CUAHSI contributions to CLM hydrology development

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Outline

- Motivation
- Opportunities to improve hydrology in CLM
  - Individual processes
    - Storage/transmission of water in soils
    - Groundwater
    - Routing
  - Heterogeneity and scaling behavior
    - Spatial variability
    - Connectivity
- Model evaluation
  - Synthetic test cases and parameter sensitivity analysis
  - Multivariate and multi-scale model evaluation
  - Model benchmarks
- Summary and outlook

Motivation

- CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc.) supports/enables community activities to advance hydrologic science

- New CUAHSI initiative to improve the representation of hydrologic processes in Earth System models
  - Initial focus on CESM
  - Emphasis on model evaluation (model agnostic)

- Two initial questions
  1. What are the key opportunities to improve the representation of hydrologic processes in Earth System Models?
  2. How can we accelerate modeling advances?

- Effort just starting: completed the first review paper

  Clark, M.P., Y. Fan, D.M. Lawrence, J.C. Adam, D. Bolster, D.J. Gochis, R.P. Hooper, M. Kumar, L.R. Leung, D.S. Mackay, R.M. Maxwell, C. Shen, S.C. Swenson, and X. Zeng, 2015: Improving the representation of hydrologic processes in Earth System Models. *WRR, under review*.

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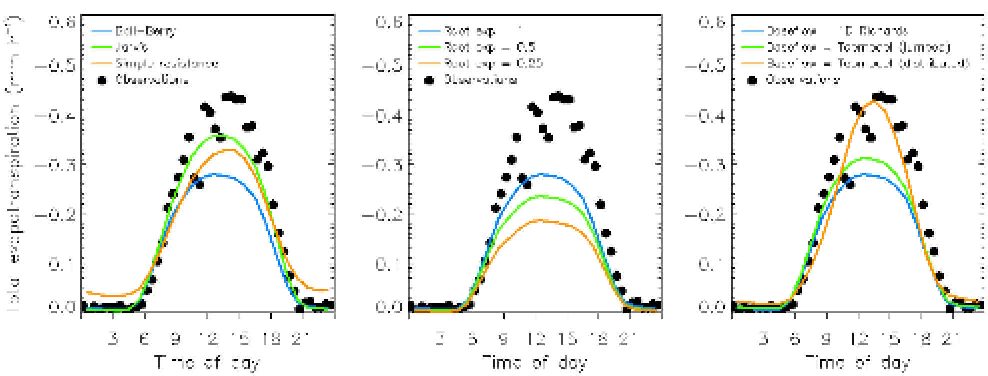
Storage/transmission of water in soils

- Standardization/flexibility in the solution of Richards equation
  - The three forms of Richards equation vs. the Zeng-Decker approach
  - Iterative and non-iterative solutions; option for adaptive sub-stepping
  - Multi-domain implementation to simulate flow through macropores
- Representation of infiltration at the upper boundary
  - VIC, Topmodel, others?
- The lower boundary condition
  - Depth to bedrock
  - Coupling of saturated-unsaturated flow processes (e.g., moving lower boundary)

