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A mesh-independent flow direction model for flow routing

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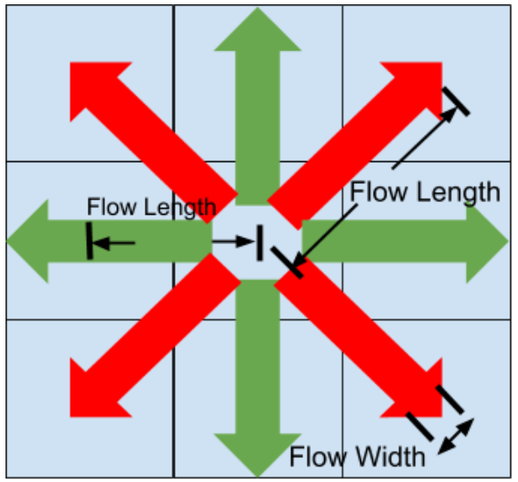
Takeaway message

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)

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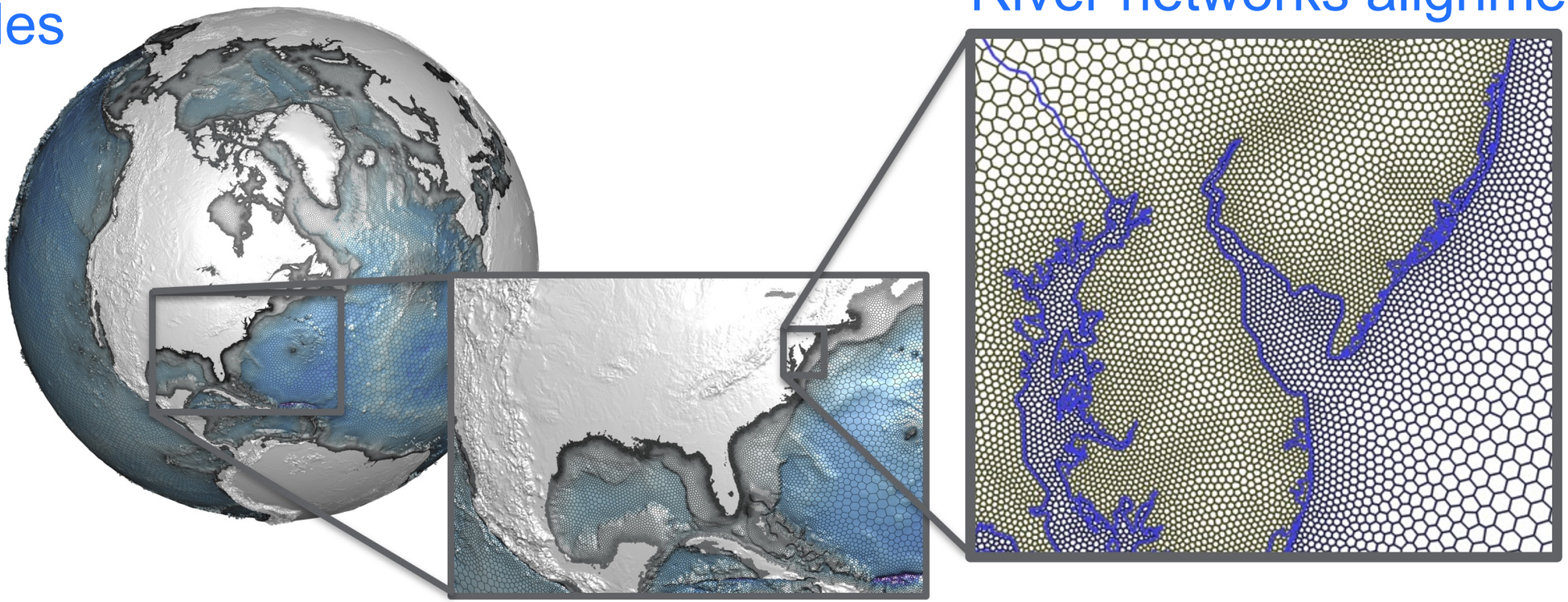
No.	Model	Spatial resolution
1	HDTM 1.0	0.5°
2	Macro-PDM	0.5°
3	MPI-HM	0.5°
4	GWAVA	0.5° / 0.1°
5	VIC	2°
6	LaD	1°
7	WaterGAP	0.5°
8	PCR-GLOBWB	0.5°
9	LPJmL	0.5°
10	WASMOD-M	0.5°
11	H08 (H07)	1° / 0.5°
12	ISBA-TRIP	1°

