A Catchment-based Hydrologic And Routing Model System (CHARMS) with Explicit Surface Water Bodies

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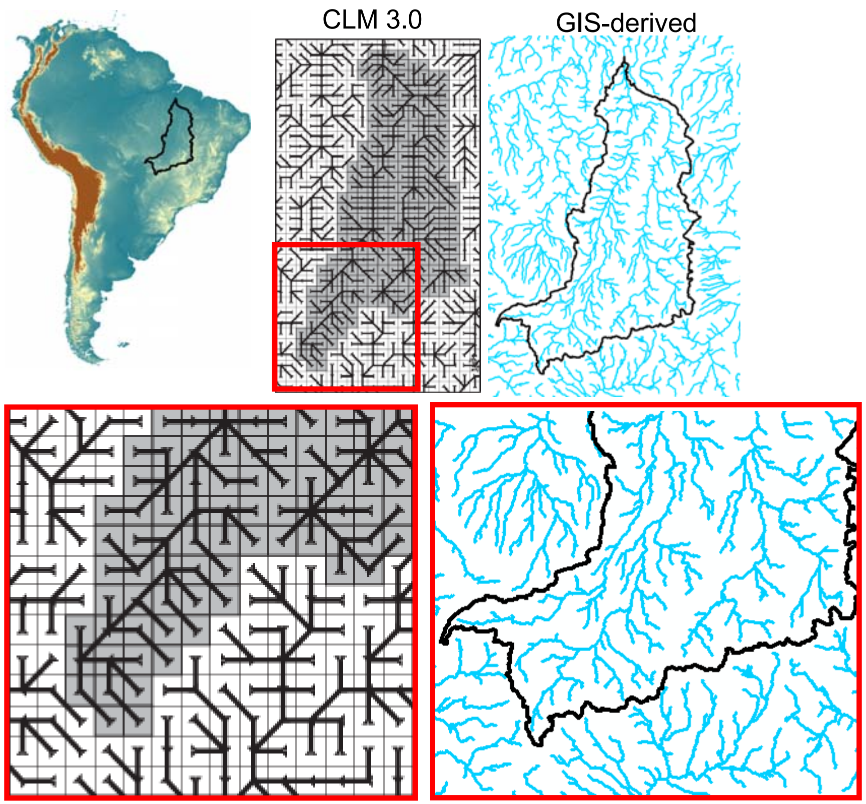
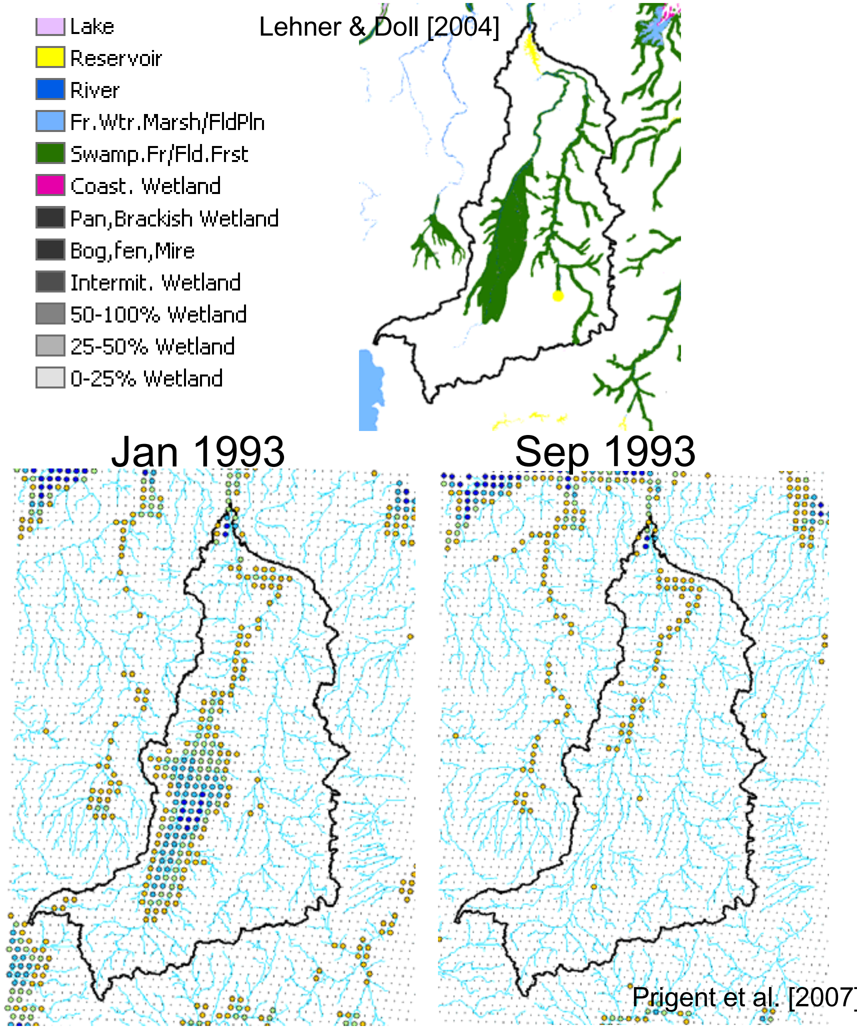
NCAR CLM Land Model Working Group Meeting, Feb 20, Boulder, Colorado

Surface Water Bodies within Land Surface Models

- ❑ typically ignored
- ❑ river networks inaccurate
- ❑ fixed modeling units (e.g., CLM)
- ❑ no seasonal variations

