Surface and Groundwater Interactions and Their Impacts on Simulated Water and Energy Budgets Under Droughts

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Motivation

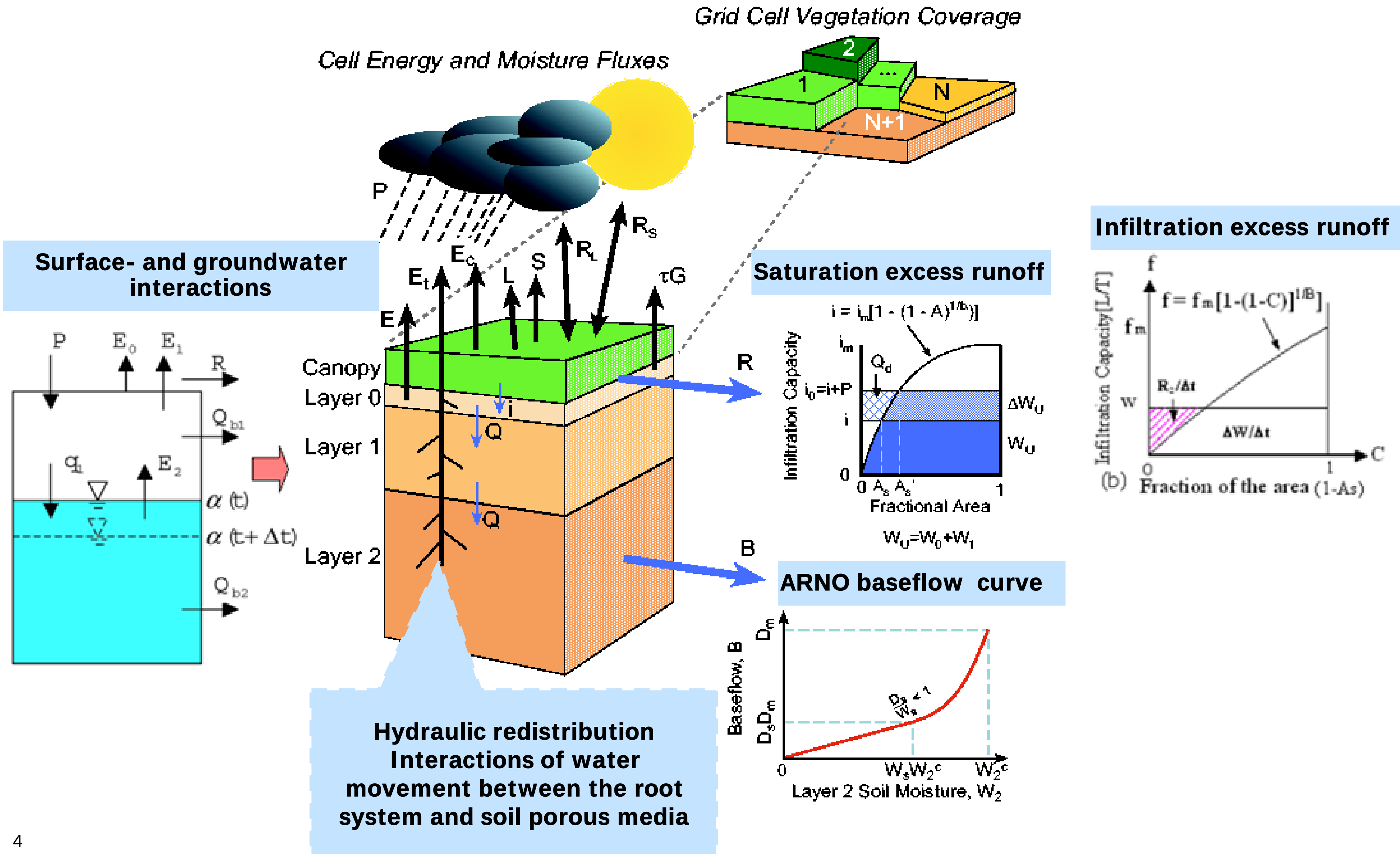
- AR4 models predicted warmer and dryer conditions in the subtropical regions, leading to mega droughts in the future due to global warming

- Surface - groundwater interactions may play important roles at different stages of droughts through modifications of root zone soil moisture and plant physiological responses and feedbacks in the climate system