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

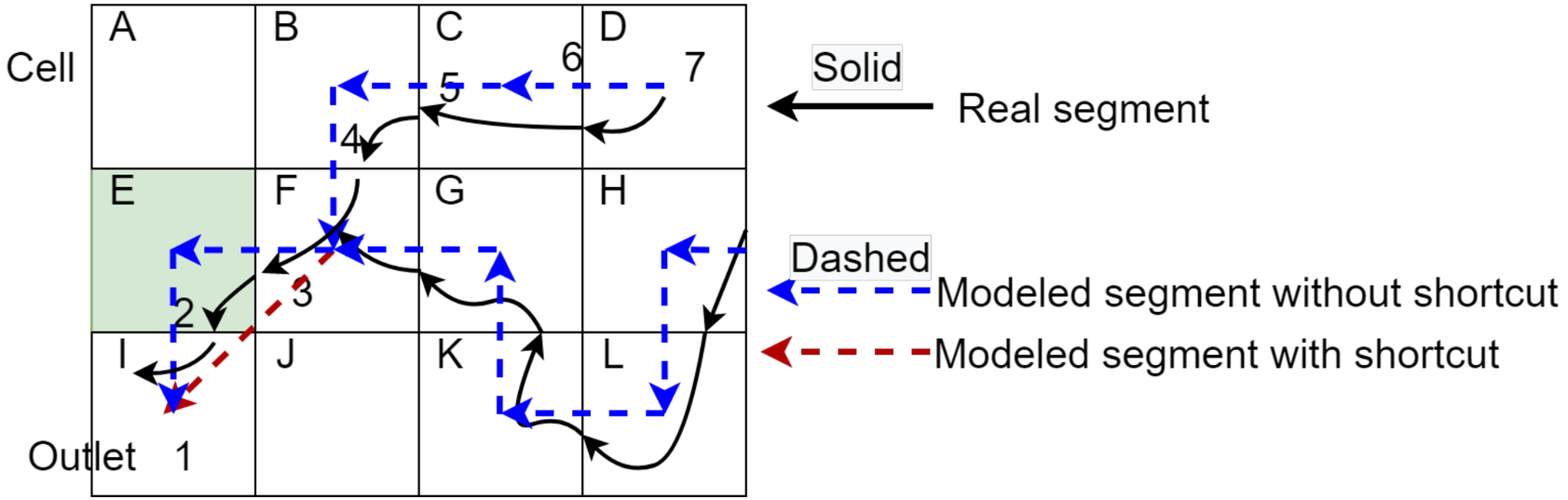
Flow direction modeling

- DEM
- HydroSheds

Stream burning, depression removal, et al.

Topological relationship-based river network

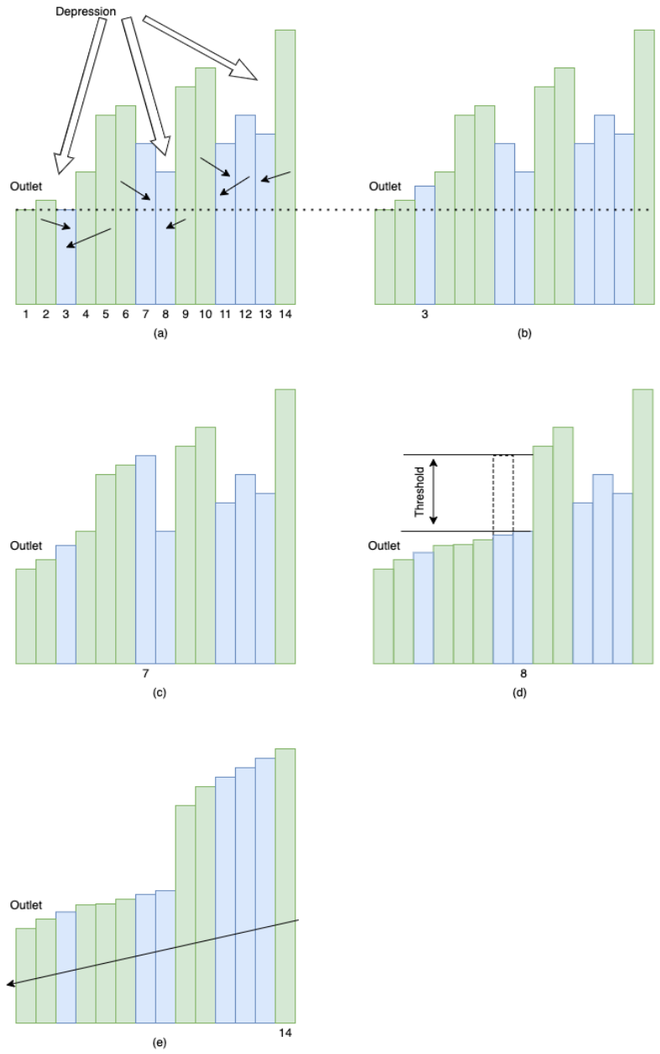
Definition: topological relationships include both neighboring information and upstream/downstream information.



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

(Liao, et al. 2022 JAMES)

