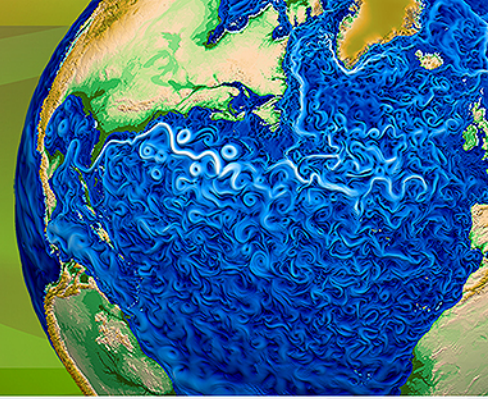




Accelerated Climate Modeling
for Energy

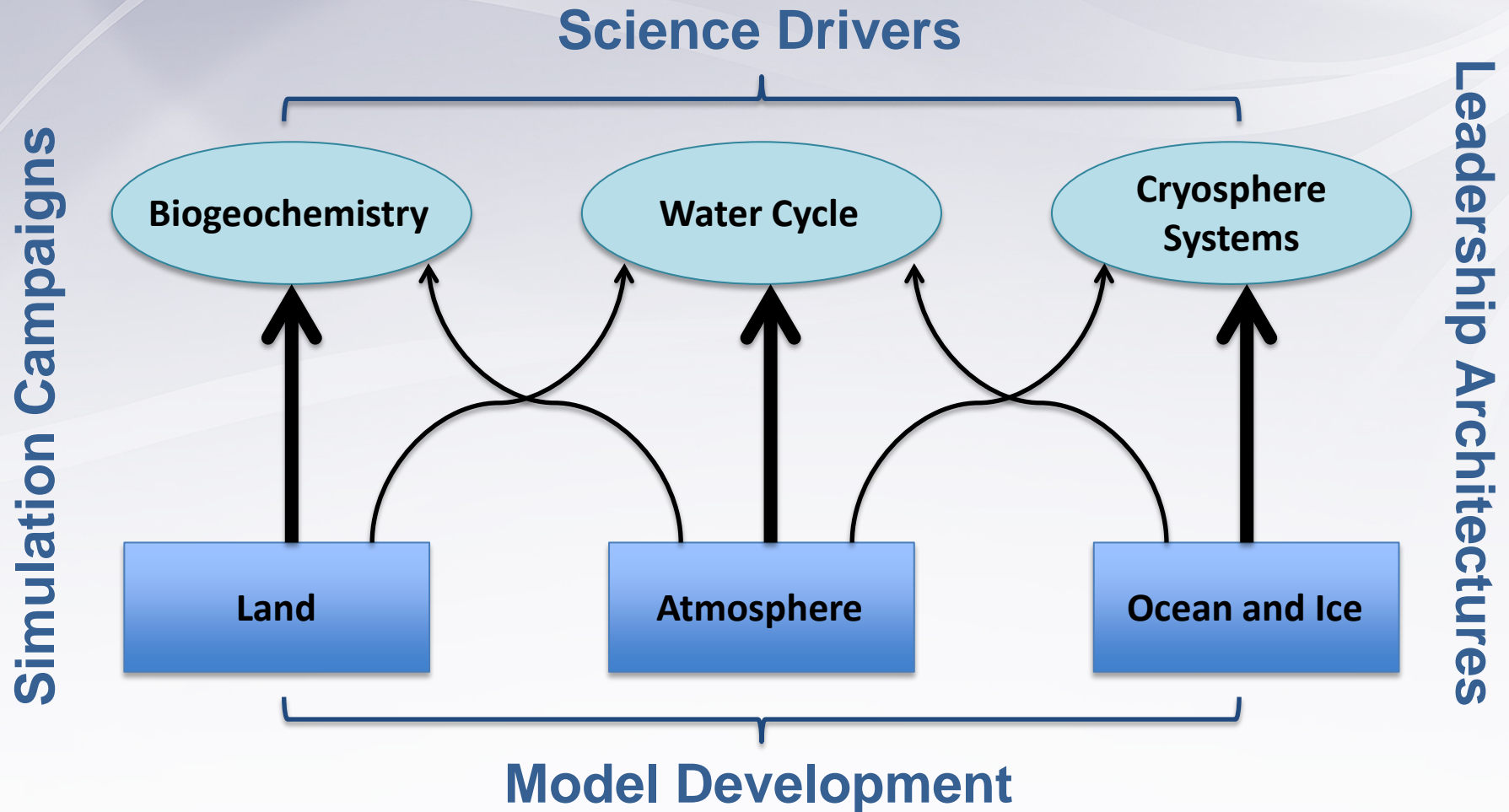


Modeling Surface Water – Groundwater Interactions in the ACME Earth System Model

L. Ruby Leung

Pacific Northwest National Laboratory

ACME addresses critical science questions and DOE mission-specific climate change applications