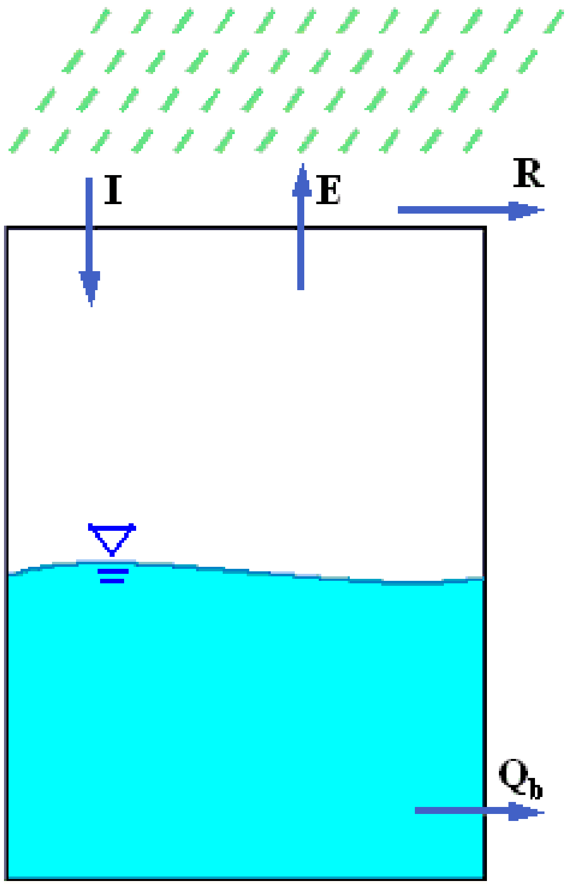
Approach

- Improve hydrological simulations for arid conditions to account for:
  - Hydraulic redistribution in the soil-root system
  - Plant capacitance, carbon assimilation, plants growth
  - Surface water and groundwater interactions
- Implement selected parameterizations of the Variable Infiltration capability (VIC) model and new developments into the Community Land Model (CLM)
- Use offline and coupled simulations to evaluate model and perform numerical experiments to investigate the role of vegetation, surface, and subsurface processes on mega drought

Merging of CLM4 and VIC



Dynamic representation of surface and groundwater interactions



Liang et al., JGR, 2003

Change of soil moisture | Diffusion term | Drainage term

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

Change of water table depth

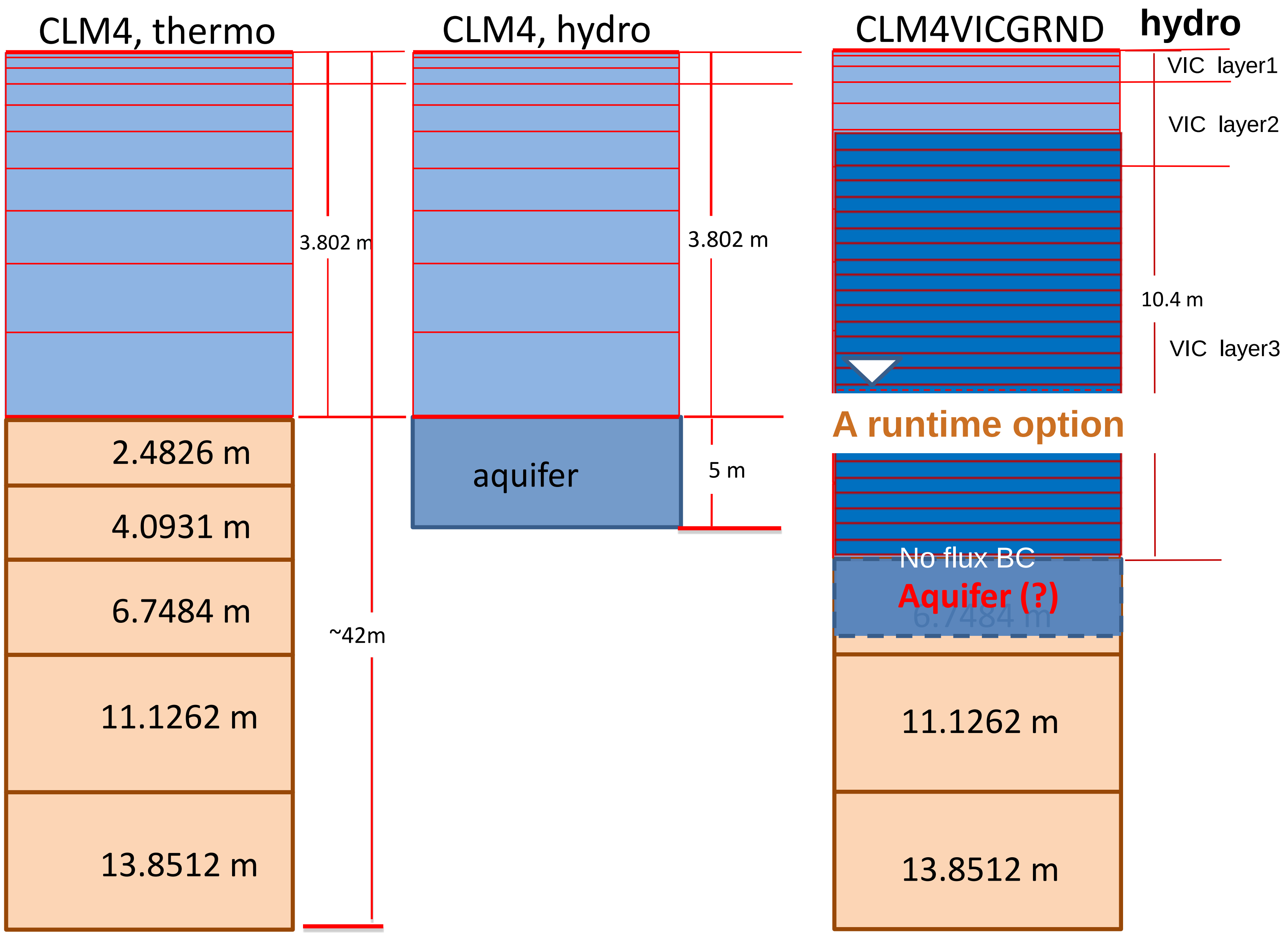
θ_s porosity
$n_e(t)$ effective porosity