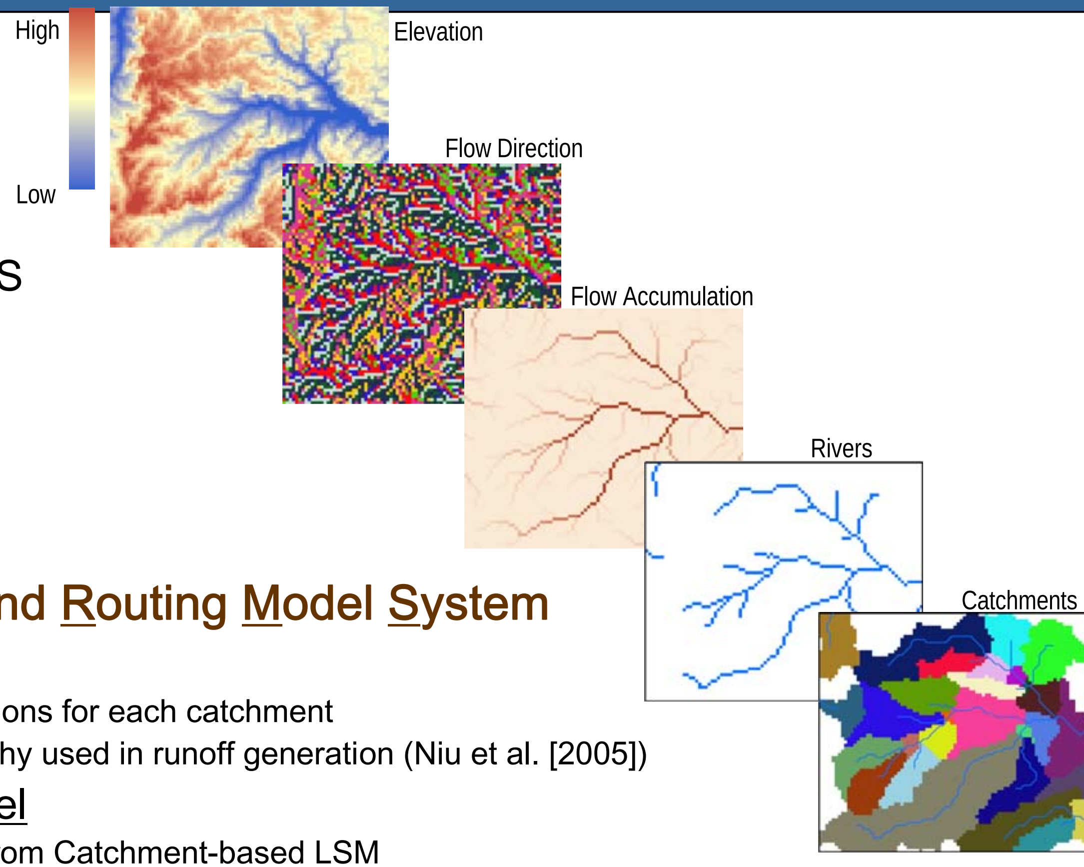




- ❑ **Objective:** incorporate river transport and floodplain water storage in LSMs
- ❑ **Approach:** catchment-based instead of grid-based

Overall Framework

- Catchment-based Model
  - catchment is the modeling unit
  - fine resolution elevation data
  - river paths and catchment boundaries obtained using a GIS
    - ArcHydro (Maidment, [2002])



- <u>C</u>atchment-based <u>H</u>ydrologic <u>A</u>nd <u>R</u>outing <u>M</u>odel <u>S</u>ystem
  - 1 <u>Catchment-based LSM</u>
    - water and energy balance computations for each catchment
    - statistics of sub-catchment topography used in runoff generation (Niu et al. [2005])
  - 2 <u>Catchment-based Routing Model</u>
    - generates streamflow using inputs from Catchment-based LSM

1 <u>LSM</u>

Input
Met. data

Output:
Water fluxes
Runoff (surf)
Runoff (base)
Energy fluxes

2 <u>Routing Model</u>

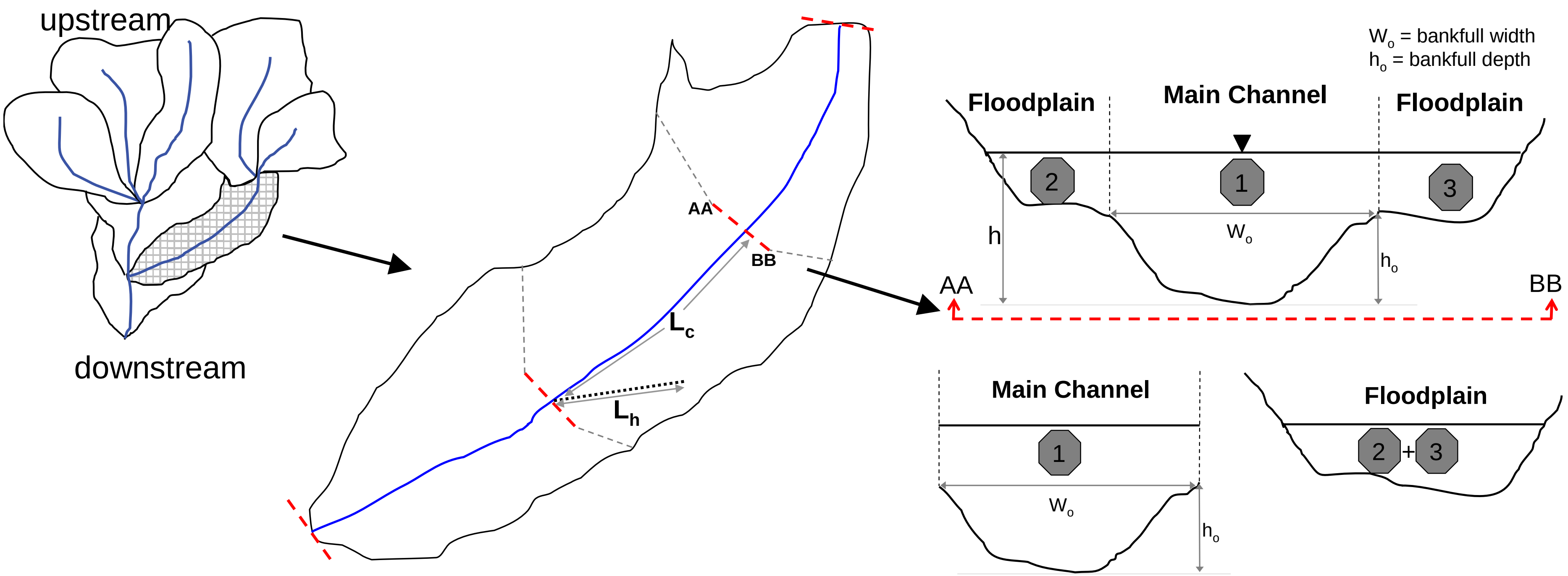
Input:
Runoff (surf + base)

Output:
Streamflow
Flow depth
Inundation extent
Floodplain storage

<u>**Note: catchment vs grid**</u>
- computational resources are similar
- can be implemented at various "resolutions"

Routing Model in CHARMS

- Keefer & McQuivey [1974]
- Becker & Kundzewicz [1987]
- Garbrecht & Brunner [1991]
- Olivera & Maidment [1999]
- Olivera et al. [2000]



