Development of River Routing and Groundwater Models in CLM

L. Ruby Leung, Maoyi Huang, Hongyi Li, Yinghai Ke,
Mark Wigmosta, Andre Coleman
Pacific Northwest National Laboratory

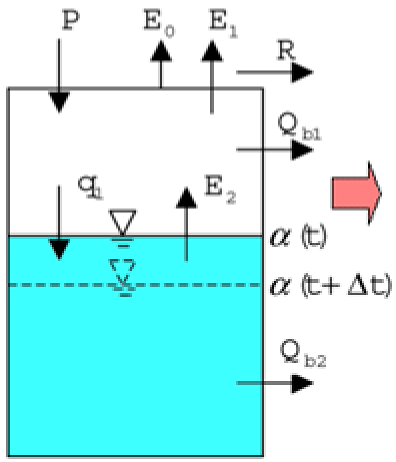
CESM Land Model Working Group Session

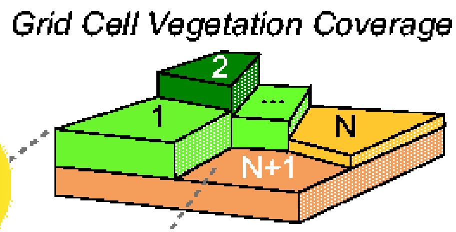
21 June 2011, Breckenridge, CO

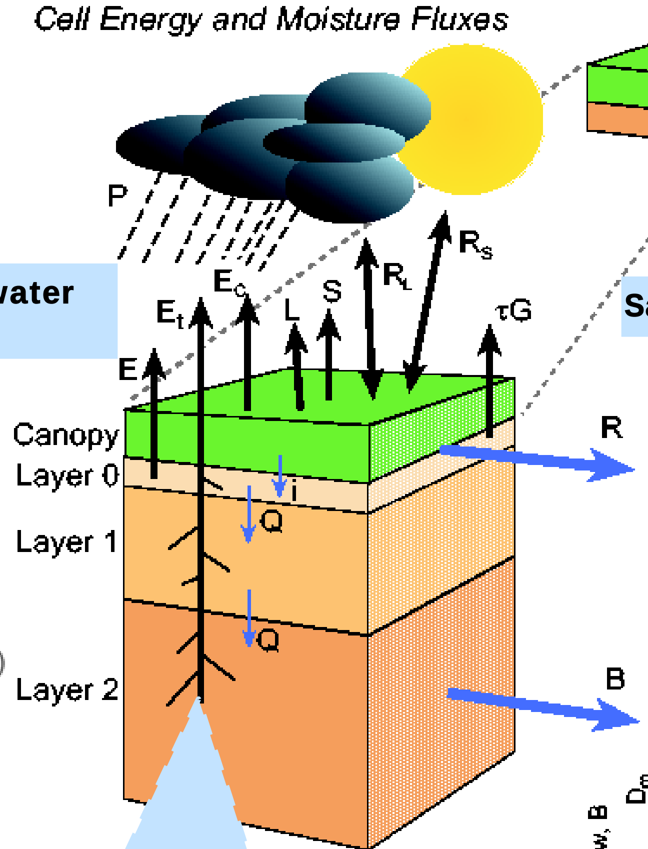
Pacific Northwest
NATIONAL LABORATORY

Introducing VIC soil hydrology to CLM

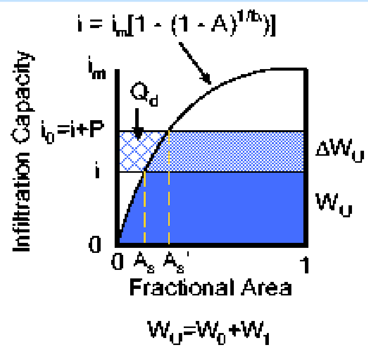
Surface- and groundwater interactions



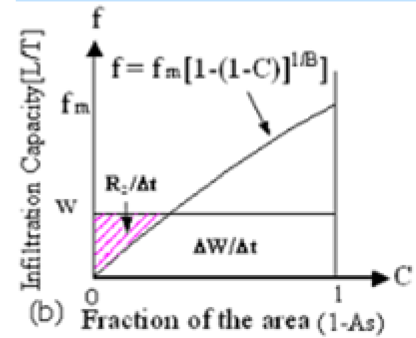




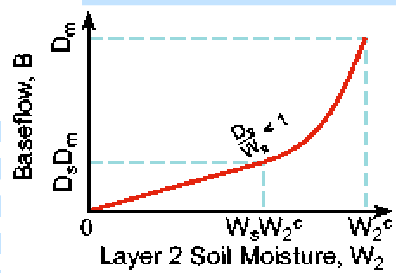
Saturation excess runoff



Infiltration excess runoff



