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

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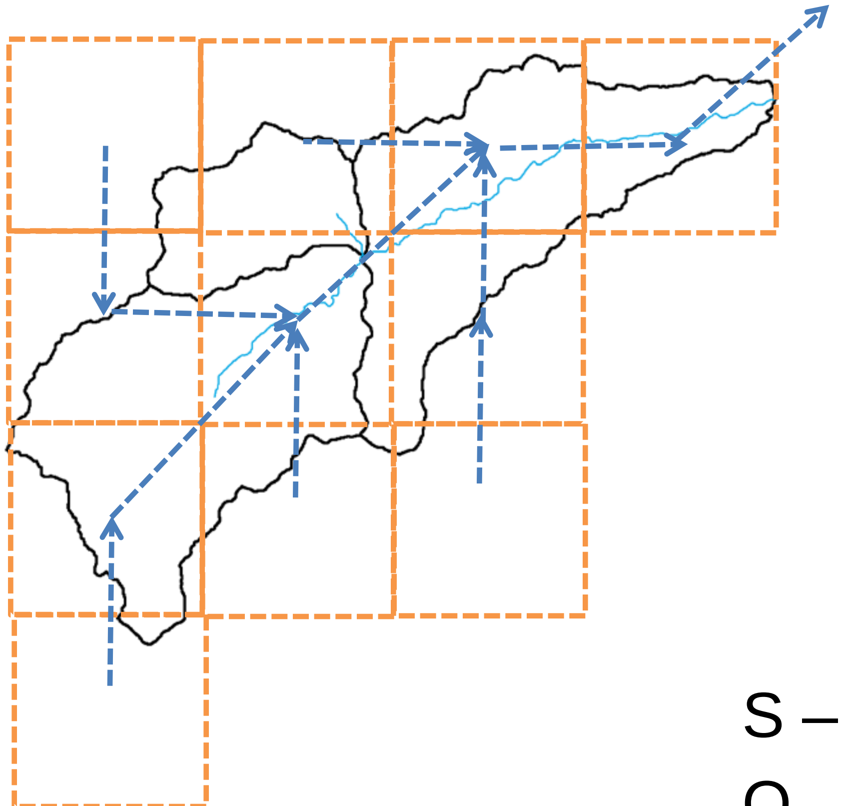
Motivation: Why runoff routing is important?