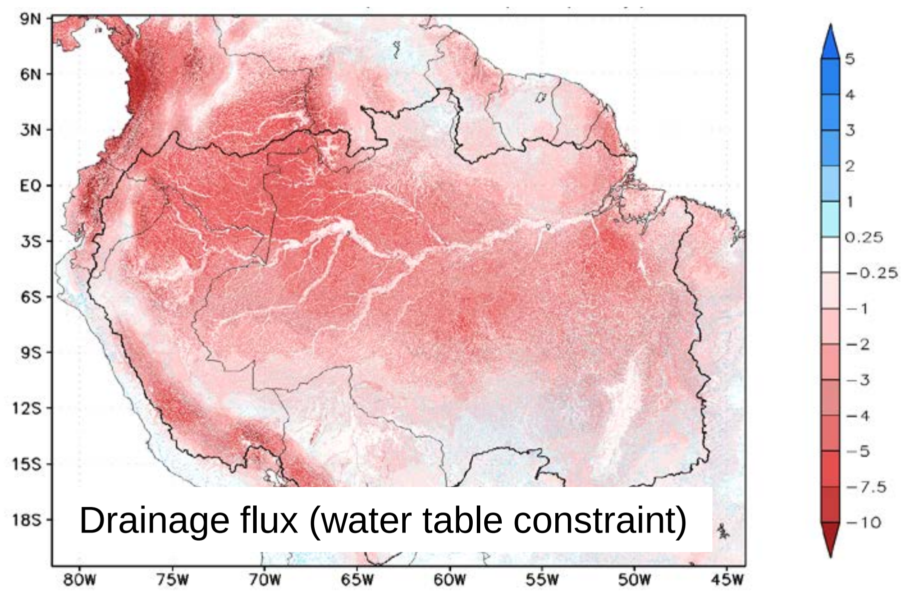
http://soilandwater.bee.cornell.edu/

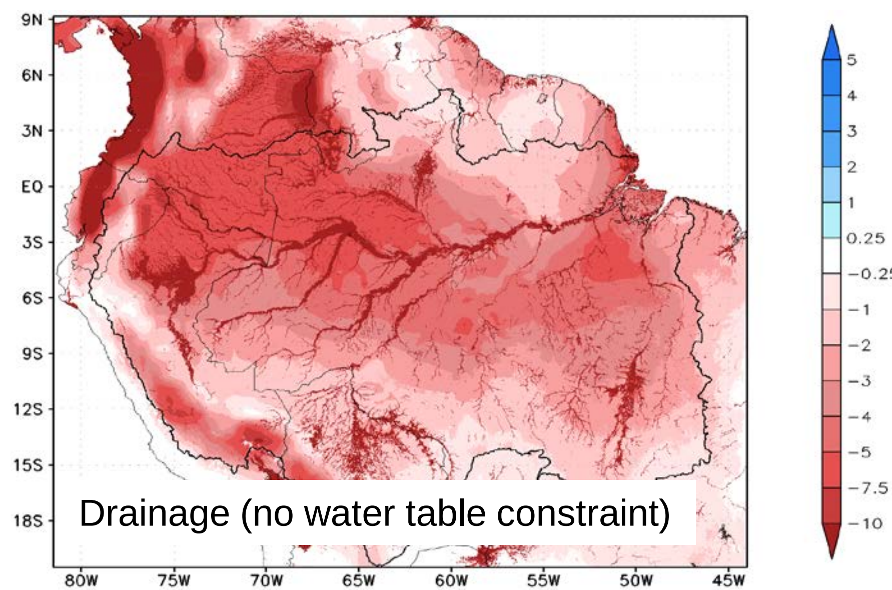
Groundwater

- Between-grid flow
  - 2D (vertically integrated) flow
  - 3D solutions?
- Sub-grid dynamics
  - Saturated flow dynamics
    - *Implicit Topmodel approach*
    - *Explicitly simulate flow among multiple sub-grid tiles*
      e.g., kinematic, HSB
  - Coupling with the soil column
    - *Sink term in Richards' eqn*
    - *Moving lower boundary*



Clark et al., under review

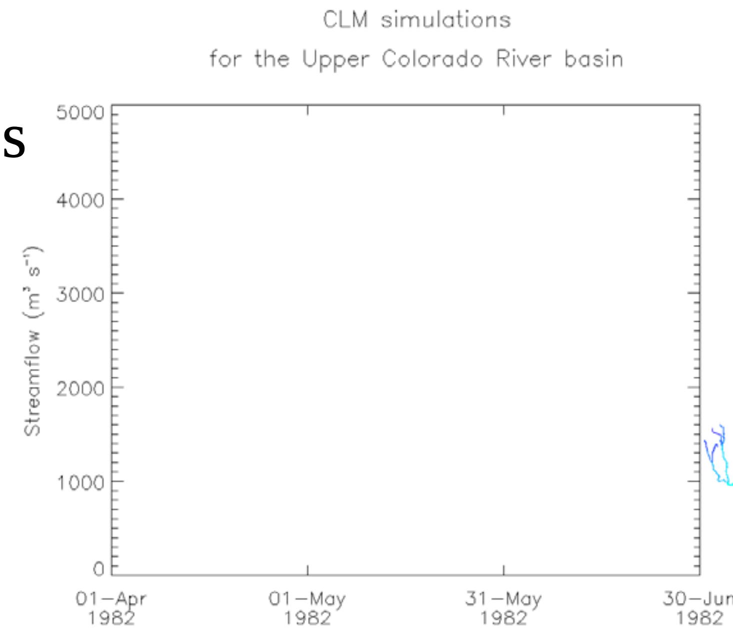


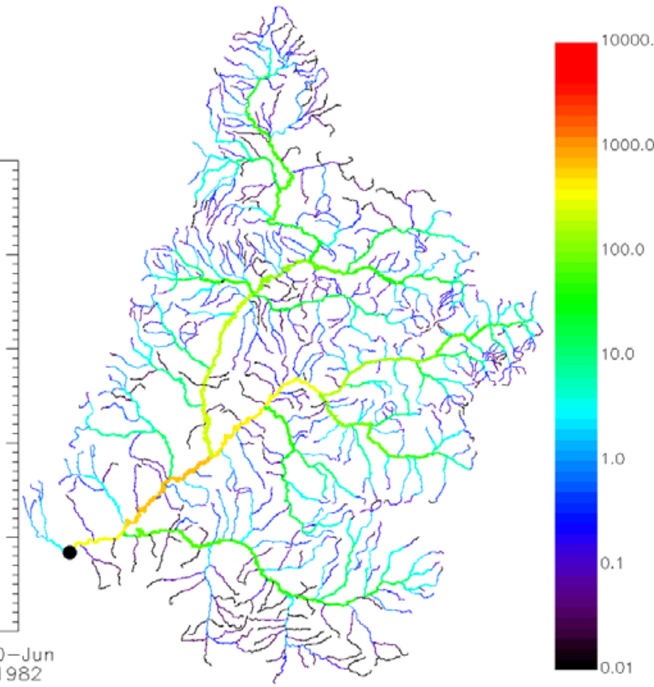


Miguez-Macho and Fan, 2012

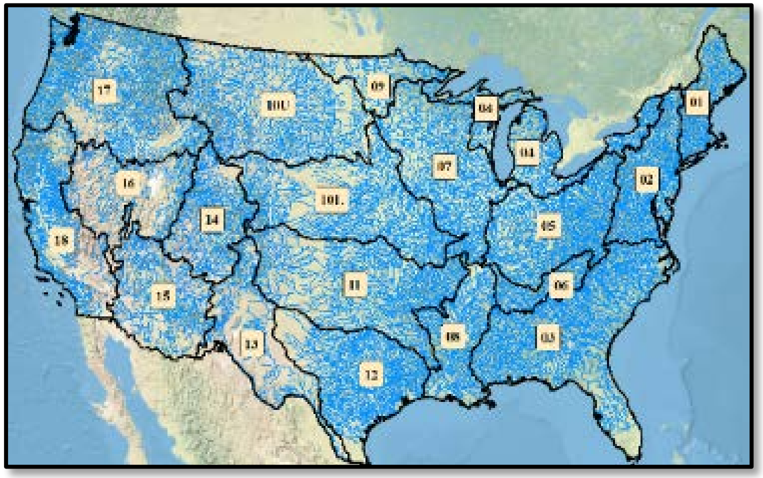
Routing

- Different methods
  - Source-to-sink
  - Function of reach storage
    - *kinematic wave*
  - Diffusive wave



