Macro-scale hydrology, does shallow groundwater make a difference?

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UBC/UW Meeting
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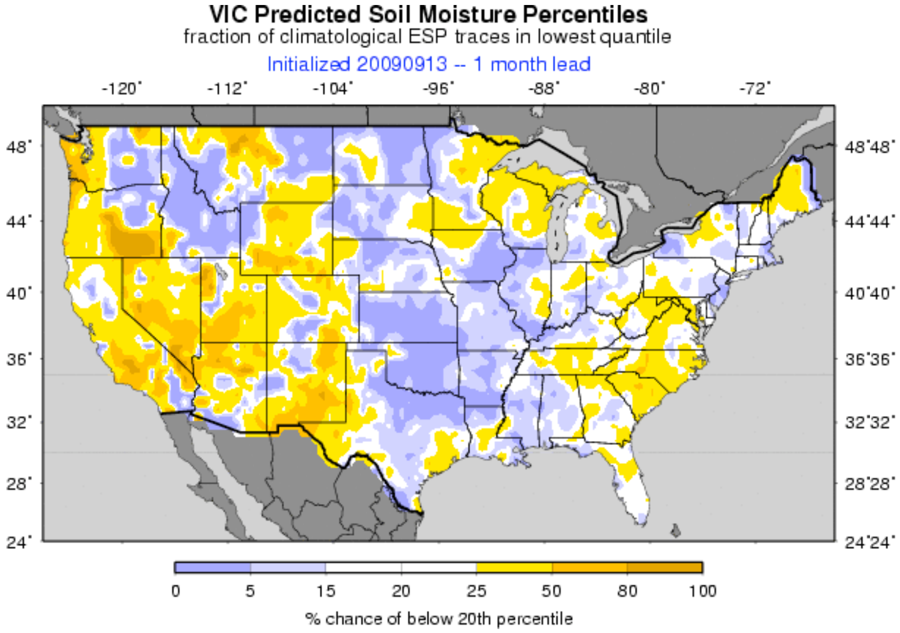
Overview

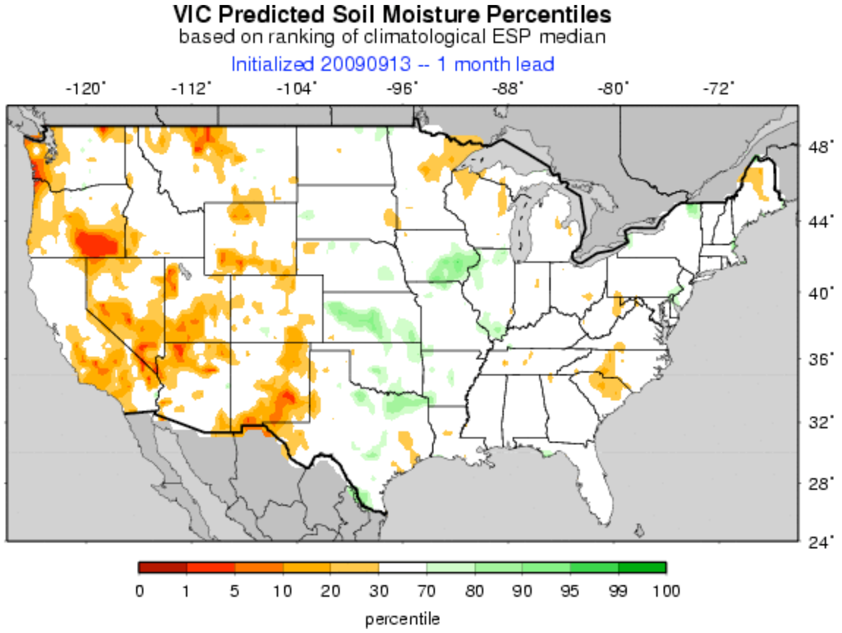
- Introduction/Motivation
- Modeling Approaches
    - Macro-scale groundwater models
    - VIC model modifications
- Model Results
    - Little Wabash River, IL
- Conclusions

Questions

- How does the absence of shallow groundwater in a land surface model impact the water budget it produces?
- Would shallow groundwater impact drought characterization and forecasting?

Surface Water Monitor Drought Forecasts

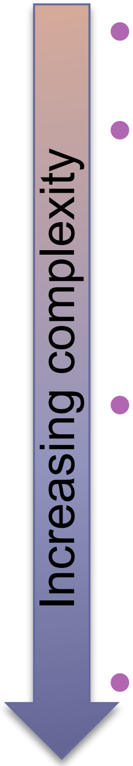




- Forecasts runoff and soil moisture percentiles based on ensemble medians and the probability of drought conditions for 1-, 2- and 3-month lead times.
- 2 types of forecast ensembles:
  - 1960-99 climatology
  - ENSO-determined subsets from 1950-2002 climatology

Modeling approaches

Groundwater in Macro-scale Land Surface Models



- TOPMODEL-based
- Solving soil moisture for unsaturated zone and pressure head profiles for saturated zones separately
- Solving soil moisture profile by applying Richard's equation to unsaturated zone and treating water table as moving boundary
- Solving hydraulic pressure profile for unsaturated and saturated zones together

SIMGM (Niu et al. 2007)

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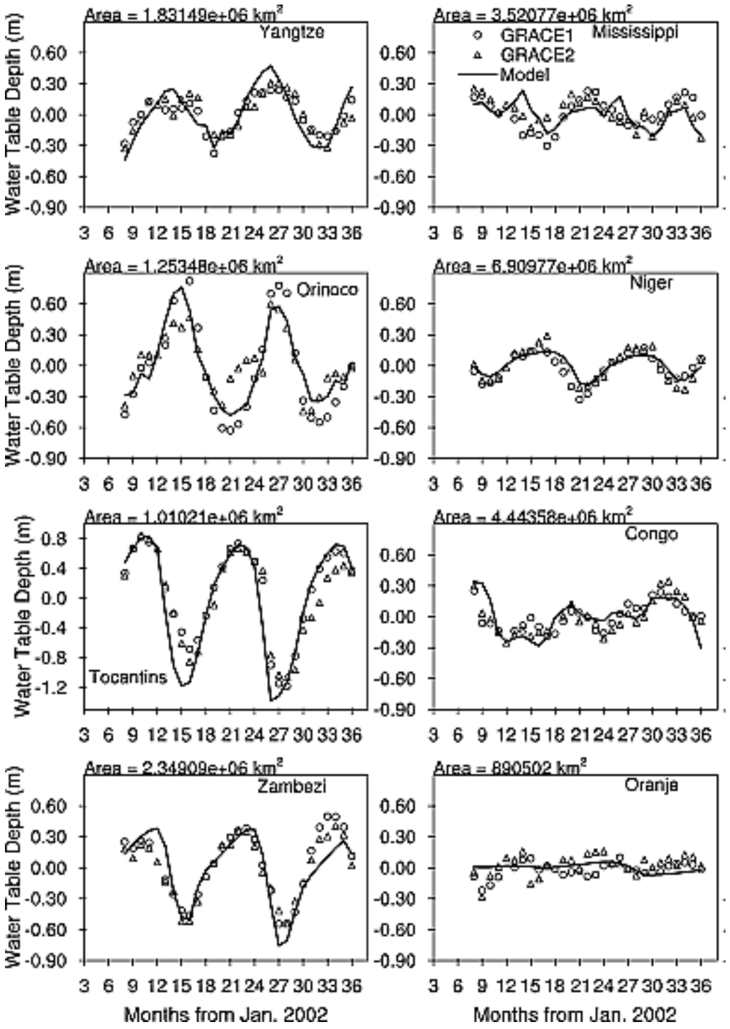

VIC-ground (Liang et al. 2003)

