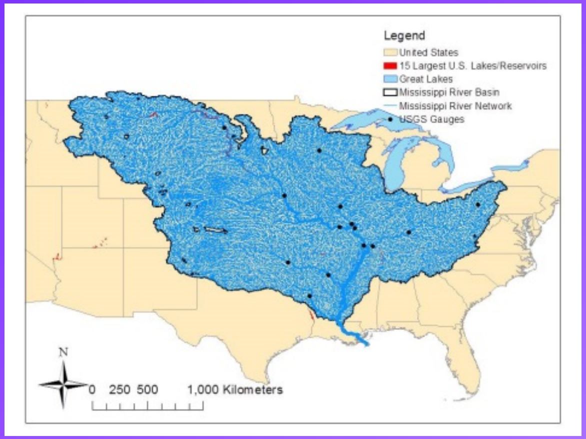
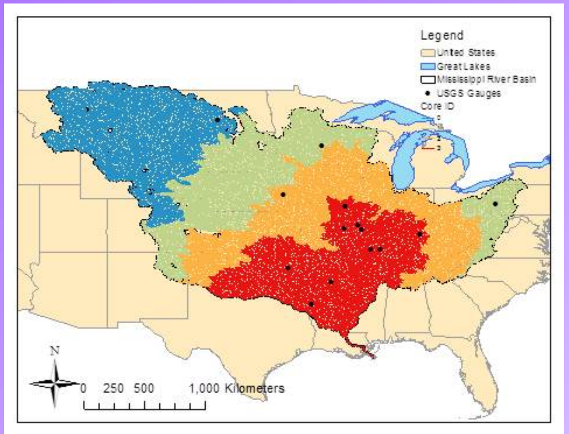




Modeling the Mississippi River Basin with RAPID

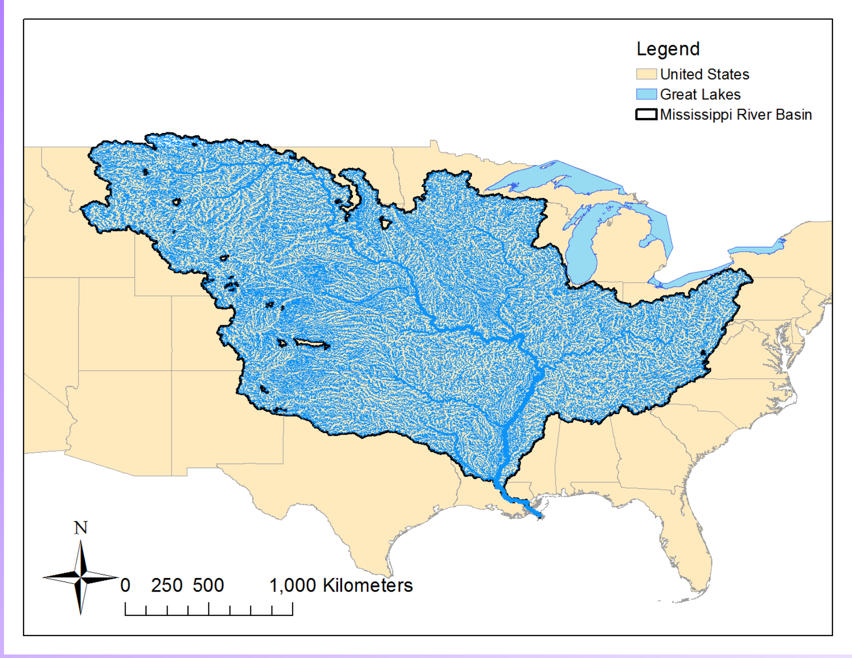
Cédric H. David
James S. Famiglietti
Zong-Liang Yang
Victor Eijkhout

Continental scale hydro model inter-comparison for SWOT

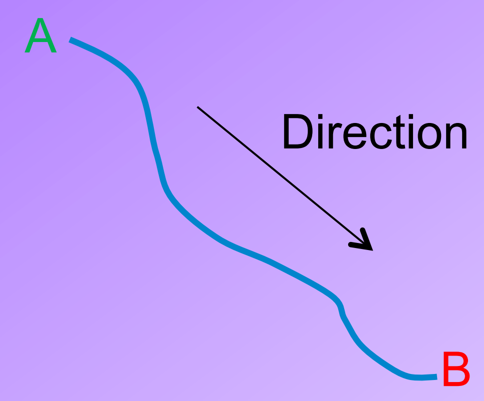
31 Aug 2016

Outline

- **RAPID**
- Some data processing
- Simulations
- Discussion

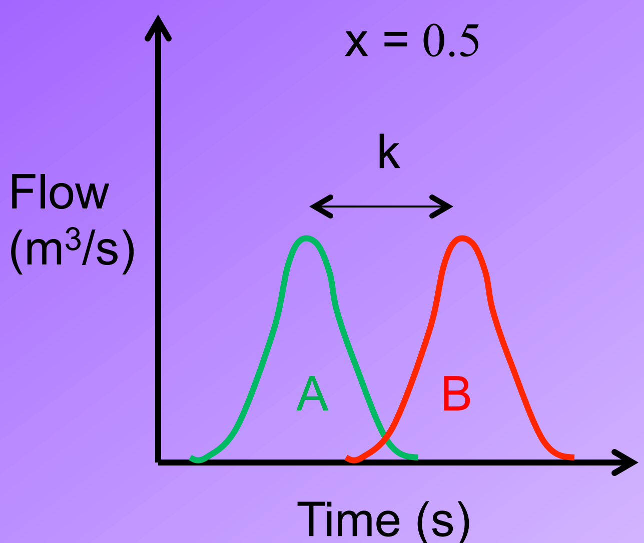


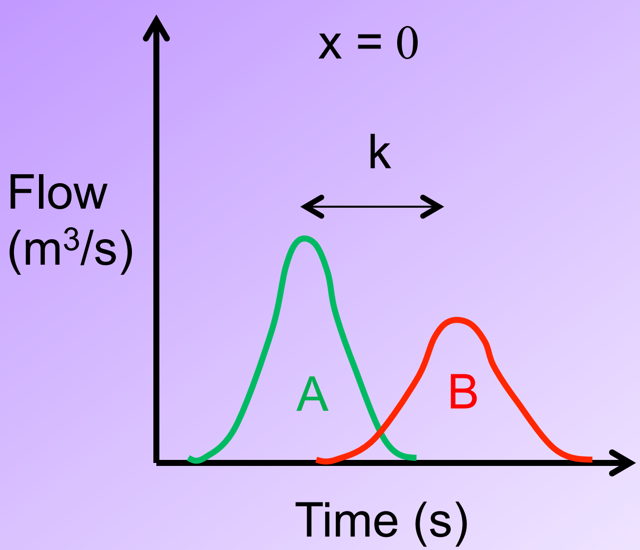
RAPID is based on the Muskingum method



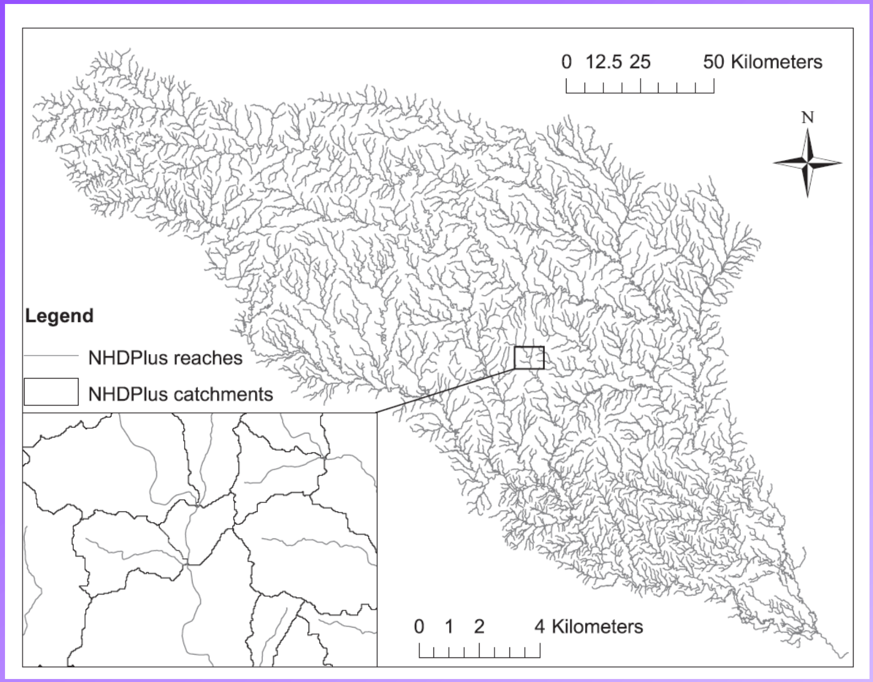
k is a time ($k \geq 0$) related to the celerity of the flow wave

x is a non-dimensional parameter ($0 \leq x \leq 0.5$) related to diffusion of the flow wave





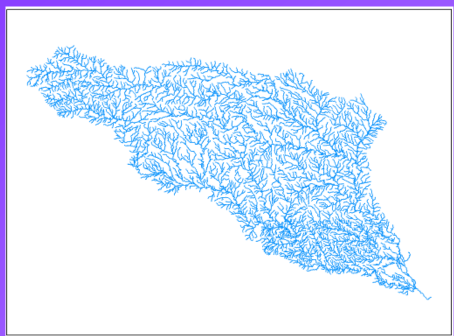
Relationship between rivers and their catchments in RAPID

