Climate-Soil-Vegetation Control on Groundwater Table Dynamics and its Feedbacks in a Climate Model

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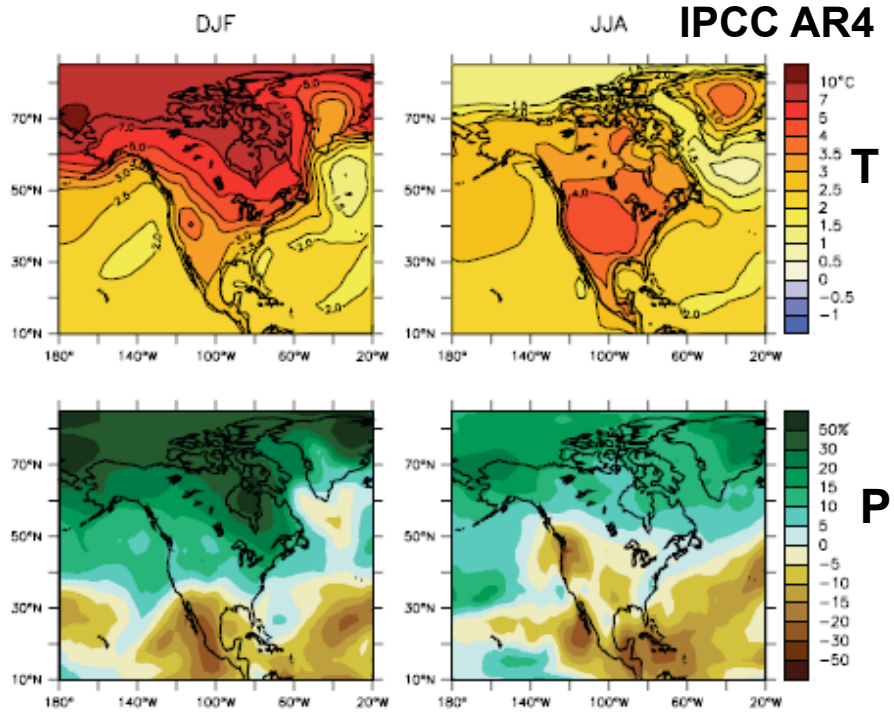
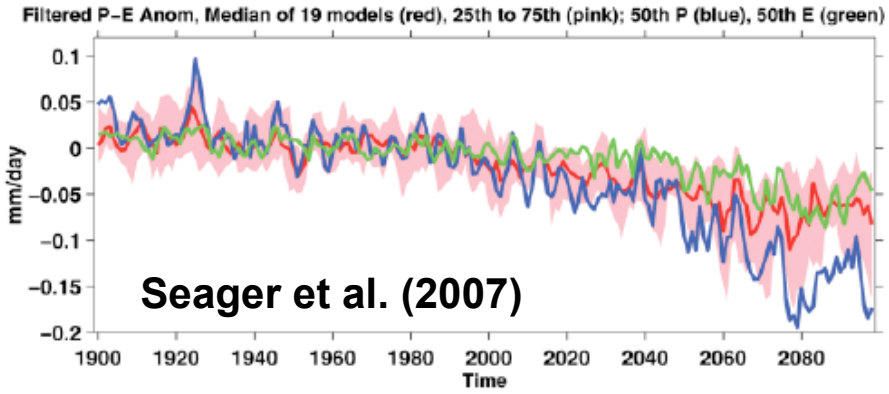
Climate Models Projected Increased Warming and Drying in the Southwest

AR4 Models projected:

- Poleward expansion of subtropical high and poleward displacement of storm tracks
- Strengthening of subtropical high resulting in more drying over land in the summer
- Drying is mainly driven by reduced precipitation, and warmer temperatures increase evaporative demand
- Earlier snowmelt, and reduced soil moisture amplify summer drying and warming



Models projected an imminent transition to warmer and more arid climate in the Southwest