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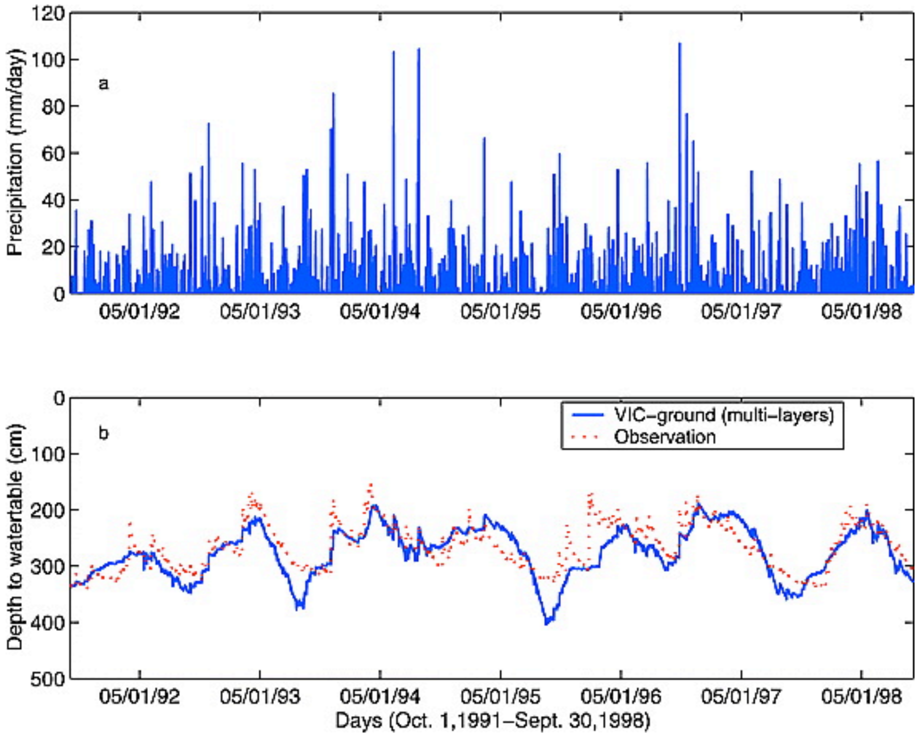

Results for Tulpehocken Creek watershed (in Pennsylvania) with a drainage area of 172 km^2

SIMGM (Niu et al. 2007)

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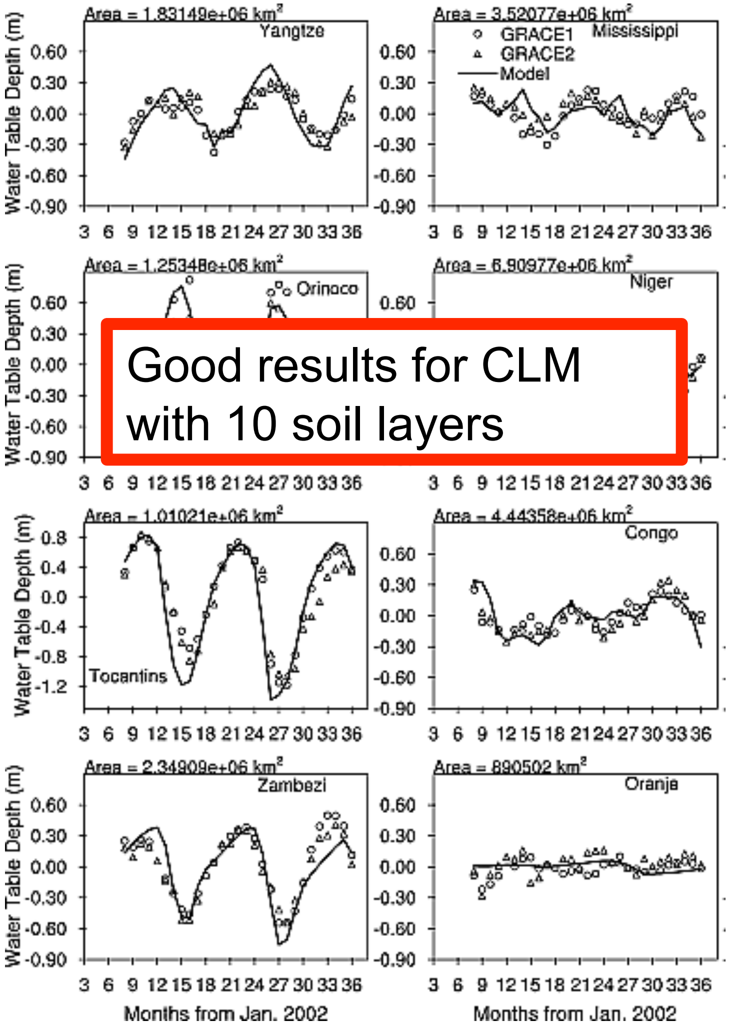
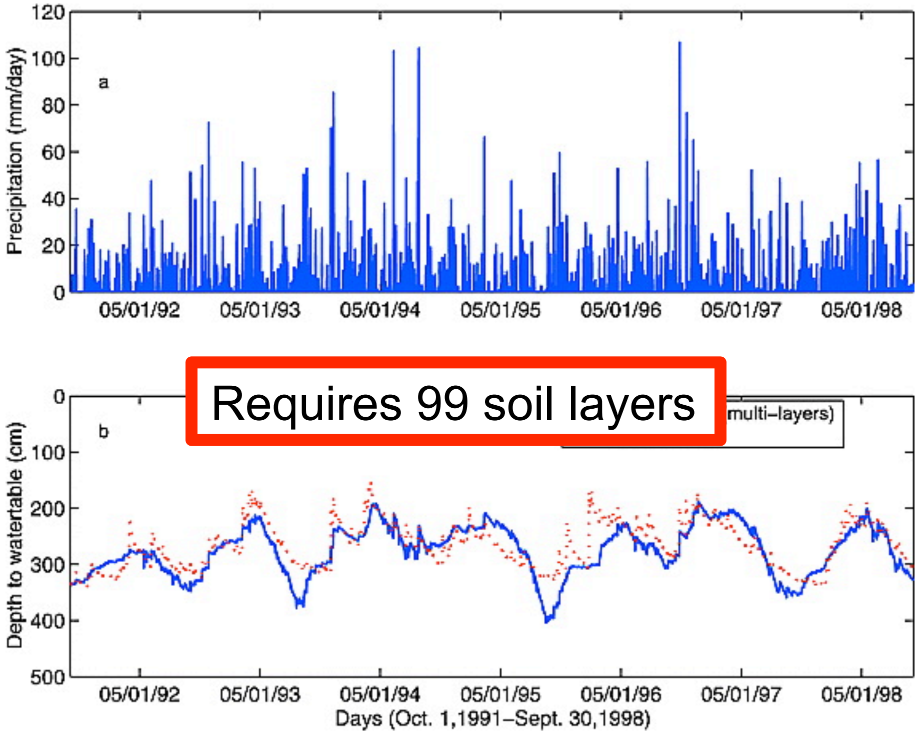


Good results for CLM with 10 soil layers

VIC-ground (Liang et al. 2003)

- Solving soil moisture profile by applying Richard's equation to unsaturated zone and treating water table as moving boundary