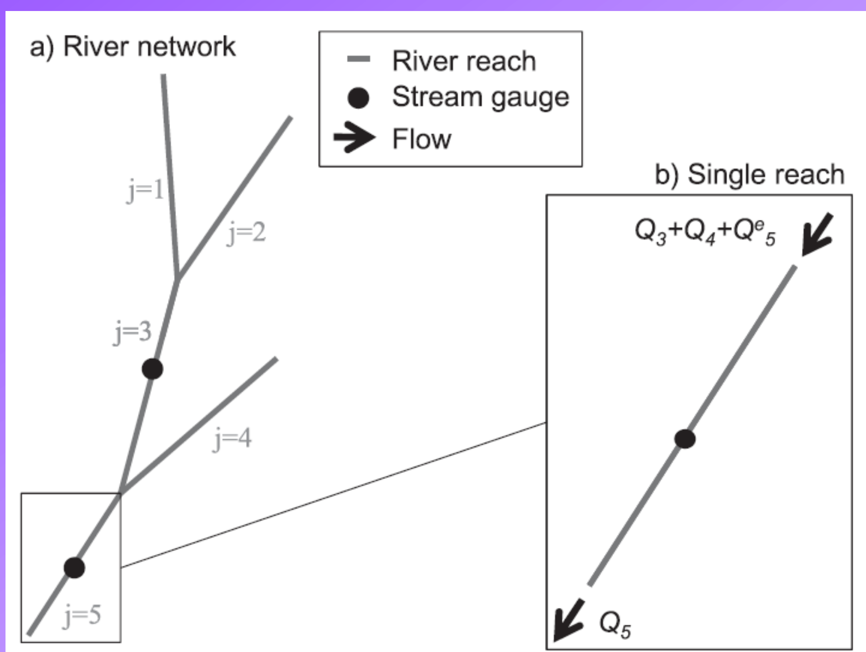


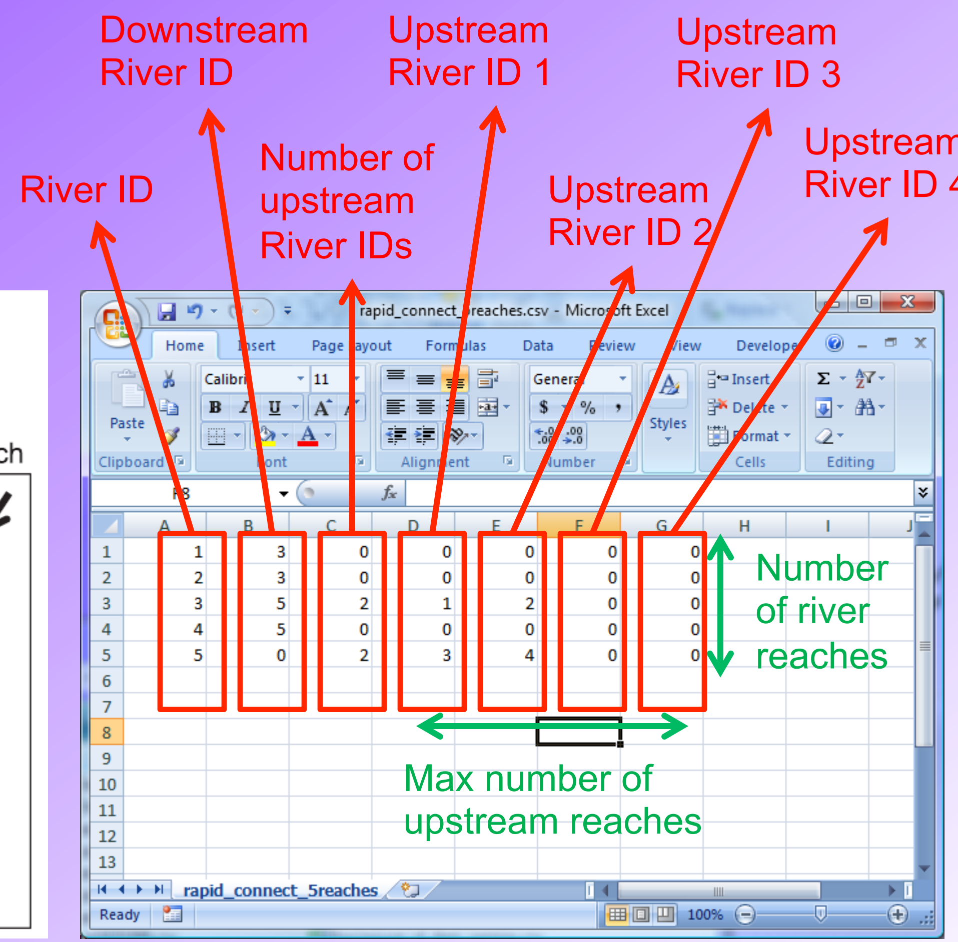
From David et al. 2011 (JHM)

1 river reach ⟷ 1 catchment

River network connectivity in RAPID

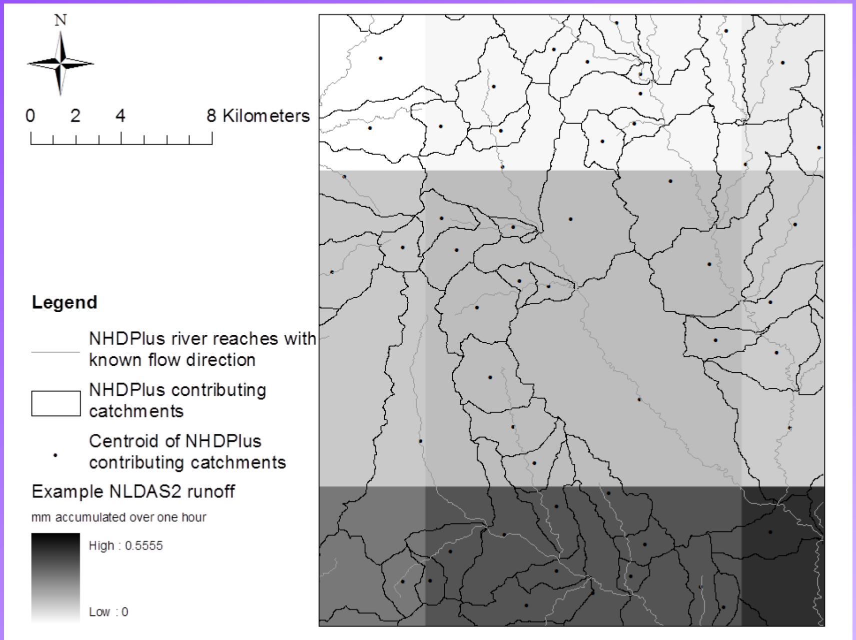






From David et al. 2011 (JHM)

Compute the inflow to rivers from runoff

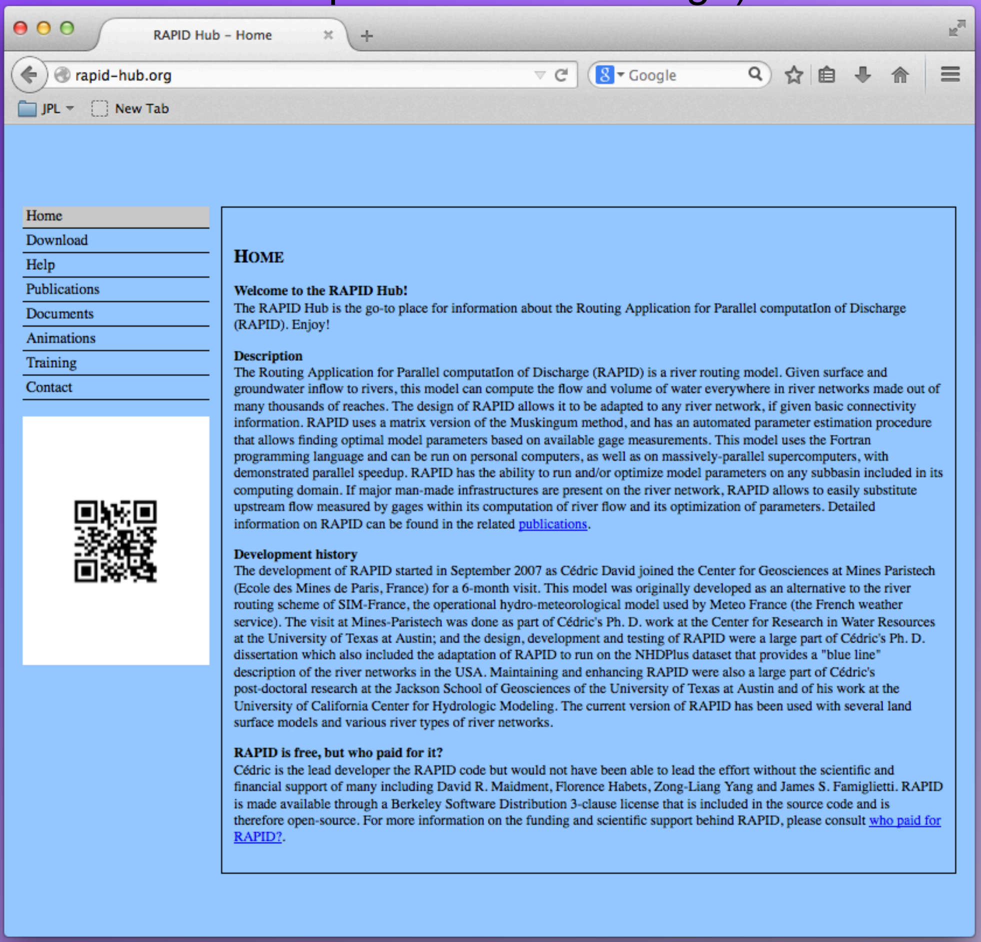


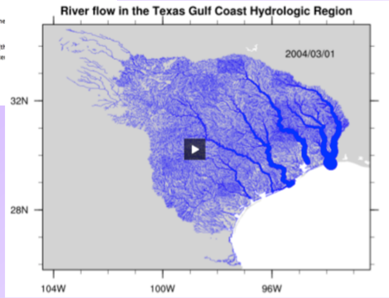
- Superimpose with map of catchments
- Using runoff value at catchment centroid and catchment area

David, Hong and Yang (2013, EMS)

RAPID website and documentation

RAPID (Routing Application for Parallel computatIon of Discharge)





Animations, tutorials, publications:
All on the RAPID website:
http://rapid-hub.org

Fostering community development

JPL
- Parallel performance
- Reservoirs/diversions
- Large-scale modeling
- Preparation for SWOT

NCAR
- Coupling with WRF-Hydro

cnes / METEO FRANCE CNRM/GAME
- Computation of water elevation
- Two new flow wave propagation schemes

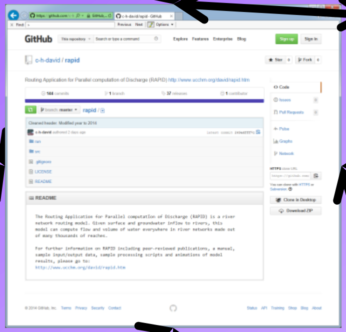
33 previously released versions of the RAPID code

Revisions tracked with git

4 official releases

GitHub

The University of Texas at Austin Jackson School of Geosciences
- Online coupling with Noah-MP
- Reservoir work



US Army Corps of Engineers

Microsoft Research
- Cloud computing

BYU
- Flood forecasting app

esri
- Processing toolbox

CRWR
- National Flood Interoperability experiment

Illinois
- Optimization of water allocations

Mines ParisTech
- Online coupling with groundwater model

[Fork RAPID on GitHub](#)
[Star RAPID on GitHub](#)

[Follow me on GitHub](#)

Travis CI

RAPID is now on GitHub!!!

