Comparison of CTSM coupled river models

MOSART vs. mizuRoute

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Acknowledge to Erik Kluzek and Dave Lawrence and TSS

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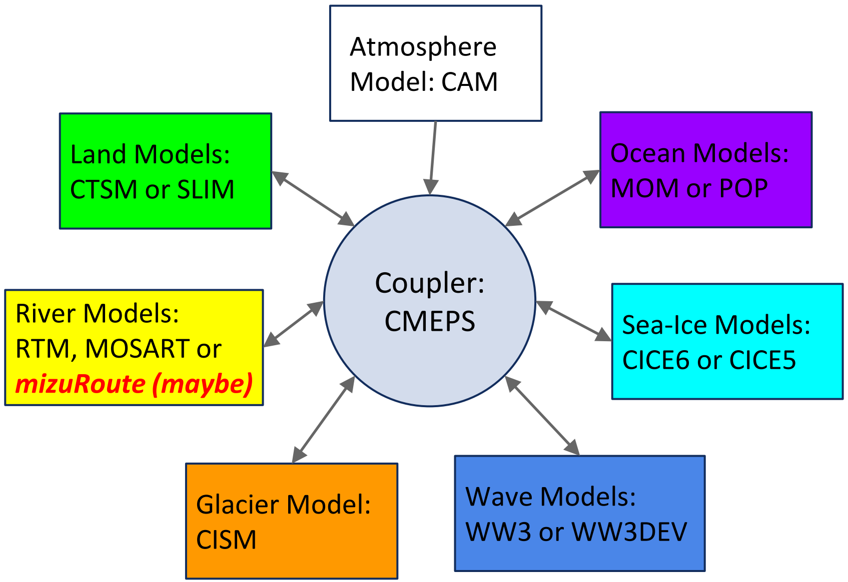
Introduction

- Planning to move CESM River component from MOSART (grid routing) to mizuRoute (vector routing).
- Need to understand differences in model behaviors to justify this plan. 1) Model skills and 2) performance
- New physics: Floodplain implementation

CESM3 (and beyond) components



From Erik Kluzek

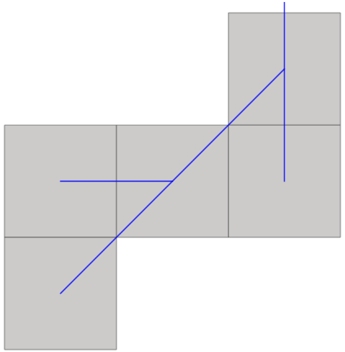
MOSART (in CESM) vs. mizuRoute

MOSART (Model for Scale Adaptive River Transport)

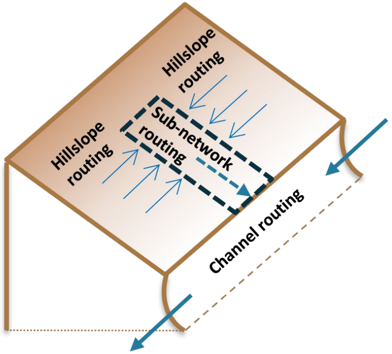
- Gridded network
- Three routing processes at each element.
  - hillslope
  - Sub-grid tributary
  - Channel (kinematic wave)

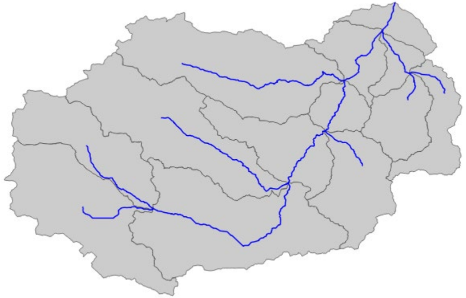
mizuRoute

- Vector network
- Two routing processes at each element.
  - hillslope
  - Channel (multiple methods)

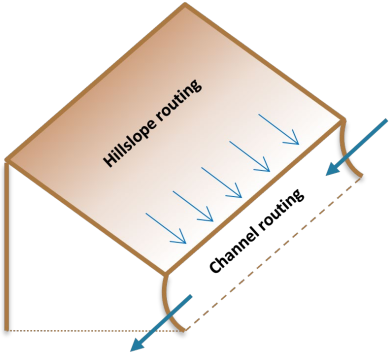


Within a box





Within a polygon



Model setups

CTSM5.1 f09_f09 grid (0.5°)

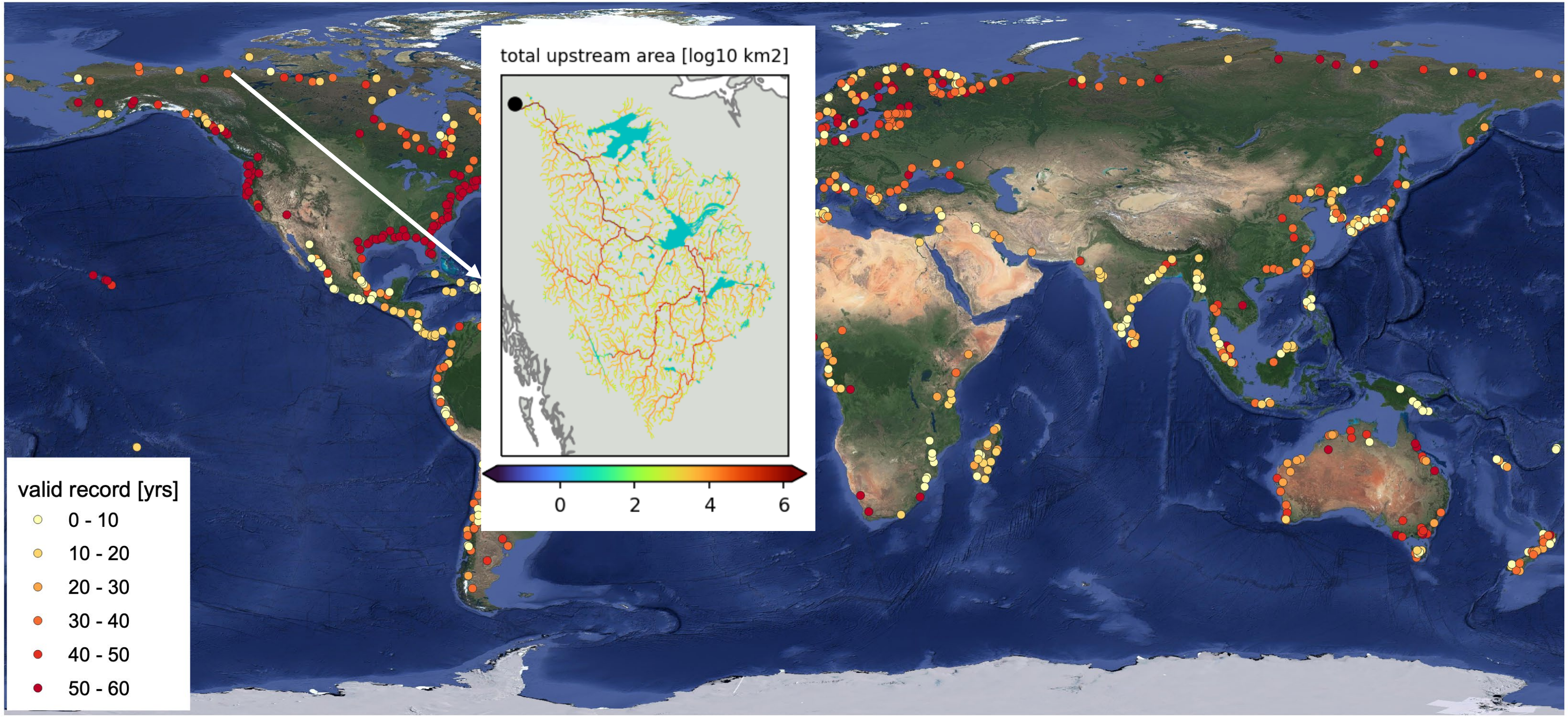
GSWP3 forcing

Sim. period: 1960-1999

River configurations

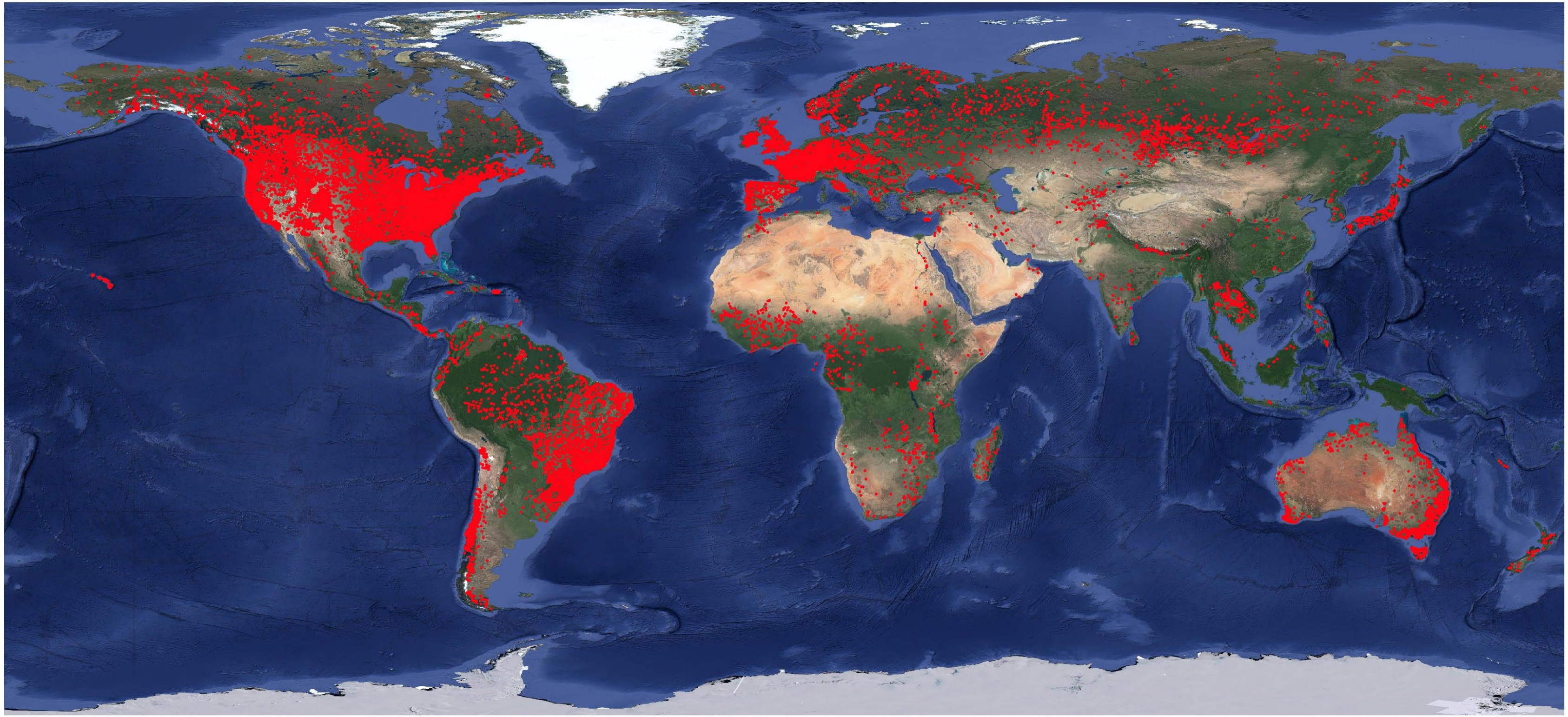
	model	grid
mosart 0.5°	MOSART	0.5° (94,613 land / 259,200 total)
mizuRoute HDMA	mizuRoute (IRF routing)	HDMA (295,335 basins)
mizuRoute HDMA+lake	mizuRoute (IRF routing)	HDMA with hydroLakes (294,041 basins, 4236 lakes)
mizuRoute HDMA+lake irrigation	mizuRoute (IRF routing)	HDMA with hydroLakes
mizuRoute HDMA+lake dfw	mizuRoute (diffusive wave routing)	HDMA with hydroLakes
mizuRoute 0.5°	mizuRoute (IRF routing)	0.5°