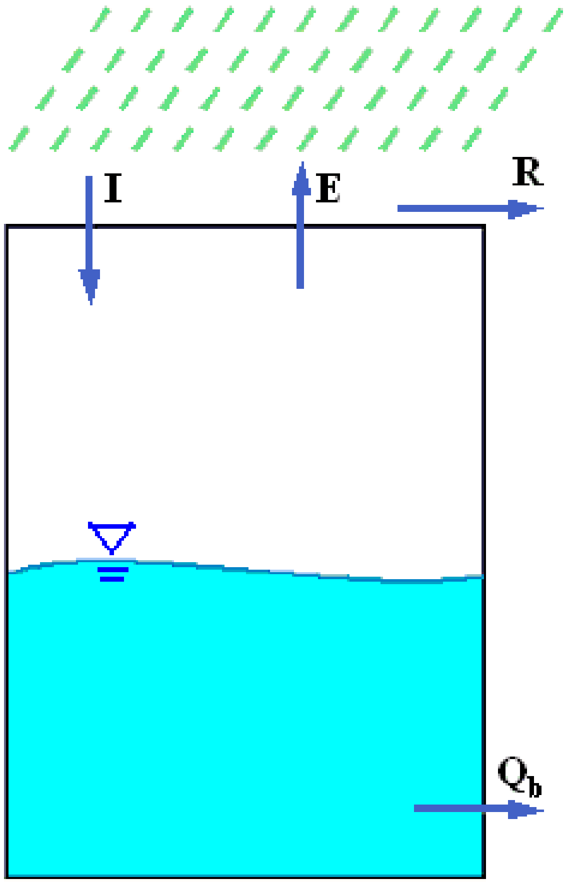
ARNO baseflow curve



Hydraulic redistribution Interactions of water movement between the root system and soil porous media

Pacific Northwest NATIONAL LABORATORY

VICGROUND: A Dynamic representation of surface and groundwater interactions



Change of soil moisture · Diffusion term · Drainage term

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

Change of water table depth

θ_s porosity
$n_e(t)$ effective porosity

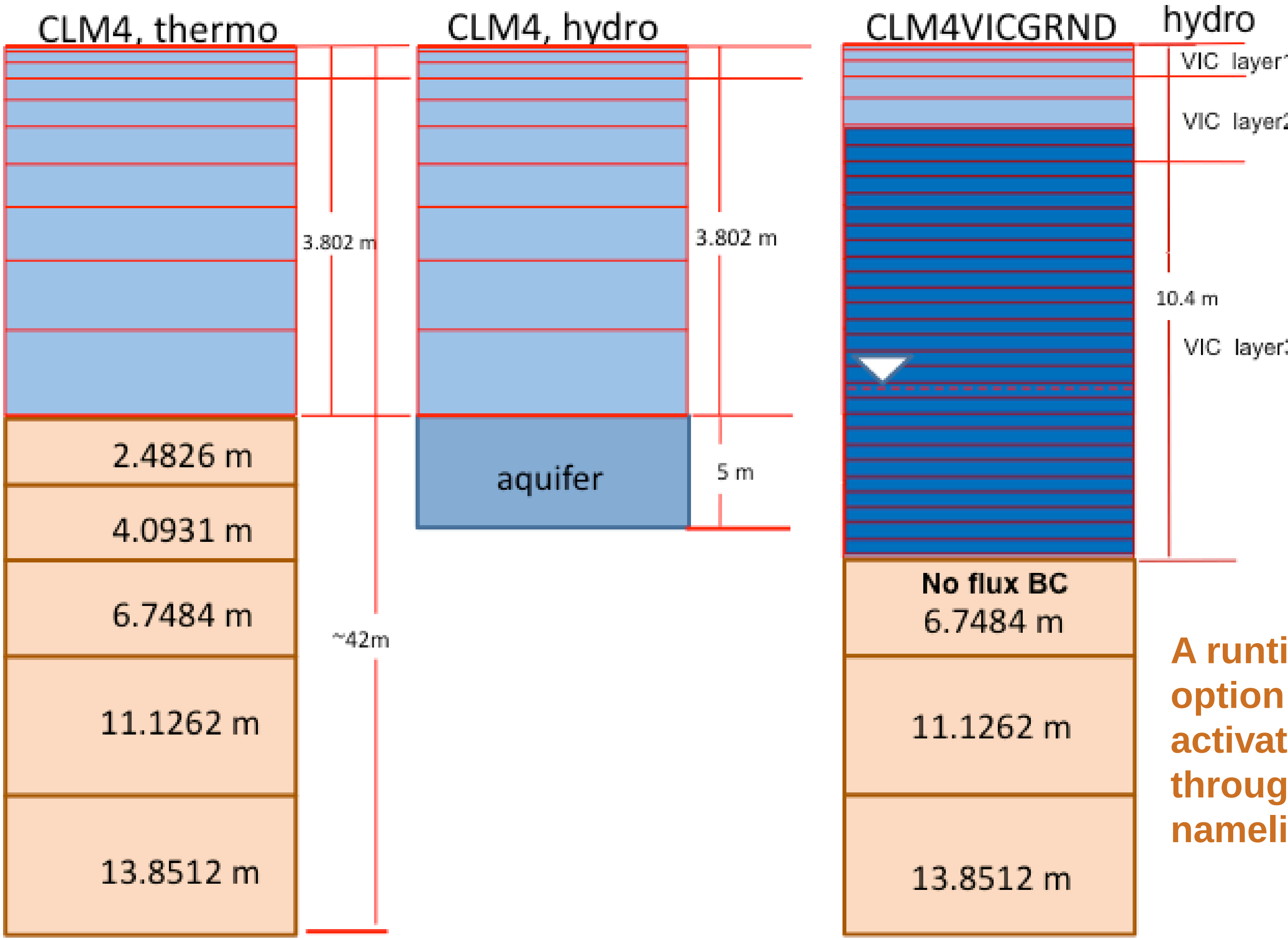
$$\alpha(t+\Delta t)-\alpha(t) = \frac{1}{\theta_s + n_e(t)} \times \left[\bar{\theta}(t+\Delta t)-\bar{\theta}(t) - \int_t^{t+\Delta t}(p - R - Q_b - E_t)\cdot dt\right]$$