Topological relationship-based flow direction modeling: stream burning

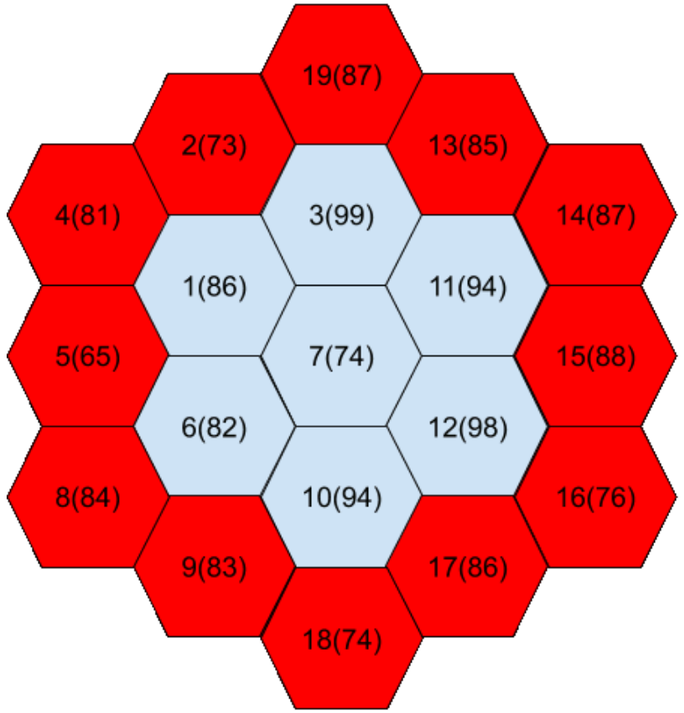


- River networks are precisely maintained through topological relationships.
- Topological relationship, i.e., **upstream-downstream,** allows the adaptive stream burning.

(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)

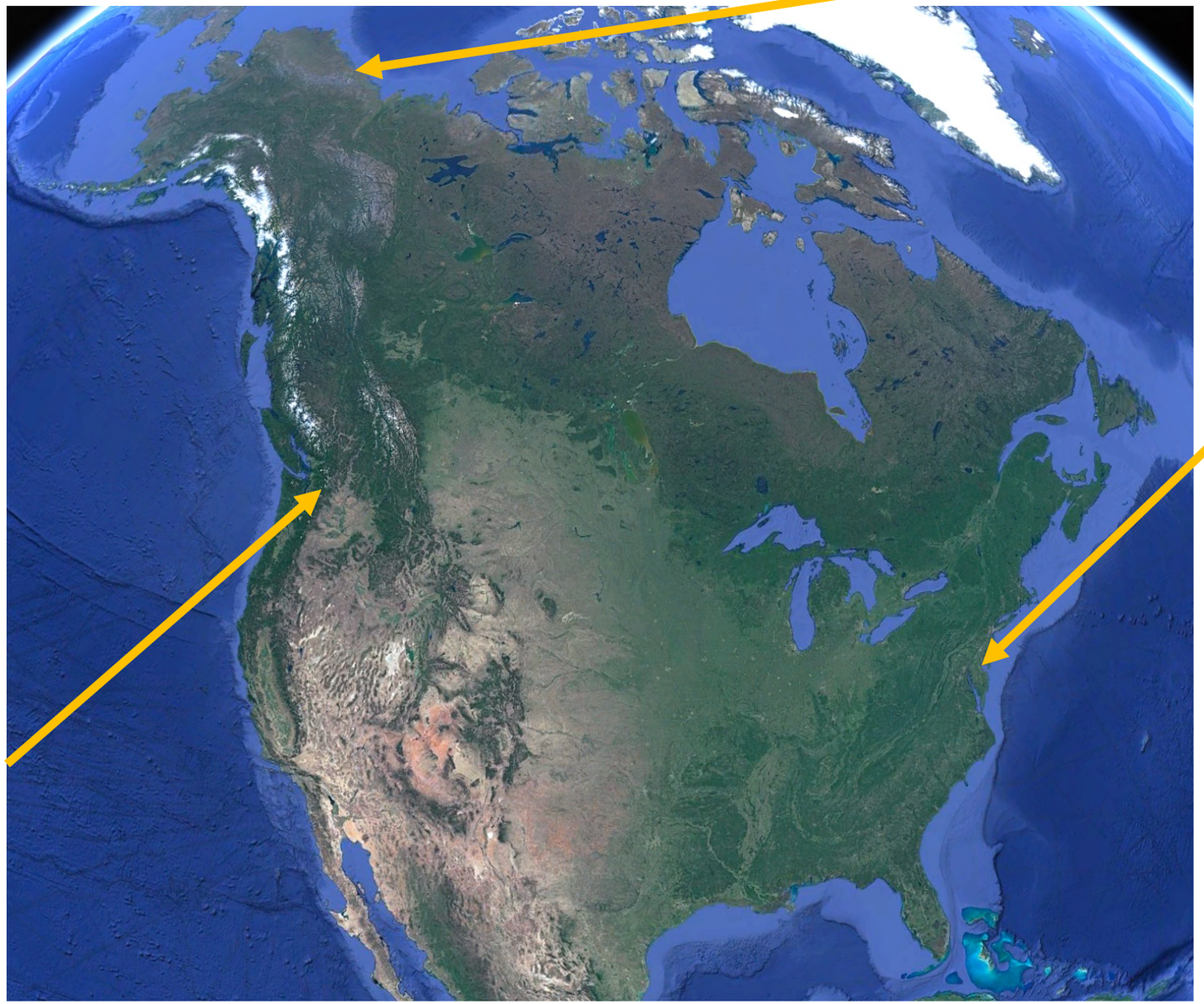
Application

Structured:
- Lat-long
- Projected
- Hexagon

Unstructured:
- MPAS

Columbia
(6.7 x 10^5 km^2)