D19 - Monthly reference flow sites (near oceans)



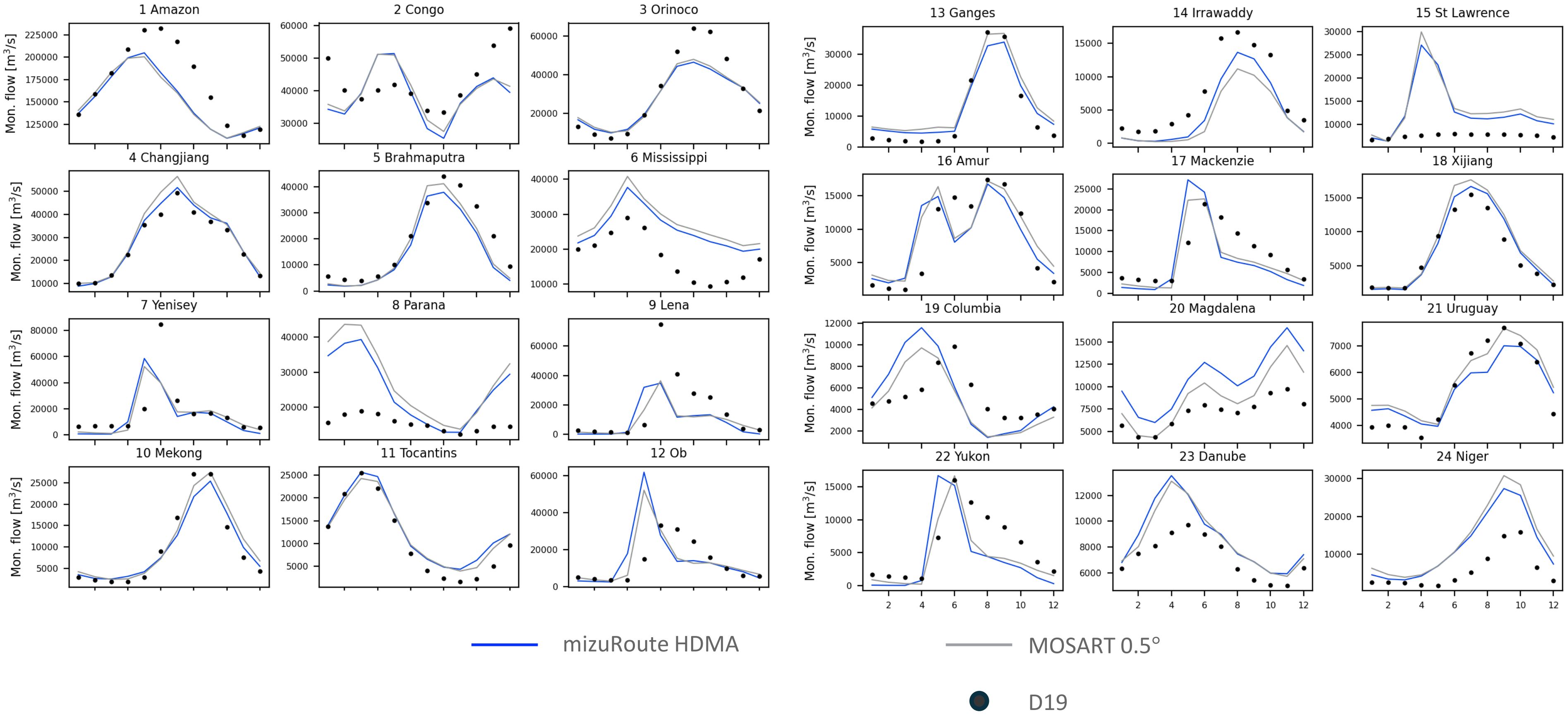
922 River sites, providing long-term monthly flow based on observed data (USGS, GRDC etc.) and CLM (using CLM-obs relationship) for missing data (Dai et al., 2009; Dai 2019)

B14 - Daily reference flow sites (including interior)

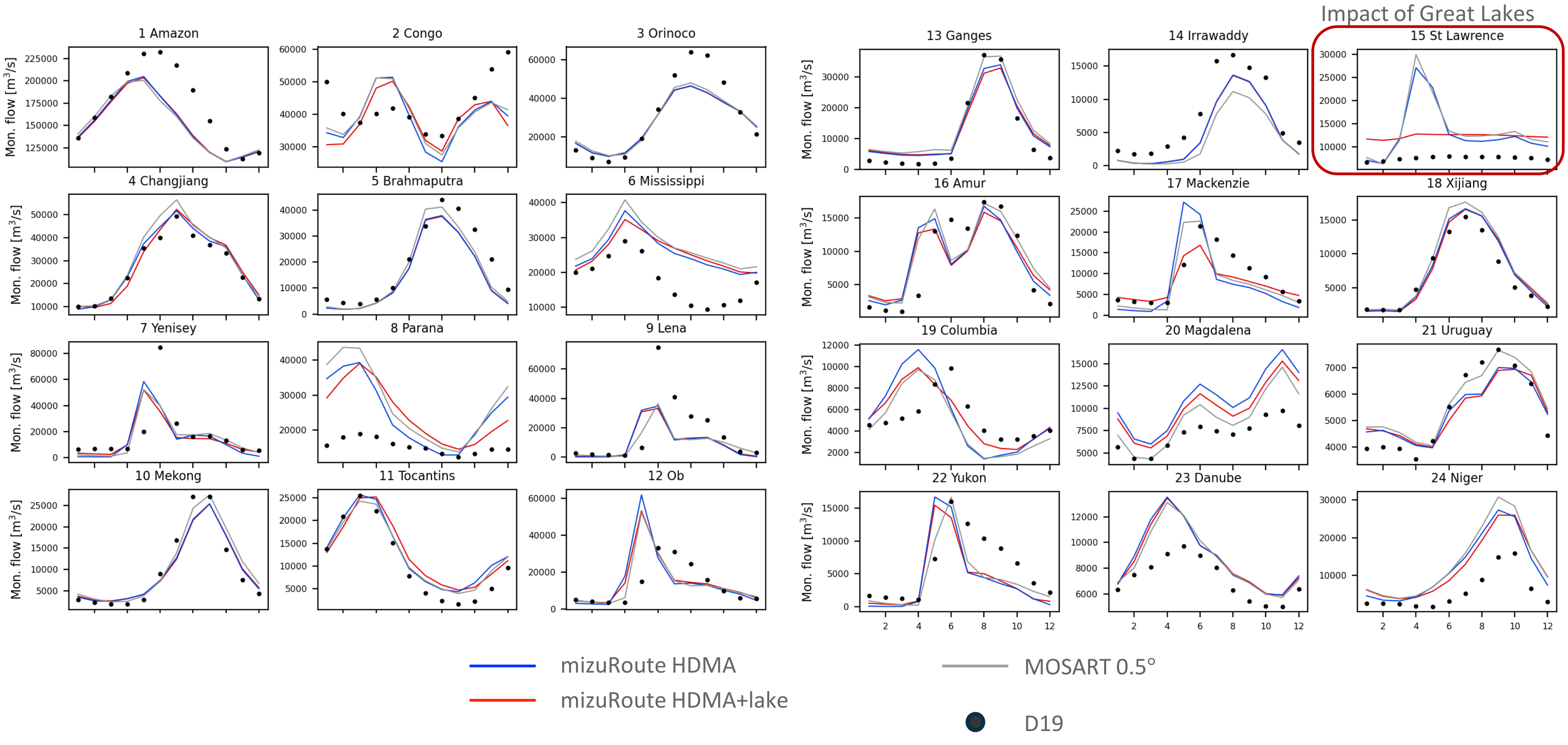


21,884 gauge sites (USGS, GRDC etc.) providing daily observed flow with varying recode lengths (Beck et al., 2014). Note all the gauges are not captured by modeled river network.