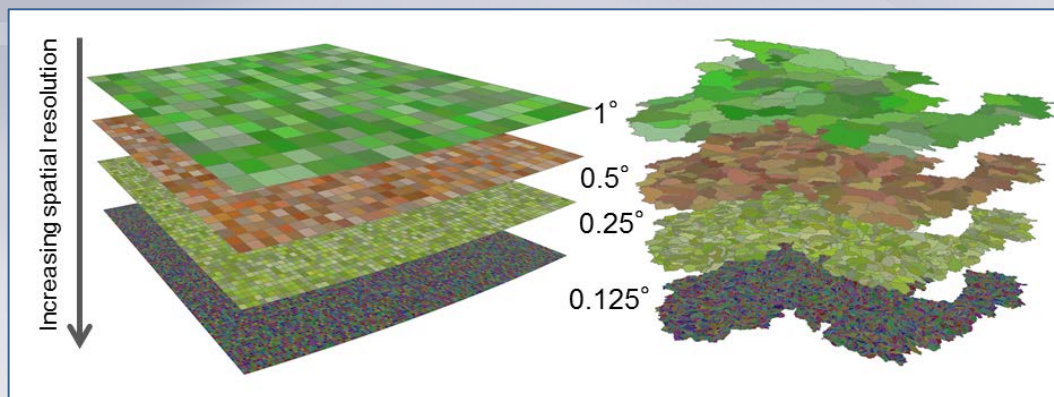


10-year Vision

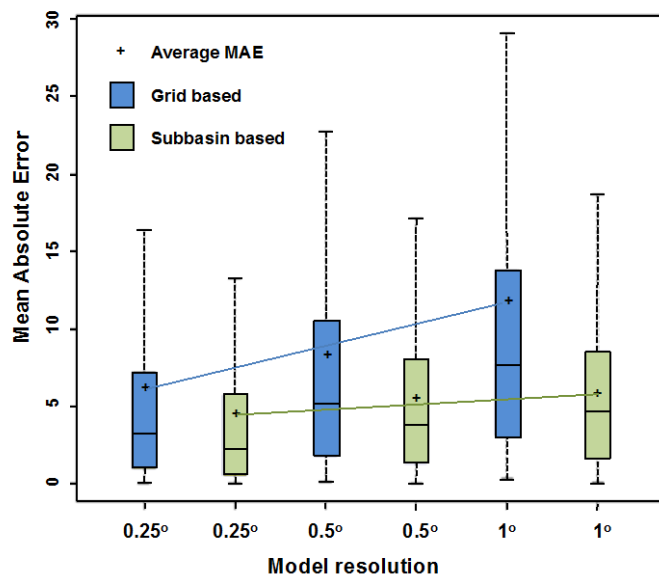
- **Water Cycle:** How will the integrated water cycle, extending from bedrock to the tropopause, evolve in a warmer climate with changes to land and water use, and changing concentration of atmospheric radiative forcing agents?
- **Biogeochemistry:** How will coupled terrestrial and coastal ecosystems drive natural sources and sinks of carbon dioxide and methane in a warmer environment?
- **Cryosphere Systems:** How will regional variations in sea level rise interact with more extreme storms to enhance the coastal impacts of sea level rise?

Representation of spatial heterogeneity

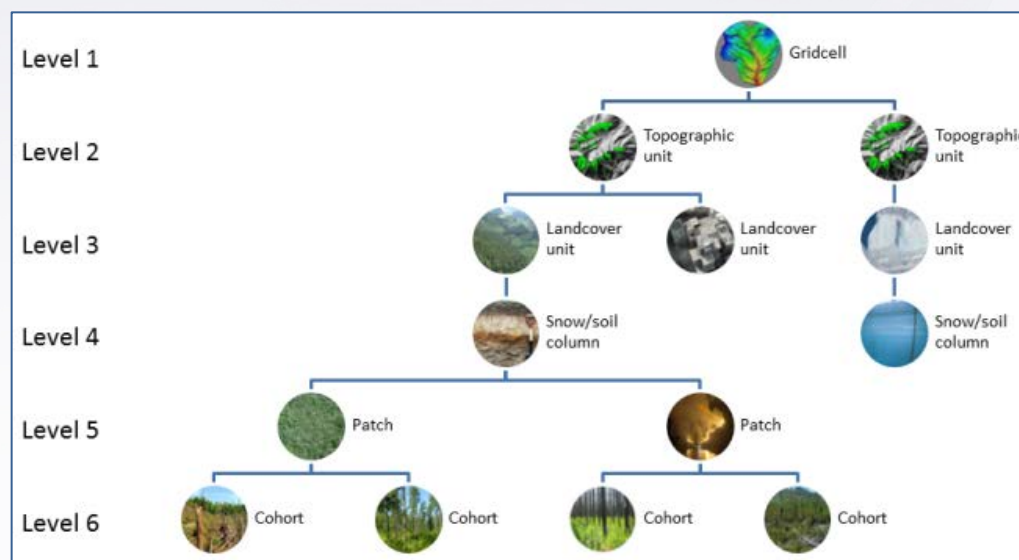
Watershed representation improves model scalability



Total Runoff



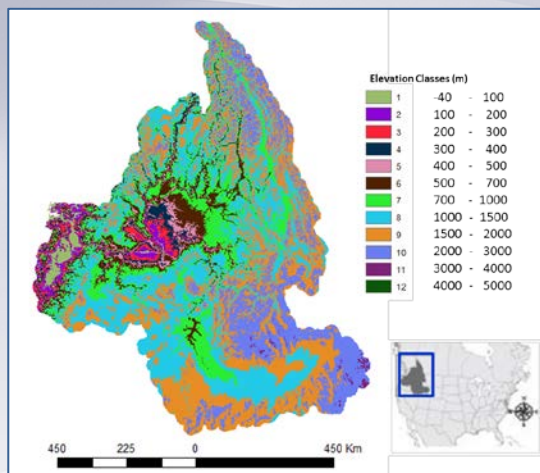
Hierarchical subgrid structure



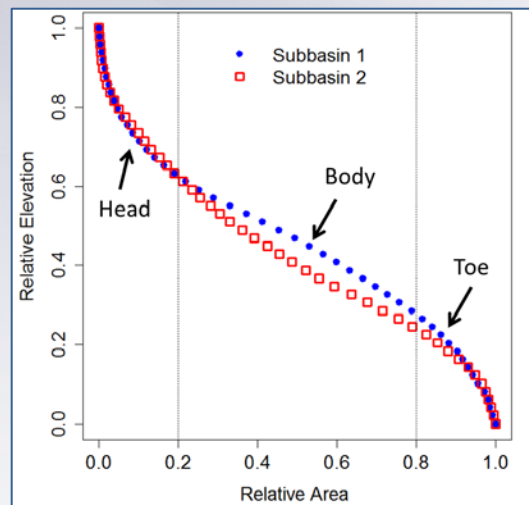
(Tesfa et al. 2014 JGR; Tesfa et al. 2014 GMD)

Representation of spatial heterogeneity

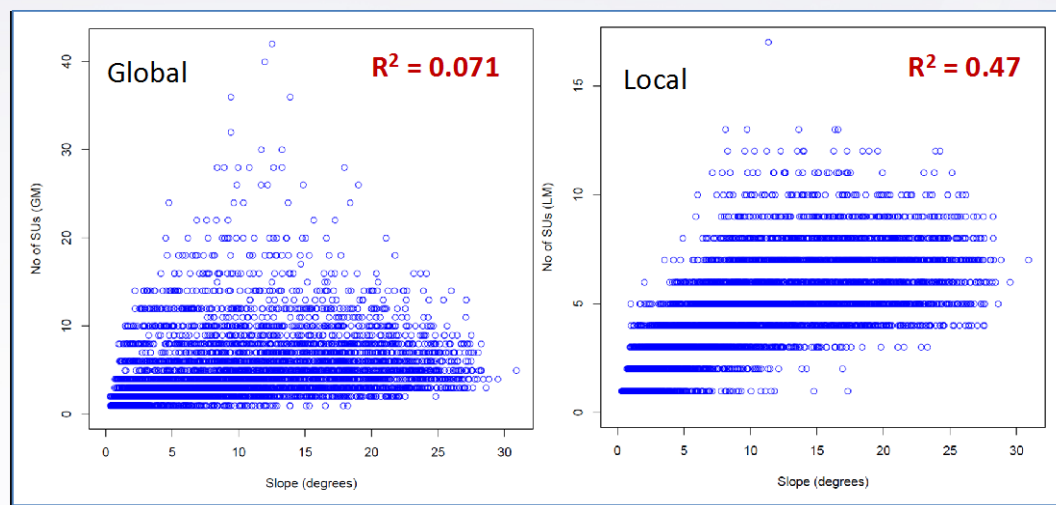
Global method: Same elevation classification of the whole domain



