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Climate-soil-vegetation control on groundwater-supplied evapotranspiration in the global modeling context

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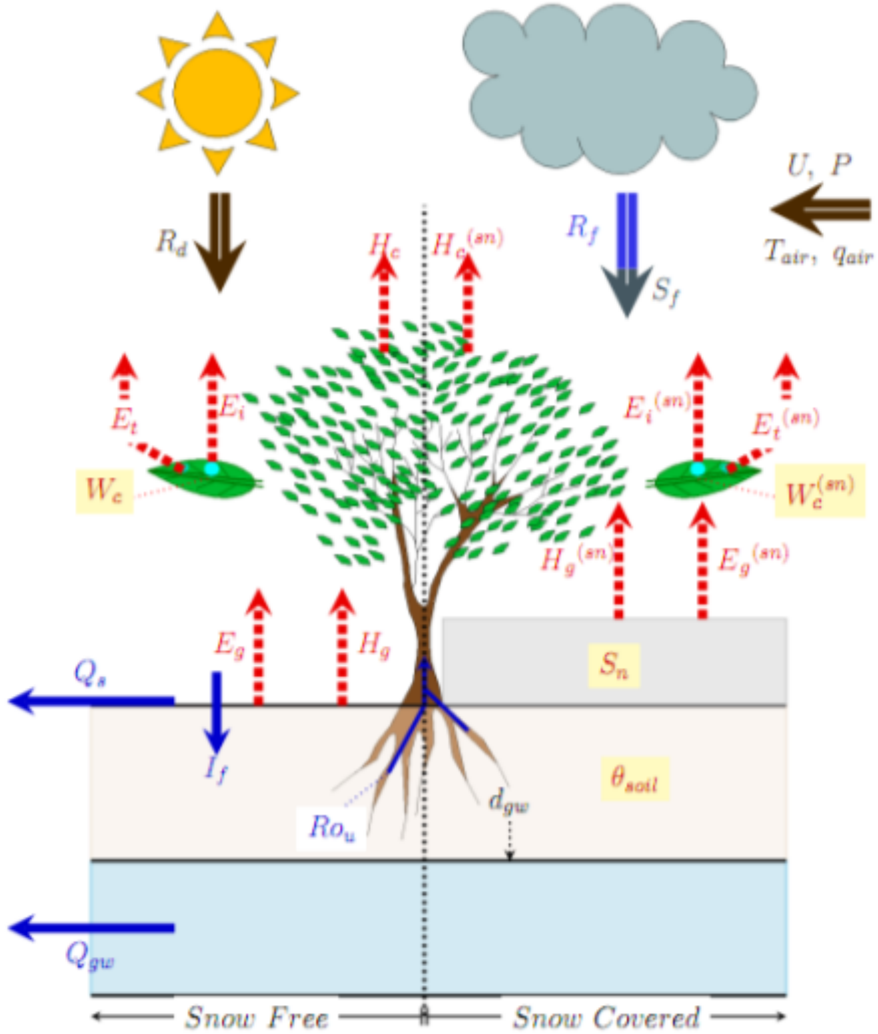
Motivation and Objective

- Groundwater dynamics affects land surface hydrology as it can alter the partitioning of :
  - precipitation into runoff and evapotranspiration (ET).
  - runoff into its components.
  - saturated and unsaturated soil moisture.
- GW-supplied moisture has been found to enhance ET in regional as well as global scales.
  - *e.g., York et al., 2002; Liang et al., 2003; Yeh and Eltahir, 2005a,b; Niu et al., 2007; Fan et al., 2007; Maxwell and Kollet, 2008 etc.*
- But, the factors leading to increase in ET have not been analyzed in global scale.

Evaluate the <u>control of climate, soil, and vegetation</u> on GW-supplied ET in global-scale.

Model Description



- MATSIRO Land Surface Model- Minimal Advanced Treatments of Surface Integration and Runoff developed at AORI & NIES in Japan (Takata et al., 2003).
- Energy and water balance are solved at snow-covered and snow-free ground and canopy surfaces.
- Considers majority of hydrological processes including representation of the water table dynamics (Koirala et al., submitted).

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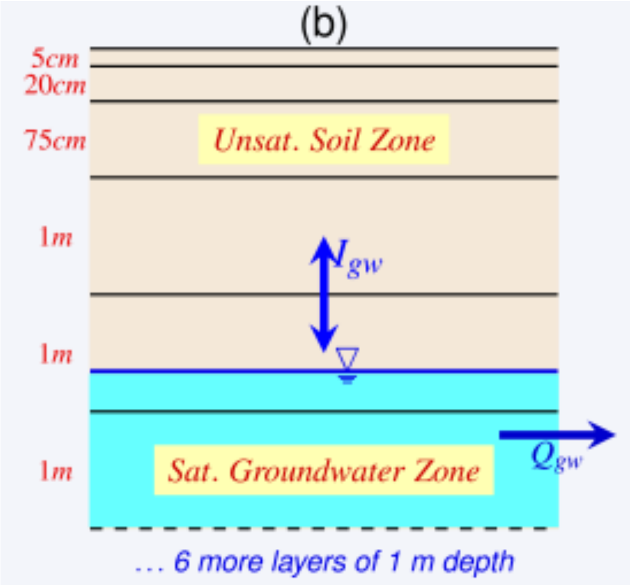
Groundwater representation



- Dynamic- size of unsaturated soil zone depends upon water table depth.
- Saturated and unsaturated soil zones interact through GW recharge:

$$I_{gw} = k\left(\frac{d\psi}{dz} - 1\right)$$

$$C_f = k\frac{d\psi}{dz}$$

$$G_f = k$$

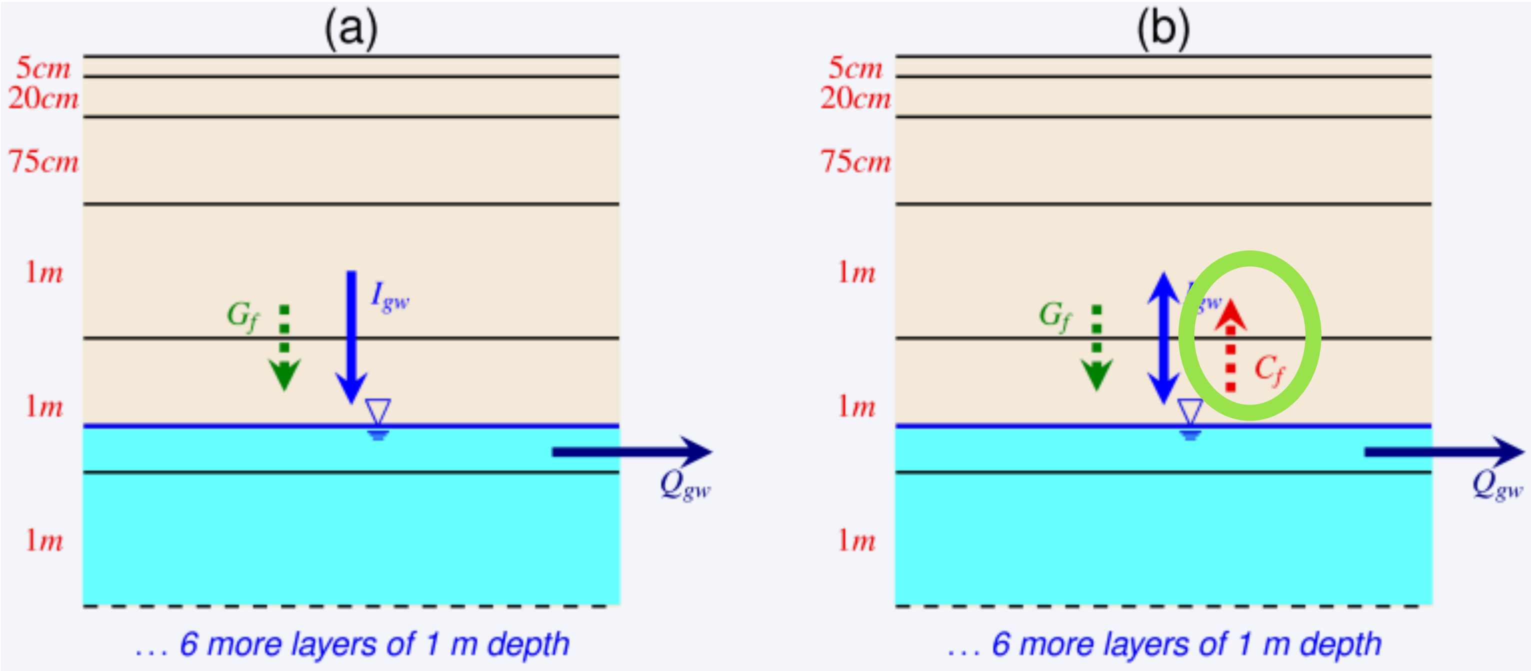
k: unsaturated hydraulic conductivity
ψ: unsaturated matric potential
dz: difference in elevation head
C_f: Capillary flux
G_f: Gravity drainage

