# A mesh-independent flow direction model for flow routing

Chang Liao[1], Donghui Xu[2], Tian Zhou[2], Darren Engwirda[2], Matthew G Cooper[2], Gautam Bisht[2], Zeli Tan[2], Hong-Yi Li[2], and L. Ruby Leung[2]

[1]Earth scientist
[2]Affiliation not available

March 9, 2023

Pacific Northwest
NATIONAL LABORATORY

PNNL@AGU
EXPLORE >> INTERPRET >> APPLY

# A mesh-independent flow direction model for flow routing

**Chang Liao**
Earth scientist

U.S. DEPARTMENT OF ENERGY BATTELLE

# Collaborators

Pacific Northwest NATIONAL LABORATORY

Chang Liao
Tian Zhou
Donghui Xu
Matt Cooper
Gautam Bisht
Zeli Tan
L Ruby Leung

Los Alamos NATIONAL LABORATORY

Darren Engwirda

UNIVERSITY of HOUSTON

Hongyi Li

Integrated Coastal Modeling (ICoM) is funded by multiple programs in the Earth and Environmental System Science Division of DOE's Office of Science

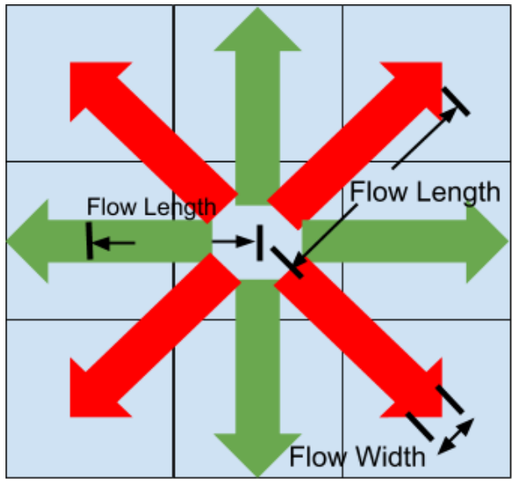
# Takeaway message

We developed a mesh-independent flow direction model to generate flow routing parameters for spatially-distributed hydrologic models at regional and global scales.

# Motivation: the classical D4/D8 approach

Most regional-scale surface hydrologic models:

- High-quality DEM-based
- Projected coordinate system, i.e., m/km




(Liao, et al. 2020 EMS)

All the global-scale hydrologic models (GHM):

- Upscaling
- Geographic coordinate system, i.e., degree

(Sood & Smakhtin. 2013 HSJ)

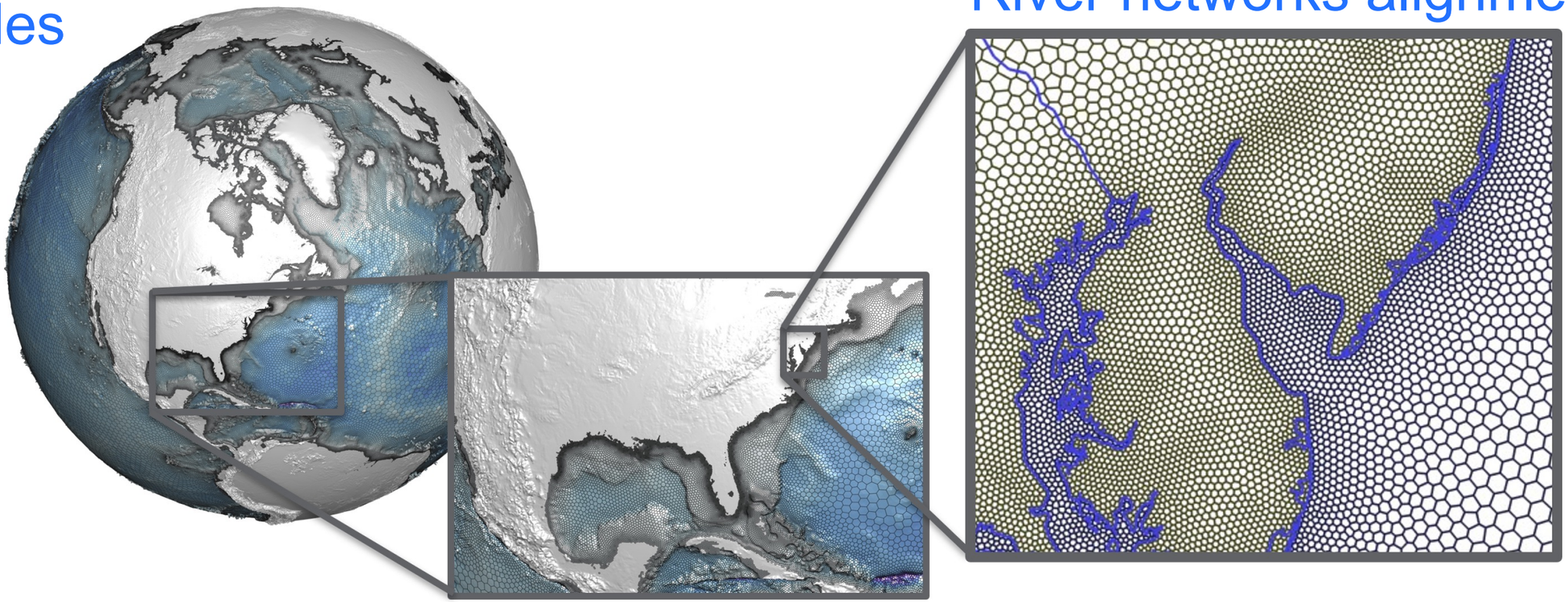
PNNL@AGU
EXPLORE » INTERPRET » APPLY

| No. | Model | Spatial resolution |
|---|---|---|
| 1 | HDTM 1.0 | 0.5° |
| 2 | Macro-PDM | 0.5° |
| 3 | MPI-HM | 0.5° |
| 4 | GWAVA | 0.5° / 0.1° |
| 5 | VIC | 2° |
| 6 | LaD | 1° |
| 7 | WaterGAP | 0.5° |
| 8 | PCR-GLOBWB | 0.5° |
| 9 | LPJmL | 0.5° |
| 10 | WASMOD-M | 0.5° |
| 11 | H08 (H07) | 1° / 0.5° |
| 12 | ISBA-TRIP | 1° |

# Motivation: unstructured mesh-based approach

Better representation of the high latitudes

River networks alignment



Balance between computational cost and spatial resolution

Seamless land-ocean coupling

(JIGSAW unified land-river-ocean Model for Prediction Across Scales (MPAS) mesh, Darren Engwirda)

# Method & Data

Mesh generation

- DEM
- HydroSheds

When using unstructured mesh, river networks and other hydrological features including dams can be burnt in the mesh.