Local method: Elevation classification based on hypsometric analysis



- Taking advantage of hypsometric analysis, the local method captures slope variability implicitly better than the global method
- Subgrid topography will be represented using non-geolocated subgrid landunits defined by the local method

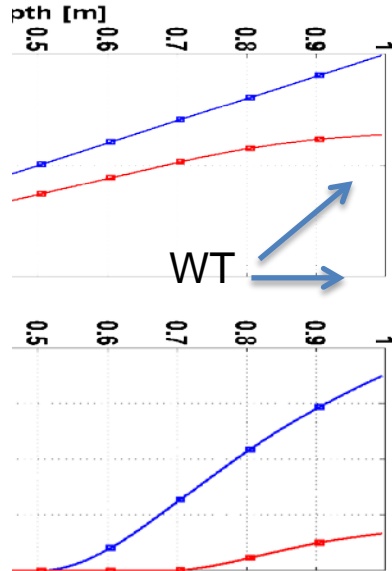


(Tesfa et al. 2016 GMDD)

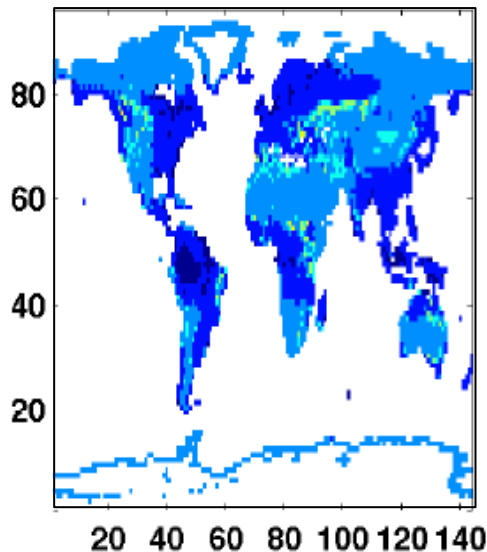
Variably Saturated Subsurface Model (VSFM)

- Unified physics in unsaturated and saturated zone
- Uses PETSc for numerical solution
- Benchmarked against PFLOTRAN and global water table depth predictions
- Integrating distributed bedrock depth