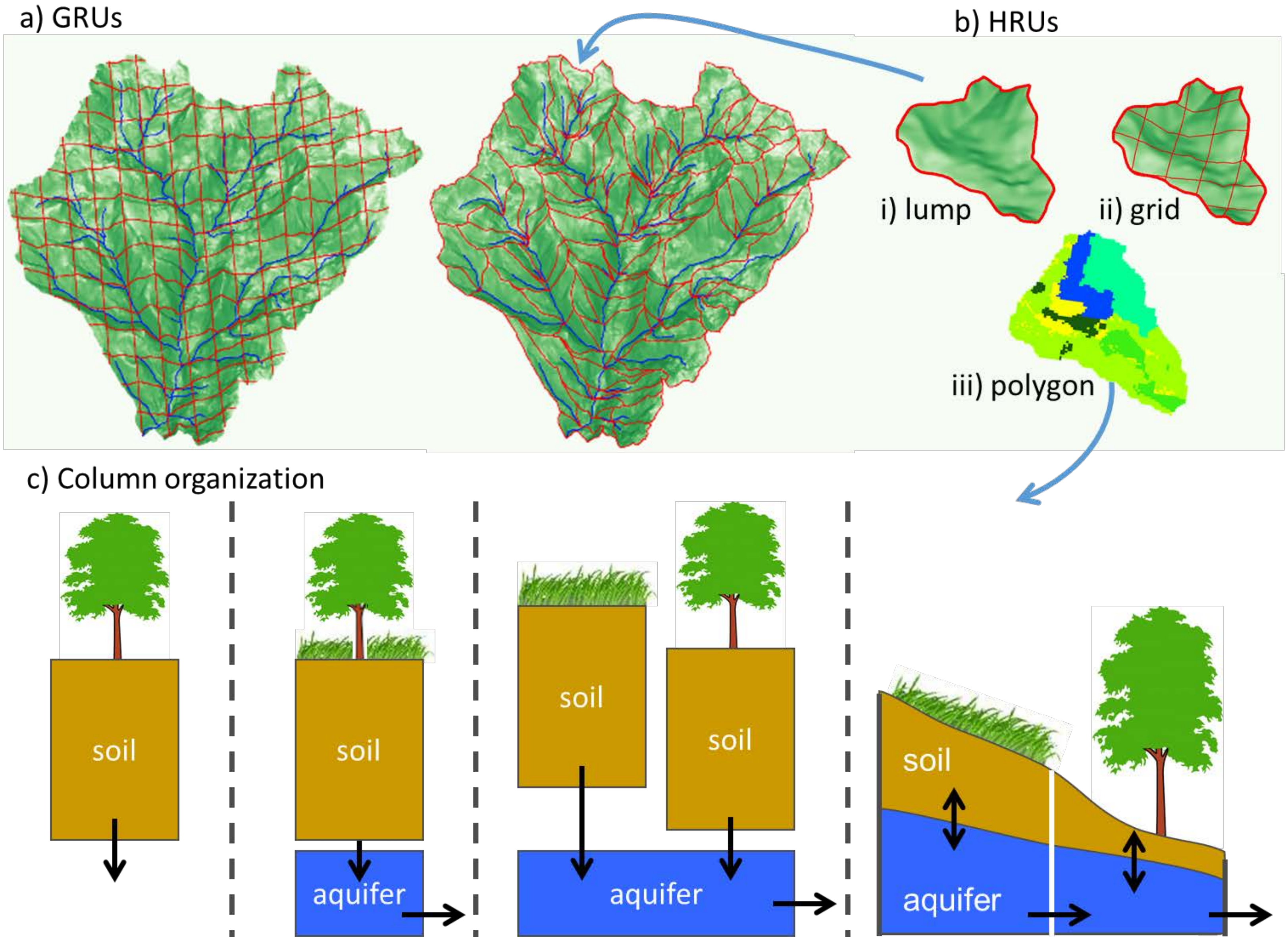


- Key issue: spatial data/parameters
  - Network topology
  - Estimating the hydraulic geometry of rivers (role of satellite data)



USGS geospatial fabric

Spatial variability and connectivity



Clark et al.
(under review)

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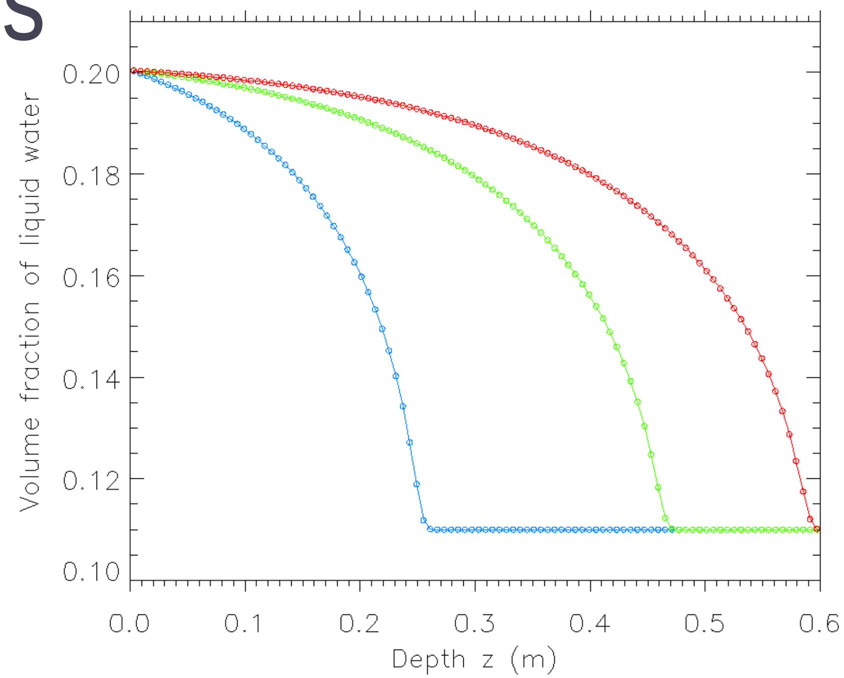
Model evaluation