- 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

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

S – storage with a cell

Q – flow entering/leaving the cell

R – runoff generation within the cell

v -- velocity of channel flow, **0.35m/s globally**

d -- distance between cell centers

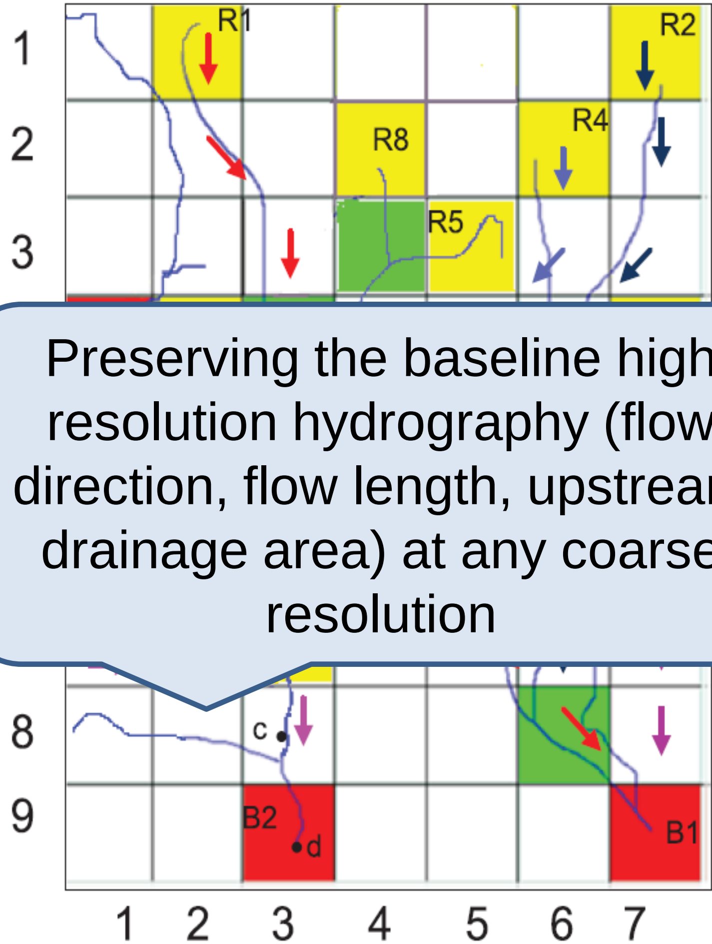
Limitations of RTM

- 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

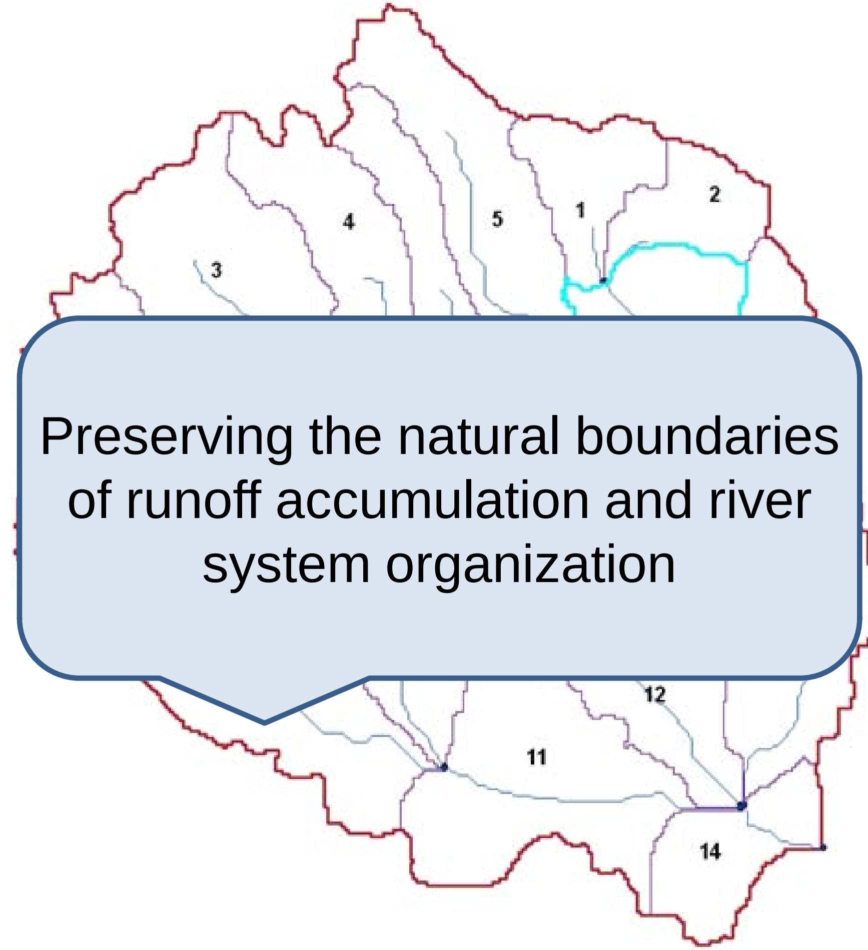
- Better representation of spatial structure;
- Better representation of physical processes.