Requires 99 soil layers

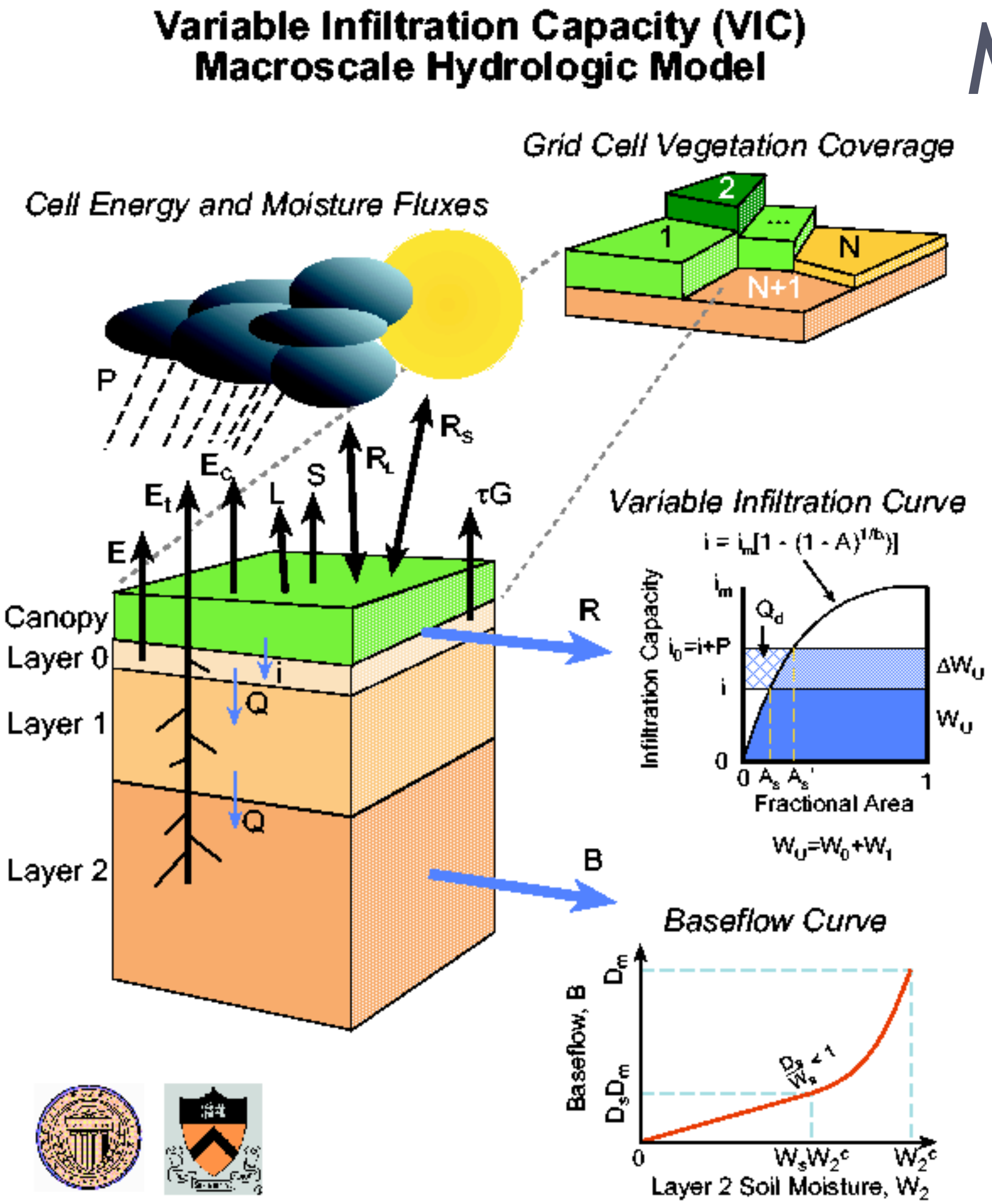
Results for Tulpehocken Creek watershed (in Pennsylvania) with a drainage area of 172 km^2

Macro-scale modeling needs

- Must be computationally efficient

Resolution	Continental U.S. Number of grid cells	West-wide Region (including Mexico) Number of grid cells
1/2º x 1/2º	3,322	~2,672
1/8º x 1/8º	56,335	42,767
100 m x 100 m	~563,350,000	~427,670,000

Model Set-up



Commonalities:

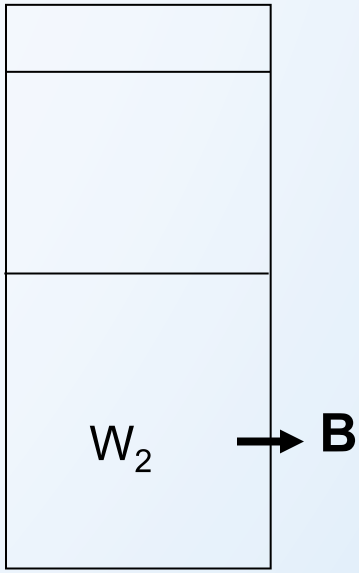
1) Forcings: Precipitation, Tmax, Tmin, Wind
2) Sub-grid cell vegetation, roots distributed in soil layers
3) Surface runoff, Variable Infiltration Curve
4) Soil and canopy evaporation
5) Transpiration from vegetation
6) Snow
7) Energy balance optional
8) Vertical soil moisture drainage

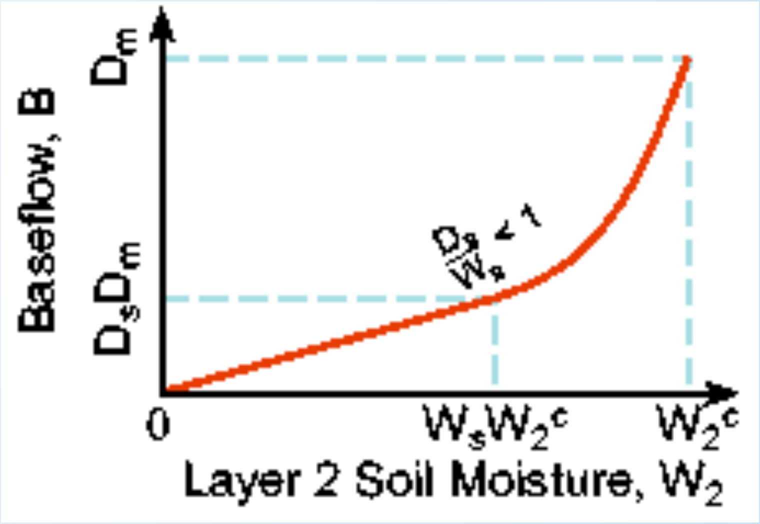
Differences:

1) VIC-SIMGM includes unconfined aquifer
2) Subsurface flow parameterization

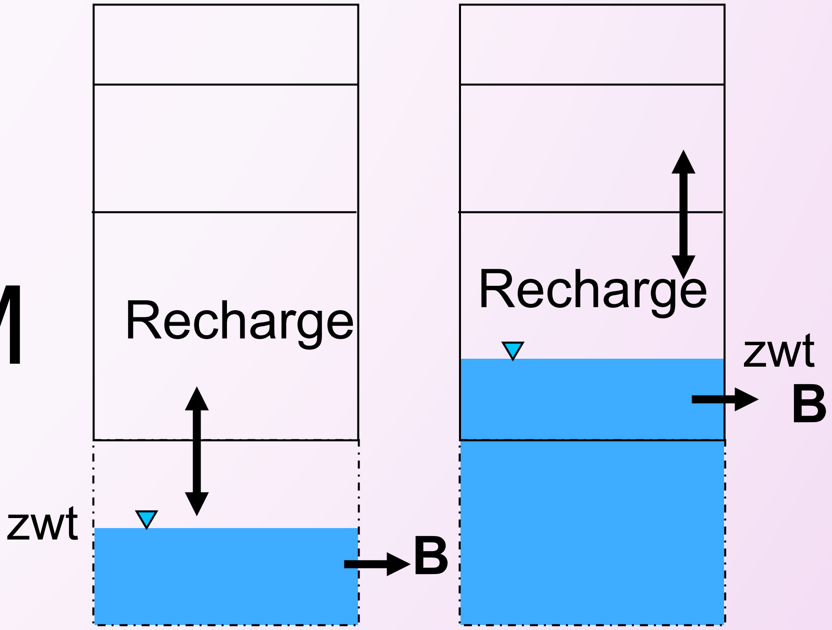
Subsurface flow (baseflow)