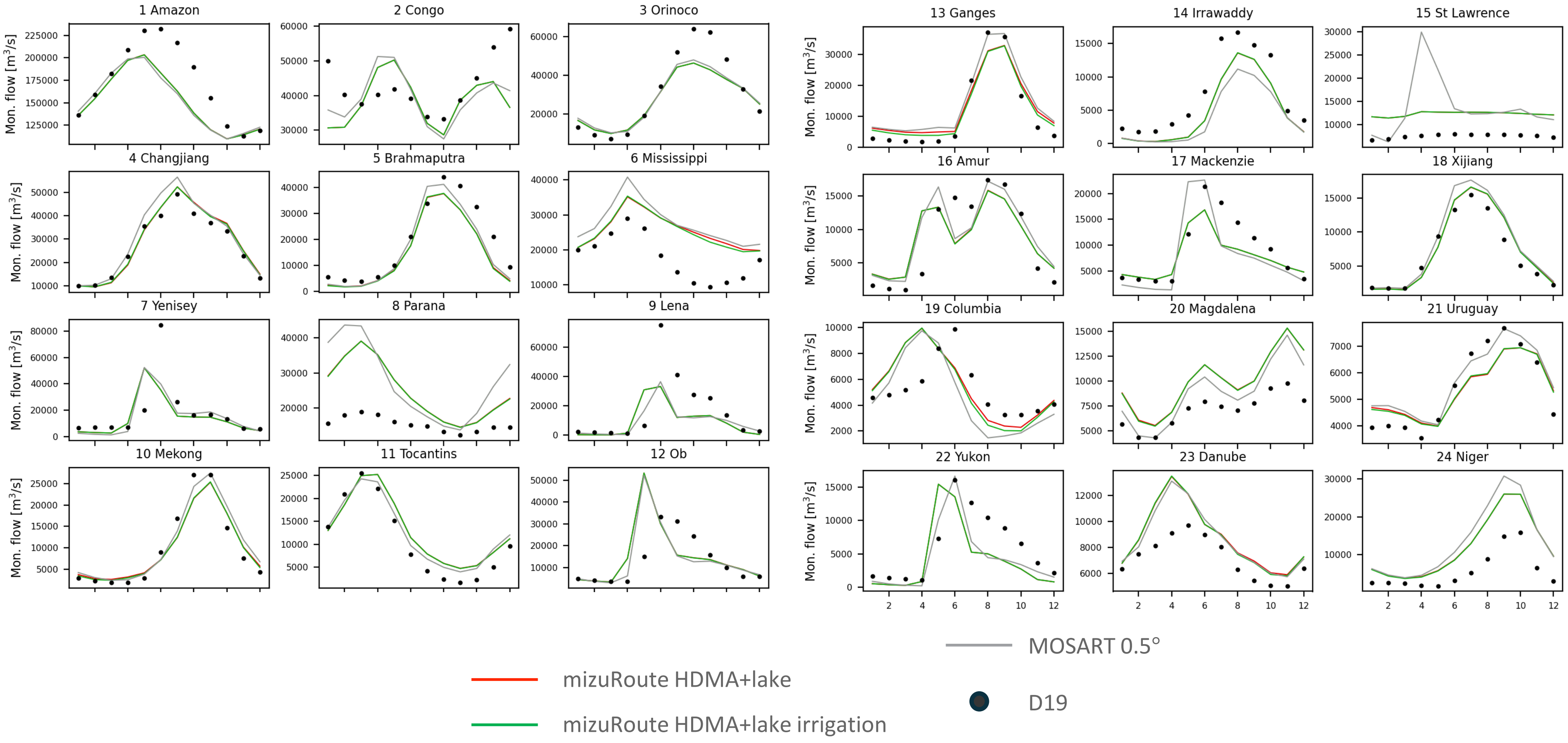
Seasonality (1960-1999) – MOSART vs mizuRoute



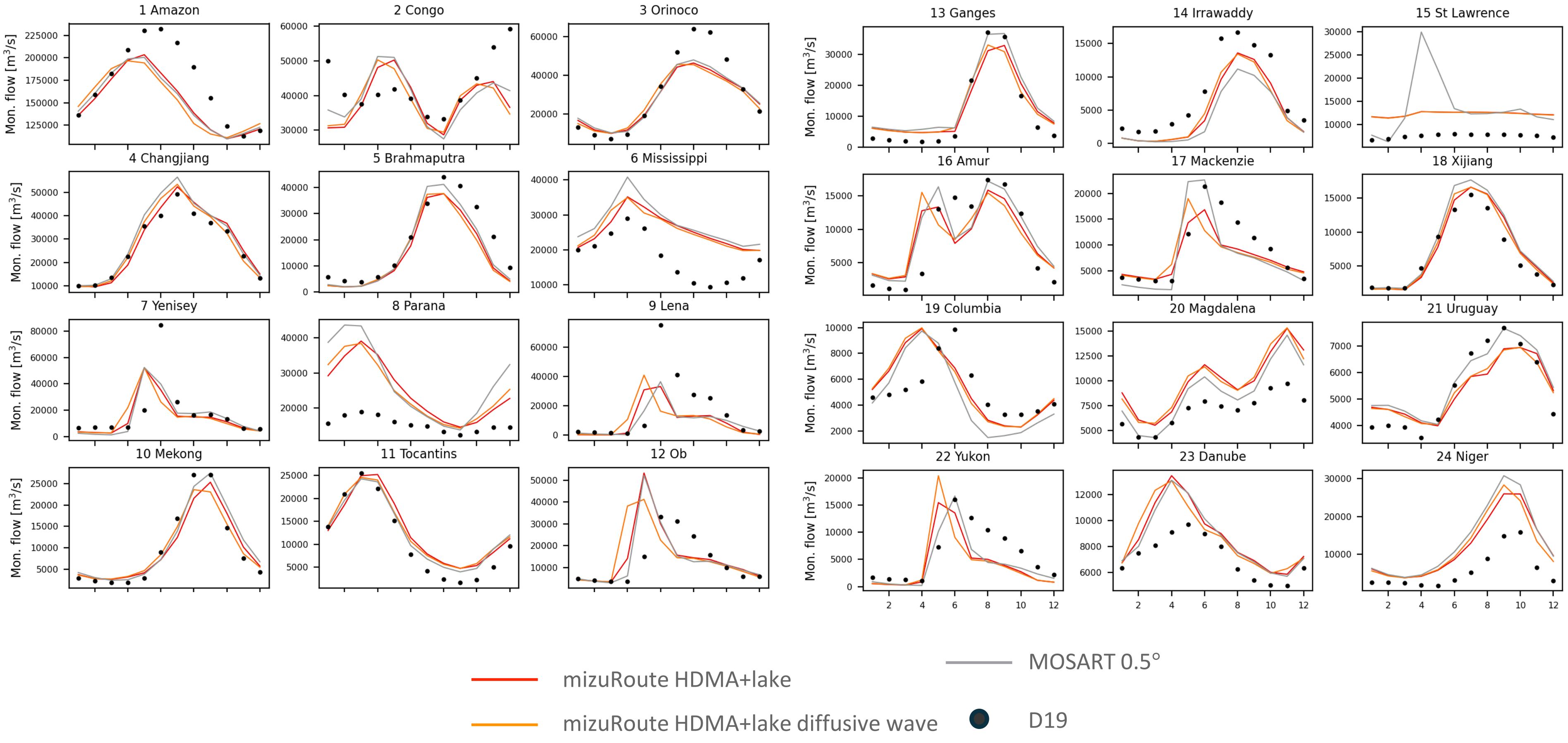
Seasonality (1960-1999) – no lake or lake



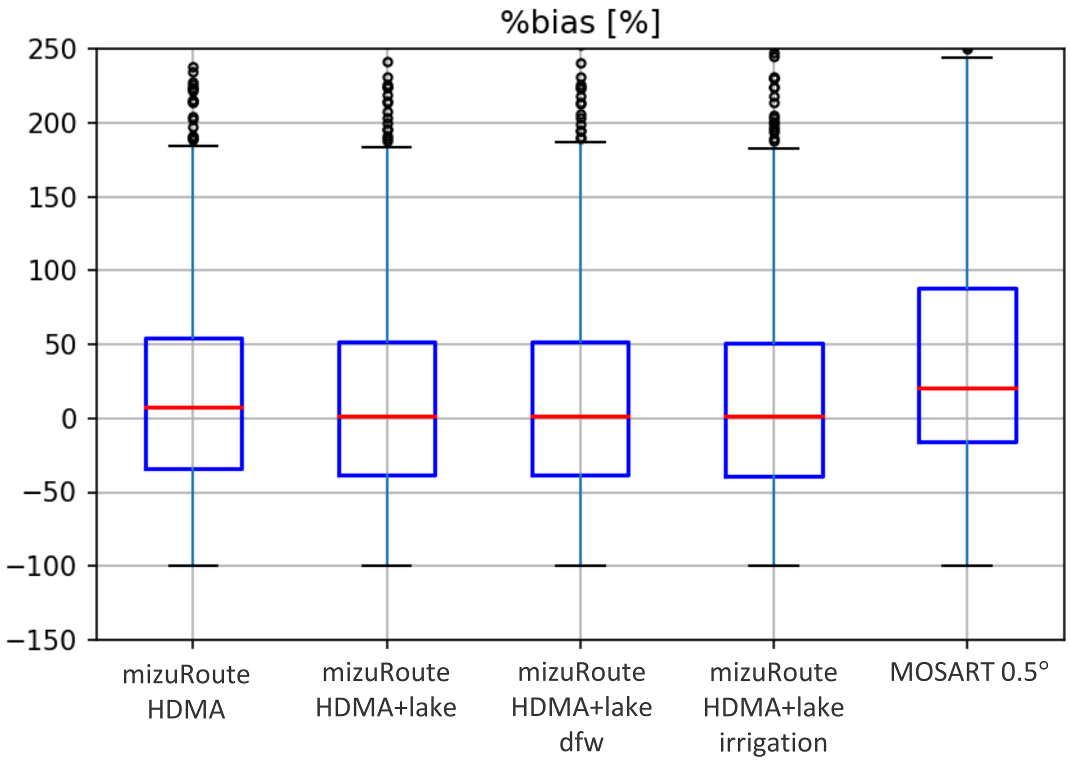
Seasonality (1960-1999) – irrigation or not



Seasonality (1960-1999) – routing effects



Monthly discharge bias (1960-1999)



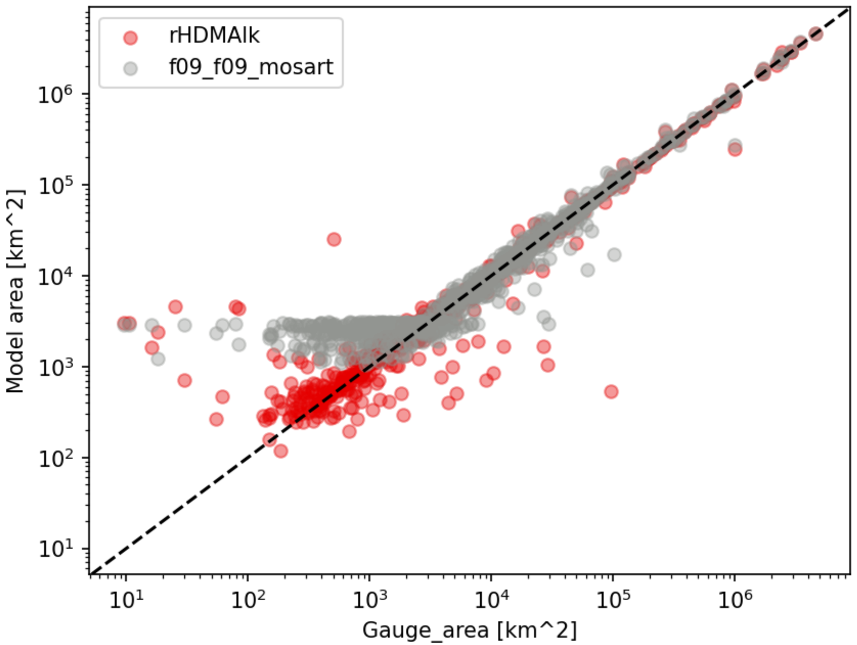
Using all D19 reference sites.

