Evaluating and improving CLM hydrologic processes for integrated earth system modeling at regional scales

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15 March 2011
CLM LMWG meeting, Boulder, Colorado

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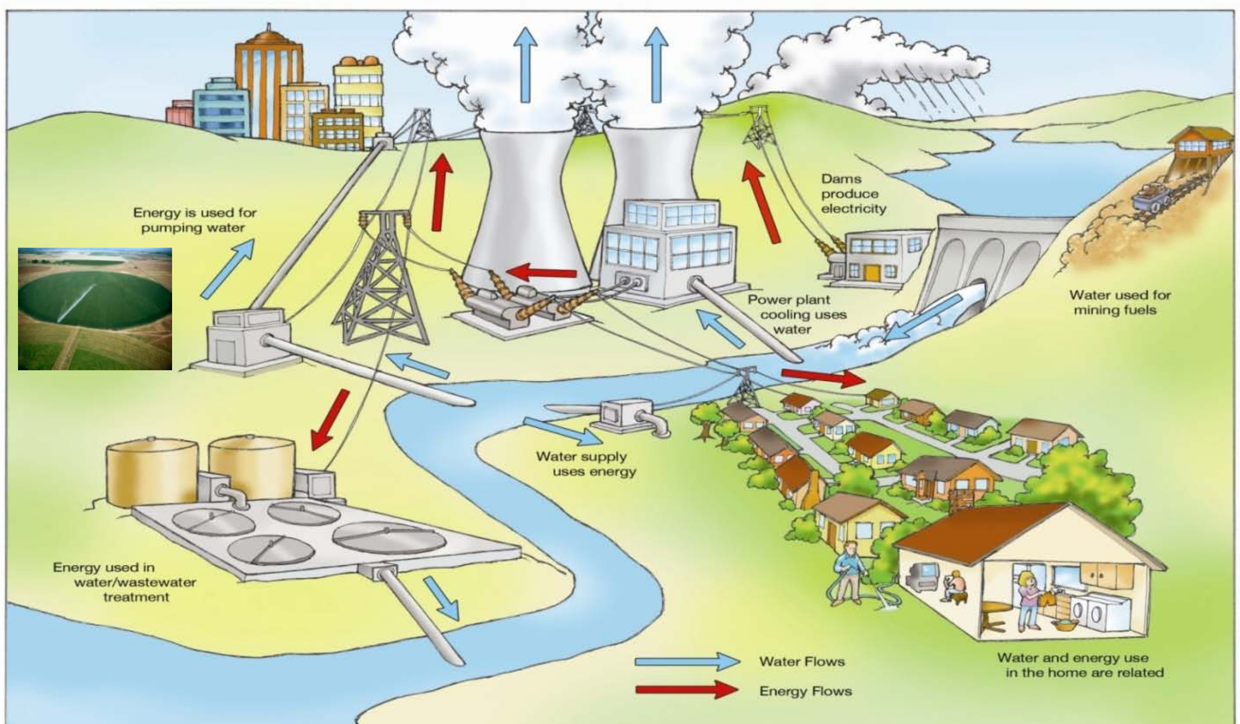
Motivation

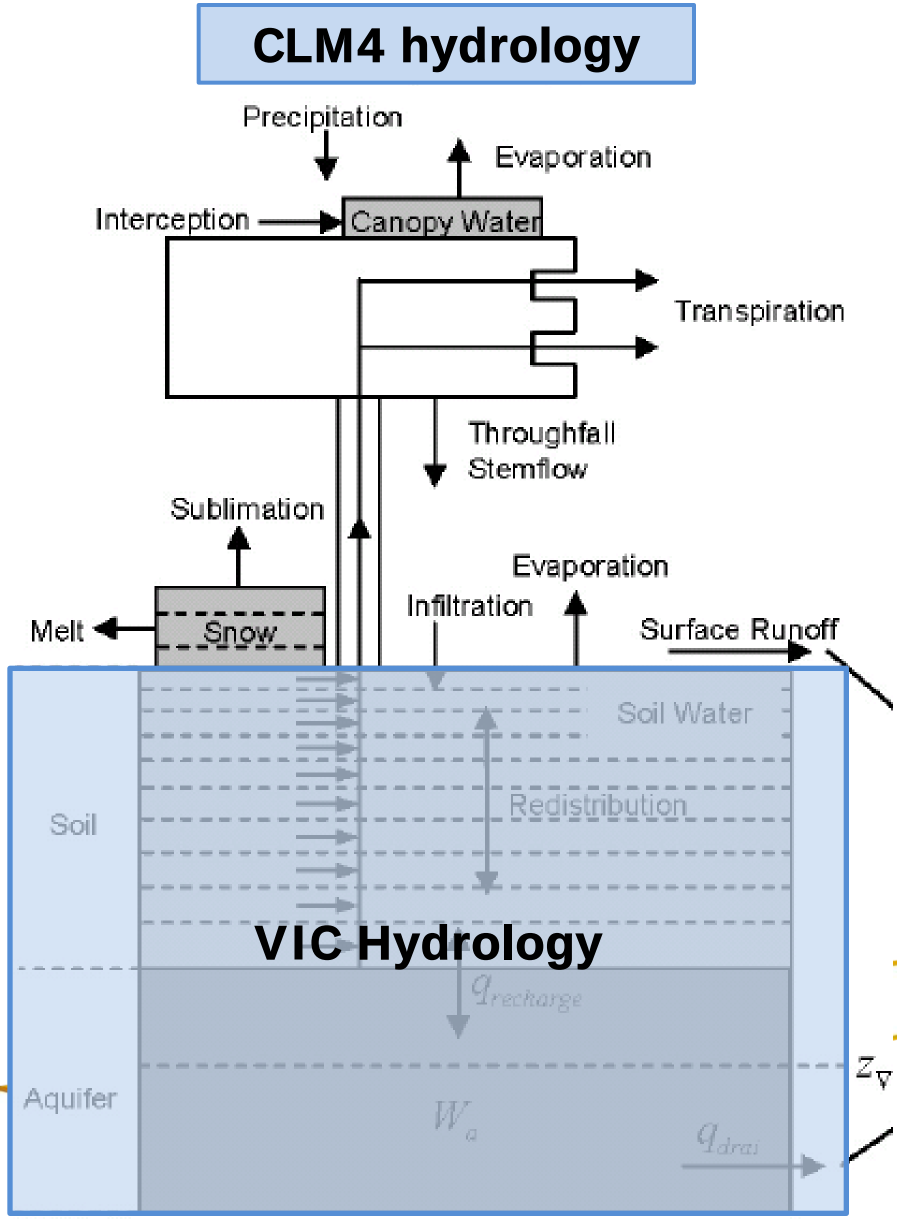
- An integrated regional earth system model (iRESM) is now under development at PNNL. Such a model requires:
  - Improved accuracy in simulating the physical systems for better predictions of future climate change and impacts at regional scales;
  - Better representation of spatial heterogeneity to realistically simulate water-energy-landuse interactions across spatial scales;
  - More complete representations of the human system for evaluating impacts of alternative mitigation and adaptation strategies.