- ❑ river channels divided into smaller routing reaches
- ❑ streamflow computation
  - cross-sectional geometry used to partition total flow (empirical Manning's equation)
  - main channel (faster) and floodplain (slower) flow routed separately (convection-diffusion equation)

- ❑ streamflow @ inflow/outflow section of every routing reach

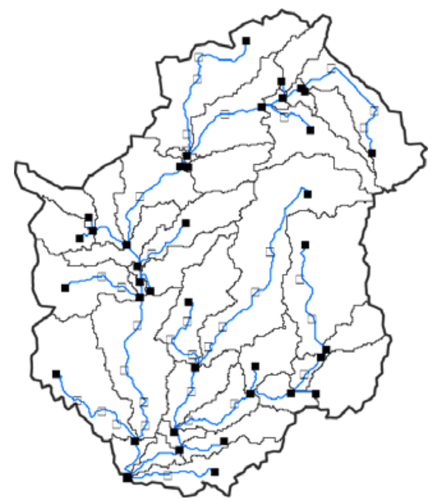
$$Q(t) = \underbrace{Q_{h,surf}(t) + Q_{h,base}(t)}_{\text{hillslope}} + \underbrace{Q_{chnl}(t)}_{\text{main channel}} + \underbrace{Q_{fldp}(t)}_{\text{floodplain}}$$

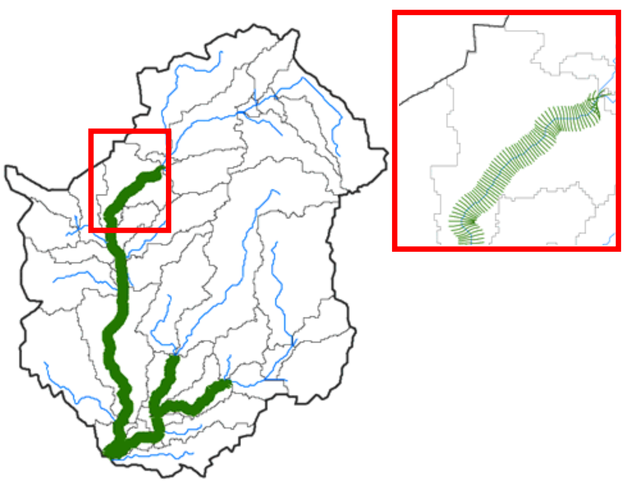
Study Domain, Datasets & Models

- Wabash River Basin (~74000 km^2)
  - no major lakes and reservoirs
  - historical <u>unregulated</u> streamflow data
- Data
  - Elevation data
    - GTOPO30: 1 km, global
  - Streamflow Data
    - HCDN: Slack and Landwehr [1992], 1874-1988, daily
  - Meteorological Data
    - precipitation: Maurer et al. [2002],1/8^0, 1949-2000, daily
    - other vars: Sheffield et al. [2006], 1^0, 1948-2000, 3-hrly
- Channel cross-section data
  - SRTM elevation data, 90 m
  - profiles @ 1-km intervals
  - downstream of HCDN stations

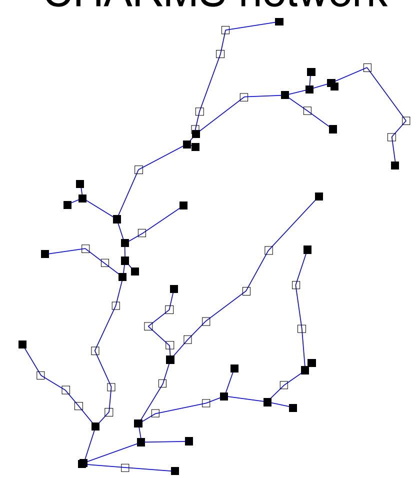
  - Empirical relationship between discharge and channel geometry used by routing model
- LSM in CHARMS
  - NCAR CLM (CLM 3.0 **)
  - catchment-based version of CLM
  - catchment-based datasets