Outline

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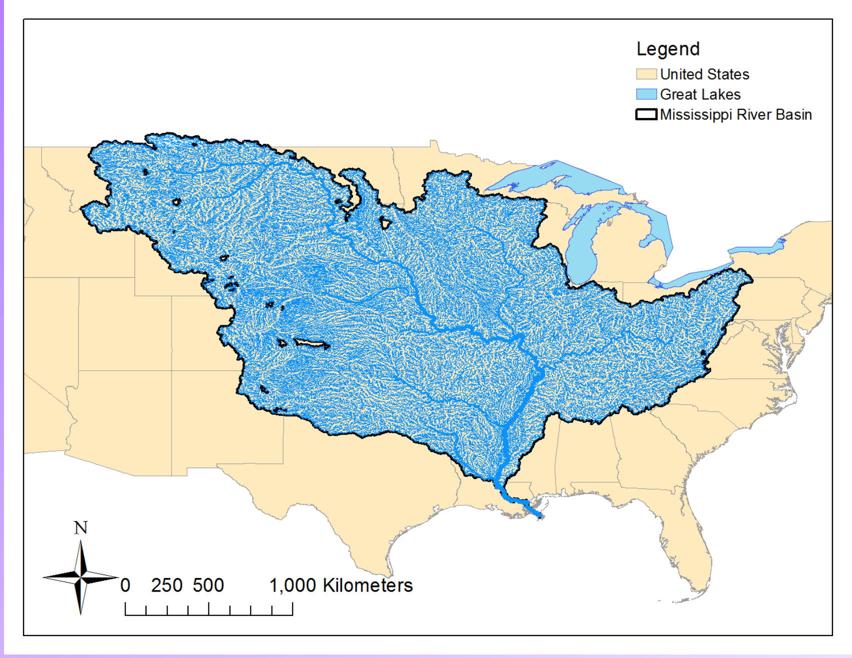


HydroSHEDS

Eos, Vol. 89, No. 10, 4 March 2008

EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 89 NUMBER 10
4 MARCH 2008
PAGES 93–100

New Global Hydrography Derived From Spaceborne Elevation Data

PAGES 93–94

To study the Earth system and to better understand the implications of global environmental change, there is a growing need for large-scale hydrographic data sets that serve as prerequisites in a variety of analyses and applications, ranging from regional watershed and freshwater conservation planning to global hydrological, climate, biogeochemical, and land surface modeling. Yet while countless hydrographic maps exist for well-known river basins and individual nations, there is a lack of seamless high-quality data on large scales such as continents or the entire globe. Data for many large international basins are patchy, and remote areas are often poorly mapped.

In response to these limitations, a team of scientists has developed data and created maps of the world's rivers that provide the research community with more reliable information about where streams and watersheds occur on the Earth's surface and how water drains the landscape. The new product, known as HydroSHEDS (Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scales), provides this information at a resolution and quality unachieved by previous global data sets, such as HYDRO1k [*U.S. Geological Survey (USGS)*, 2000].

HydroSHEDS, which was developed by the Conservation Science Program of the World Wildlife Fund, is based primarily on elevation data obtained during NASA's Shuttle Radar Topography Mission (SRTM) [*Farr and Kobrick*, 2000]. At the most basic level, the kind of hydrographic information provided by HydroSHEDS will allow scientists and managers to create digital river maps and delineate watershed boundaries. These maps can then be coupled with a variety of other data sets or applied in computer simulations to perform more sophisticated analyses, such as the routing of river flow within hydrological models.

Data already have been completed for South and Central America, Asia, Africa, and Australia. These data are available for download from the USGS Earth Resources Observation and Science (EROS) Data Center. Data for the remaining landmasses of Europe and North America will be released within the next 6 months.

Data Development

The HydroSHEDS database contains both raster and vector layers describing the topography, drainage networks, and watersheds of the Earth's surface. The primary data source used in the development of HydroSHEDS was the SRTM digital elevation model, with ancillary data sources including the SRTM Water Body Data (see http://edc.usgs.gov/products/elevation/swbdguide.doc), the river networks of the Digital Chart of the World (DCW) [*Environmental Systems Research Institute (ESRI)*, 1993] and ArcWorld [*ESRI*, 1992], and the Global Lakes and Wetlands Database [*Lehner and Döll*, 2004].

The processing steps of generating HydroSHEDS are detailed in the data set's technical documentation [*Lehner et al.*, 2006]. Several of the procedures used in developing HydroSHEDS represent standard techniques

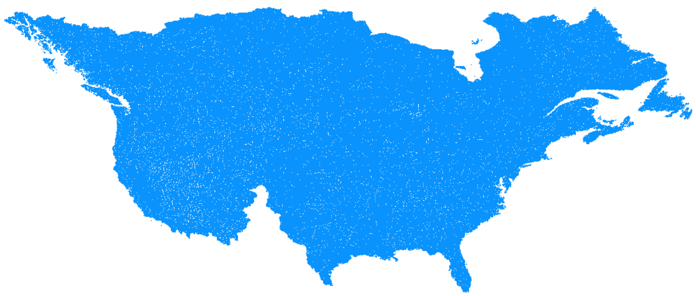
Fig. 1. HydroSHEDS river network and endorheic areas in Africa.

BY B. LEHNER, K. VERDIN, AND A. JARVIS

Lehner et al. (2008)

http://hydrosheds.cr.usgs.gov/index.php

HydroSHEDS for North America



Rivers (vector file)

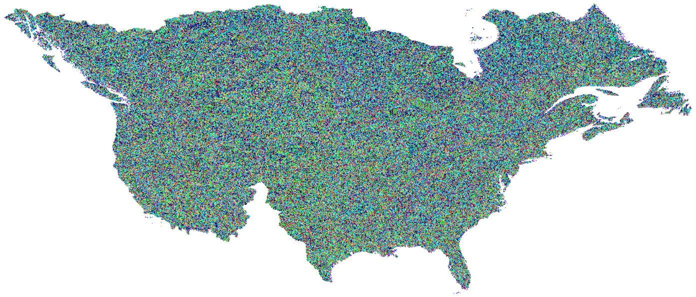
Table

na_riv_15s

FID	Shape *	ARCID	UP_CELLS
0	Polyline	1	291
1	Polyline	2	183
2	Polyline	3	544
3	Polyline	4	167
4	Polyline	5	449
5	Polyline	6	285
6	Polyline	7	147
7	Polyline	8	102
8	Polyline	9	137
9	Polyline	10	243
10	Polyline	11	208
11	Polyline	12	903
12	Polyline	13	122
13	Polyline	14	106
14	Polyline	15	131
15	Polyline	16	109
16	Polyline	17	220
17	Polyline	18	128
18	Polyline	19	101
19	Polyline	20	827
20	Polyline	21	126
21	Polyline	22	174
22	Polyline	23	2660
23	Polyline	24	417
24	Polyline	25	206
25	Polyline	26	355
26	Polyline	27	1121
27	Polyline	28	1478
28	Polyline	29	2532
29	Polyline	30	114
30	Polyline	31	3180
31	Polyline	32	176
32	Polyline	33	3450

1 (0 out of 467819 Selected)

na_riv_15s



Flow direction (raster file)

Major Basins (vector file – beta)

Table

na_bas_15s_beta

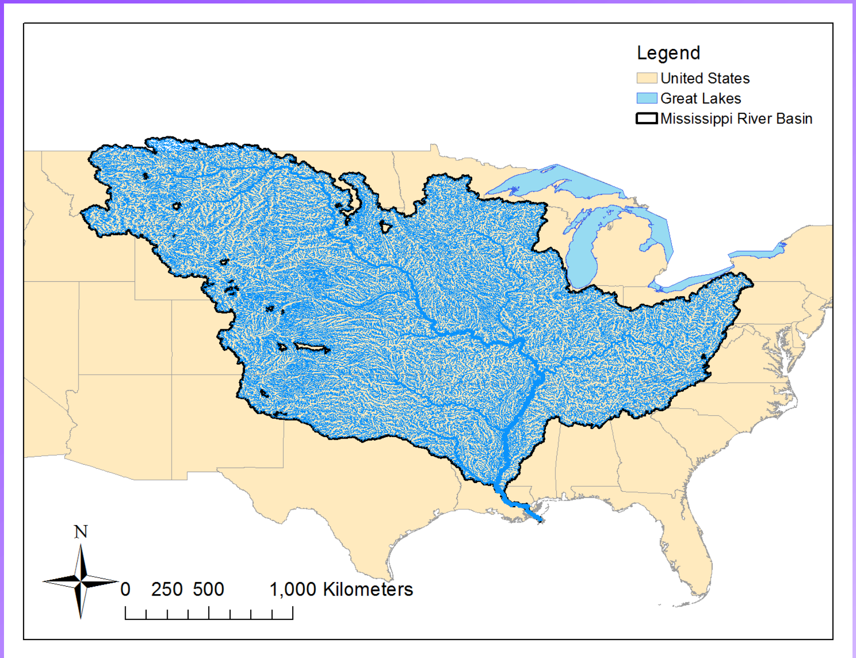
FID	Shape *	BASIN_ID	AREA_SQKM
0	Polygon	1	0.1
1	Polygon	2	0.2
2	Polygon	3	0.2
3	Polygon	4	0.2
4	Polygon	5	0.2
5	Polygon	6	0.1
6	Polygon	7	0.1
7	Polygon	8	0.1
8	Polygon	9	0.1
9	Polygon	10	0.1
10	Polygon	11	0.1
11	Polygon	12	0.1
12	Polygon	13	0.1
13	Polygon	14	0.2
14	Polygon	15	0.2
15	Polygon	16	0.2
16	Polygon	17	0.2
17	Polygon	18	0.1
18	Polygon	19	0.1
19	Polygon	20	0.1
20	Polygon	21	0.1
21	Polygon	22	0.2
22	Polygon	23	0.2
23	Polygon	24	0.2
24	Polygon	25	0.1
25	Polygon	26	0.1
26	Polygon	27	0.1
27	Polygon	28	0.1
28	Polygon	29	0.1
29	Polygon	30	0.1
30	Polygon	31	0.1
31	Polygon	32	0.1
32	Polygon	33	0.3

1 (0 out of 448914 Selected)