Change of total soil moisture in the unsaturated zone

Net water recharge to the groundwater body

Liang et al., JGR, 2003

Implementation of VICGROUND to CLM



A runtime option activated through the namelist

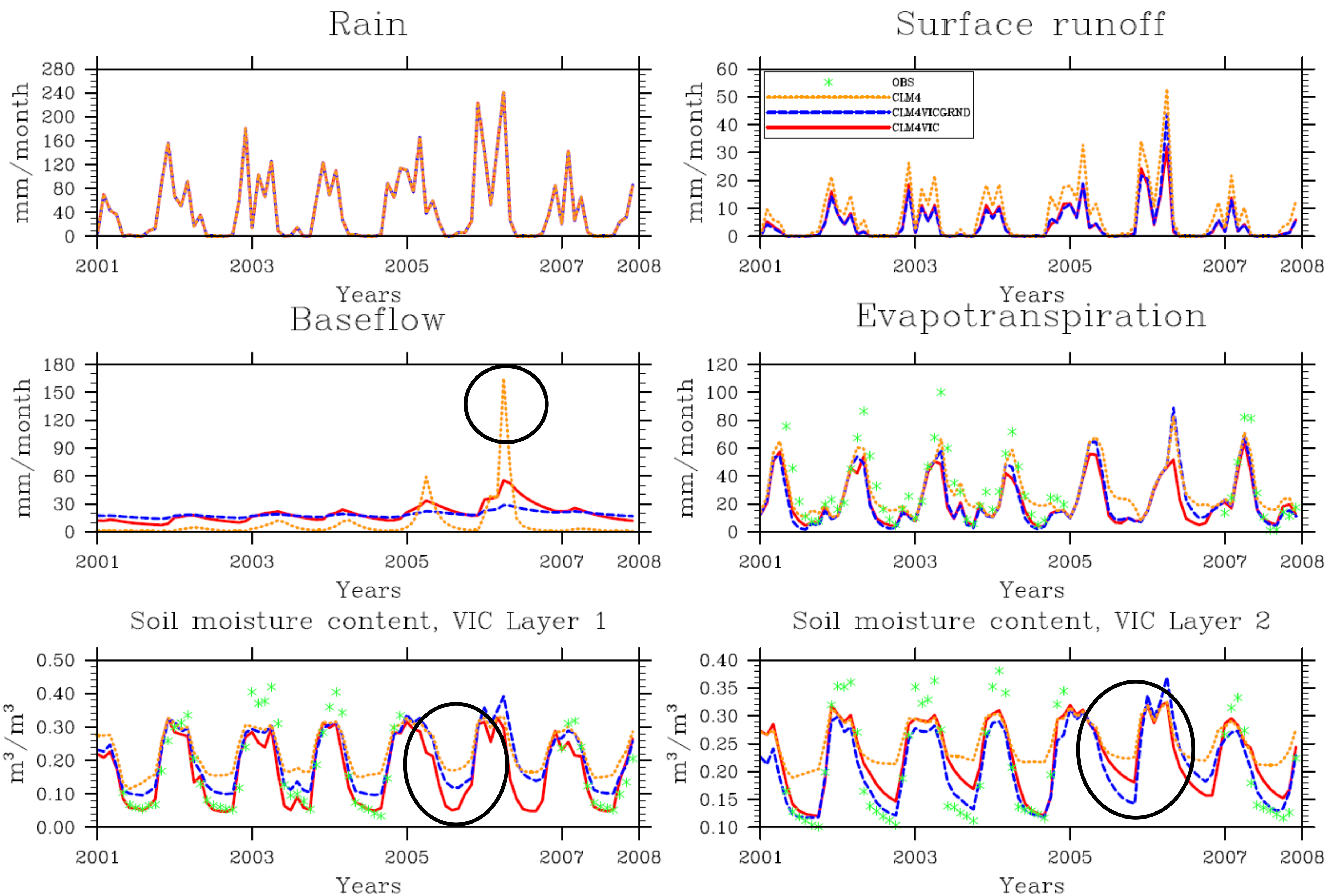
Preliminary testing at Tonzi Ranch, CA

- Soil and vegetation information, and atmospheric forcing provided by the NACP site synthesis team
- CLM4 : Default parameter values
- CLM4VIC and CLM4VICGROUND parameters:
  - VIC curve shape parameter: $b = 0.1$
  - Maximum baseflow: $D_{smax} = 2$ mm/day
  - ARNO baseflow curve shape parameters:

    $D_s = 0.05$, $W_s = 0.5$

Pacific Northwest
NATIONAL LABORATORY

Simulated water budget at Tonzi Ranch



River Transport Model (RTM) in CLM

Approach:

- Study area divided into cells
- Flow direction is determined by D8 algorithm
- Cell-to-cell routing using a linear advection model