Improving the representation of spatial structure



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

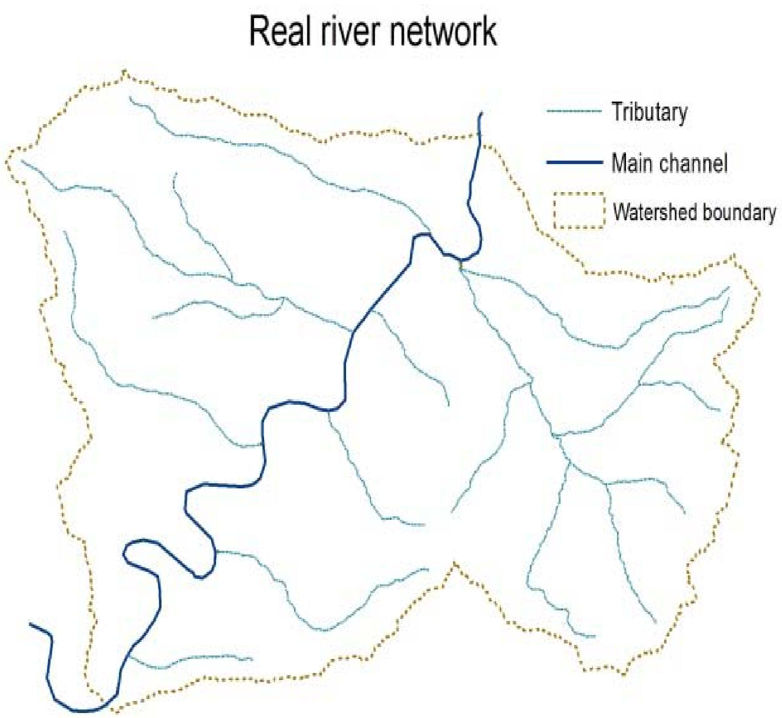
Hierarchical dominant river tracing (Wu et al., 2011)

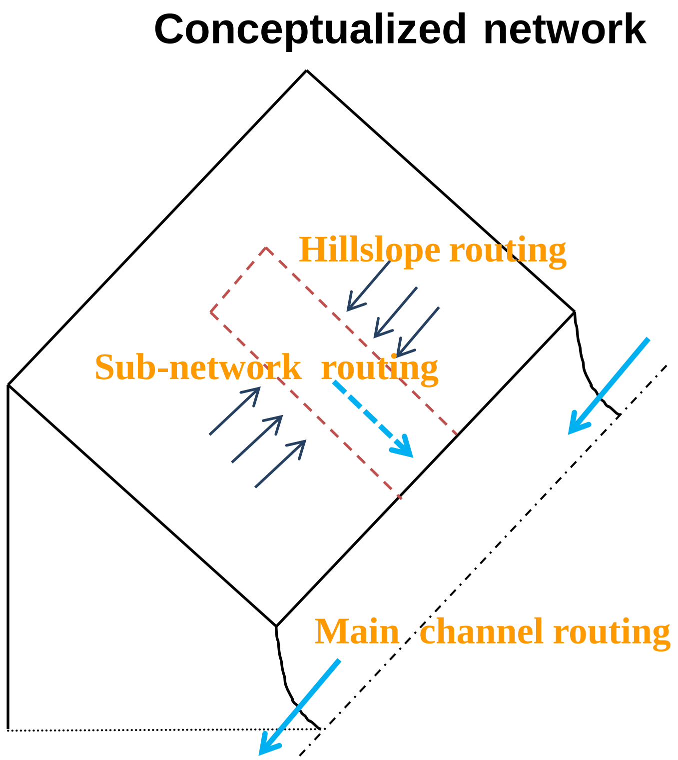


Preserving the natural boundaries of runoff accumulation and river system organization

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)