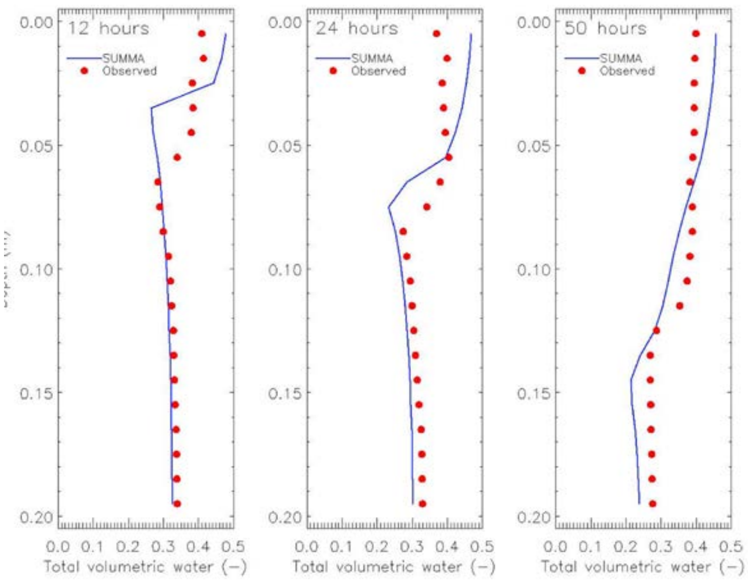
- Synthetic test cases and parameter sensitivity analysis
  - Have we implemented the model equations correctly?
  - Are model results corrupted by numerical errors?
  - What are the tradeoffs between computational efficiency and the fidelity of process representations
- Multivariate and multi-scale model evaluation
  - Do we adequately represent observed processes?
  - Are we adequately representing the spatial heterogeneity and hydrologic connectivity?
  - At what space-time scales do we lose/gain information?
- Model benchmarking
  - Data, information, knowledge and wisdom: Do we make adequate use of the data on meteorology, vegetation, soils and topography?
  - Use of simple models (statistical, bucket) as benchmarks

Synthetic test cases

- Celia 1990: Infiltration into a dry soil
  - Modified CLM
    - *van Genuchten soil retention functions*
    - *head boundary conditions*
    - *iterative solution*



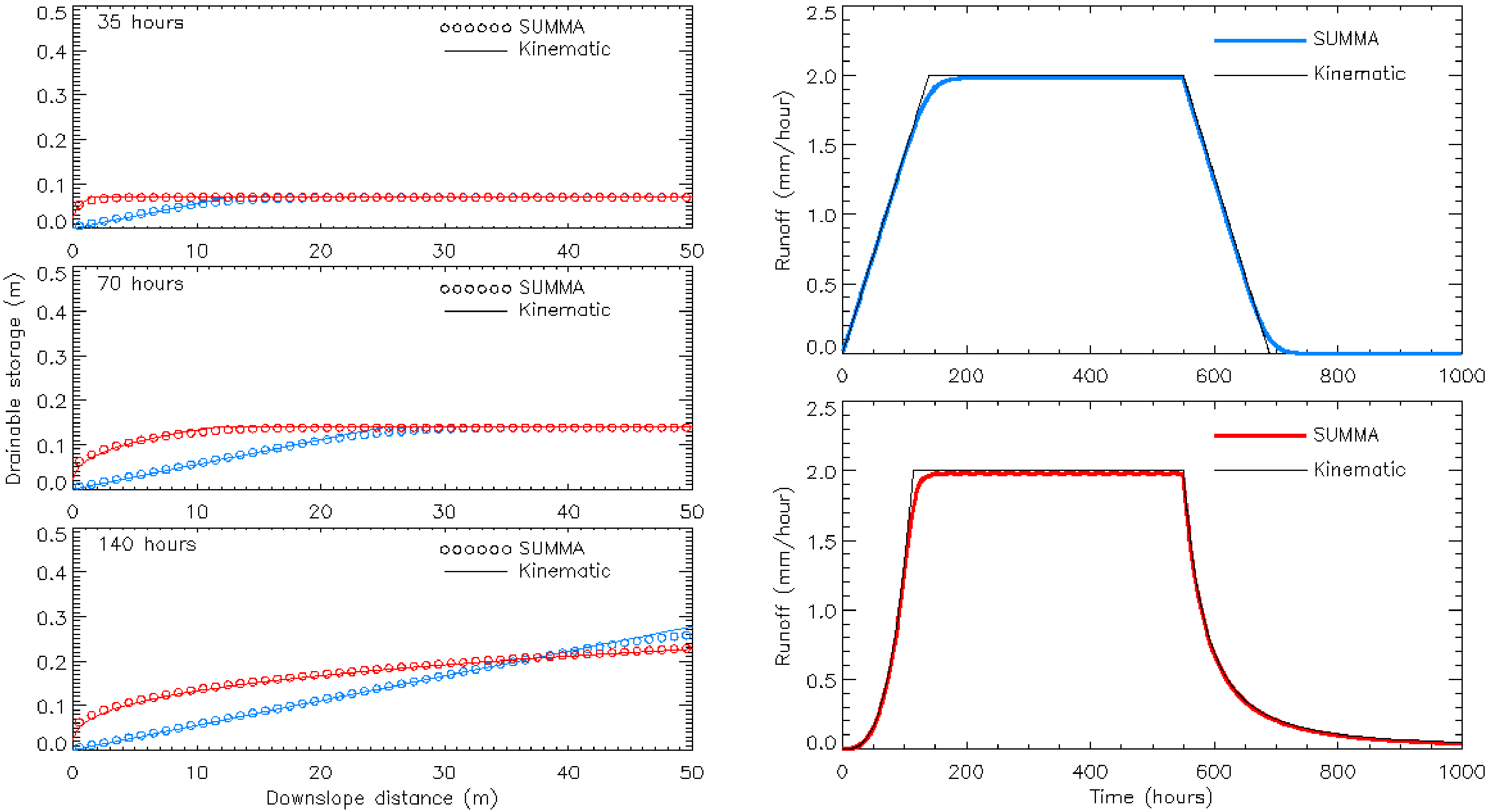
- Mizoguchi 1990 lab column experiment
  - Evaluate cryosuction processes