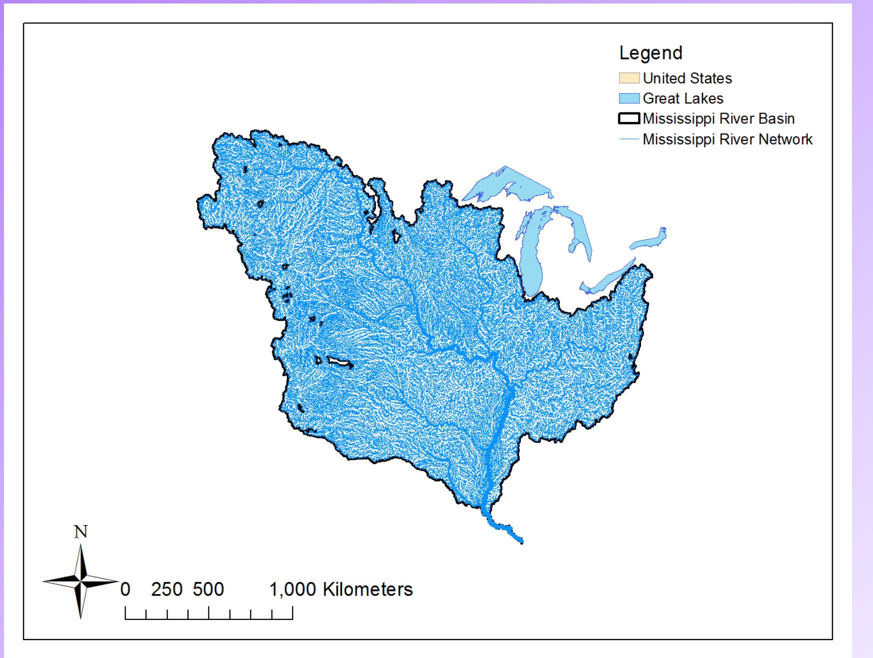
na_bas_15s_beta

Also DEM, conditioned DEM, and Flow accumulation

Computing the length of each river reach



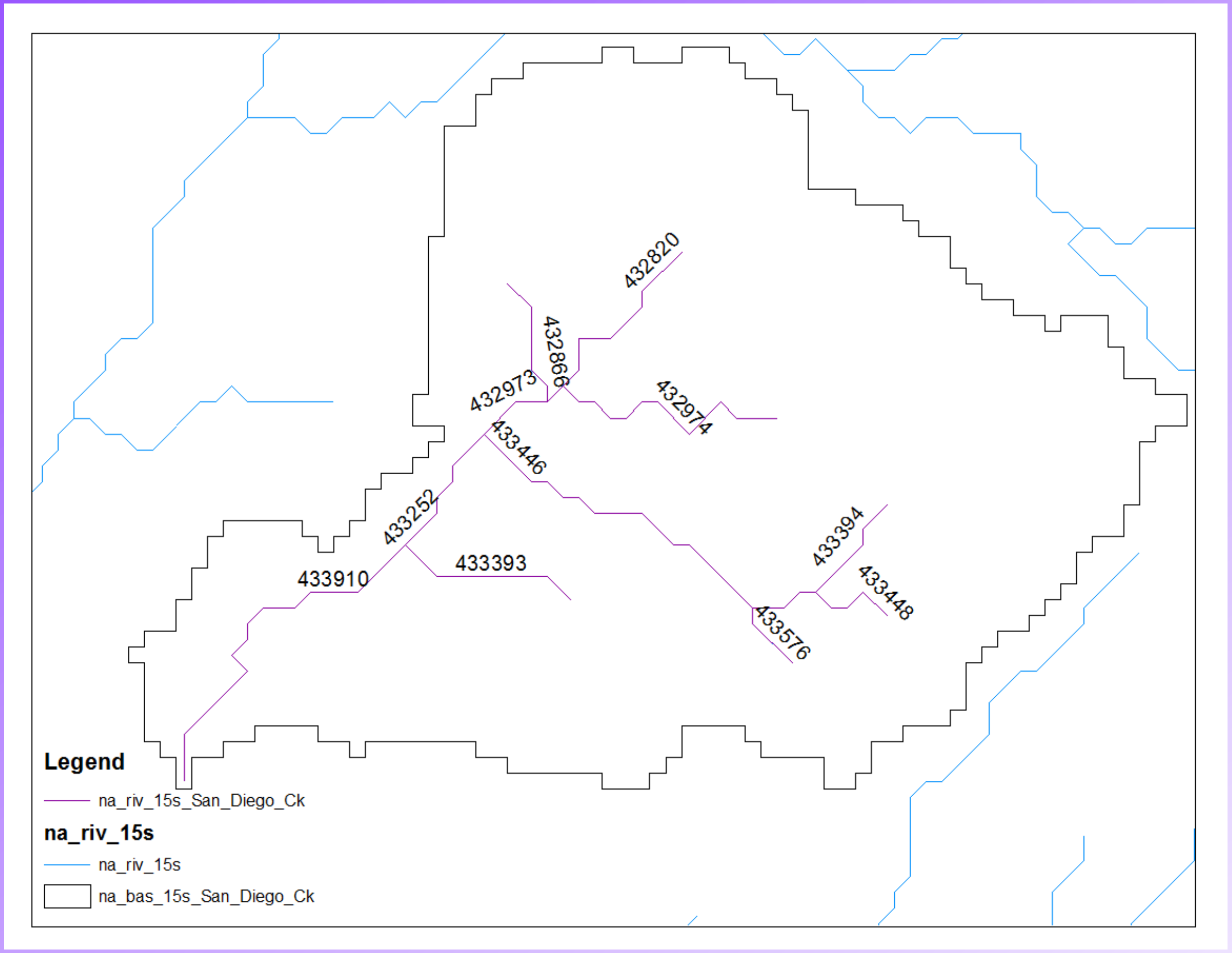
Geographic Coordinate System



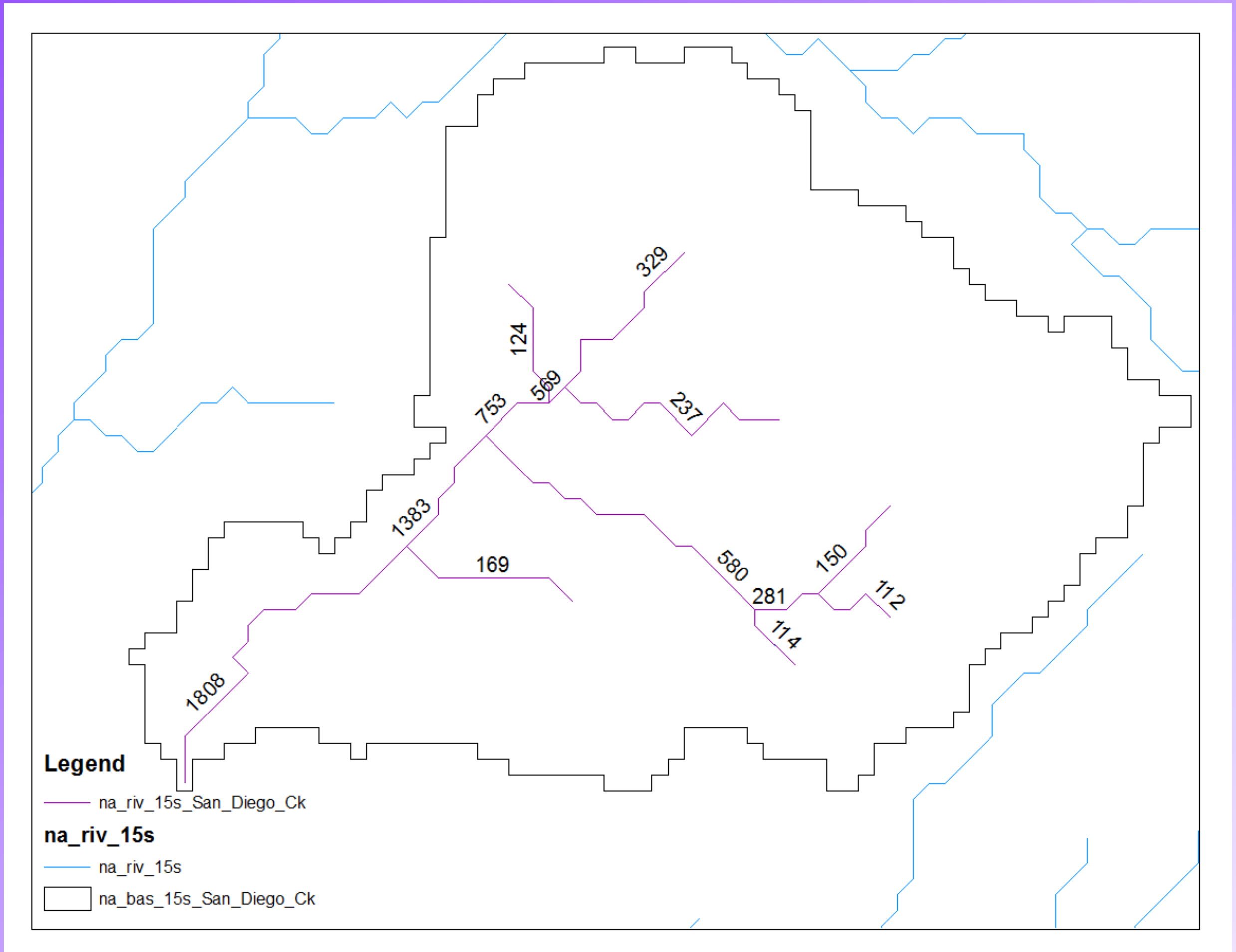
Projected Coordinate System

(Because RAPID flow wave celerity based on length)