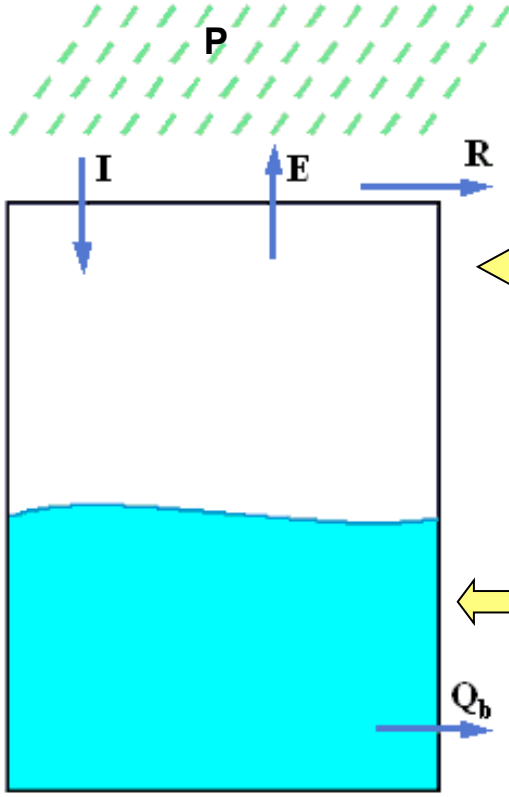
As part of the DOE IMPACTS project on abrupt climate change, we are investigating:

- The role of land-atmosphere interactions on the magnitude and duration of droughts, focusing on surface/ subsurface hydrologic and vegetation processes

- The impacts of dust from droughts on atmospheric heating and the influence on the North American monsoon circulation

- This presentation focuses on representation of groundwater table dynamics in climate model to improve understanding of the influence of climate, soil, and vegetation on groundwater table dynamics, and its feedbacks on regional climate

Surface and Subsurface Water Interactions
(Liang et al. 2003 JGR)



Change of soil moisture

Diffusion term

Drainage term

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D(\theta)\frac{\partial \theta}{\partial z} \right) - \frac{\partial K(\theta)}{\partial z} - sink(z,t)$$

Change of water table depth

θ_s porosity
$n_e(t)$ effective porosity

$$\alpha(t+\Delta t) - \alpha(t) = \frac{1}{\theta_s + n_e(t)} \times \left[\bar{\theta}(t+\Delta t) - \bar{\theta}(t) - \int_t^{t+\Delta t} (p - R - Q_b - E_t) \cdot dt \right]$$