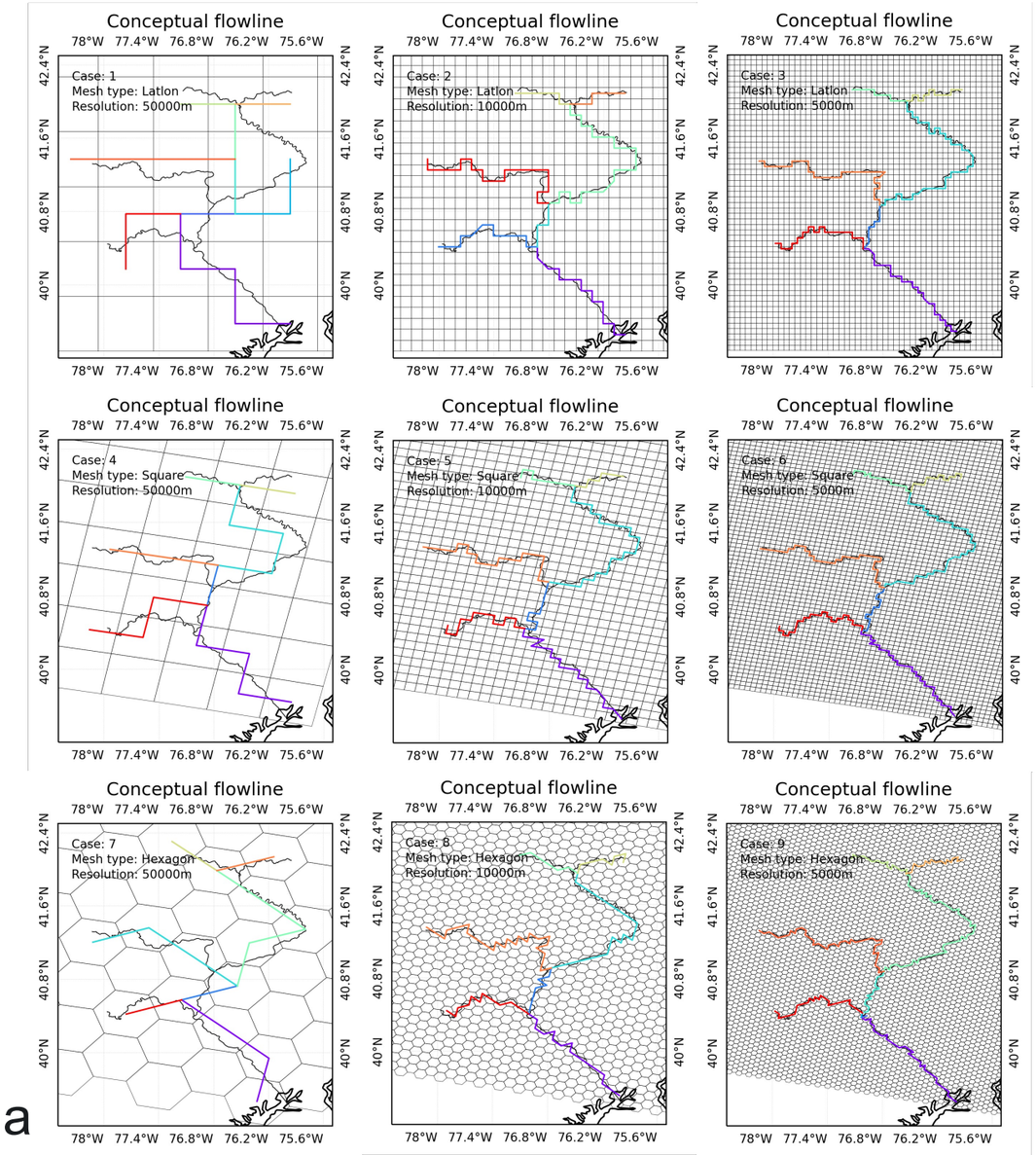
Sagavanirktok (1.5 x 10^4 km^2)