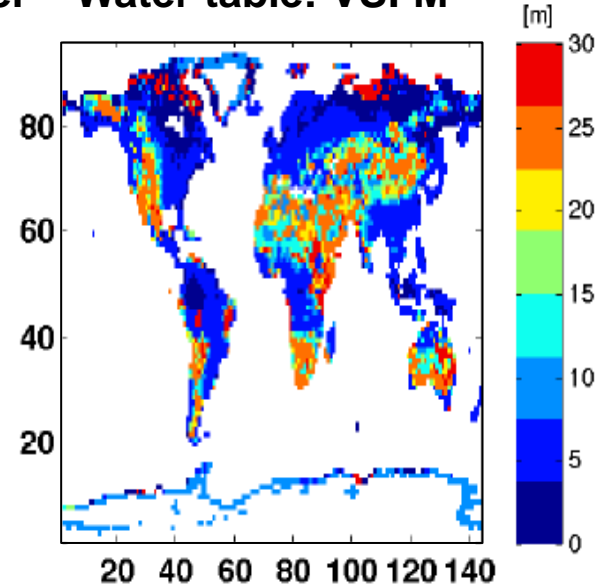
Water table dynamics benchmark



Water table: Default model

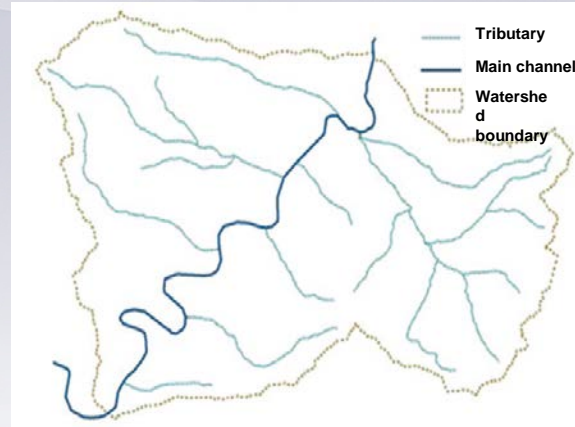


Water table: VSFM

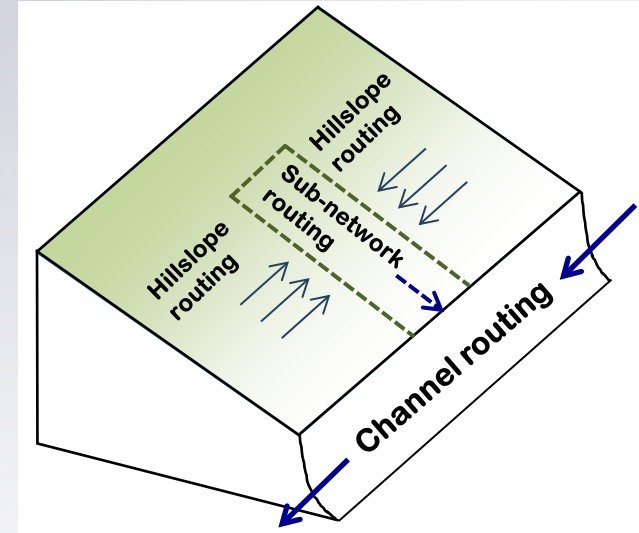


Scale adaptive river transport

Real River Network



Conceptualized River Network



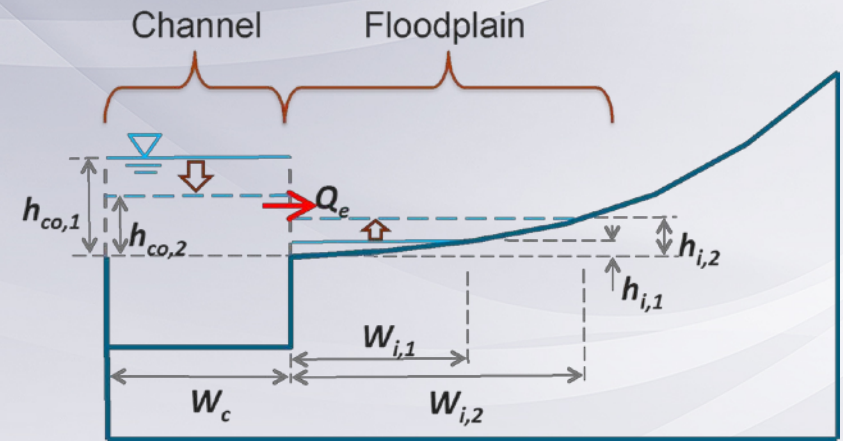
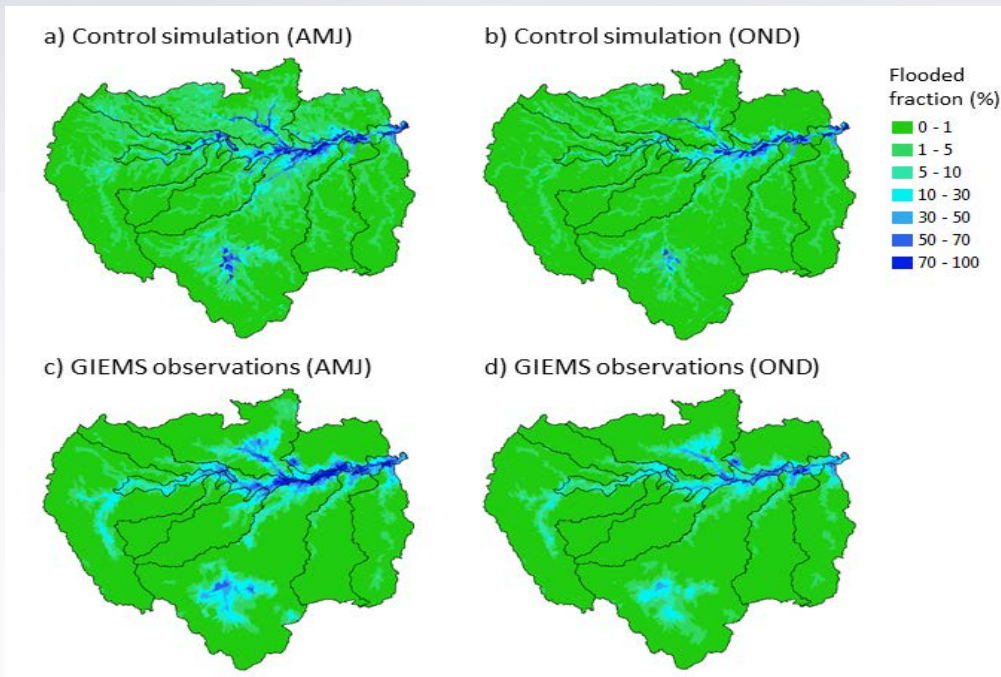
Model for Scale-Adaptive River Transport (MOSART)

- **Hillslope routing:**
 - Account for impacts of overland flow on soil erosion, nutrient loading, etc.
- **Sub-network routing:**
 - Scale adaptive across different resolutions to reduce scale dependence
- **Main channel routing:**
 - Explicit estimation of in-stream conditions (velocity, water depth, etc.)

Inundation dynamics

- Inundation influences:
 - Land-atmosphere interactions
 - Surface water – groundwater interactions
 - River – floodplain exchange

Average spatial pattern of Amazon flood extent for 1995-2007



- The Amazon represents 15% of the world's total river discharge
- Floodplains and wetlands account for ~14% of the entire basin
- One-way coupling of ALM and MOSART will be extended to improve representation of terrestrial – river interactions

Representing human influence

- Irrigation **location, timing, amount, source and methods** are key aspects in irrigation modeling
- **Location:** based on gridded irrigation area map
- **Timing:** fixed with checks at 6:00AM
- **Amount:** calibration to match observations at regional/local scales
- **Source:** surface water and abstraction from aquifer
- **Method:** drip, flood, and sprinkler

The key difference among the three schemes lie in the irrigation water use efficiency