Change of total soil moisture in the unsaturated zone

Net water recharge to groundwater body

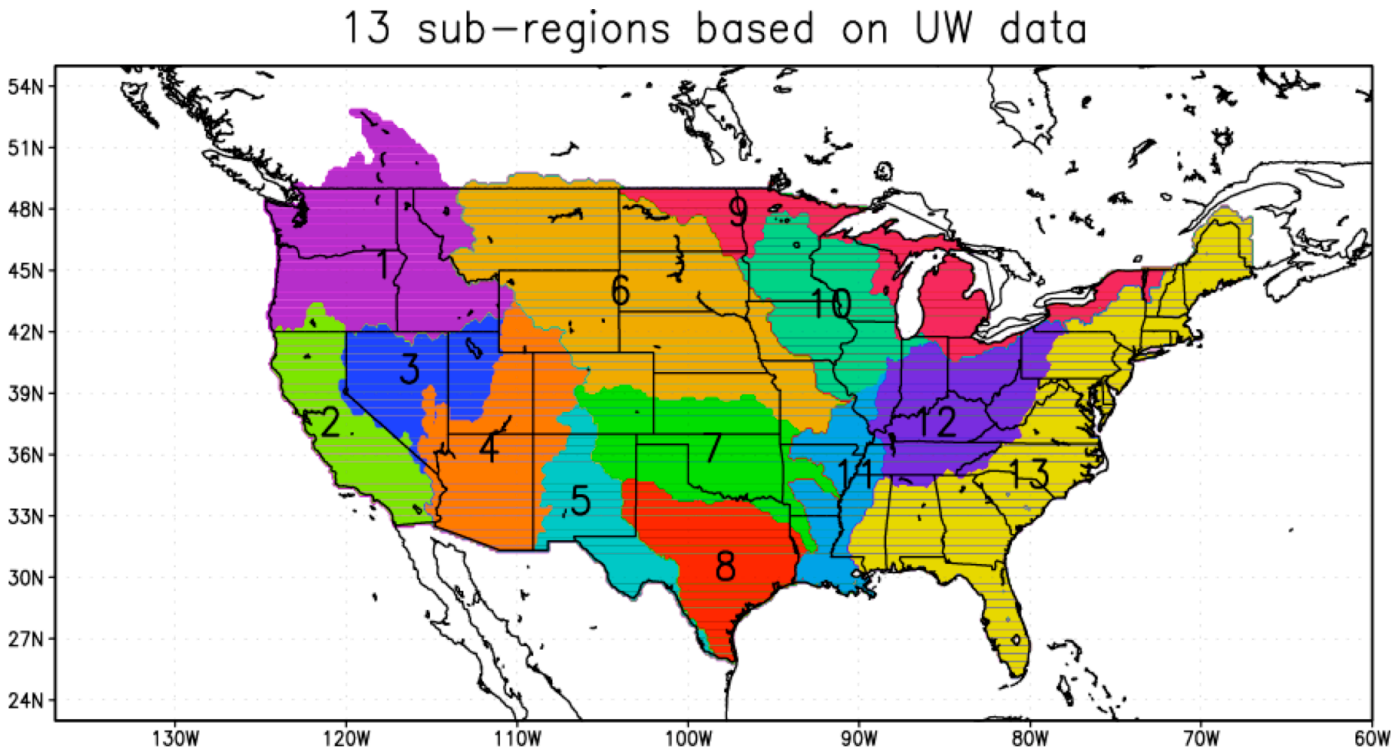
Model Development and Testing

- The dynamic groundwater approach of Liang et al. (2003) has been implemented in the Variable Infiltration Capacity (VIC) model coupled with MM5
- Three simulations have been performed using MM5-VIC over North America at 60 km grid resolution (1986 – 2002)

  - Two simulations were performed with 2 m and 5 m soil depth to determine the impacts of soil depth