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

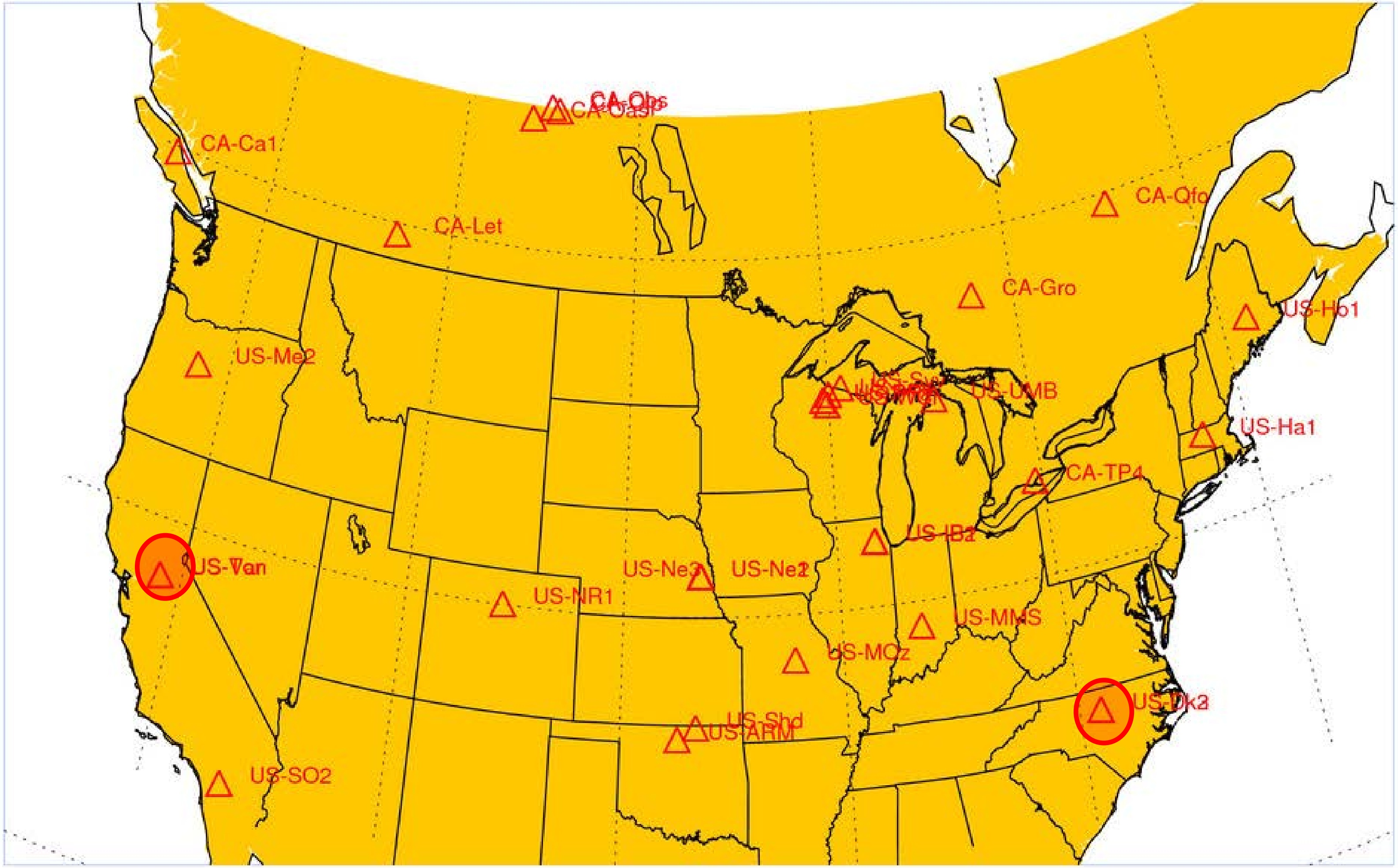
Change of total soil moisture in the unsaturated zone