- Water Balance of GW reservoir (Yeh & Eltahir, 2005a,b):

$$S_y\frac{\Delta d_{gw}}{\Delta t} = I_{gw} - Q_{gw}$$

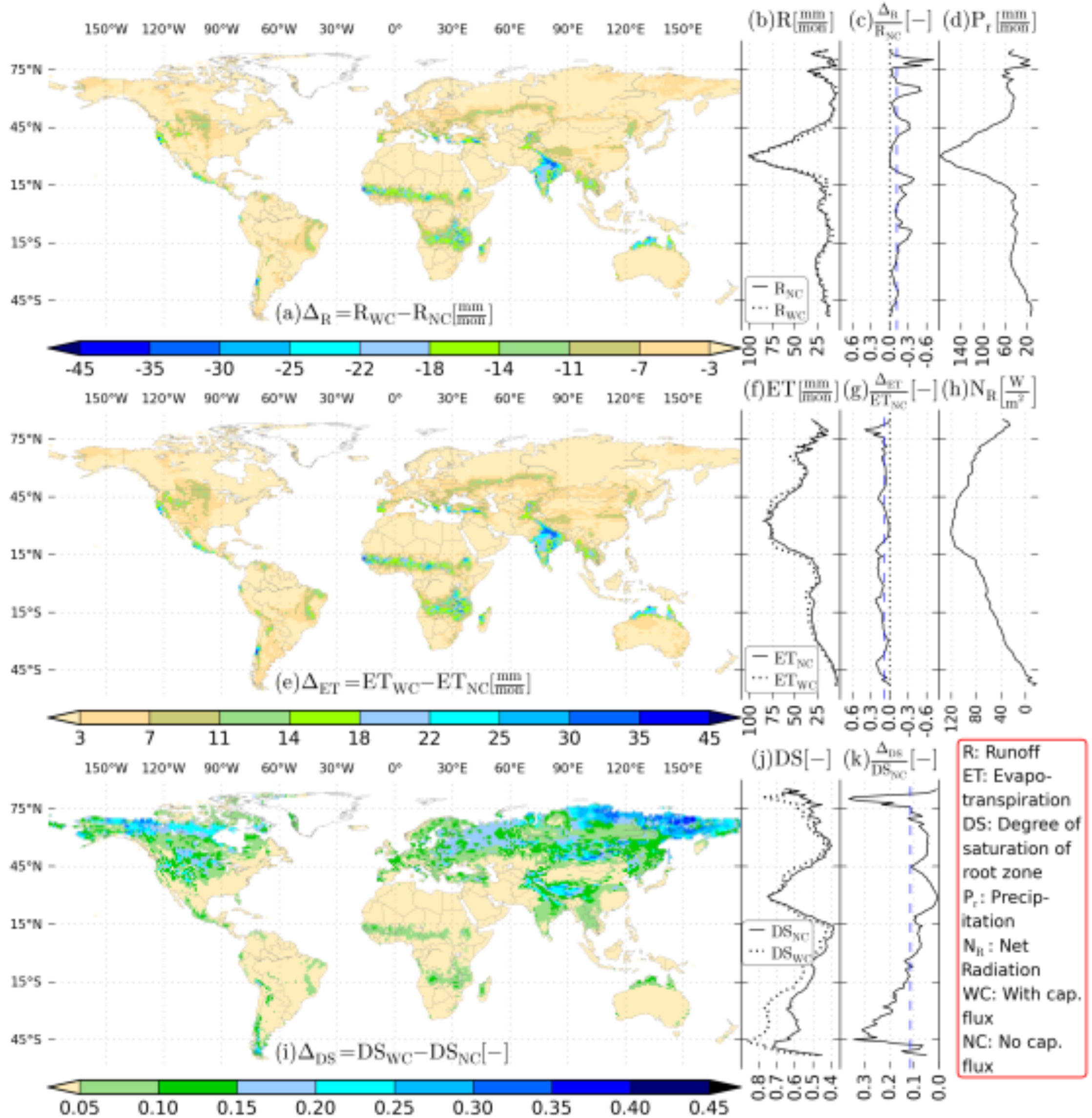
S_y: Specific yield, I_{gw}- recharge, Q_{gw} is baseflow

