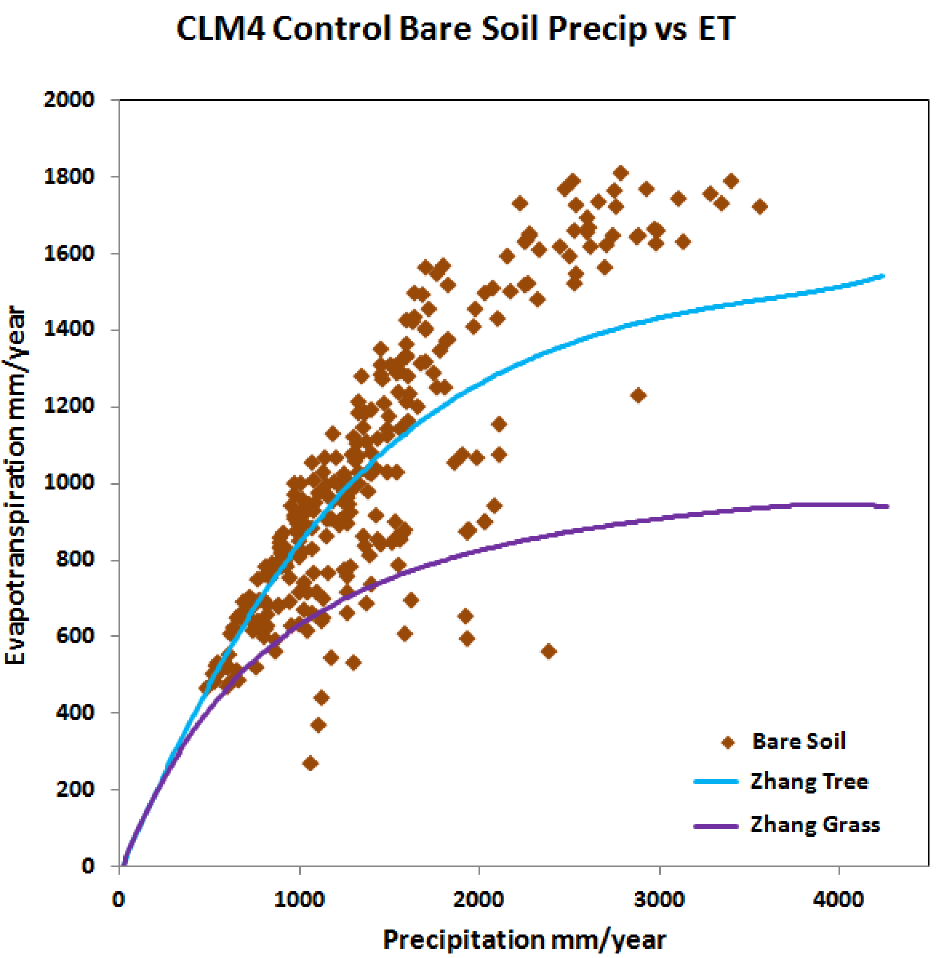
3. Offline CLM4(RSoil) – Vegetation Removal – Annual ET

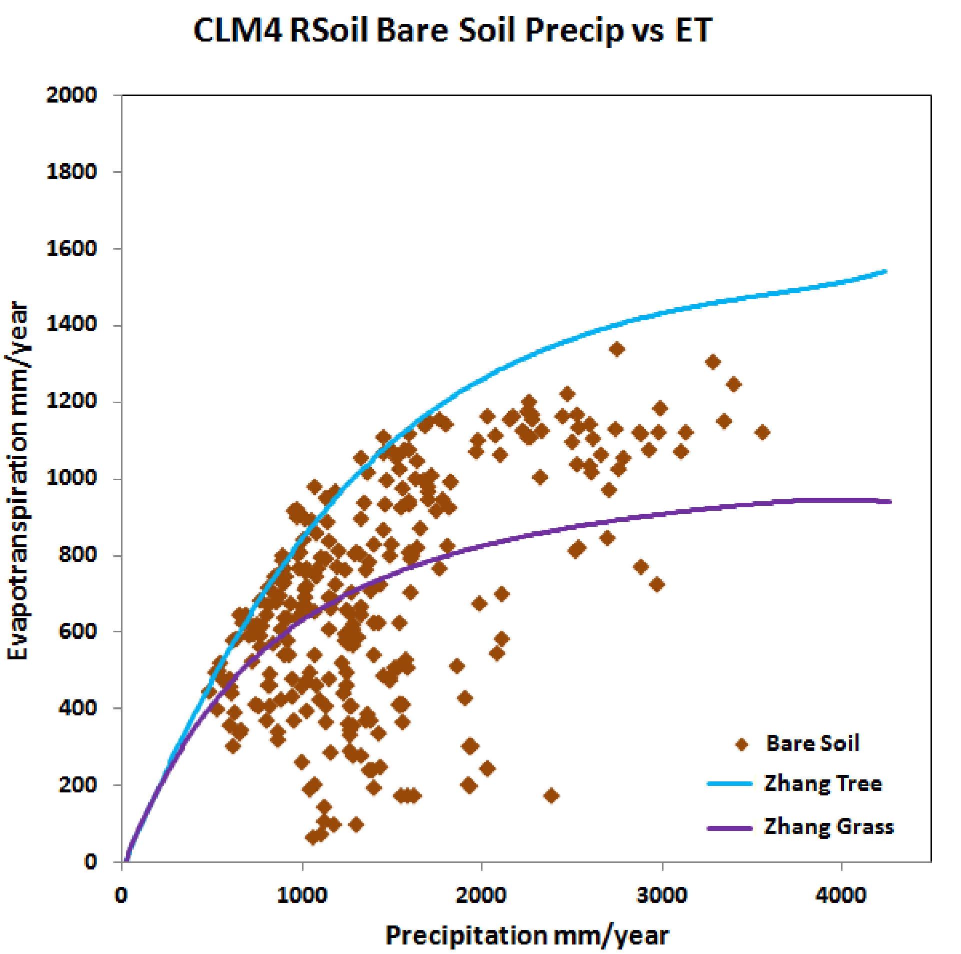


3. Offline CLM4(RSoil) – Veg. Removal – Annual Runoff



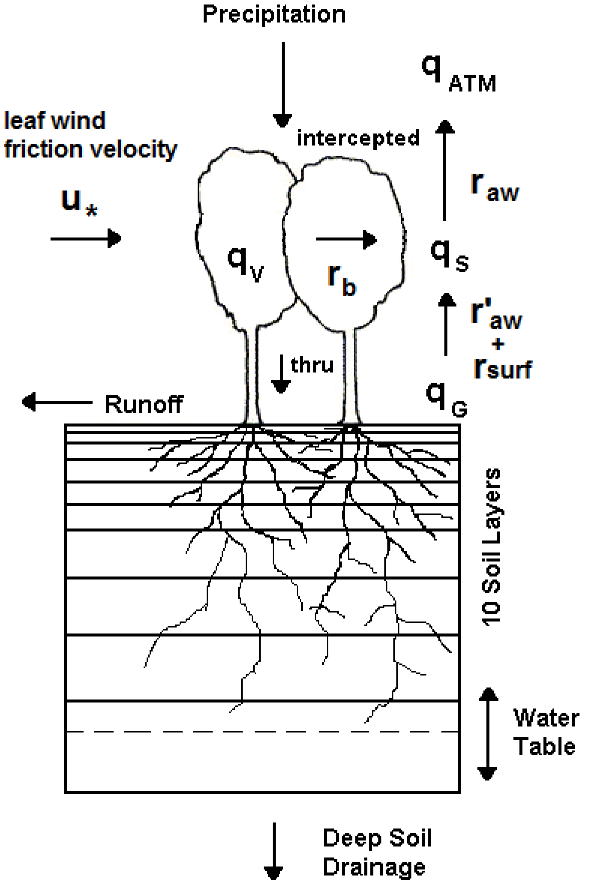
3. Offline CLM4 – CLM4 (Rsoil) Bare Soil Precip v ET