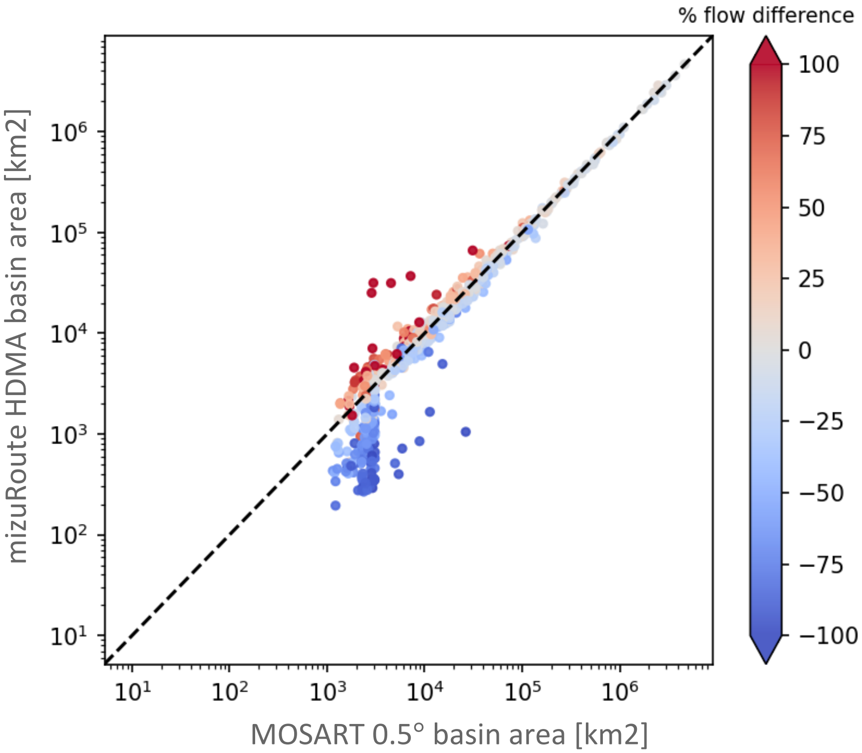
MOSART 0.5° runs: More sites have higher positive bias.

Main error sources: runoff error and drainage area

dfw==diffusive wave routing, including pressure gradient (water height) effect on river flow, with friction coef. = 0.01

Drainage area error and flow bias

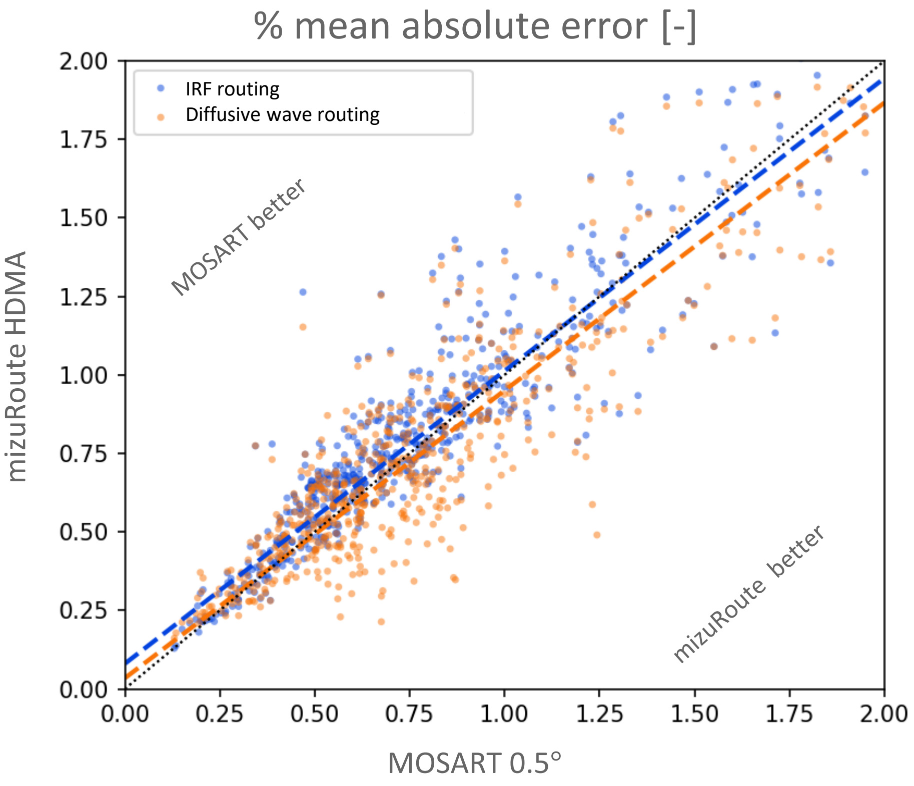


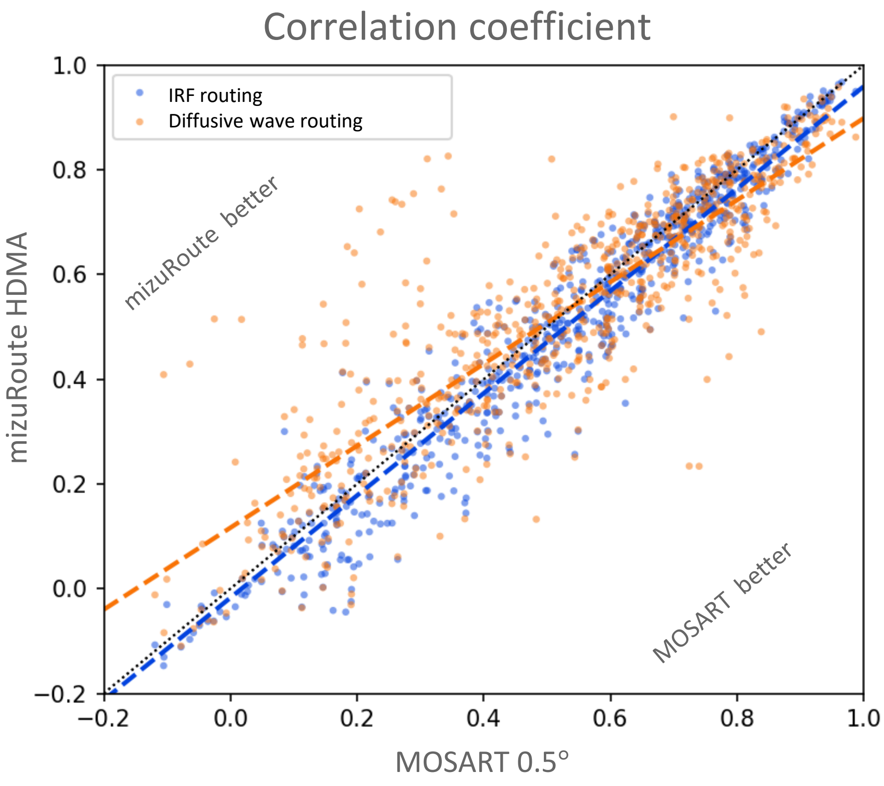


0.5° network does not resolve smaller river basin.

Flow difference = mizuRoute flow - MOSART flow

Daily discharge (1960-1999)





fitness metrics: daily observation at B14 daily gauges

Timing

Factors affecting the timing (*default* MOSART vs mizuRoute):

History outputs

- MOSART: 2D grid output including the whole globe.
- mizuRoute: vector output including land-only.

Process representations

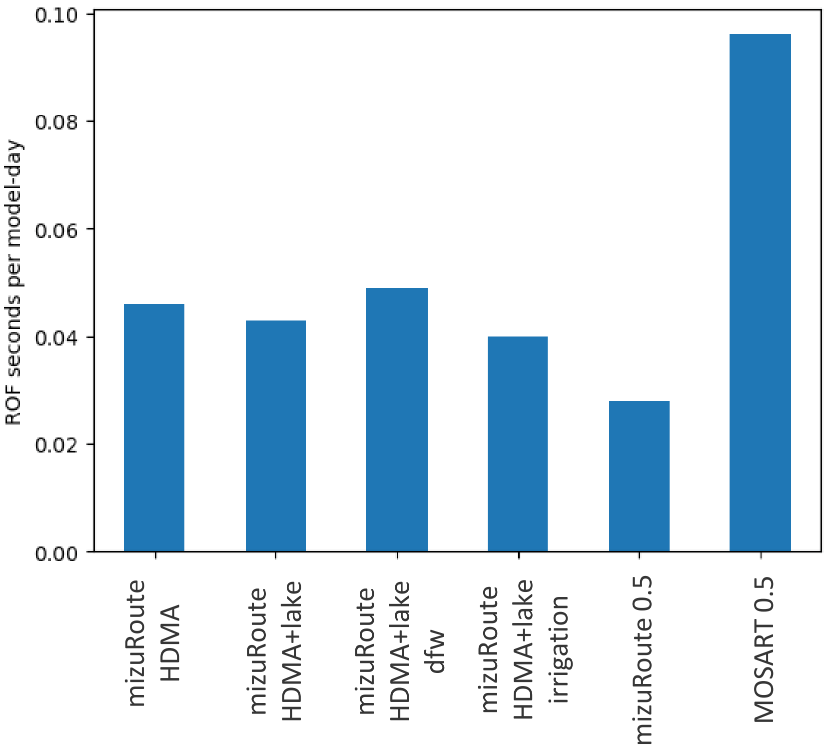
- MOSART: 3 processes (overland, tributary, & channel routing).
- mizuRoute: 2 processes (overland & channel routing).