River network representation

- HydroSheds

Topological relationship-based conceptual river networks

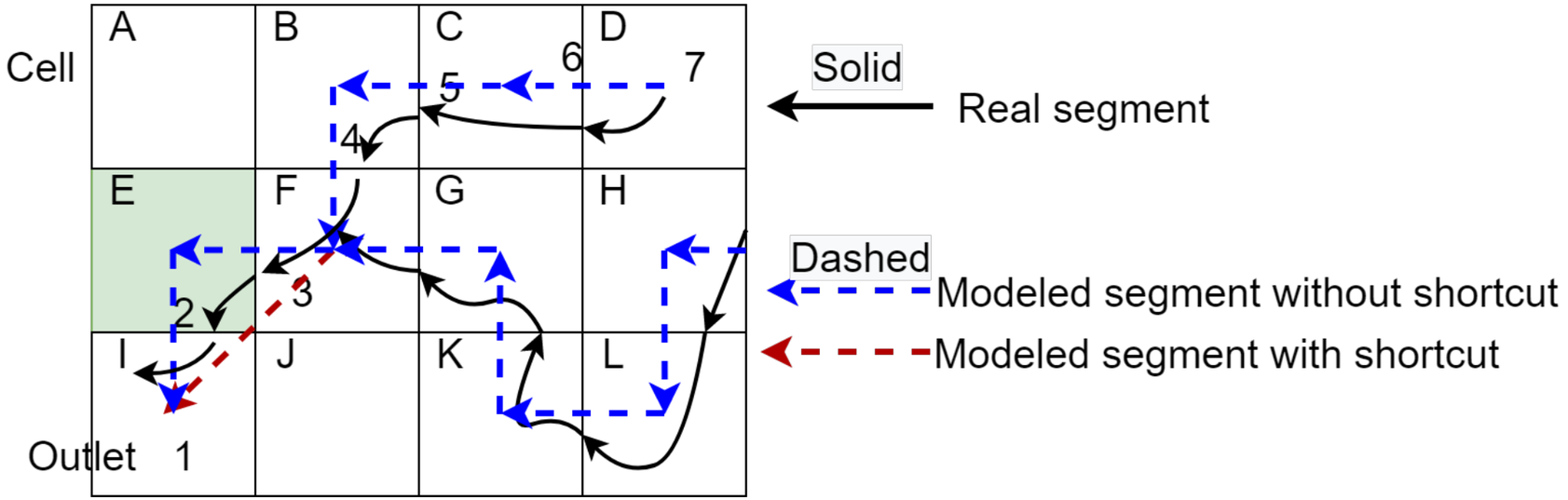
Flow direction modeling

- DEM
- HydroSheds

Stream burning, depression removal, et al.

# Topological relationship-based river network

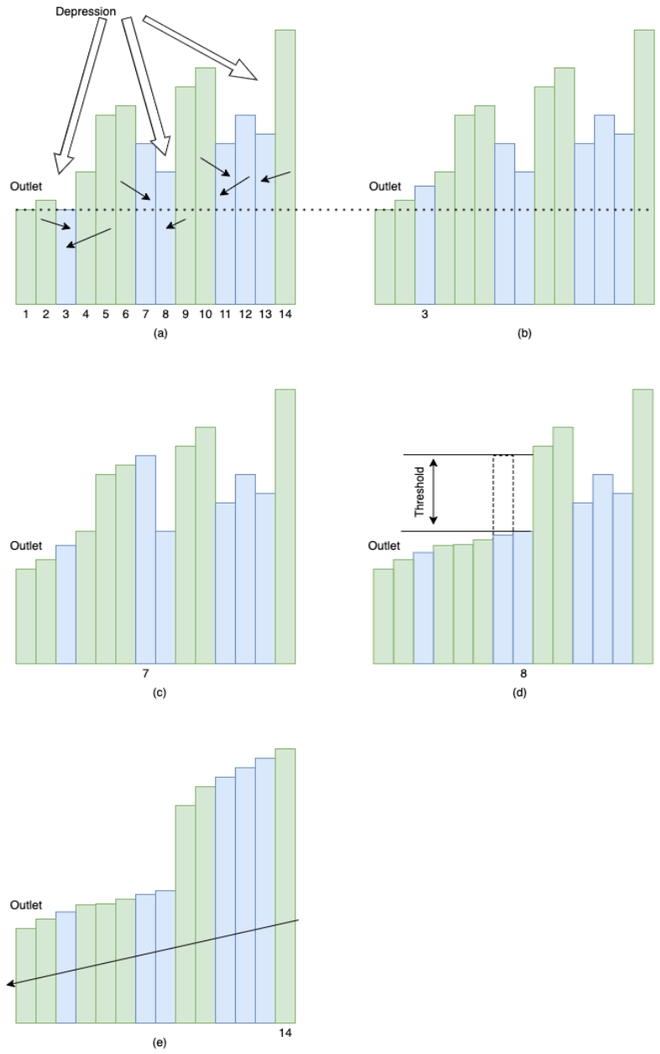
**Definition: topological relationships include both neighboring information and upstream/downstream information.**




Mesh and flowline intersections are used to track river network precisely.