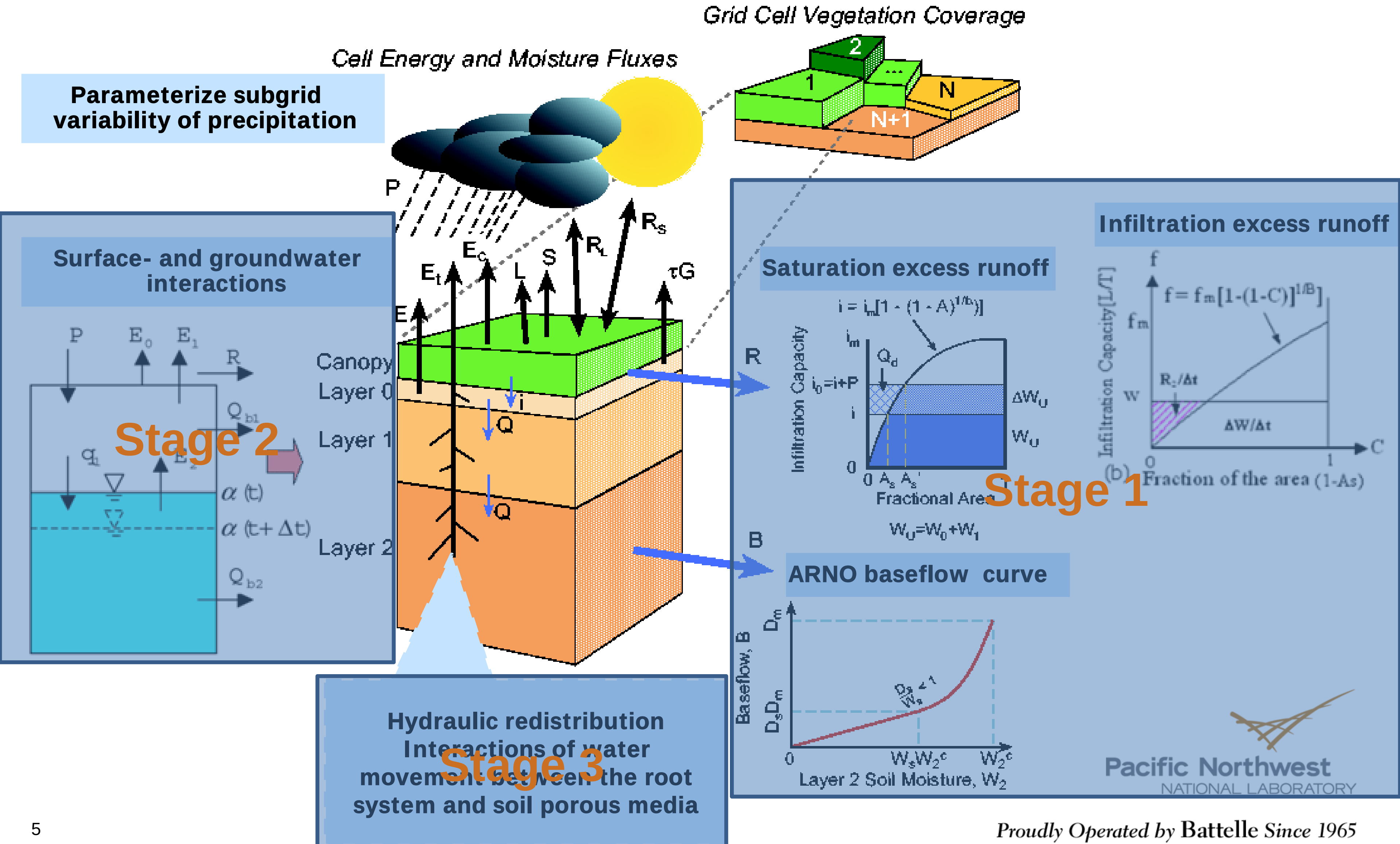
Development tasks

- Community Land Model 4.0 (CLM4) will serve as the land component of iRESM to represent geophysical and biogeochemical processes:
  - Evaluate and improve CLM hydrology parameterizations: CLM4 vs. CLM4VIC
  - Develop high-resolution input datasets
- Extend CLM beyond the grid-based representation of the land surface:
  - A semi-distributed extension of CLM (DCLM) with watersheds as the computational units.
  - Couple WRF, CLM and ROMS
- Add water management components to DCLM, such as irrigation and reservoir operation

