

River Routing for the Mississippi River Basin using Grid and Vector Based River Networks

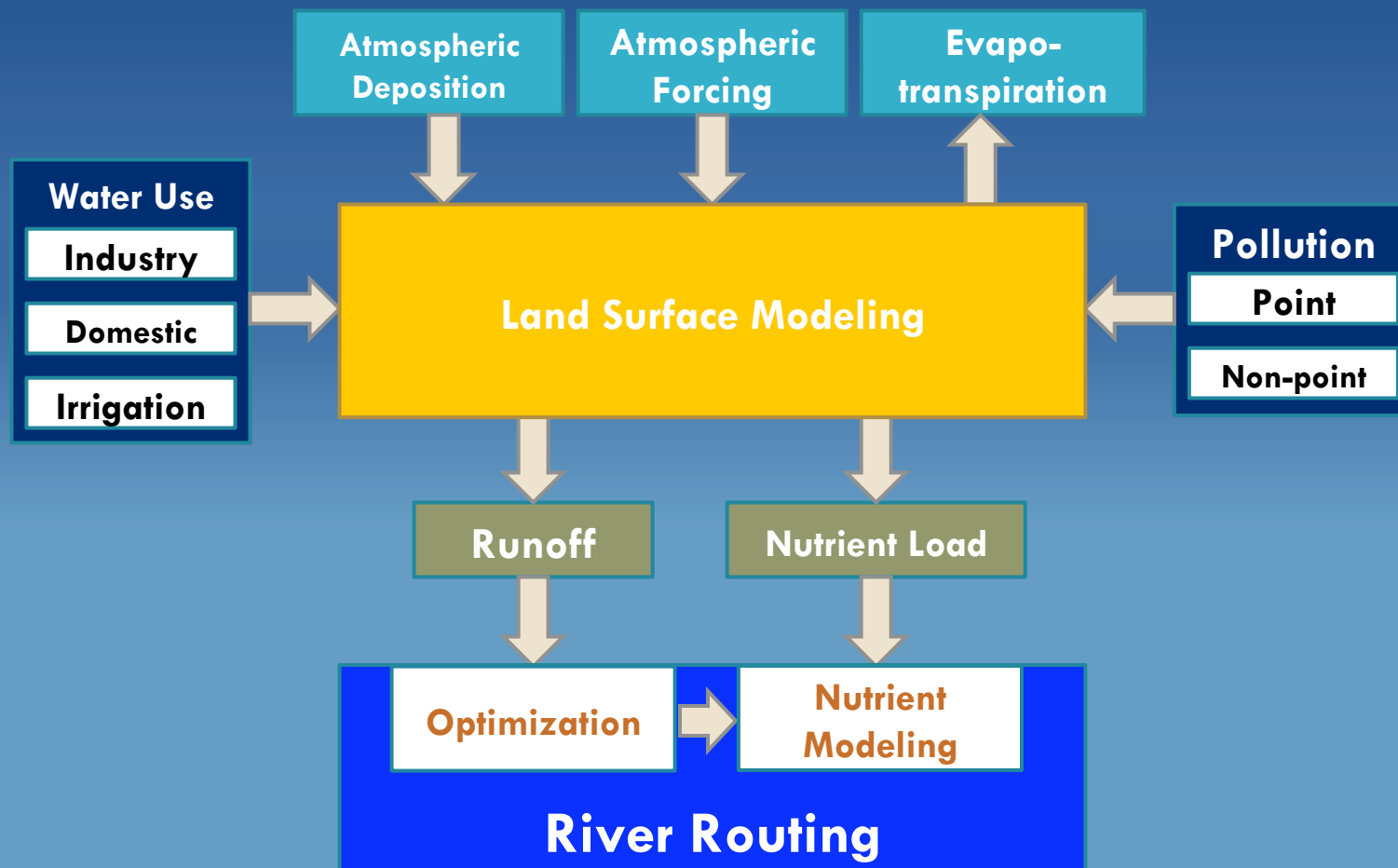


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WCRP OSC
Climate Research in Service to Society

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Tasks for NASA Interdisciplinary Science (IDS) Project



Two types of river networks

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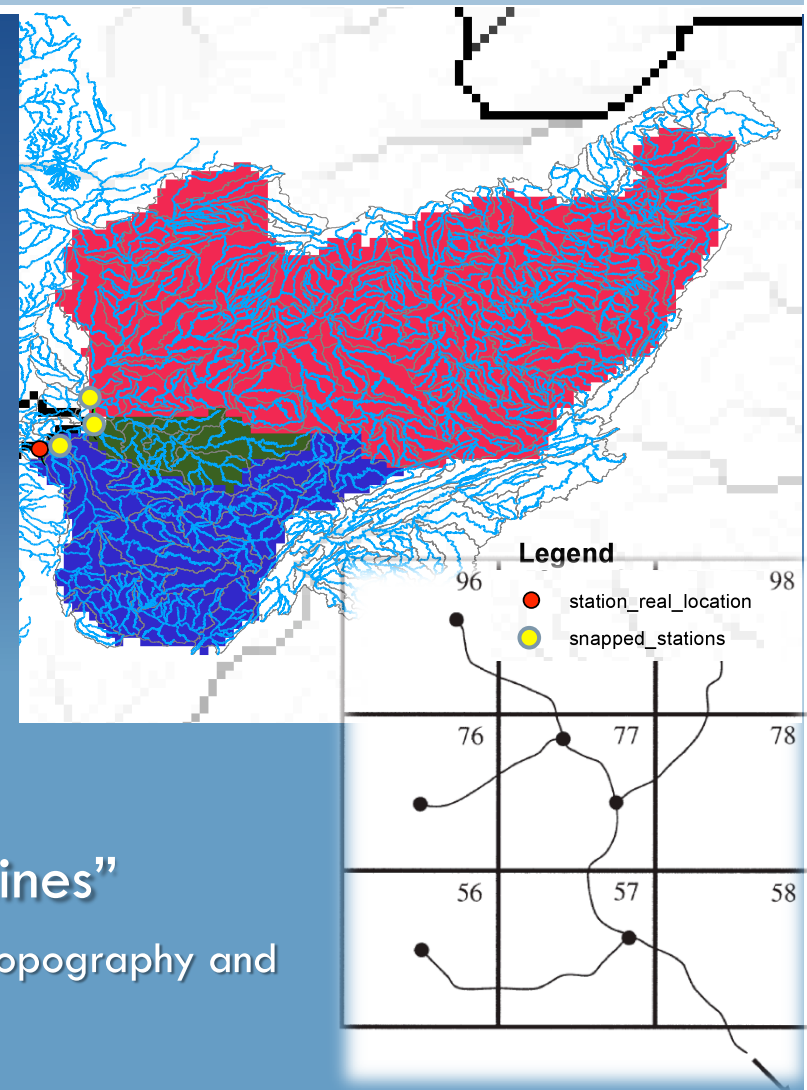
Research question: Can we use the blue lines from the map for river routing? Does it make a difference?