(Liao, et al. 2022 JAMES)

# Topological relationship-based flow direction modeling: stream burning

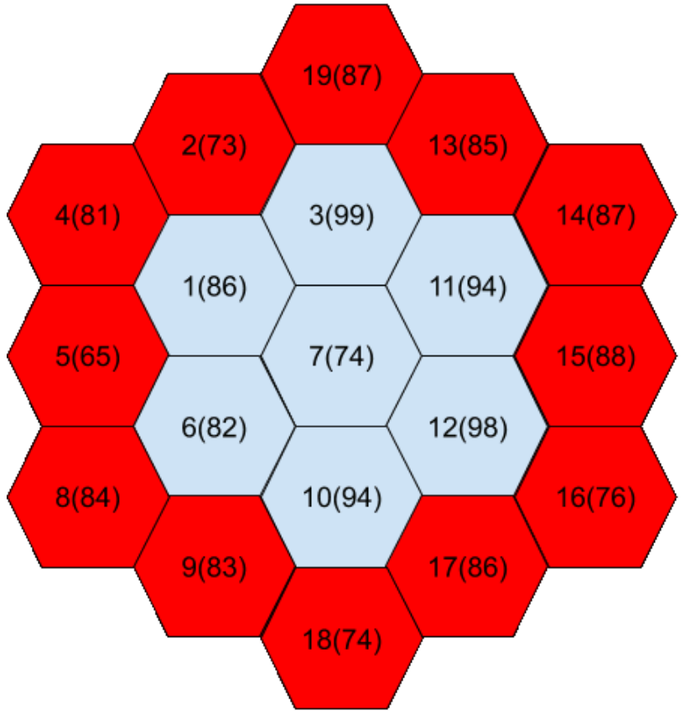



- River networks are precisely maintained through topological relationships.
- Topological relationship, i.e., **upstream-downstream,** allows the adaptive stream burning.

(Liao, et al. 2022 JAMES)

# Topological relationship-based flow direction modeling

- Based on an existing priority-flood depression-filling model, HexWatershed.
- Modified to consider river networks.




❖ Both stream burning and depression removal are mesh-independent.

(Liao, et al. 2020 EMS)

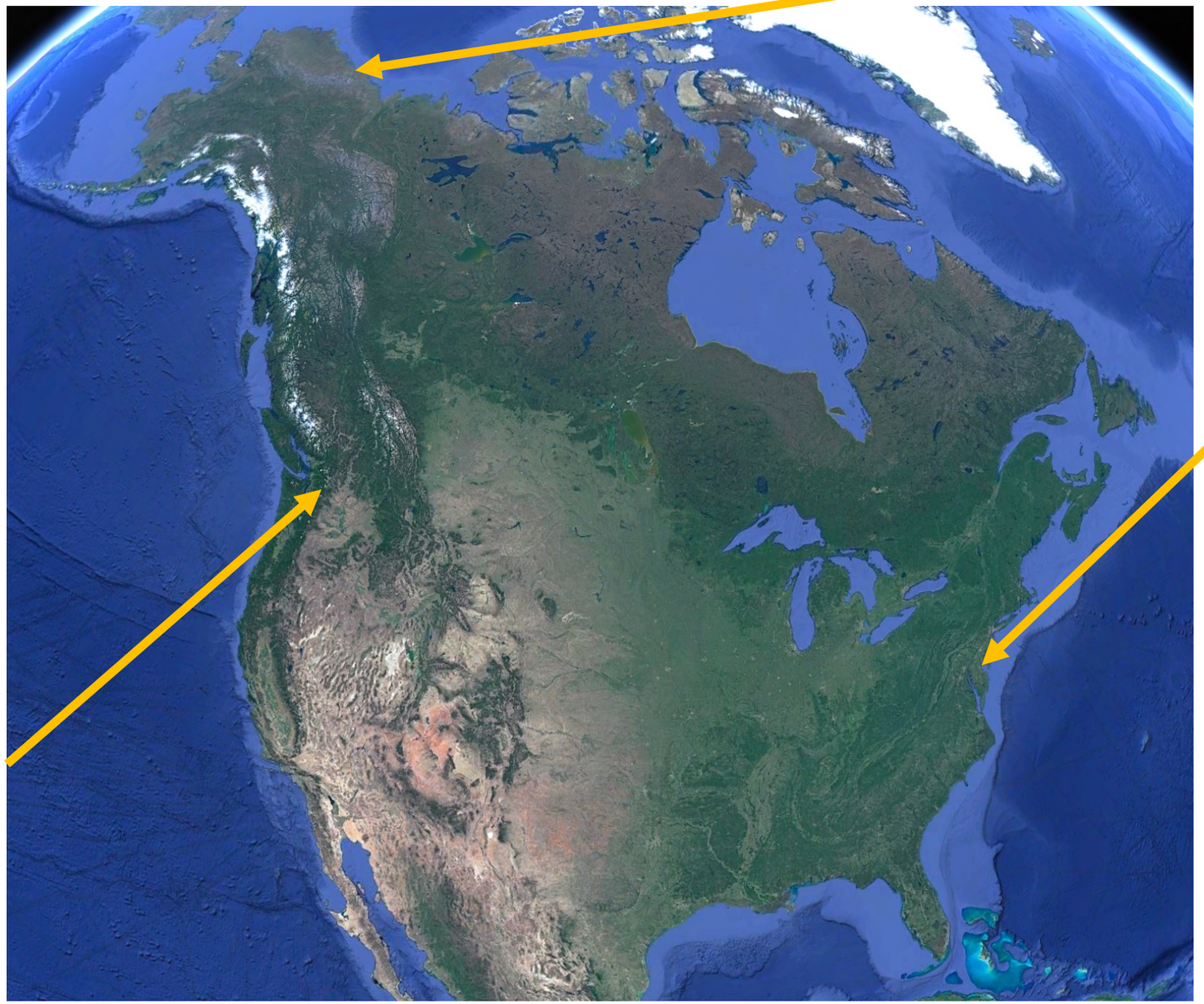
# Application

Structured:
- Lat-long
- Projected
- Hexagon

Unstructured:
- MPAS

Columbia
(6.7 x $10^5$ $km^2$)