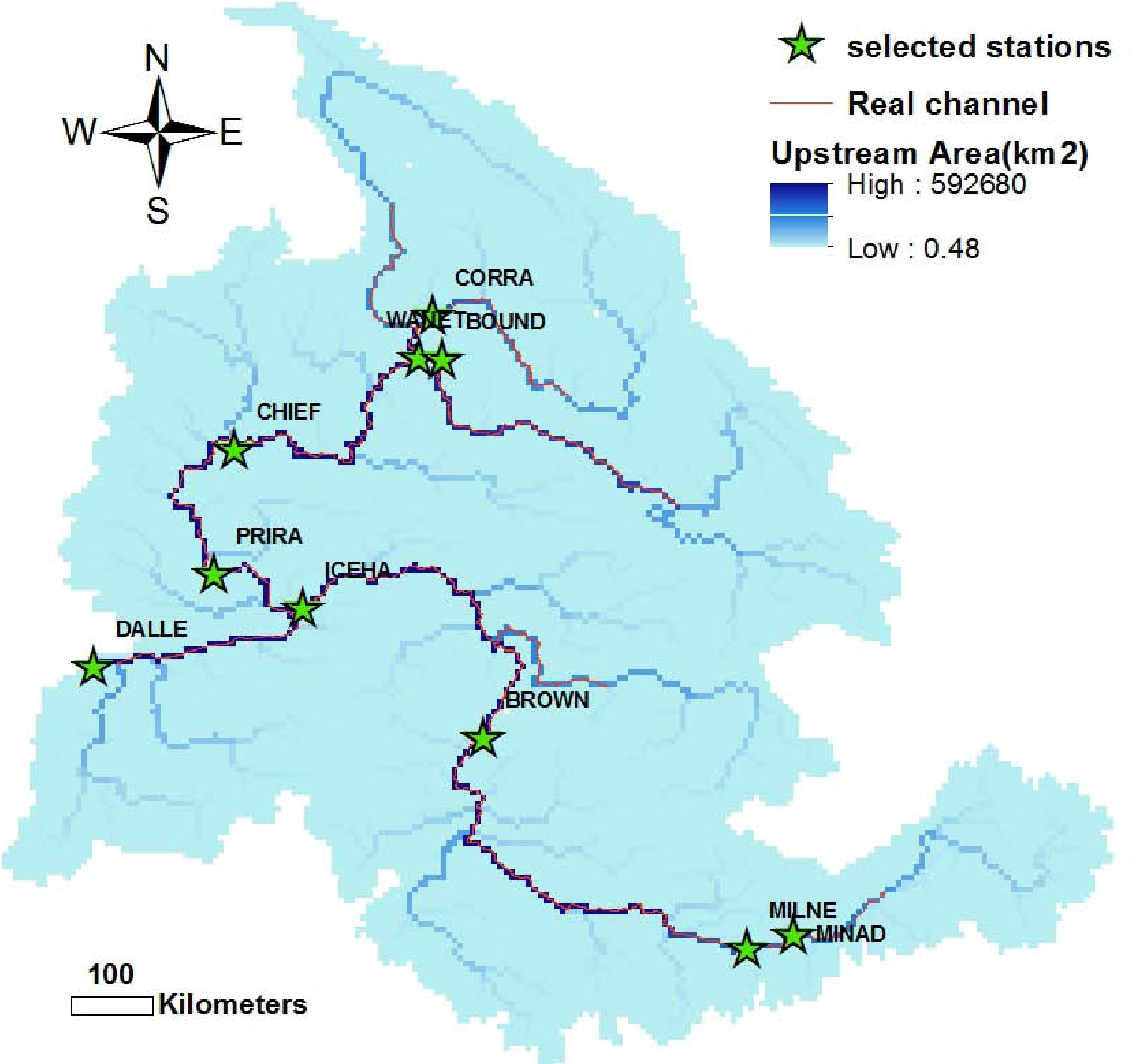
Scale adaptive between-grid routing
(scale independent main channel network)

Kinematic wave method

Kinematic wave method
Muskingum-Cunge method
Diffusion wave method

(Li et al., JHM, in review)