  - One simulation was performed using 5 m soil depth with the dynamic groundwater component
- WRF and CLM being coupled through the CCSM flux coupler (CPL7) (RACM group, Leung)
- Groundwater module being transferred to CLM3.5 (Xu Liang)
- WRF and VIC being coupled through the CCSM flux coupler (Lettenmaier's group)

Regional Analysis



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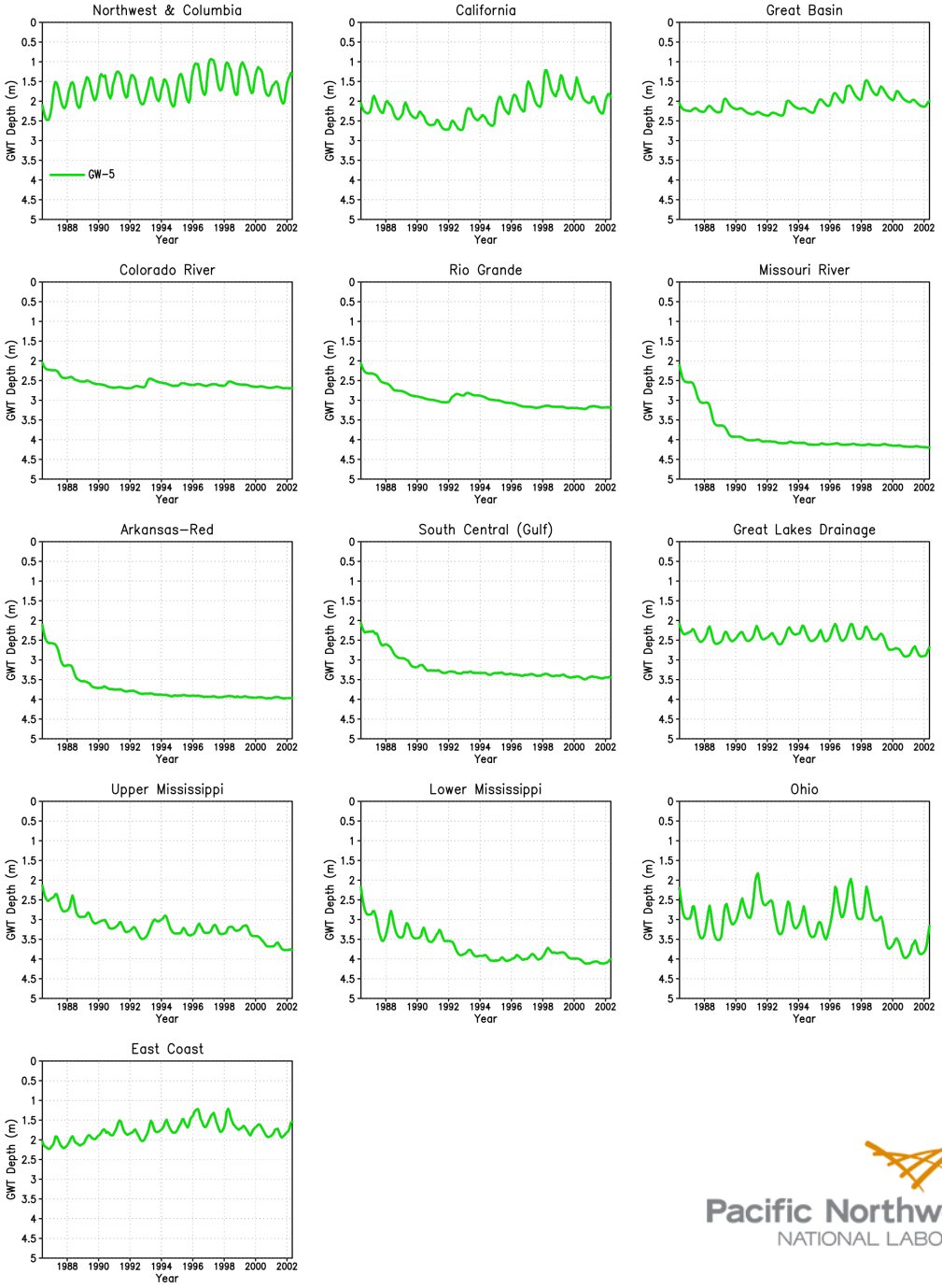
Simulated GWT Depth for 13 River Basins