□ Gridded river network

- Traditional method
- Requires GIS processing (sinks, flow direction, flow accumulation, etc.)
- Requires careful placement of gauges where flow accumulation is high (snapping)
- Approximate basin delineation

□ Vector River Network or “mapped blue lines”

- NHDPlus dataset provides a coherent description of topography and hydrographic features for the United States
- Gauges located directly on NHDPlus



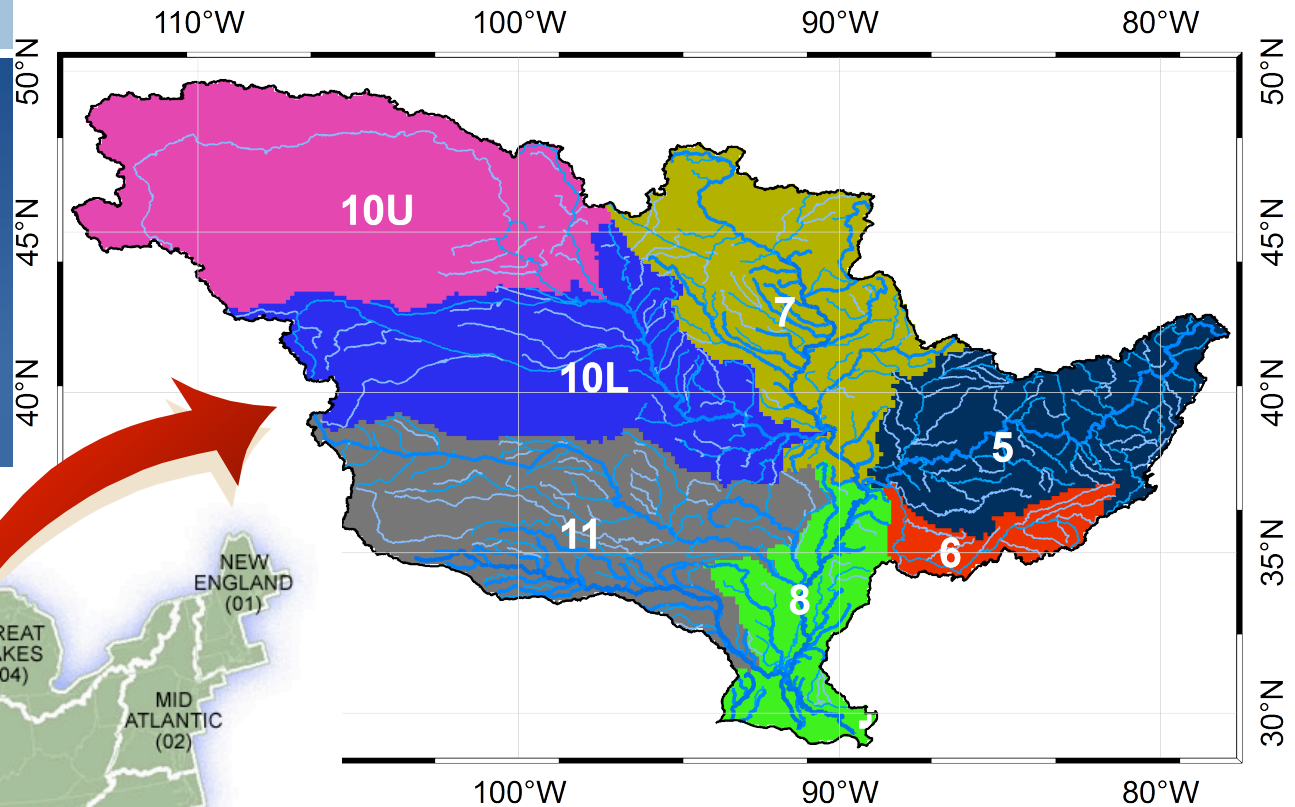
Ref.: Olivera and Raina, 2003

Study Area



Mississippi River Basin

6 HUC2 regions



Mississippi River Basin

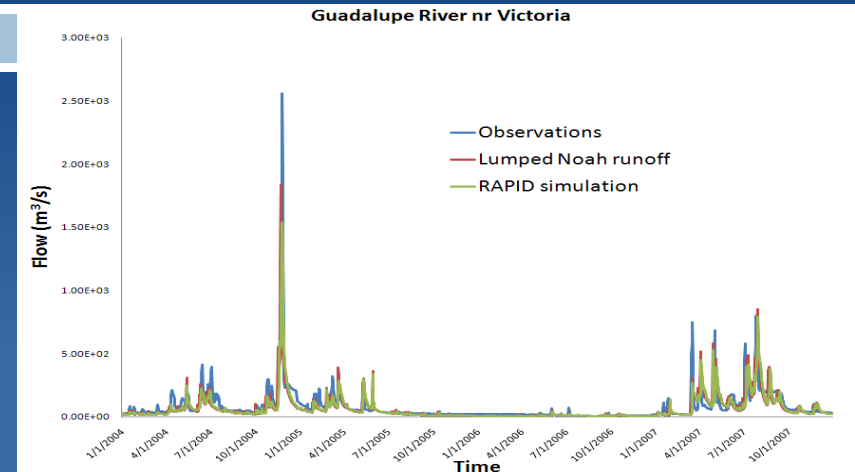
~3.3 million km²

Grid: 0.125° × 0.125°

River model

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- RAPID (Routing Application for Parallel computation of Discharge)
- Uses Muskingum method (k =time x =no dimension)
- Computes flow and automatically optimizes model parameters
- Actual parallel speedup
- Model code, input data and animations are available online