4. Why Is CLM4 Tree and Grass Transpiration Similar?

Transpiration



CLM4:

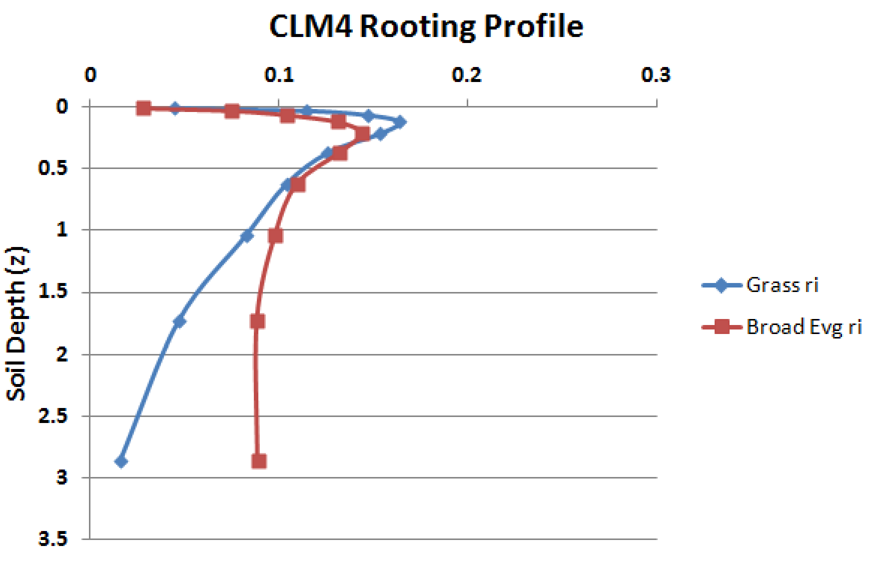
The soil moisture stress is calculated from individual soil layer stress and PFT rooting distribution as:

$$\beta_{\mathrm{TRAN}} = \sum_{i=1}^{10} r_i \, f_R(w_i)$$

Where the rooting profile is from Zeng et al. (2001):

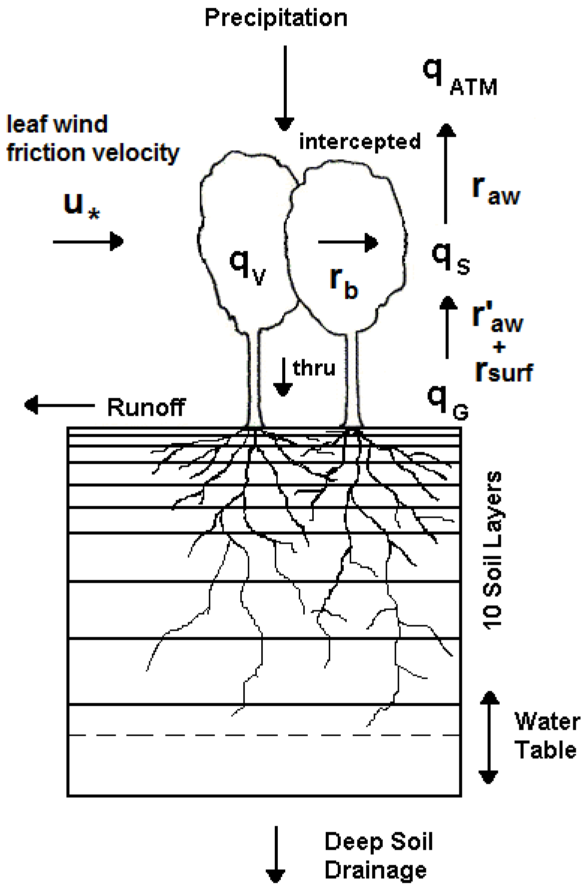
$$r(z_{soil}) = 1 - 0.5\left(\exp(-a\, z_{soil}) + \exp(-b\, z_{soil})\right)$$

And *a* and *b* are PFT specific extinction parameters



4. CLM4 Jackson et al (1996) Root Profile

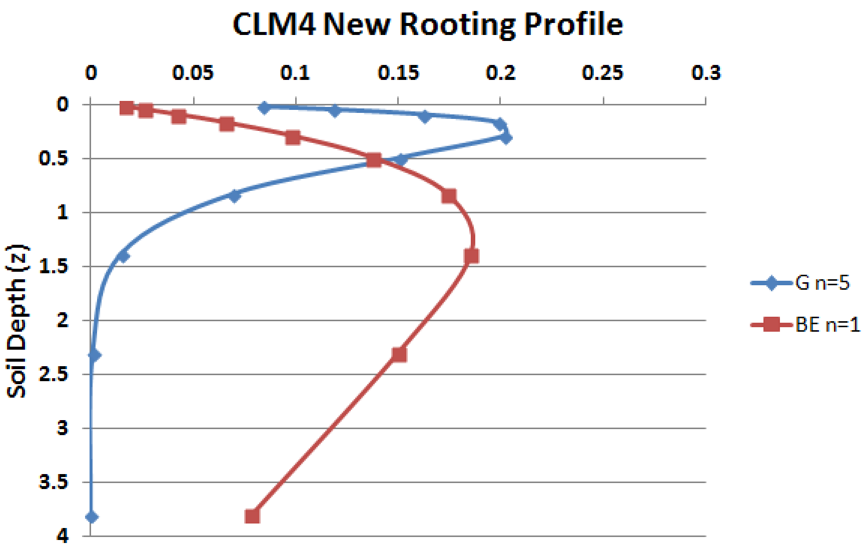
Transpiration



CLM4:

Simplify rooting profile:

$$r(z_{soil}) = 1 - \exp(-n\, z_{soil})$$



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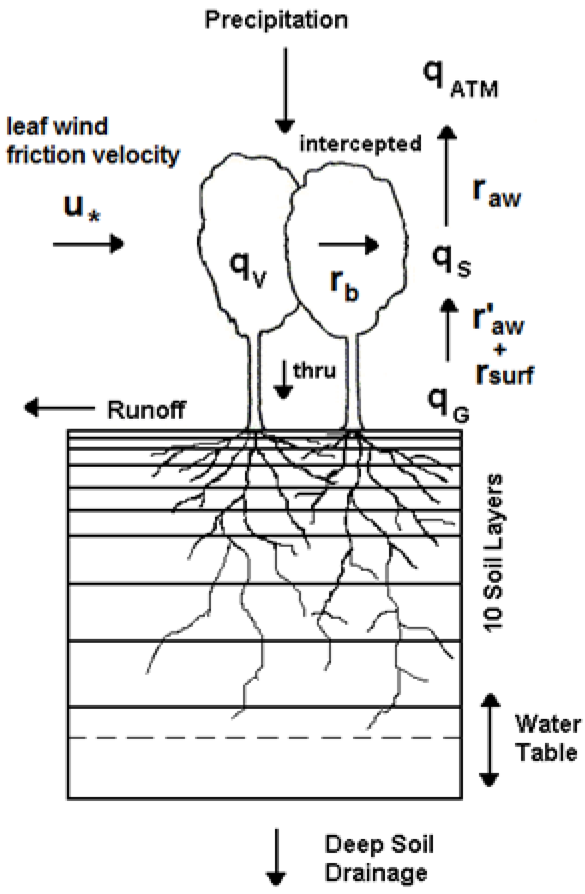