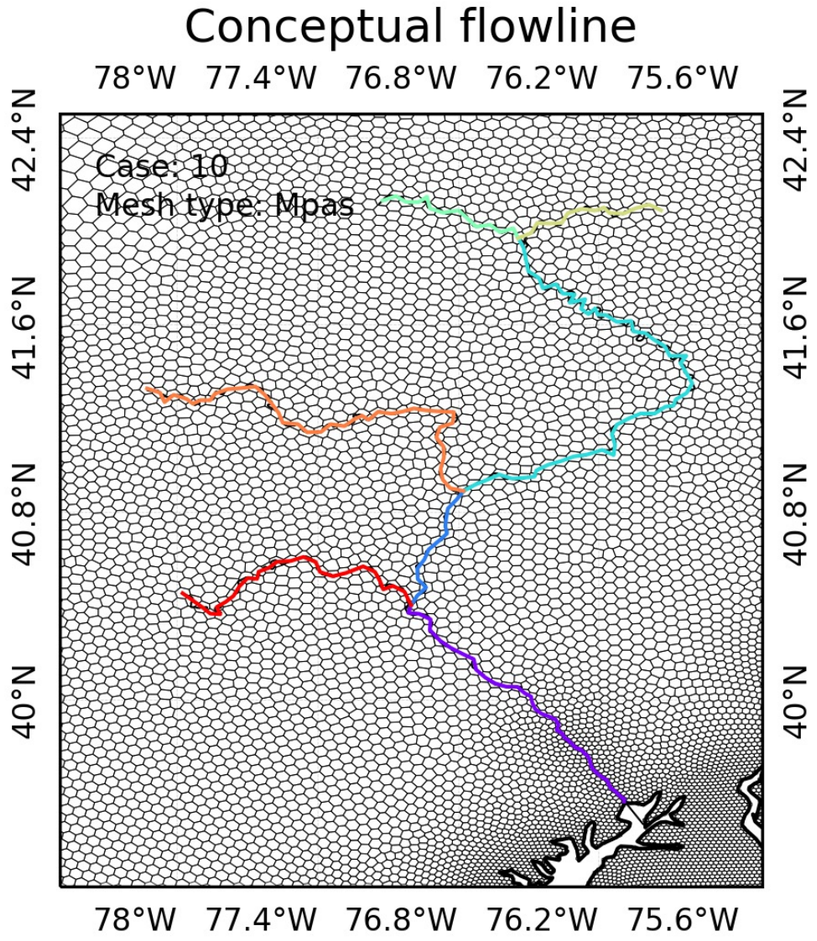


Susquehanna
(7 x 10^4 km^2)

(Image: Google Earth)

Results: conceptual river networks

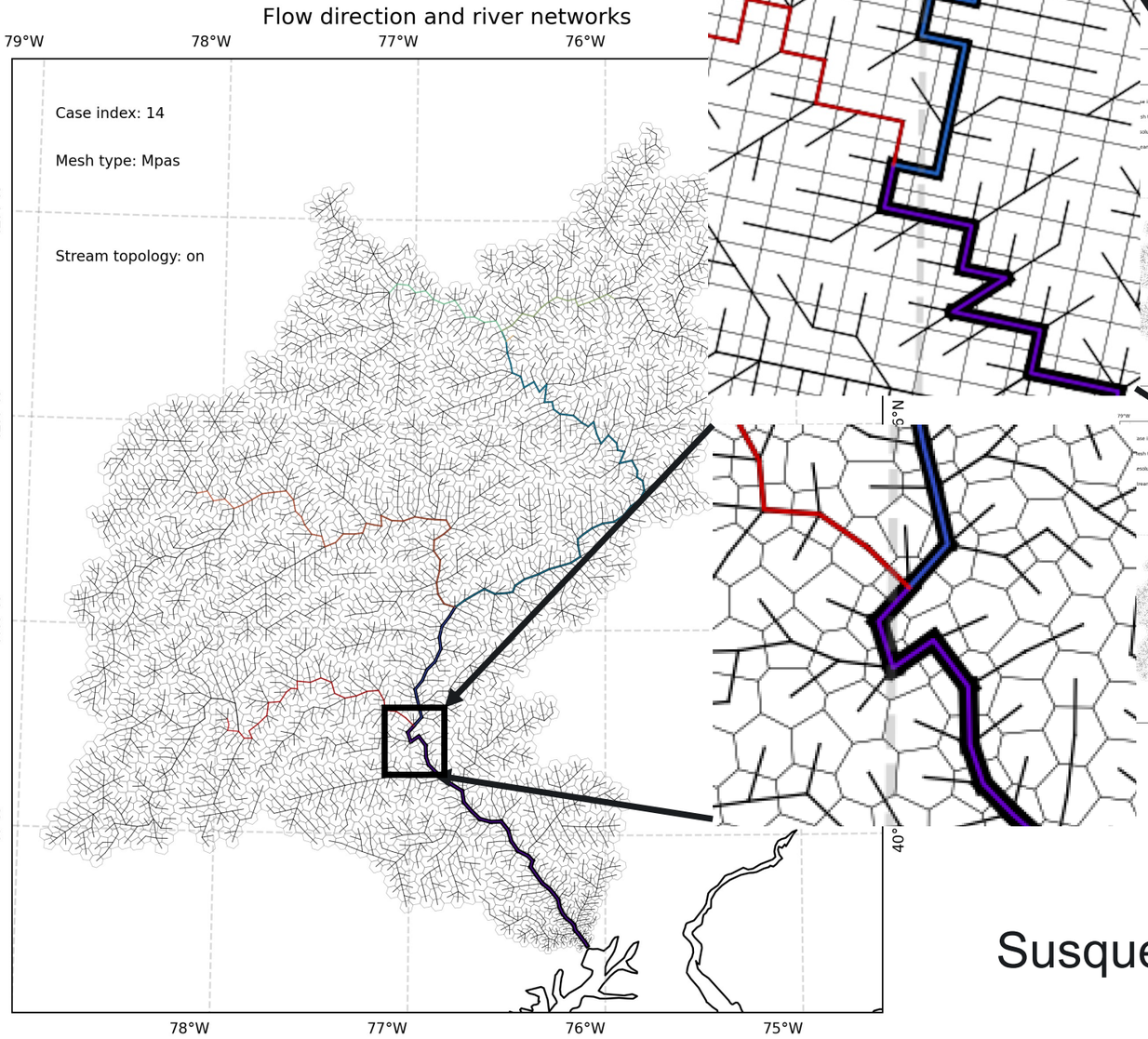




Susquehanna

(Liao, et al. 2022 JAMES)