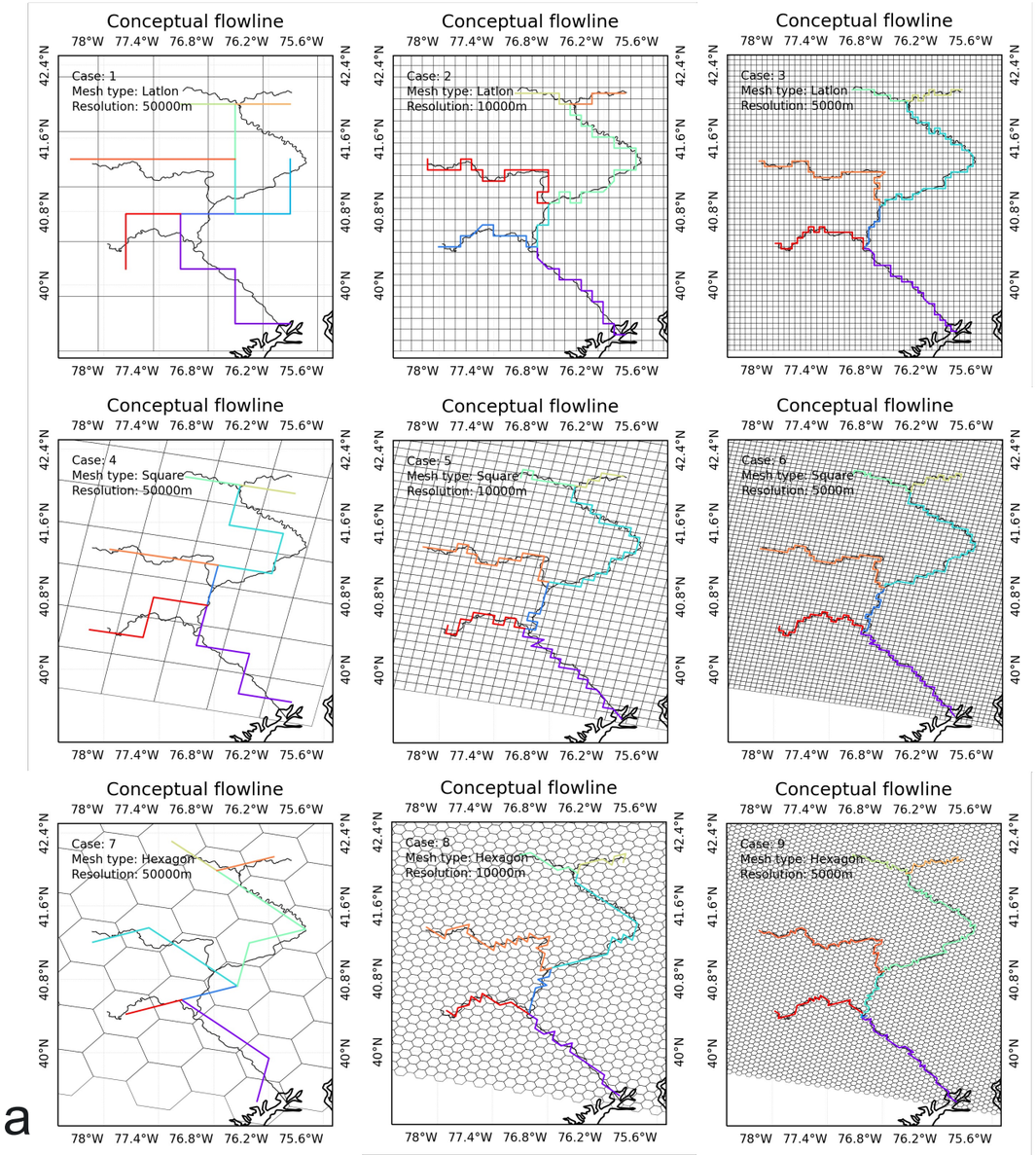
Sagavanirktok (1.5 x $10^4$ $km^2$)