David et al. (2011a, JHM) (2011b, Hydro. Proc.)

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RAPID

Description
RAPID (Routing Application for Parallel computation of Discharge) is a river routing model. Given surface and groundwater inflow to rivers, this model can compute flow and volume of water everywhere in river networks made out of many thousands of reaches. The design of RAPID allows it to be adapted to any river network, if given basic connectivity information. RAPID uses a matrix version of the Muskingum method, and has an automated parameter estimation procedure that allows to finding optimal model parameters based on available gage measurements. This model uses the Fortran programming language and can be run on personal computers, as well as on massively-parallel supercomputers, with actual parallel speedup. RAPID has the ability to run and/or optimize model parameters on any sub-basin included in its computing domain. If major man-made infrastructures are present on the river network, RAPID allows to easily substitute upstream flow by gage measurements during both computation of river flow and optimization of parameters. Detailed information on RAPID can be found in the related [publications](#).

Development history
Designing, developing and testing RAPID were a large part of my Ph. D. work at the Center for Research in Water Resources at the University of Texas at Austin. The development of this model started in September 2007 as I joined the Center for Geosciences at Ecole des Mines de Paris (Mines ParisTech), France for a 6-month visit. RAPID was originally developed as a substitute for the river routing scheme of SIM-France, the operational hydro-meteorological model used by Météo France (the French weather service). The code has since then been adapted to run on the NEDPlus dataset that provides a "blue line" description of the river networks in the USA. For the current NEDPlus version of RAPID, several land surface models can be used to compute inflow to the river network.

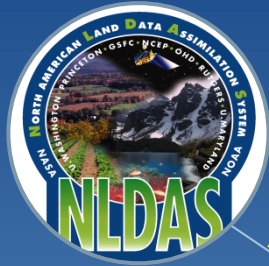
Code
The source code for RAPID can be downloaded [here](#). Input data including network connectivity, lateral inflow from the land surface (computed with Noah-MP) and gage measurements (from USGS NWIS) for a 4-year run (between 2004-01 and 2007-12) in the Guadalupe and San Antonio River Basins in Texas can be downloaded [here](#). Input data corresponding to the river network of SIM-France is available [here](#) for 10 years between 1999-08 and 2005-07.

Documents
A succinct guide on how to compile and run RAPID for the test-case provided is available [here](#). Some information on the data model used for inputs in RAPID can be found [here](#). Explanations on the input and output files used in RAPID are available [here](#). A guide on how to download USGS NWIS observations and format them for RAPID is [here](#).

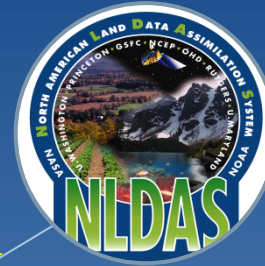
Animations
In the following animations of stream flow, the thickness of river reaches varies with the magnitude of flow rate going through them. One can see the flow waves propagating downstream. All these animations were prepared using 3-hourly outputs from RAPID. They can be played directly from this webpage (full-screen mode available) or downloaded in .avi, .tif and .mp4 formats. The latter can be uploaded to and played on iPhones.

The first animation is of the San Antonio and Guadalupe Basins in Texas, USA, over four months (between 2007-06-01 and 2007-09-30). 3-hourly surface and subsurface runoff was produced by the Noah-MP land surface model using a combination of NARR and NEXRAD for atmospheric forcing. RAPID was run at a 15-minute time step. Download [avi](#), [tif](#) or [mp4](#).