Case Study: Columbia River Basin



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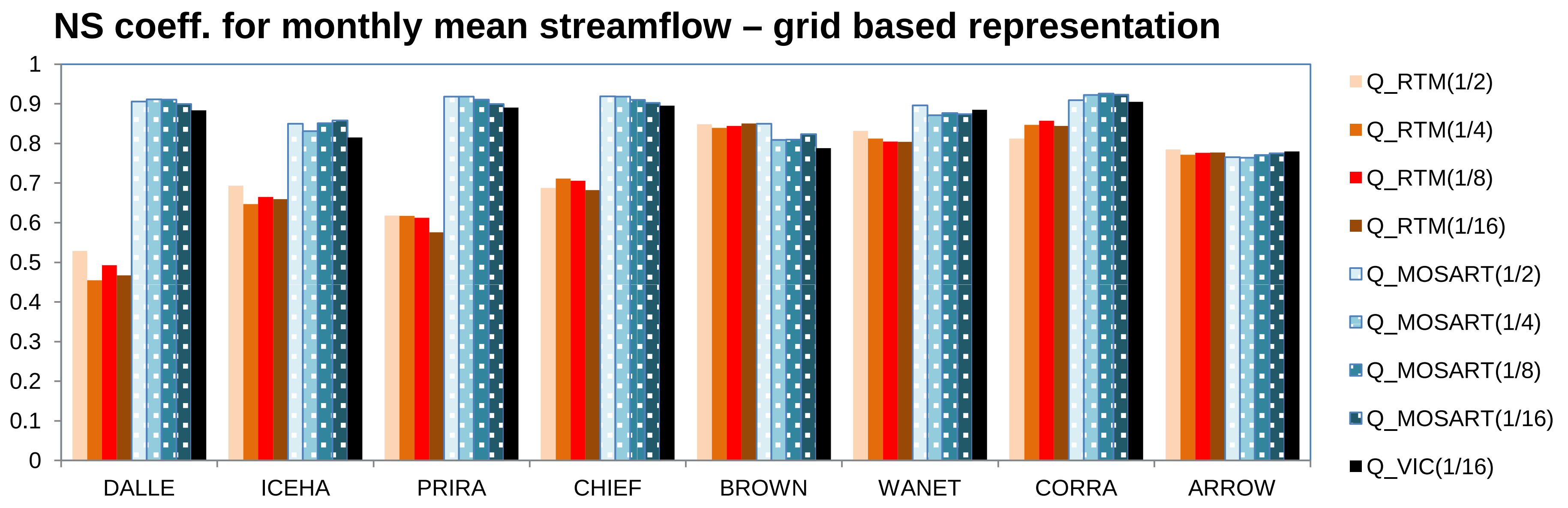
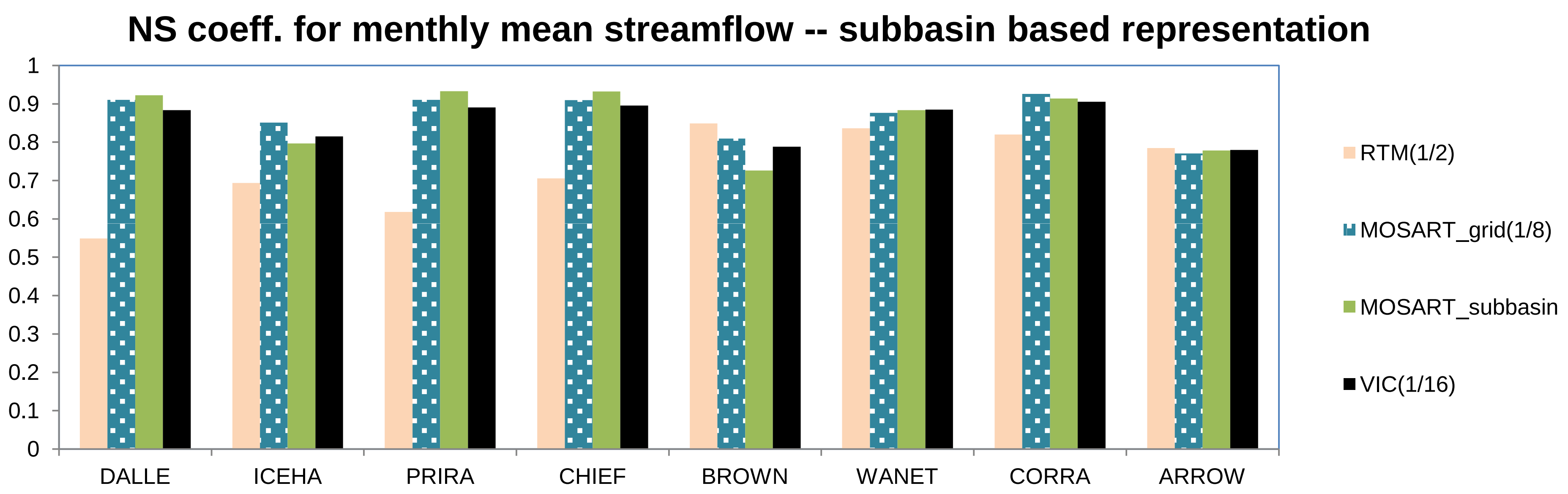
Inputs and Parameters