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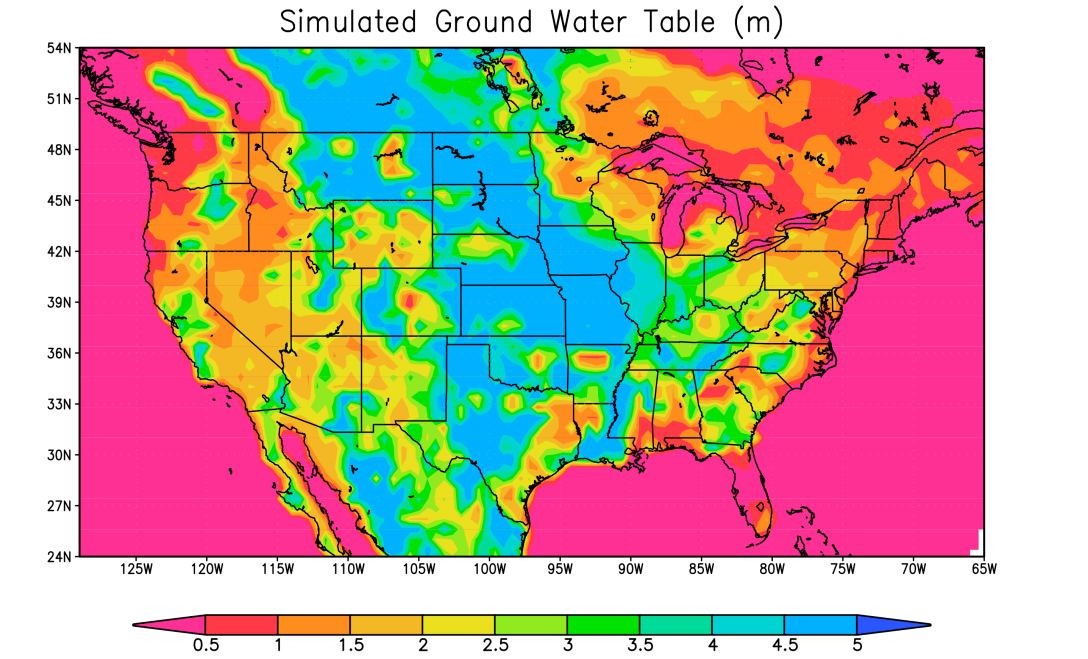
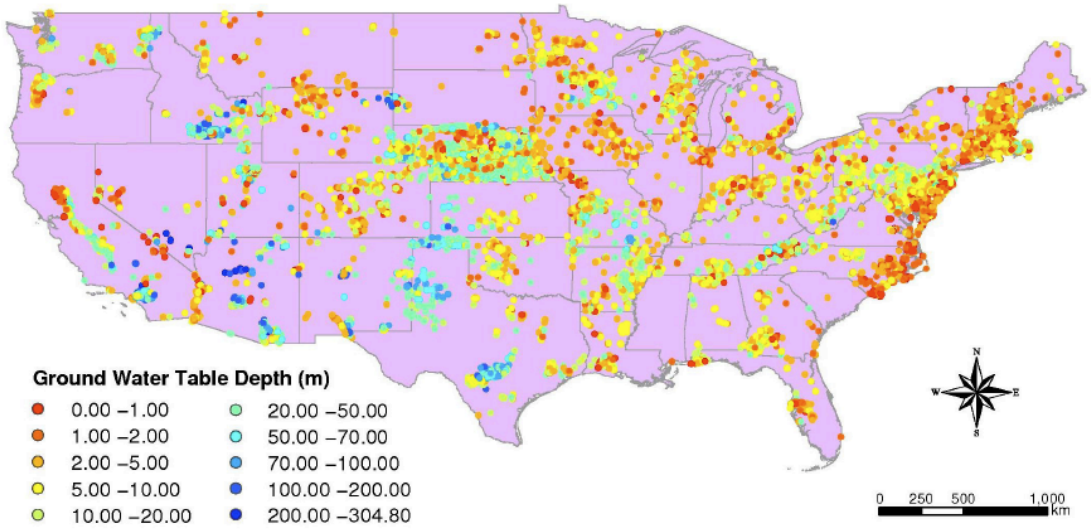
Simulated and Observed GWT Depth