Routing methods

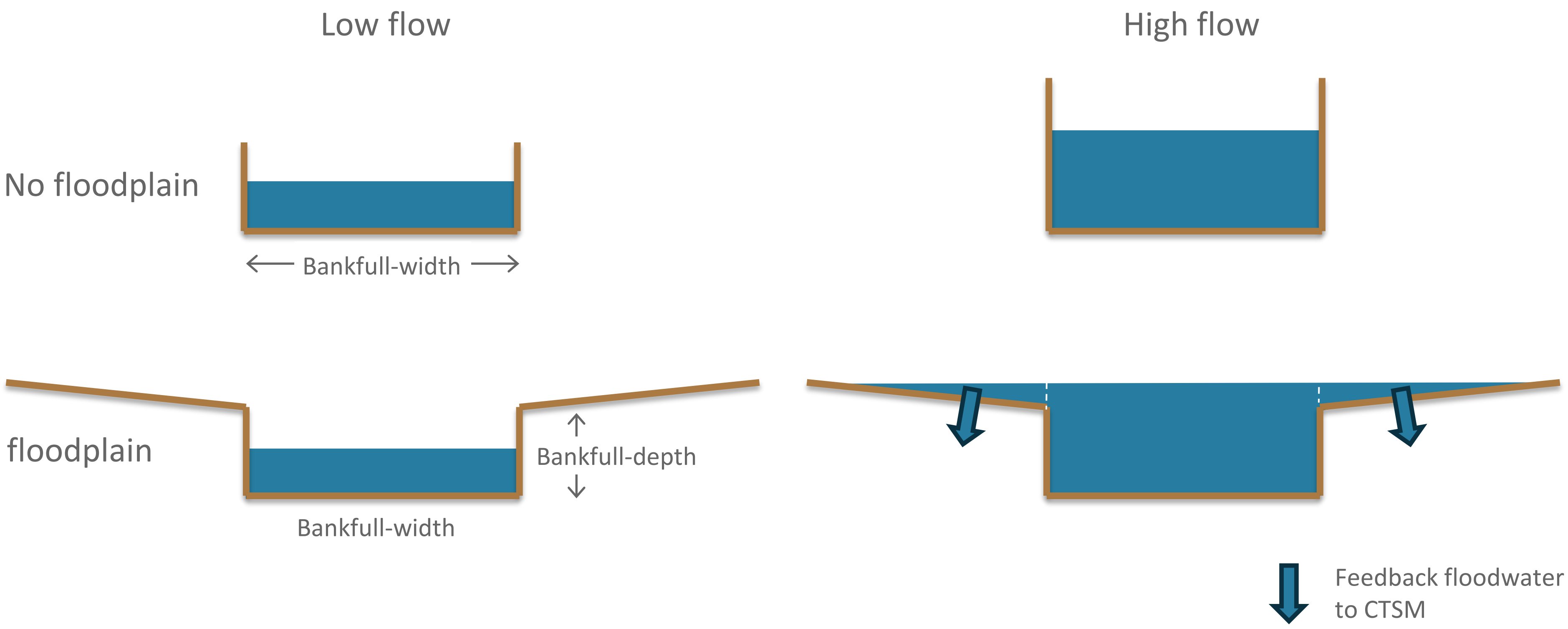
- MOSART: explicit method (using fixed small step).
- mizuRoute: Impulse Response Function (cheap and time step independent).

Parallelization

- MOSART: Round-Robin partition.
- mizuRoute: hybrid (complicated).



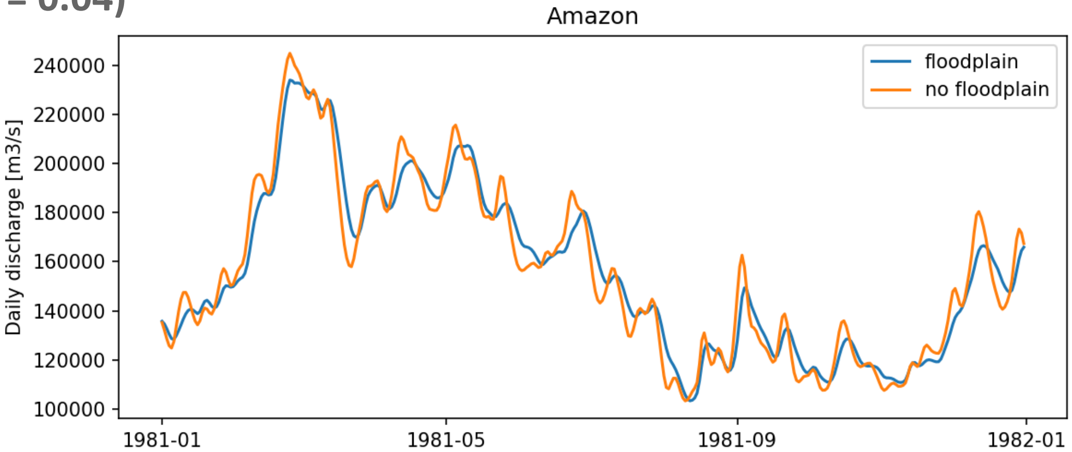
Adding Floodplain (working in progress)



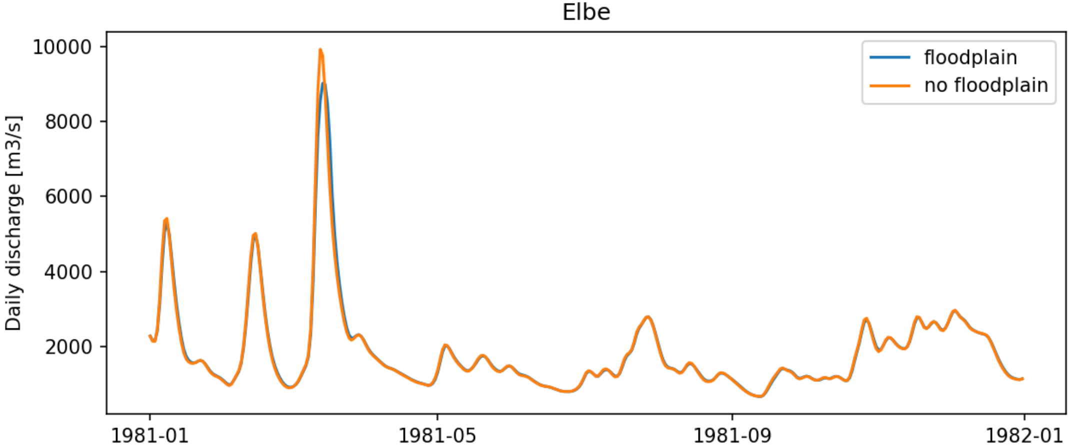
Floodplain effect on discharge

Use diffusive wave routing (friction coerf. = 0.04)

https://en.wikipedia.org/wiki/Amazon_River



https://en.wikipedia.org/wiki/Elbe



SUMMARY

- Monthly (or longer) time scales
  - Accurate drainage areas must.
  - Lakes can affect seasonality and bias.
  - Catchment based river network (mizuRoute) can capture drainage areas and shapes effectively than gridded network (MOSART).
  - Higher resolution of gridded network can improve drainage areas, but increase computing time.
- Daily time scale -> important for hydrologic study applications.
  - Routing methods (and channel parameter) matters
- Convinced to move from MOSART to mizuRoute??

Work needed for CESM3 and beyond

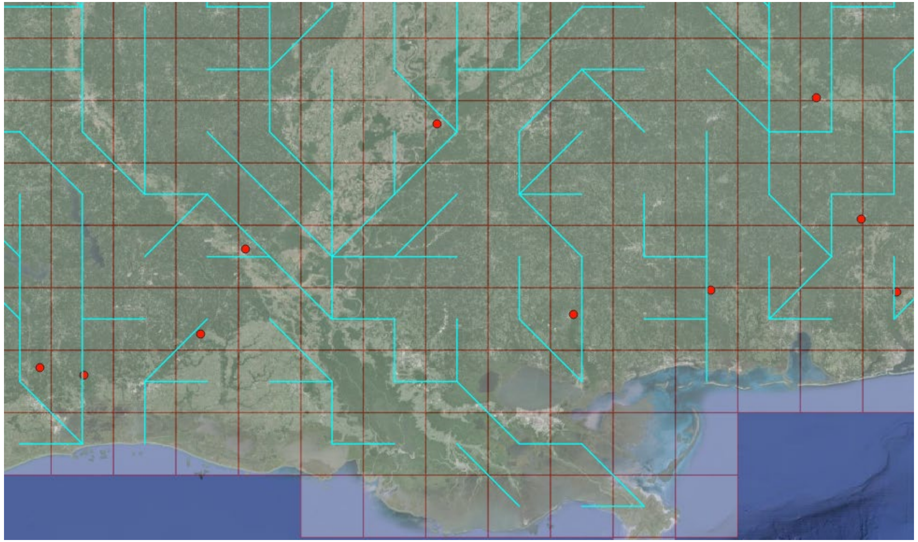
- Need to account for lake evaporation and precipitation input
- River network development for Greenland and Antarctica
- Coupling with the ocean component
- Tracers for heat, DOMs, and isotope (paleo)
- Develop paleo river network and tools

Near-term scientific research topics

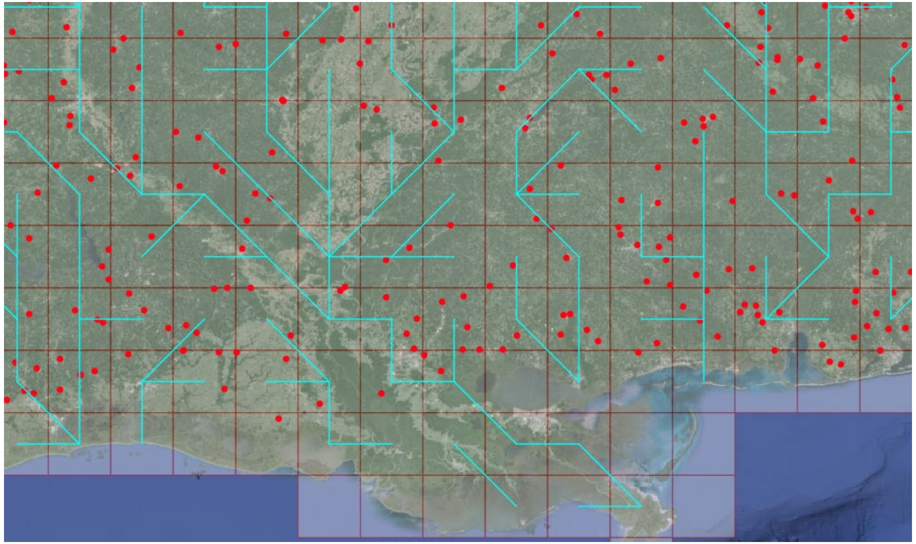
- Re-evaluating discharge to the oceans – Annual volumes, seasonality and long-term trend.
- Evaluation of historical lake volume based on observations (where available) and long-term trends and projections.
- River channel geometry estimates and their impacts on discharges