Clark et al., WRR (under review)

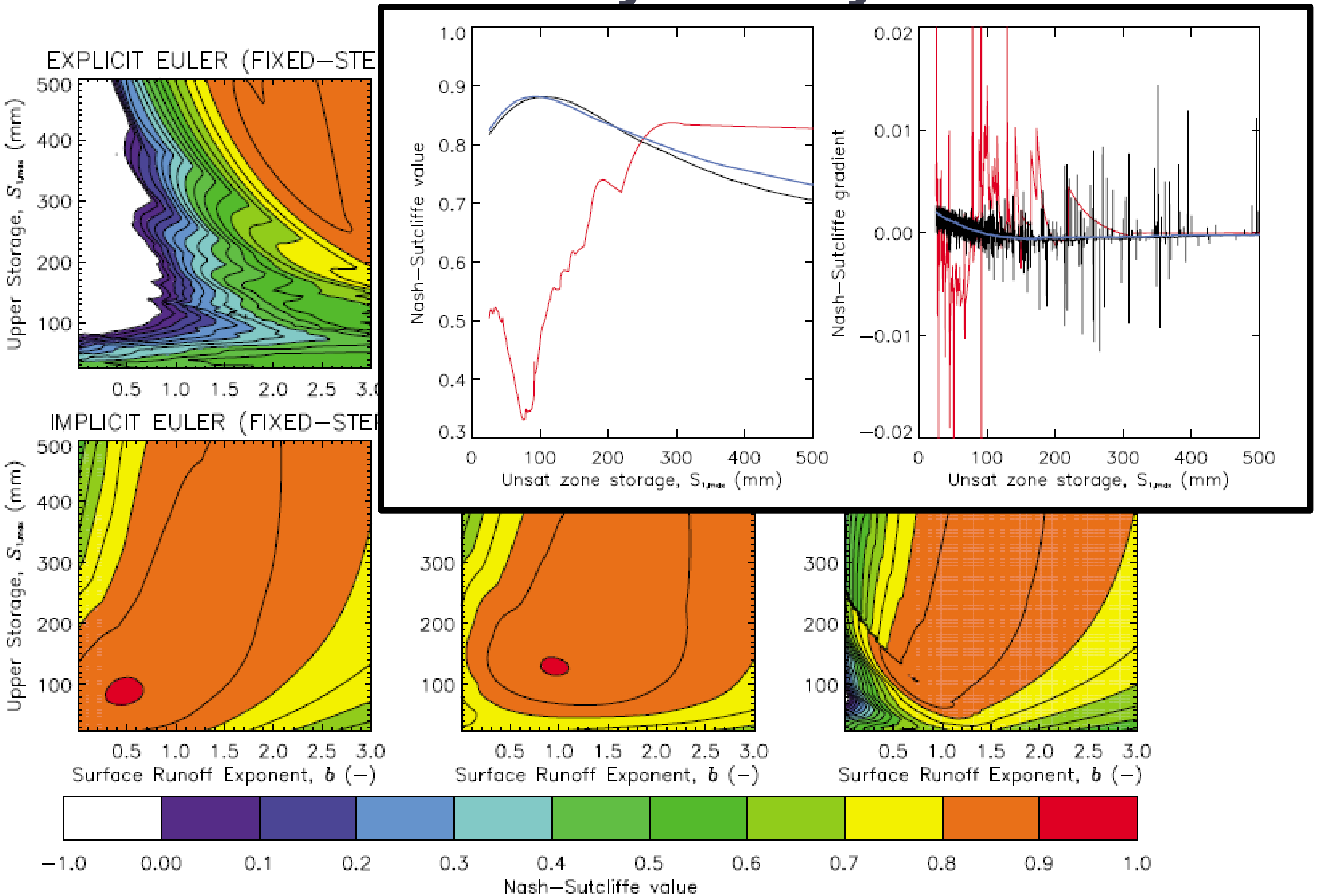
Synthetic test cases

- Wigmosta (1994): Flow along a plane of constant slope



Clark et al., WRR (under review)