Data and Experiments



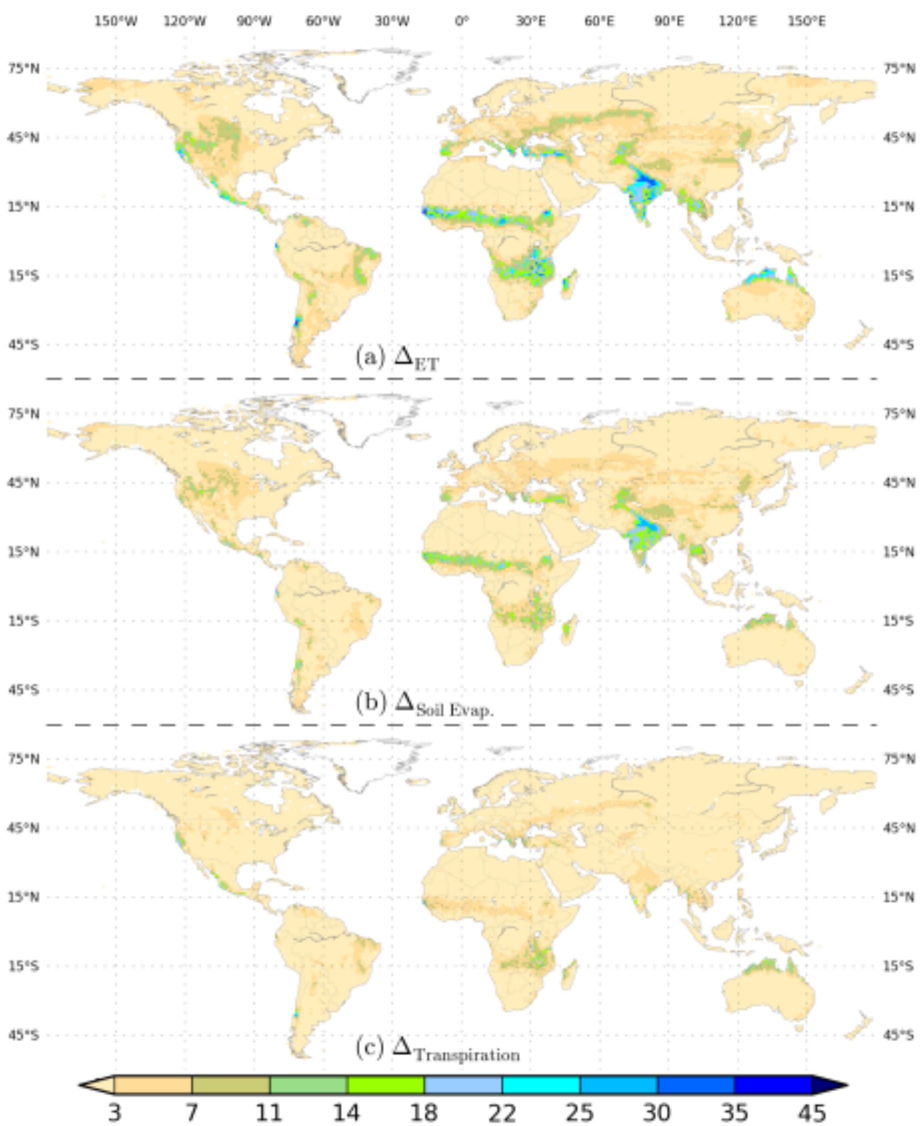
- Two simulations were carried out: one not considering capillary flux from GW reservoir (NC) and the other considering it (WC).
- Both simulations were driven by same forcing dataset (1° x 1° NCC: Ngo-Duc et al., 2005) and external parameters (GSWP-2: Dirmeyer et al., 2006).
- Simulation period is 15 years from 1985-1999.

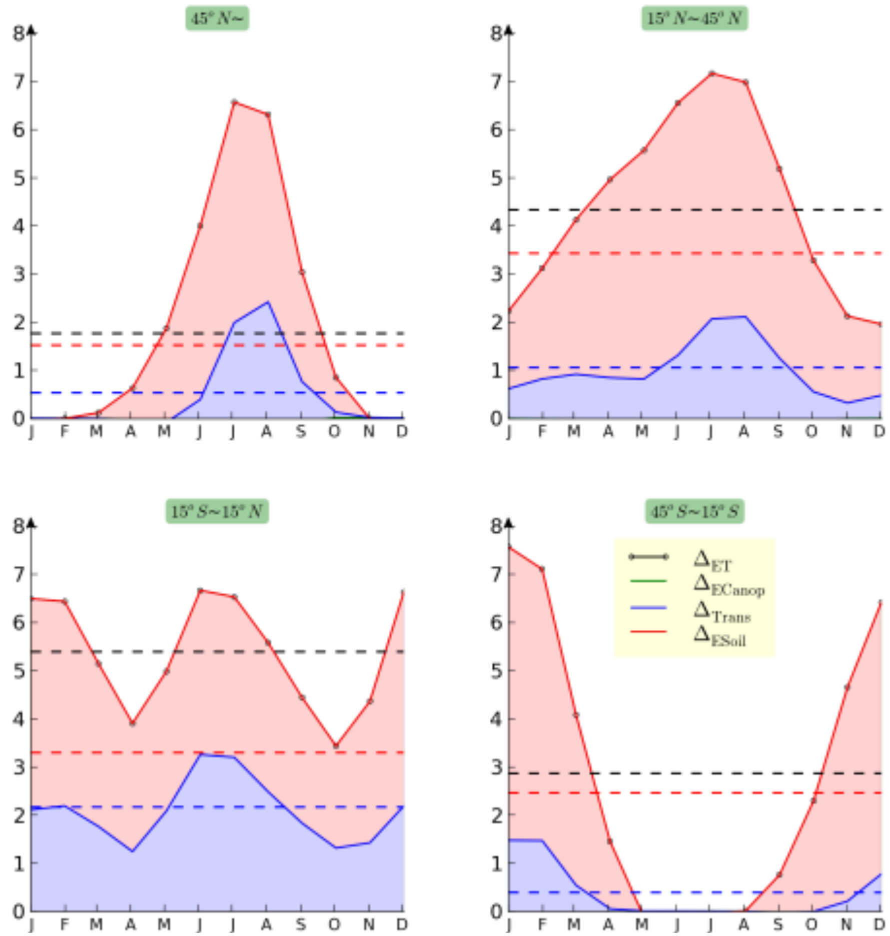
ET and Runoff



- Globally ~9% (5200 km^3/yr) increase in ET and similar decrease in runoff.
- Widespread increase in root zone moisture content.
- Semi-arid regions and regions have largest increase in ET.
  - Transition zones between dry and wet regions.
- Arid regions: No increase as water table is too deep.