HydroSHEDS river IDs

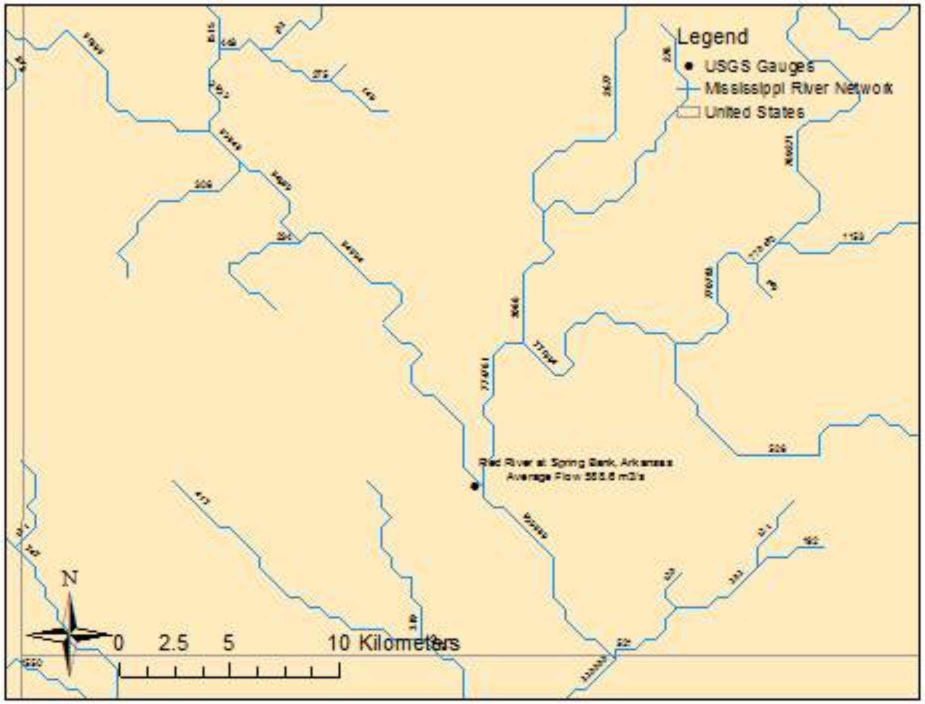


HydroSHEDS cumulative catchment size

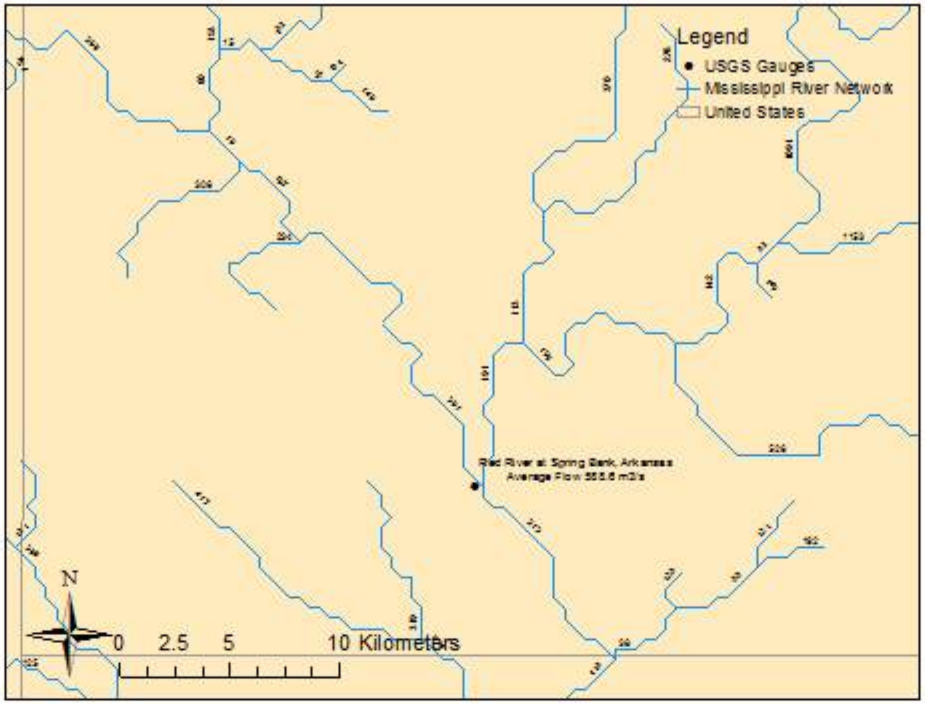


The unit for catchment size is number of 15-second grid cells

Compute the non-cumulative catchment area



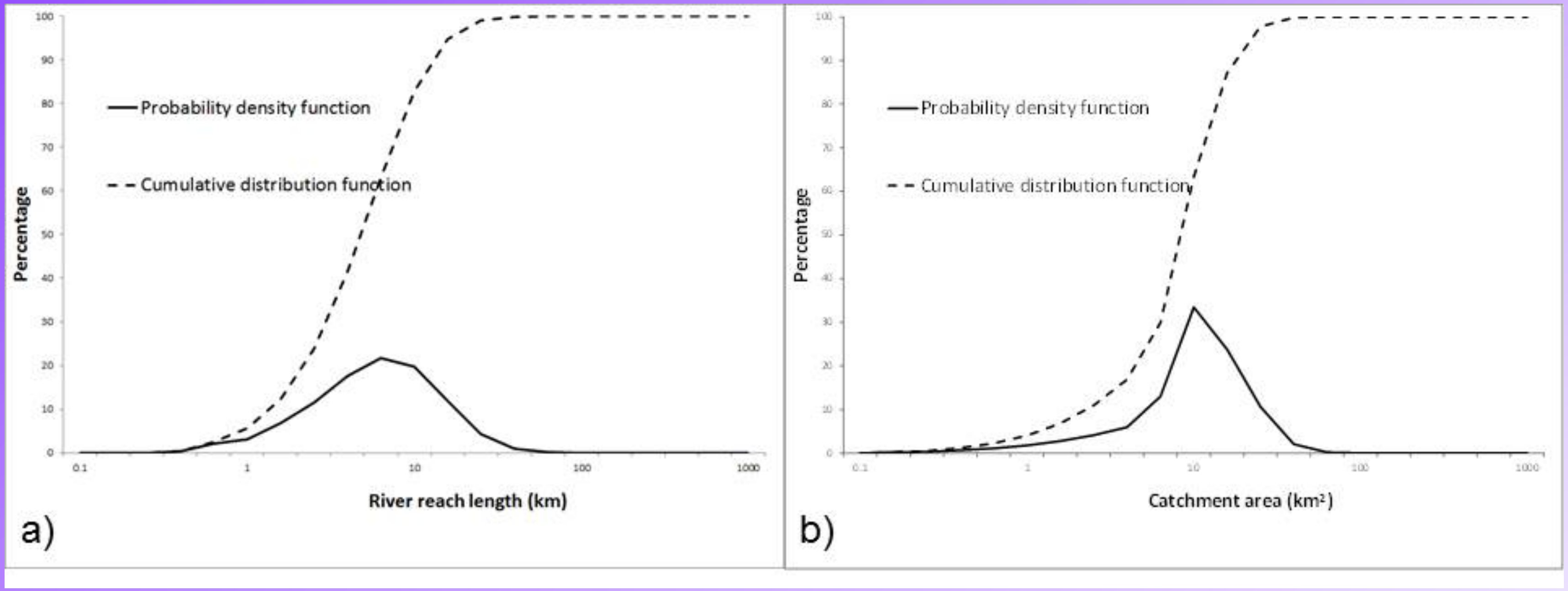
Cumulative



Non-cumulative

Some statistics about the computing domain

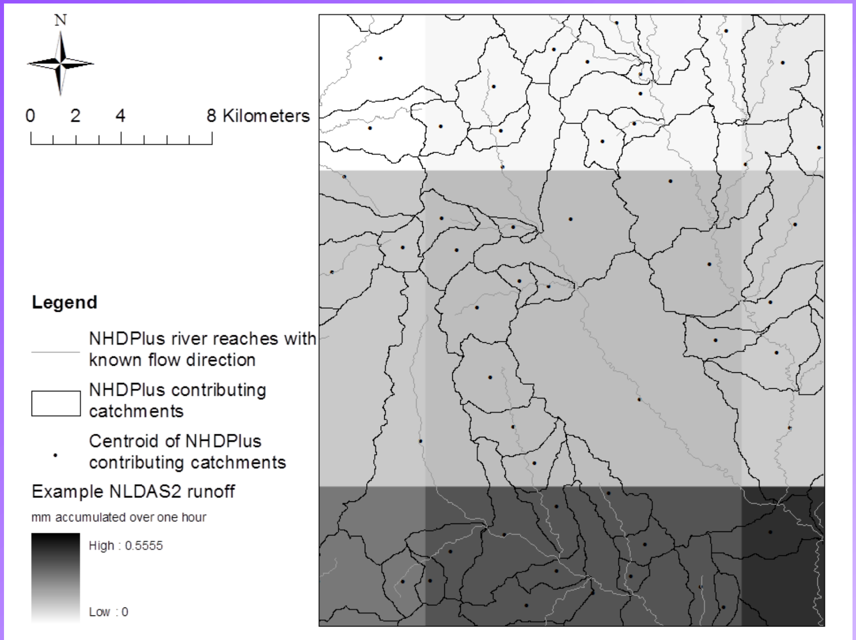
102,229 river reaches and catchments



River reaches vary in size from 0.29 to 101.50 km (**mean: 6.20 km**, median: 4.79 km, standard deviation 5.29 km).

Contributing catchments vary in size from 0.14 to 542.78 km^2 (**mean: 31.11 km^2**, median: 24.79 km^2, standard deviation 25.66 km^2).

Compute the inflow to rivers from NLDAS2



David, Hong and Yang (2013, EMS)

- Download NLDAS2 .grb files
- Convert .grb to .nc files and extract runoff fields
- 3-hourly average
- 6-hour shift (UTC-CST)
- Superimpose with map of catchments

Advantages of using HydroSHEDS for SWOT

WATER RESOURCES RESEARCH, VOL. 49, 1–5, doi:10.1002/wrcr.20440, 2013

A simple global river bankfull width and depth database

Konstantinos M. Andreadis,[1] Guy J.-P. Schumann,[1] and Tamlin Pavelsky[2]

Received 25 October 2012; revised 15 July 2013; accepted 19 July 2013.

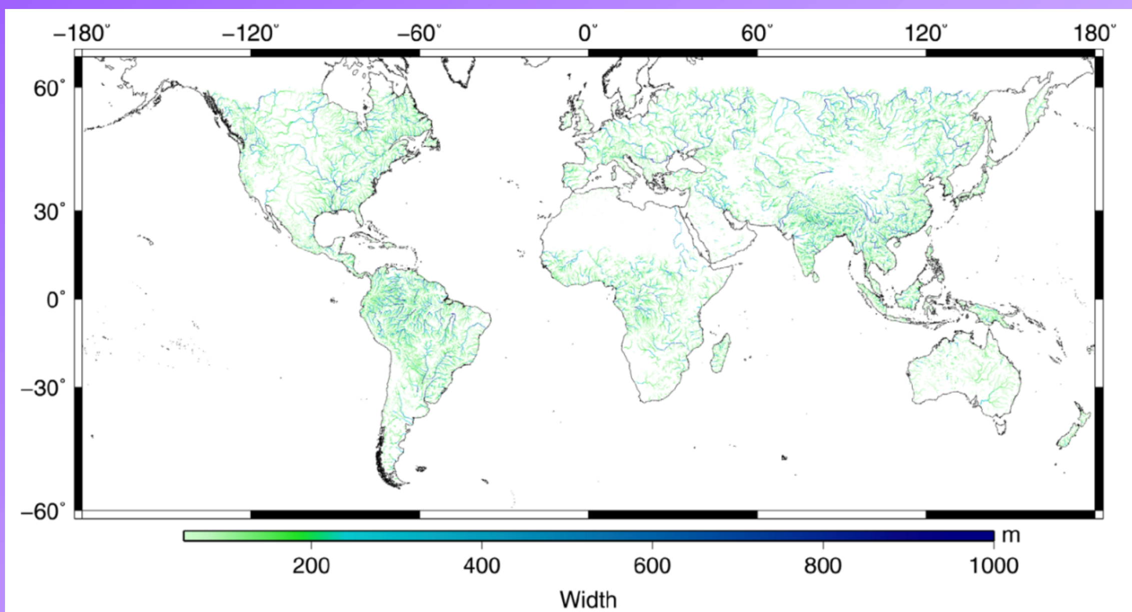


Figure 2. Map of river widths globally, with a threshold of 50 m (not shown) and 1000 m (reaches with larger widths reset with this value) applied for display purposes.