Net water recharge to the groundwater body

Implementation of VICGROUND in CLM4



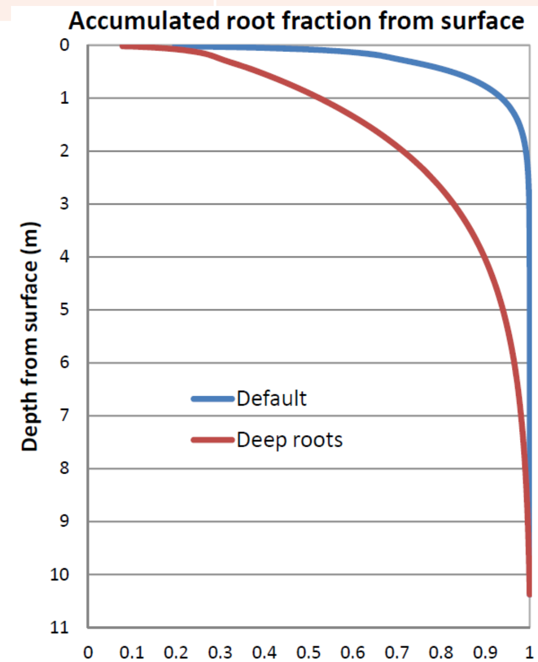
Testing at NACP flux tower sites



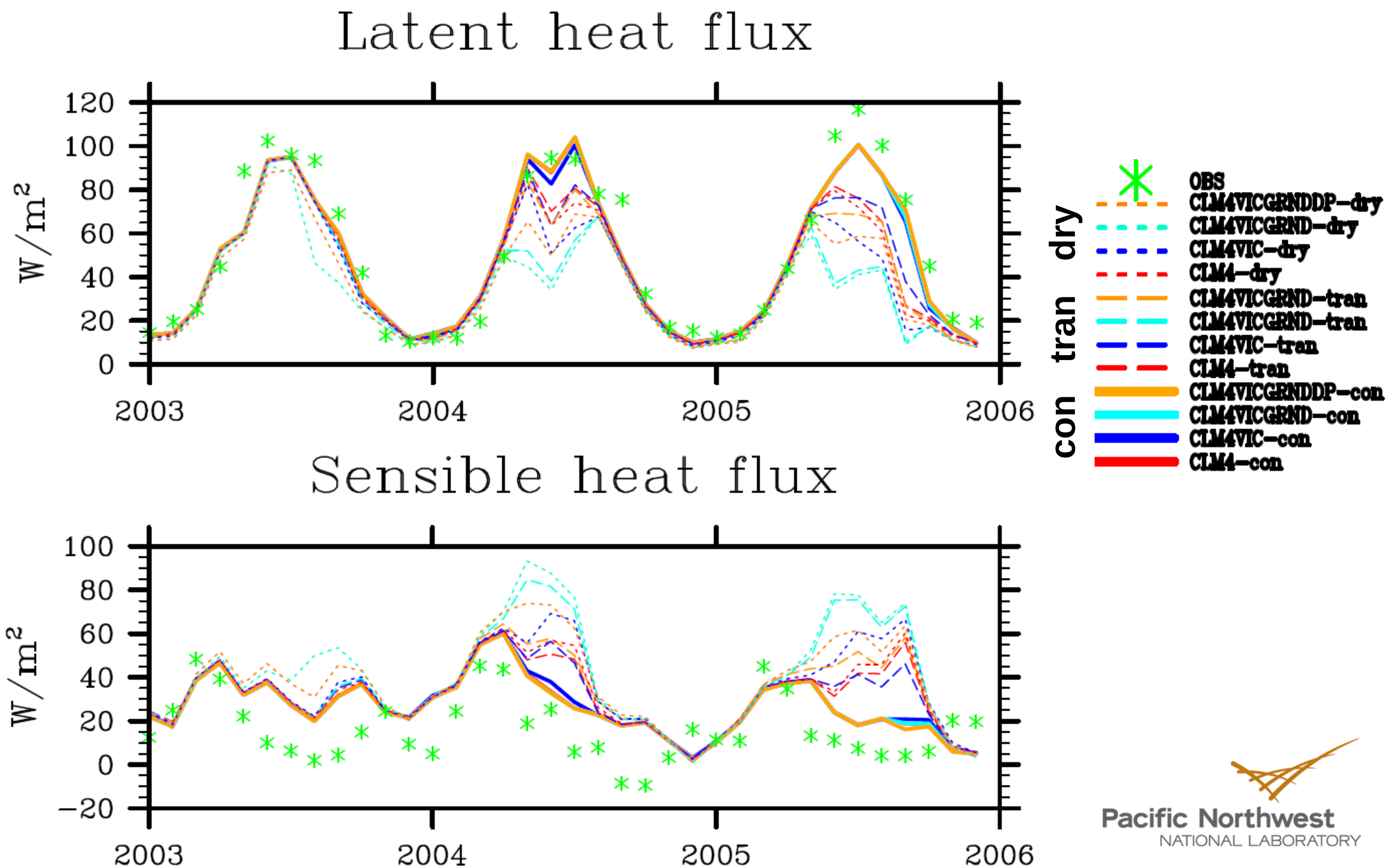
Numerical experiments

Scenarios	Control	Transient	Dry
CLM4 CLM4VIC CLM4VICGRND	Atmos: Observed Initial: Spinup Par: Default	Atmos: 0.5 prcp Initial: Control Par: Default	Atmos: 0.5 prcp Initial: Spinup Par: Default
CLM4VICGRNDDP	Par: Deep roots	Par: Deep roots	Par: Deep roots

