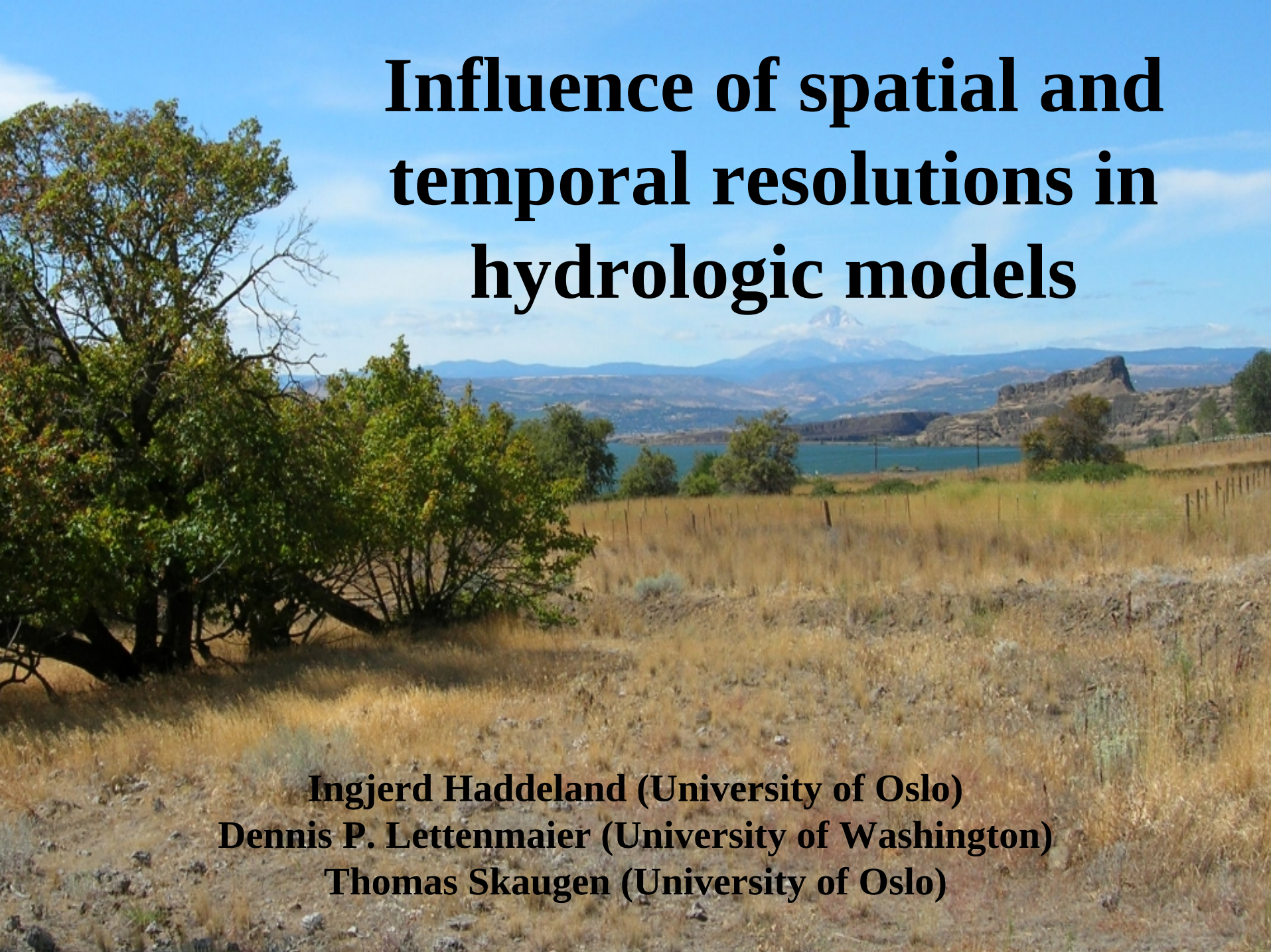


Influence of spatial and temporal resolutions in hydrologic models

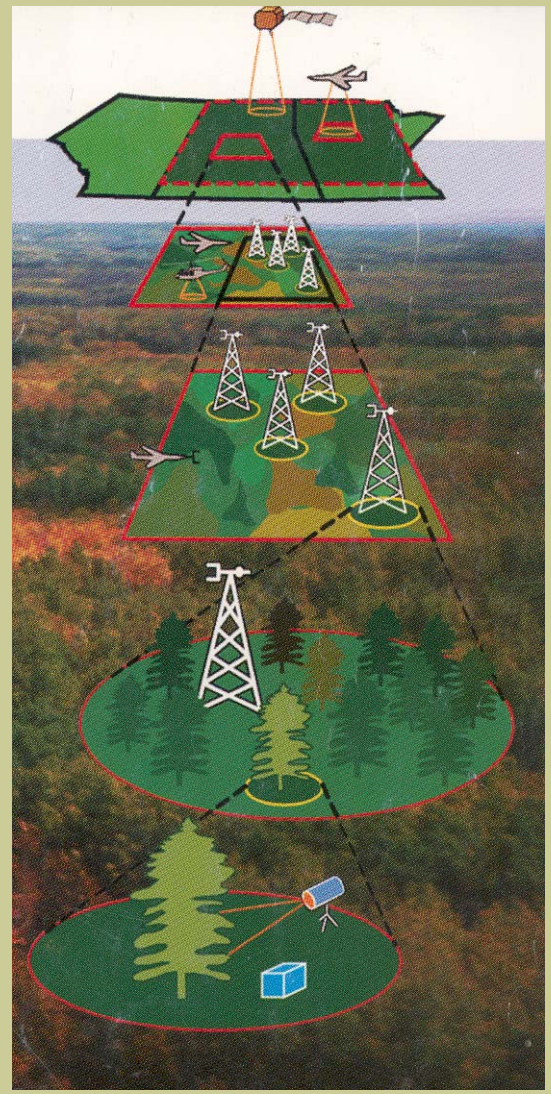
Ingjerd Haddeland (University of Oslo)
Dennis P. Lettenmaier (University of Washington)
Thomas Skaugen (University of Oslo)

Outline

- Background, motivation
- Variable Infiltration Capacity (VIC) model
- Spatial aggregation:
  - Rhone, Columbia and Arkansas-Red River basins