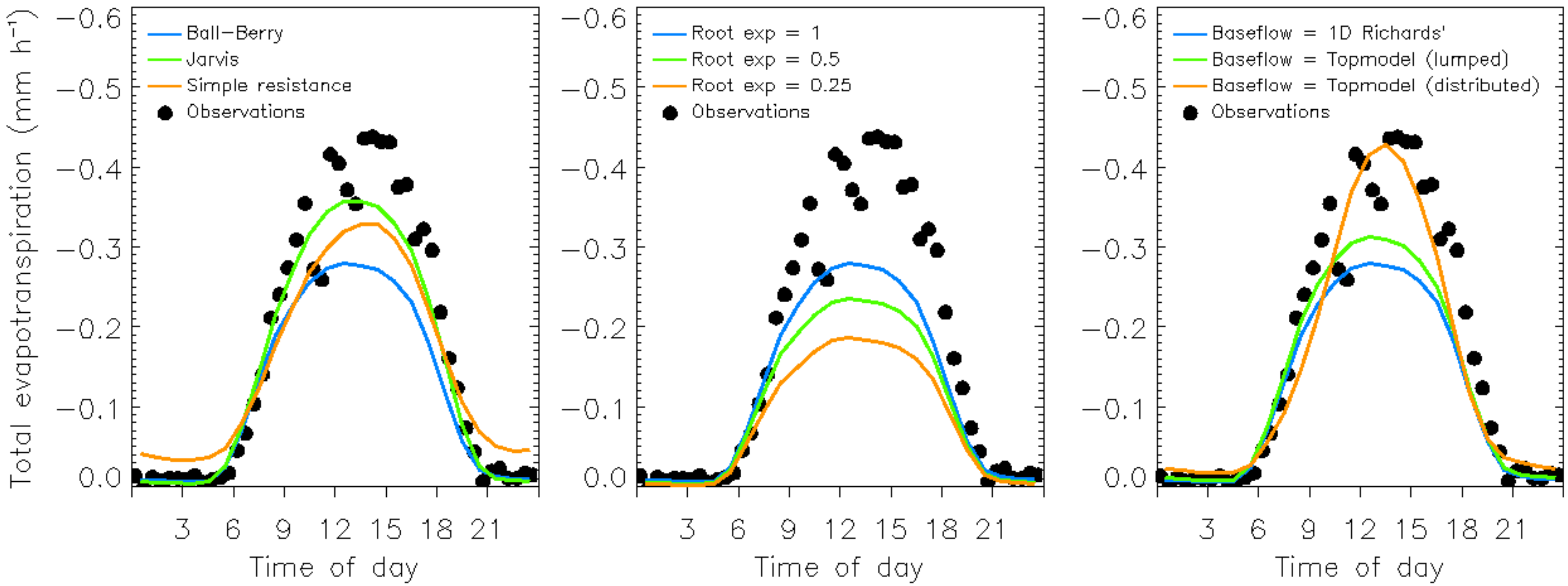
Parameter sensitivity analysis



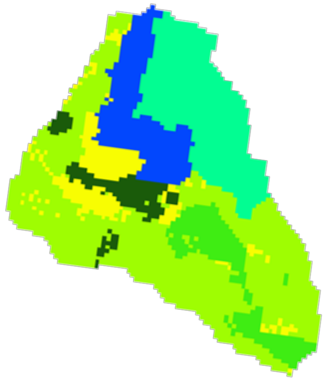
Clark and Kavetski, WRR (2010)