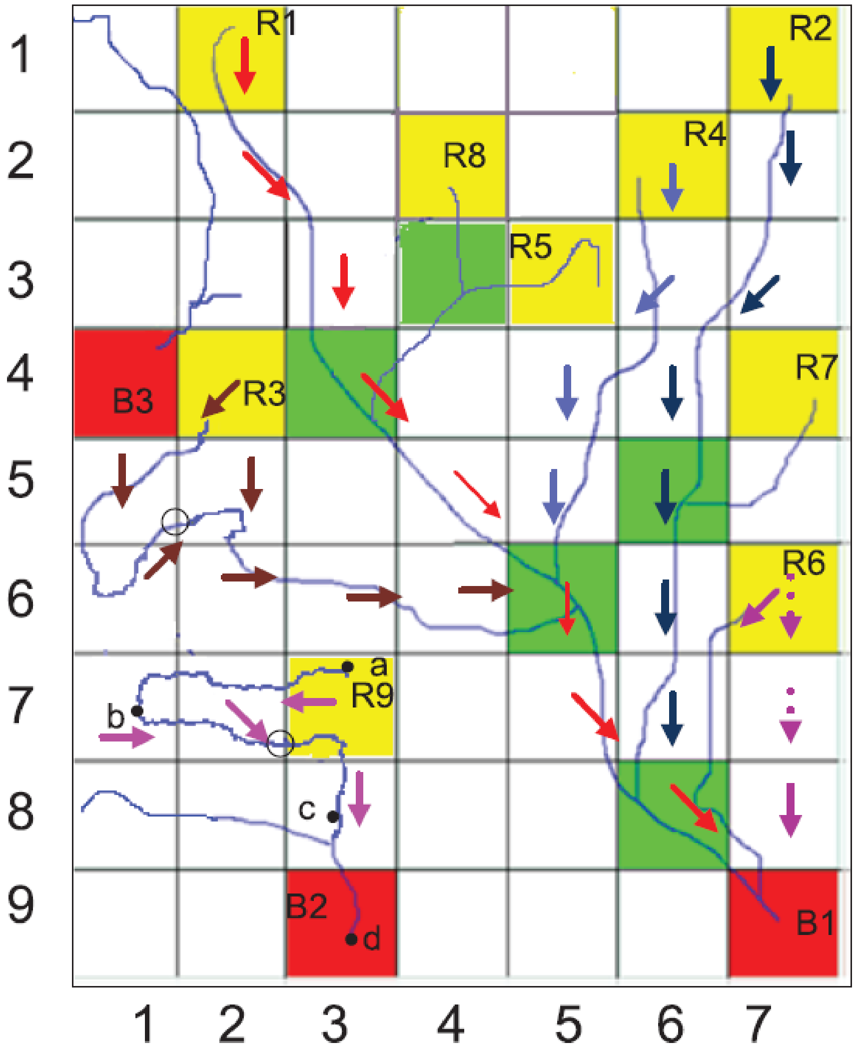
Limitations:

- Poor representation of river network
- Routing across hillslope and local small channels not included
- Assuming constant, uniform channel velocity

$$\begin{cases} \frac{dS}{dt} = \sum Q_{in} - Q_{out} + R \\ Q_{out} = \frac{v}{d} S \end{cases}$$

Pacific Northwest NATIONAL LABORATORY

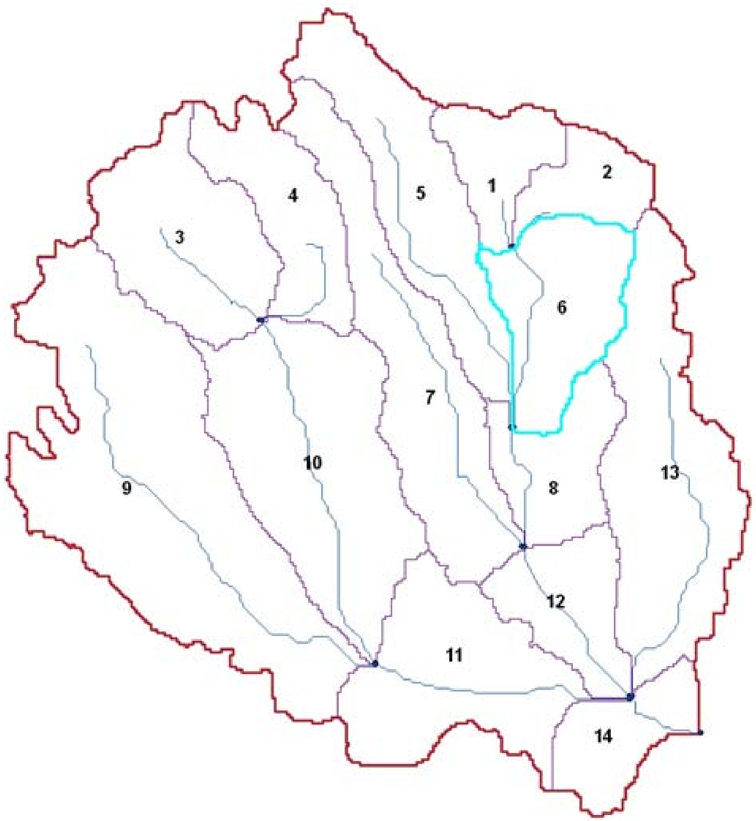
Improved grid based routing scheme



Wu et al. (2011)

- Delineation of river network using a hierarchical dominant river tracing algorithm
- Hillslope routing with kinematic wave method
- Sub-network routing with kinematic wave method
- Main channel routing with Muskingum-Cunge method or variable storage method

Subbasin based routing scheme



- Delineation of river network at various scales based on high resolution global dataset (Hydrosheds)
- Consistency with the natural boundary of streamflow observation
- Similar governing equations as in the grid based scheme
- Channel width and bankful depth estimated by empirical Hydraulic Geometry relationship