  - Conclusions
- Temporal aggregation:
  - Ohio and Arkansas-Red River basins
  - Conclusions

Motivation and objective

- Hydrological data are just pieces.....
  - Pieces of the water balance
  - Pieces in space
  - Pieces in time

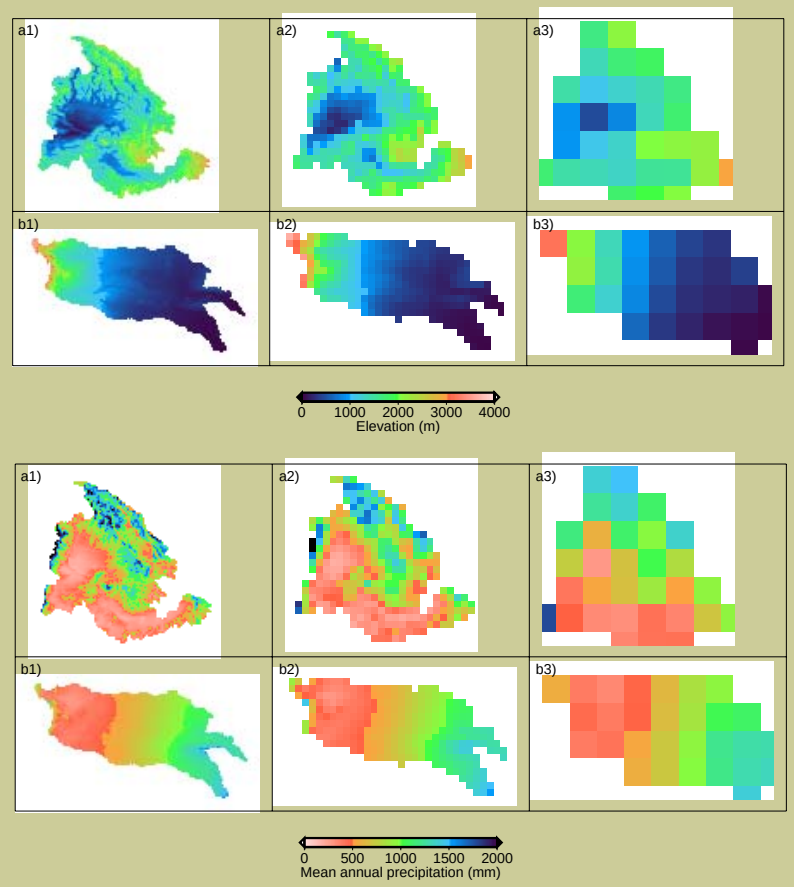


Motivation and objective

- Hydrological data are just pieces.....
  - Pieces of the water balance
  - Pieces in space
  - Pieces in time