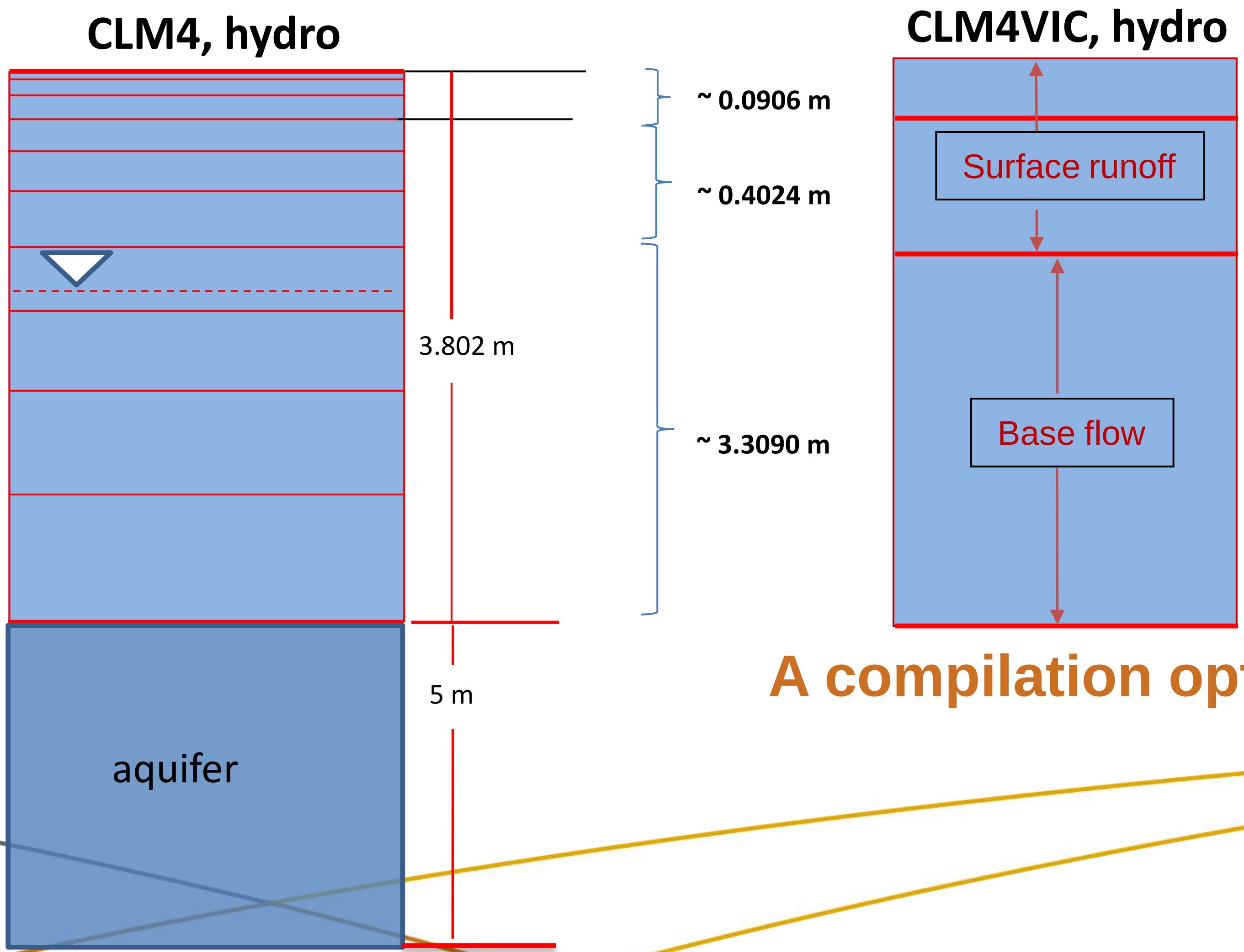
Merging of CLM4 and VIC



Merging of CLM4 and VIC

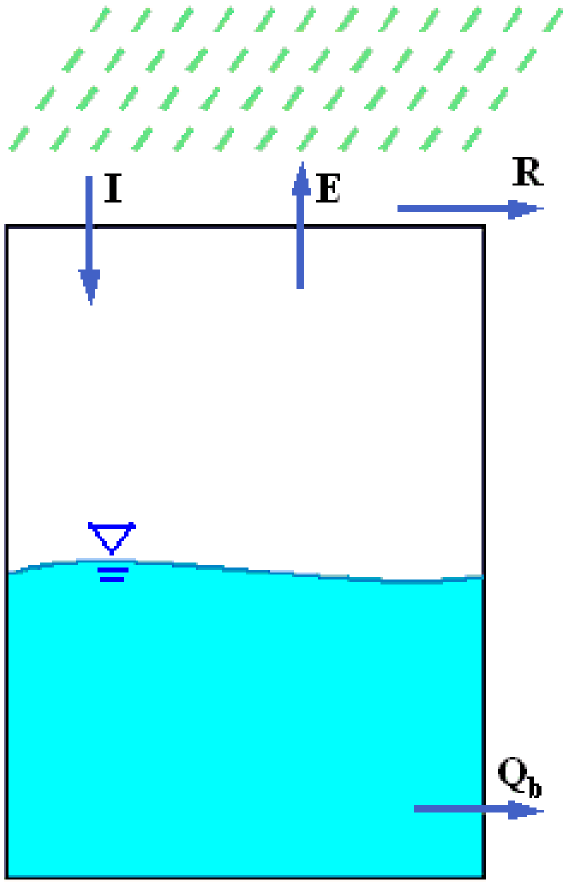


Incorporate VIC hydrology into CLM4



A compilation option

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

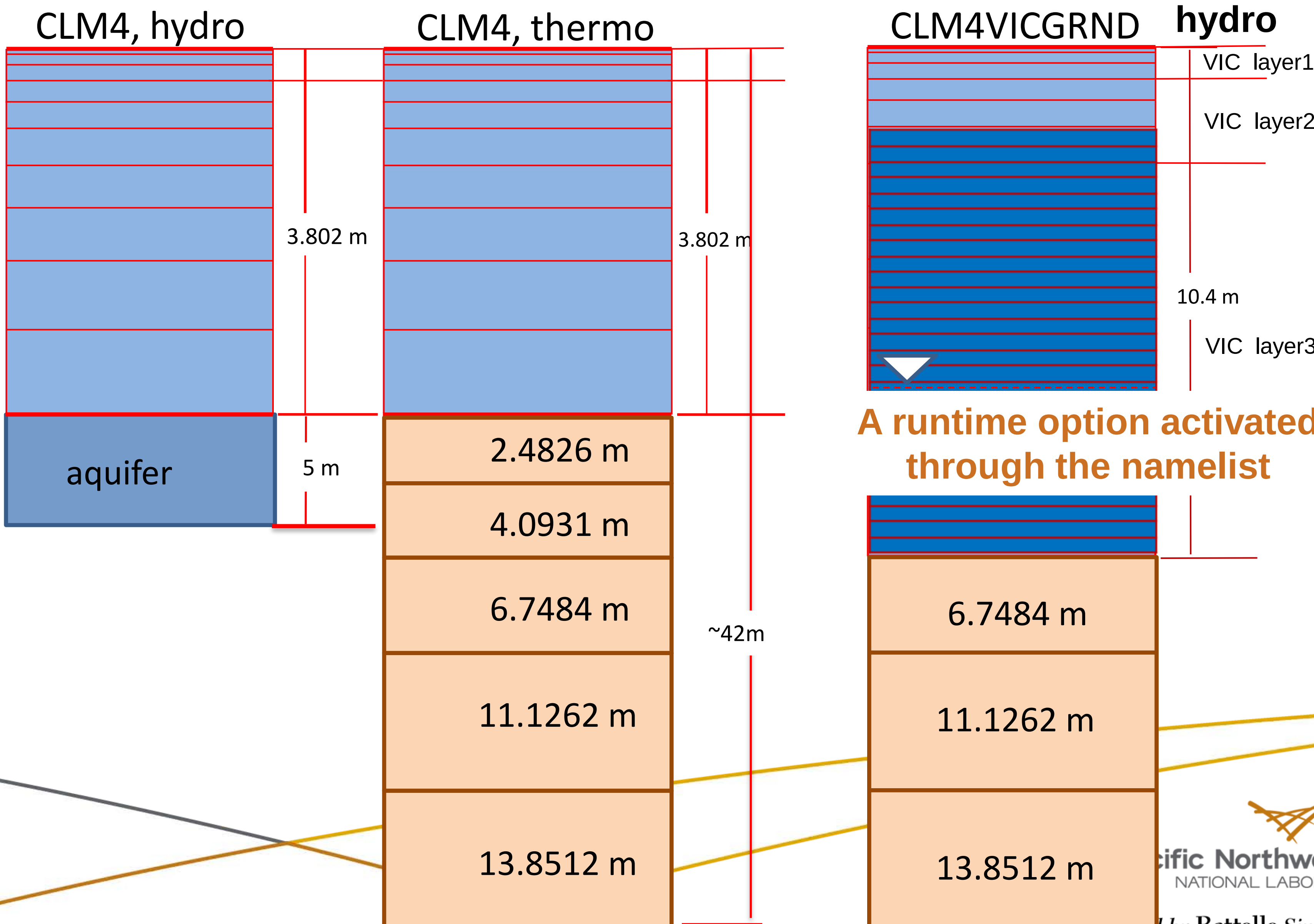
$$\overbrace{\alpha(t+\Delta t)-\alpha(t)} = \frac{1}{\theta_s + n_e(t)} \times$$

$$\left[\underbrace{\bar{\theta}(t+\Delta t)-\bar{\theta}(t)} - \underbrace{\int_t^{t+\Delta t}(p - R - Q_b - E_t)\cdot dt}\right]$$

Change of total soil moisture in the unsaturated zone

Net water recharge to the groundwater body

Implement the groundwater module



A runtime option activated through the namelist

Runoff parameterizations
Surface runoff

CLM 4.0

- Based on the concept of TOPMODEL. Both saturation and in... runoff are co...
- Satu... bas... parar... rs d...

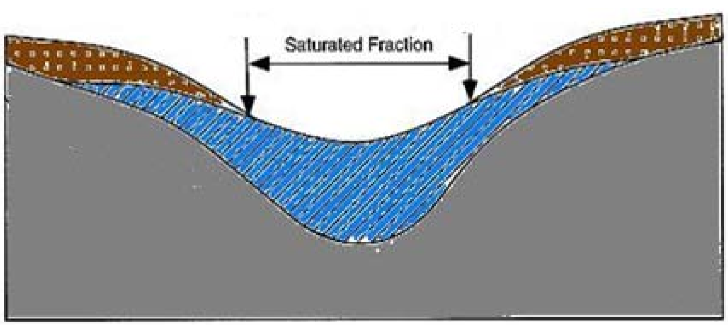
Topo. Index Dist. Shape parameter: DEM

Max. Sat. Area, DEM

Decay factor

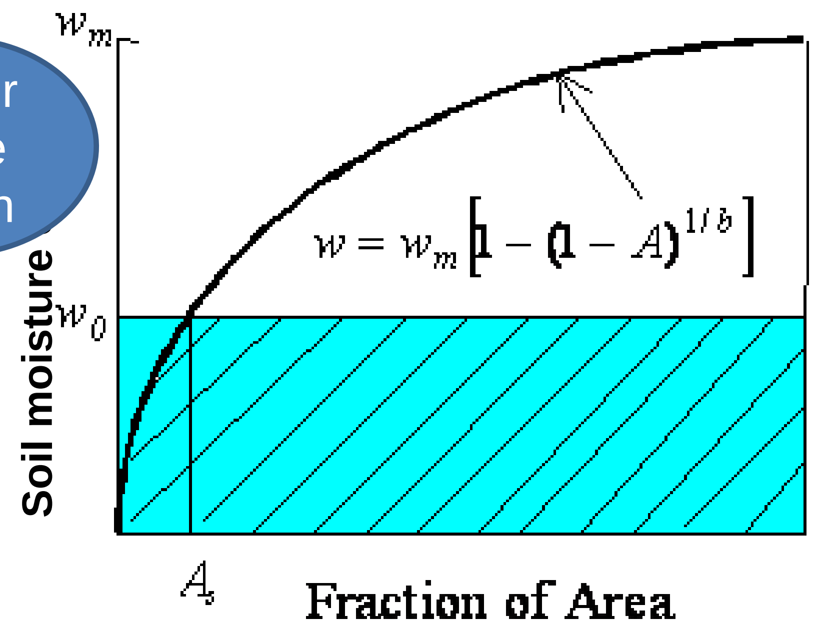
Water table depth

$$F_{sat} = F_{\max} e^{-C_s f z_\nabla}$$



VIC

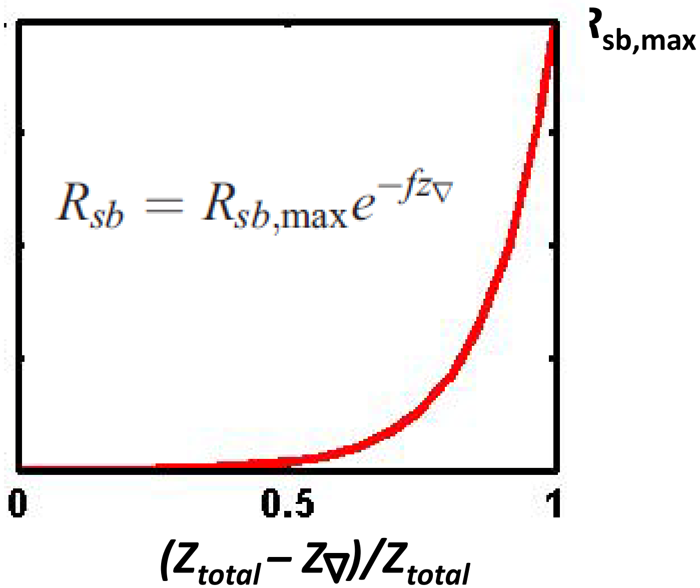
- Surface runoff is calculated as the difference between throughfall and infiltration.
- Infiltration is controlled by the spatial distribution of soil storage capacity.