Potential advantages of the new routing schemes

- More complete representation: runoff generation → hillslope routing → sub-network routing → main channel routing

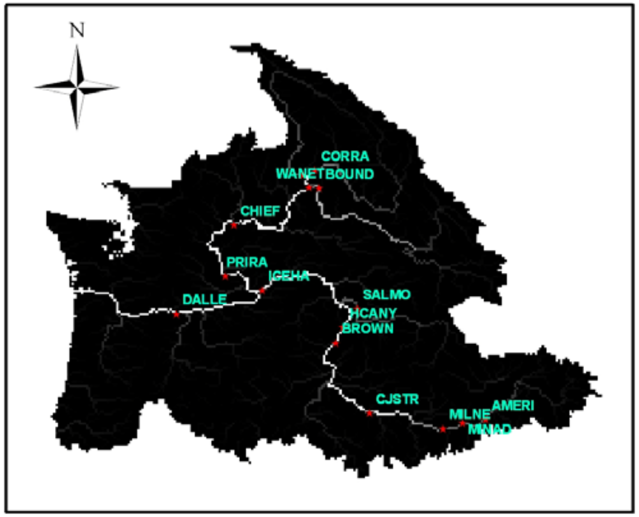
- More flexibility to incorporate subgrid heterogeneity, such as land use, topography and variable contributing area

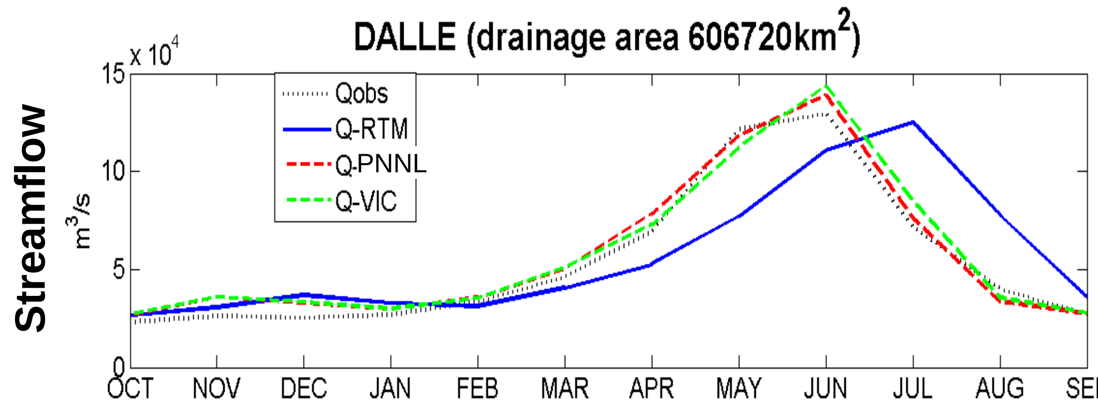
- Explicitly estimate channel water depth and velocity, allowing easy coupling between hydrological and biogeochemical processes within the earth system modeling framework