Motivation and objective

- Representation of spatial variations in soil properties, topography and precipitation
- Spatial resolution of available input data and hydrologic models changes frequently
- Choice of spatial/temporal scale: Is often based on computational considerations, or issues related to the resolution of the observations.



Science questions

- How are model simulations impacted by changing the spatial resolution?
- How different does models evaluated at two temporal scales perform?
- Is it possible to reconcile simulations performed at different scales?

Previous studies: Examples

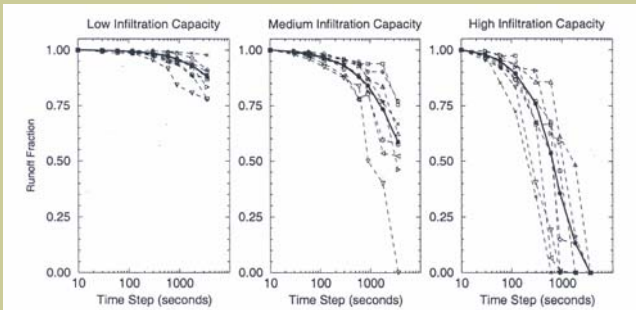


Figure 2. Total storm runoff simulated using true parameters as a fraction of true runoff, Phi-index model. Individual storm events are shown by open symbols and dotted lines; a longer calibration record is shown by solid symbols and line. For longer sampling intervals, increasing undersimulation of runoff occurs. Among the individual storms, those that are more variable have a more extreme response to the smoothing than storms that are generally more uniform.

Holmann-Dodds et al., *Journal of Geophysical Research*, 1999

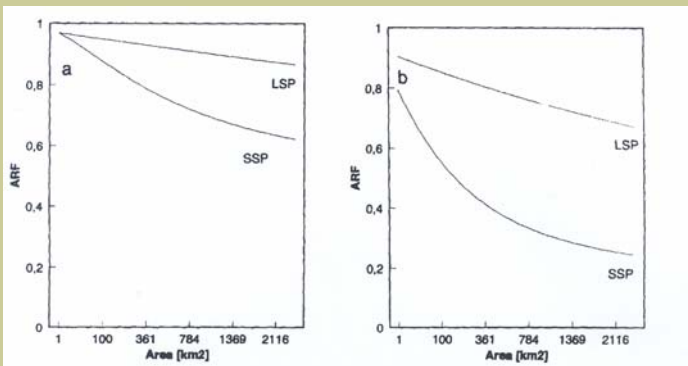
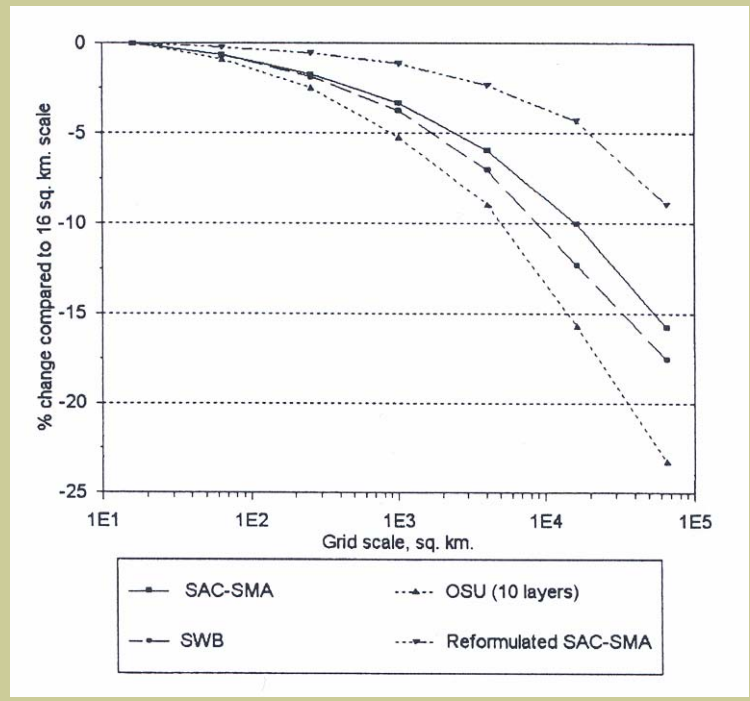


Fig. 7. ARF curves for probabilities of exceedance 0.1 (a) and 0.01 (b).