Runoff parameterizations
Subsurface runoff

CLM 4.0

- The subsurface runoff is computed as follows



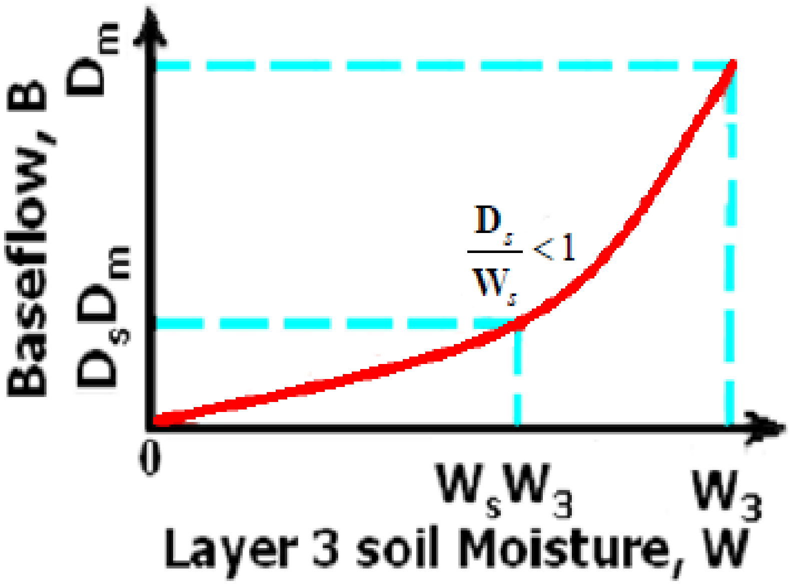
- *Default parameters:*

$R_{sb,max} = 5.5\times10^{-3}$ kg m^{-2}s^{-1}

$f = 2.5$ m^{-1}.

VIC

- The ARNO formulation



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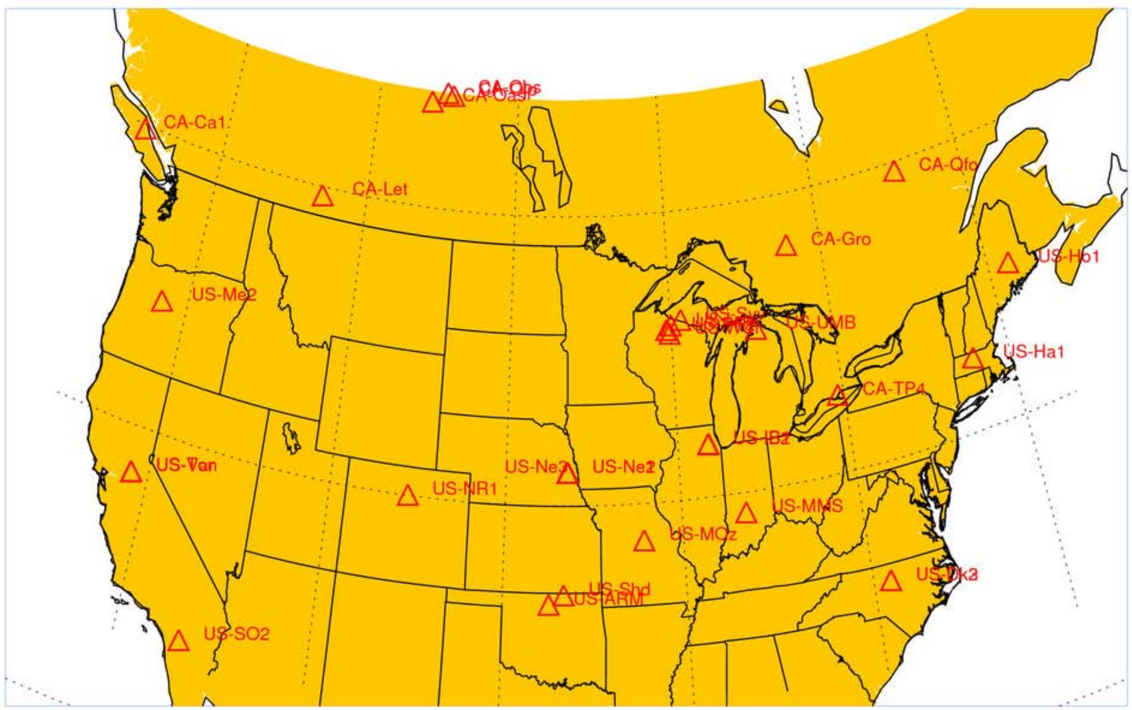
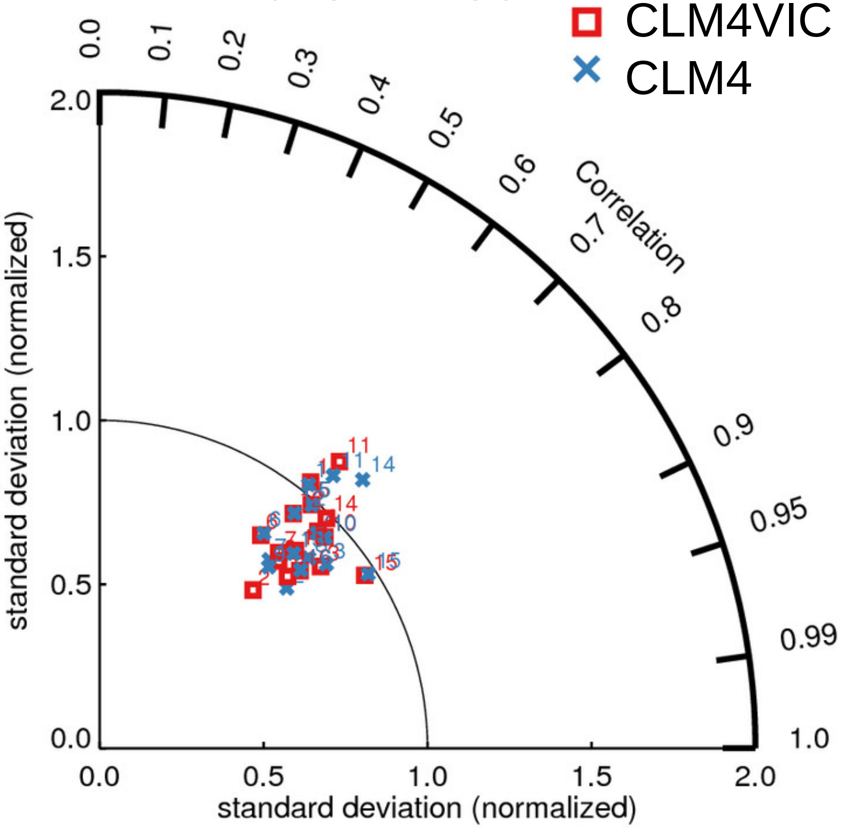
Comparison at flux tower sites
control run

- Soil and veg information, and meteo. forcing from the NACP site synthesis team.
- CLM4 : default parameter values
- 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