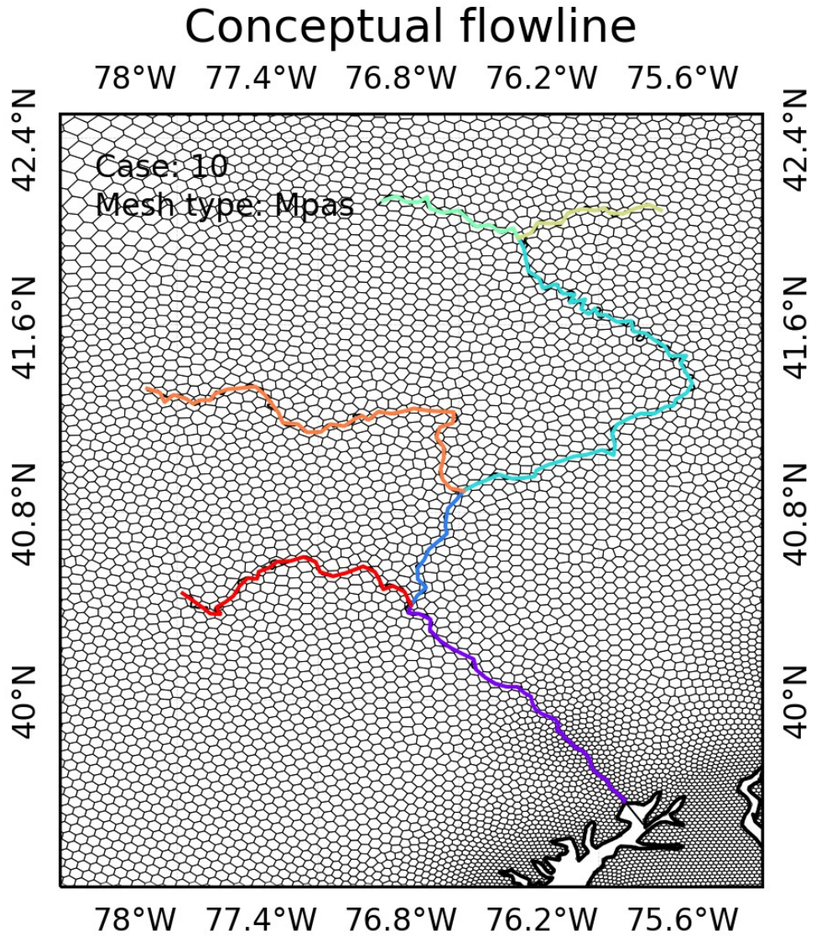


Susquehanna
(7 x $10^4$ $km^2$)

(Image: Google Earth)

# Results: conceptual river networks

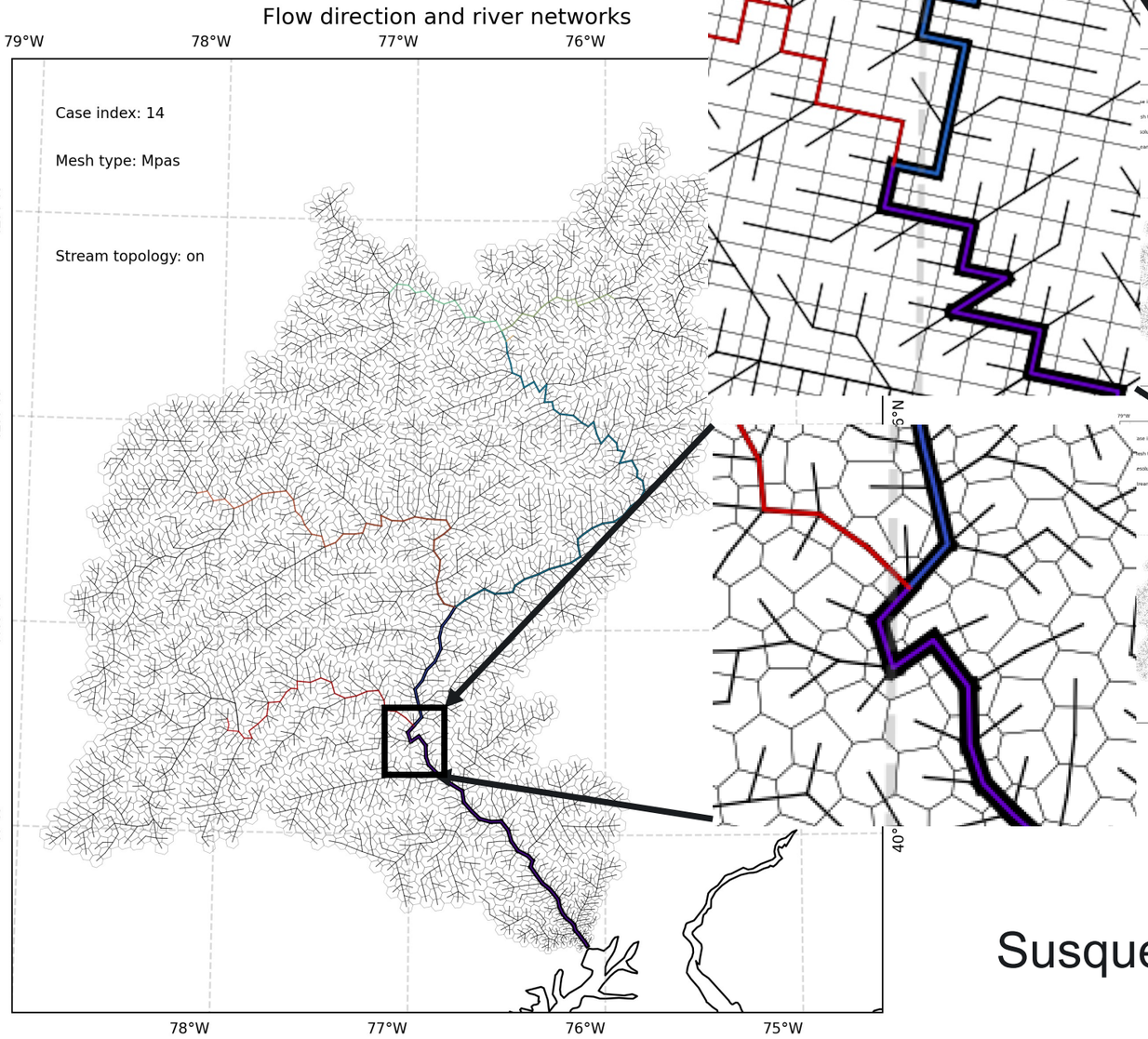



Susquehanna

(Liao, et al. 2022 JAMES)