Data Sources



- Mosaic surface and subsurface runoff
- Convert data
- Ongoing Noah-MP



- Grid-based river network
- Delineate watershed



Forcing data

River network

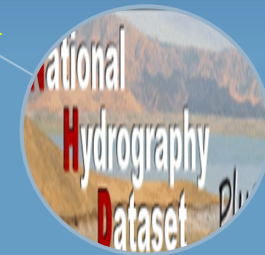
Observations

River network

RAPID river model



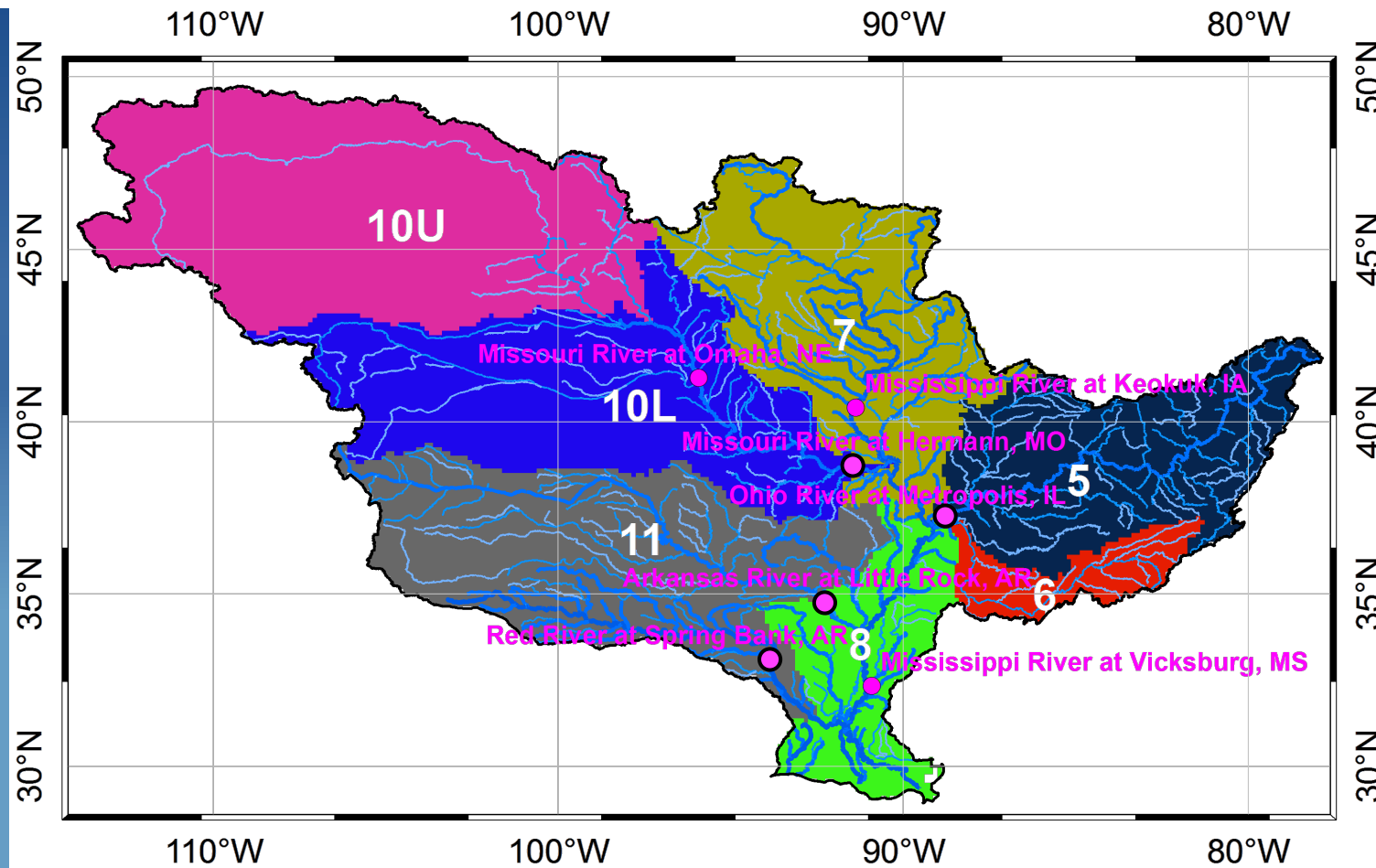
- Daily data
- Stream Gauges



- Vector-based River Network
- Catchment data
- Vector networks are increasingly becoming available for the globe (HydroSHEDs, CarTHAgE)

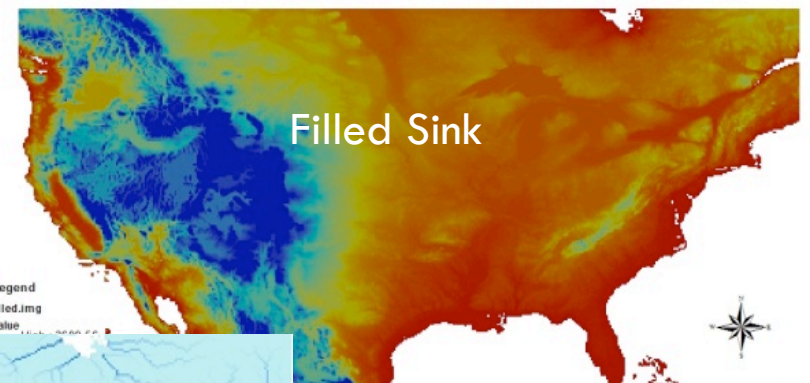
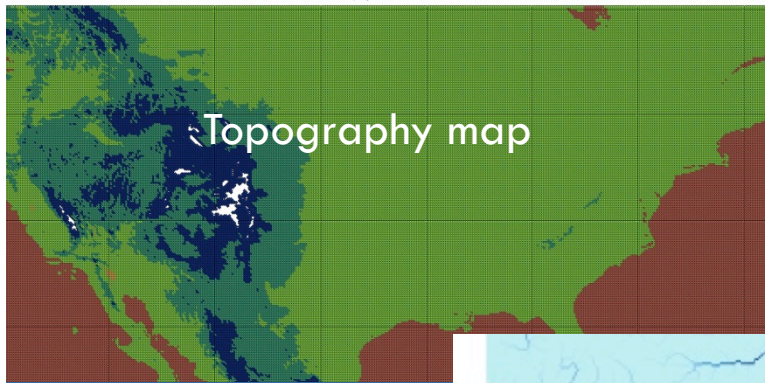
10-year data, 2000-09 and 3-hourly input file

USGS Gauges



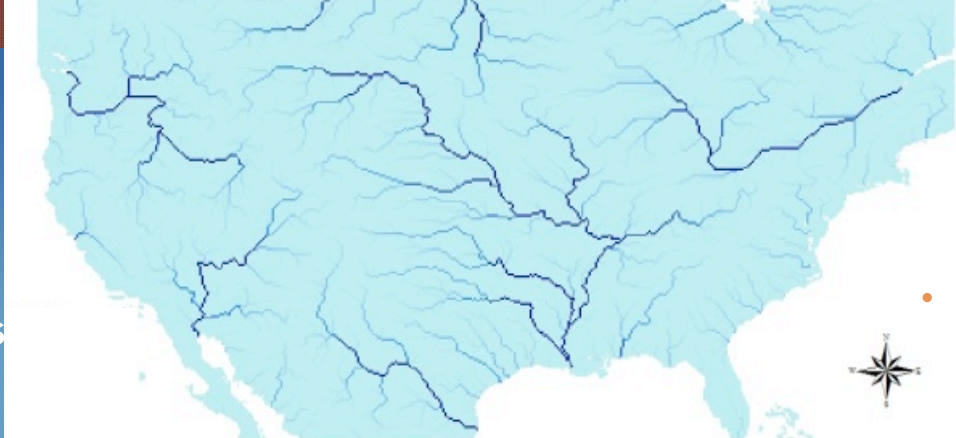
So many gauges available, most studies only use between 4-10 stations

