A Physically Based Runoff Routing Model for Land Surface and Earth System Models

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Motivation: Why runoff routing is important?

- Linkage between land surface and ocean (to complete global water cycle);

- Linkage between human and nature (surface water withdrawal, reservoir operation, etc.);

- Linkage between water and other fluxes (Carbon, sediment, nutrients etc.).

Objectives: What kind of model do we need?

- Consistent process representation across various scales (global, regional, local);

- Easy to be coupled with water management module;

- Easy to be coupled with other fluxes.
River Transport Model (RTM) in CLM 4.0

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

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

\[
Q_{out} = \frac{v}{d} S
\]

S – storage with a cell
Q – flow entering/leaving the cell
R – runoff generation within the cell
v -- velocity of channel flow, 0.35 m/s globally
d -- distance between cell centers
Limitations of RTM

- Over-simplification of river networks;
- Over-simplification of physical processes.
  - Global constant channel velocity
  - No account for sub-grid heterogeneity

Improvement could be achieved by

- Better representation of spatial structure;
- Better representation of physical processes.
Improving the representation of spatial structure

Preserving the baseline high resolution hydrography (flow direction, flow length, upstream drainage area) at any coarse resolution

Hierarchical dominant river tracing (Wu et al., 2011)

Preserving the natural boundaries of runoff accumulation and river system organization

Subbasin-based representation
Improving the representation of physical processes

- Hillslope routing to account for event dynamics and 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 status (velocity, water depth etc.).
Model for Scale Adaptive River Transport (MOSART)

Scale adaptive within-grid routing
(scalable sub-network channel)

Scale adaptive between-grid routing
(scale independent main channel network)

Kinematic wave method
Muskingum-Cunge method
Diffusion wave method

(Li et al., JHM, in review)
Case Study: Columbia River Basin
Inputs and Parameters

- Daily runoff generation from Variable Infiltration Capacity model (VIC) at 1/16 degree resolution (UW hydrology group)

- Spatial delineation and network based on HydroSHEDS
  - DRT algorithm for grid-based representation 1/16, 1/8, ¼ and ½ degree resolutions
  - ArcSWAT package for subbasin-based representation (average size ~109km²)

- Manning’s roughness for hillslope routing set to 0.4, for channel routing set to 0.05

- Evaluation against monthly naturalized streamflow data at selected major stations
Improved streamflow simulations

NS coeff. for monthly mean streamflow – grid based representation

![Bar chart showing NS coefficients for monthly mean streamflow with grid-based representation for different basins.](chart1)

NS coeff. for monthly mean streamflow -- subbasin based representation

![Bar chart showing NS coefficients for monthly mean streamflow with subbasin-based representation for different basins.](chart2)

Large drainage area  Small drainage area
Improved timing at major gauge stations

Dalles Station (drainage area 606720 km²)

Chief Joseph Station (drainage area 193024 km²)

Waneta Station (drainage area 66048 km²)

Corra Linn Station (drainage area 45312 km²)

Timing simulated by RTM is off
Realistic channel velocity estimation — comparison with observation

The “observed” channel velocity has been reduced by dam operation etc.

But still, mostly higher than 0.35m/s
Realistic channel velocity estimation — Comparison with a hydraulic model
Summary and future work

- We have developed a new routing module, MOSART, for both grid- and subbasin-based representations;

- The performance of MOSART is consistently superior to RTM at various resolutions, and comparable with VIC routing model when tested over the Columbia River Basin;

- MOSART provides realistic estimation of channel velocities, which was assumed to be constant in RTM and VIC;

- Incorporating MOSART into the CESM framework and its global test;

- Developing a water management module coupled with MOSART;

- Evaluating MOSART at finer temporal resolutions.
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