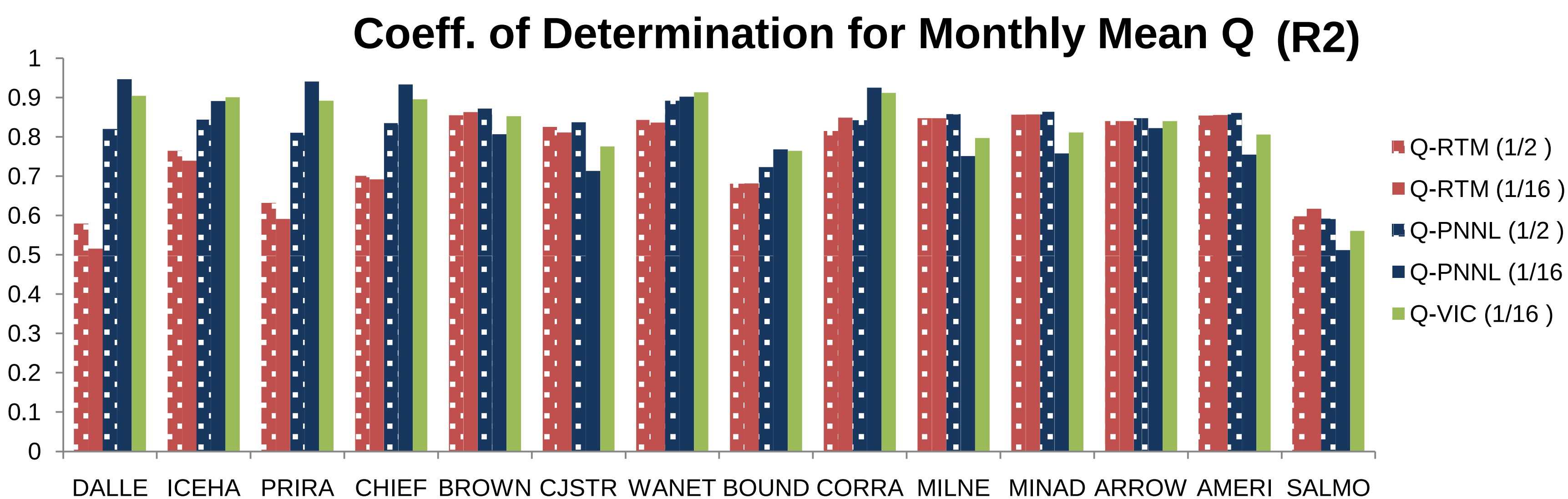
Offline testing of grid-based routing

- Daily runoff simulated by VIC at 1/16º resolution (UW) is used as inputs to the river routing models
- RTM and PNNL routing models are applied at 1/2º and 1/16º resolutions at daily time step for 01/01/1979 - 12/31/1989, and results are analyzed for 10/01/1979 - 09/30/1989 (10 water years)
- RTM does not require calibration
- PNNL routing model is not calibrated - the only parameters, Manning's roughness for the hillslope and channel, are set as 0.4 and 0.05 for the time being
- Simulations are compared against naturalized monthly streamflow and UW VIC routed streamflow at multiple stations on the main channels