GIS-derived network



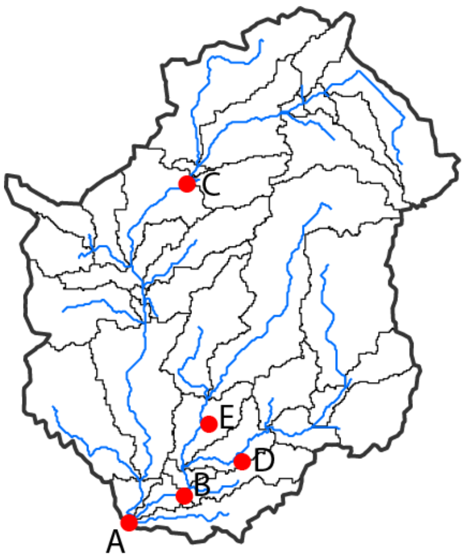


CHARMS network

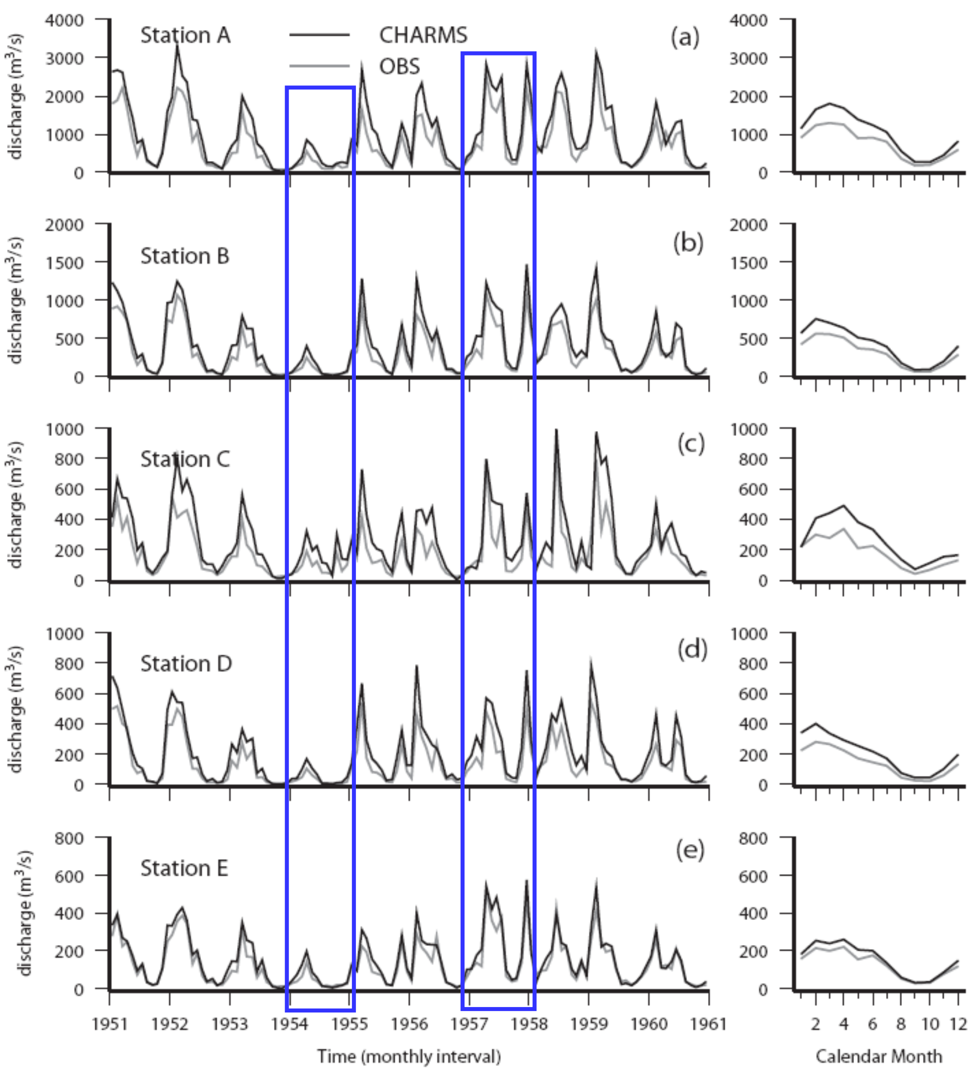


Results: Streamflow Simulation

- Simulation period 1949-1960, 1-hr time steps LSM, 6-hr time steps routing model



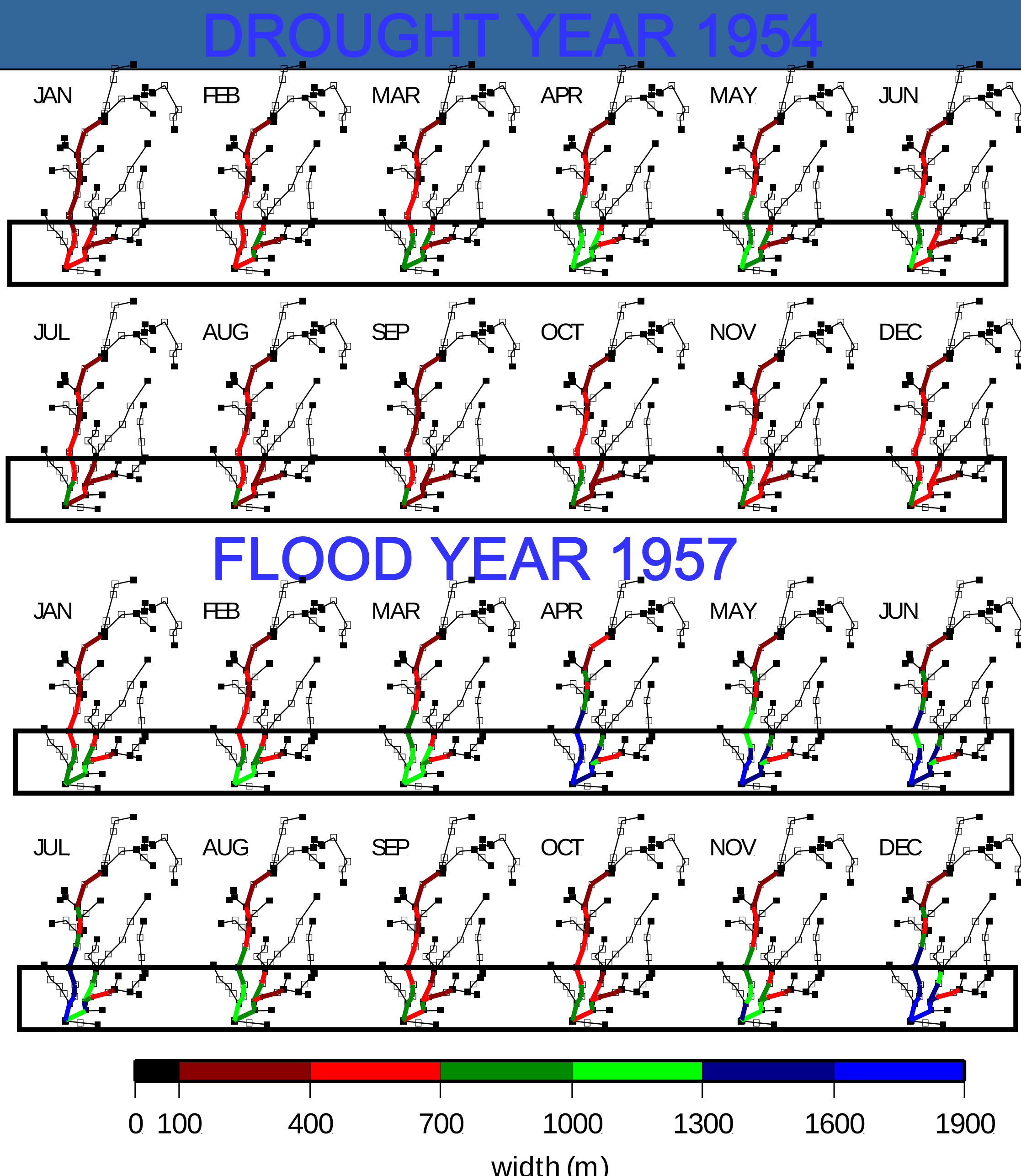
- Reasonable simulation of streamflow
  - CLM known to overestimate runoff, especially in Winter and Spring
    - underestimation of ET
    - problems with precip. data?
  - No calibration of model parameters



Goteti et al. [2007], Submitted to *JGR-Atmospheres*

Results: Inundation Extent Simulation

- Inundation extent follows the seasons
- Inundation extent generally higher for the downstream reaches
- Annual variation in the downstream reaches 100-700 m (drought year) and 400-1900 m (flood year)
- Implement CHARMS over a larger domain



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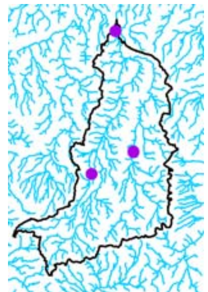
Some Modeling Challenges