Reference sites on MOSART 0.5

D19 sites on MOSART 0.5°

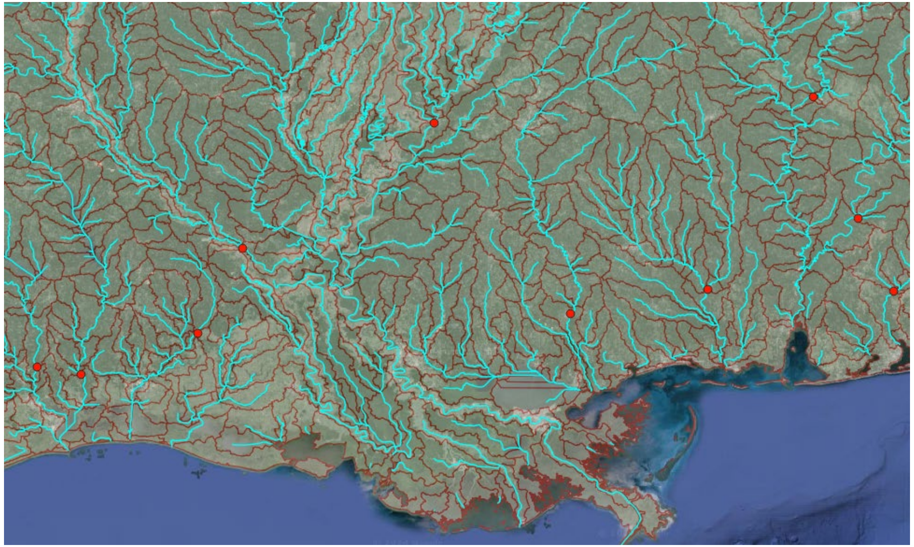


B14 gauges on MOSART 0.5°

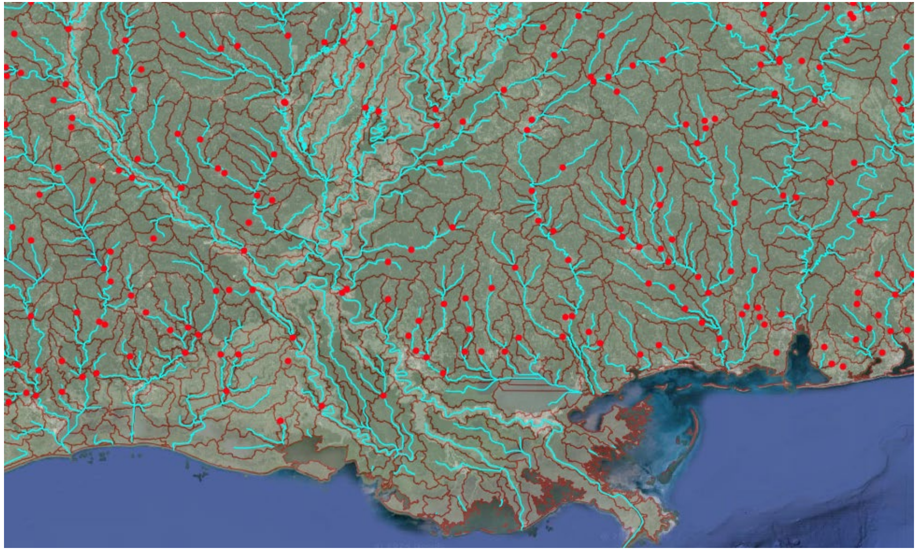


Reference sites on HDMA

D19 sites on HDMA

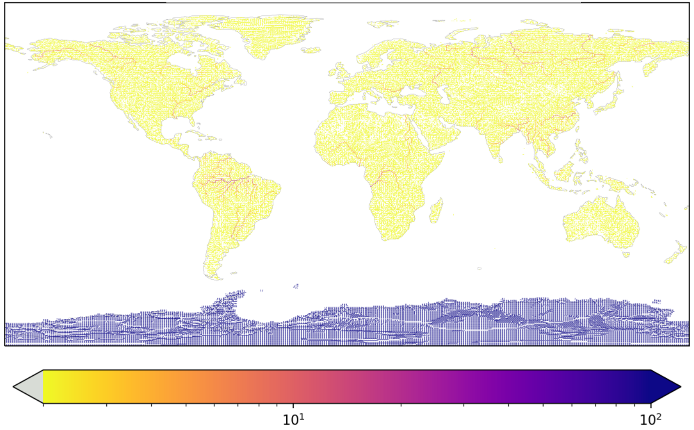


B14 sites on HDMA

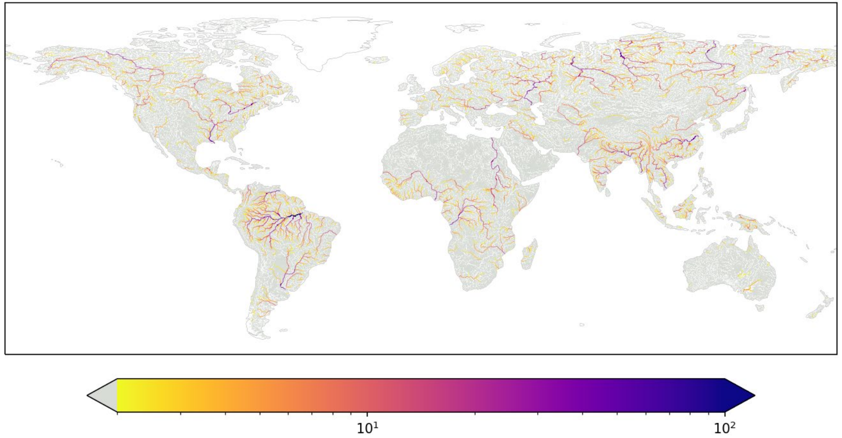


MOSART vs mizuRoute channel properties

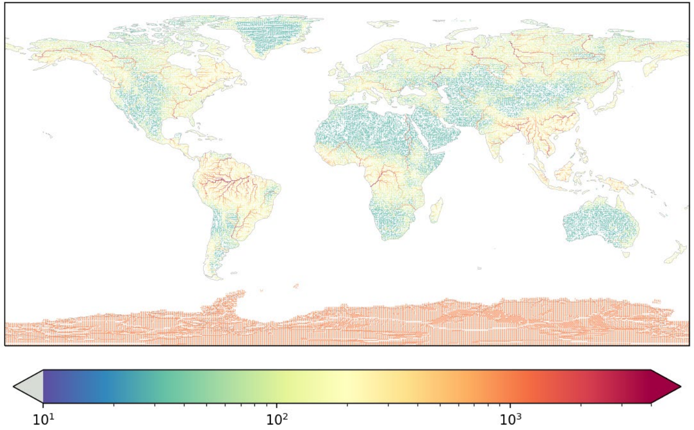
MOSART bank-full depth [m]



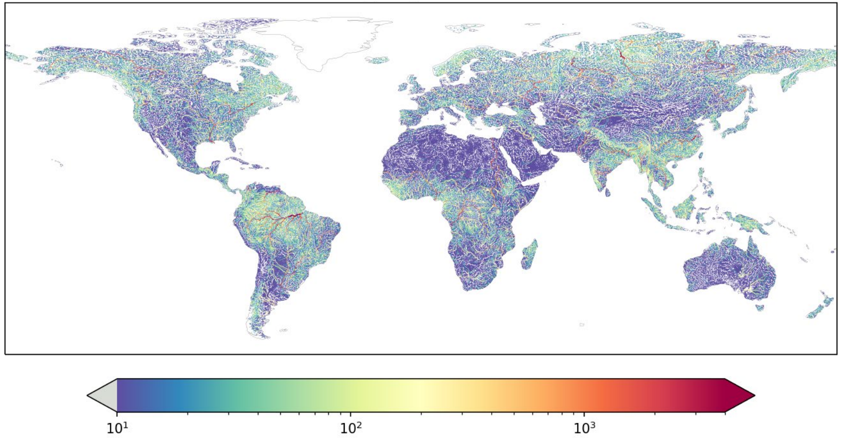
mizuRoute bank-full depth [m]



MOSART bank-full width [m]

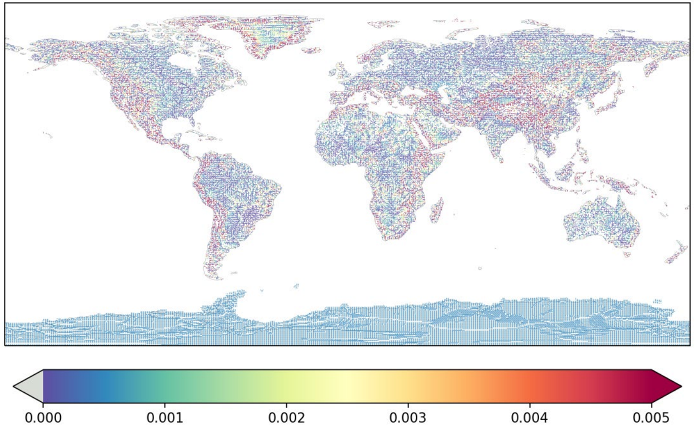


mizuRoute bank-full width [m]

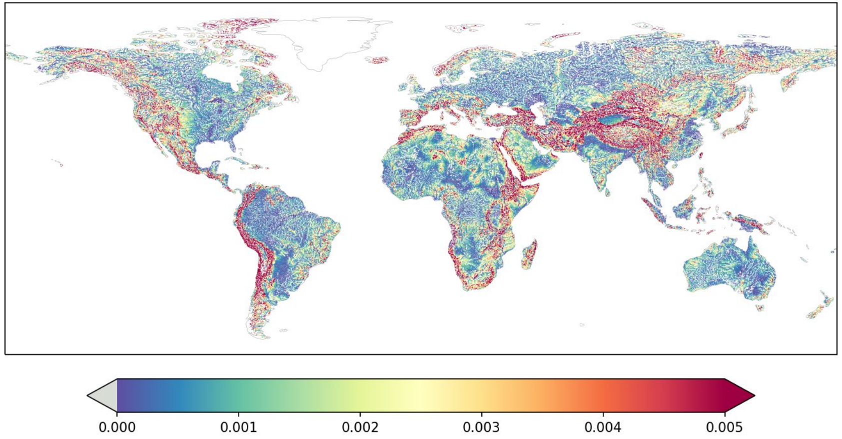


MOSART vs mizuRoute channel properties

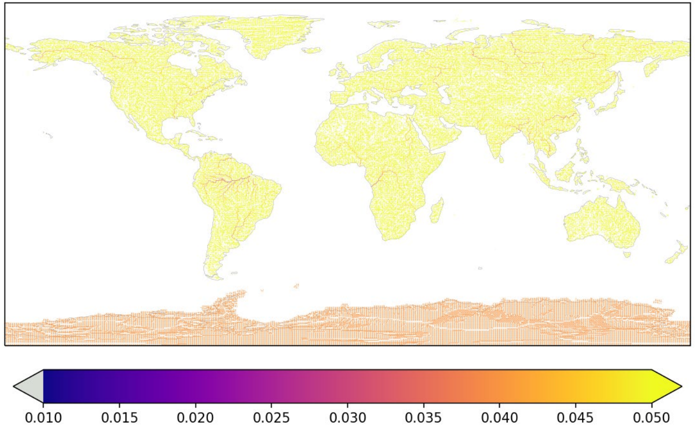
MOSART slope [-]



mizuRoute slope [-]