Case study: Columbia River Basin

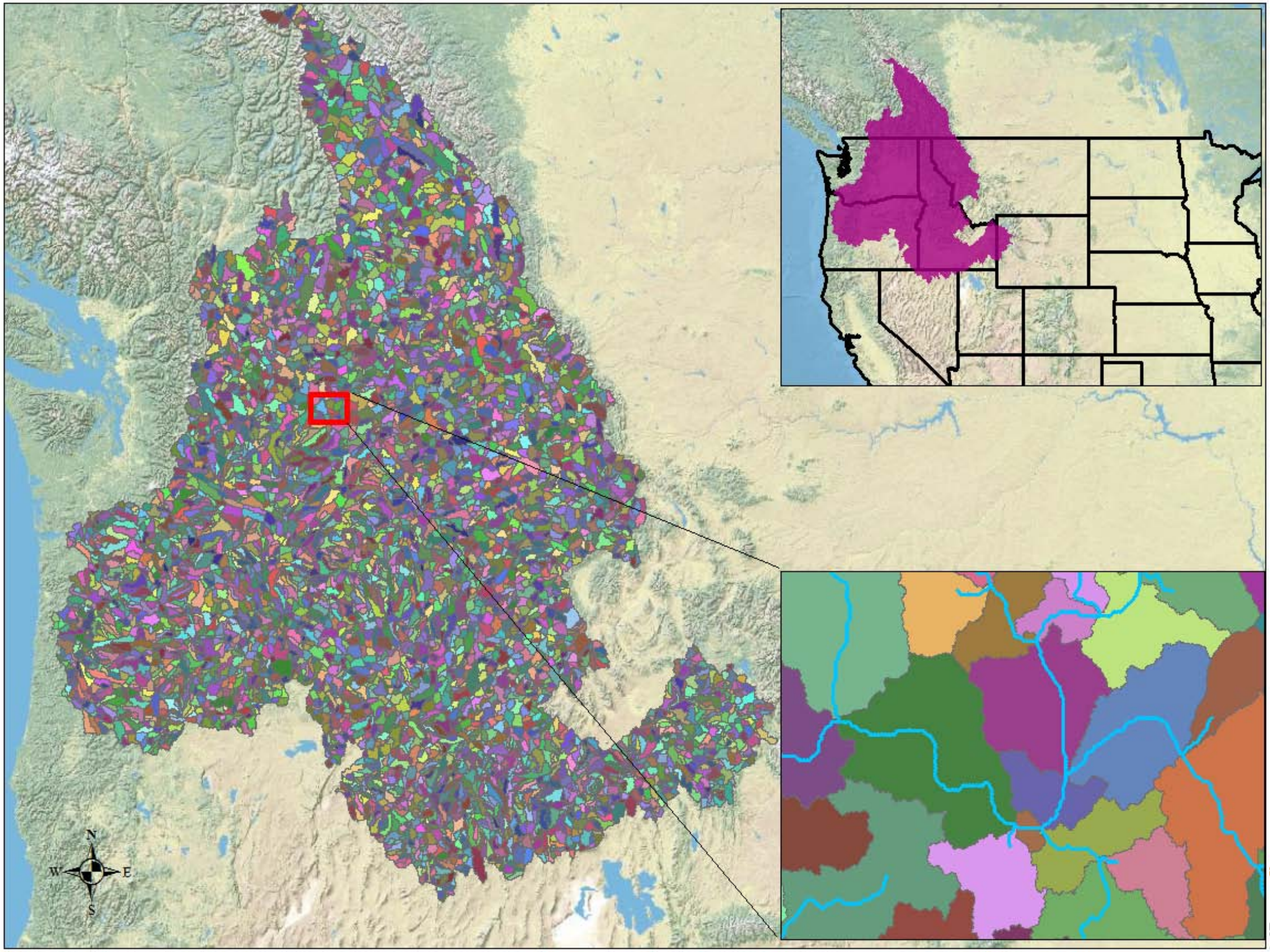






Large drainage area ⟷ Small drainage area

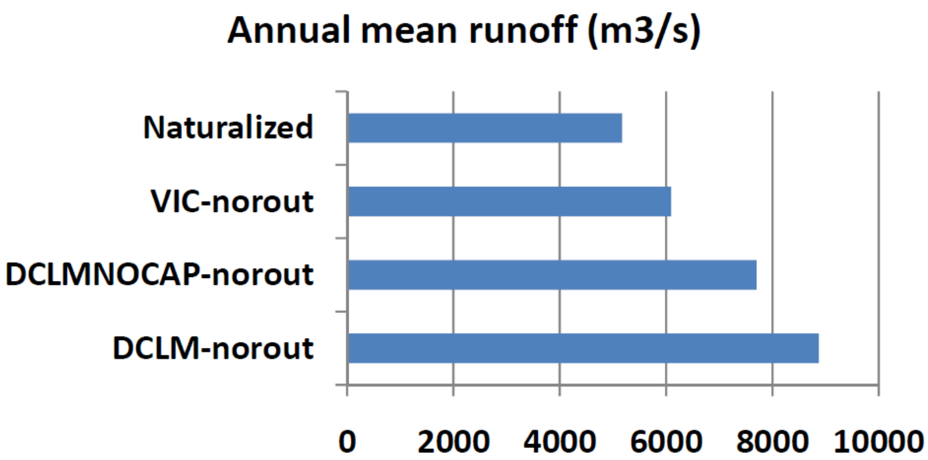
Testing of a subbasin approach: Columbia River



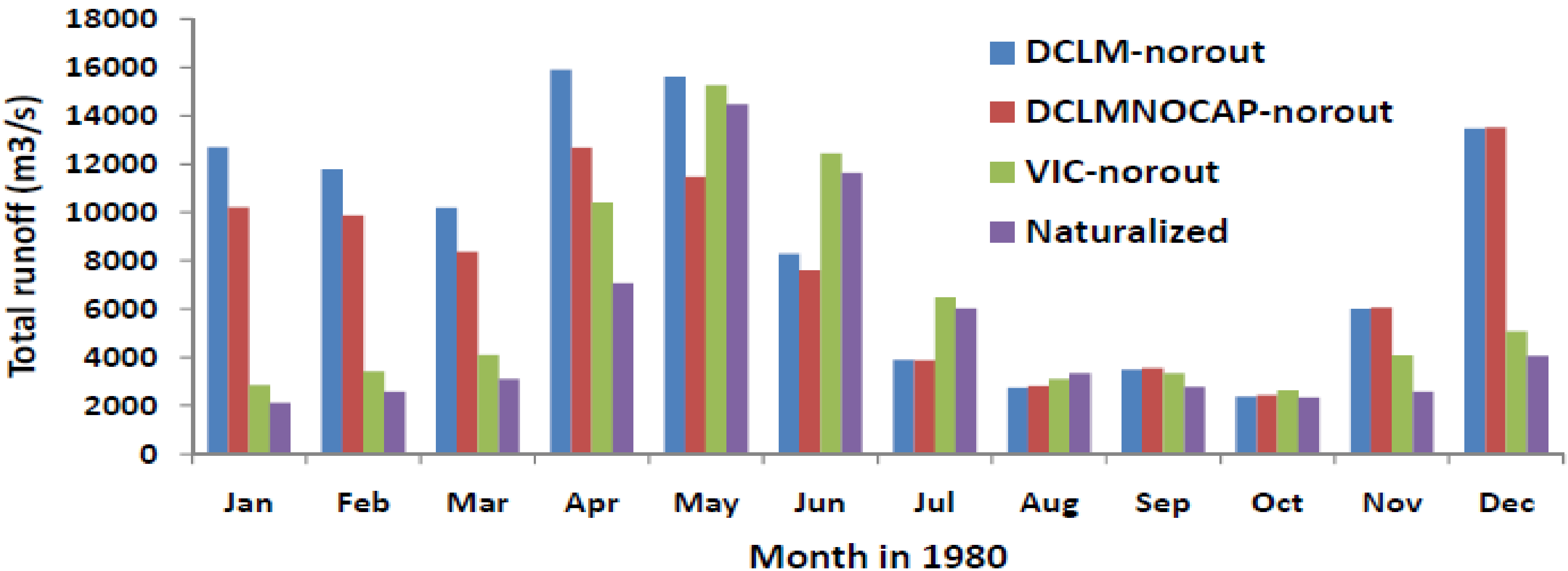
Model setup over the Columbia River Basin

- Watershed boundaries and river network:
  - HydroSHED global 90m DEM and 15 arcsec river networks
  - ArcSWAT for Watershed delineation and river network generation
  - 5999 subbasins with an average size of ~100 km (~1/8º resolution)
  - Within each watershed, main channel was generated with channel length, width, slope, upstream and downstream information
  - Hydrologic parameters, such as F_{max}, were estimated based on HydroSHED
- Meteorological Forcing: Hourly NLDAS-2 1/8º data regridded to the subbasins using area-weighting
- MODIS PFT (500m) and land surface parameters (1km)
- Soil: 10-min soil texture (IGBP) and 0.5º soil color
- The watersheds were organized as a pseudo-grid:
  - **DCLM4**: standard configuration, snow capped at 1000 mm, no routing
  - **DCLM4NOCAP**: snow capped at 4000 mm, no routing
  - Validation datasets: **VIC** simulation from UW without routing and monthly naturalized streamflow at Dalles

Accumulated runoff at Dalles (outlet)