CLM4:

$$E_v = -\rho_{ATM} \frac{q_S - q_{sat}(T_v)}{r_{total}}$$

Stomatal resistance is from Ball-Berry:

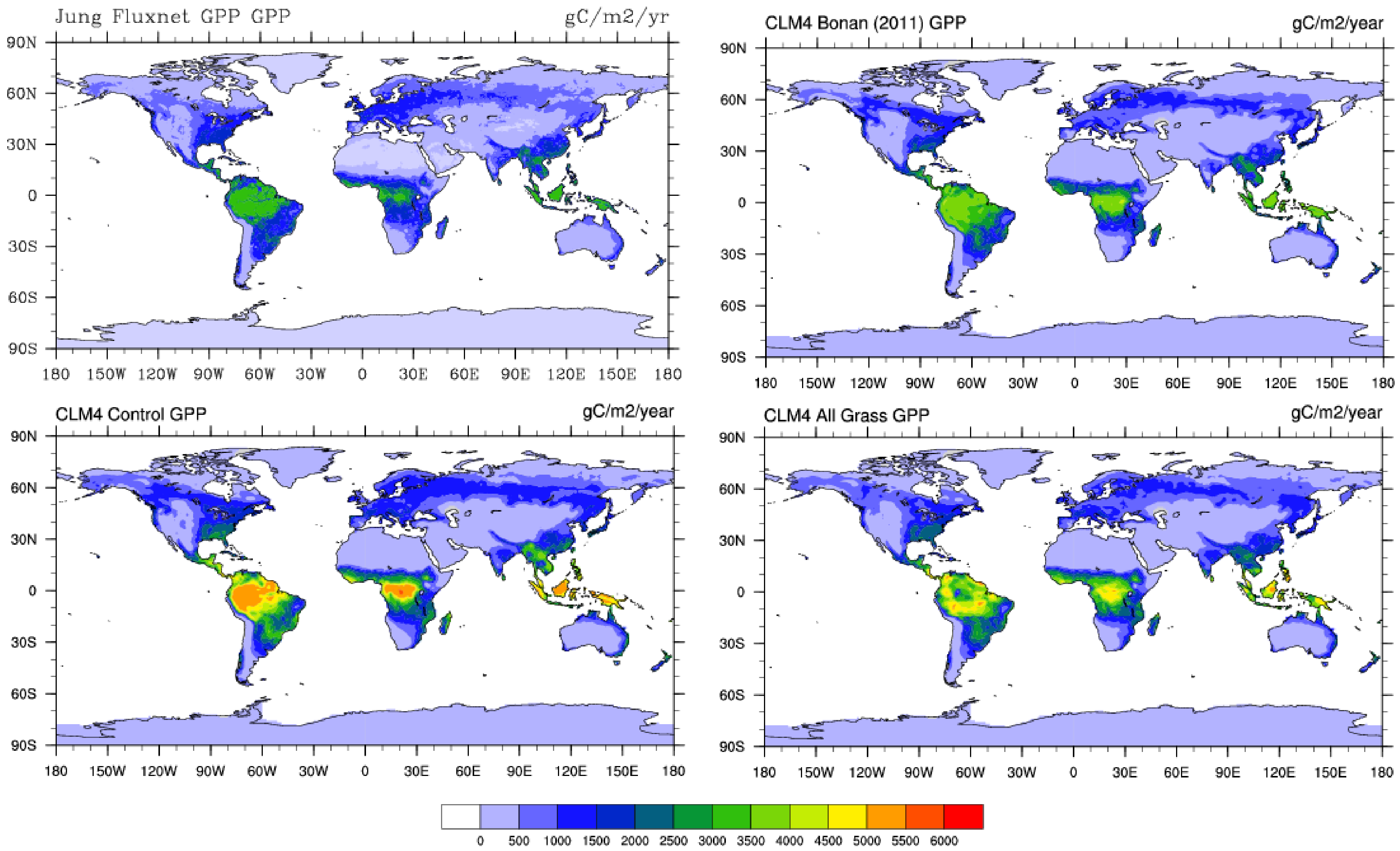
$$\frac{1}{r_s} = m \frac{A}{c_s} \frac{e_s}{e_i} P_{ATM} + b \qquad (\mu\,\mathrm{mol\,m^{-2}\,s^{-1}})$$

Bonan G. B. et al. (2011)

We found Photosynthesis and Transpiration were excessively high compared to FLUXNET derived observations. This was improved through:

- Revised Two Stream Radiation Model
- Revised Leaf Photosynthesis
- Revised Canopy Scaling

5. Offline CLM4 – Impact of Photosynthesis – Annual GPP



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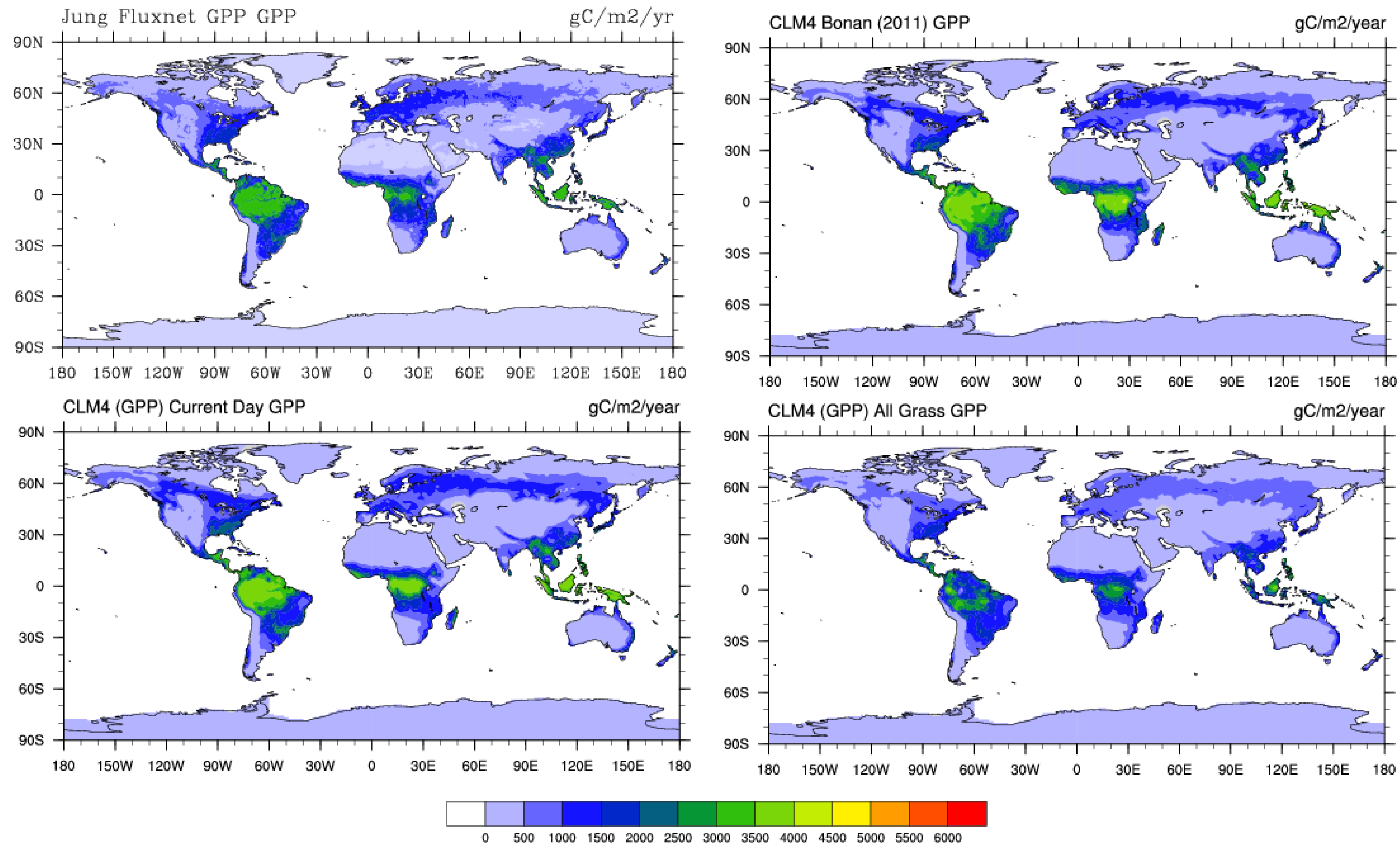