Flow direction

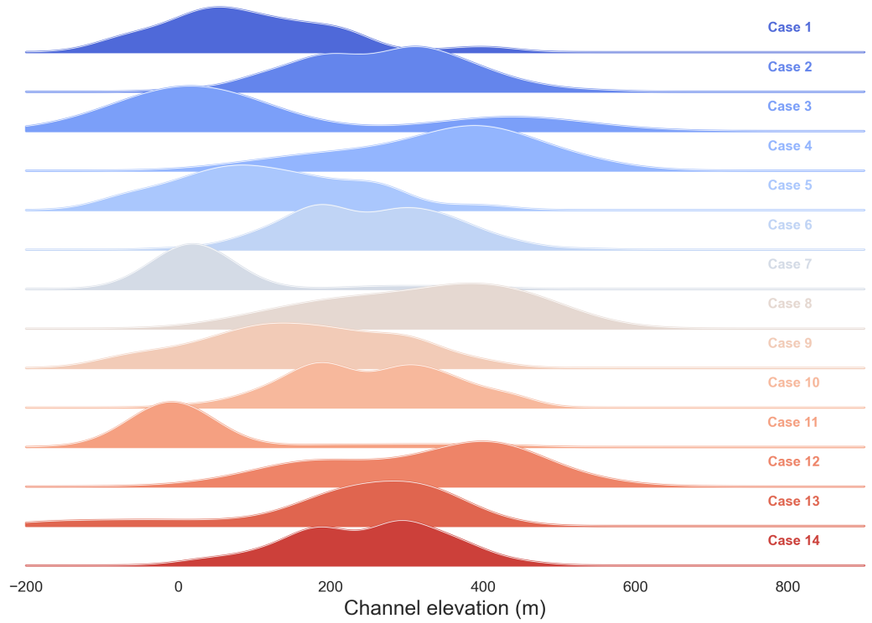


Susquehanna

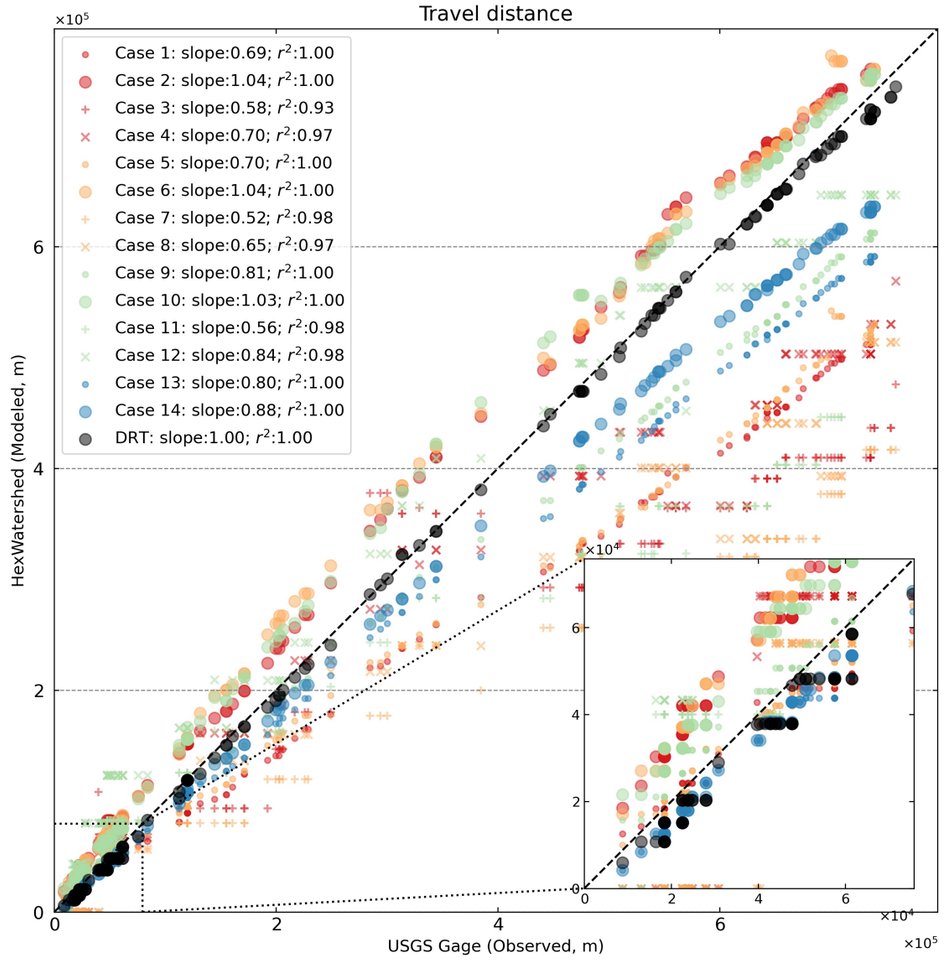
(Liao, et al. 2022 JAMES)