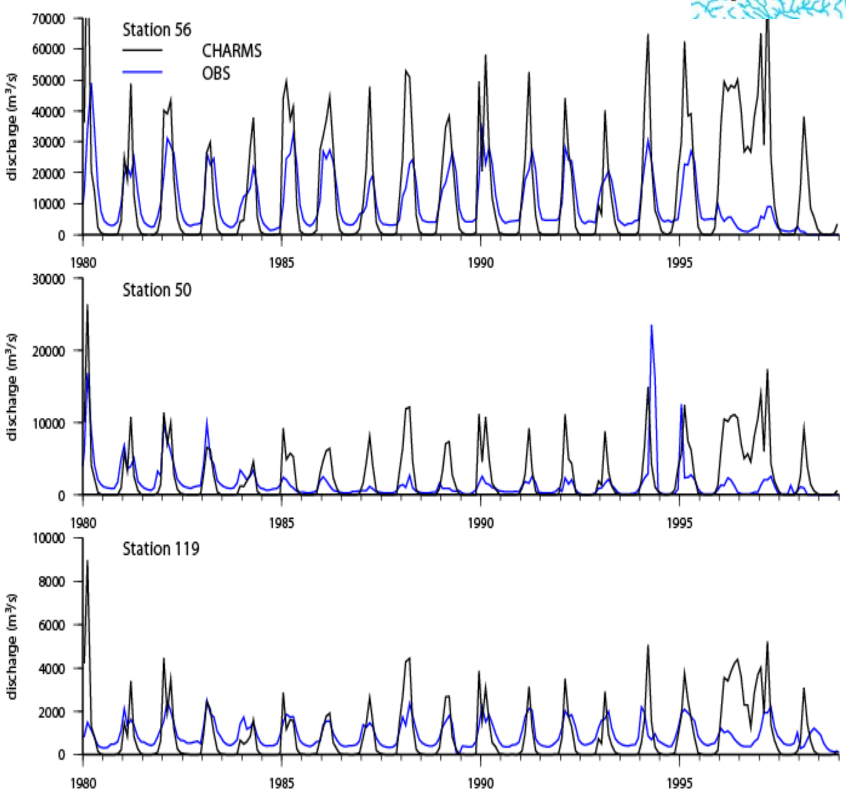
- ❑ Inadequate data
- ❑ Use satellite-based products

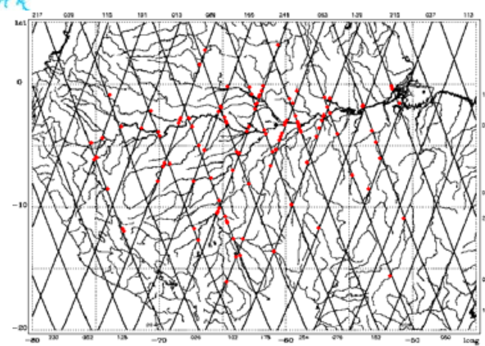
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/index.cfm



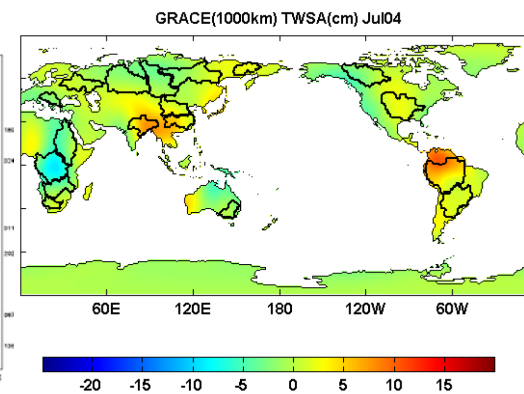
Preliminary simulations for the Tocantins Basin

- GLDAS forcing
- monthly avg runoff (no routing), 1980-2000

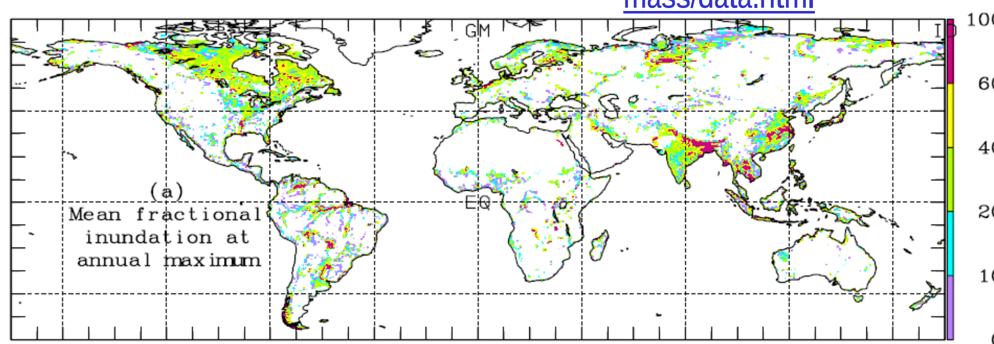




http://essic8.umd.edu/~cmb/webtext/



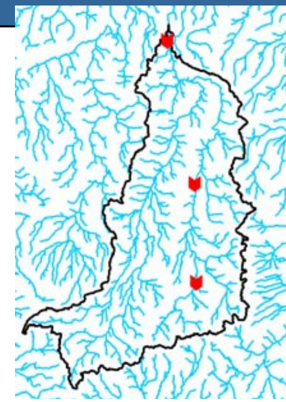
http://www.ess.uci.edu/~hydrogroup/mass/data.html

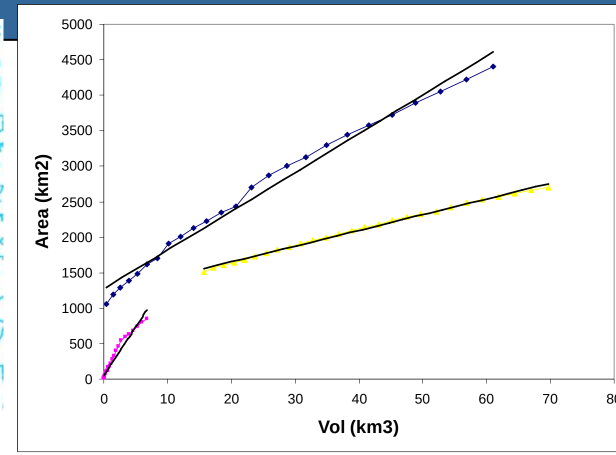


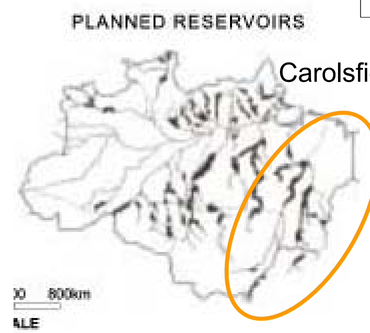
Prigent et al., *J. Geophys. Res.*, 2007