VIC

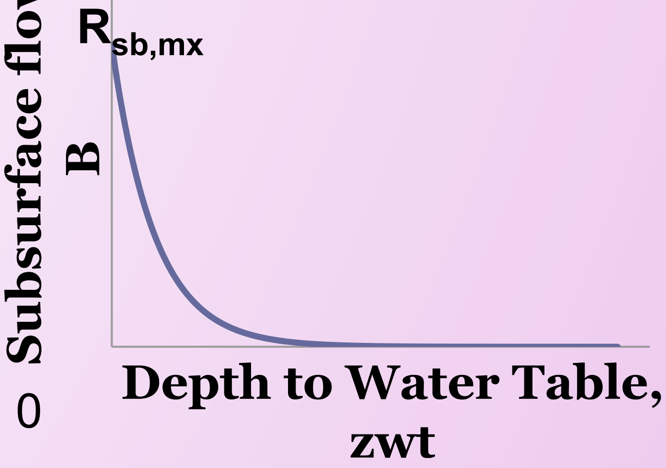




VIC-SIMGM



$$R_{sb} = R_{sb,max} e^{-f z_\nabla}$$



SIMple Groundwater Model

$$\frac{dW_a}{dt} = Q - R_{sb}$$

$$R_{sb} = R_{sb,max} e^{-f z_\nabla}$$

$$Q = -K_a \frac{dh}{dz}$$

W_a = aquifer storage

Q = recharge to groundwater

R_{sb} = groundwater discharge

$R_{sb,max}$ = maximum groundwater discharge

f = decay factor

K_a = hydraulic conductivity

h = matric potential + gravity (elevation) potential