Multivariate evaluation

- Example: Reynolds Creek CZO

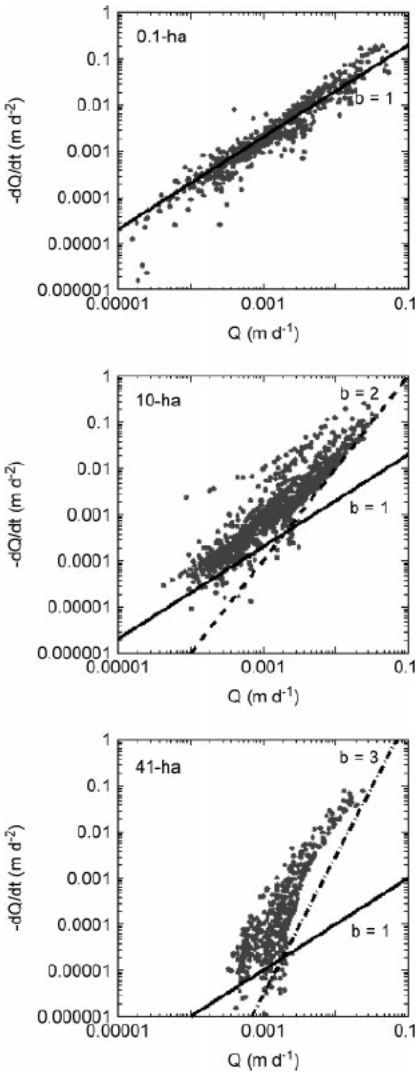


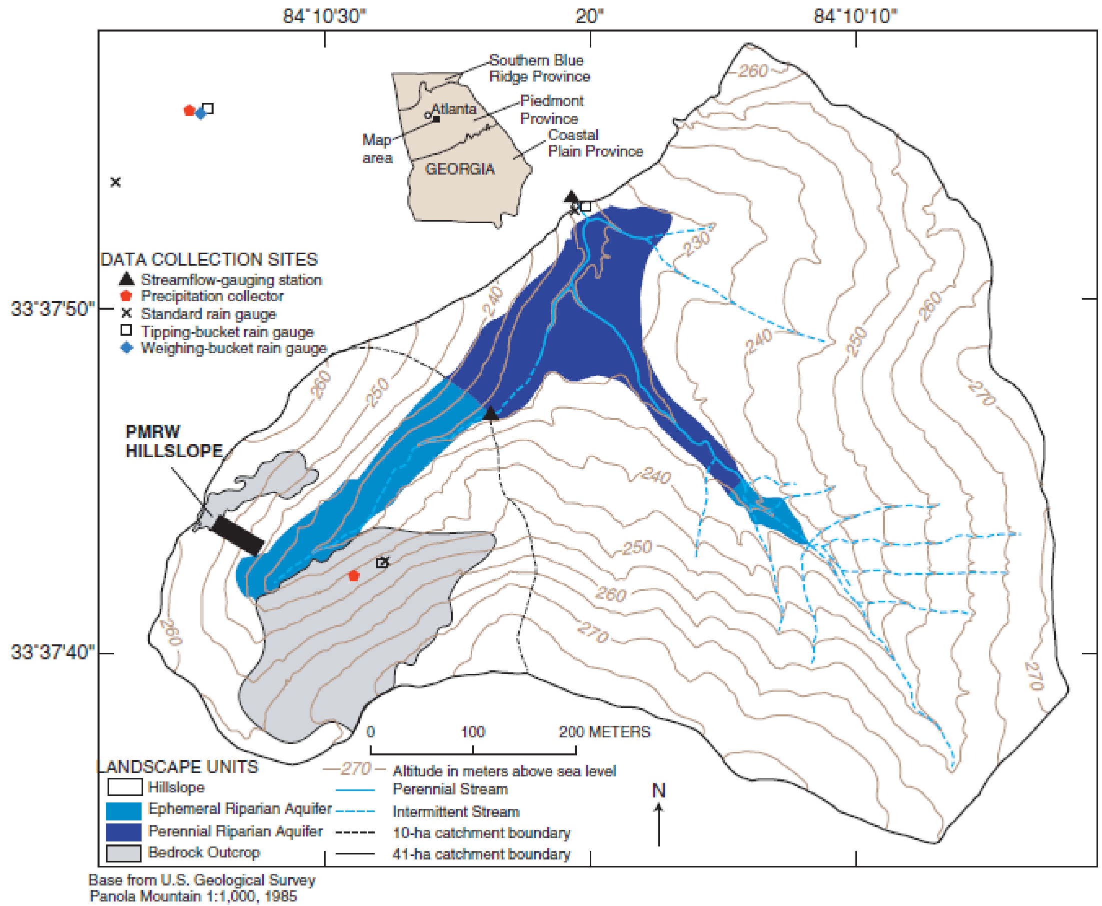
Clark et al., WRR (under review)



Multi-scale evaluation

- Example: Panola Mountain Research Watershed



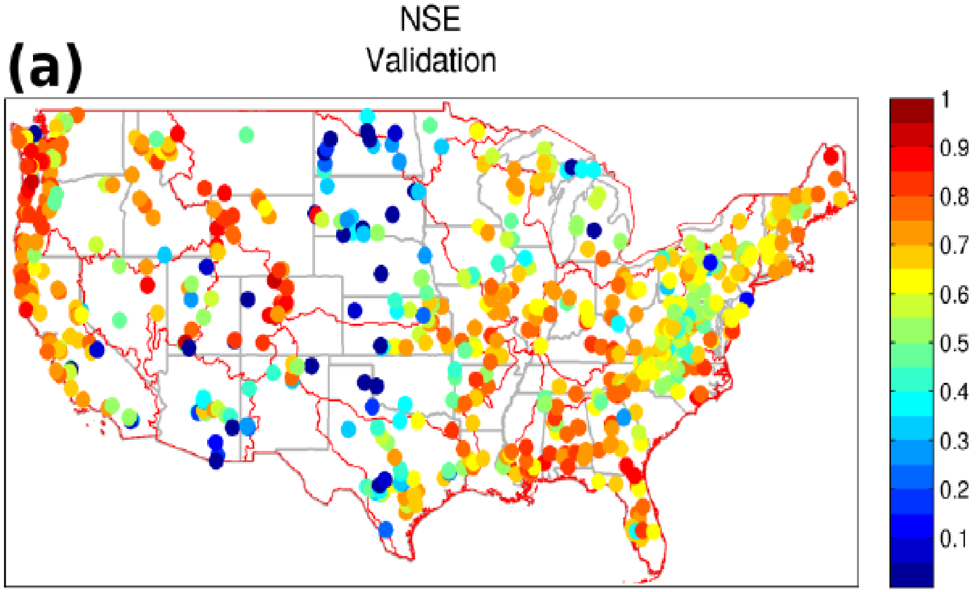


Clark et al., HP (2009)

Towards formal model benchmarks

-- what are our expectations for model performance?

- The NERD approach (statistical models as benchmarks)
- Bucket-style models as a statistical model



Can more complex models extract the same information content from the available data on meteorology, vegetation, soils and topography?

If not, why not?

What work do we need to do in order to ensure that physically realistic models perform better than models with inadequate process representations?

Newman et al., HESS (in press)

Model constraints?