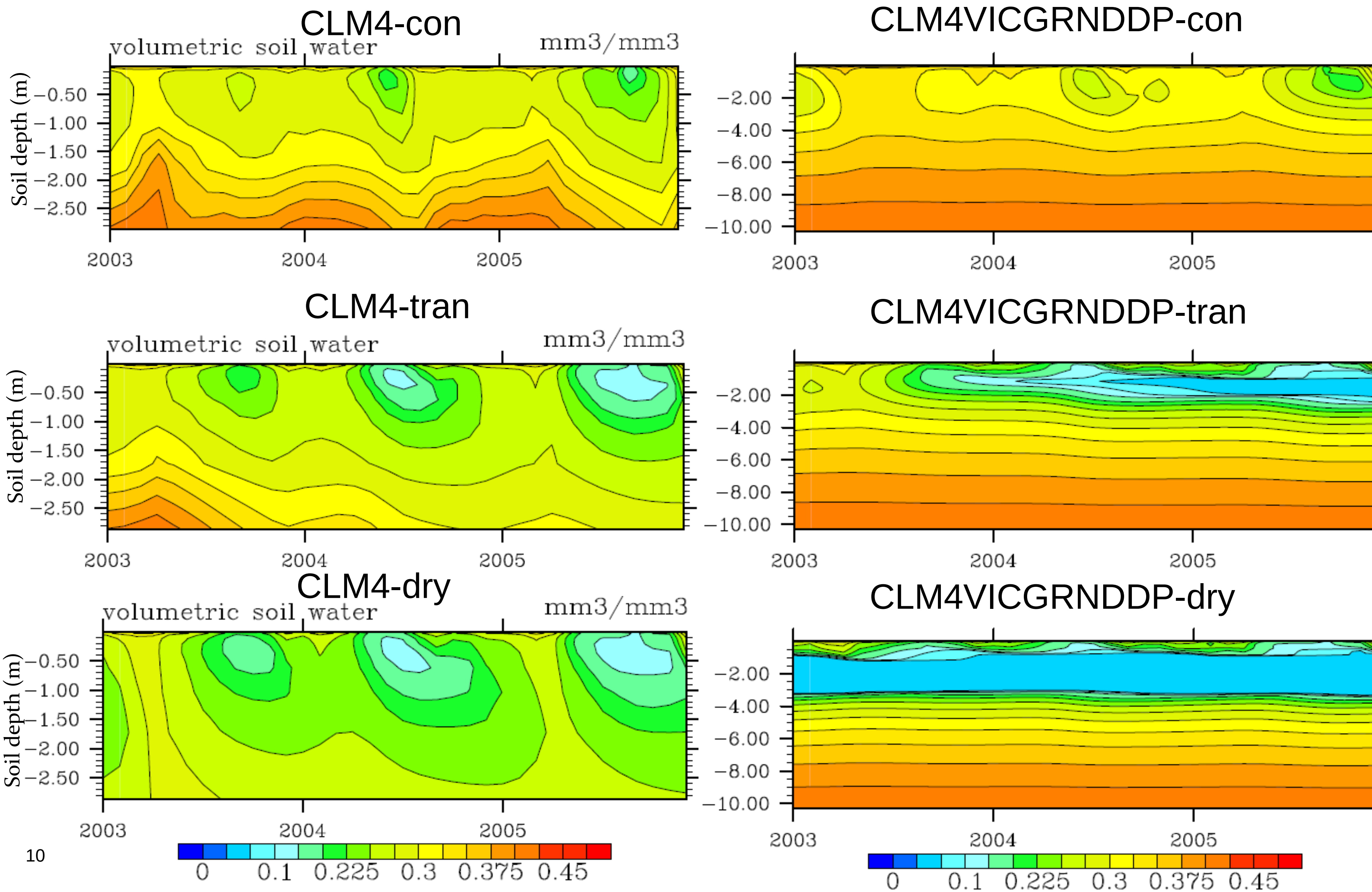
- CLM4 parameters from default input datasets
- VIC parameters were fixed across sites
  - VIC curve shape parameter: $b = 0.1$
  - Maximum baseflow: $D_{smax} = 2$ mm/day