MOSART manning n [-]



mizuRoute manning n [-]

0.01 everywhere

Used for diffusive wave (not used for IRF)

Diagnostic package

Mimic current ROF diagnostics

Building on Jupyter-notebook

Set 7 Description: **Line plots, tables, and maps of RTM river flow and discharge to oceans**

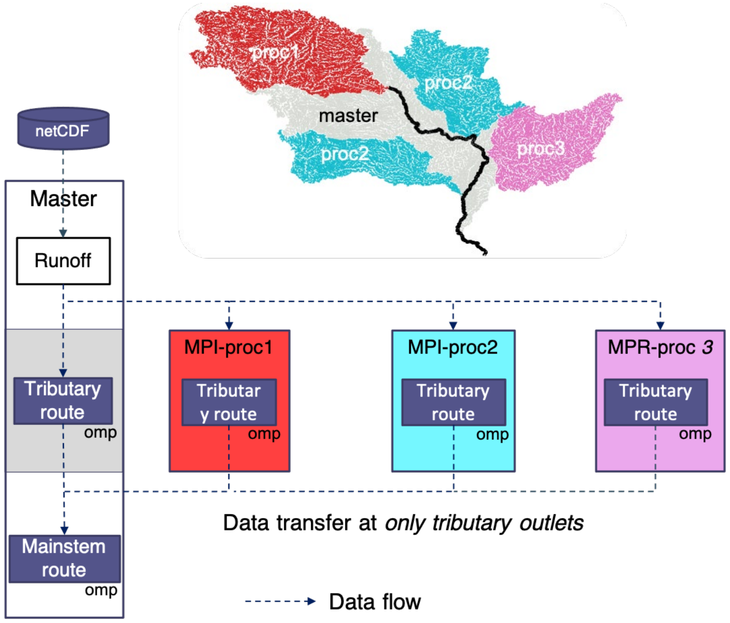
TABLE	
RTM flow at station for world's 50 largest rivers	table
SCATTER PLOTS	
RTM flow at station versus obs for world's 50 largest rivers (QCHANR)	plot
LINE PLOTS	
Mean annual cycle of river flow at station for world's 10 largest rivers (QCHANR)	plot
Annual discharge into the Global Ocean (QCHOCNR)	plot
Annual discharge into the Atlantic Ocean (QCHOCNR)	plot
Annual discharge into the Indian Ocean (QCHOCNR)	plot
Annual discharge into the Pacific Ocean (QCHOCNR)	plot
Mean annual cycle of discharge into the oceans (QCHOCNR)	plot
MAPS	
Station locations (50 largest rivers)	Map
Ocean Basins	Map
River Flow (QCHANR)	Model1 vs Model2

MOSART vs mizuRoute
model physics and numerical solution

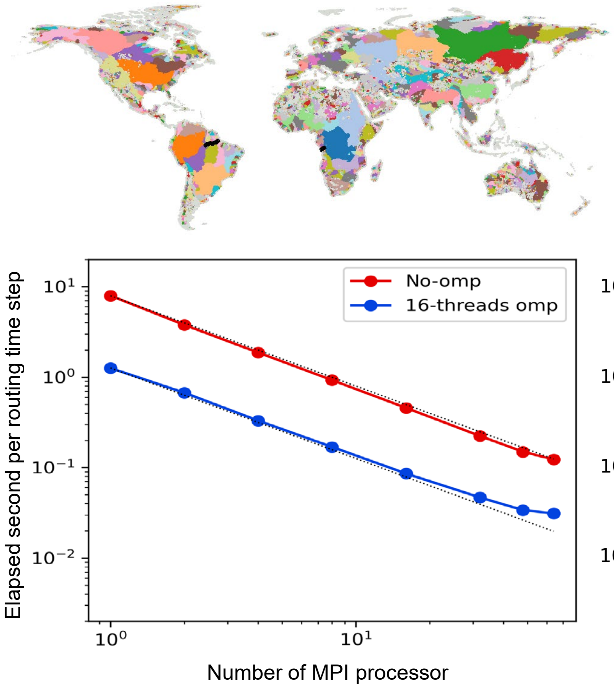
	MOSART	mizuRoute
Discharge equation	Manning equation	Impulse Response Function
Numerical solution	Euler, explicit, operator splitting (continuity equation)	Euler, explicit, operator splitting (continuity equation)
routing time step	1hr	1day
coupling time step	3hr	1 day

mizuRoute

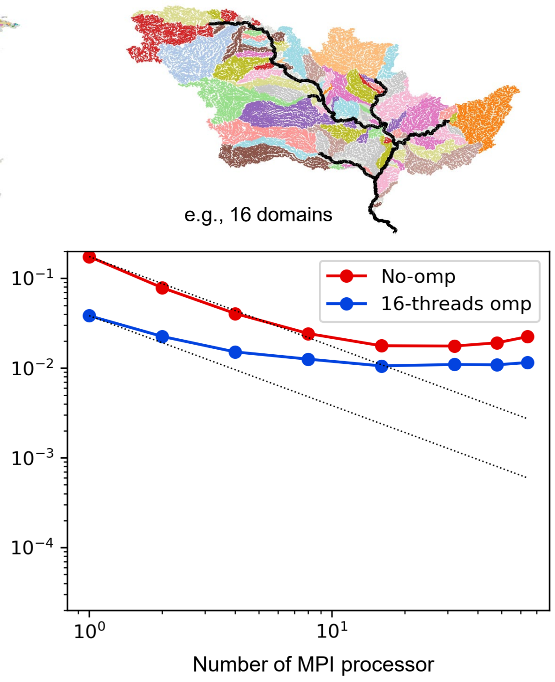
- River network, topological-based routing model (in contrast to gridded routing model)
- Hybrid parallel computing (MPI + openMP)
- Multiple routing schemes



Scaling for routing over global



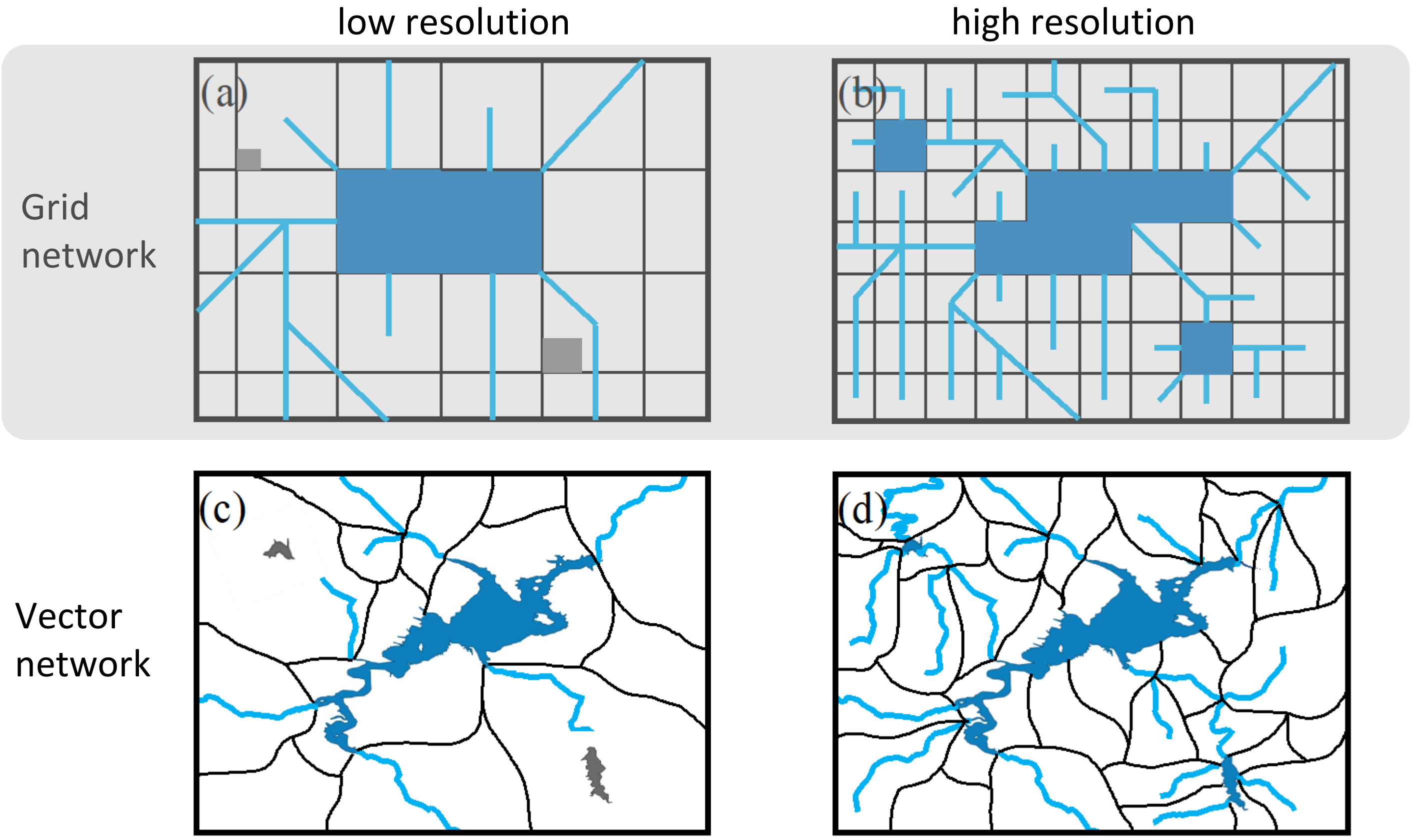
Scaling for routing over Mississippi



Mizukami et al., 2016 (GMD); 2022 (JAMES)