Skaugen, *Journal of Hydrology*, 1997



Koren et al., *Water Resources Research*, 1999

VIC: Variable Infiltration Capacity Model

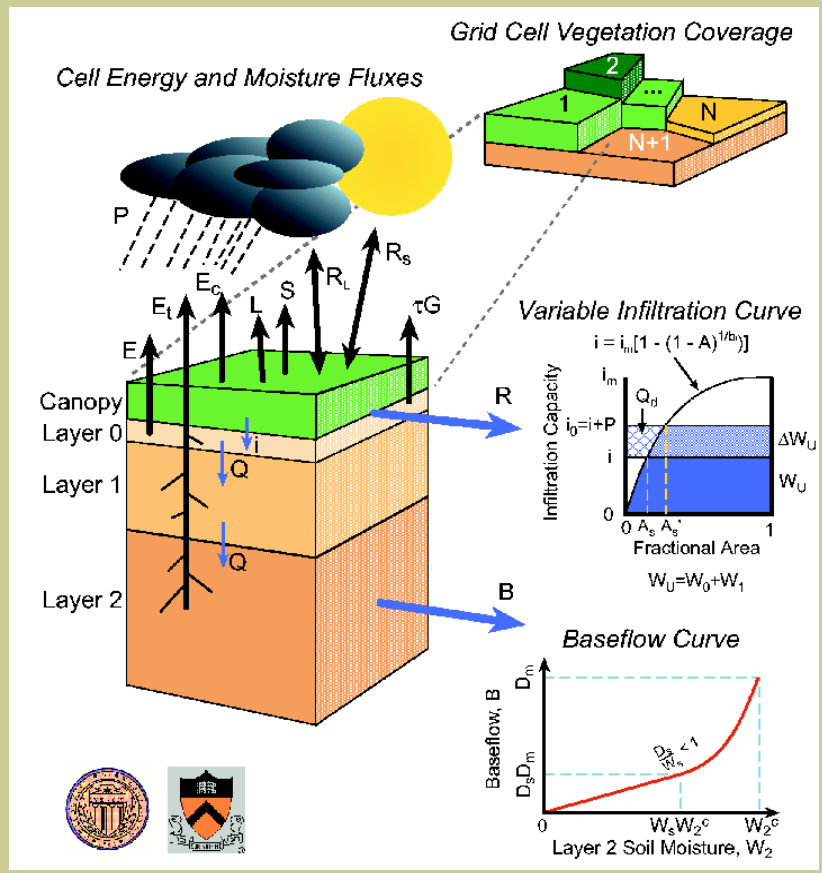
- N soil layers (3)
- N vegetation types (10)
- N elevation bands (10)

- Energy balance
  - winter/summer

- Variable infiltration
- Nonlinear baseflow

- Distributed precipitation

- Typical scale of application: 1/8 - 2 degrees latitude by longitude, 1 hr to 24 hr temporal resolution