Drip Irrigation



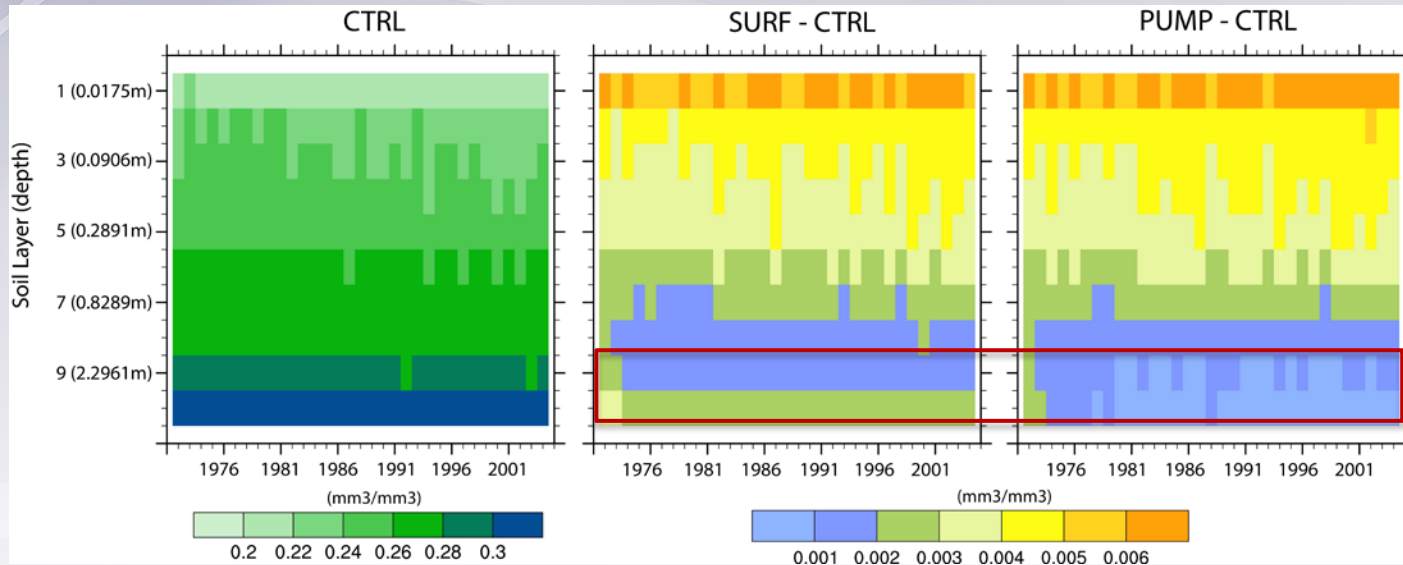
Flood Irrigation



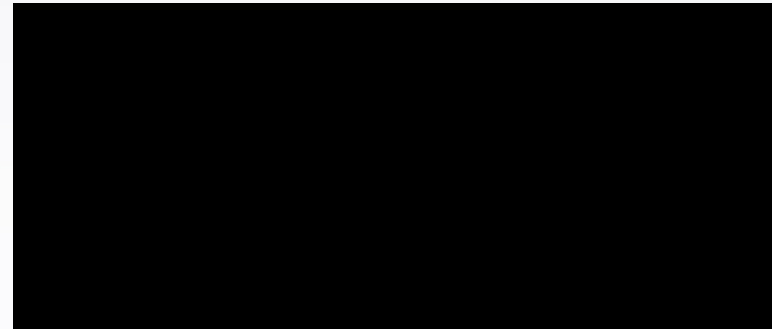
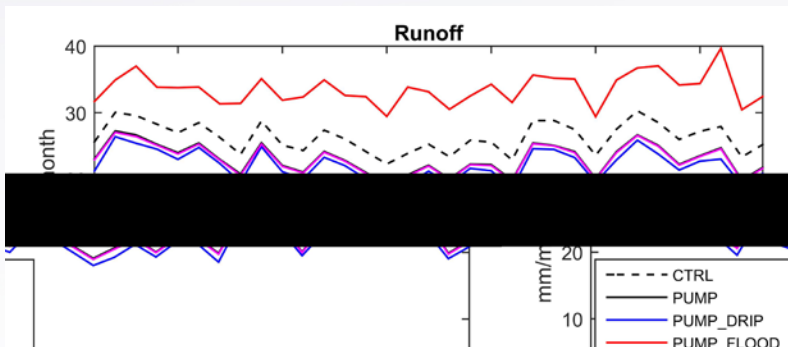
Sprinkler Irrigation

Representing human influence

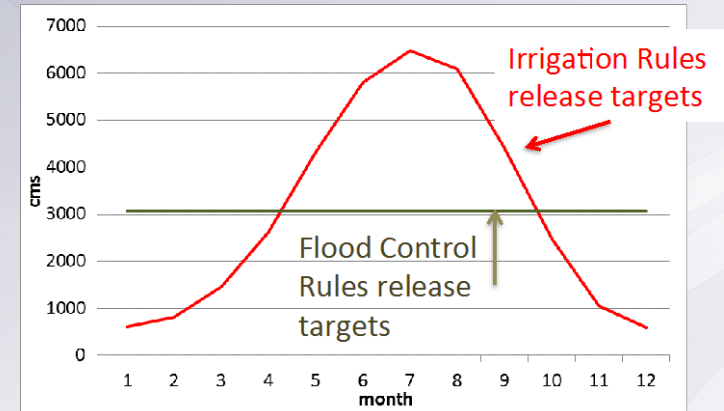
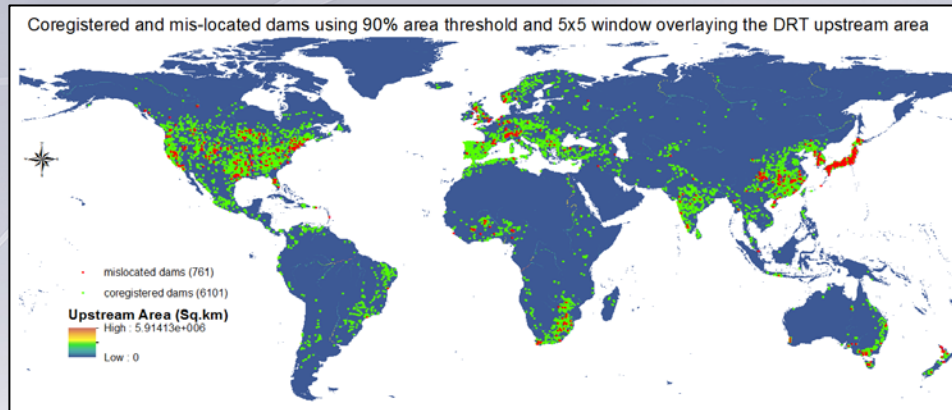
Pumping produces smaller increase of soil moisture in the bottom soil layers - enhanced recharge rate to aquifer lowers water use efficiency by pumping



Irrigation impacts differ significantly with the irrigation methods used



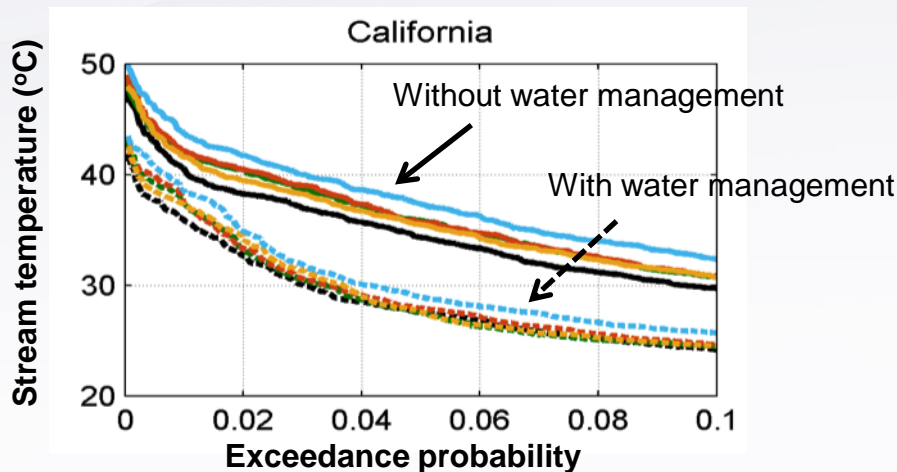
Dams have large impacts on rivers



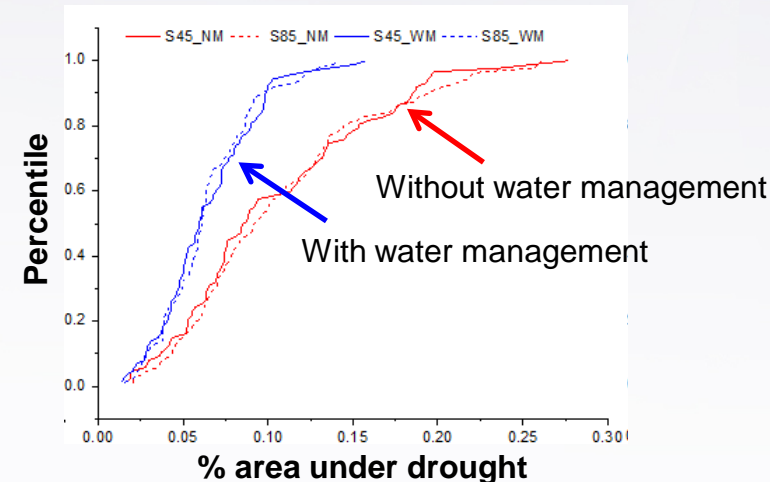
Monthly release targets at Grand Coulee for different rules scenarios

Water management has significant impacts on extreme stream temperature and droughts