Future Work

- Anthropogenic influences
  - Changing water management practices
  - Changing land use practices
- CHARMS is a first step towards a framework for understanding coupled Earth system interactions - with a realistic representation of surface water bodies
- Future additions to CHARMS
  - lakes/wetlands
  - groundwater-surface water interactions
  - river-atmosphere interactions

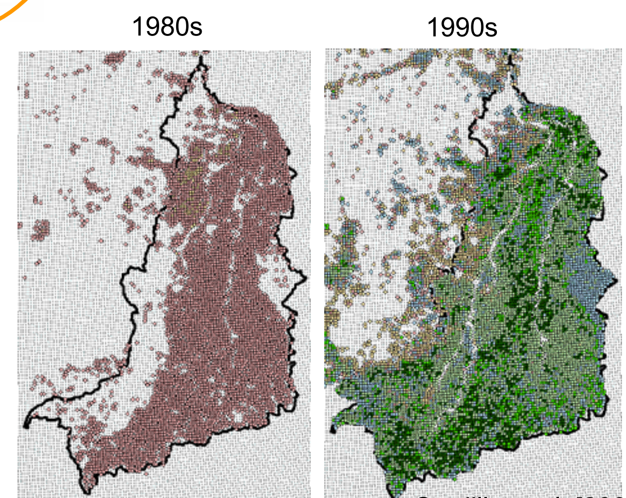






Carolsfield et al. [2004]

% agricultural area = (cultivated + natural pasture + planted pasture)
- 0 - 5
- 6 - 13
- 14 - 26
- 27 - 39
- 40 - 52
- 53 - 65
- 66 - 78



Cardille et al. [2002]

Thank you!

Station ID	Station Name	Drainage Area	
		HCDN	ArcHydro[CHARMS]
03377500 (A)	Wabash River, Mt. Carmel, IL	74165	-2.5% [-2.5%]
03374000 (B)	White River, Petersburg, IN	28814	-4.1% [-4.2%]
03335500 (C)	Wabash River, Lafayette, IN	18822	-3.5% [-4.0%]
03373500 (D)	East Fork White River, Shoals, IN	12761	-1.0% [-3.8%]
03360500 (E)	White River, Newberry, IN	12142	-5.7% [-4.3%]

Station	r	$RMSE$	ME
A	0.92	468	0.65
B	0.90	224	0.64
C	0.77	207	0.25
D	0.76	190	0.10
E	0.82	108	0.56

Station	r	$RMSE$	ME
A	0.97	382	0.71
B	0.98	146	0.81
C	0.93	124	0.44
D	0.97	91	0.68
E	0.97	41	0.89

Transport from hillslopes to the river channel

$$T_{h,surf} = \left(\frac{n_o \, L_h \, \sqrt{S_h}}{r_{surf}^{2/3}(\tau)} \right)^{3/5} \Big/ \Delta T$$

$$T_{h,base} = \left(\frac{\phi \, L_h}{\kappa \, S_h} \right) \Big/ \Delta T$$

$$U_{h,surf}(\tau) = \frac{1}{T_{h,surf}} \qquad \tau = 1, \ldots, T_{h,surf}$$

$$U_{h,base}(\tau) = \frac{1}{T_{h,base}} \qquad \tau = 1, \ldots, T_{h,base}$$

$$Q_{h,surf}(t) = A_h \sum_{\tau=0}^{\tau=\Lambda} r_{surf}(t-\tau) \, U_{h,surf}(t-\tau)$$

$$Q_{h,base}(t) = A_h \sum_{\tau=0}^{\tau=\Lambda} r_{base}(t-\tau) \, U_{h,base}(t-\tau)$$

Transport within river channels and floodplains

$$\frac{\partial Q_{chnl}}{\partial t} + V_c \frac{\partial Q_{chnl}}{\partial x} - D_c \frac{\partial^2 Q_{chnl}}{\partial x^2} = 0$$

$$V_c = \frac{dQ_{chnl}}{dA_c} = \frac{1}{W} \frac{dQ_{chnl}}{dh}$$

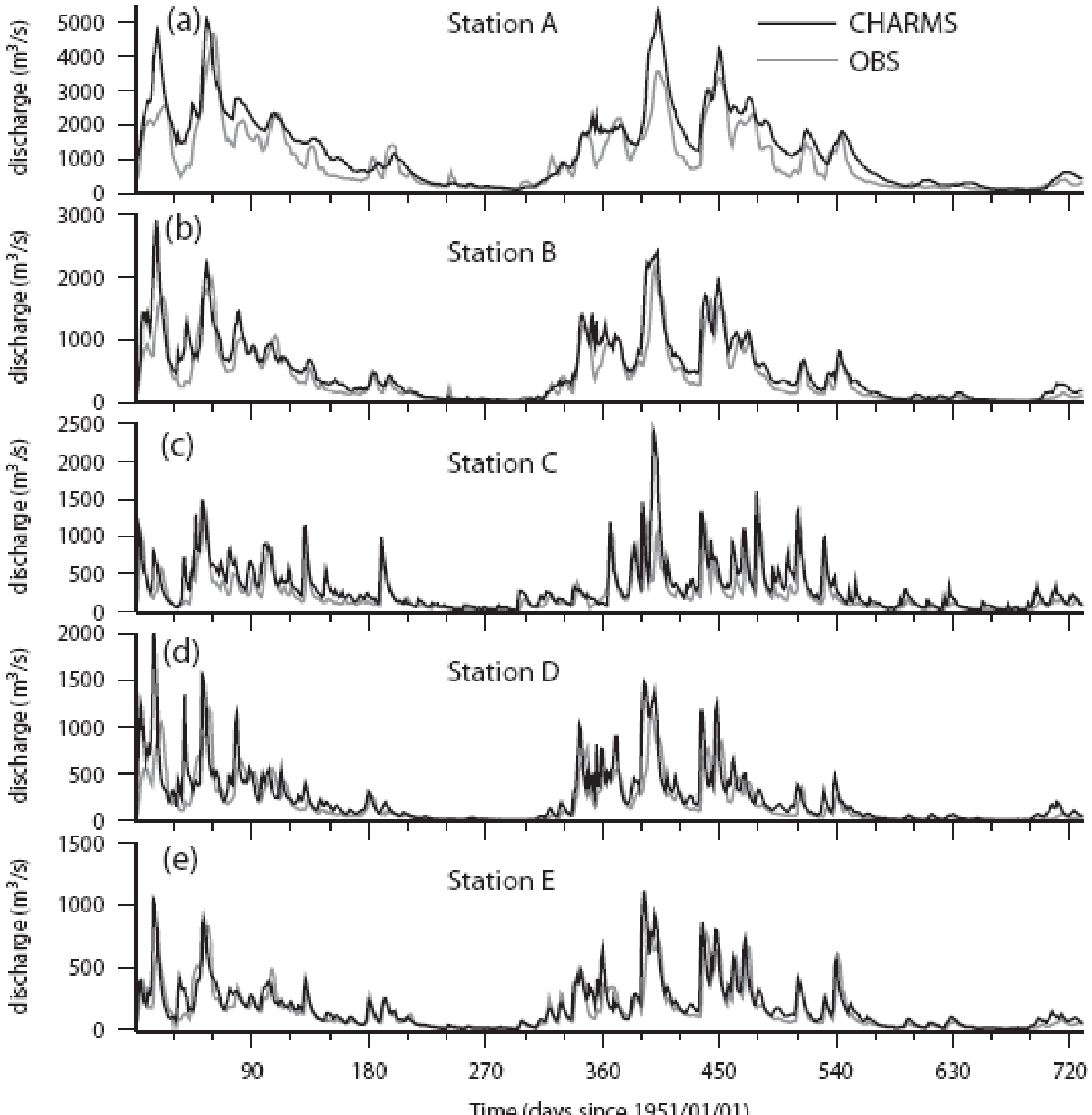
$$D_c = \frac{Q_{chnl}}{2 \, W \, S_{chnl}}$$