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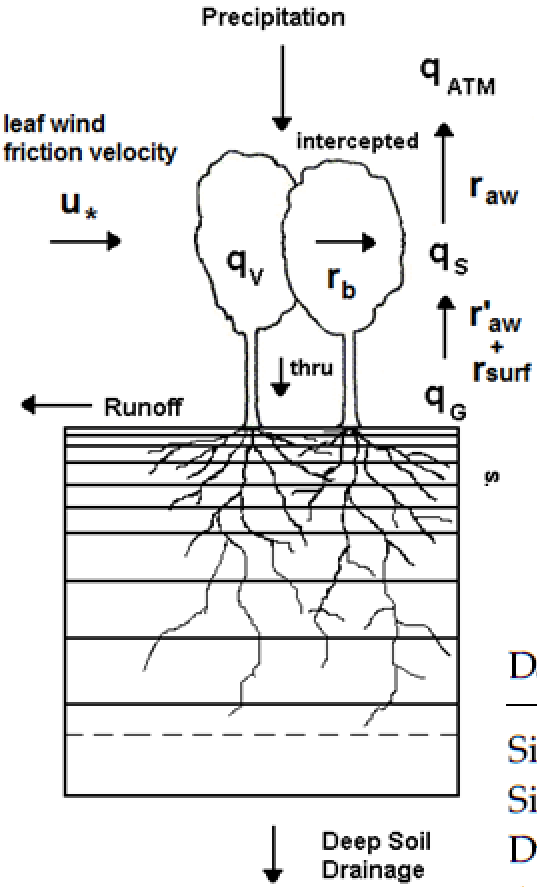

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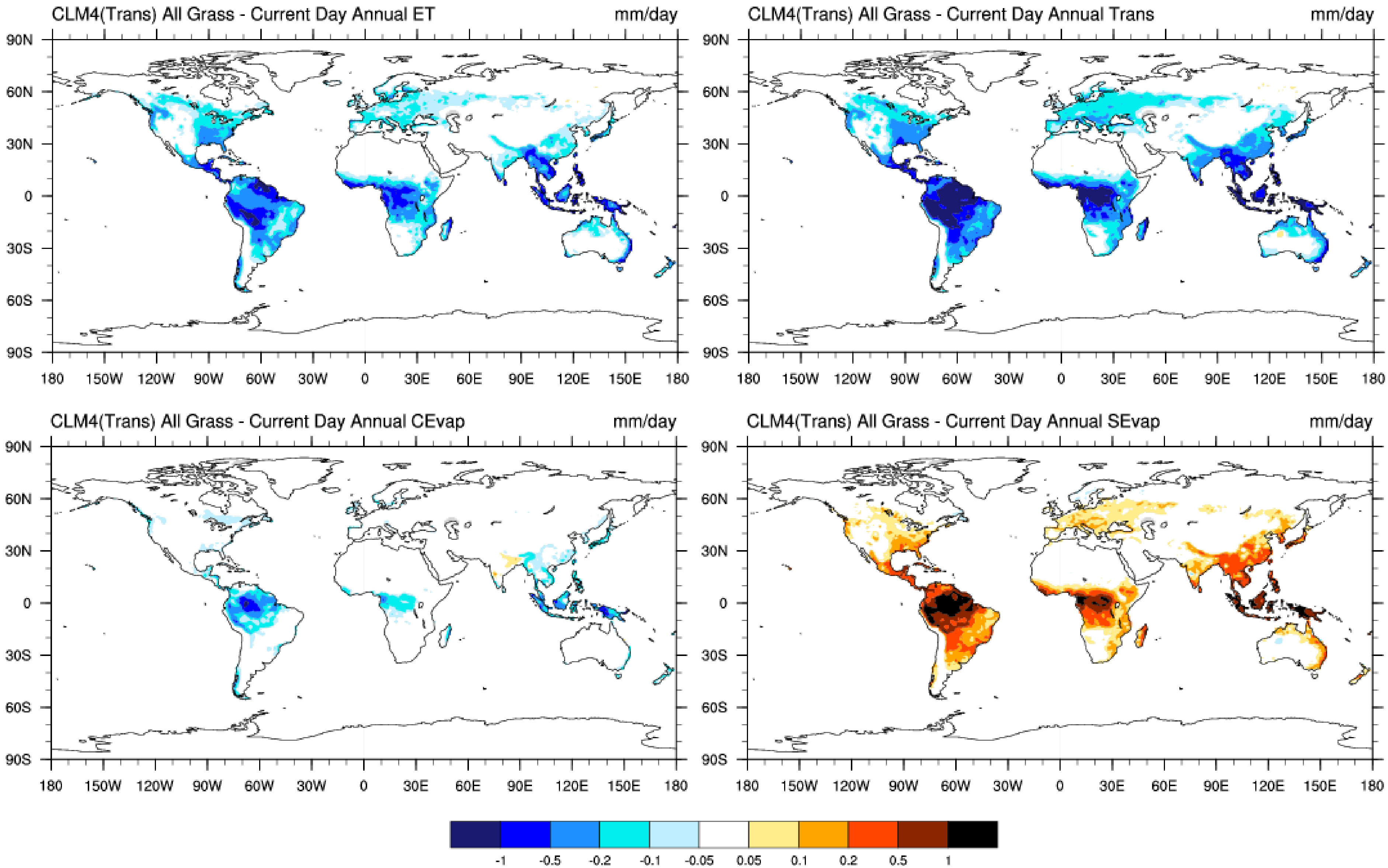
Medlyn et al (2011) New *m* parameters for PFTs

		Eqn (2) (Ball *et al*. 1987)		
Dataset	*n*	g_0	g_1	R^2
Sitka A	77	0.039 (0.004)	4.55 (0.38)	0.651
Sitka B	27	0.027 (0.008)	5.17 (0.67)	0.704
Duke Pine	136	0.057 (0.019)	7.14 (1.36)	0.170
Alpine Ash	60	0.016 (0.016)*	11.98 (1.0)	0.716
Macchia	47	0.038 (0.008)*	9.09 (0.92)	0.684
Fagus	24	−0.002 (0.015)*	11.24 (0.88)	0.881
Savanna	77	0.048 (0.015)	13.62 (0.89)	0.756
Red Gum	96	0.016 (0.007)	15.27 (1.03)	0.702