# Flow direction



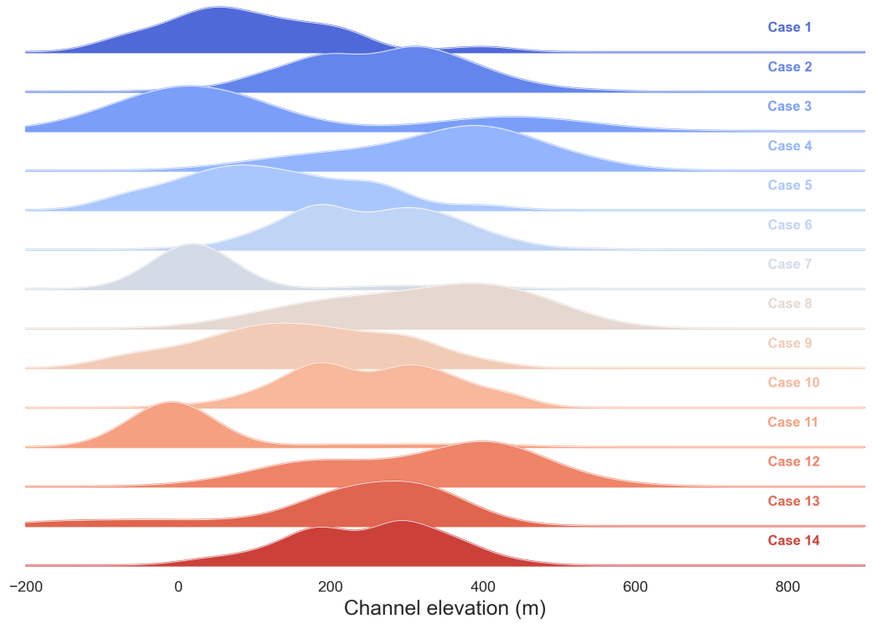



Susquehanna

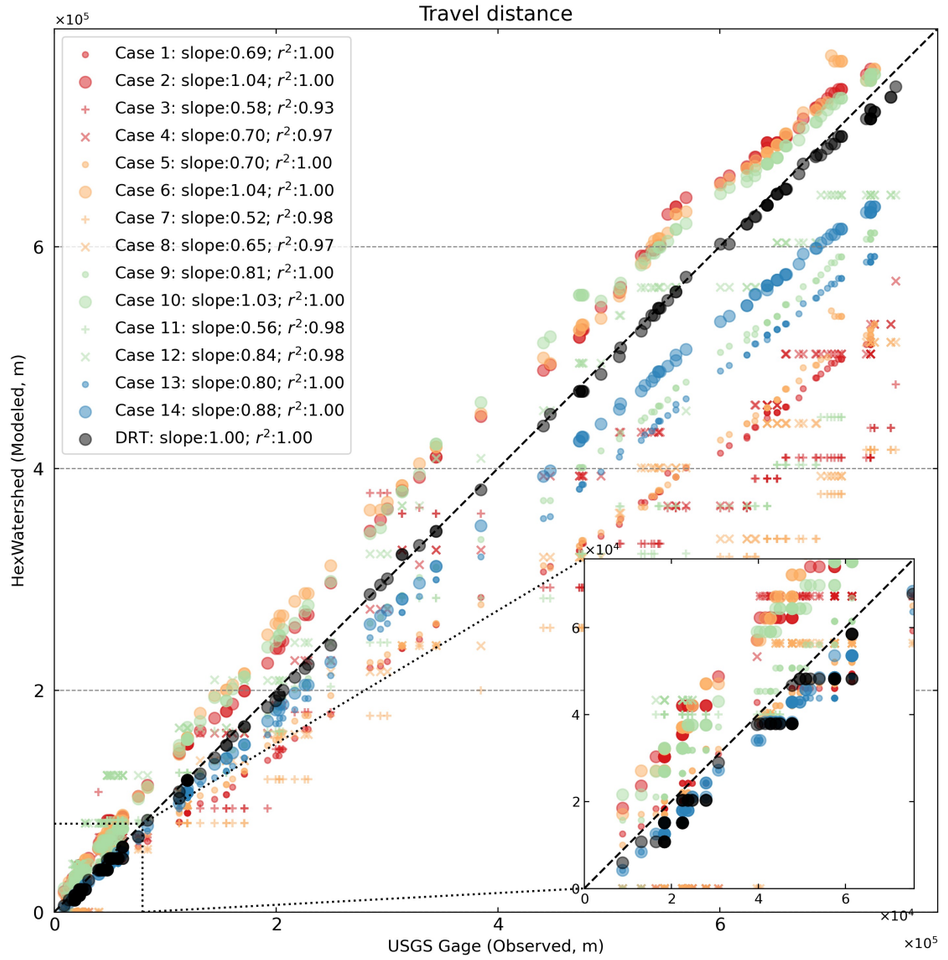
(Liao, et al. 2022 JAMES)

# Metrics

Topological relationship-based stream burning produces more realistic channel elevations.