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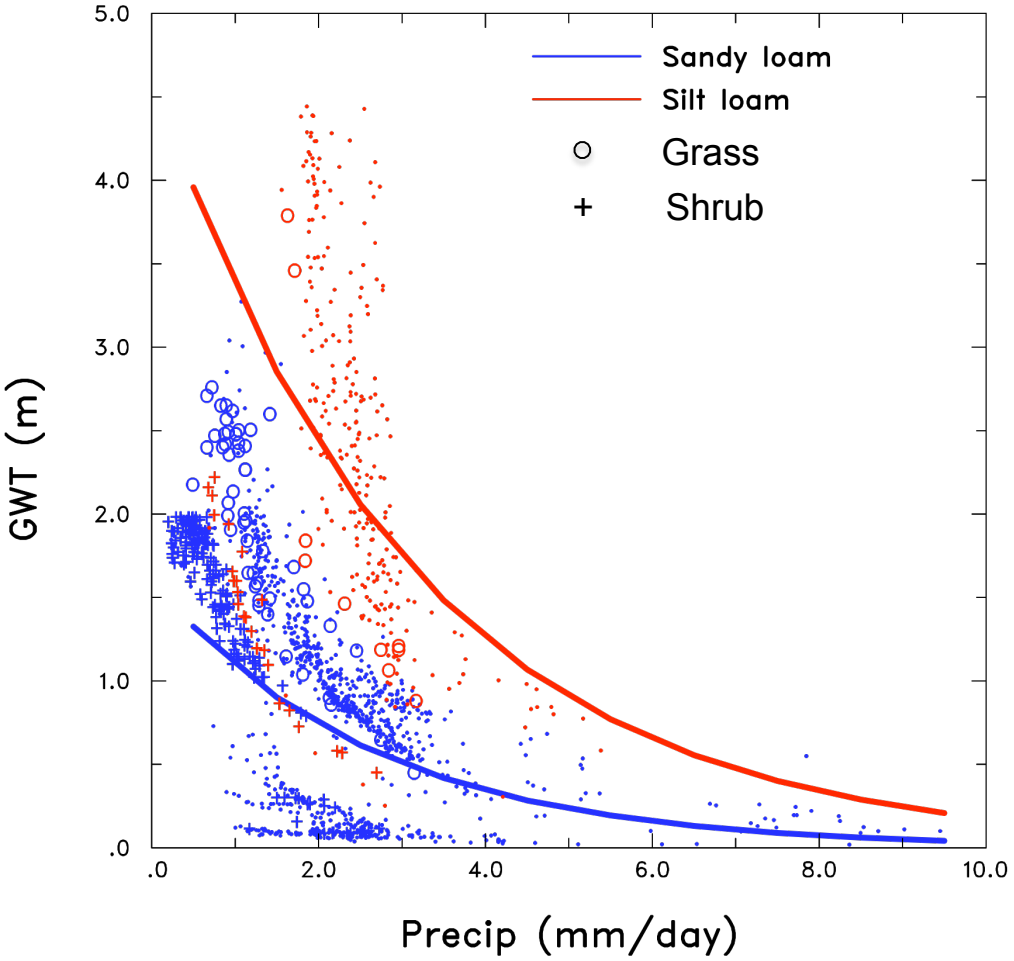
Climate, Soil, and Vegetation Control on GWT Depth