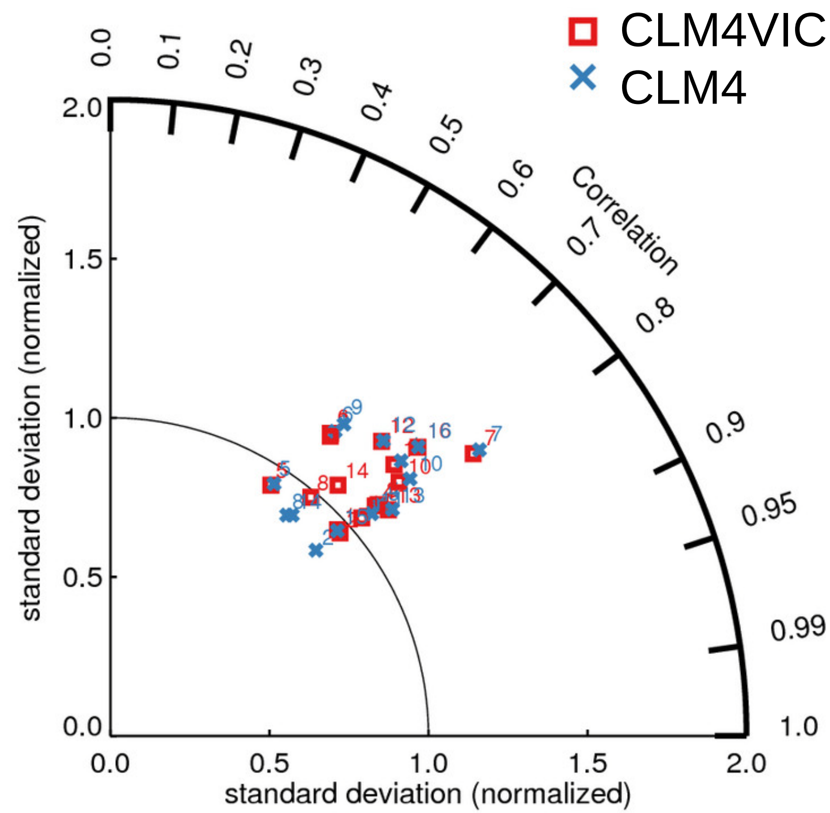


Simulated energy fluxes at the NACP sites

Latent heat



Sensible heat



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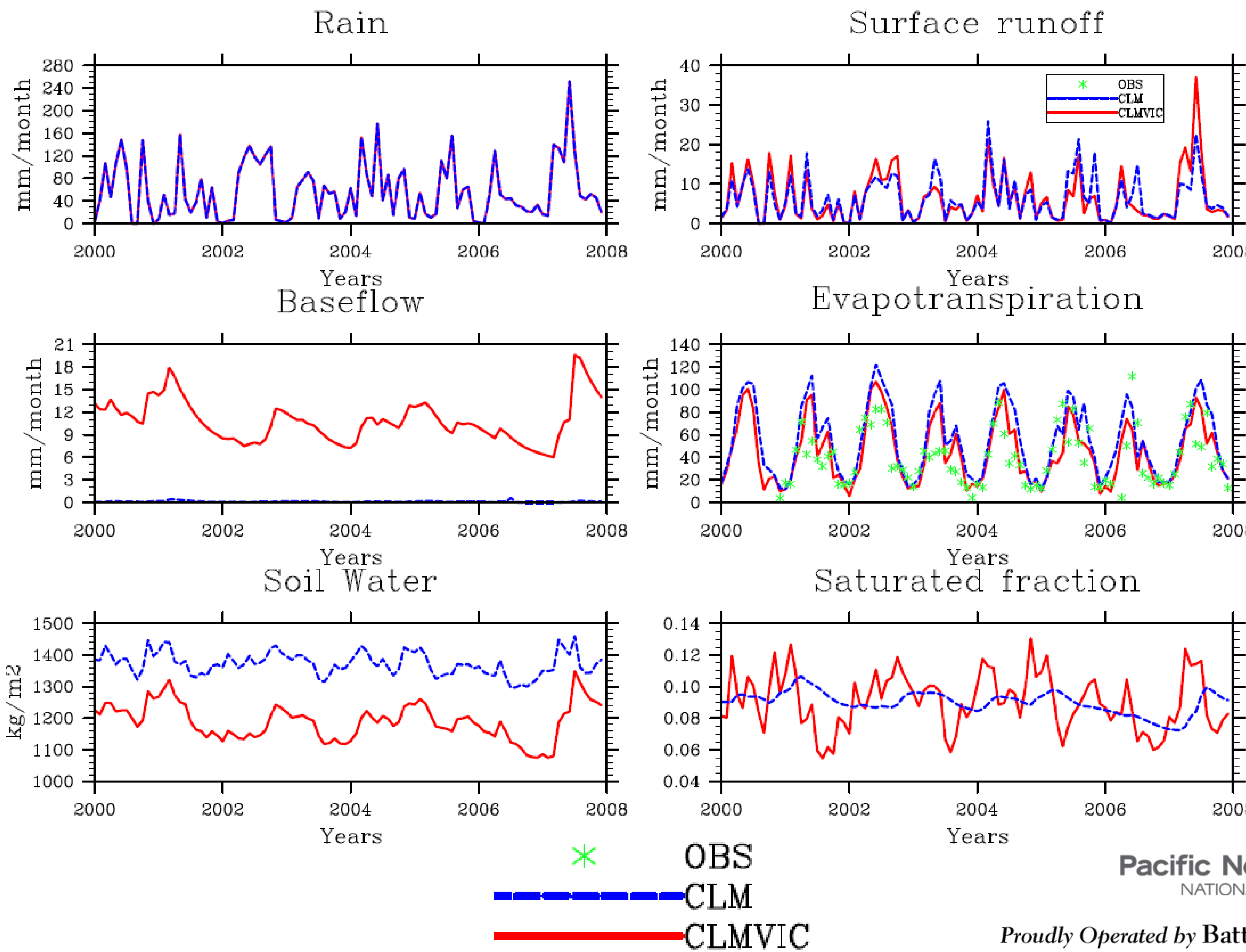
Simulated water budget at selected sites
ARM SGP main, croplands



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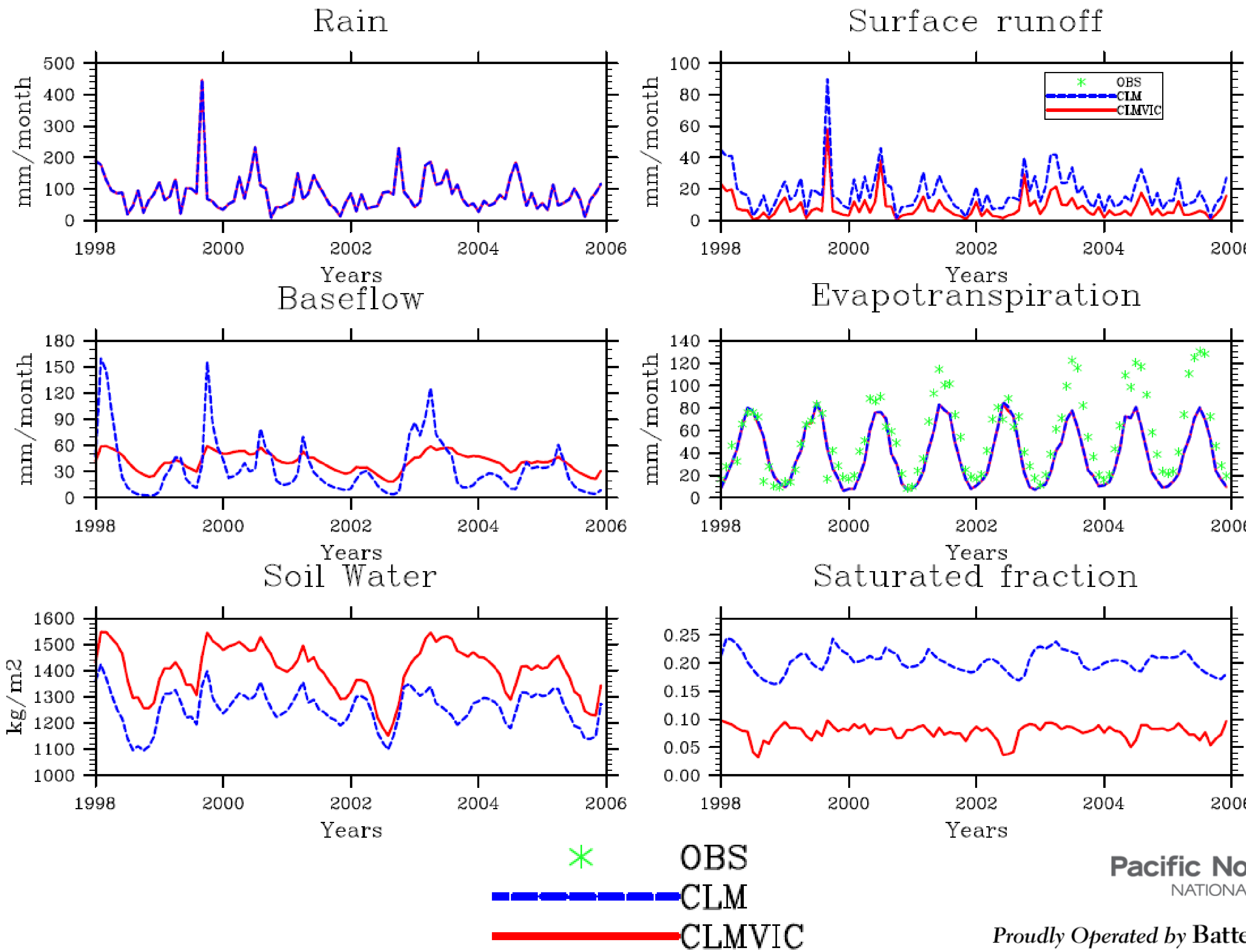
Simulated water budget at selected sites