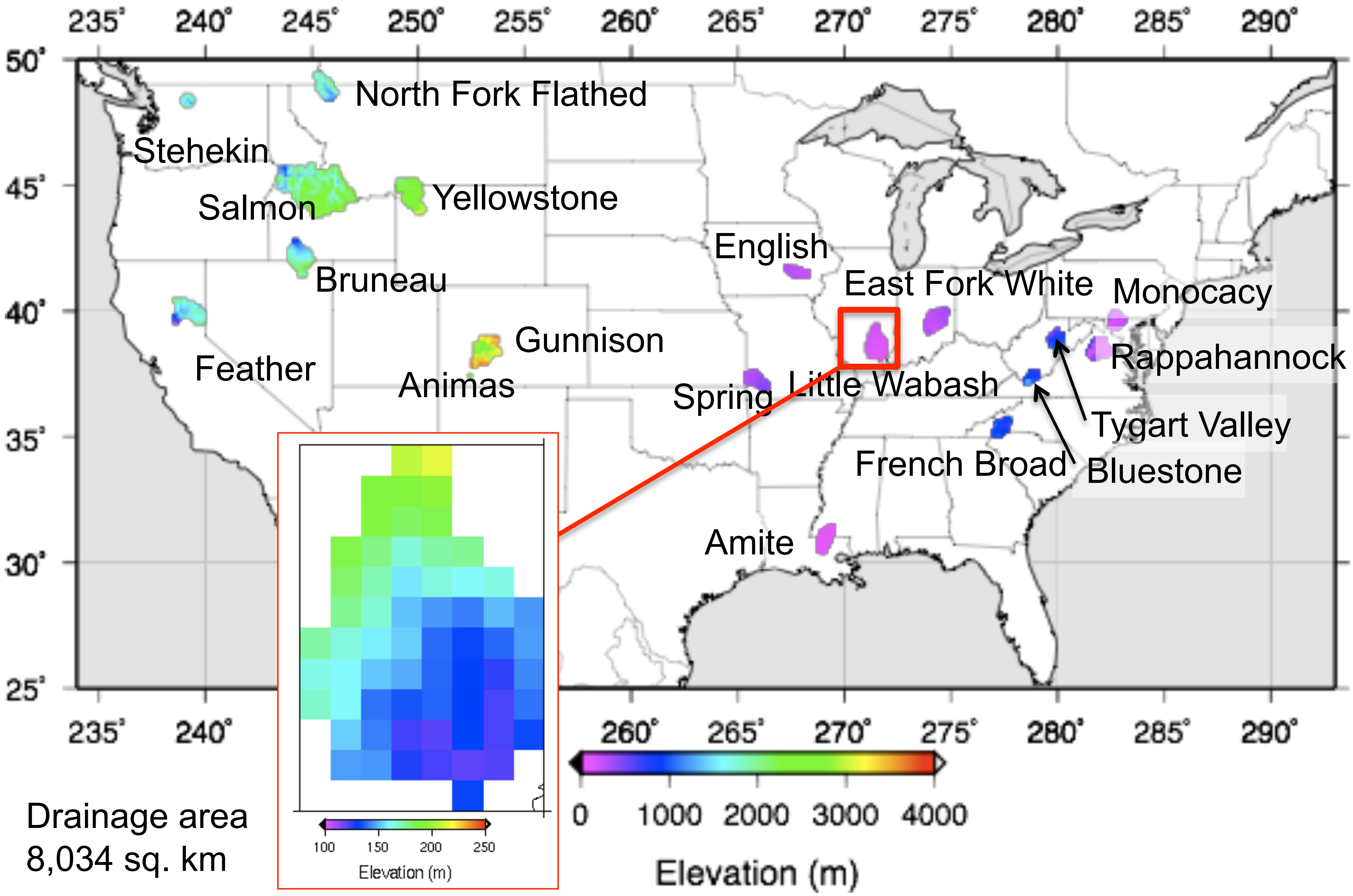
z = layer depth

z_∇ = depth to water table

$$z_\nabla = F(z_{bot}, W_a, \text{specific yield, effectiveporosity})$$

Model Application and Results

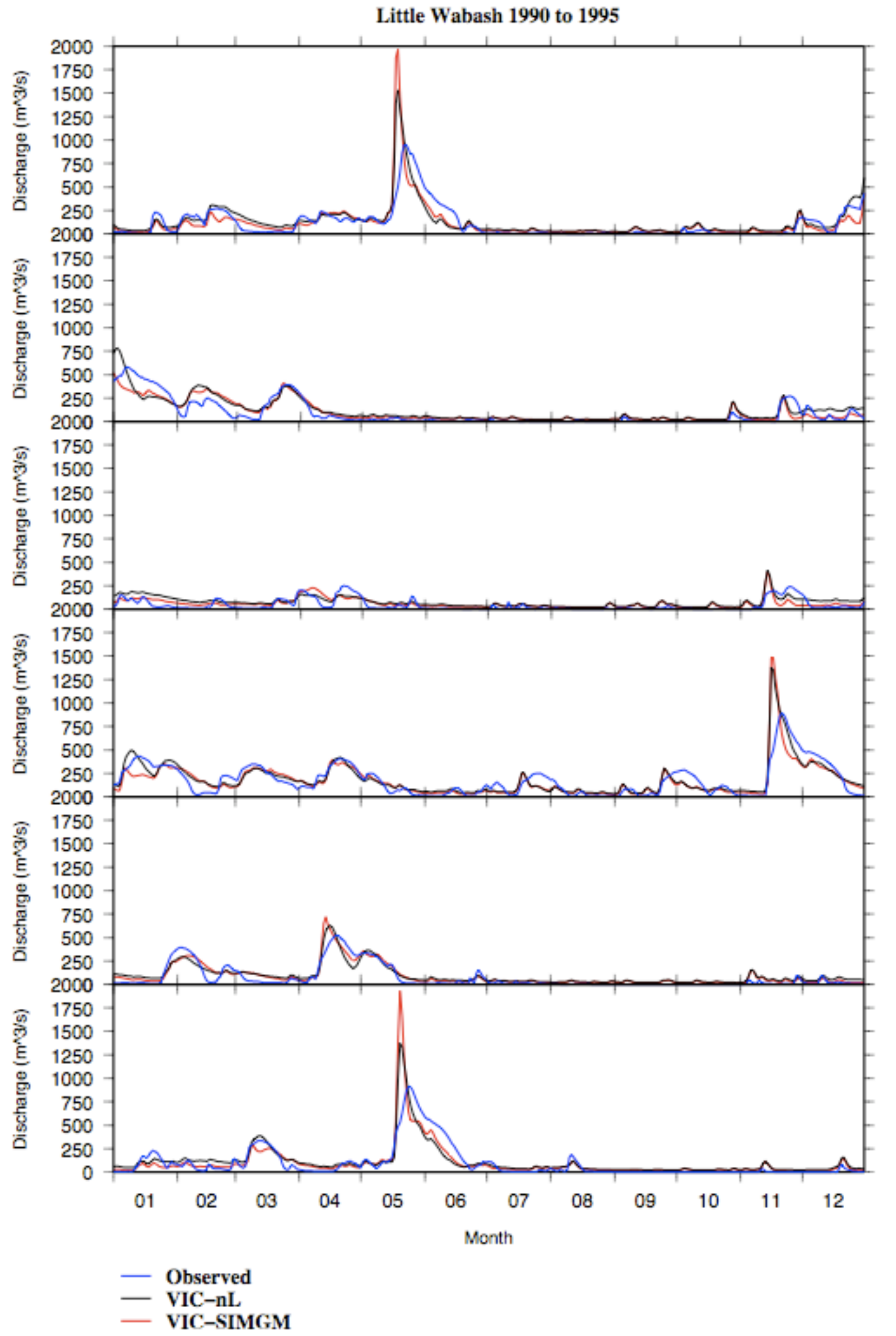
Test sites



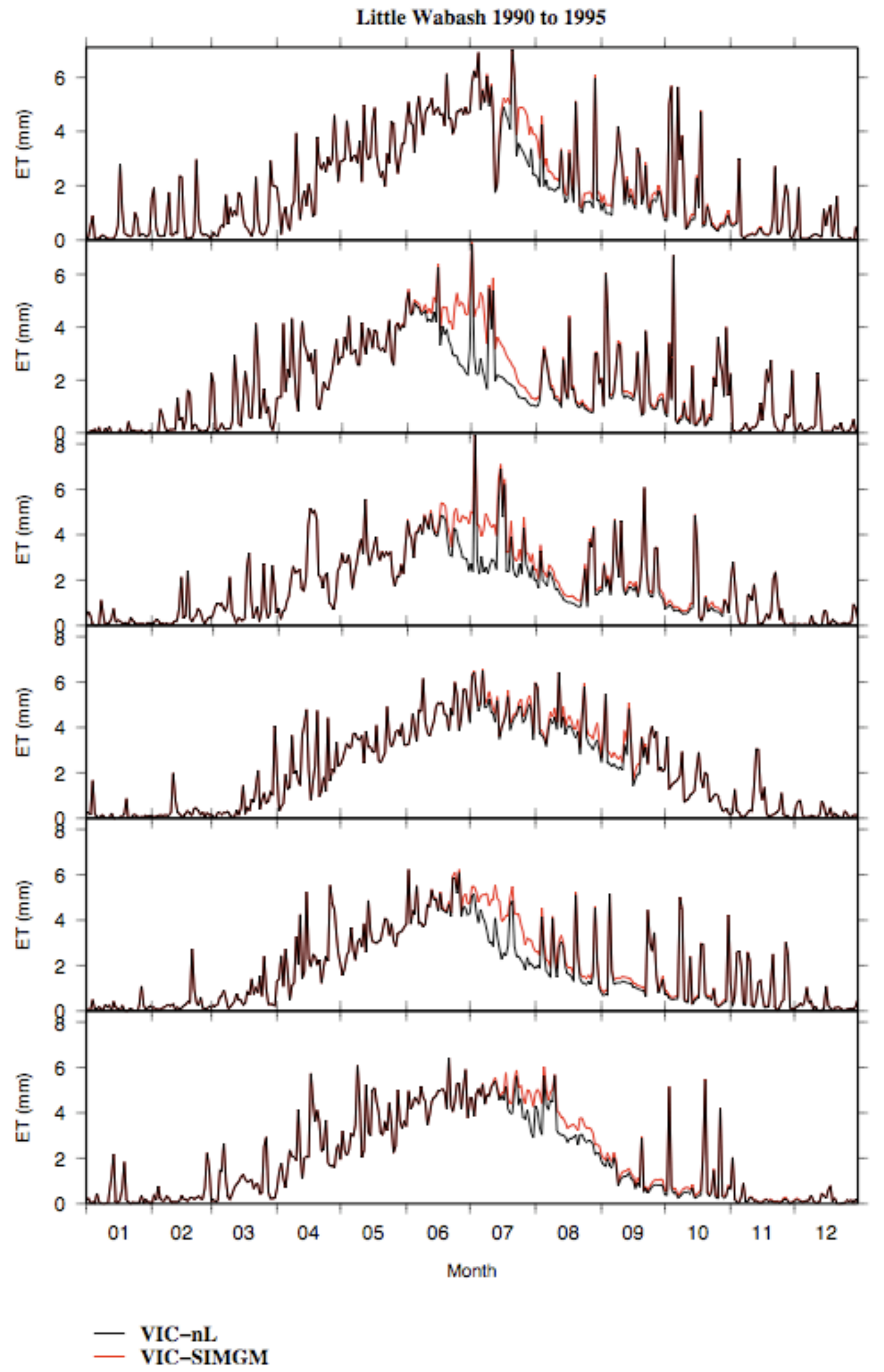
Drainage area
8,034 sq. km

Daily Streamflow

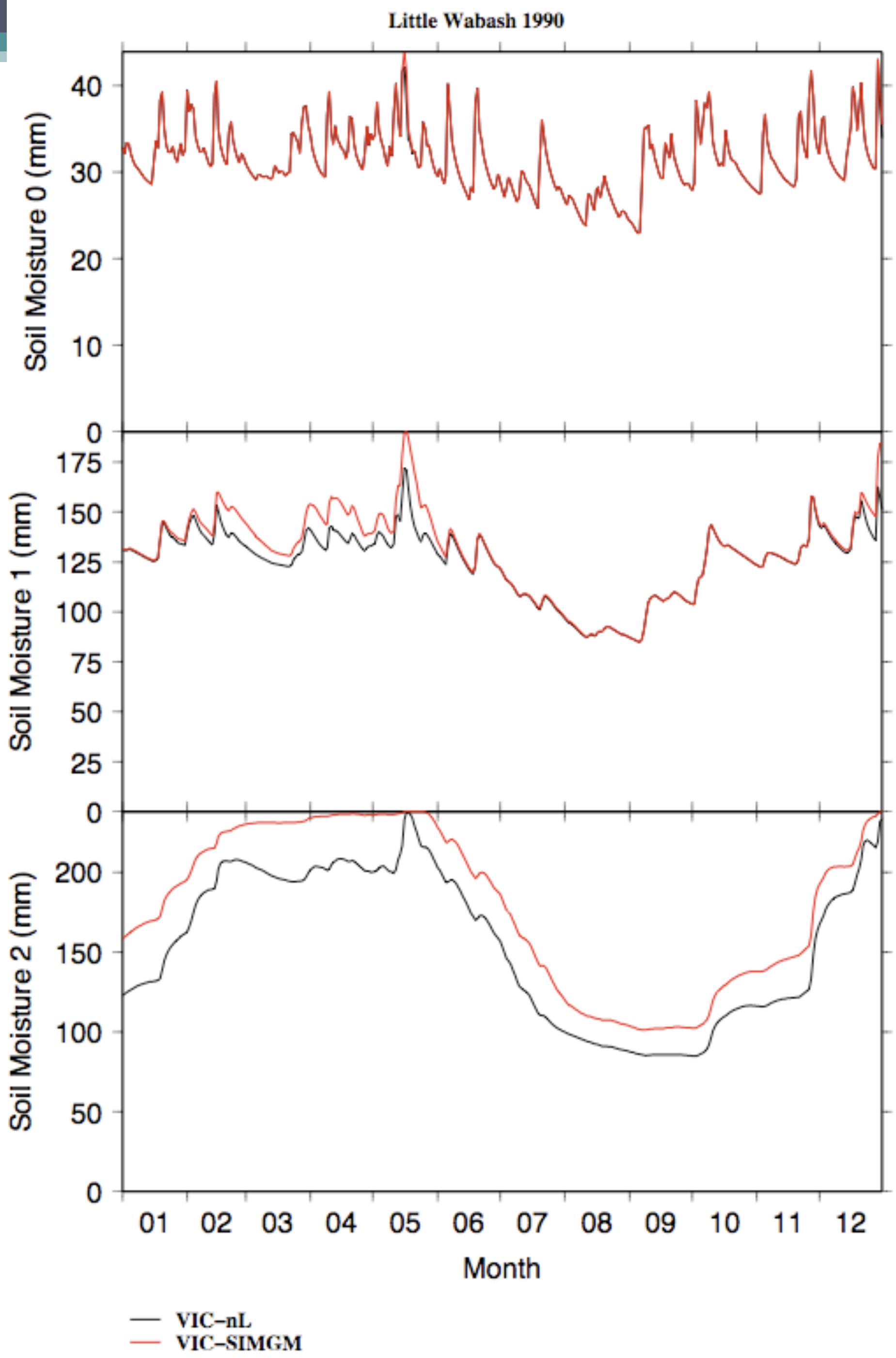
1953-99	VIC-nL	VIC-SIMGM
NSE of daily Q	0.69	0.62
NSE of ln (daily Q)	0.42	0.59
R^2	0.75	0.66