Metrics

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



Susquehanna

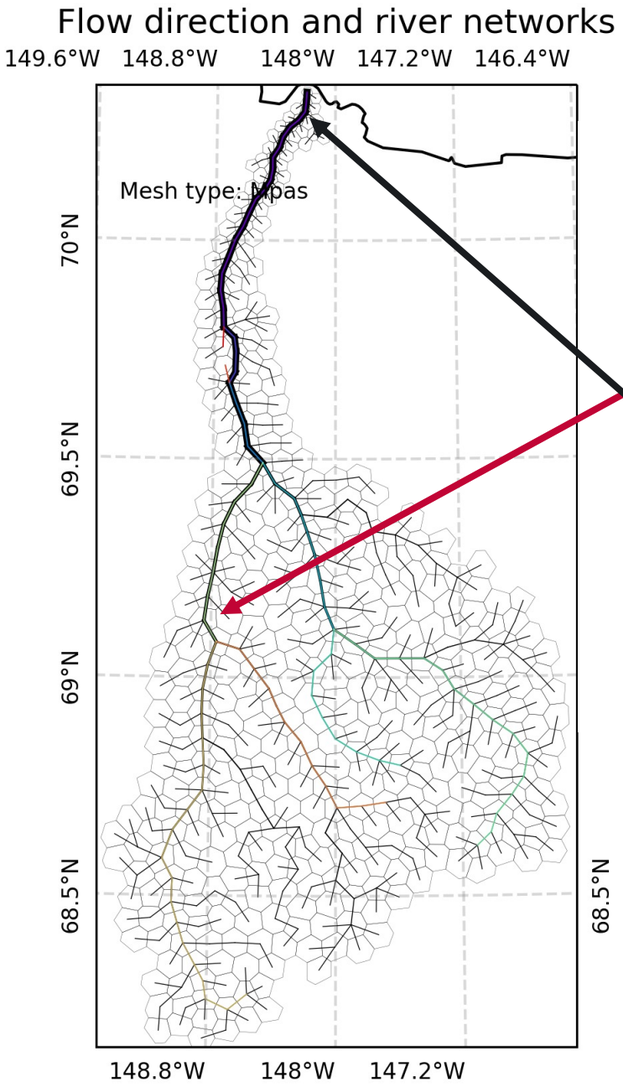


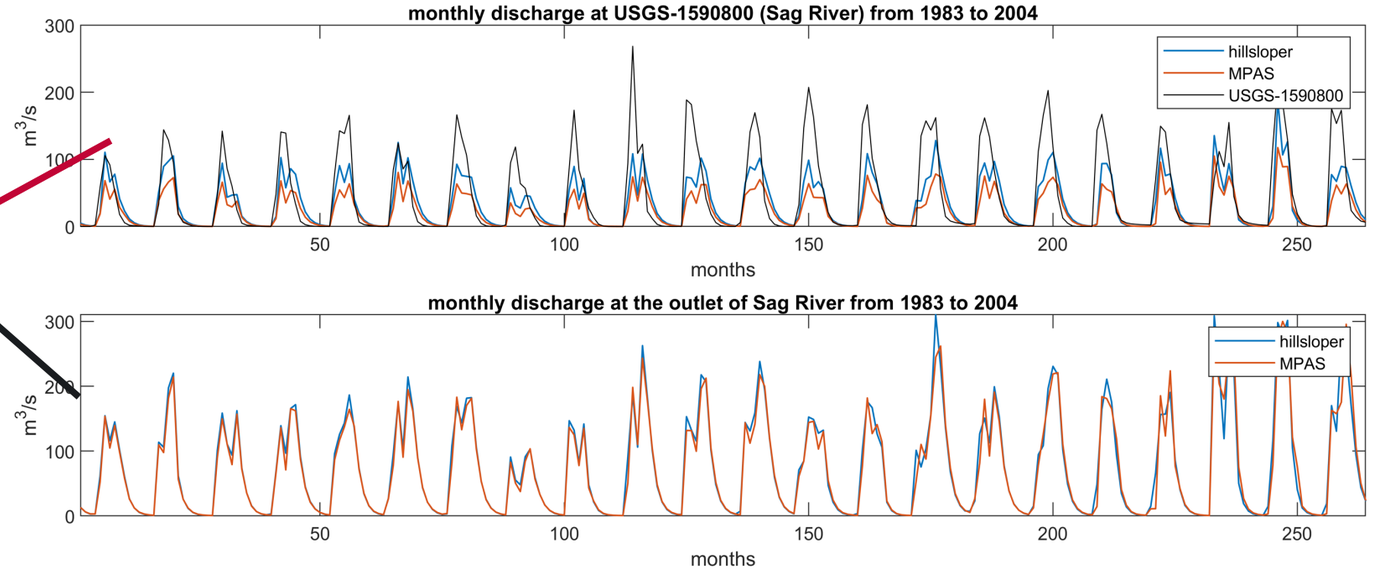
Travel distance can be reconstructed from mesh type and resolution.

(Liao, et al. 2022 JAMES)

Flow direction: Sagavanirktok river basin

Mesh resolution: 2~7km.