Derived from SRTM measurements

Vector-based (blue lines and not grid cells) → SWOT will see actual water bodies (10-100 m swath resolution), not 1° grid cells

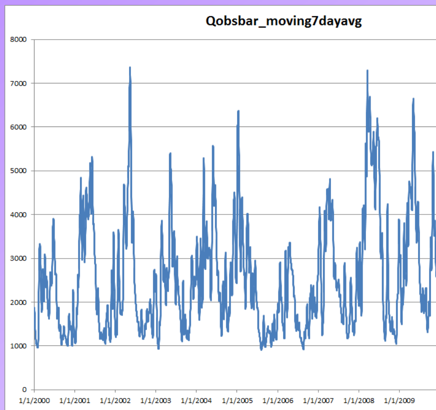
Some existing preliminary interest from the SWOT community

Selecting gauging stations

Missouri River at Bismarck, North Dakota
Missouri River at Omaha, Nebraska
Missouri River at Hermann, Missouri
Mississippi River at Saint Paul, Minnesota
Mississippi River at Keokuk, Iowa
Mississippi River at Grafton, Illinois
Mississippi River at Saint Louis, Missouri
Mississippi River at Thebes, Illinois
Ohio River at Sewickley, Pennsylvania
Ohio River at Louisville, Kentucky
Ohio River at Metropolis, Ohio
Arkansas River near Haskell, Oklahoma
Arkansas River at Murray Dam near Little Rock, Arkansas
Red River at Spring Bank, Arkansas

2000 is the driest and 2008 is the wettest (Upper Mississippi Floods of 2008)

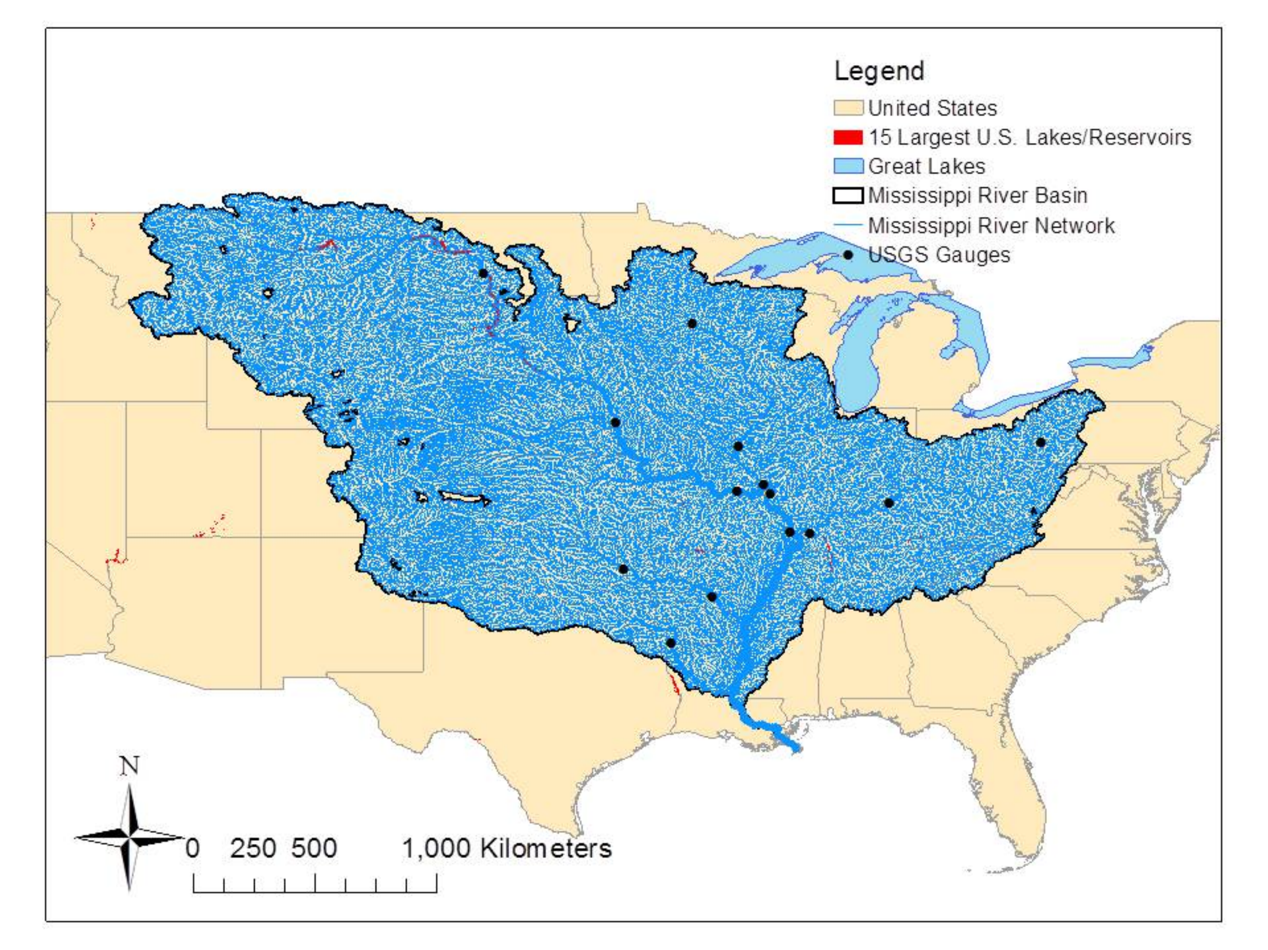
year	average flow
2000	1893.3
2001	2629.5
2002	2516.3
2003	2345.8
2004	2847.8
2005	2229.2
2006	1908.5
2007	2585.4
2008	3464.0
2009	3152.1



Selection based on 6 published studies

Close to gauge: Missouri River at Garrison Dam, North Dakota (use	Wood et al. [1997]
	Wood et al. [1997]
Upstream of confluence with Mississippi River	Wood et al. [1999], Maurer et al. [2001], Lohmann et al. [2004]
Close to large metropolitan area, centennial gauge	
	Maurer et al. [2001], Lohmann et al. [2004]
Downstream of confluence with Illinois River	
Centennial gauge, downstream of confluence with Missouri River	
Upstream of confluence with Ohio River	David et al. [2013a]
Close to large metropolitan area (Pittsburg)	
Close to large metropolitan area	
Downstream of confluence with Tennesse River, upstream of confl	Maurer et al. [2001], Lohmann et al. [2004]
	Abdulla et al. [1996]
Close to gauge: Arkansas River at Little Rock, Arkansas (used in pu	Abdulla et al. [1996], Lohmann et al. [1998]
Close to gauge: Red River at Shreveport, Louisiana (used in publishe	Abdulla et al. [1996], Lohmann et al. [1998]

Ready to run!



Legend
United States
15 Largest U.S. Lakes/Reservoirs
Great Lakes
Mississippi River Basin
Mississippi River Network
USGS Gauges
N
0 250 500 1,000 Kilometers

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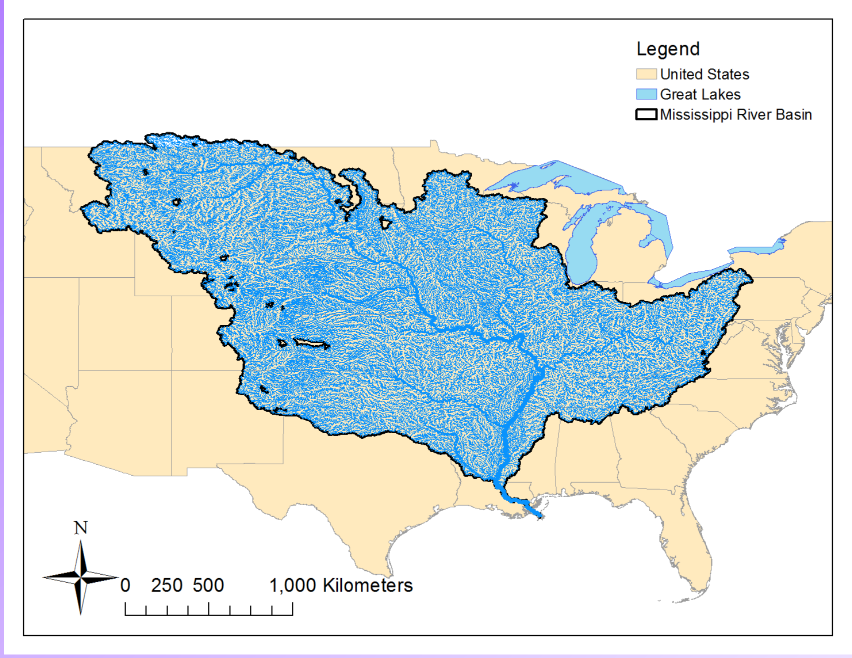
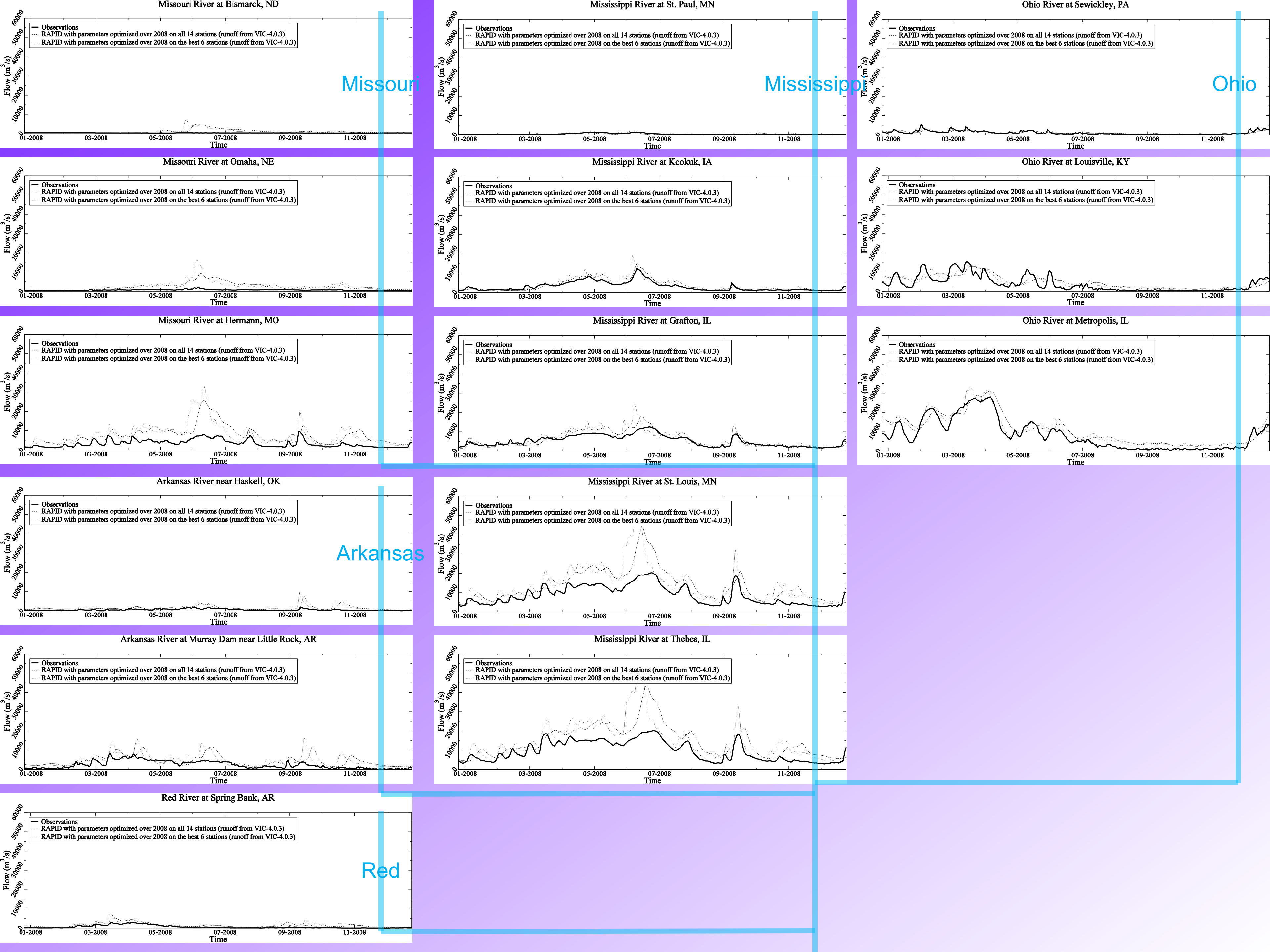