Gridded River Network



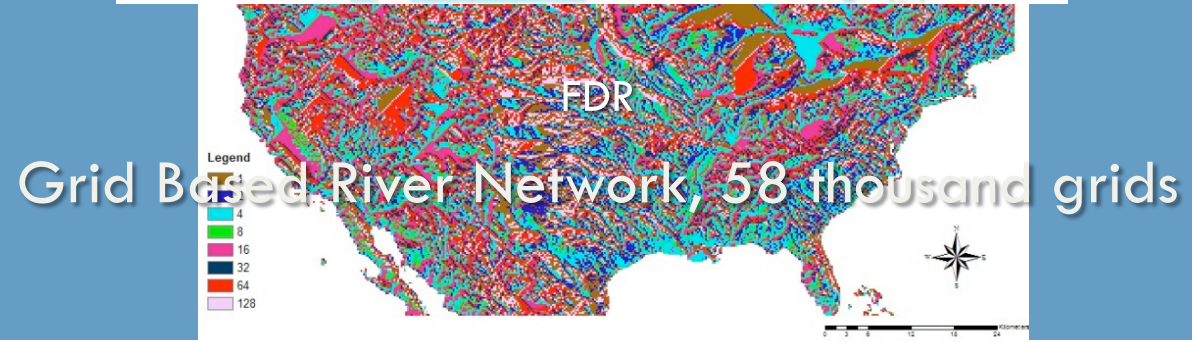
GIS Process

- Hydrology Tools



IS Process

- Spatial Analyst

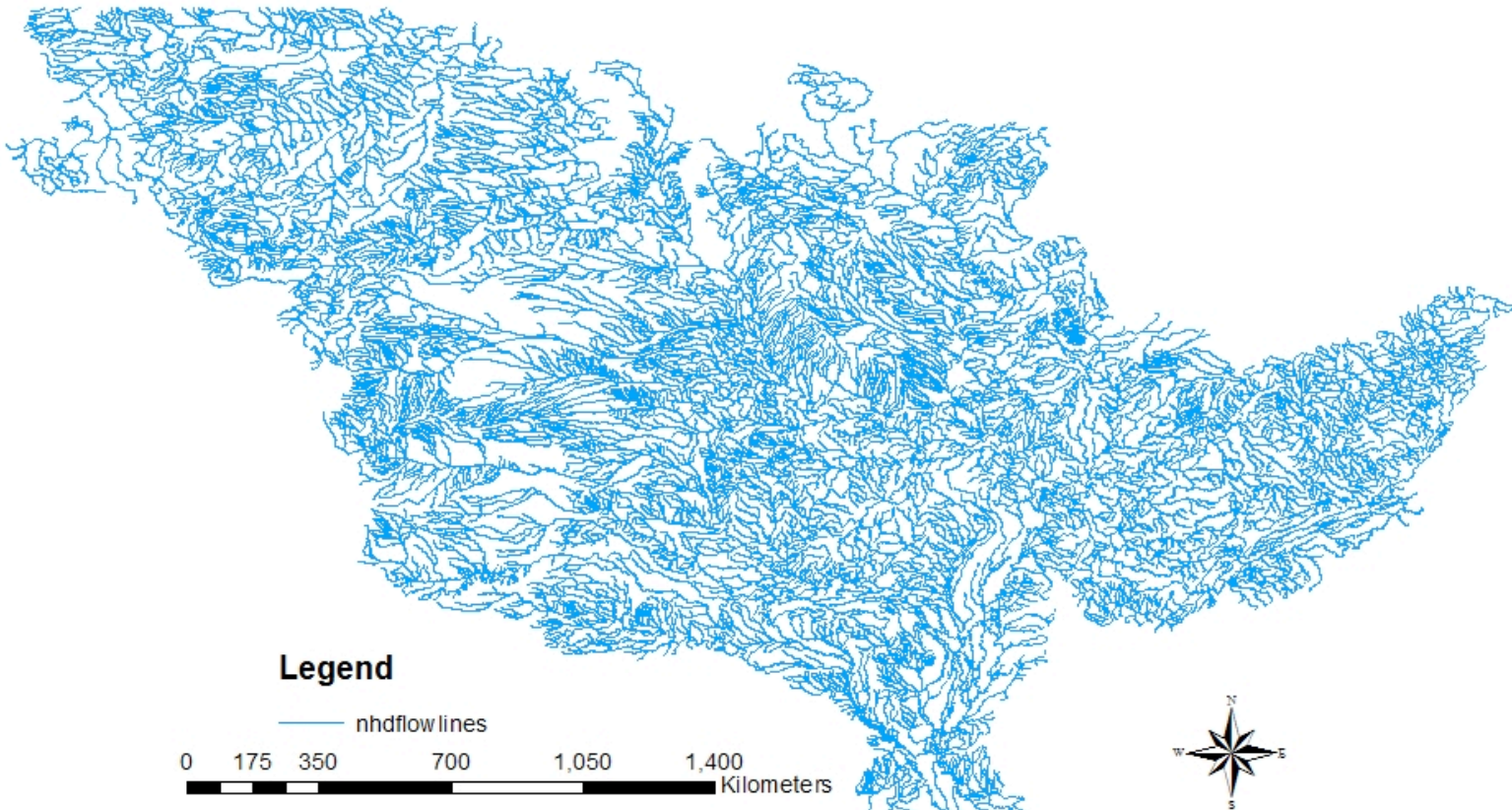


Vector River Network

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Region

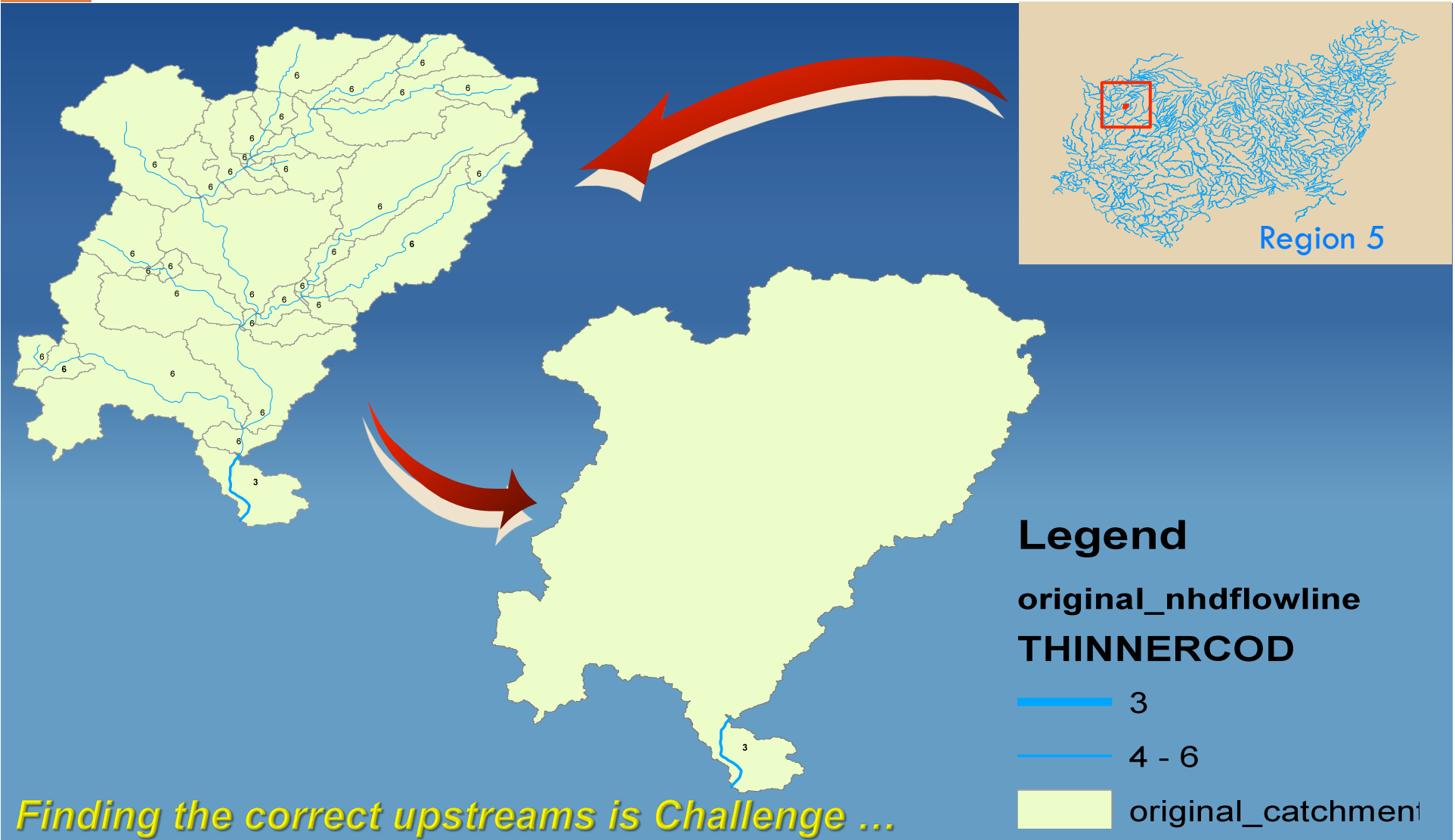


200 thousand rivers

Region8

Reduce Simulation Time ...

Upscaling of Catchment



Finding the correct upstreams is Challenge ...

Experimental design



- Two optimization cost function ($\phi 1$ and $\phi 2$), both taking several gauging stations into account