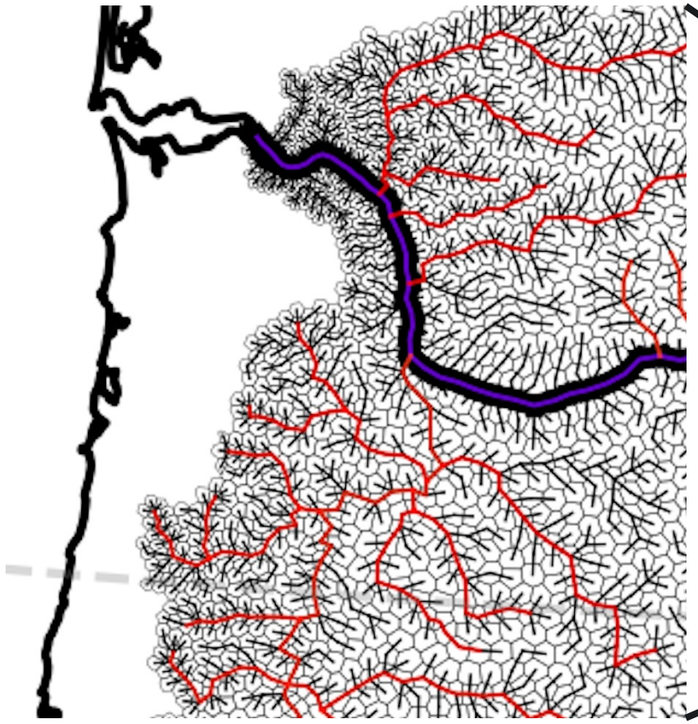


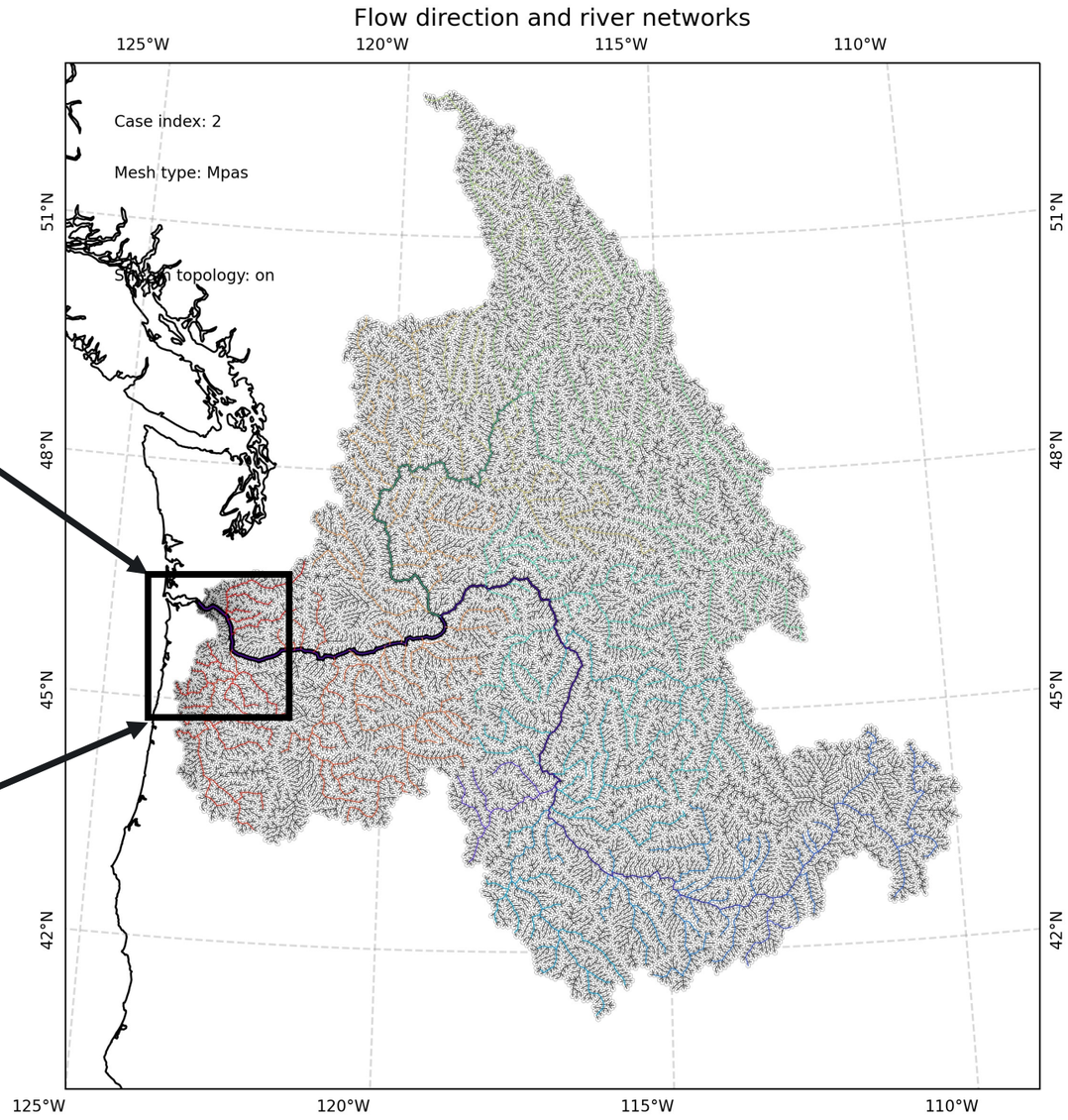


Modeled river discharge at the USGS gage station (1590800) and outlet. Both model configurations are forced by the Global Reach-level Flood Reanalysis (GRFR) runoff.

(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. • 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. • 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 • 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 • **HexWatershed**: https://github.com/changliao1025/pyhexwatershed

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