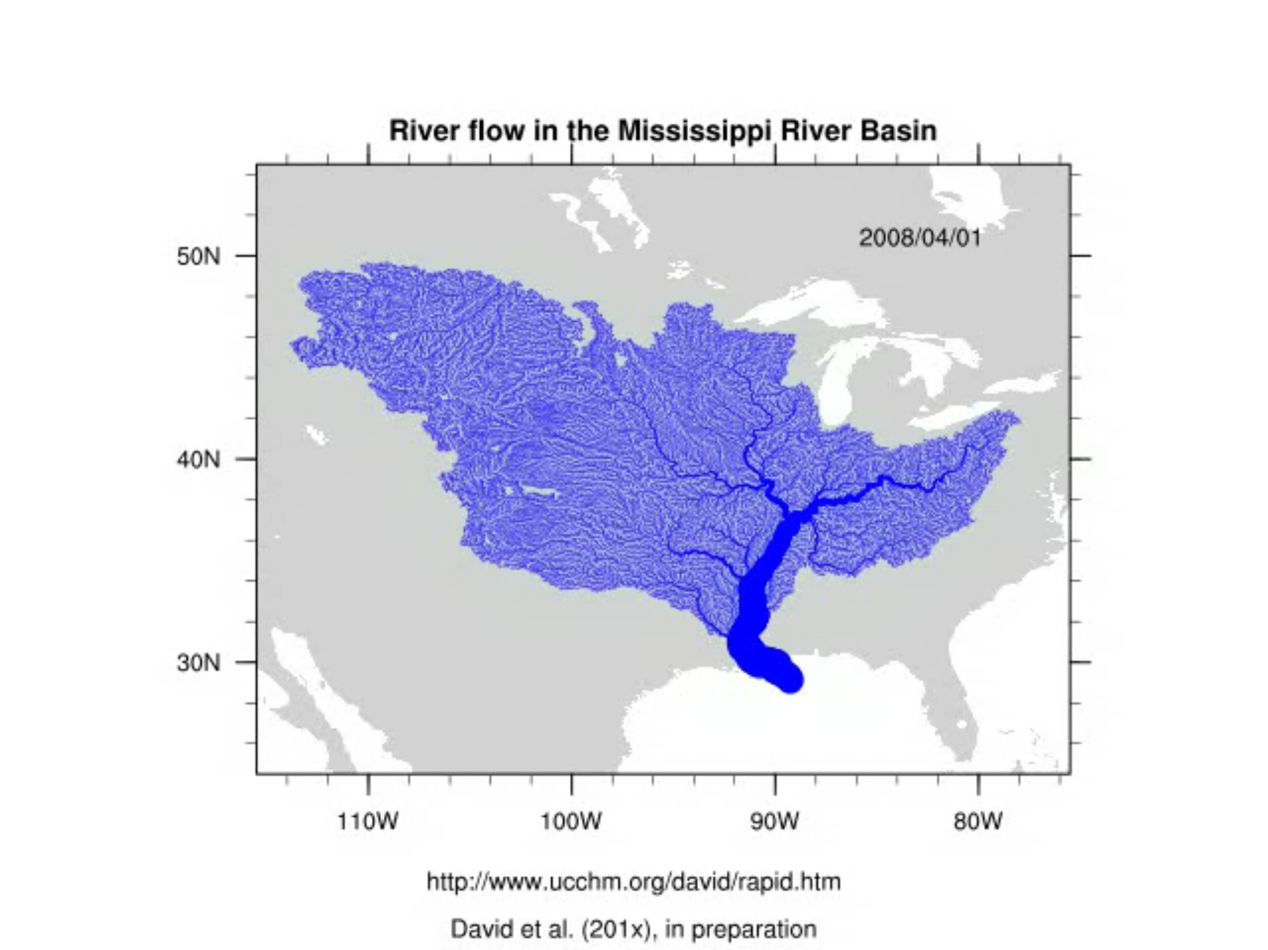
Missouri River at Bismarck, ND
Mississippi River at St. Paul, MN
Ohio River at Sewickley, PA
Missouri River at Omaha, NE
Mississippi River at Keokuk, IA
Ohio River at Louisville, KY
Missouri River at Hermann, MO
Mississippi River at Grafton, IL
Ohio River at Metropolis, IL
Arkansas River near Haskell, OK
Mississippi River at St. Louis, MN
Arkansas River at Murray Dam near Little Rock, AR
Mississippi River at Thebes, IL
Red River at Spring Bank, AR
Observations
RAPID with parameters optimized over 2008 on all 14 stations (runoff from VIC-4.0.3)
RAPID with parameters optimized over 2008 on the best 6 stations (runoff from VIC-4.0.3)
Flow (m3/s)
Time
Missouri
Mississippi
Ohio
Arkansas
Red

Aftermaths: flow statistics

			Initial optimization (slower celerity)			Further optimization (faster celerity)		
Name	rivID	Average Flow (observat	Average Flow (model)	RMSE	E	Average Flow (model)	RMSE	E
Missouri River at Bismarck, North Dakota	231083	466.9	907.3	843.4	-55.32	908.5	885.8	-61.14
Mississippi River at Saint Paul, Minnesota	266984	401.5	477.0	380.0	0.24	477.1	520.3	-0.42
Missouri River at Omaha, Nebraska	328965	755.6	1919.2	1809.9	-50.45	1921.8	2000.6	-61.87
Ohio River at Sewickley, Pennsylvania	339344	989.5	1002.6	573.9	0.53	1003.3	457.1	0.70
Mississippi River at Keokuk, Iowa	341237	2188.4	2974.8	1299.4	0.26	2977.9	1539.4	-0.04
Mississippi River at Grafton, Illinois	363260	3417.3	4439.1	1678.7	0.46	4445.6	1962.6	0.27
Missouri River at Hermann, Missouri	367121	2083.1	4969.0	4048.3	-7.23	4976.8	4276.9	-8.19
Mississippi River at Saint Louis, Missouri	368199	5546.1	9504.1	5381.2	-1.37	9520.4	5617.9	-1.58
Ohio River at Louisville, Kentucky	373295	3622.7	4357.8	2695.2	0.28	4369.3	2170.3	0.54
Ohio River at Metropolis, Ohio	389189	8127.9	10375.1	4580.0	0.42	10413.0	3577.2	0.64
Mississippi River at Thebes, Illinois	389491	6078.5	10237.9	5669.8	-1.20	10257.4	5788.0	-1.30
Arkansas River near Haskell, Oklahoma	407204	303.4	1019.5	997.3	-6.49	1020.3	1030.7	-7.00
Arkansas River at Murray Dam near Little Rock, Arkansas	420653	1294.1	2986.1	2355.2	-1.77	2990.0	2442.9	-1.98
Red River at Spring Bank, Arkansas	440065	588.4	1418.0	1195.6	-1.73	1420.0	1310.5	-2.28

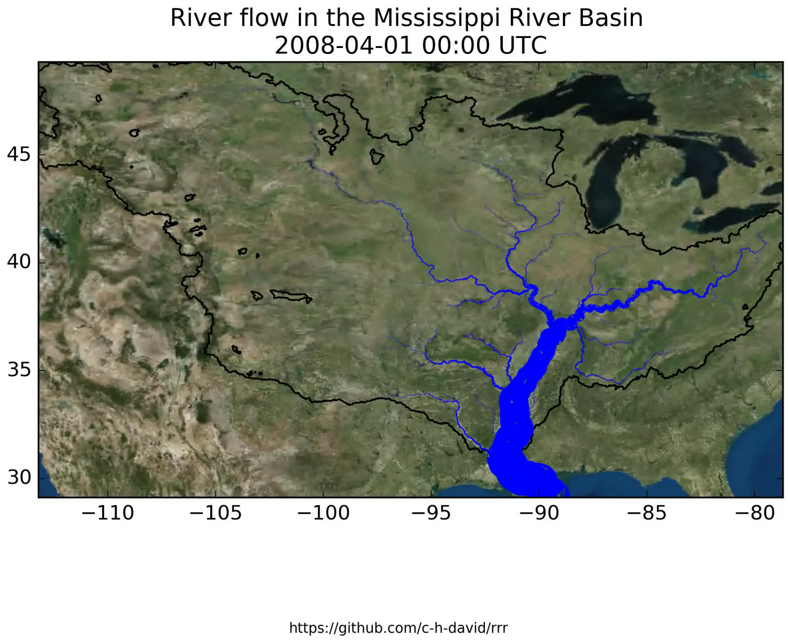
Missouri River: poor simulations (modeling system produces twice the observed flow)
Upper Mississippi River: good simulations (better stats when slow wave)
After confluence of Upper Mississippi and Missouri: poor simulations
Ohio River: good simulations (better stats when fast wave)
Arkansas and Red River: poor simulations (modeling system produces twice the observed flow)

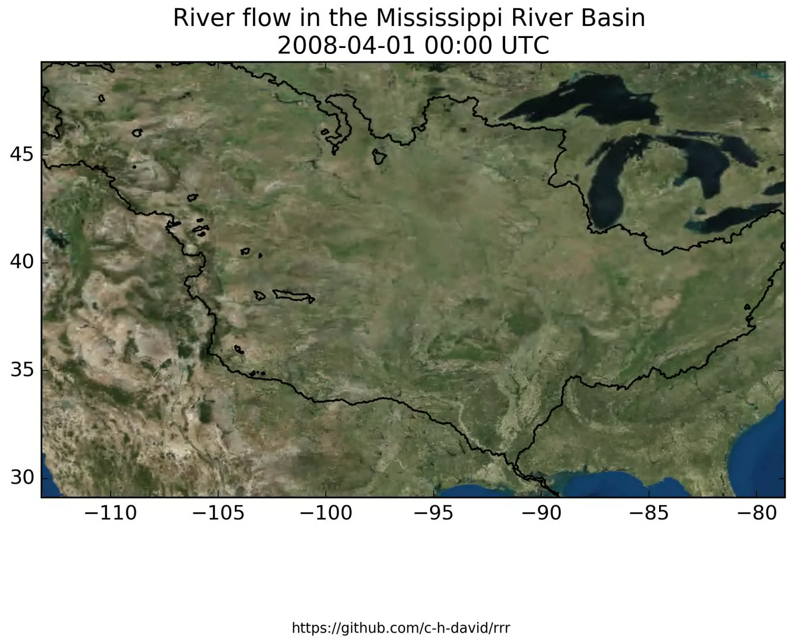
Animation



River flow in the Mississippi River Basin
2008/04/01
50N
40N
30N
110W
100W
90W
80W
http://www.ucchm.org/david/rapid.htm
David et al. (201x), in preparation