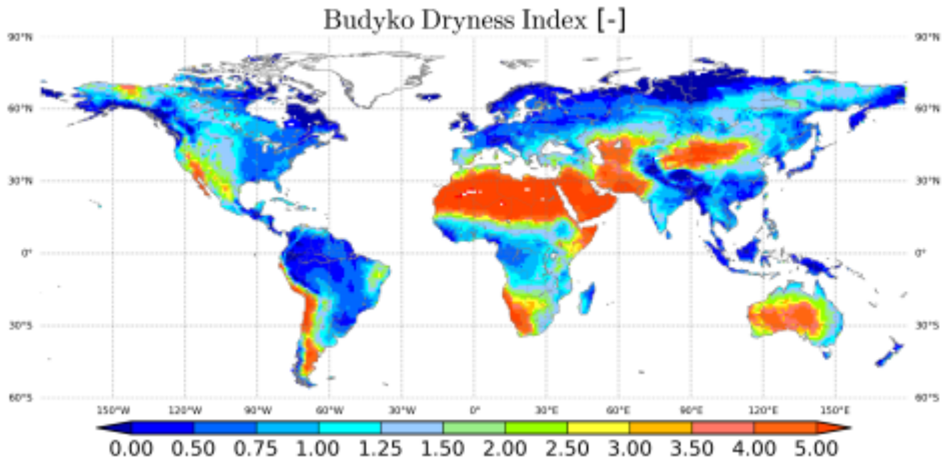
Dominant Mechanism



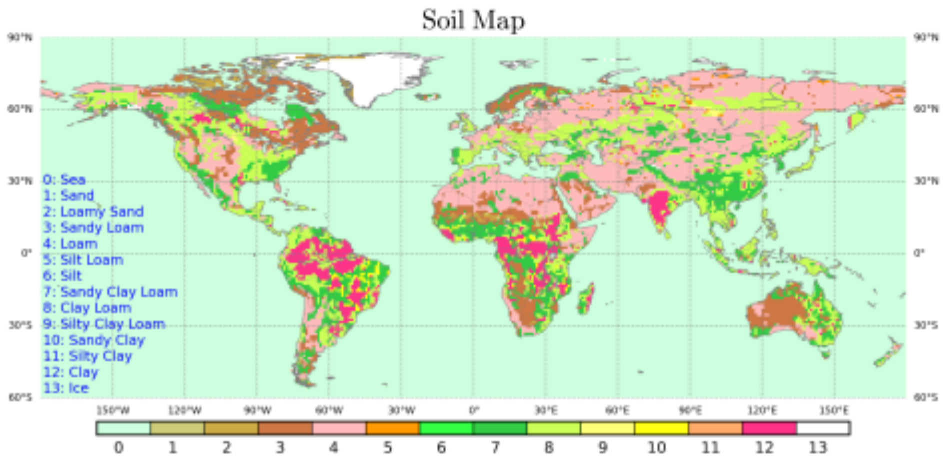


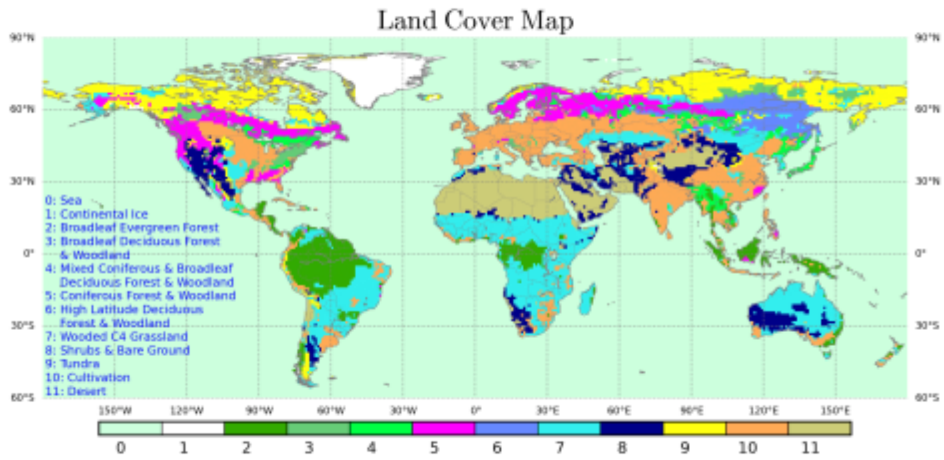
- Increase in ET is mainly due to increase in soil evap. in dry season.

Controlling factors?

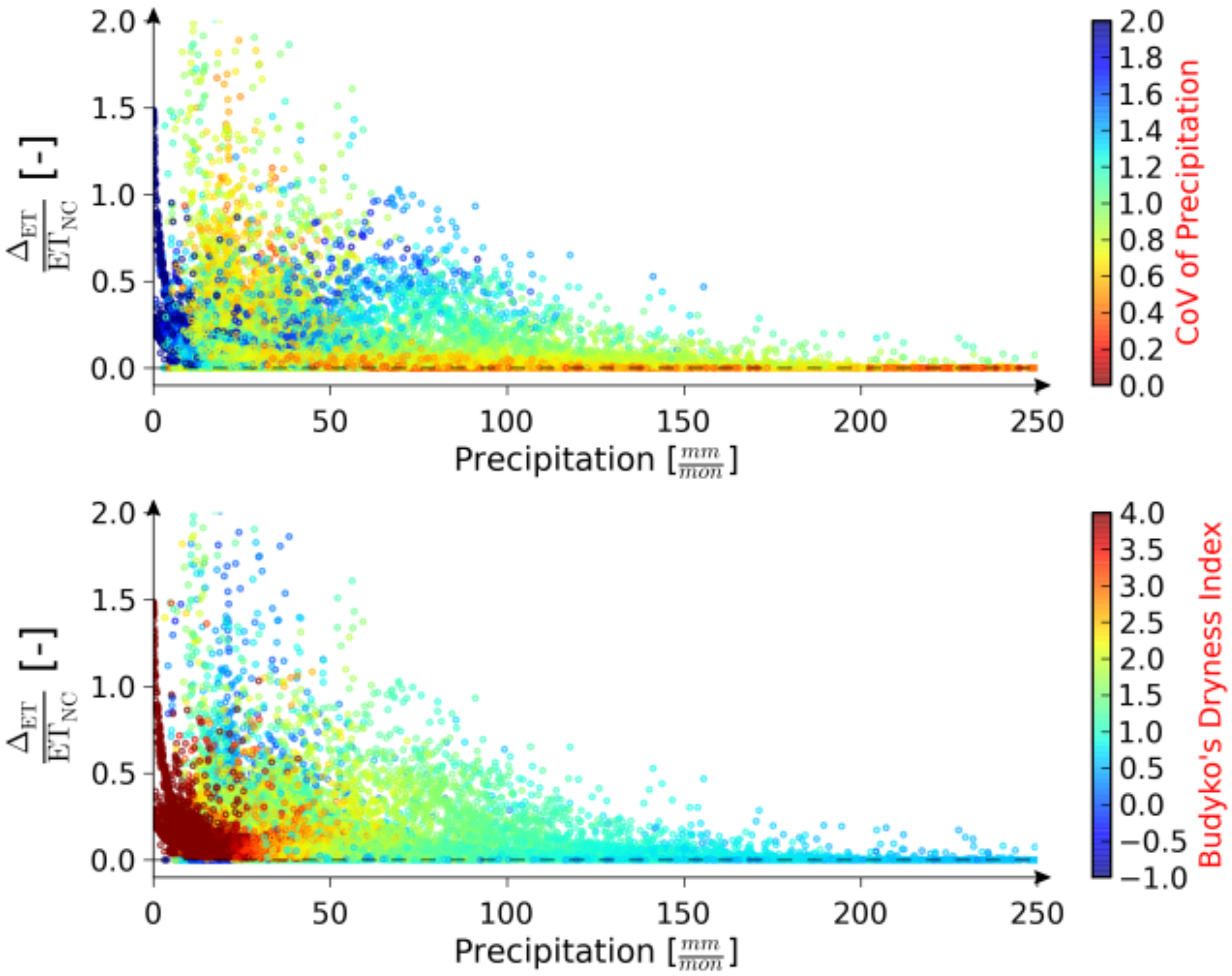


- What controls the spatial and temporal variation in GW-supplied ET in global scale and to what extent?
  - Climate?
  - Soil?
  - Vegetation?