Exceedance Probability of high stream temperature

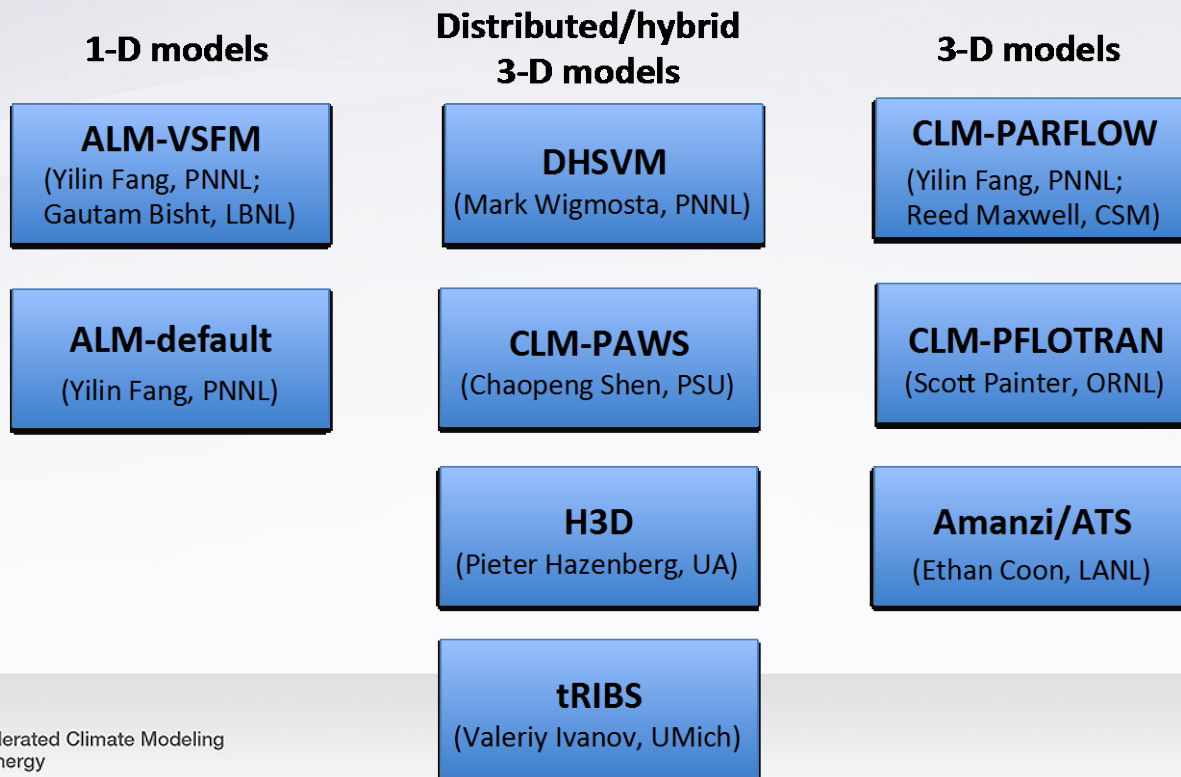


Frequency of severe droughts in the U.S.

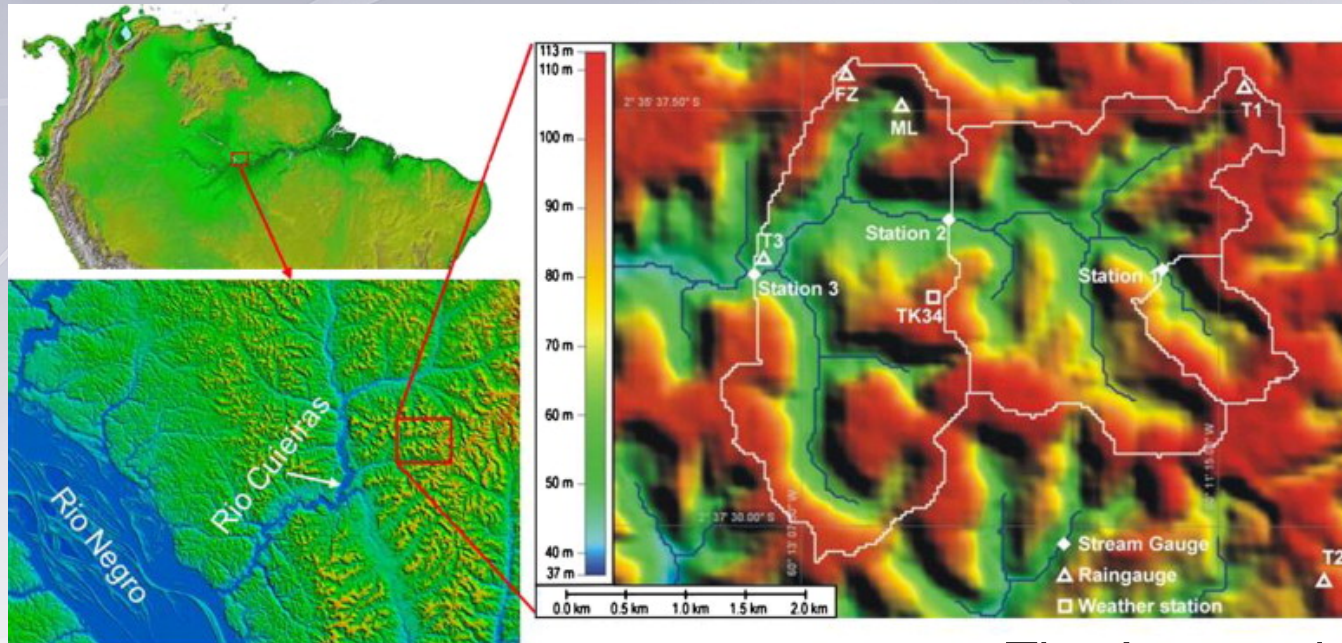


Modeling hydrologic processes in the Amazon basin

- Understanding hydrological processes that control water available to plants is essential for predicting how tropical forests respond to droughts
- Systematic benchmarking and process-based evaluation of hydrologic simulations may provide insights for improving hydrologic modeling in ESMs
- A hierarchy of one-dimensional to three-dimensional models are evaluated and compared at the Asu catchment (K34)



Experimental design



The Asu catchment
(Cuartas et al. 2012, J. Hydrology)

- ALM (single point)
 - Default 15 vertical layers; dominant vegetation broadleaf evergreen tree
- ParFlow (61 x 50 grid cells)
 - Horizontal resolution at 90 m; DEM derived from 30 m Asu catchment DEM
 - Vertical soil layer thickness varies from 0.4 m to 2 m