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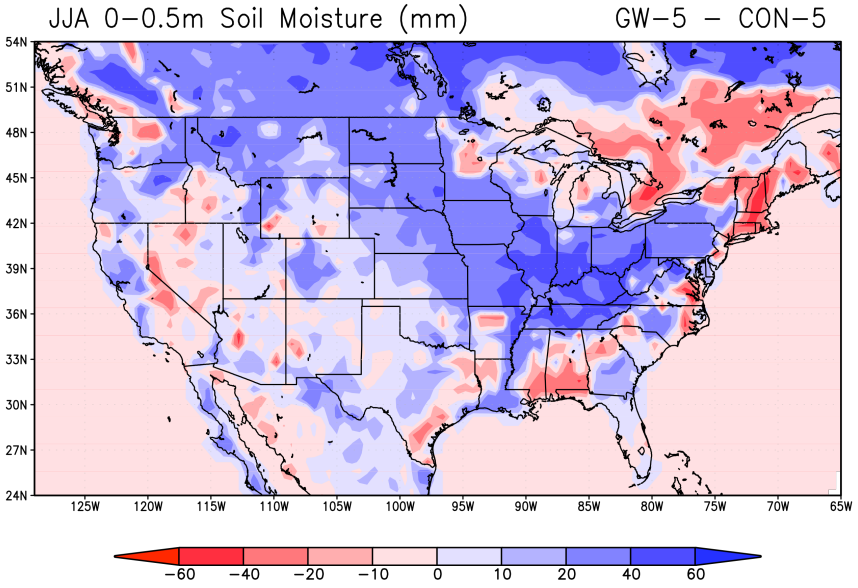
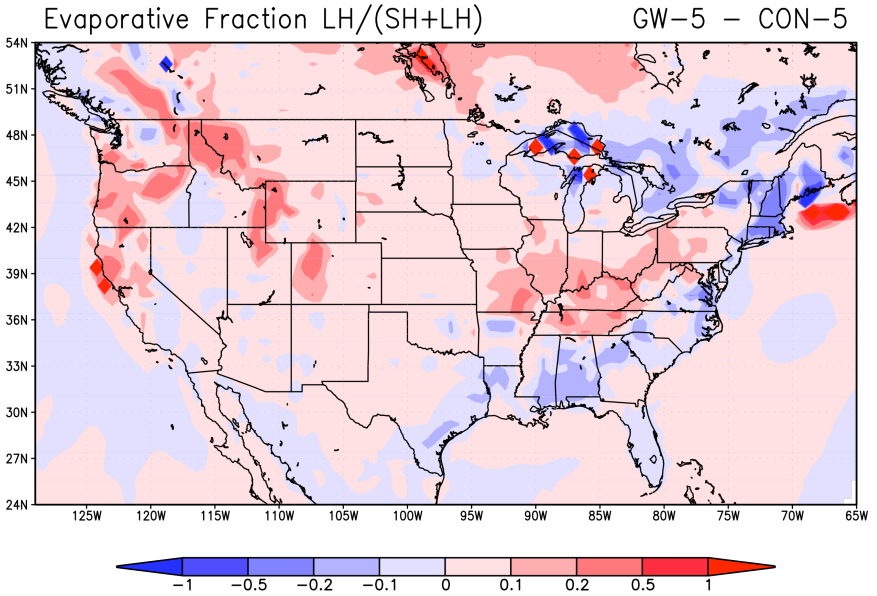
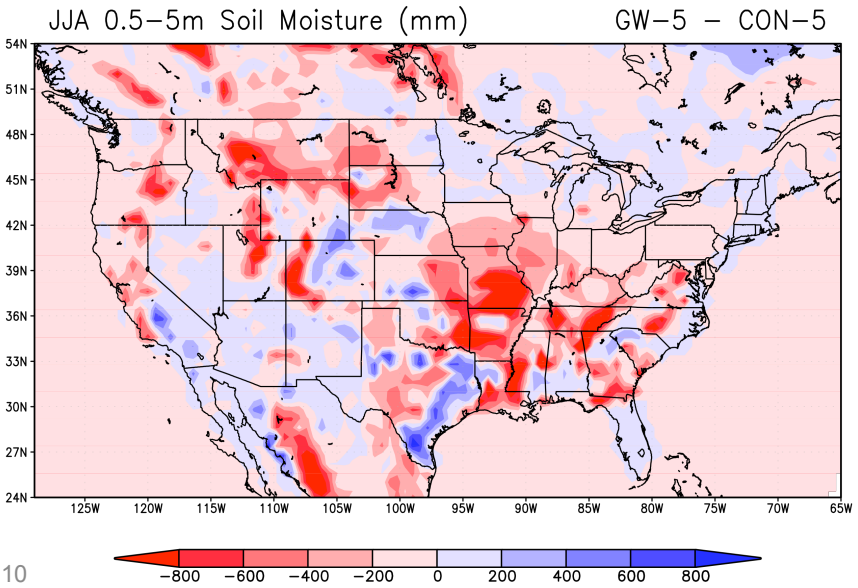
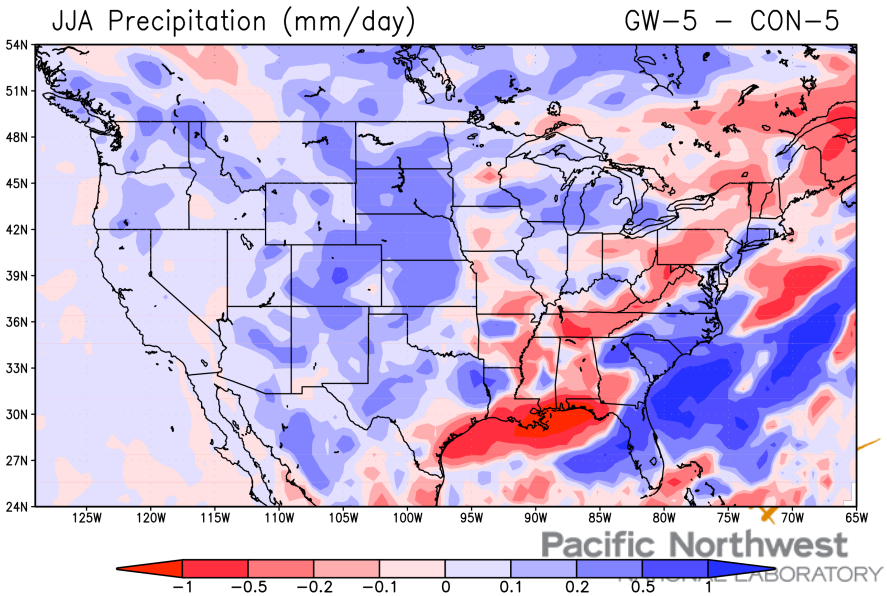
The Influence of GWT Dynamics