SWOT data look alike





Thickness of blue lines is function of simulated *discharge*
10-year simulation using RAPID (2000-2009), 15-min time step, output every 3-hr
Sub-sampling based on orbit at 890 km altitude, 77.6° inclination, 20.86 days repeat
No observational error accounted for here

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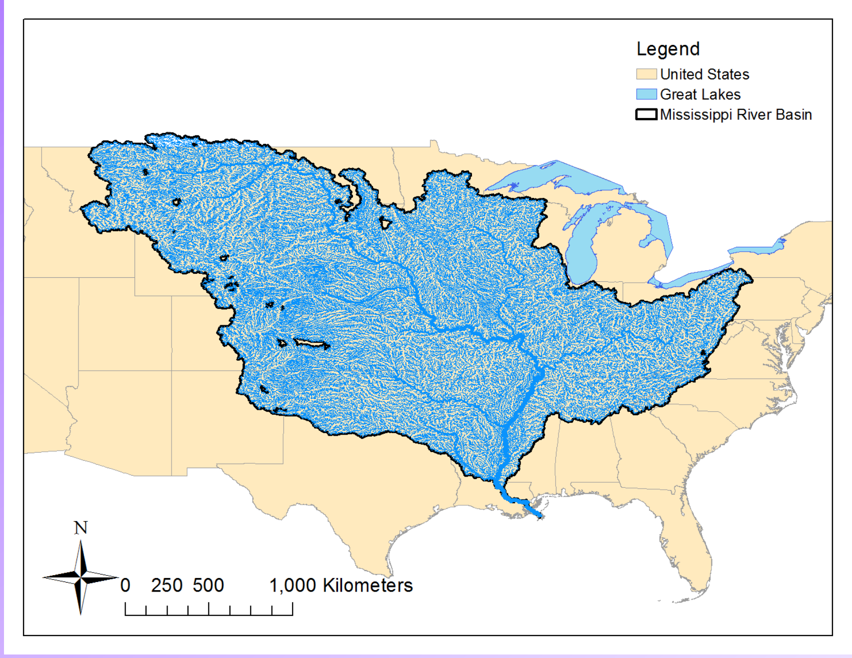
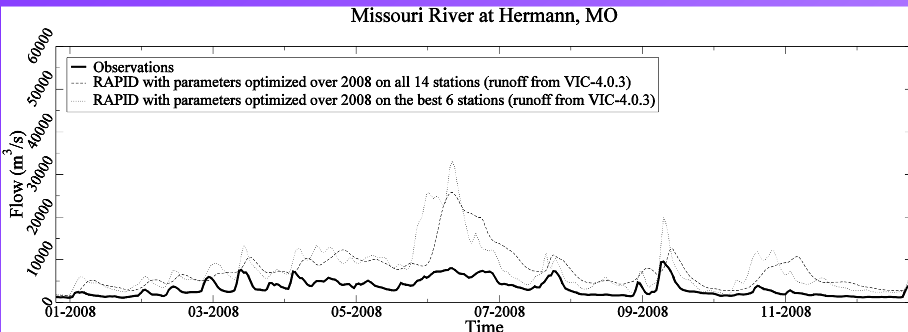
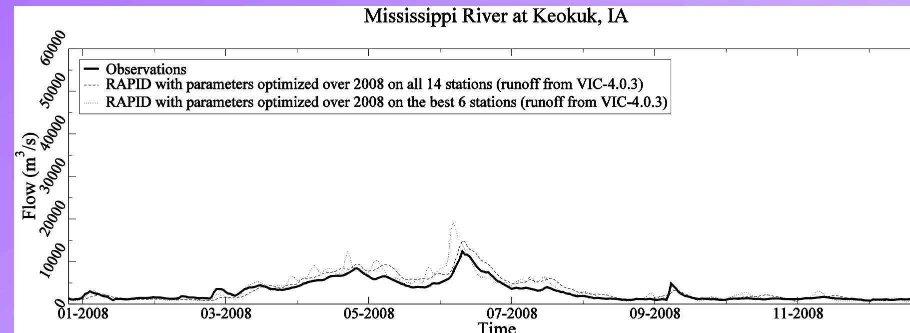
- **Discussion**



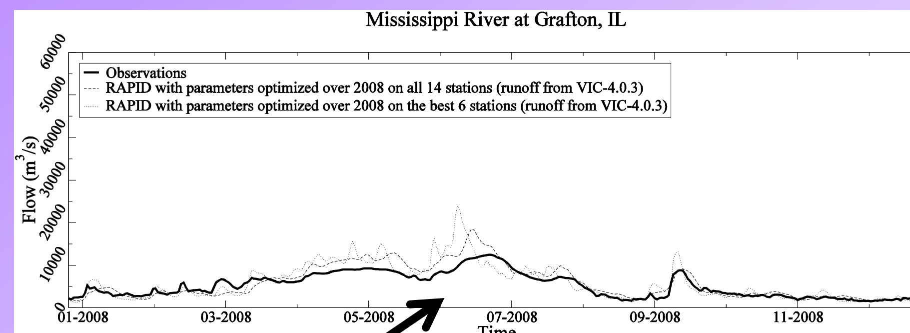
Aftermaths: hydrographs

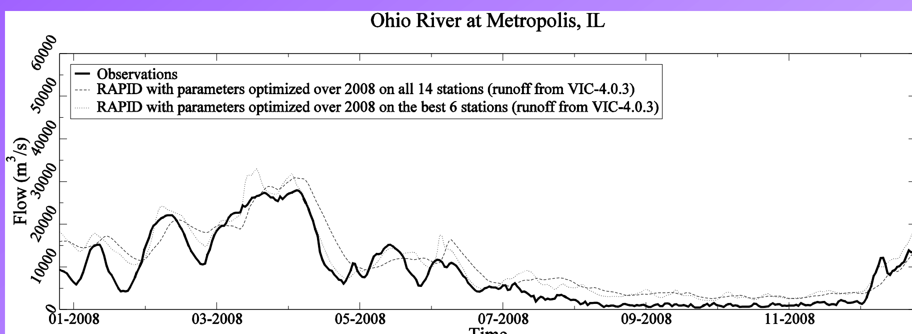




Not bad!

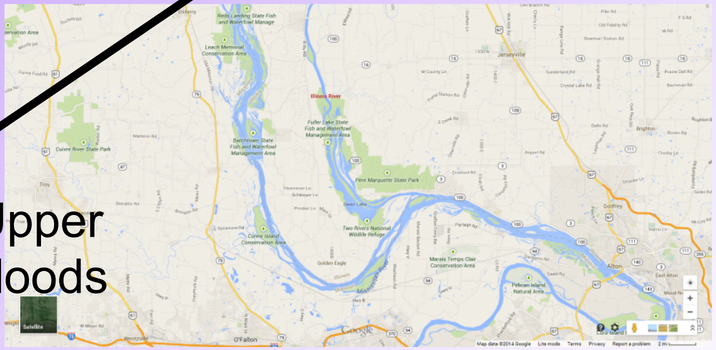
RAPID lacks reservoir module





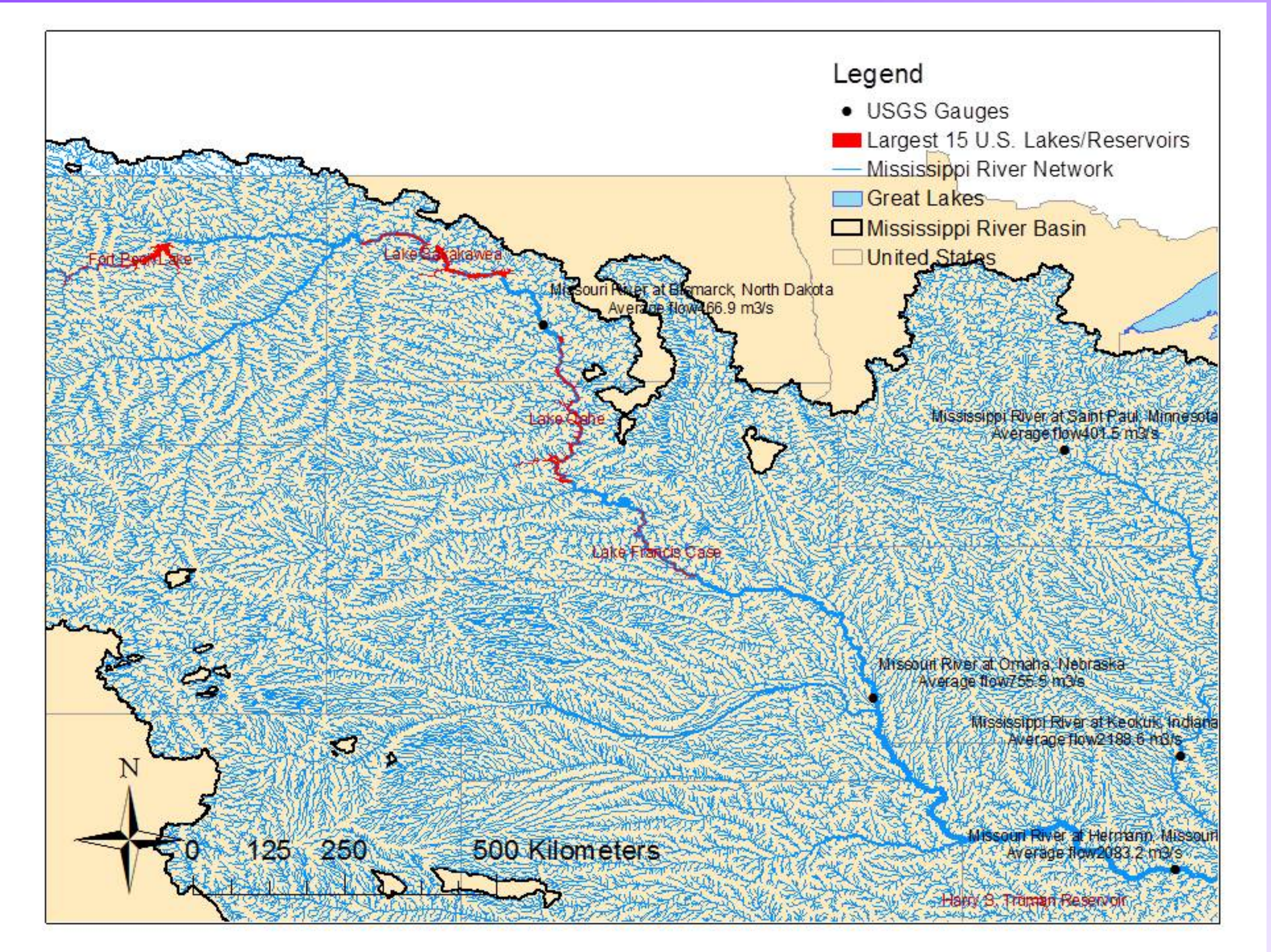
Not bad!

Backflow? Flood?



June 2008 Upper Mississippi floods

8 of the 15 largest U.S. lakes/ reservoirs are in domain



Thank you!
Questions?