- 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 ~109km^2)
- 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

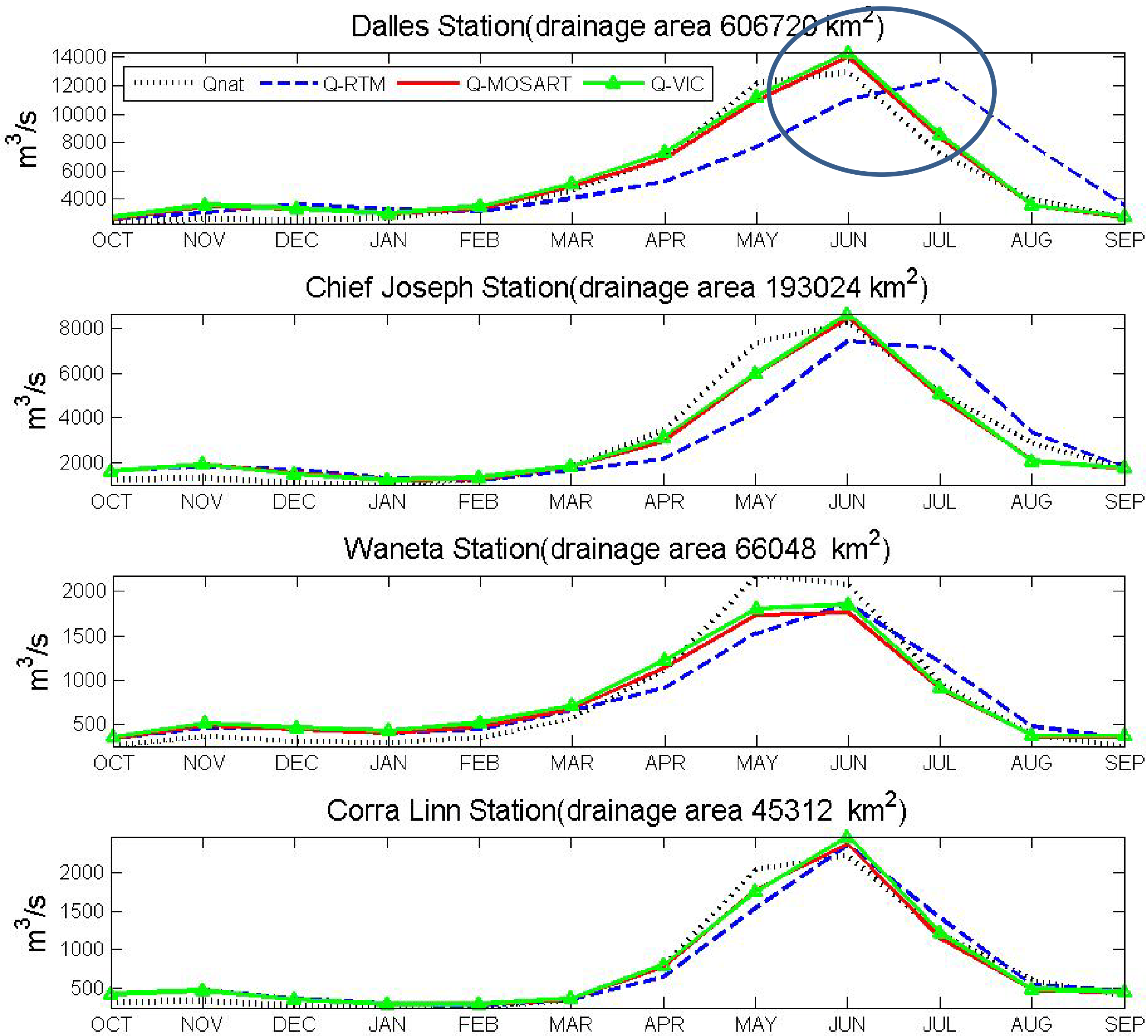
Improved streamflow simulations





Large drainage area ↔ Small drainage area

Improved timing at major gauge stations