VIC: Variable Infiltration Capacity Model

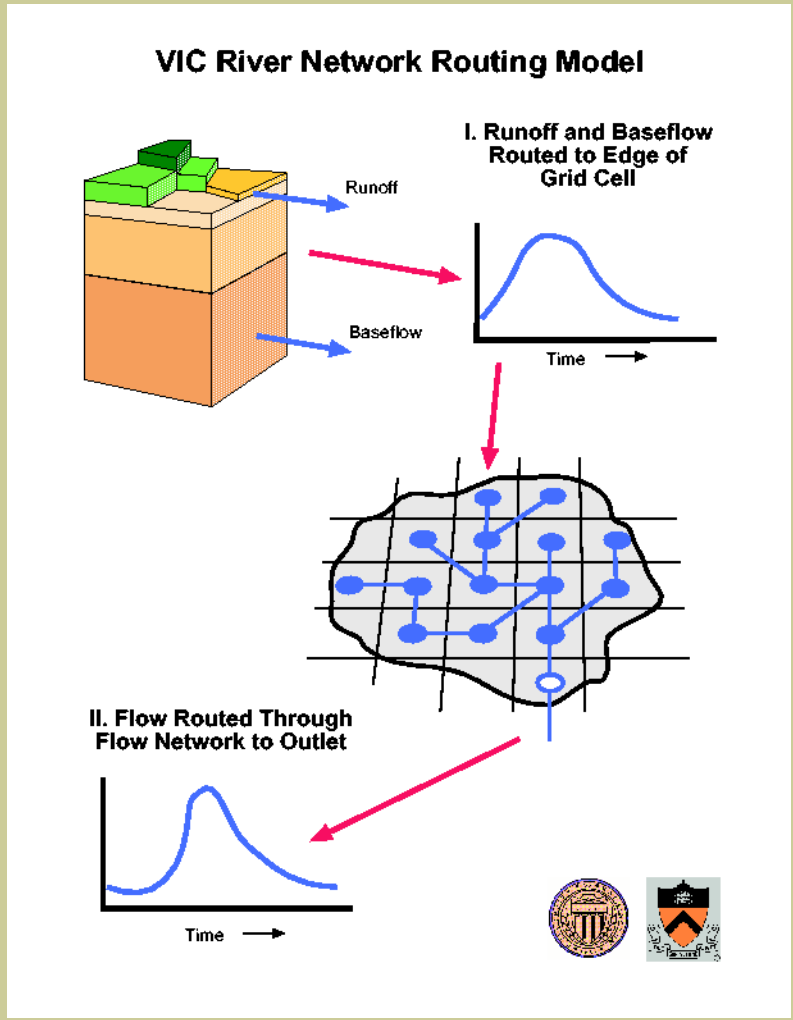
- N soil layers (3)
- N vegetation types (10)
- N elevation bands (10)

- Energy balance
  - winter/summer

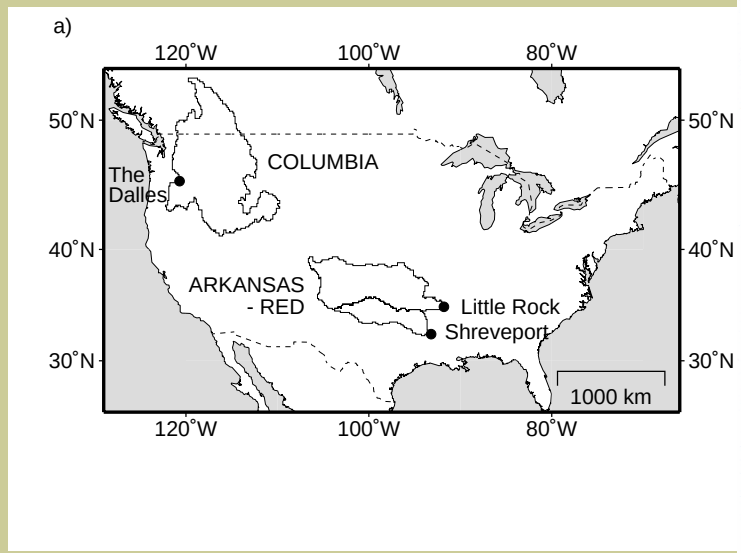
- Variable infiltration
- Nonlinear baseflow