6. Offline CSIB – Vegetation Removal – Annual ET



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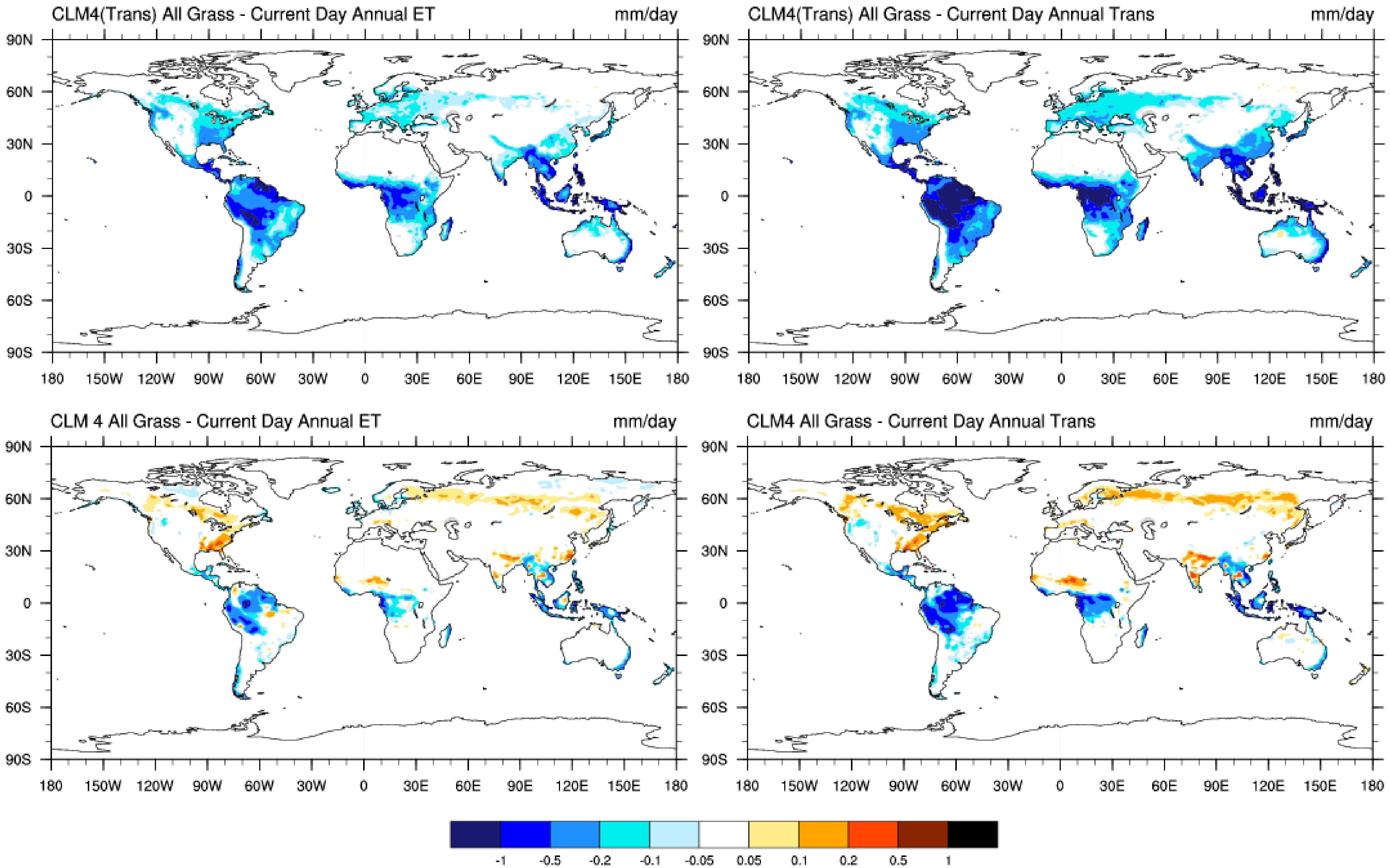
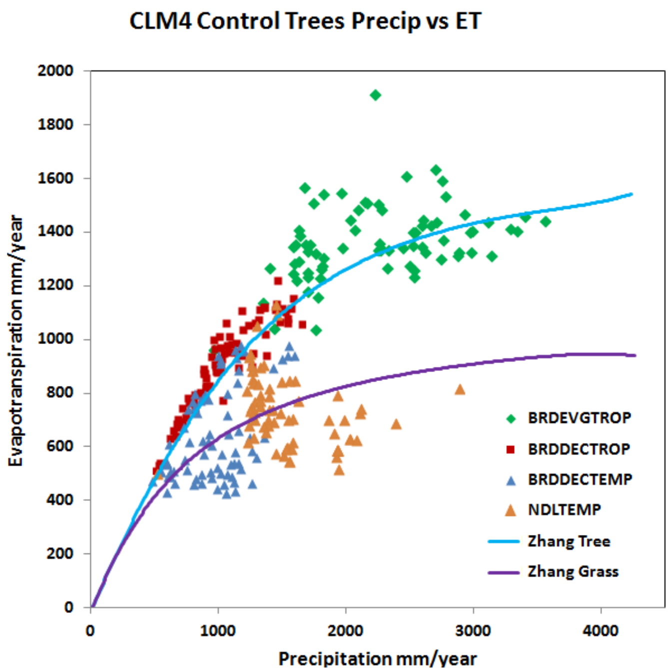
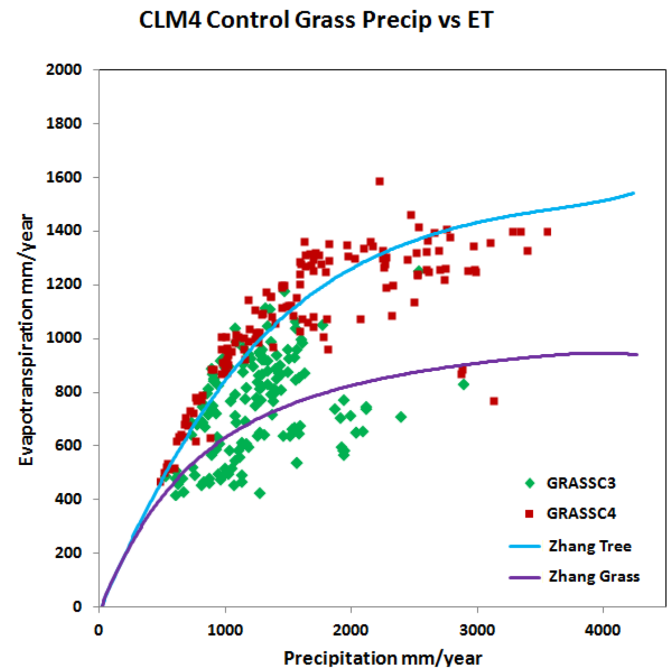
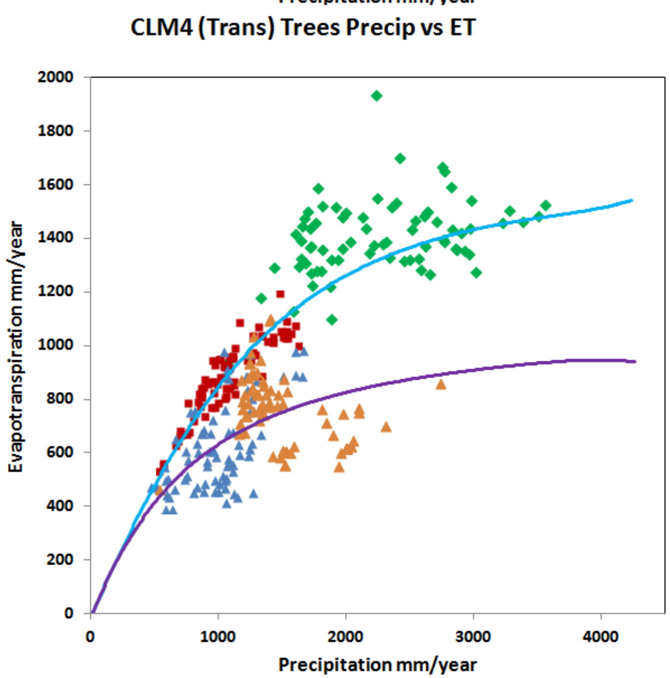
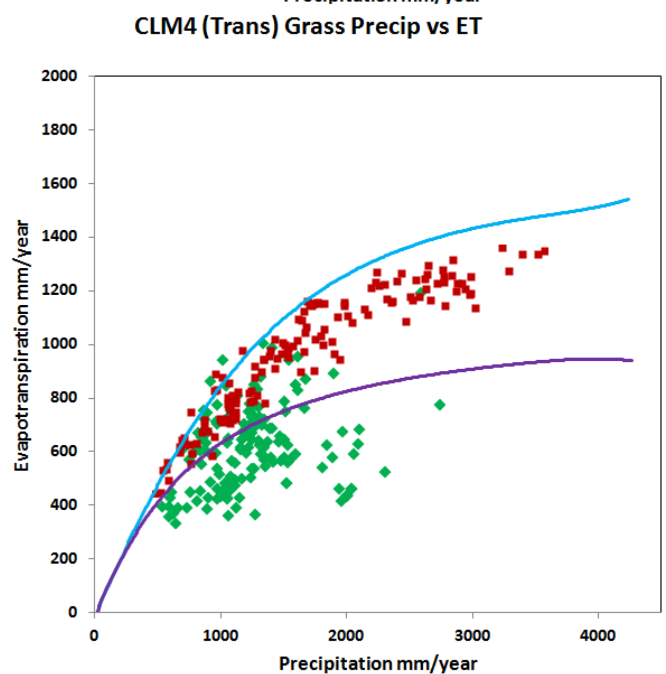