$$U_{chnl}(\tau) = \frac{1}{2\tau \sqrt{\pi(\tau/T_c)/\Pi_c}} \, exp\left\{ -\frac{[1-(\tau/T_c)]^2}{4(\tau/T_c)/\Pi_c} \right\}$$

$$T_c = \left(\frac{L_c}{V_c} \right) \Big/ \Delta T$$

$$\Pi_c = \frac{L_c \, V_c}{D_c}$$

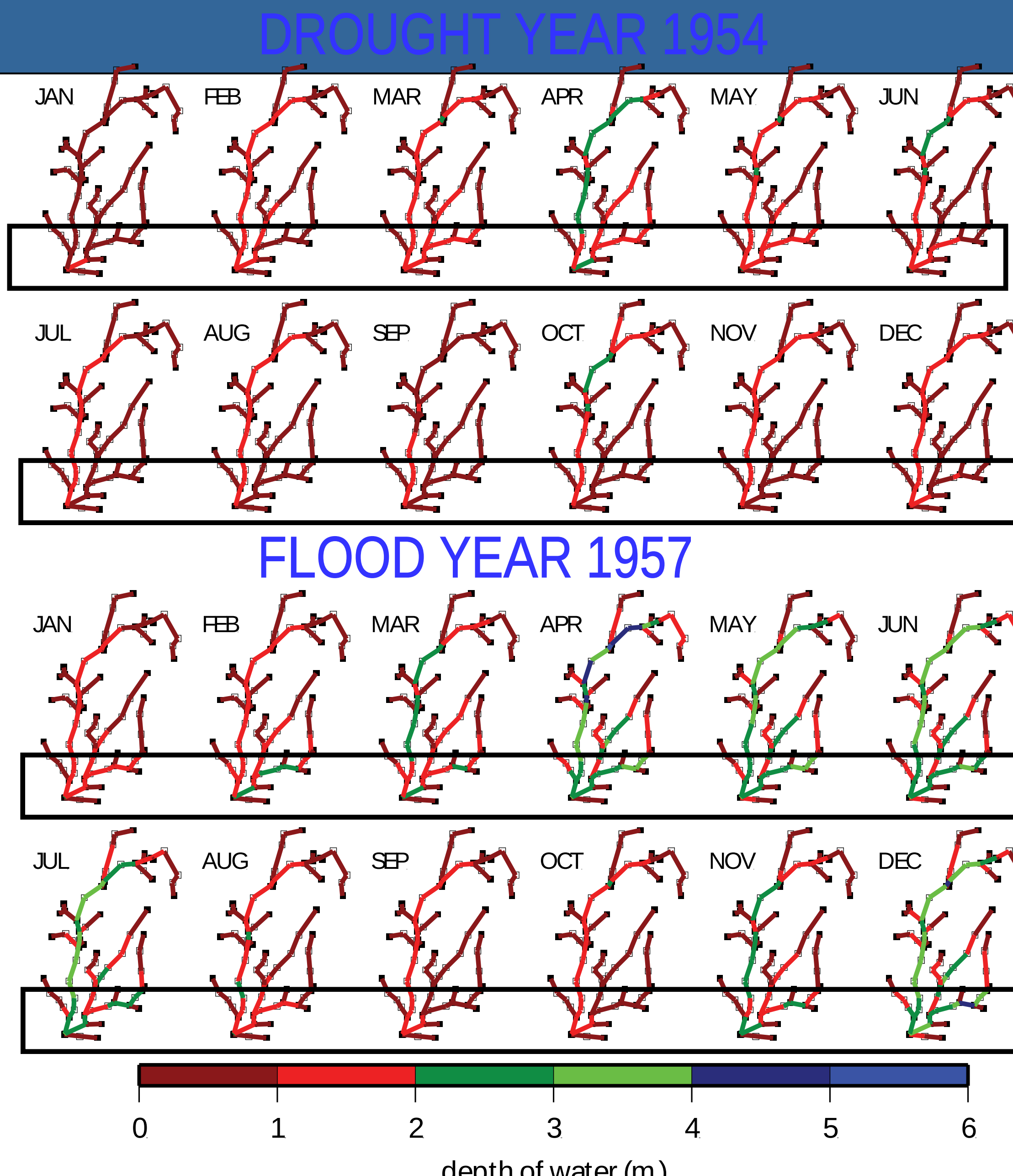
$$Q_{chnl}(t,\ downstream) = \sum_{\tau=0}^{\tau=\Lambda} Q_{chnl}(t-\tau,\ upstream) \, U_{chnl}(t-\tau)$$



