Development of River Routing and Groundwater Models in CLM

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CESM Land Model Working Group Session

21 June 2011, Breckenridge, CO
Introducing VIC soil hydrology to CLM

Cell Energy and Moisture Fluxes

Surface- and groundwater interactions

Canopy Layer 0
Layer 1
Layer 2

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

Saturation excess runoff

Infiltration excess runoff

ARNO baseflow curve

Grid Cell Vegetation Coverage

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VICGROUND: A Dynamic representation of surface and groundwater interactions

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

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

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: $D_{\text{smax}} = 2 \text{ mm/day}$
  - ARNO baseflow curve shape parameters:
    $$D_s = 0.05, \ W_s = 0.5$$
Simulated water budget at Tonzi Ranch

Rain

Surface runoff

Baseflow

Evapotranspiration

Soil moisture content, VIC Layer 1

Soil moisture content, VIC Layer 2
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

\[
\frac{dS}{dt} = \sum Q_{in} - Q_{out} + R
\]

\[
Q_{out} = \frac{v}{d} S
\]
**Improved grid based routing scheme**

- 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

Wu et al. (2011)
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 1/16° resolution (UW) is used as inputs to the river routing models.

- RTM and PNNL routing models are applied at 1/2° and 1/16° 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

Coef. of Determination for Monthly Mean Q (R2)

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 (~1/8° 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 1/8° data regridded to the subbasins using area-weighting

- **MODIS PFT (500m) and land surface parameters (1km)**

- **Soil:** 10-min soil texture (IGBP) and 0.5° 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