  - ARNO baseflow curve shape parameters: $D_s = 0.05$, $W_s = 0.5$



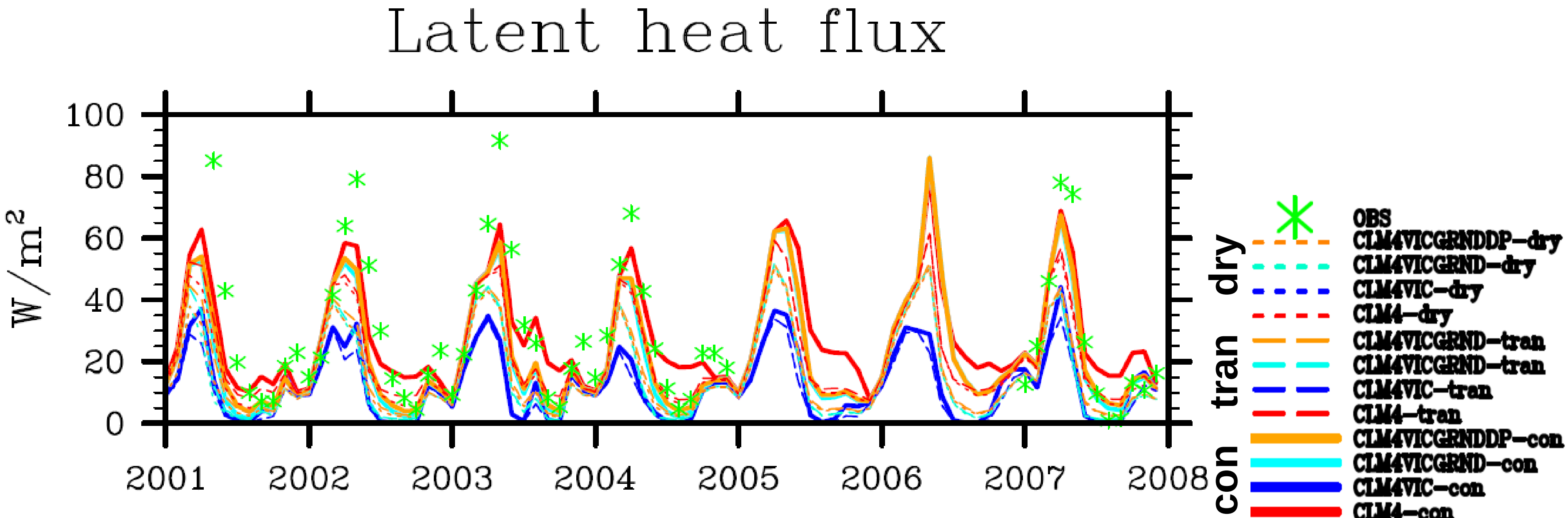
Impacts on energy fluxes
Duke Forest, Deciduous Broadleaf