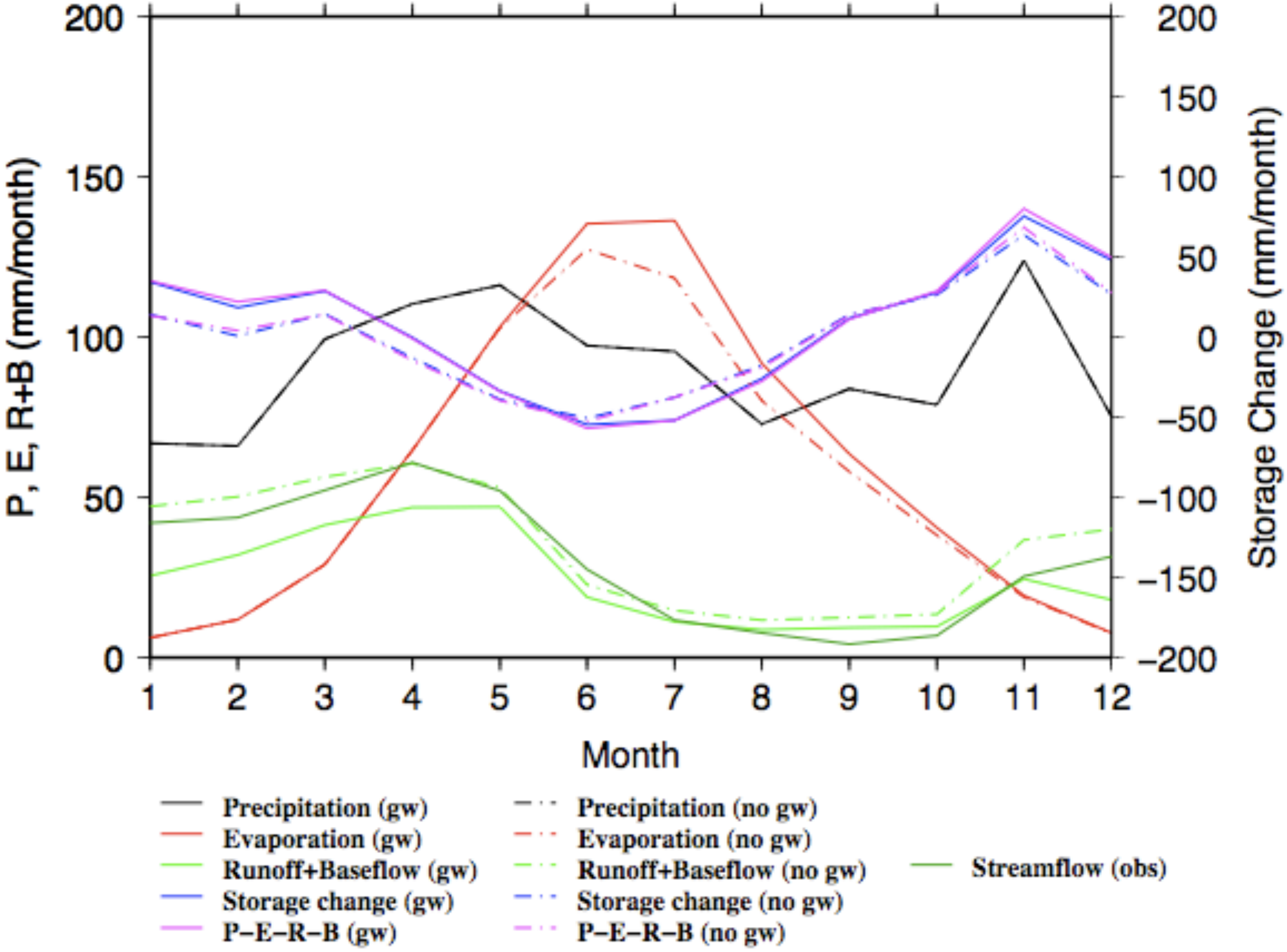
Daily Evapo-transpiration



Daily
Soil Moisture

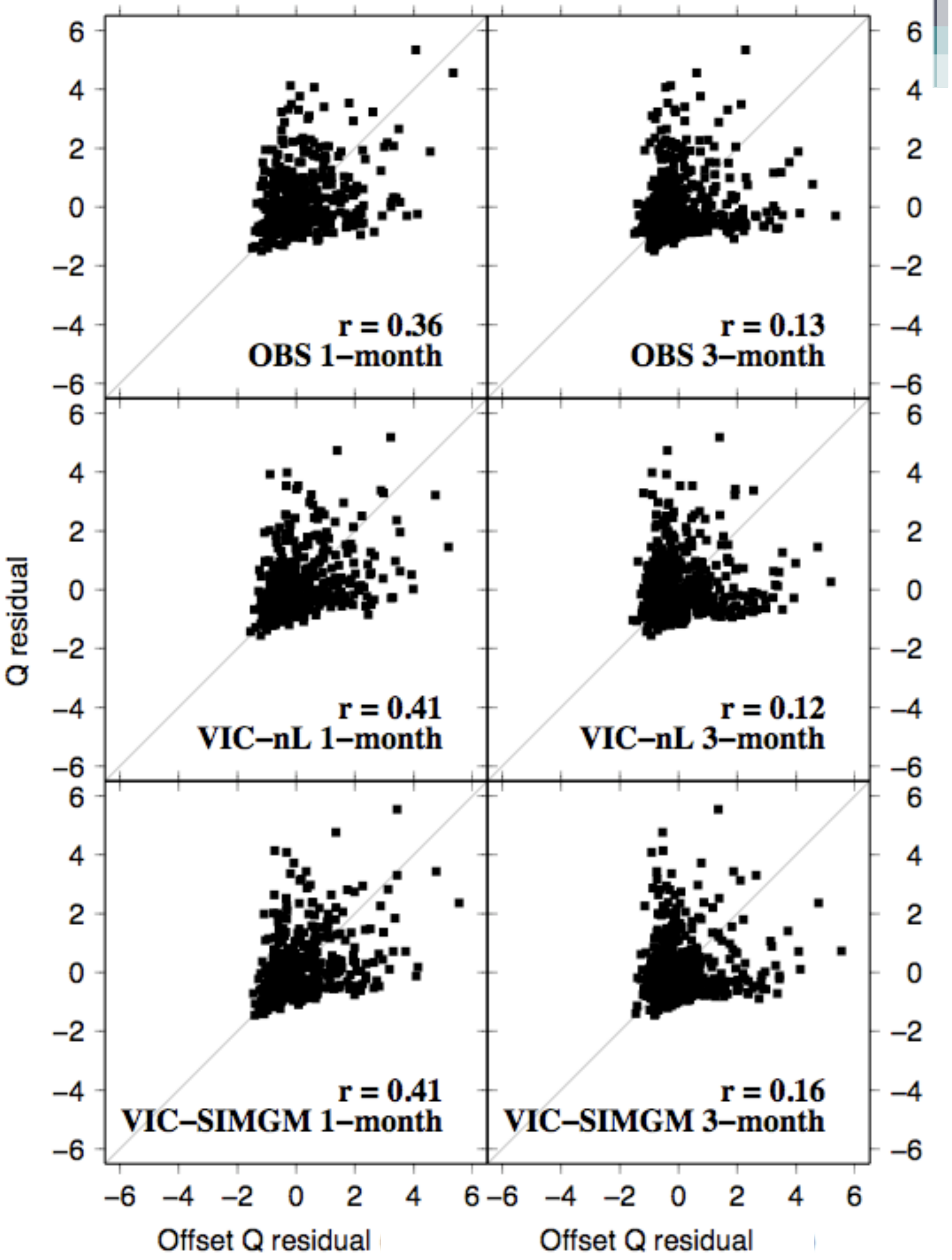


Average Monthly Water Balance 1984-1998



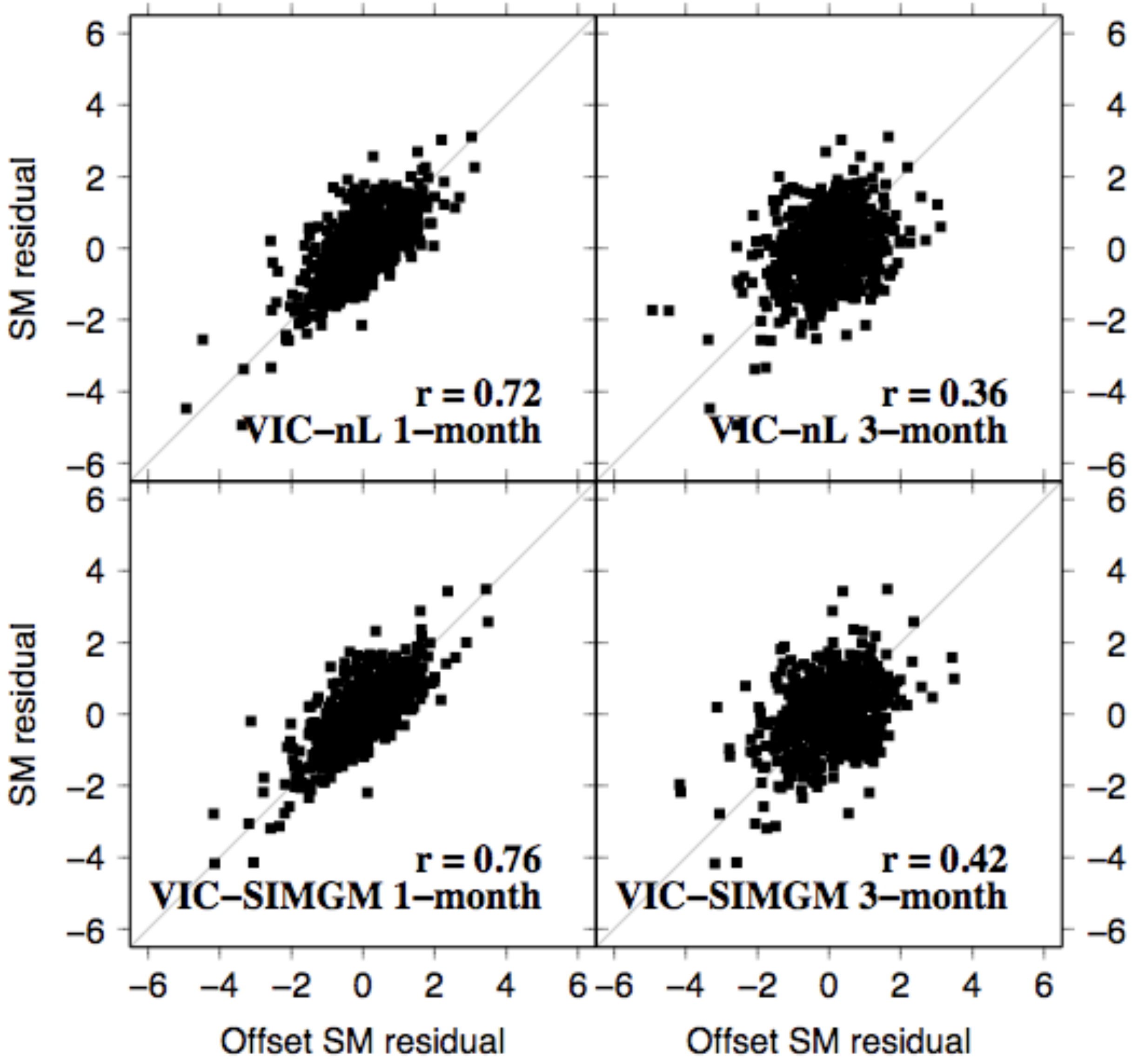
Streamflow Persistence

- $Q_{residual}=(Q_{i,mo}-\mu_{Q,mo})/\sigma_{Q,mo}$
- Correlations between flow in month 1 (Q residual) with flow in month n (Offset Q residual)
- VIC-SIMGM performs similarly well as VIC-nL



Soil Moisture Persistence

- $SM_{residual}=(SM_{i,mo}-\mu_{SM,mo})/\sigma_{SM,mo}$
- VIC-SIMGM soil moisture shows a slightly stronger correlation with past soil moisture



Conclusions

For the Little Wabash River in Illinois,

- VIC-SIMGM can produce comparably reasonable streamflow estimates to those of VIC-nL
- The inclusion of groundwater primarily impacts:
  - Deep layer soil moisture
  - Summertime evapotranspiration
- VIC-SIMGM has a slightly higher lagged correlation than VIC-nL but the differences seem unlikely to have a strong impact on drought forecasting.

Acknowledgements