6. Offline CLM4 – Tree – Grass – Bare Soil Precip v ET









7. Conclusions

1. CLM 4 simulates higher Bare Soil evaporation than Forest evapo-transpiration

2. Grass PFTs behave hydrologically similar to Tree PFTs even with half of the Leaf Area Index

3. The high Bare Soil evaporation can be resolved through some form of surface resistance. Even the highly resolved soil water diffusion model Bittelli et al (2008) requires some form of soil resistance.

4. Grass PFT evapotranspiration are substantially reduced through:
   - Changing root profiles to Jackson et al (1996)
   - Reduced Photosynthesis following Bonan et al (2011)
   - Changes in tree and grass transpiration/assimilation slope parameter in the Ball-Berry model following Medlyn et al (2011)

5. C4 Grasses still have higher than the catchment level precipitation – evapotranspiration relationships described in *Zhang et al.* (2001)

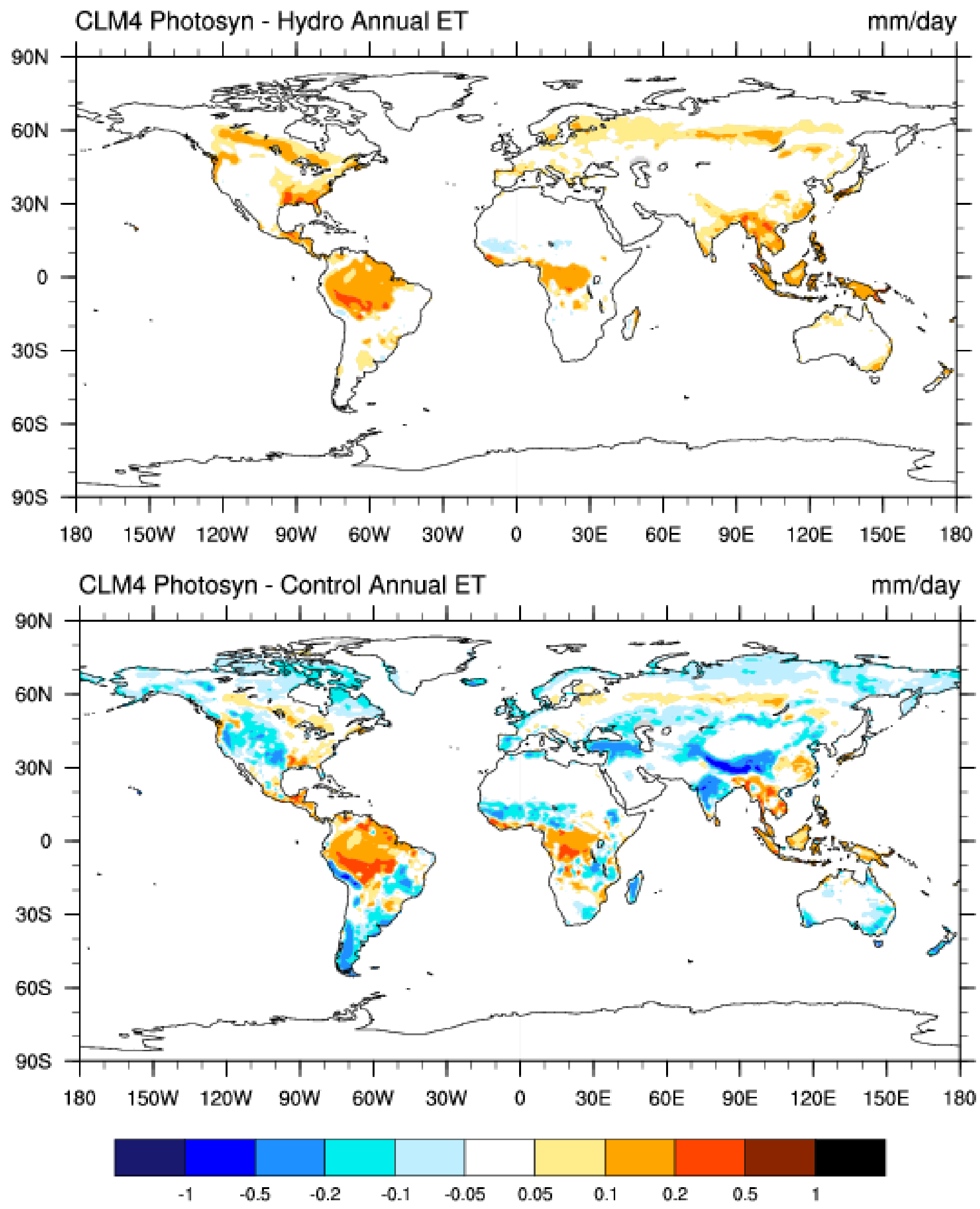
7. Conclusions - Continued

1. Currently performing Extreme Land Cover Change fully coupled CESM 1.1.1 experiment with control CLM4 and modified CLM4