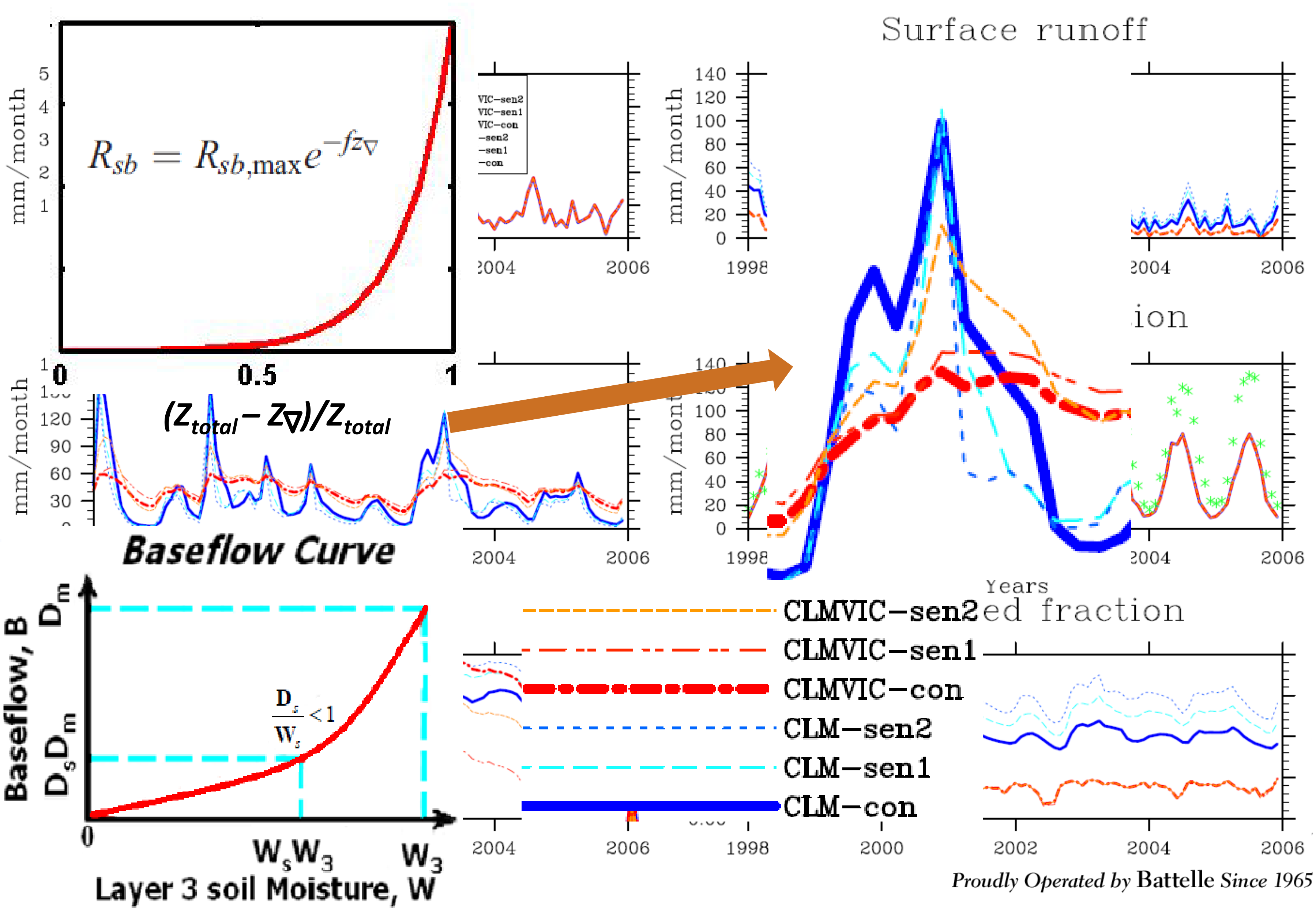
Duke forest, evergreen needleleaf



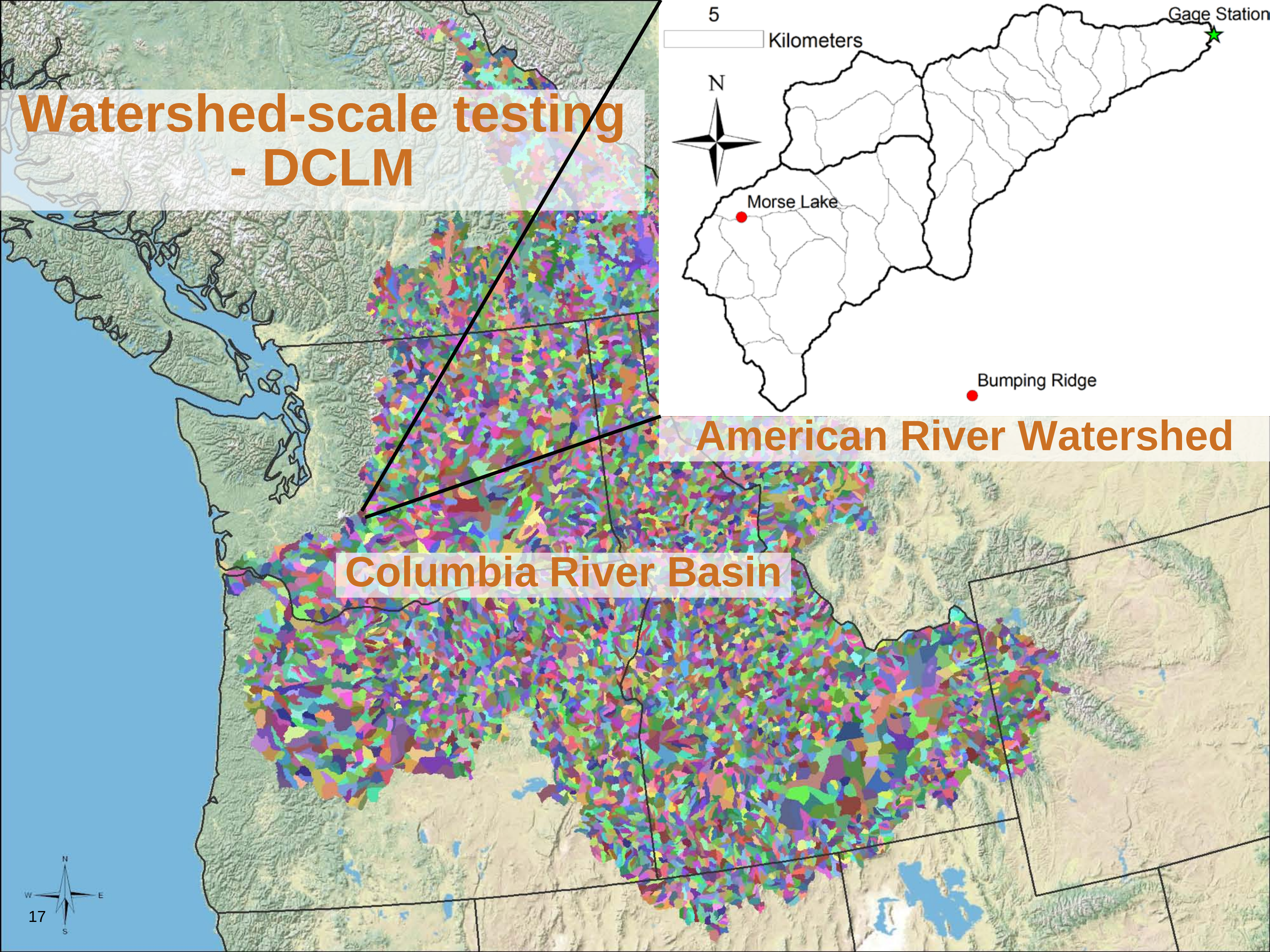
Sensitivity experiments
subsurface flow parameters

Experiments	CLM4		CLM4VIC	
	$R_{sub,max}$ (mm/s)	f (m^{-1})	D_{smax} (mm/day)	W_s
control	=475.5 mm/day	2.5	2.0	0.5
Sen1	5.5×10^{-4}	2.5	47.50	0.5
Sen2	1.0×10^{-4}	2.5	8.64	0.5
Sen3	5.5×10^{-3}	4	8.64	0.7
Sen4	5.5×10^{-3}	8	2.0	0.7
Sen5	5.5×10^{-3}	1	47.50	0.7