- Four types of spatial variability of Muskingum k

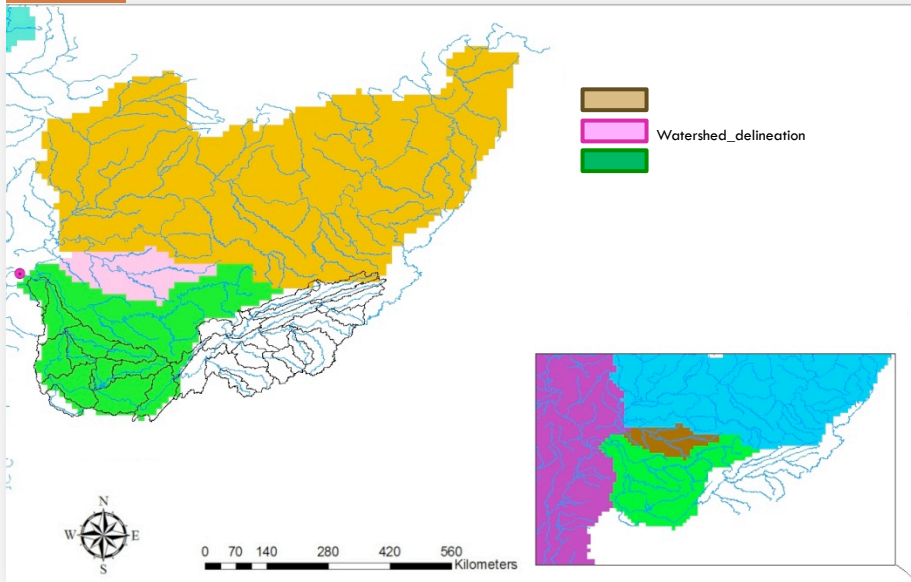
$$K_{ini}^1 = \frac{\bar{L}}{C_0} \quad K_{ini}^2 = \frac{L_i}{C_0} \quad K_{ini}^3 = \alpha \frac{L_i}{\sqrt{S_i}}$$

$$K_{ini}^4 = \alpha \frac{L_i}{(\sqrt{S_i})'}; \quad (\sqrt{S_i})' \in P[0.05, 0.95]$$

where: \bar{L} is the mean of the river length, C_0 is the reference water wave celerity; L_i is the river length; S_i is the river slope and α is the inverse of the velocity.