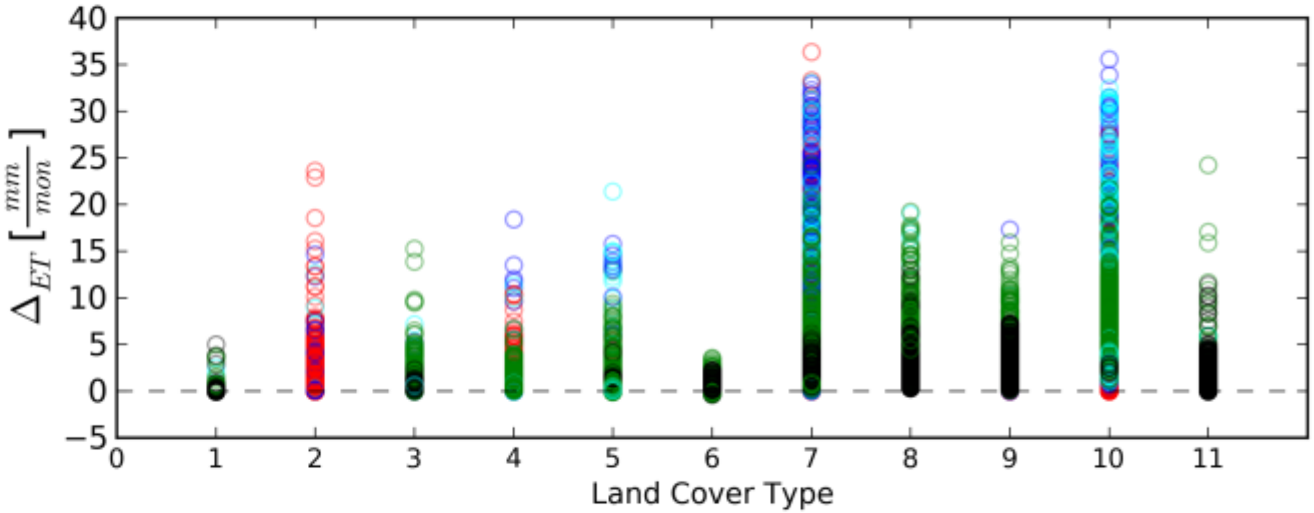


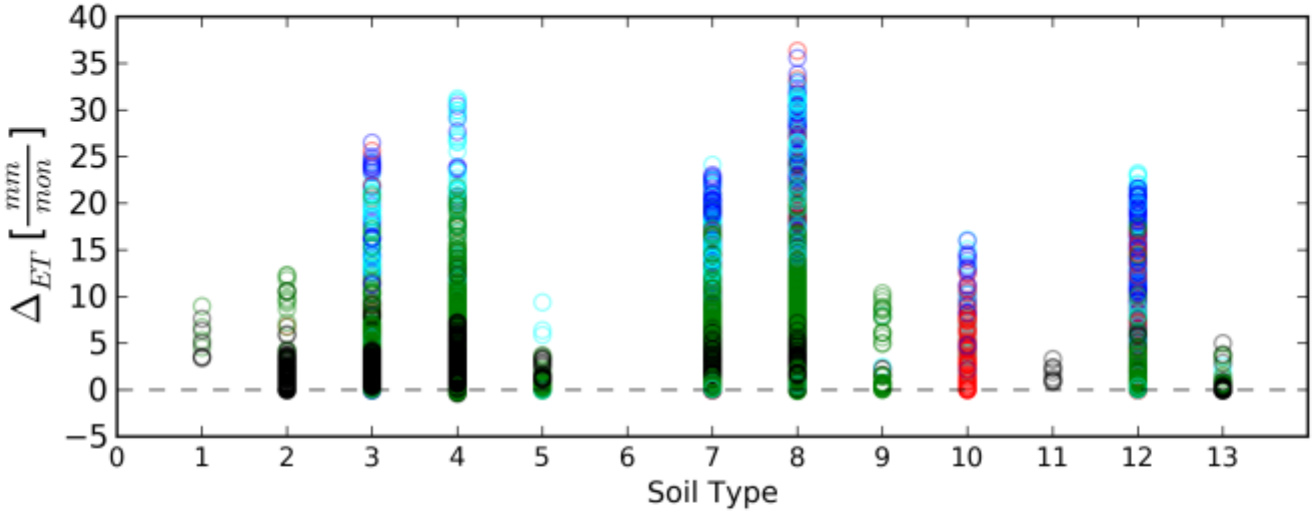
ET vs Climate



- Grid cells with large precipitation (wet) have lower increase in ET.
- Seasonal variation of precipitation is a key factor.
  - Grids with conspicuous dry season have larger increase.
- Dry regions and extremely humid regions have less increase in ET

ET vs Soil and Land Type





- Some soil/land type have larger increase in ET than others.
  - Is it due to their properties or geographical location?
- Actual soil/vegetation responses are affected by climate.
  - To what extent these effects can be isolated?

Soil Resistance to Evap.

- The response of soil evaporation to soil moisture is controlled by two variables:

Soil Resistance

$$R_{soil} = \frac{\alpha_1 (1 - W)}{\alpha_2 + W}$$

$$\alpha_1 = 800$$

$$\alpha_2 = 0.2$$

W: degree of saturation of soil

Soil Relative Humidity

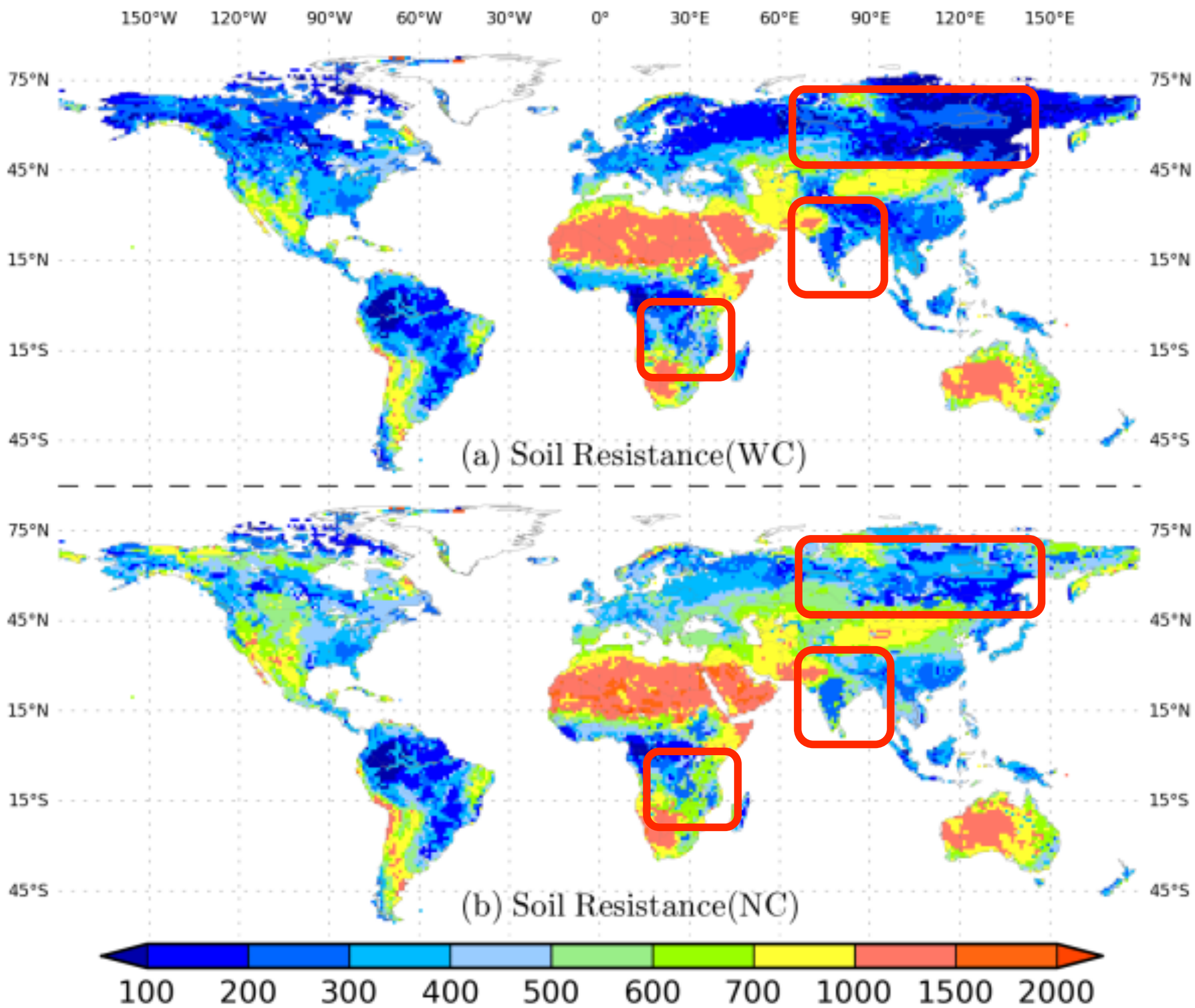
$$E = \rho_a C_E u_a \left[\alpha q_{sat}(T_g) - q_a\right]$$

$$\alpha = e^{\frac{g\psi}{R_w T_g}}$$

α (HSL): relative humidity of soil, Ψ: unsaturated matric potential, and T_g: temperature of the soil layer

Both factors depend on actual soil moisture (governed by climate).