mizuRoute-Lake

Model representation of lakes and rivers

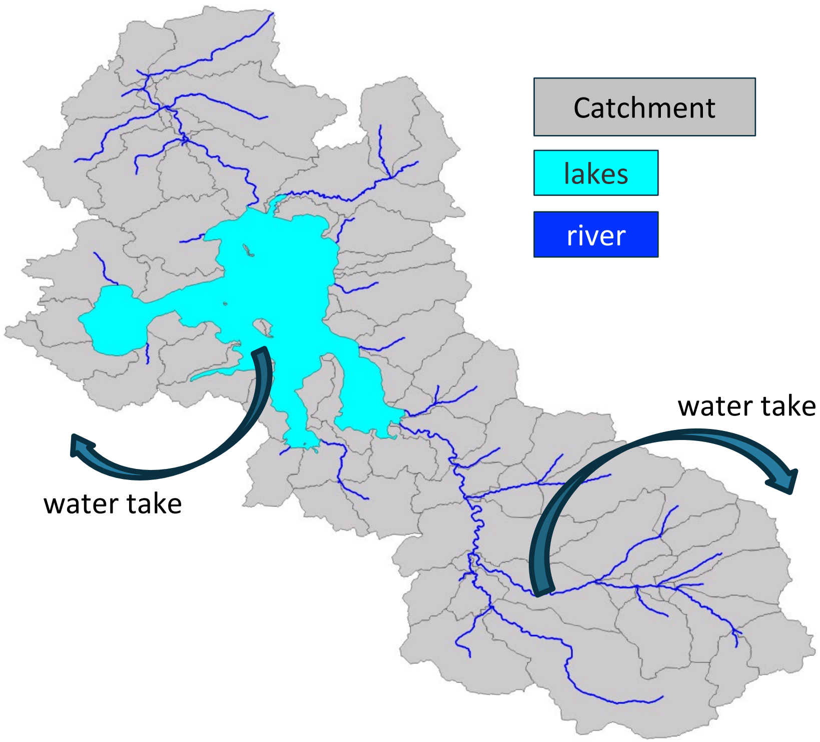


Gharari et al., 2024 WRR, almost there!

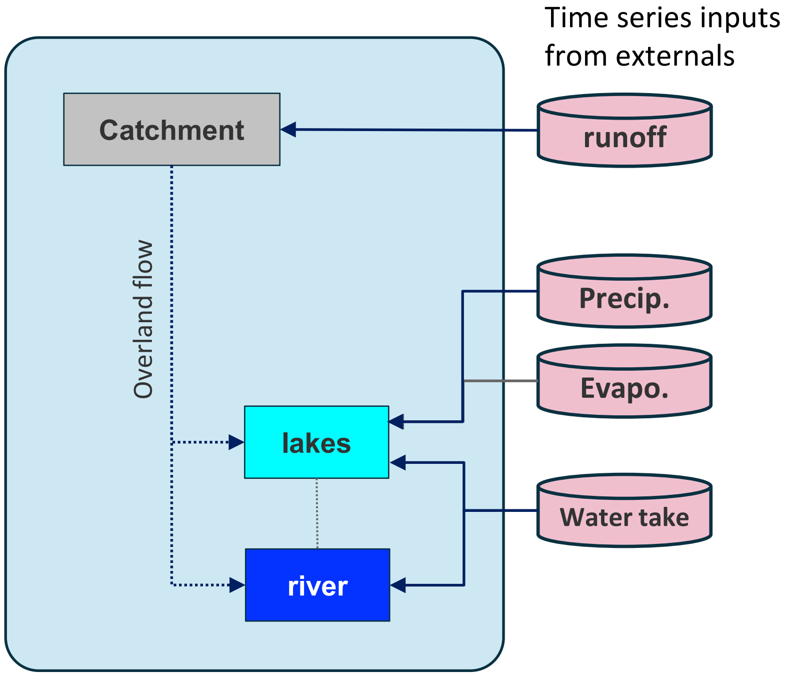
mizuRoute-lake

Multi-model approach for lakes and reservoirs

river-lake system schematics



model

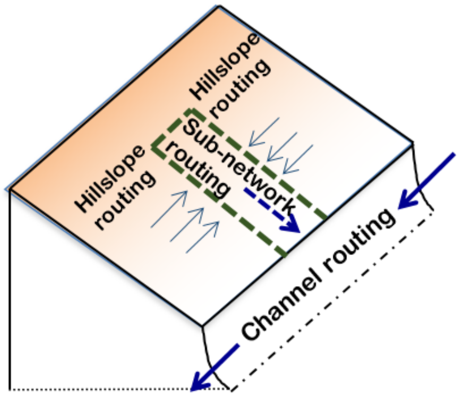


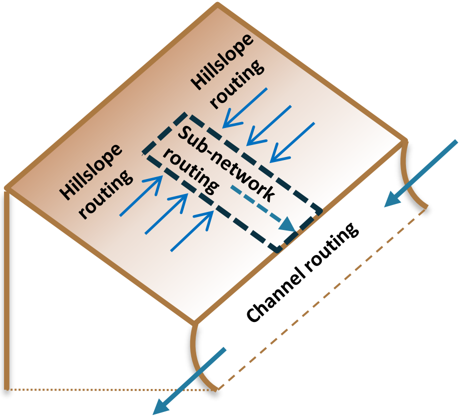
Lake discharge model

Lake discharge models: parametric or data driven

	Feature	Source
endorheic	no discharge	-
D03	$Q = a(S - S_0)(\frac{S - S_0}{S_{max} - S_0})^b$	Doll et al, 2003
H06	Complex (13 parameters, monthly demands), demand based operation	Hanasaki et al., 2006
HYPE	Less complex (15 parameters), zone based-hydropower operation	Arheimer et al., 2019
Target Volume	Data driven, useful for data assimilation	-

Gharari et al., 2024 WRR, almost there!


Hillslope routing
Hillslope routing
Sub-network routing
Channel routing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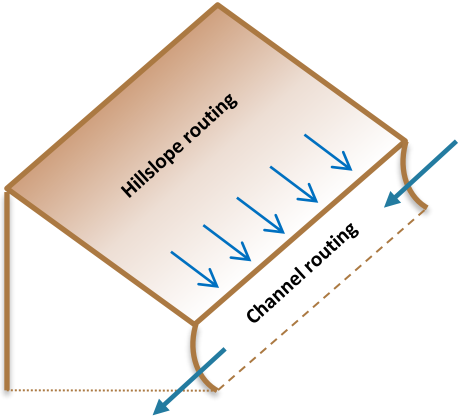
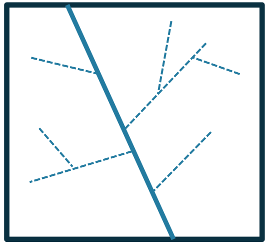
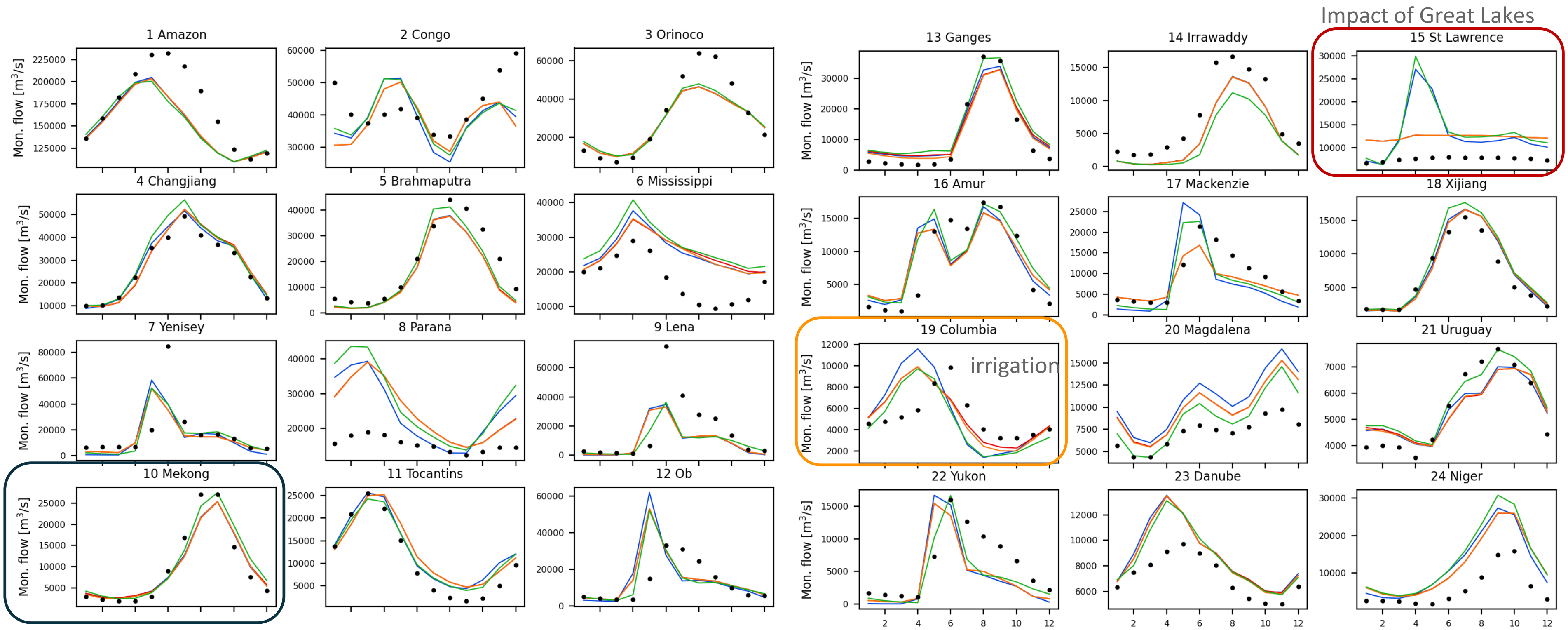

Hillslope routing
Channel routing



Summary

- Discharge difference at monthly (or longer) scale is mainly due to drainage area difference, contributing difference in volume bias. Routing physics have minor impacts for coarse time scale. Lakes do affect seasonality and bias.
- MOSART 0.5° is too coarse to resolve small basins, leading overestimation of discharge for those basins. Increasing resolution (e.g. 0.125°) could resolve this to some degree, but increase significant computing time.
- For mizuRoute, plan to move from the most simple routing-Impulse response Function to the more physical-based routing method to improve fidelity of river flow physics and facilitate other physical process implementation (e.g., floodplain).

Seasonality (1960-1999)



No lake impact!
Missing lots of dams

mizuRoute HDMA
mizuRoute HDMA+lake
mizuRoute HDMA+lake irrigation
MOSART 0.5°
D19