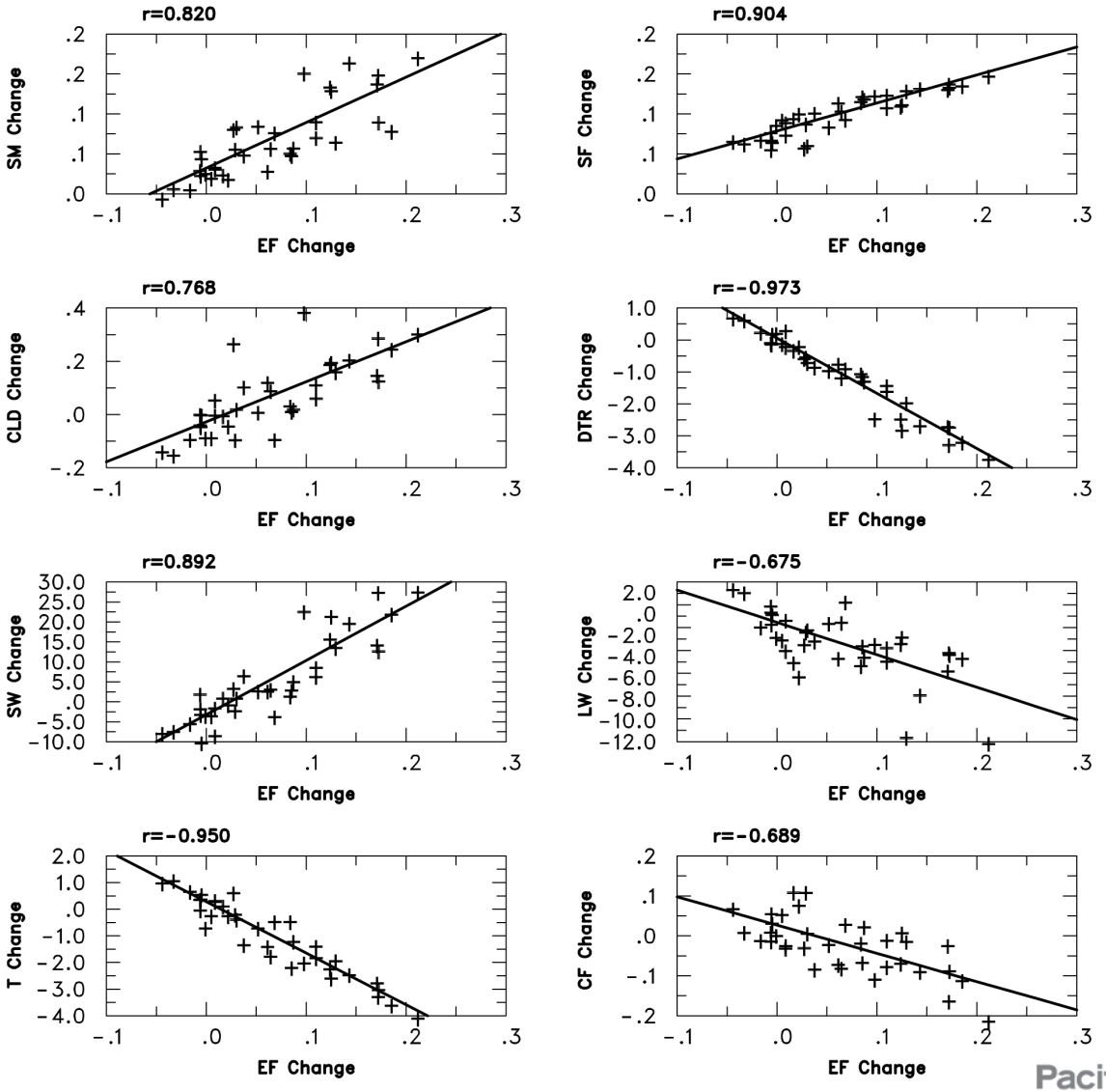








Land-Atmosphere Interactions



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Summary

- A dynamic groundwater module has been implemented in VIC and tested in a fully coupled MM5-VIC model
- GWT is found to depend most strongly on precipitation, but soil and vegetation properties also exert important influences and introduce regional scale features
- Groundwater table dynamics influences climate mainly through changes in the partitioning of soil moisture between the surface and subsurface layers, which influence the partitioning of latent and sensible heat fluxes (EF)
- Changes in EF then influence cloudiness (cloud water content and cloud top height), radiation, surface temperature, and convective/nonconvective rainfall
- Generally introducing groundwater table dynamics reduces the dry bias in the Missouri and Arkansas-Red river basins

Future Work

- Transfer groundwater table module to CLM
- Test fully coupled WRF-CLM with and without groundwater table dynamics
- Introduce other model changes to more dynamically simulate the influence of vegetation and subsurface processes (e.g., hydraulic redistribution, plant water storage)
- Perform numerical experiments to study the role of surface and subsurface processes on droughts