- Thanks to:
    - USGS for funding
    - Guo-Yue Niu for providing SIMGM code

Extra slides

SIMGM: Recharge (Q)

Water table in “aquifer”

- Recharge from Darcy’s Equation:

$$Q = -K_a \frac{-z_\nabla - (\psi_{bot} - z_{bot})}{z_\nabla - z_{bot}}$$

$$= K_a + K_a \frac{\psi_{bot}}{z_\nabla - z_{bot}}$$

Gravitational Drainage

Capillary Rise

- ● Hydraulic Conductivity in Aquifer

$$K_a = k_{bot} \frac{(1 - e^{-f(z_\nabla - z_{bot})})}{f(z_\nabla - z_{bot})}$$

Water table in soil column

- No exchange between “aquifer” and soil column

$$Q_i = -K_{i,\nabla} \frac{(\psi_{sat} - z_\nabla) - (\psi_i - z_i)}{z_\nabla - z_i}$$

$$= K_{i,\nabla} + K_{i,\nabla} \frac{\psi_i - \psi_{sat}}{z_\nabla - z_i}$$

Gravitational Drainage

Capillary Rise

- ● Hydraulic Conductivity between layers based on soil texture and water content

SIMGM: Discharge (R_{sb})

- TOPMODEL-based formulation
  - Topographic (or wetness) index: $\lambda=\ln(a/\tan\beta)$
    - a = specific catchment area, tan β= local surface topographic slope