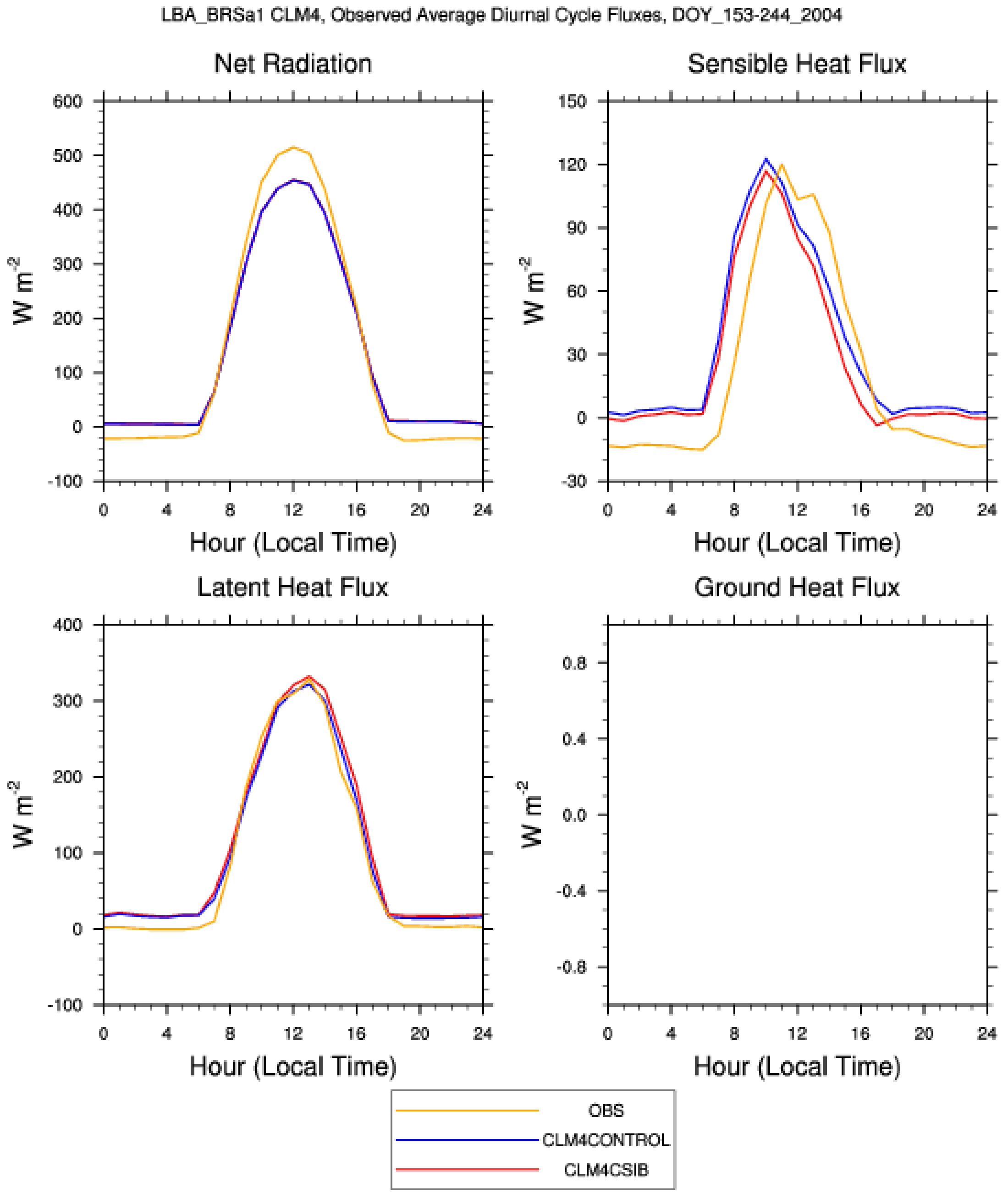
2. Next Step is to look at these experiments in CLM 4.5 with new hydrology, photosynthesis and transpiration parameterizations

3. Investigate the impacts with CLM-CN rather than with prescribed Satellite Phenology

X. Offline CLM4 – Impact of Photosynthesis – Annual ET



4. PTCLM – Impact of Flux Tower Simulations – LBA



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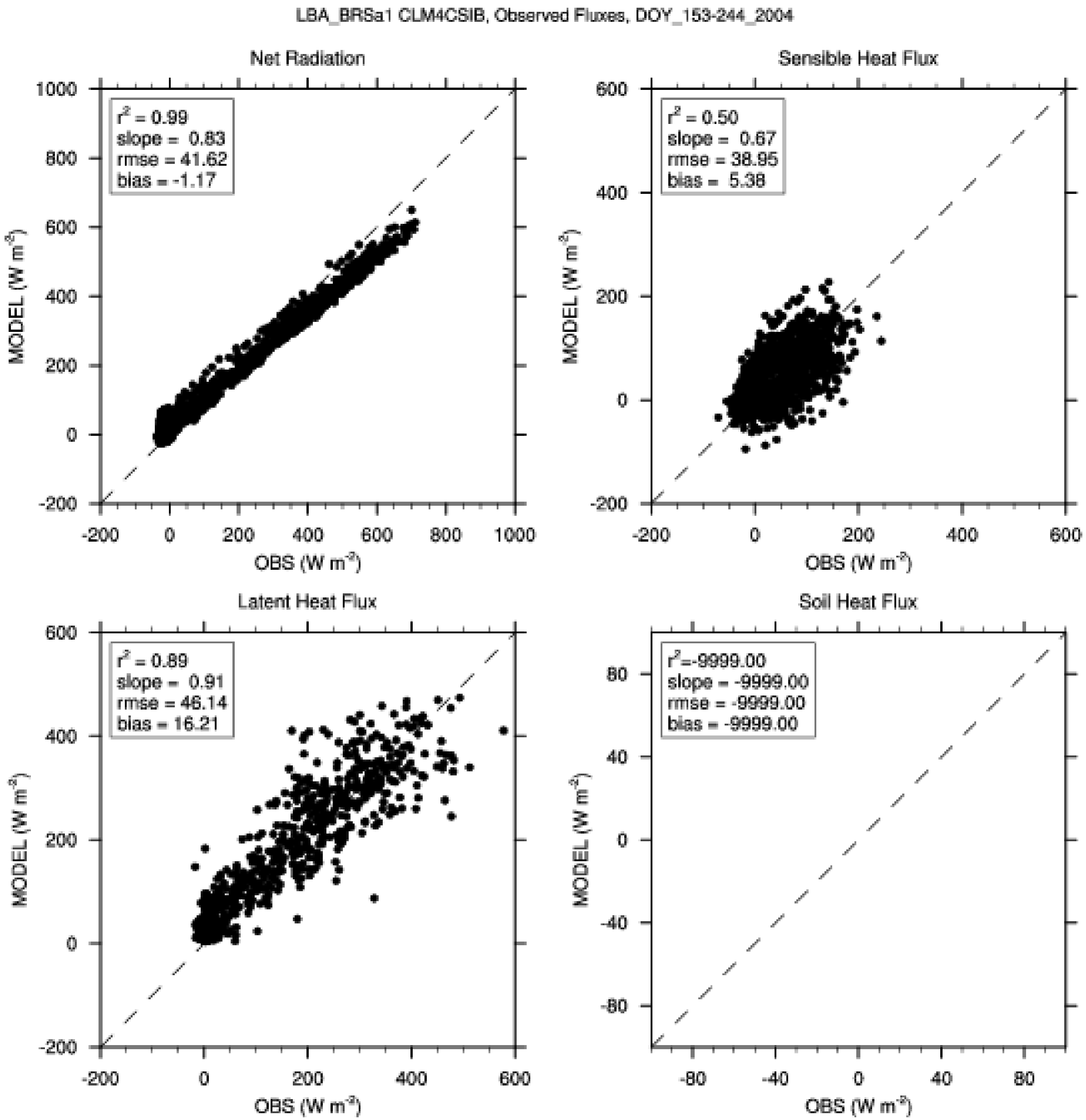
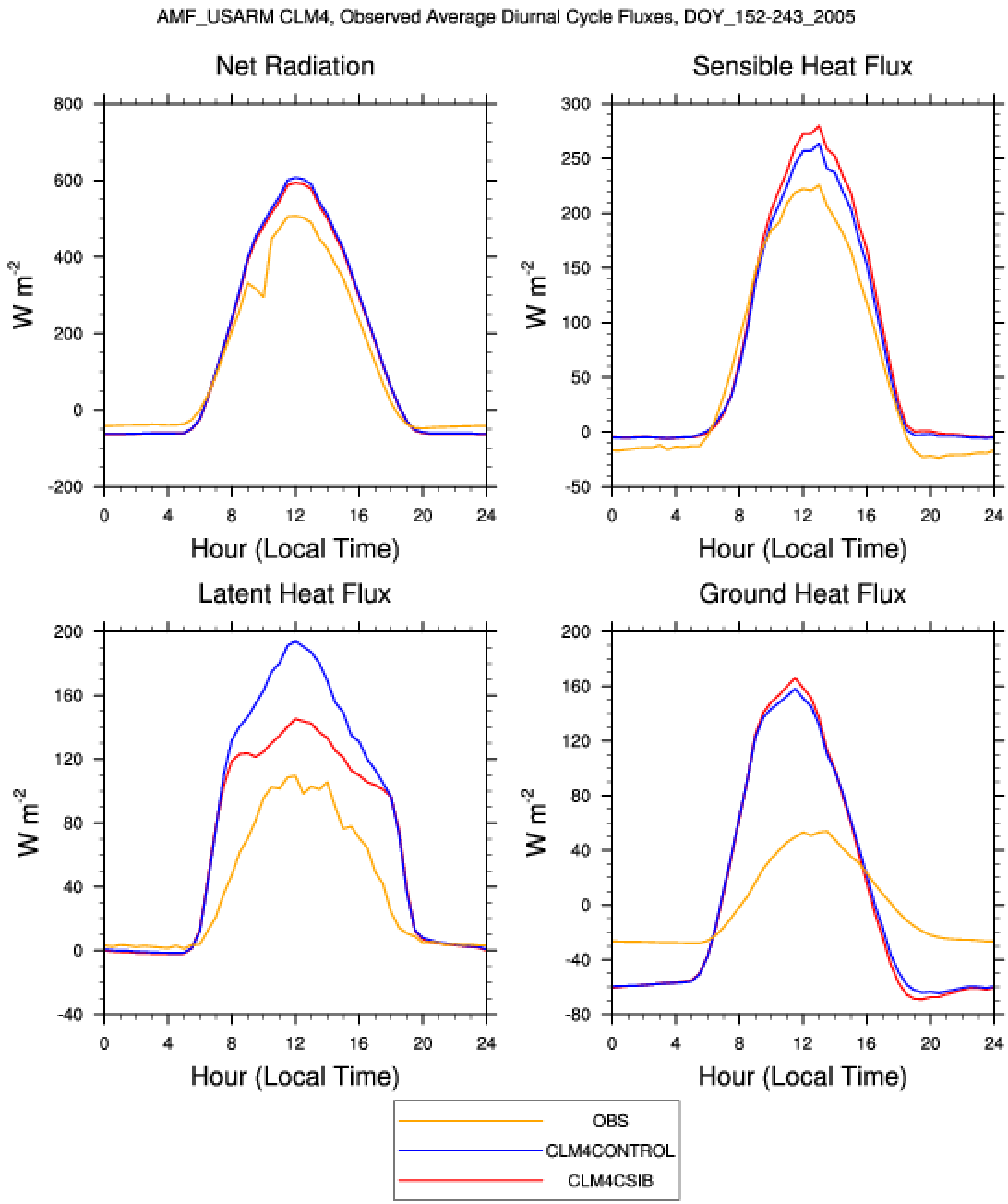