Water Resources Research

AN AGU JOURNAL

Opinion Articles

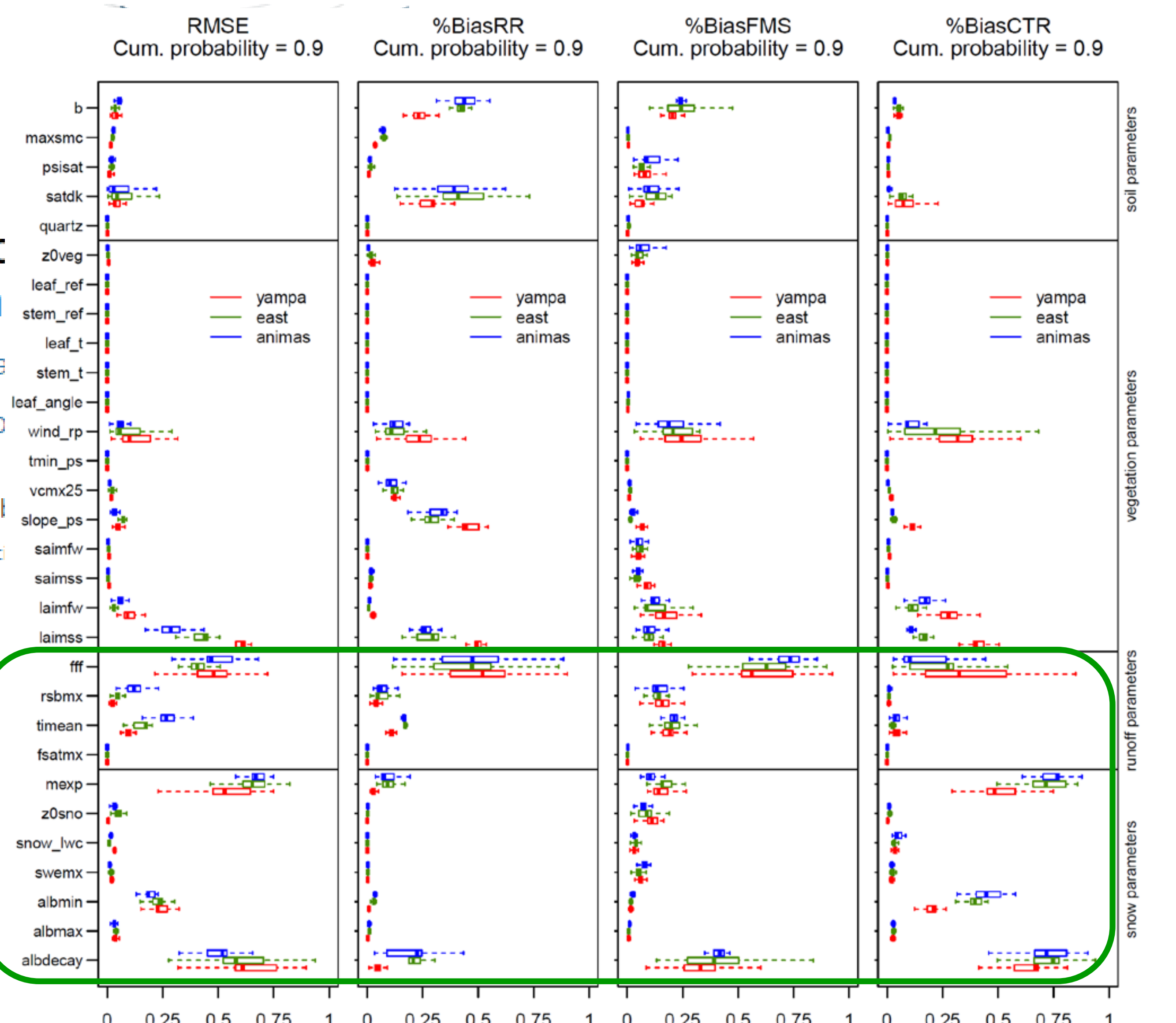
Are we unnecessarily c of complex process-ba

Pablo A. Mendoza, Martyn P. Cla

Balaji Rajagopalan, Luis Samaniego

Accepted manuscript online: 27 Novem

DOI: 10.1002/2014WR015820 View/save c



Hard coded parameters are the most sensitive ones

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More generally: What are the key issues that constrain progress in model development?

- Unsatisfactory process representation
  - Missing processes (e.g., spatial heterogeneity, groundwater)
  - Dated/simplistic representation of some processes
- Limited capabilities to isolate and evaluate competing model hypotheses
  - The failure of MIPs and the need for a controlled approach to model evaluation and improvement
- Insufficient recognition of the interplay between model parameters and process parameterizations
  - Parameter vs. process emphasis in land-surface and hydrologic modeling
- Inadequate attention to model implementation
  - Impact of operator-splitting approximations in complex models
  - Bad behavior of conceptual hydrology models
- Ignorance of uncertainty in models and data
  - To what extent does data uncertainty constrain our capabilities to effectively discriminate among competing modeling approaches?
  - Are we so "over-confident" in some parts of our model that we may reject modeling advances in another part of the model?

Moving forward: Addressing key challenges through a hydrologic process team

- Process representations
  - Representation of sub-grid variability (CLM ideal because of flexible hierarchal data structures)
    - Land model runs on a different (finer, unstructured) grid than the atmosphere
    - Explicit representation of sub-grid variability for a subset of processes (e.g., stomatal resistance)
    - Implicit representation of sub-grid variability using sub-grid probability distributions
    - New process parameterizations suitable for use at larger spatial scales (e.g., radiation transmission)
    - Effective model parameter values suitable for use at larger spatial scales (e.g., hydraulic conductivity)
    - Others?
      - *Key question: At what scale do different processes become important?*
  - Representation of hydrologic connectivity across a hierarchy of spatial scales
    - Within-grid processes (e.g., hillslope-riparian interactions)
    - Explicit representation of regional groundwater
    - Stream-aquifer interactions
  - Geophysical data sets and a-priori parameter estimation
    - "New" geophysical parameters (e.g., soil depth, permeability) → digital crust
    - Evaluate choice of transfer functions to relate geophysical parameters to model parameters
    - A process-based focus on parameter estimation (use of data from research watersheds)
    - Application of upscaling approaches
  - Water management
- Model infrastructure
  - Better forcing data (with uncertainty)
  - Trade-offs between predictive accuracy and computational efficiency
    - Computational requirements for different processes
  - Overall code design
    - Modularity, separating numerics from the physics, parameter visibility

The unified approach to hydrologic modeling