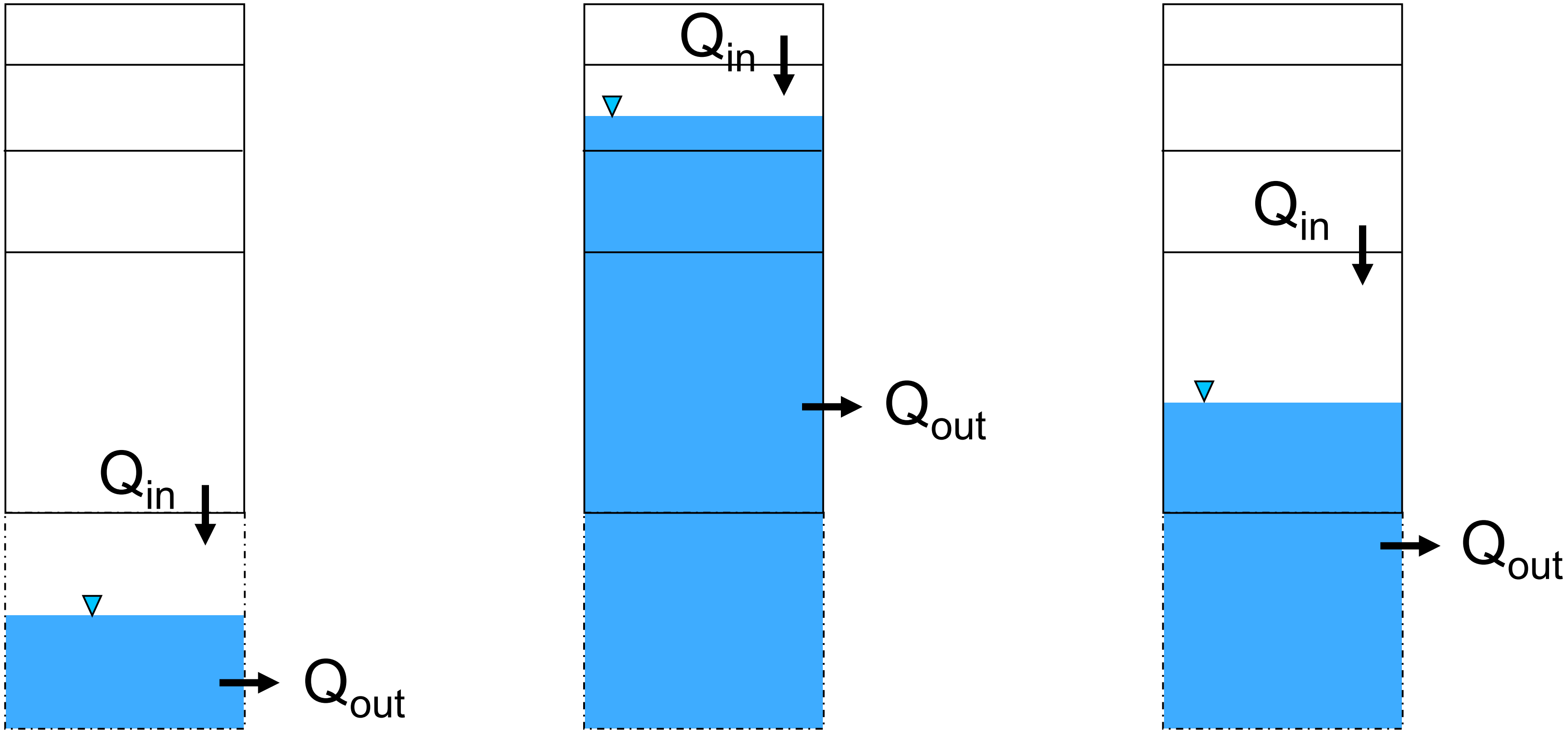
$$R_{sb} = R_{sb,max} e^{-fz_\nabla}$$

    - *f* can be determined by sensitivity analysis or calibration against a hydrograph recession curve
    - $R_{sb,max} = \alpha K_{sat}(0) e^{-\lambda}/f$
    - $\alpha \quad K_{sat}$
  - Issue: Not enough high resolution (~30 m x 30 m) DEM data to calculate λ. Calibrated to 16 wells in Illinois and performed sensitivity analysis to justify applying globally.

SIMGM: $W_a = W_a + (Q-R_{sb})*dt$

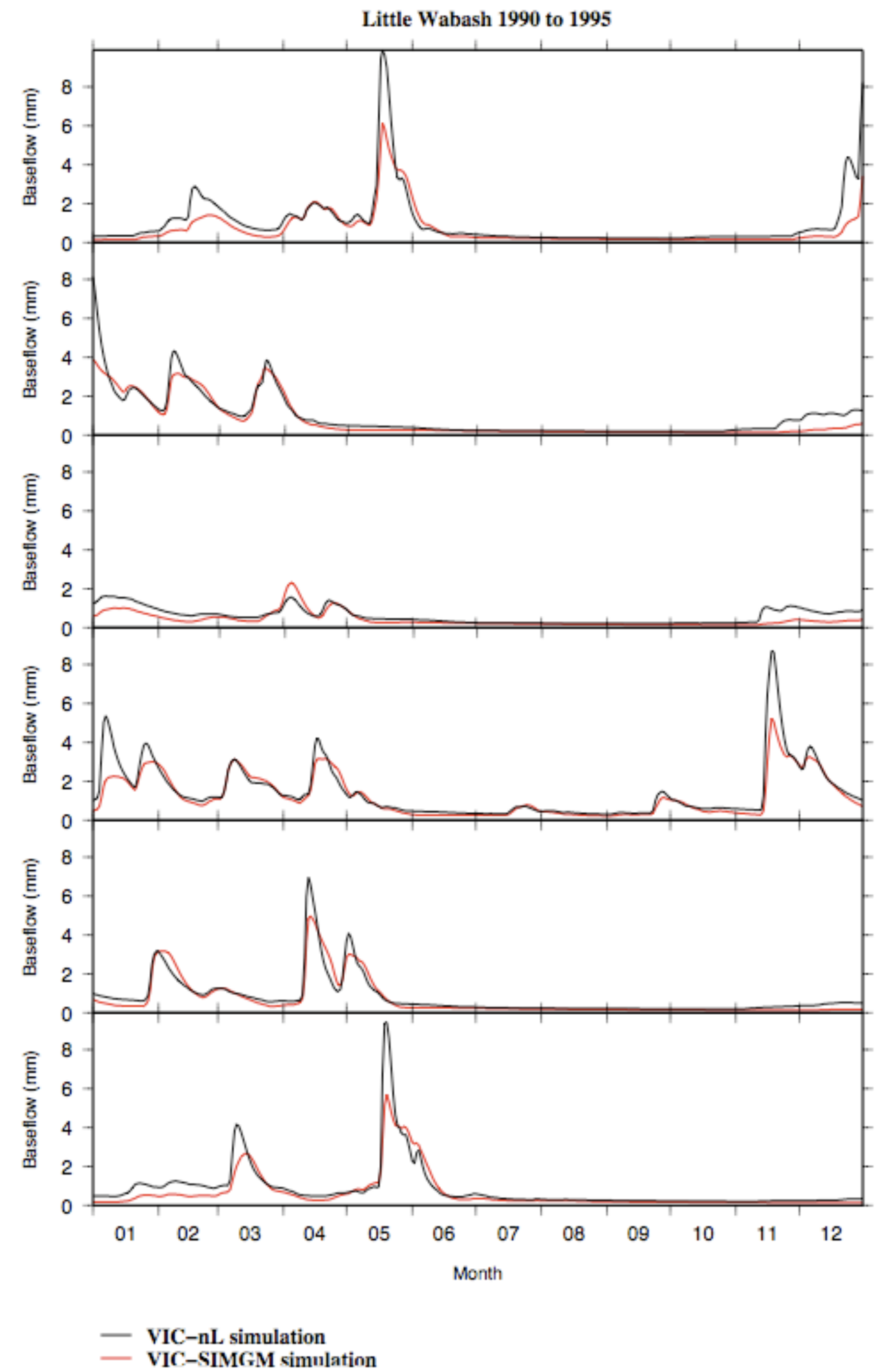
$$z_{wt} = z_{bottom} - \frac{W_a}{S_y} + 25$$

$$z_{wt} = z_{bottom} - \frac{W_a - S_y * 25}{\eta_e}$$

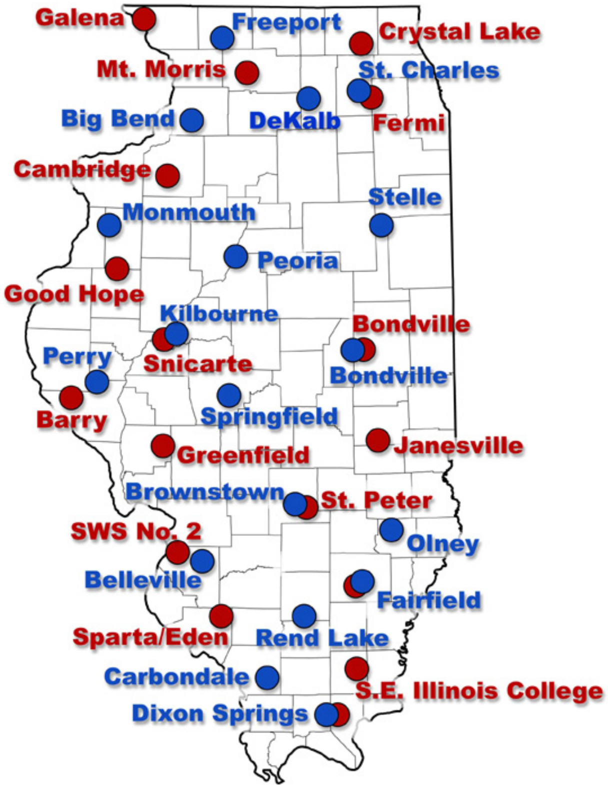


$$z_{wt} = z_{bottom} - \frac{W_a - S_y * 25 - water\ in\ soil\ air\ pores}{\eta_e}$$

Daily Baseflow



Daily Depth to Water Table



● **WARM Wells** From late 1980s

● **ICN Wells** From ~1997

http://www.sws.uiuc.edu/warm/sgwdata/wells.aspx