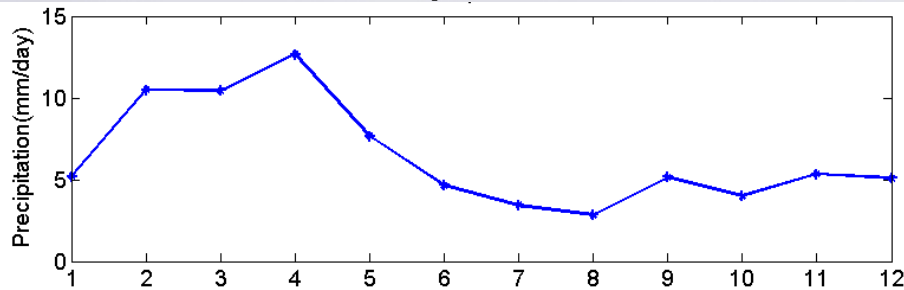
Modeling experiments

- Hydrologic model structures:
 - ALM: 1D with default vs. VSFM soil hydrology
 - ParFlow: 3D (driven by ALM $P - E$ vs. CLM-ParFlow)
- Sensitivity to soil parameters:
 - Soil porosity and permeability
 - Spatially uniform (ALM) vs. spatially variable (Cuartas)
 - Root distribution (impacts on transpiration)
 - Soil depth (impacts on groundwater table depth)
 - Ratio of K_h/K_v (impacts of lateral flow)

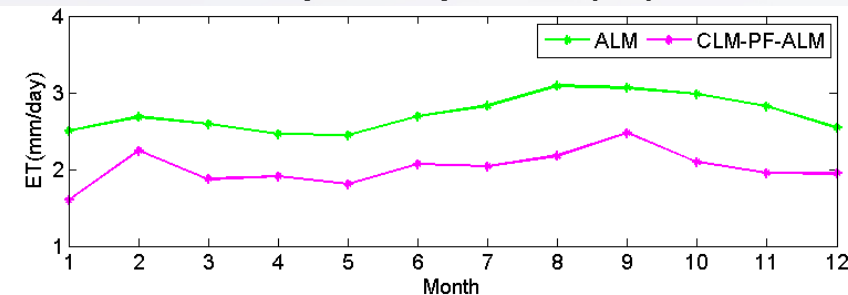
Groundwater table and streamflow

- Large seasonality in precipitation but small seasonality in ET - an energy limited regime?
- ALM (default or VSFM) simulates very shallow WTD – streamflow driven by precipitation
- Driven by ALM water flux and using the same soil parameters, ParFlow simulates very different WTD and streamflow, indicating the importance of lateral flow
- Large sensitivity of WTD to soil parameters and model structure

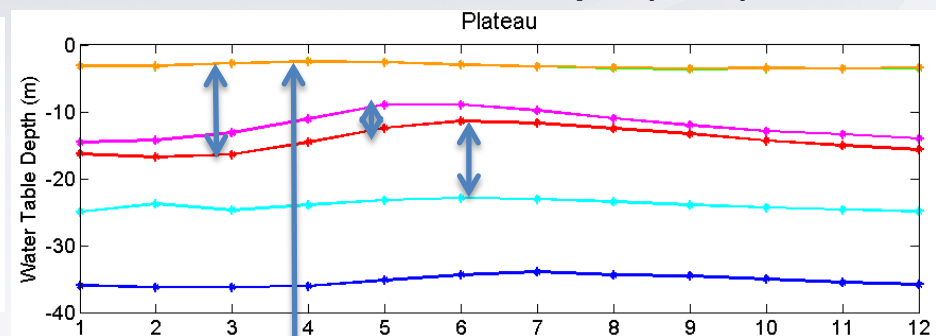
Precipitation



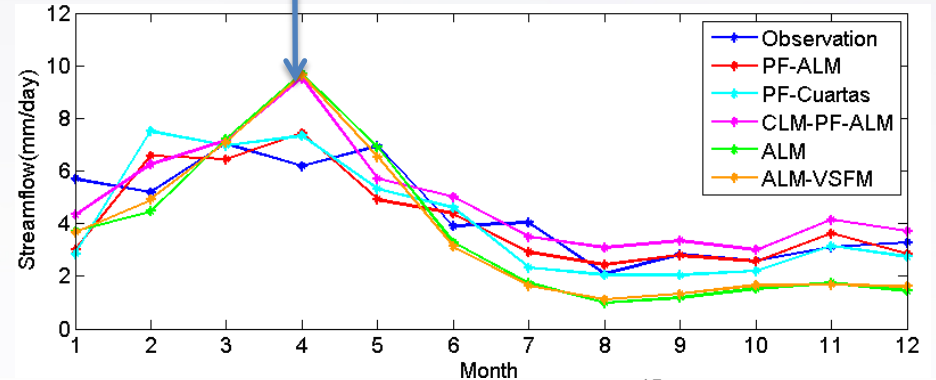
Evapotranspiration (ET)



Groundwater table depth (WTD)



Streamflow



15

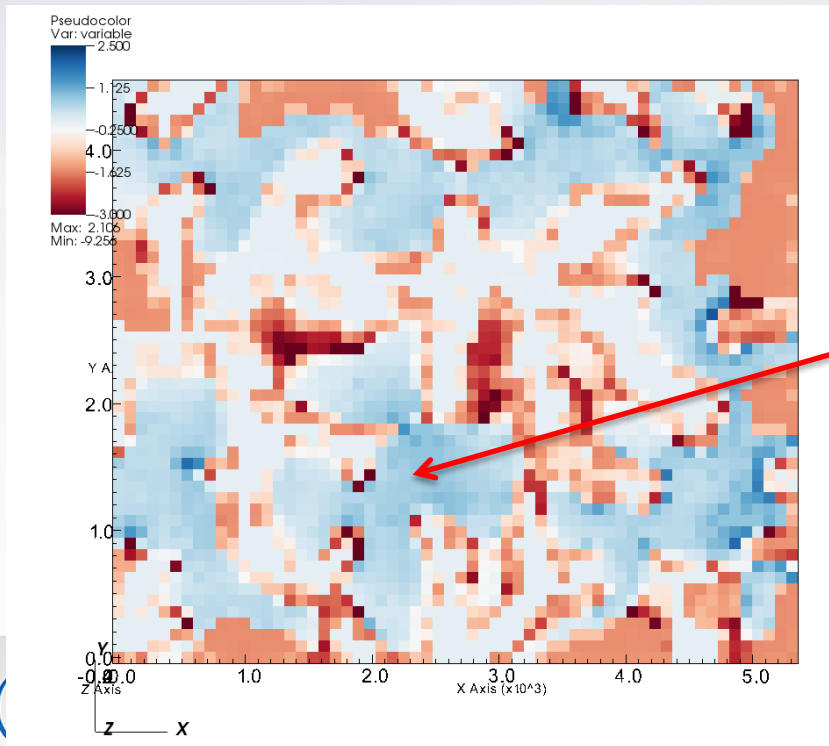
Sensitivity to soil parameters: seasonal variability