Sensitivity experiments
Duke forest, Evergreen Needleleaf



Watershed-scale testing - DCLM

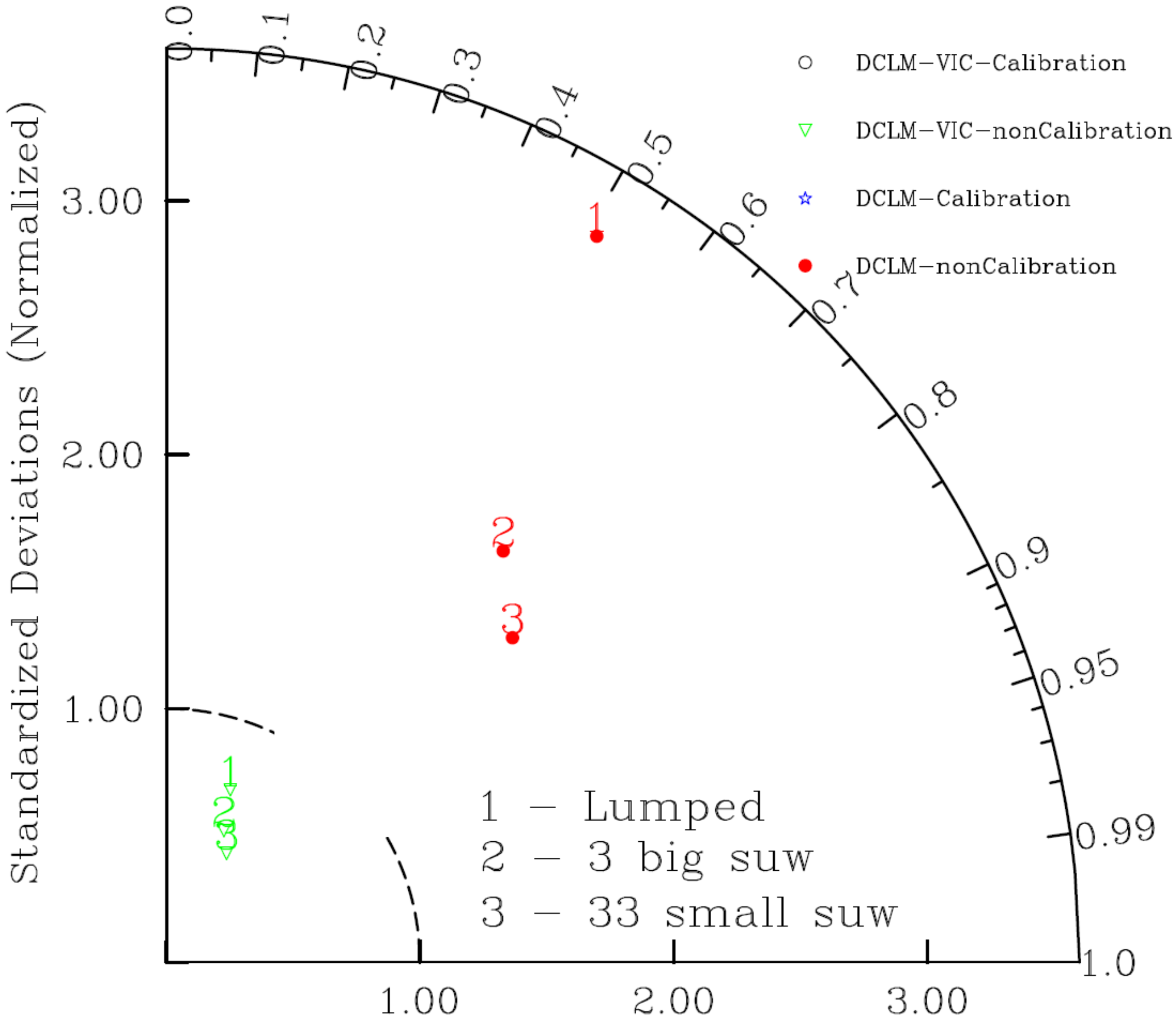


Experimental Design

- **American River Watershed**
  - Snow-dominated mountainous area, annual preci. about 1900mm
  - Sandy soil overlaid by evergreen forest and deciduous shrub
- **Three levels of spatial discretization based on 30m DEM**
  - Level 1: lumped, total area of 204 km^2
  - Level 2: 3 big subbasins, average area of 68 km^2
  - Level 3: 33 small subbasins, average area of 6.2 km^2
- **Simulations for water year 2004 – 2010**
  - Each subbasin is treated as a single unit in the semi-distributed mode
  - Hourly precipitation and temperature were interpolated from the NRCS SNOTEL sites Morse Lake and Bumping Ridge. Hourly solar radiation data were generated by a meteorological model.
  - Land cover, LAI, SAI and vegetation heights derived from MODIS
  - Soil properties from STATSGO.
  - F_{max} and C_s estimated based 30m DEM

Simulated runoff from DCLM

comparison with observed daily streamflow



Summary of CLM4 vs. CLM4VIC comparison

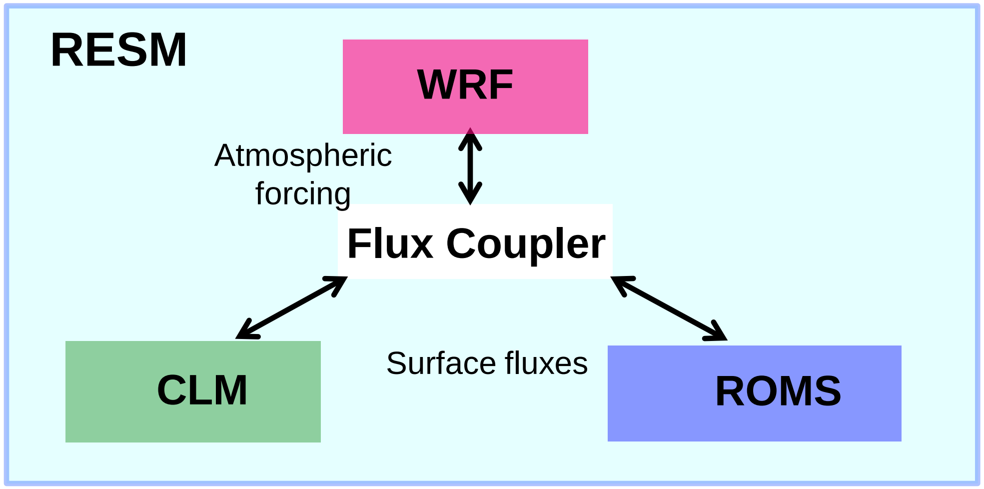
- Streamflow responses from CLM4 and CLM4VIC are distinctly different, which are determined largely by model structures and underlying assumptions.

- In regional applications, we need to (1) evaluate the appropriateness of the models under different site conditions; (2) calibrate or use regionalized parameter values for more realistic simulation of streamflow.

- Even for a small watershed, CLM4 performs better if spatial heterogeneity is represented.

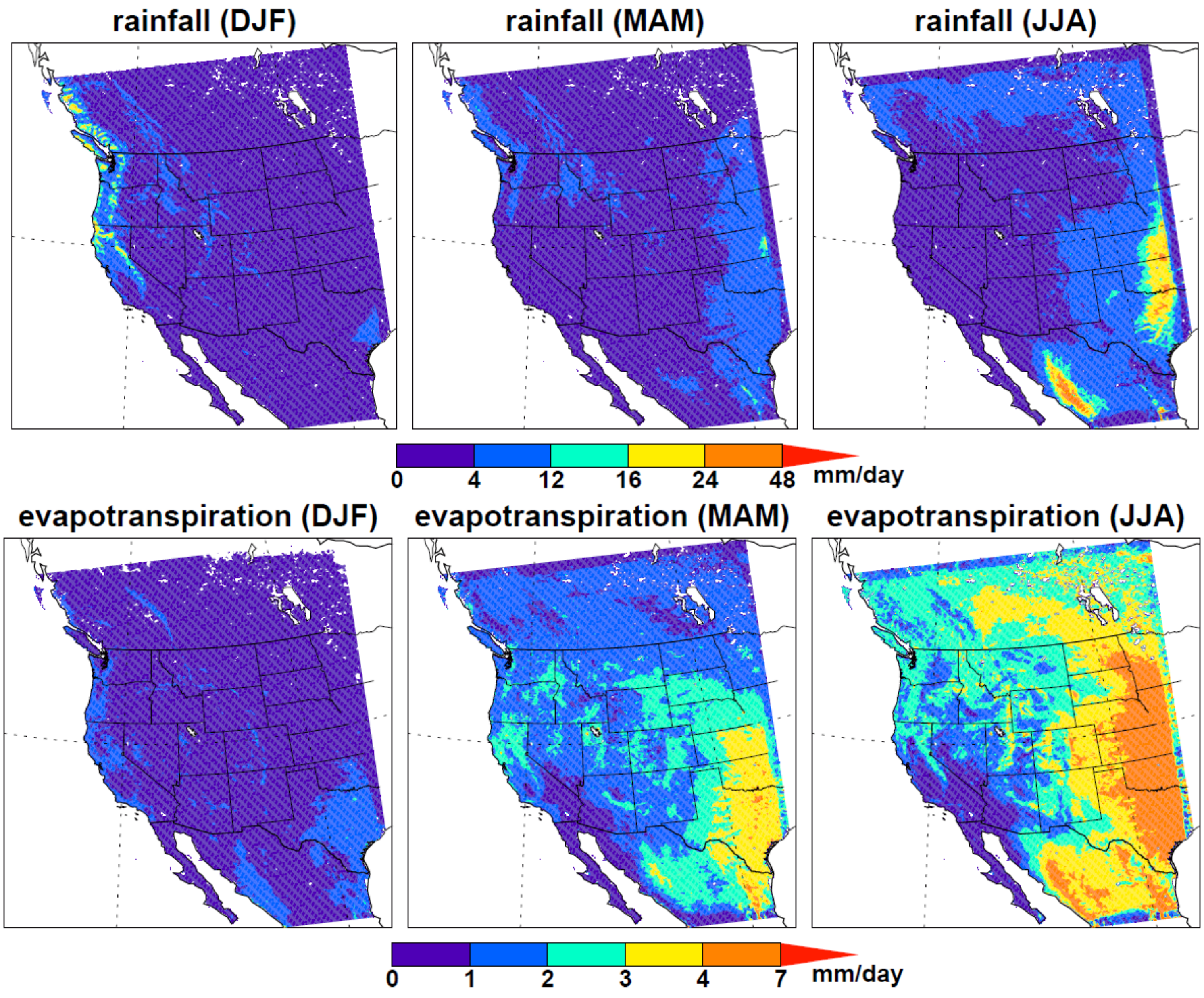
- This study highlights the importance of evaluating both the energy and hydrologic components of CLM4 for applications across spatial scales, especially under the context of earth system modeling.