Influence of basin delineation on 10-year Average Flow

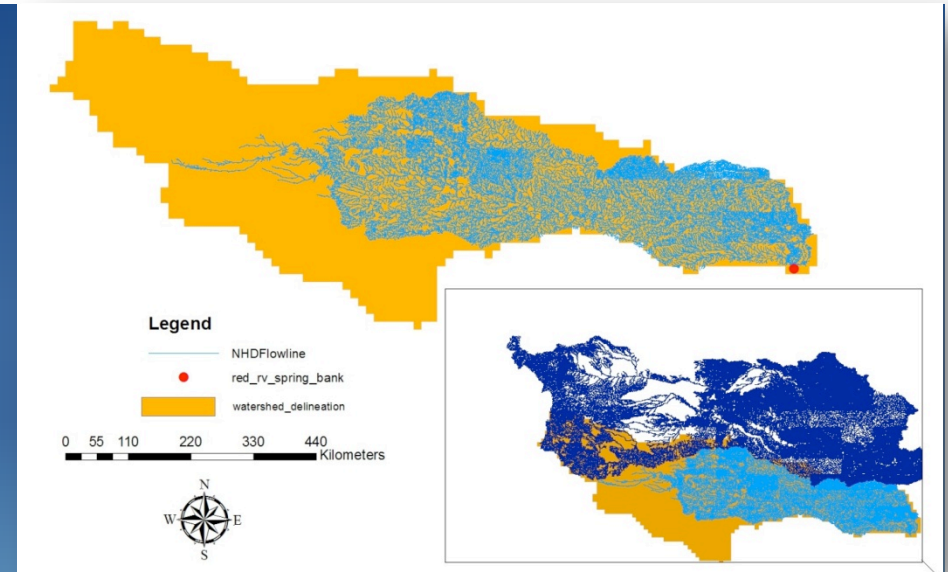
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Ohio River at Metropolis

	Average Flow (m ³)	Drainage Area(km ²)
grid	3,084	401,383
Vector	3,913	523,498

%30 bigger area produces %26 more flow ...



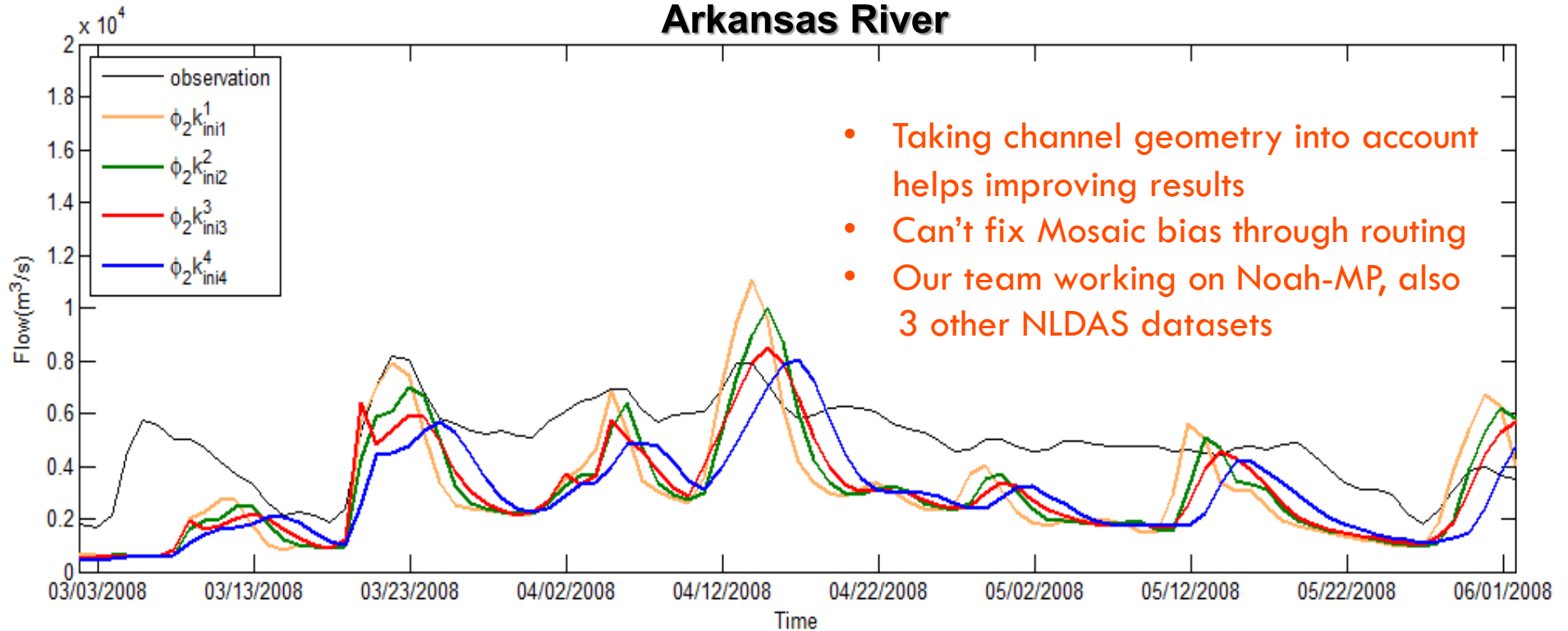
Red River at Spring Bank

	Average Flow (m ³)	Drainage Area(km ²)
grid	469	270822
Vector	376	146785

%85 bigger area produces %25 more flow ...