Timing simulated by RTM is off

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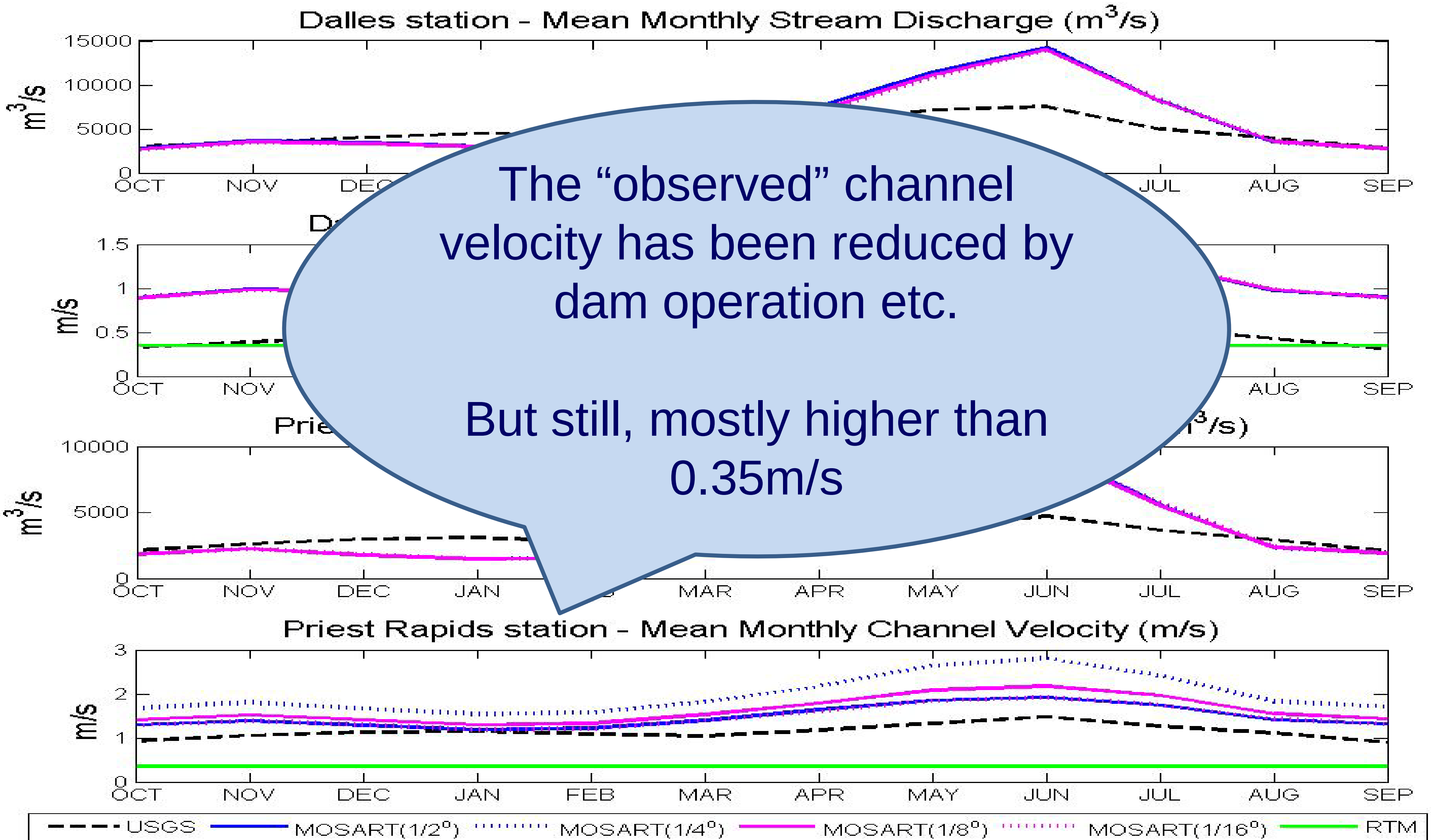
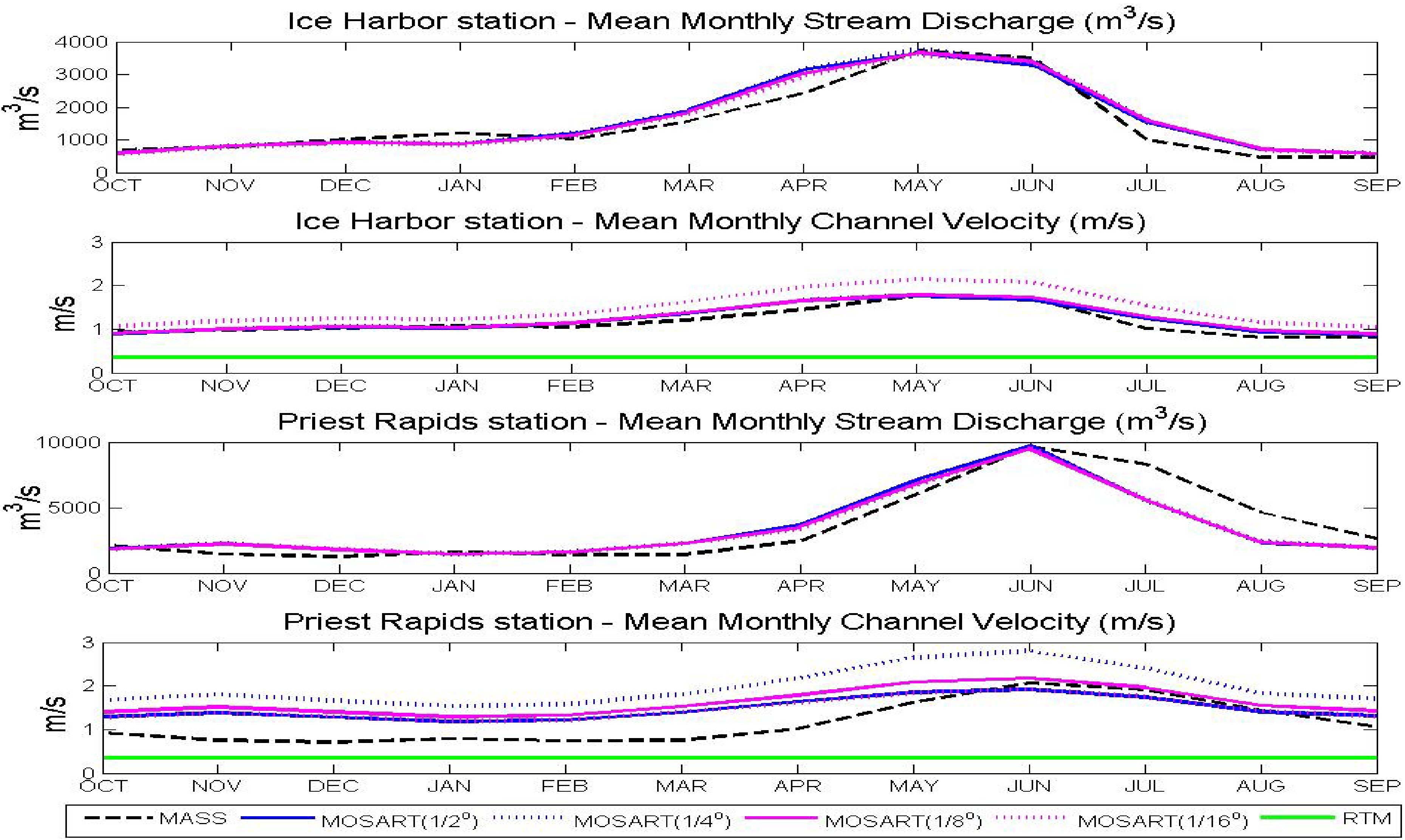
Realistic channel velocity estimation — comparison with observation



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.

Acknowledgement

- **DOE:** Strengthening the Coupling between Climate and Earth System Models (ESMs) and Integrated Assessment Models (IAMs)

- **DOE:** Climate Science for Sustainable Energy Future (CSSEF)

- **PNNL:** Integrated regional earth system modeling (iRESM) Initiative