Improving the representation of river processes in E3SM

Tian Zhou
L. Ruby Leung
Guoyong Leng
Nathalie Voisin
Hong-Yi Li
Anthony Craig
Teklu Tesfa
Yuna Mao
Outline

• Brief review of the river model (MOSART) in E3SM and developments in phase 1

• Study 1: two-way coupled irrigation scheme to connect ELM and MOSART

• Study 2: global floodplain inundation analysis

• Ongoing developments and future opportunities
Brief review of the river model in E3SM

In E3SM phase 1, the original river model RTM (River Transport Model) has been replaced by MOSART (Model for Scale Adaptive River Transport)

Hong-Yi Li et al. (2013, 2015)

- Hillslope, subnetwork, and main channel
- More physically based algorithm
Two model developments built upon MOSART

A Water Management (WM) model was developed to represent the irrigation water withdrawal and dam regulations.

Voisin et al. (2013)

A floodplain inundation model was developed to represent flood extent based on river discharge and geomorphological features in Amazon basin.

Luo et al. (2017)
One-way coupled irrigation scheme

Irrigation demand based on soil moisture ($D$)

Groundwater demand ($D_{\text{grnd}}$)

Surface water demand ($D_{\text{surf}}$)

Apply irrigation ($S_{\text{surf}} + S_{\text{grnd}}$)

$S_{\text{grnd}} = D_{\text{grnd}}$

$D \times F_{\text{grnd}}$

$D \times F_{\text{surf}}$

Surface water supply ($S_{\text{surf}}$)

Available surface water

Local runoff

Streamflow

Reservoir storage

Surface water demand ($D_{\text{surf}}$)

$S_{\text{surf}} \leq D_{\text{surf}}$

Leng, et al. (2015)
Two-way coupled irrigation scheme

Irrigation demand based on soil moisture ($D$)

Groundwater demand ($D_{grnd}$)

Surface water demand ($D_{surf}$)

Surface water supply ($S_{surf}$)

Apply irrigation ($S_{surf} + S_{grnd}$)

$D \times F_{grnd}$

$S_{grnd} = D_{grnd}$

$D \times F_{surf}$

Surface water supply ($S_{surf}$)

Available surface water

Local runoff

Streamflow

Reservoir storage

Surface water demand ($D_{surf}$)

$S_{surf} \leq D_{surf}$

Supply

Demand

Runoff

Runoff

Supply
Objectives of the study

• Implement a two-way coupled irrigation scheme and evaluate simulations for a historical 30-year period;
• Investigate the impacts of the two-way coupling scheme on representing hydrological processes and irrigation processes in contrast with the original commonly used one-way coupling scheme.

To be submitted to JAMES
<table>
<thead>
<tr>
<th>ID</th>
<th>Configuration</th>
<th>Water management</th>
<th>Fully coupled</th>
<th>Irrigation demand</th>
<th>Irrigation source</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAT</td>
<td>no-management</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1SO</td>
<td>1-way-surf-only</td>
<td>Yes</td>
<td>No</td>
<td>always met</td>
<td>surface water</td>
</tr>
<tr>
<td>1SG</td>
<td>1-way-surf-grnd</td>
<td>Yes</td>
<td>No</td>
<td>always met</td>
<td>surface water and groundwater</td>
</tr>
<tr>
<td>2SO</td>
<td>2-way-surf-only</td>
<td>Yes</td>
<td>Yes</td>
<td>partially met</td>
<td>surface water</td>
</tr>
<tr>
<td>2SG</td>
<td>2-way-surf-grnd</td>
<td>Yes</td>
<td>Yes</td>
<td>partially met</td>
<td>surface water and groundwater</td>
</tr>
<tr>
<td>2SGM</td>
<td>2-way-surf-grnd-met</td>
<td>Yes</td>
<td>Yes</td>
<td>always met</td>
<td>surface water and groundwater</td>
</tr>
</tbody>
</table>

Experimental configurations
Pink dots are reservoirs represented in the simulation
E3SM simulated annual irrigation withdrawal compared with Huang et al. (2010) across global administration units from 1981 to 1985.
withdrawal is less in 2SG (constrained surface water and fixed groundwater pumping) but more in 2SGM (unlimited pumping), compared to 1SG

evapotranspiration is less in 2SG compared to 1SG

return flow is less in 2SG and 2SGM compared to 1SG
Simulated global averaged water budget terms

- Water table depletion rate is about 2mm/yr in 2SG and 2SGM, closer to GRACE estimate 2.6mm/yr
The two-way coupled scheme is able to capture the seasonal dynamics of irrigation water allocations.
Take Mississippi as an example, the USGS reported statistics show 44% from surface water, 56% from groundwater, close to 2SG estimate (47% and 53%)
Findings

• Compared to the one-way scheme, the two-way coupling scheme with surface water constraints results in less surface water withdrawal and less return flow.

• The two-way coupled scheme better captured the groundwater depletion rate.

• The two-way coupled scheme is able to capture the seasonal dynamics of irrigation water allocations.
Uncertainties and limitations

- Representation of the irrigation application
- Water demand estimation
- Input climate data
- Fixed land use land cover data
On-going study: global flood inundation analysis

Study goals:
• Evaluate the inundation scheme in global river basins
• Understand flood generating mechanisms

Simulated basins classified by the level of human impacts

Elevation profile in a single gridcell
The flood inundation scheme is able to capture the spatial extent and the dynamics of flood inundation in global river basins.

Human impacts such as dam regulations would alter the flood inundation. Our next step is to develop a modeling scheme that couples ELM, MOSART-WM, and the inundation components.
Preliminary findings

Snow melt is the leading generating mechanisms compared to the other two

Generating mechanisms of the flood inundation are represented by RGB coded colors

Decadal correlation coefficient change between flood area and dominant generating factor
Ongoing development and testing

- Represent heat transport in MOSART and reservoir stratification to support BGC simulation (carbon, phosphorus)
  
  Li et al. (2015)

  Yigzaw et al. submitted to JAMES

- Represent the sediment transport in MOSART
  
  Tan et al. (2018)

  Li et al. to be submitted to JAMES

- Coupling WM and inundation components to represent dam regulations in terms of flood control
  
  Zhou et al. (ongoing development)
Future opportunities

- Study irrigation impacts on land-atmosphere interactions using the coupled E3SM
- Using Variably Saturated Flow Model (VSFM) to better represent soil water process in irrigation
- Coupling with GCAM to represent water demand from other sectors
- Using the same grid in ELM and MOSART (proposed topic in All-hands meeting)
- Sensitivity of the floodplain inundation to model parameters such as elevation profile, grid resolution, vegetation
Thank you