Results: ϕ_2 and 4 types of k, gridded network

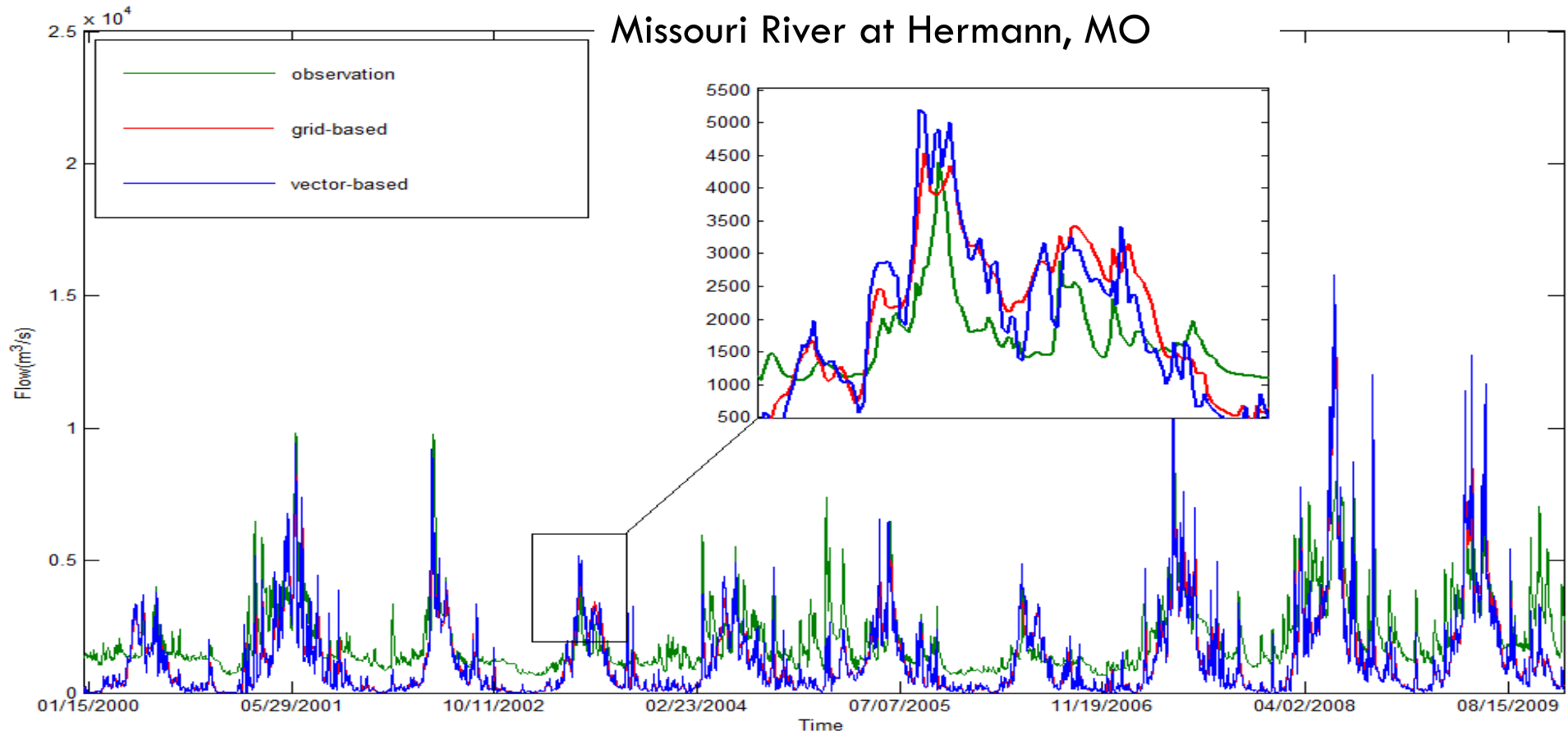
Arkansas River



- Taking channel geometry into account helps improving results
- Can't fix Mosaic bias through routing
- Our team working on Noah-MP, also 3 other NLDAS datasets

Gauging station		Observation	Lumped Model	ϕ_1				ϕ_2			
				K^1_{ini}	K^2_{ini}	K^3_{ini}	K^4_{ini}	K^1_{ini}	K^2_{ini}	K^3_{ini}	K^4_{ini}
Arkansas River at Murray Dam near Little Rock, AR	Average	1281	771	771	771	771	771	771	771	771	771
	ρ	-	0.41	0.61	0.61	0.61	0.67	0.73	0.75	0.78	0.78
	NSE	-	-0.34	0.16	0.16	0.16	0.28	0.39	0.43	0.46	0.46
	RMSE	-	1640	1298	1299	1294	1203	1102	1072	1040	1037

Results: Gridded vs. Vector Network



Select the K_{ini}^3 as a best experiment ...

Flow Animation, 3 months



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Conclusions



- **Drainage area is a key factor affecting the mean flow, particularly wetter climates**
 - **In the wet zone vector networks can reproduce drainage areas better than gridded networks can unless using very fine grids**
 - **The differences between the gridded and vector approach are small when watershed areas are comparable**
 - **The location of river gauges is more easily determined with vector river networks (no need for snapping), one can hence use as many gauges as possible**
- **The influence of optimization cost functions and spatial variability of parameters confirm previously published work**

Thank You !

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Data Sources



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More info on Mosaic being used alone

Mosaic Model

Surface-Vegetation-atmosphere transfer scheme (SVATS)

Heterogeneity of soil moisture and vegetation