Susquehanna

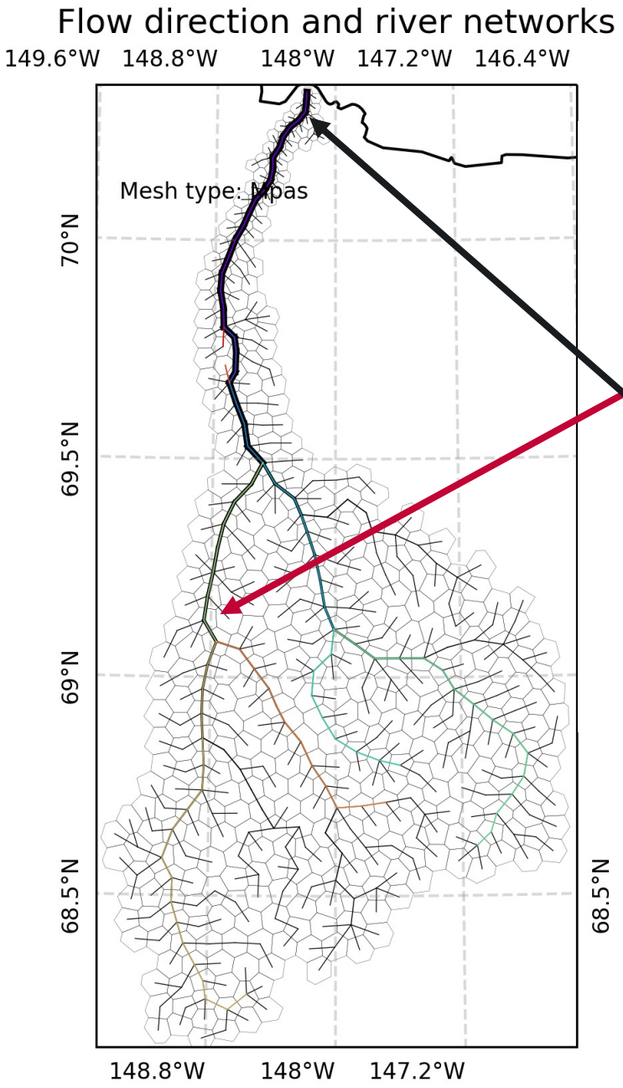


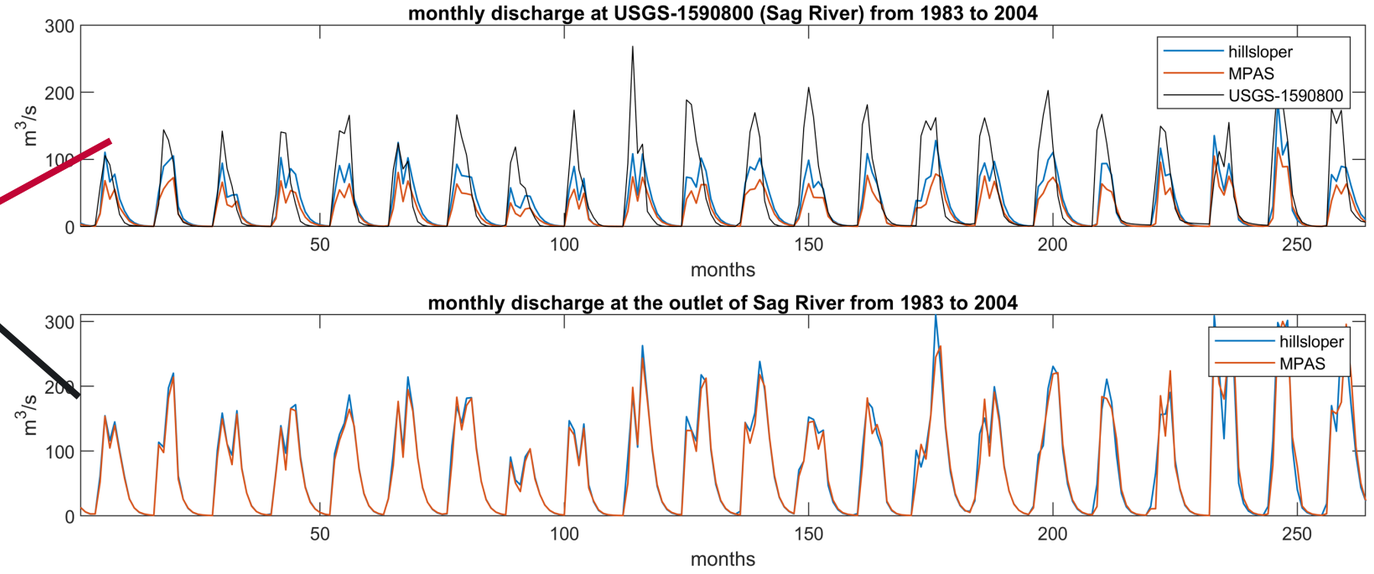

Travel distance can be reconstructed from mesh type and resolution.

(Liao, et al. 2022 JAMES)

# Flow direction: Sagavanirktok river basin

Mesh resolution: 2~7km.