The regional earth system model

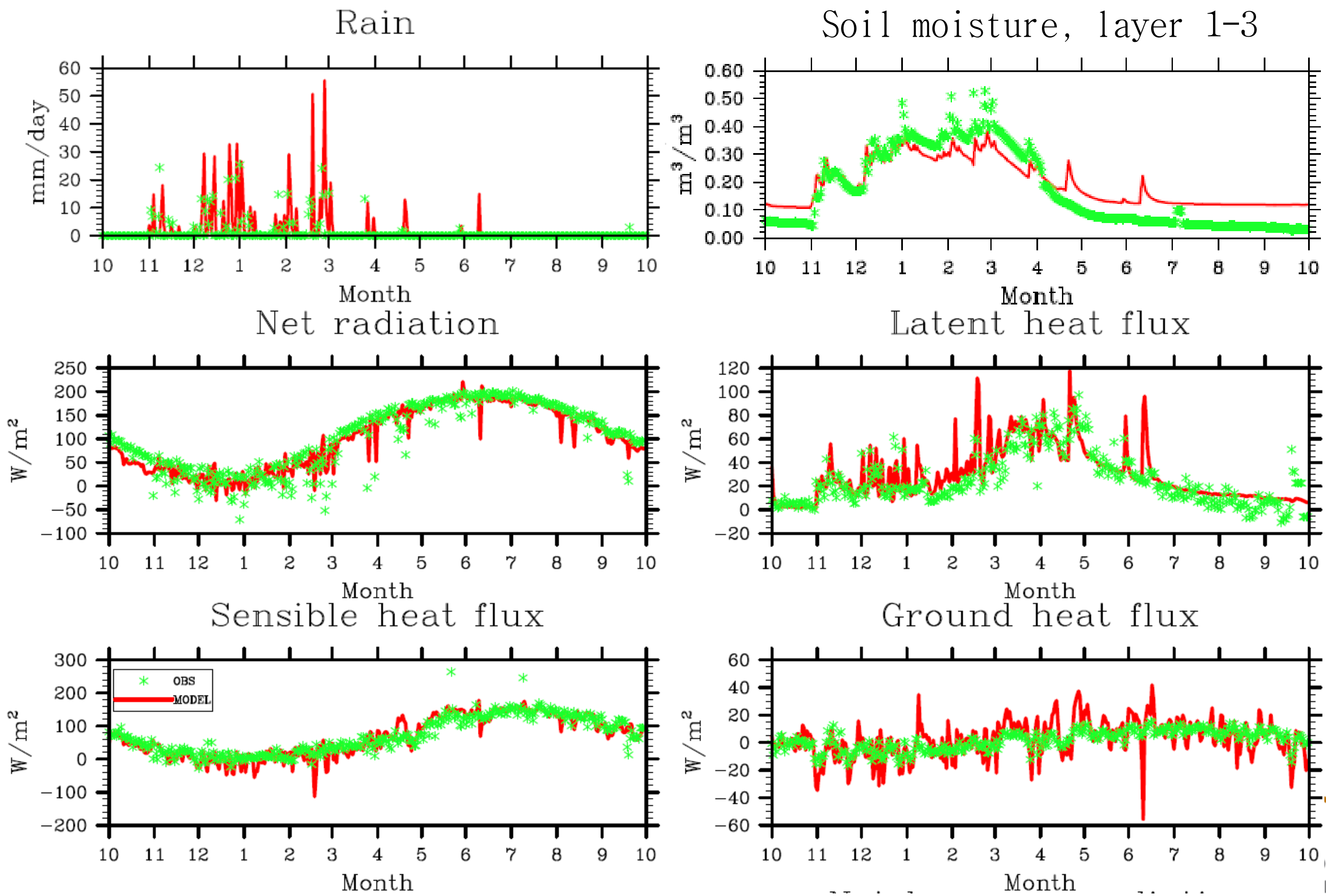


- Experiment setup:
  - Western US domain;
  - 12-km resolution;
  - Initialized with and driven by reanalysis data;
  - 0.05 degree high resolution surface dataset for CLM is used;
  - Simulation period: 10/2003 – 09/2004.

RESM results: spatial distribution



RESM results: validation at flux towers
Tonzi Ranch, California, Woody Savannas



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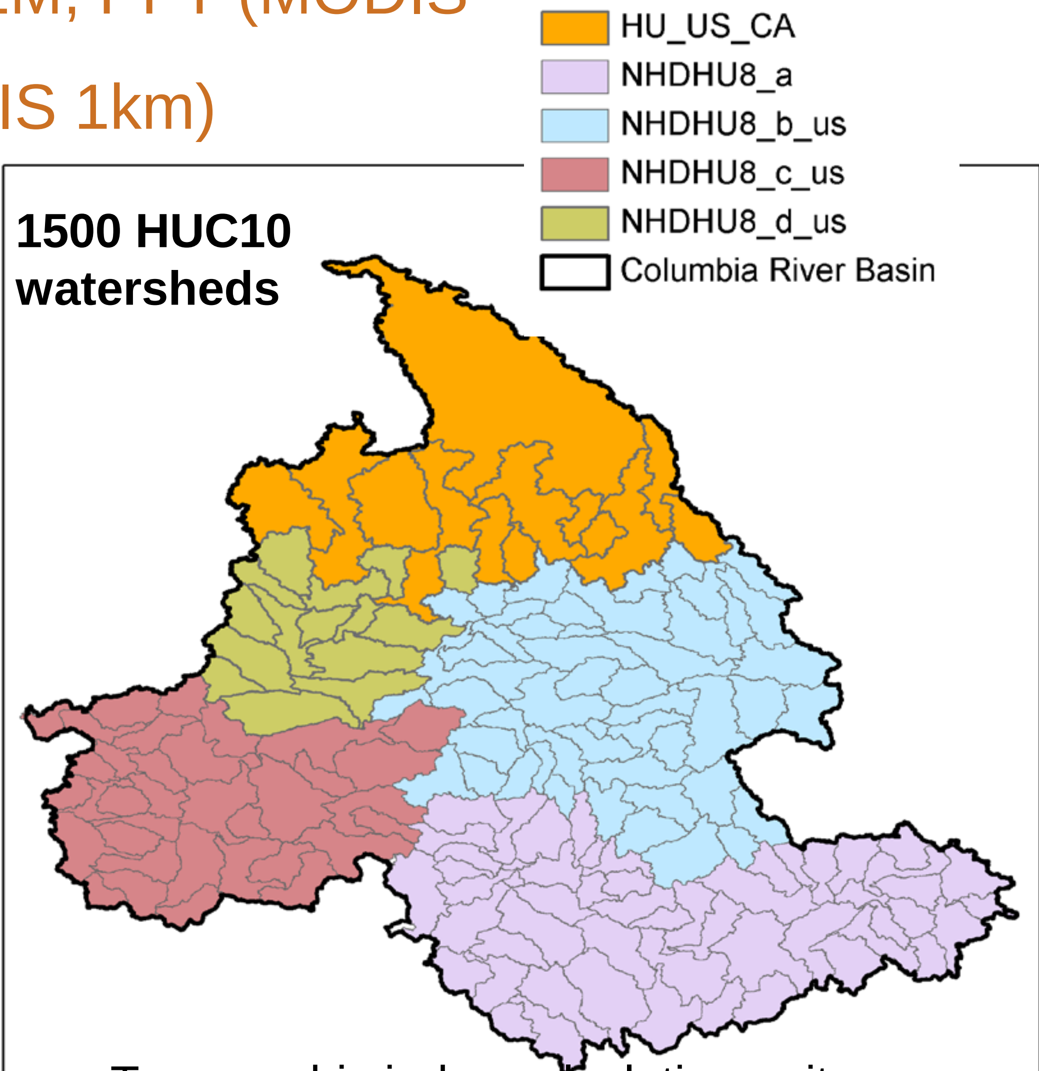
DCLM setup over the Columbia River Basin

- Surface dataset: 30m DEM, PFT (MODIS 500m), phenology (MODIS 1km)
- Routing module
- Water management module
- Mapping file between the atmospheric and land grids



Topographic index calculation unit

Acknowledgement

- PNNL: Integrated regional earth system modeling (iRESM) Initiative
- DOE: Investigation of the Magnitudes and Probabilities of Abrupt Climate Transitions (IMPACTS)
- DOE: Strengthening the Coupling between Climate and Earth System Models (ESMs) and Integrated Assessment Models (IAMs)

- X. Liang, D. Lettenmaier, A. Wang, T. Craig, R. Stockli

- NACP site synthesis team