Soil Resistance



- Soil resistance decreases significantly in high latitude and semi-arid regions for WC.
- Semi-arid regions have the largest increase in ET as abundant radiation energy is available.

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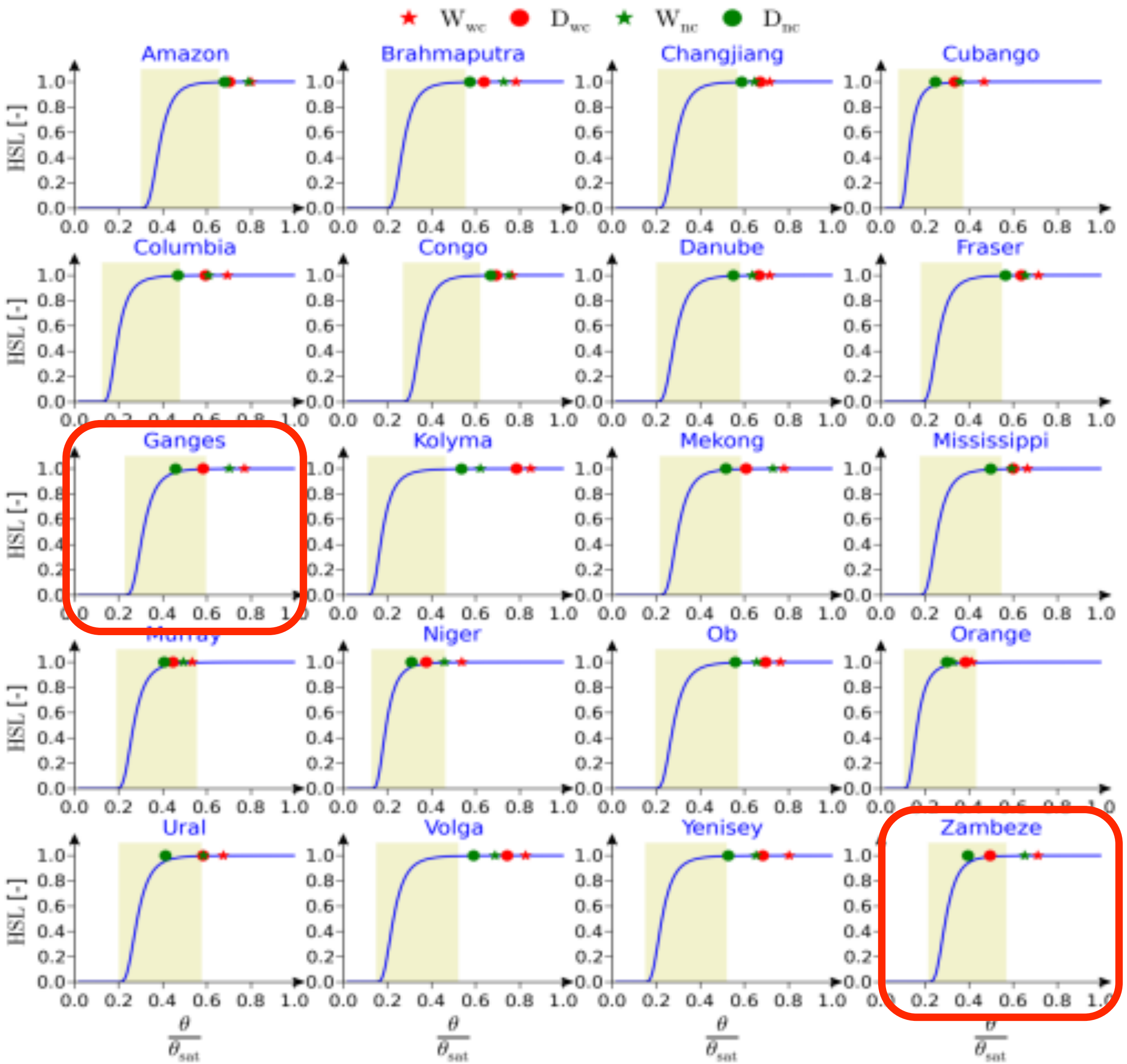
Soil Humidity vs ET



- Sensitive zone for different basins are different.
  - Due to difference in soil properties
- Dry season relative humidity is increased in almost all basins.
  - stronger in Ganges and Zambezi

Soil Stress (Transpiration)

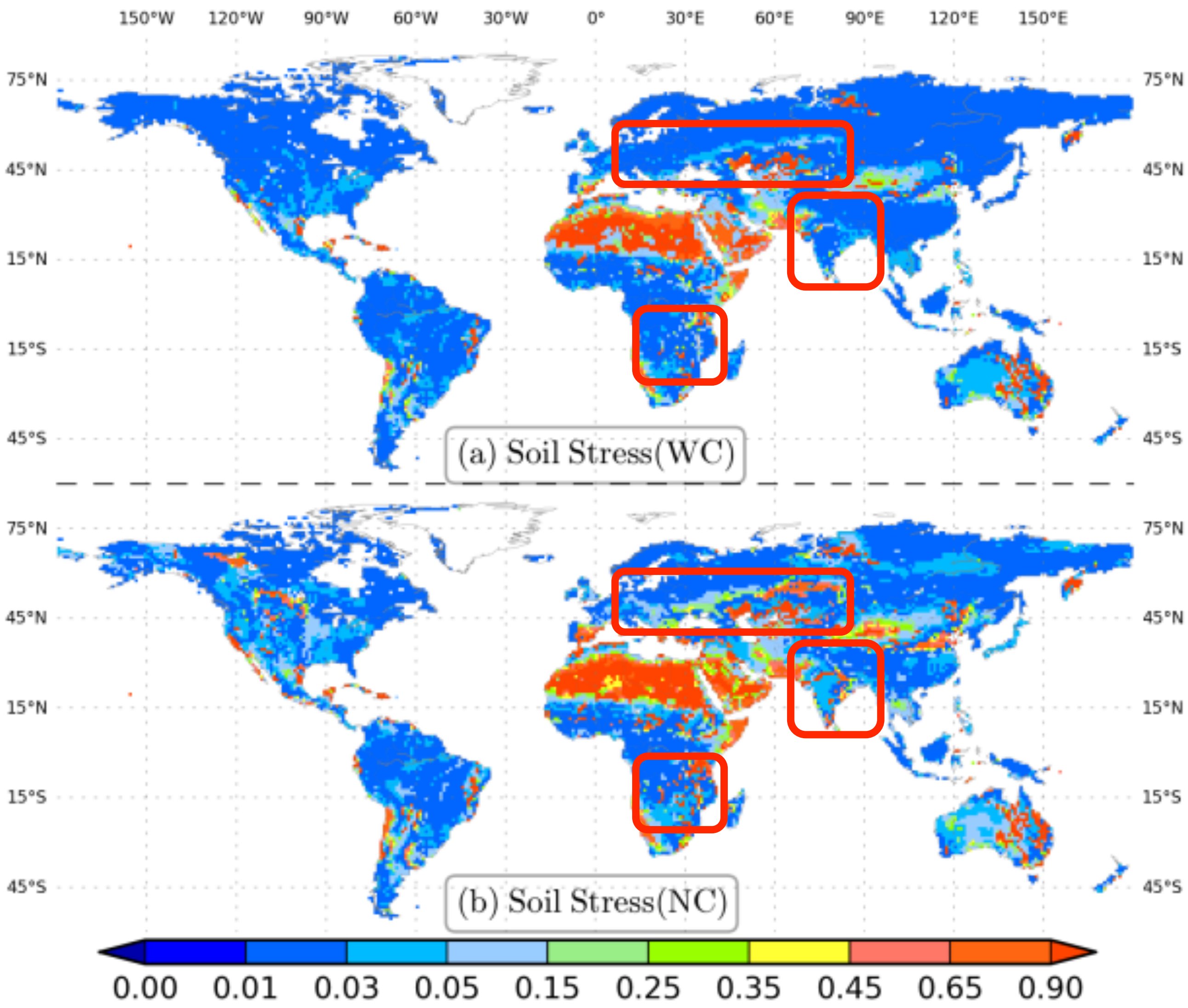
- The lack of soil moisture increases stomatal resistance.
- The soil stress against transpiration is calculated as