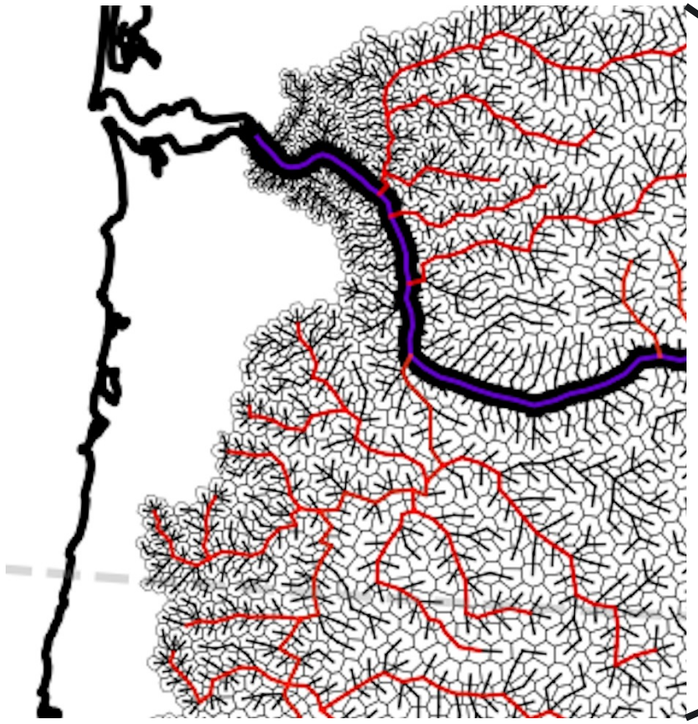


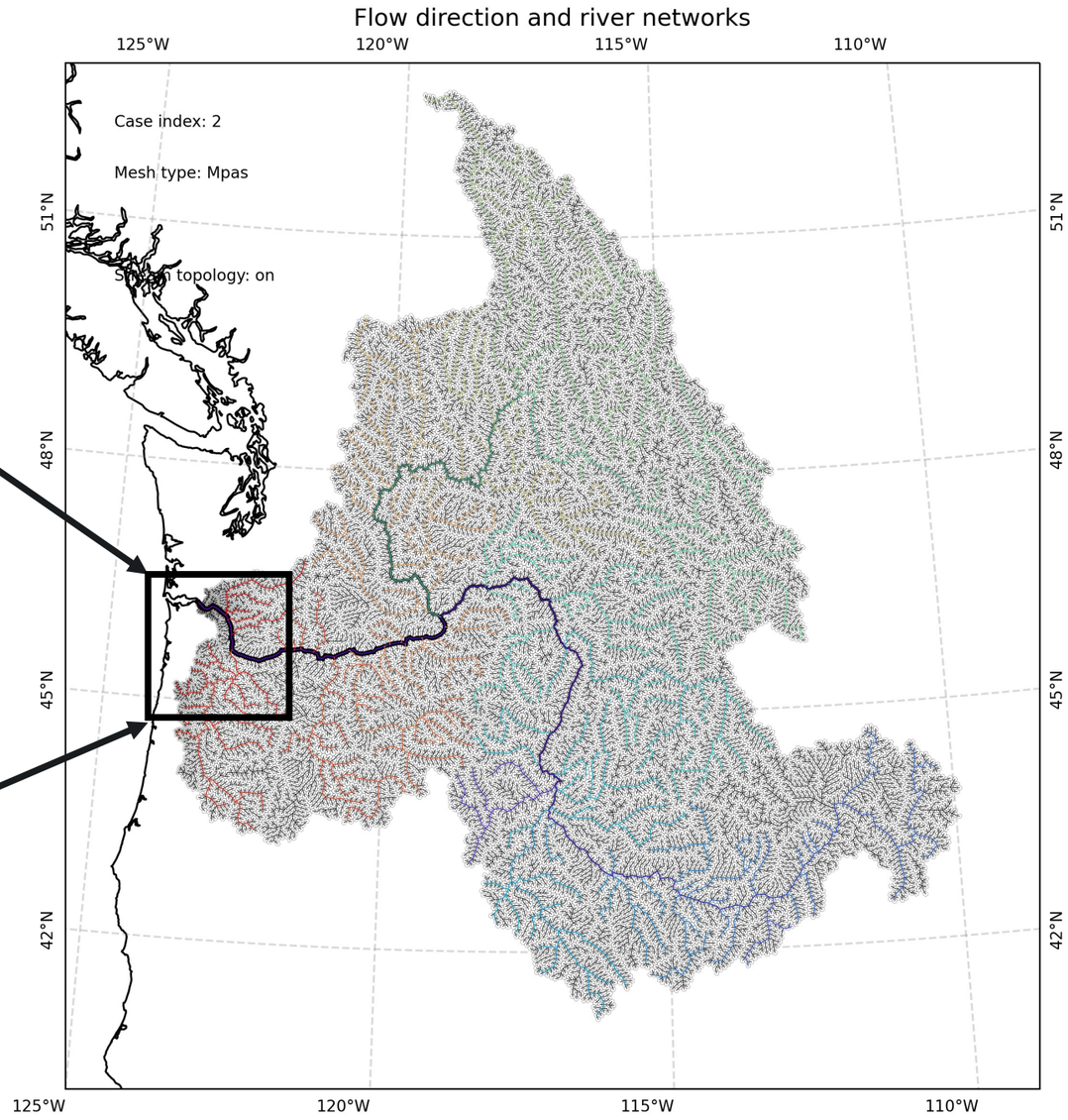




Modeled river discharge at the USGS gage station (1590800) and outlet. Both model configurations are forced by the Global Reach-level Flood Reanalysis (GRFR) runoff.

(Liao, et al. JOH in prep)

# Flow direction: Columbia river basin






Mesh resolution: 2~7km.

(Liao, et al. JOH in prep)

# Summary

- We use the topological relationship to model **river networks, flow direction,** and other flow routing parameters.
- Our method is **mesh-independent** and can be applied at regional and global scales.
- The products from our study can be used to **improve hydrography representations** in spatially-distributed **hydrology models (e.g., GHM)**, especially when unstructured meshes are used.

# References

| | |
|---|---|
| Meshing | • Engwirda, Darren, & Liao, Chang. (2021, October 9). 'Unified' Laguerre-Power Meshes for Coupled Earth System Modelling. 29th International Meshing Roundtable (IMR), Virtual Conference. https://doi.org/10.5281/zenodo.5558988 |
| Flow direction modeling | • Liao, C., Zhou, T., Xu, D., Tan, Z., Bisht, G., Cooper, M. G., ... & Leung, L. R. (2022). Topological relationship-based flow direction modeling: stream burning and depression filling.<br>• Liao, C., Zhou, T., Xu, D., Cooper, M., Engwirda, D., Li, H. Y., & Leung, L. R. Topological relationships-based flow direction modeling: mesh-independent river networks representation.<br>• Liao, Chang, Tian Zhou, Donghui Xu, Richard Barnes, Gautam Bisht, Hong-Yi Li, Zeli Tan, et al. (02/2022AD) 2022. “Advances In Hexagon Mesh-Based Flow Direction Modeling”. Advances In Water Resources 160. Elsevier BV: 104099. https://doi.org/10.1016/j.advwatres.2021.104099<br>• Liao, C., Tesfa, T., Duan, Z., & Leung, L. R. (2020). Watershed delineation on a hexagonal mesh grid. Environmental Modelling & Software, 128, 104702. https://doi.org/10.1016/j.envsoft.2020.104702 |
| Model repository | • **JIGSAW**: https://github.com/dengwirda/jigsaw<br>• **HexWatershed**: https://github.com/changliao1025/pyhexwatershed |

Pacific Northwest
NATIONAL LABORATORY

PNNL@AGU
EXPLORE » INTERPRET » APPLY


Pacific Northwest
NATIONAL LABORATORY

**Chang Liao**
Earth scientist

Atmospheric Sciences & Global Change

Phone: (509) 375 6564
Mobile: (509) 375 6564
**Email: chang.liao@pnnl.gov**

902 Battelle Blvd
Richland, 99352

**www.pnnl.gov**