X. PTCLM – Impact of Flux Tower Simulations – OK ARM



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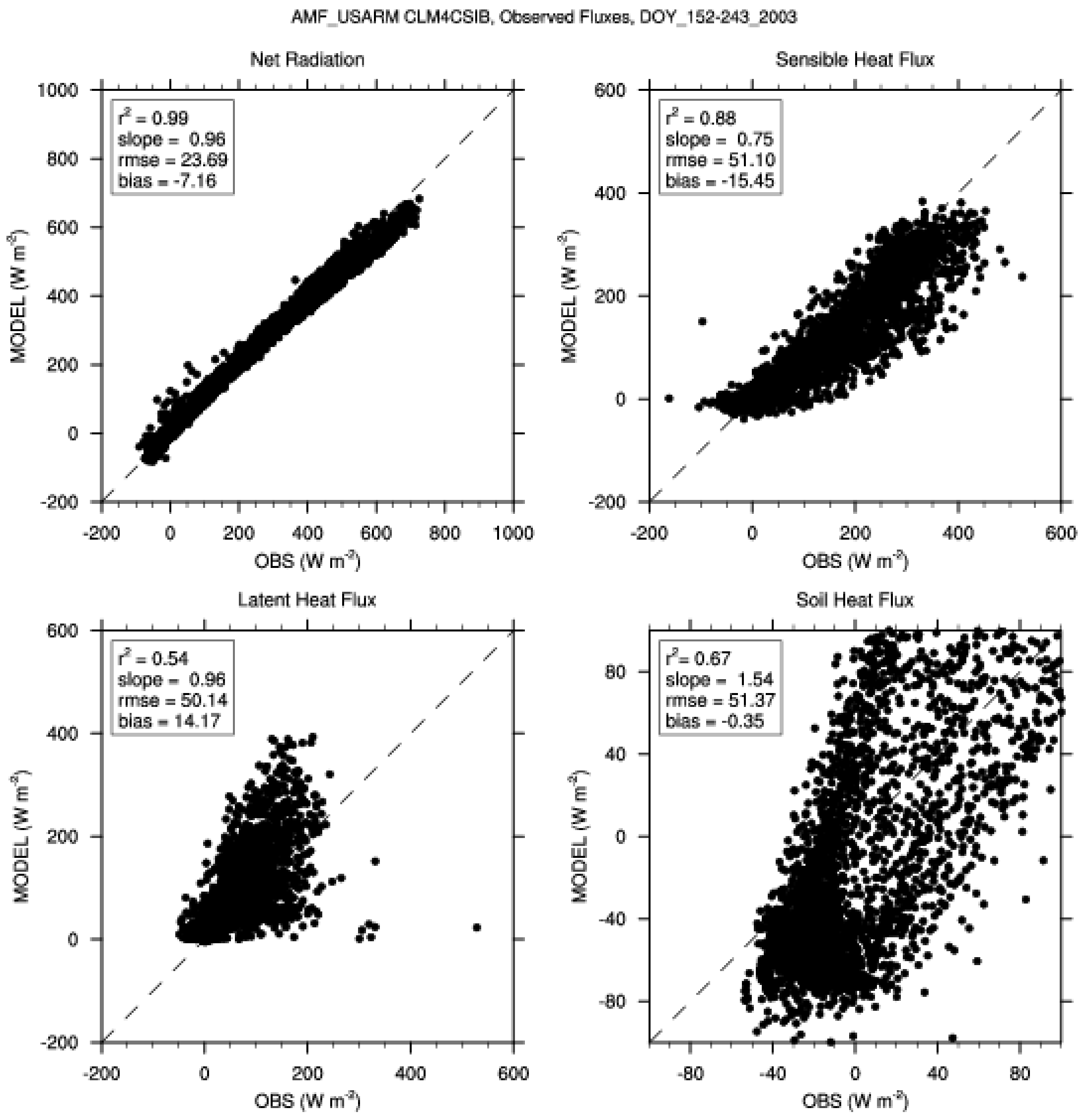

X. Offline CLM4 – Impact of Photosynthesis – Annual GPP