(a)
Station A
CHARMS
OBS
(b)
Station B
(c)
Station C
(d)
Station D
(e)
Station E
discharge (m3/s)
Time (days since 1951/01/01)

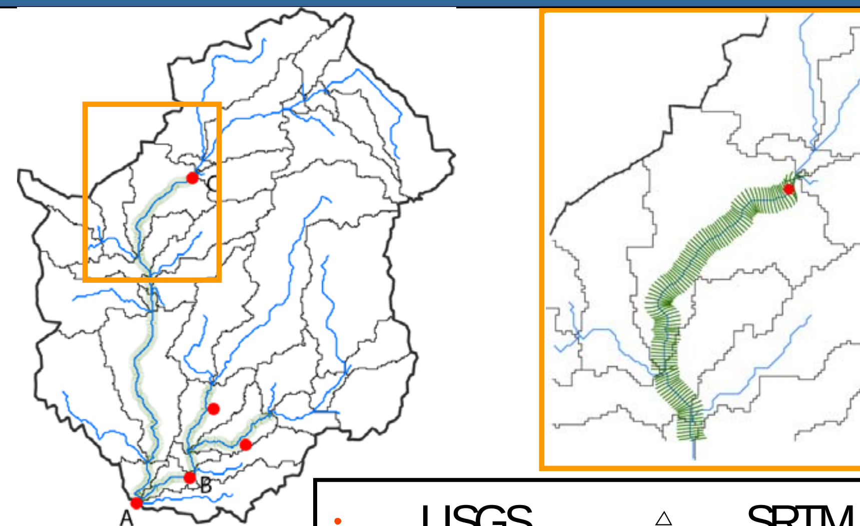
Results: River Flow Depth Simulation

- Seasonal variation in depth 2-3 m
- Annual variation in the downstream reaches 0-2 m (drought year) and 1-4 m (flood year)



Channel Cross-Section Profiles

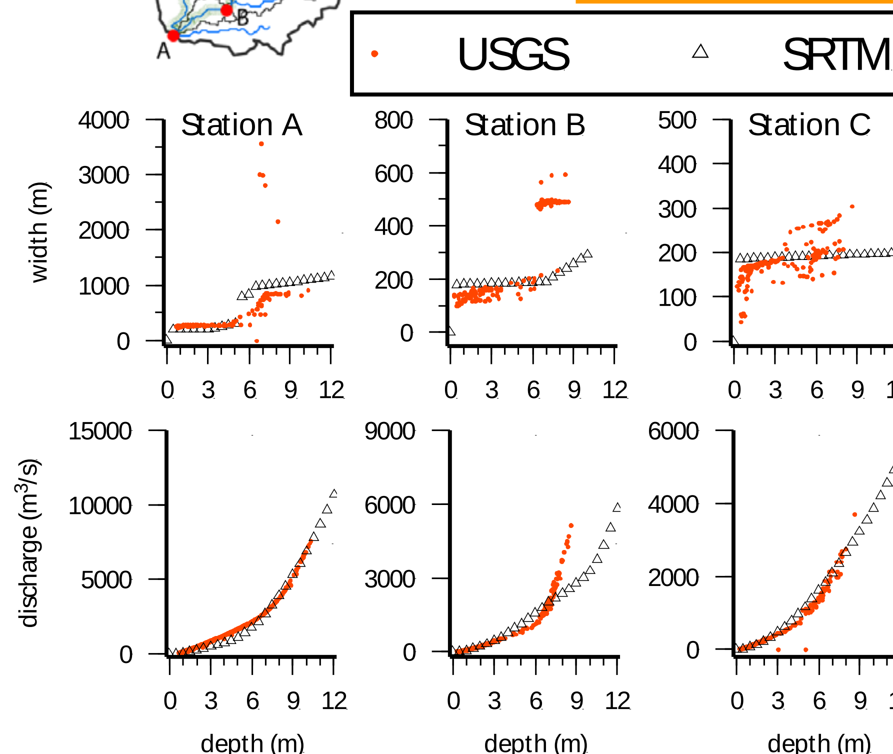
- Shuttle Radar Topography Mission (SRTM) elevation data
  - 90 m, 60 N – 50 S
  - cross-section profiles at 1-km intervals
  - downstream of HCDN/USGS stations



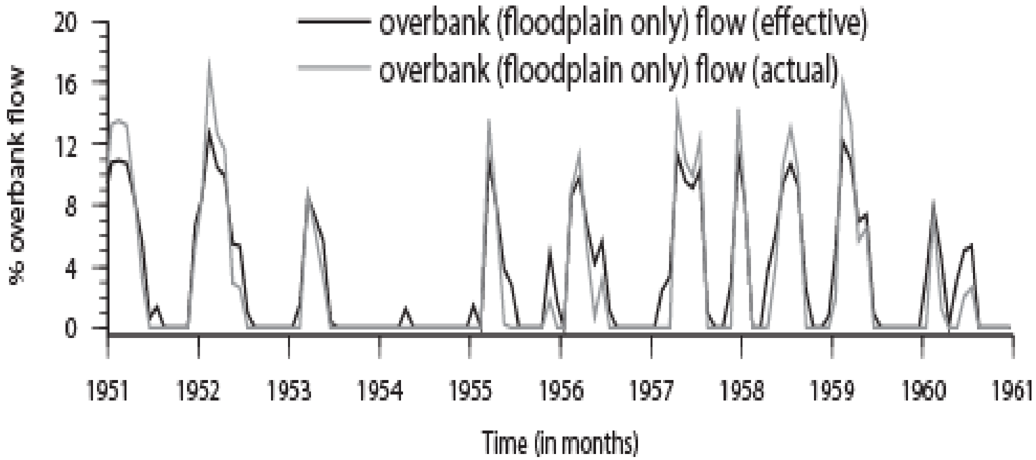
- SRTM-derived data versus USGS observations
  - depth-width
    - SRTM widths scaled by 2.0
  - discharge
    - Manning's empirical equation

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2}$$

    - *n* (chnl) = 0.030, *n* (fldp) = 0.060, S_0 = 0.02%



- Empirical relationship between discharge and channel geometry used by routing model



overbank (floodplain only) flow (effective)
overbank (floodplain only) flow (actual)
% overbank flow
20
16
12
8
4
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
Time (in months)

Inundation Data from Prigent et al.

- Global Inundation Extent (1993-2000, monthly)
- Equal area grids (773 km^2; 0.25 deg at Equator)
- Inundation < 10% (~80 km^2), not captured