$$f_w = 1 - \left[1 + e^{0.02\times(\psi_{cr} - \psi)}\right]^{-1}$$

Ψ_{cr}: Critical matric potential (depends on vegetation type), Ψ: unsaturated matric potential (depends on soil property and actual moisture condition)

  - *Higher values means larger stress*

Soil Stress



- Soil stress reduces when capillary flux is considered.
- Areas with increase in transpiration have significant reduction in soil stress.

Conclusions

- Globally groundwater-supplied capillary flux is ~9%.
- Increase in soil evaporation dominates the GW-supplied ET.
- Climate provides the major control on GW-supplied ET.
  - Sub-humid to semi-arid regions are largely influenced.
- Regions with increase in soil resistance have larger increase in ET compared to soil humidity.
  - Dependent on actual soil condition, which is related to climate itself.
- Soil stress factor against transpiration reduces when GW capillary flux is considered
  - ET is enhanced when the change is significant.

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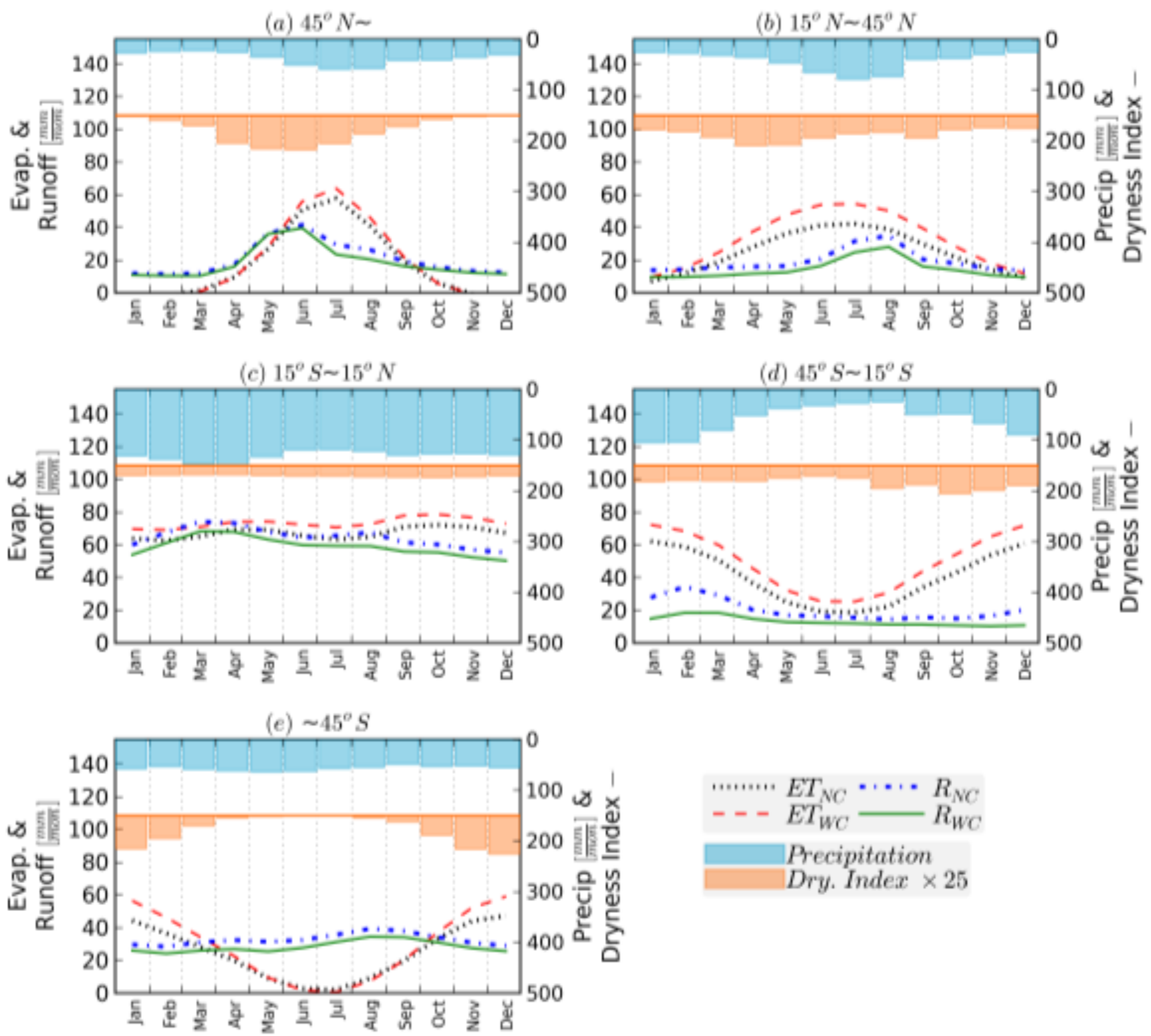
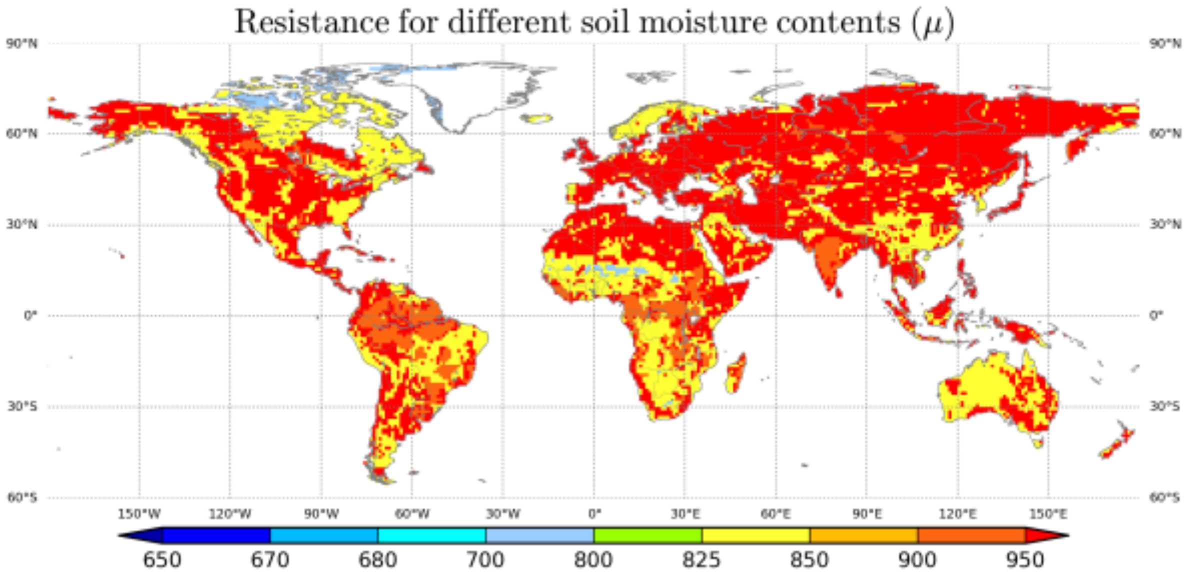
Thank you very much!!