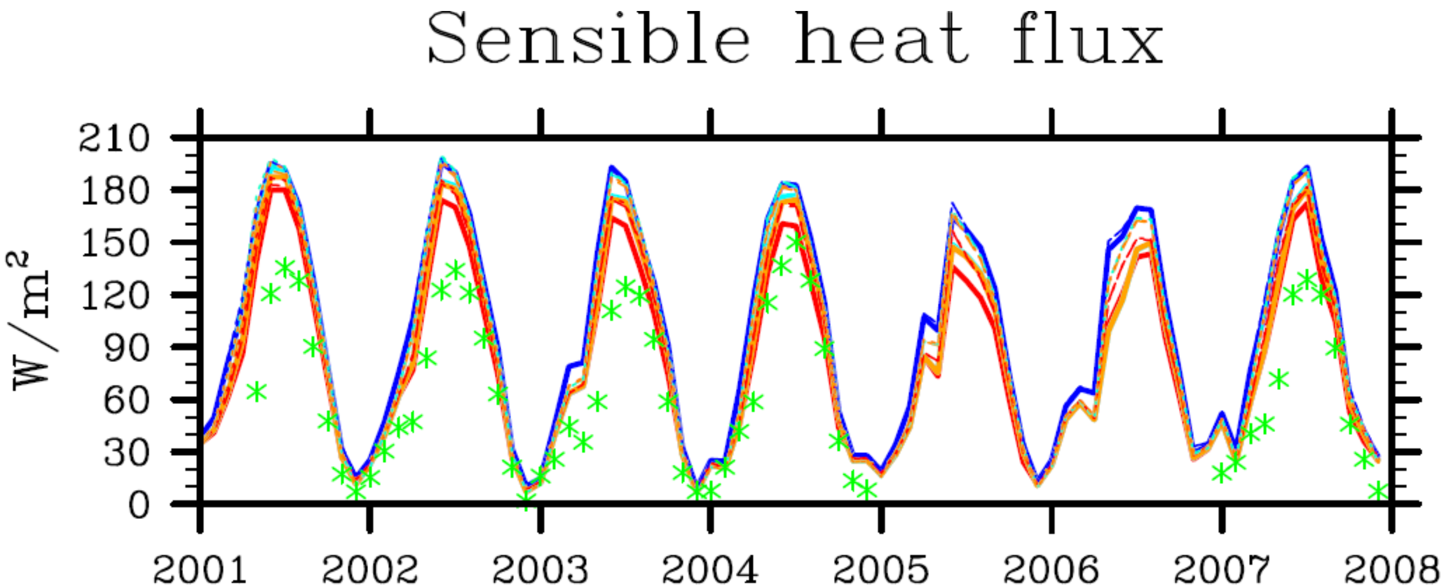


Evolution of soil moisture profiles
Duke Forest, Deciduous Broadleaf



Impacts on energy fluxes
Tonzi Ranch, Woody Savannas





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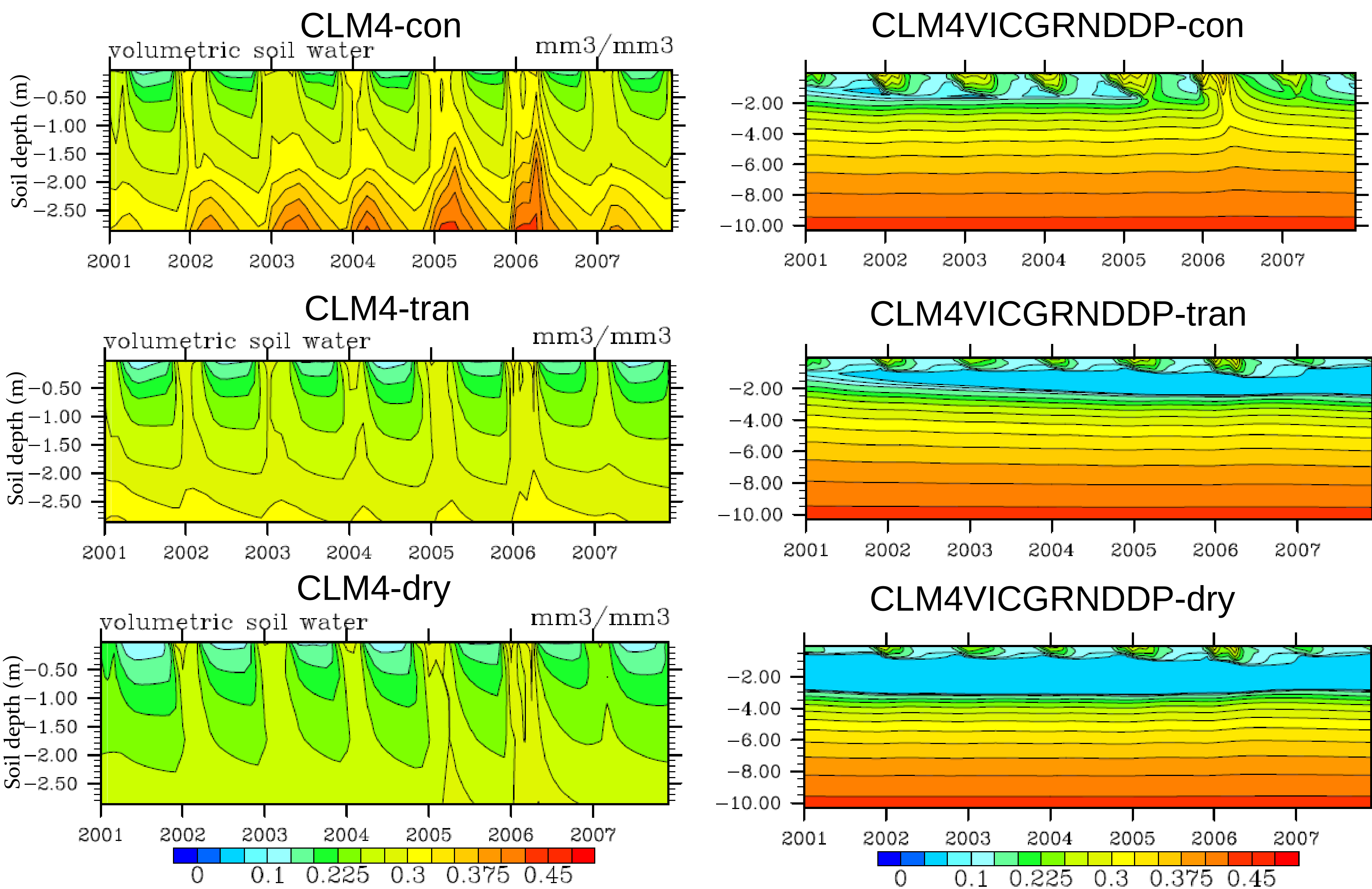
Evolution of soil moisture profiles

Tonzi Ranch, Woody Savannas



Conclusion

- In energy limited sites, different hydrologic parameterizations produce similar surface fluxes, but their response under droughts varies significantly
- In water limited sites, different hydrologic parameterizations produce different surface fluxes as well as their response to droughts
- Subsurface parameterizations and root profiles can produce distinct surface flux response to droughts
- Under prolonged droughts, surface and deep subsurface hydrologic processes could become decoupled:
  - A deep rooting profile can increase the resilience of forest ecosystems, by tapping water from deep soil layers
  - The groundwater aquifer in CLM4 helps maintain soil moisture within the lower root zone and reduces model sensitivity to drought

Acknowledgement

- DOE: Investigation of the Magnitudes and Probabilities of Abrupt Climate Transitions (IMPACTS)

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