- Groundwater response time varies with soil parameters, leading to differences in seasonal rises and declines
- Use of the Cuartas soil parameters reduces the seasonal variability of GWT at the plateau – better retaining capacity

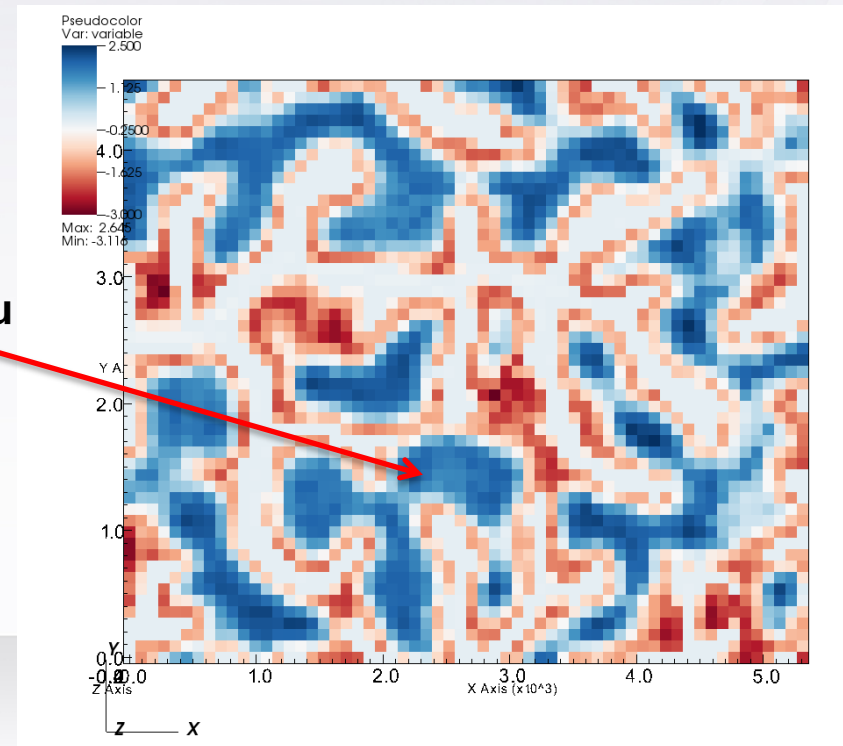
WTD₀₉₀₂₀₅ - WTD₀₄₁₅₀₅

Cuartas parameters

ALM parameters

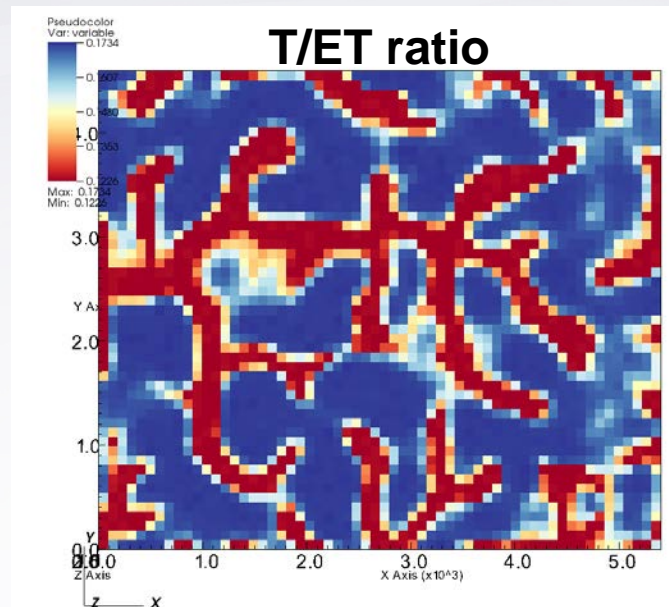
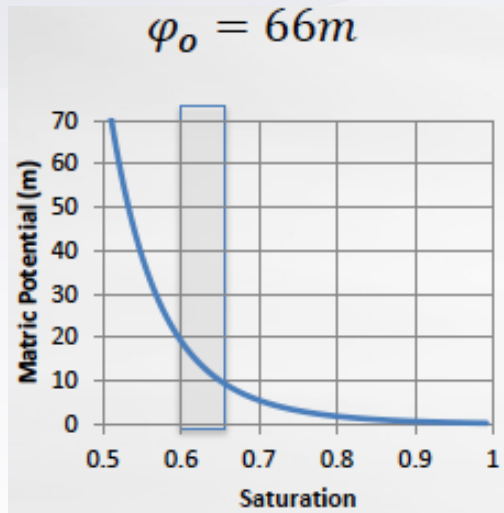


Plateau

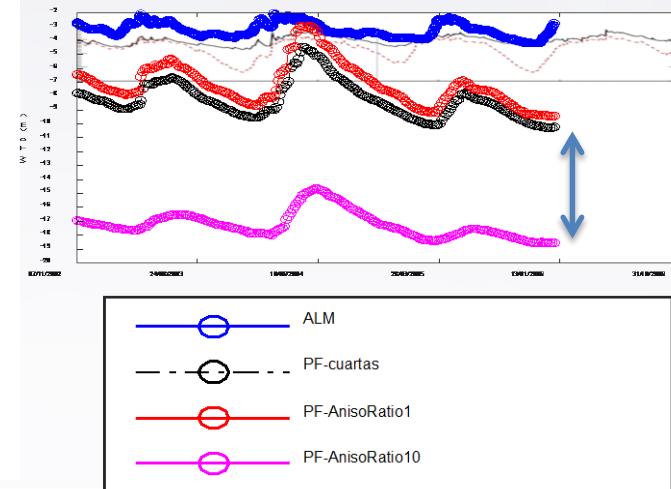


Variability of the ratio of transpiration to evapotranspiration (T/ET)

- Lowest saturation simulated by CLM-ParFlow > 0.6
- Transpiration is not water limited – root distribution has no impact
- Spatial variability in T/ET is due to different depths to available water at plateau vs. valley
- Hydraulic conductivity anisotropy has significant impact on WTD, and hence T/ET



Increasing K_h/K_v significantly lowers WTD at plateau by increasing lateral flow



Summary

- Building on CLM, the ACME Land Model (ALM) includes several new features relevant to modeling surface water and groundwater and their interactions:
 - A hierarchical subgrid structure in a watershed representation
 - A variably saturated flow model
 - A scale adaptive river transport model with floodplain inundation
 - A human component including irrigation and water management
- Model evaluation and intercomparison in the Asu catchment indicates that transpiration is not water limited:
 - T/ET is not sensitive to root distribution
 - T/ET depends on WTD, which is sensitive to hydraulic conductivity anisotropy (K_h/K_v) that influences lateral flow
 - WTD is too shallow in ALM, presumably due to the lack of lateral flow, resulting in larger streamflow seasonality than observed