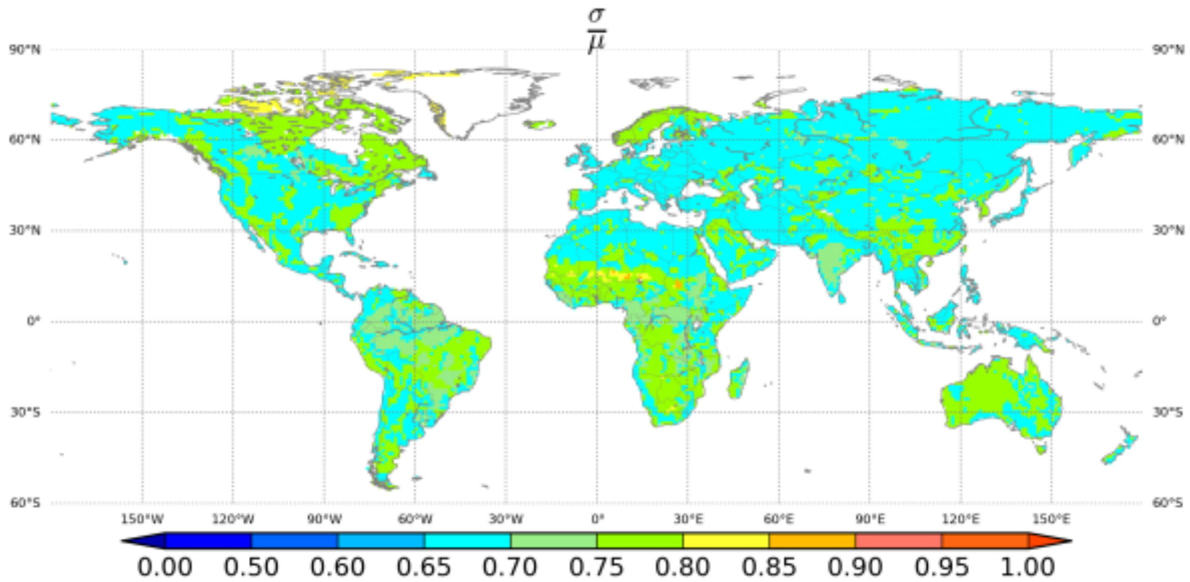
Seasonal Variation



- Increase in ET is generally governed by availability of radiation.
- In high-latitudes, ET increases slightly when radiation is available.
- In mid-latitude, ET increases in all seasons but larger in dry season.
- In tropical region with abundant radiation, ET increases consistently in all seasons.

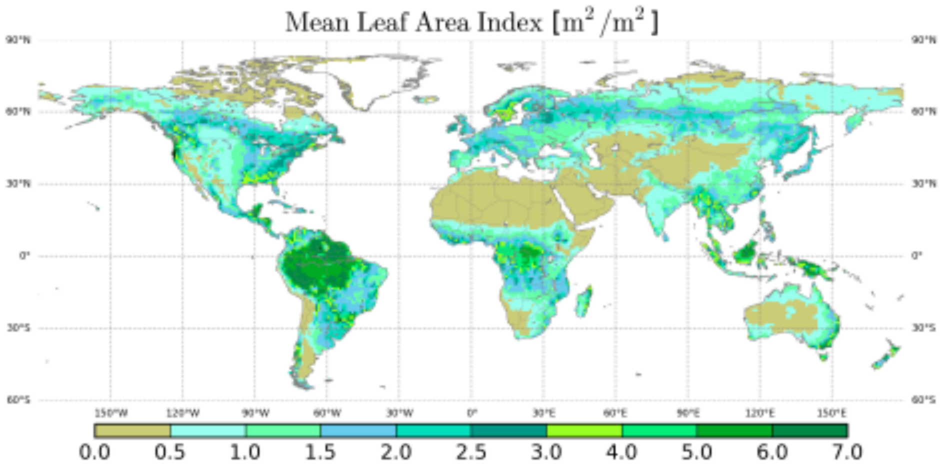
Resistance of different soils

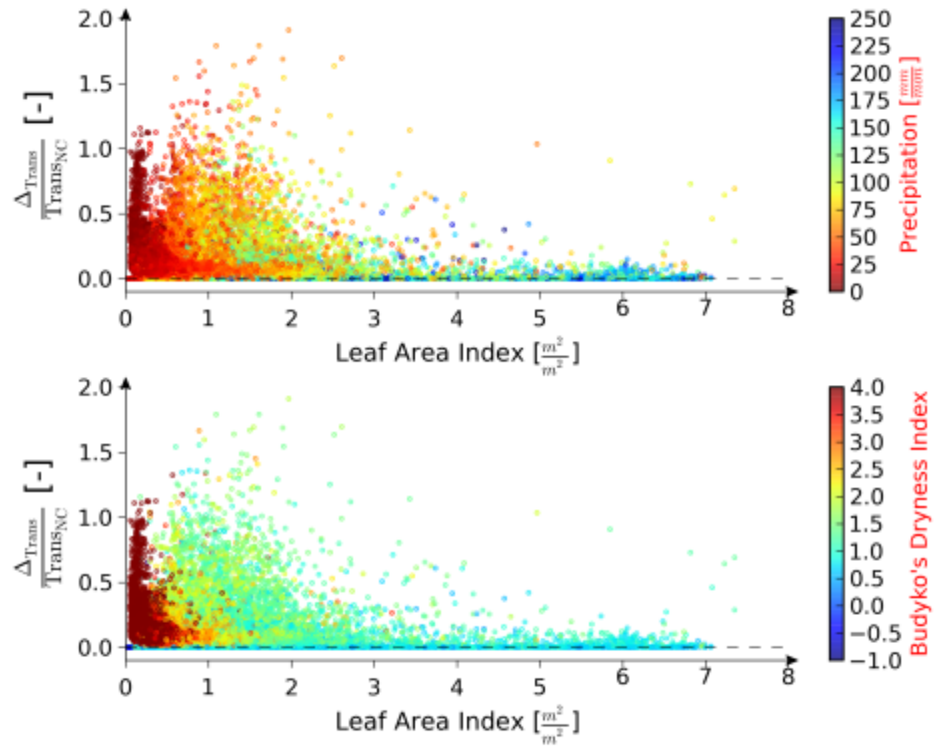




- If the climate is same throughout the world, i.e., same soil moisture.
  - Different soils should have different resistance due to their properties
- Soil moisture varied from 0.05-0.35 (global constant)
- For different soil moisture, the variation of soil resistance is low

LAI vs Transpiration





- Grids with large LAI have large precipitation.
- Grids with small LAI have large fractional increase.
- Most of the increase in transpiration in region with LAI in mid range.