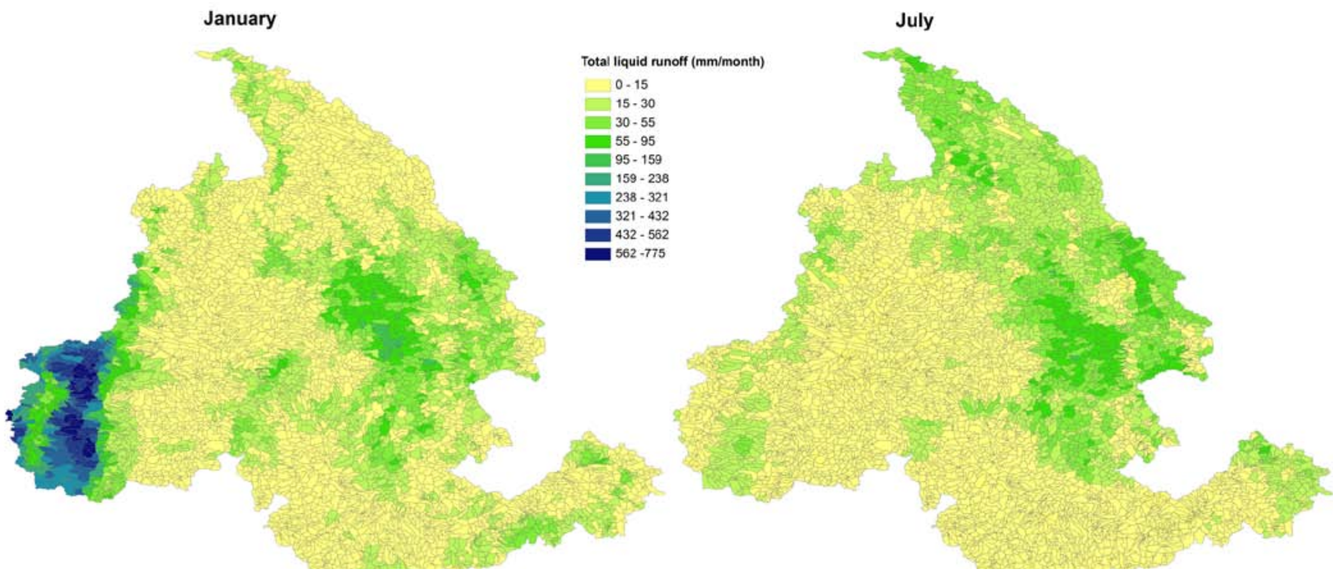


- CLM overestimated total runoff during winter and spring
- The problem is slightly alleviated by increasing snow capping threshold

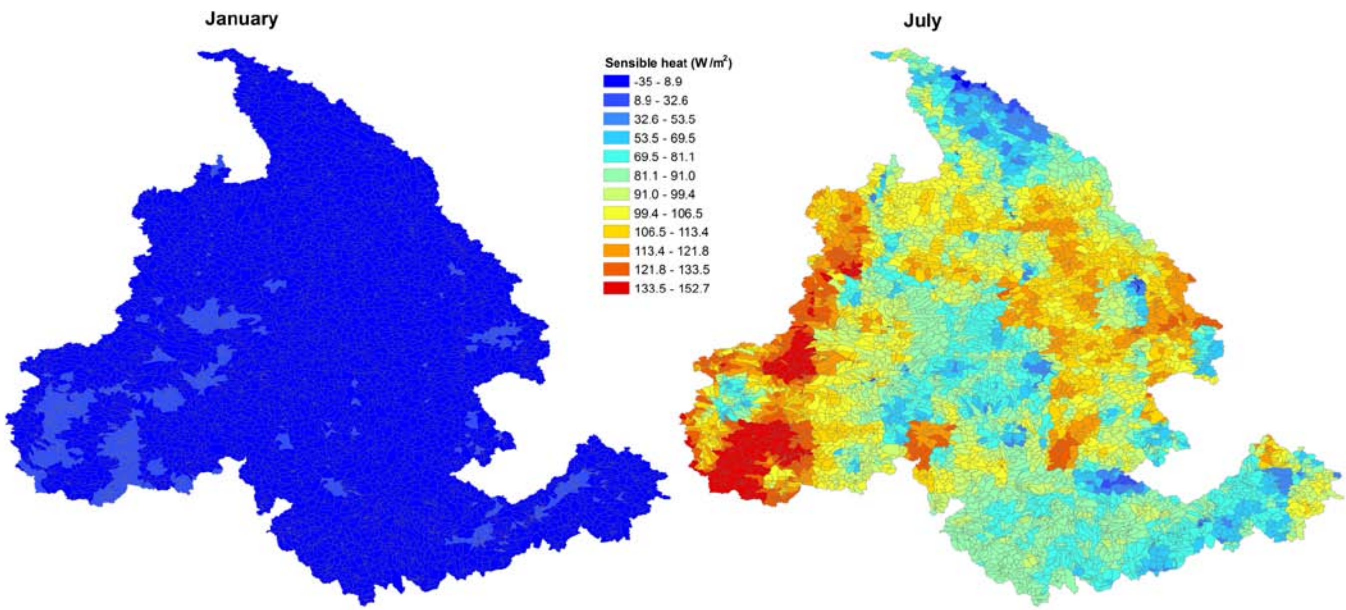


Simulated runoff and sensible heat flux

Runoff



Sensible heat flux



Ongoing and Future work

- Further testing of VICGROUND in CLM over flux towers and river basins, and in coupled simulations
- Further testing of the grid based routing at finer spatial-temporal scales
  - Comparison with observed daily/hourly streamflow at natural basins
  - Comparison with results from a hydraulic routing model
- Test the subbasin based routing in Columbia River basin
- Implement and test online river routing
- Couple routing module with water management module
- Global testing of all new components