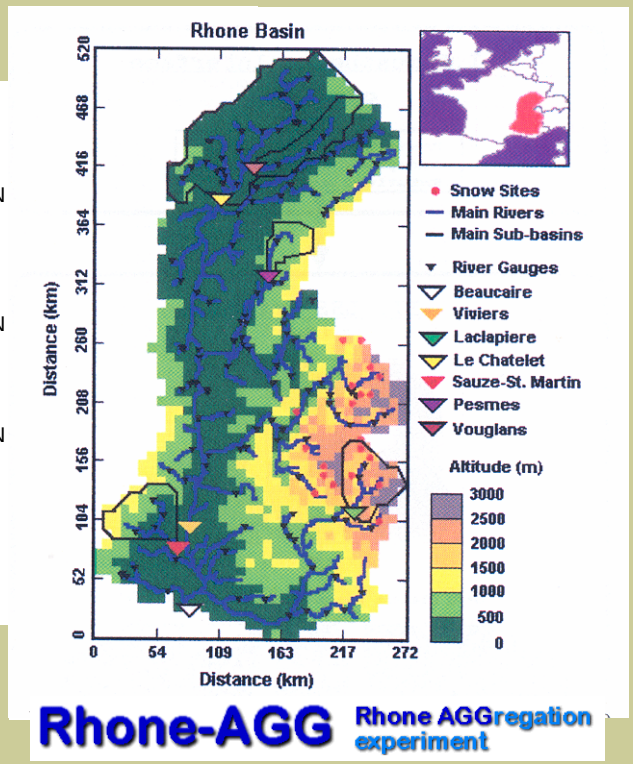
- Distributed precipitation

- Typical scale of application: 1/8 - 2 degrees latitude by longitude, 1 hr to 24 hr temporal resolution



Spatial aggregation: Study areas





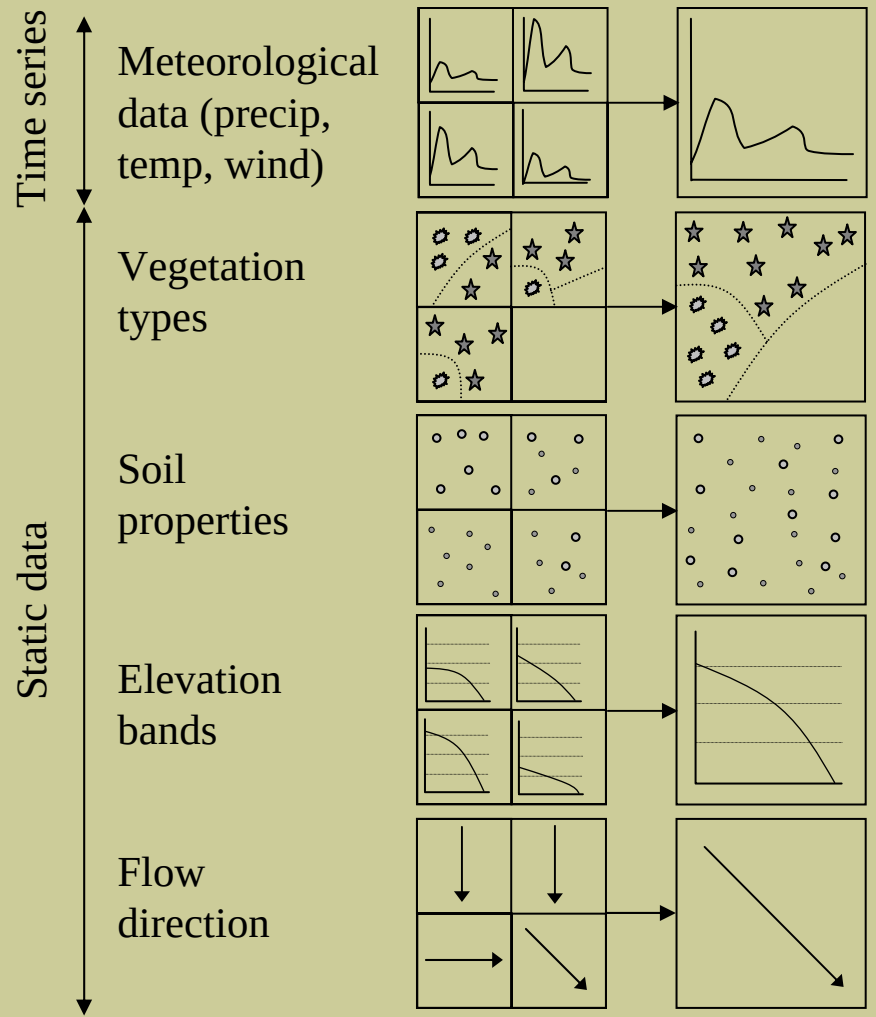
Aggregation method

Rhone:

- 8*8 km
- One-half and one degree

Columbia and Arkansas-Red:

- One-eighth degree (~12.5 km*12.5 km)
- One-quarter, one-half, one and two degrees



Results: RhoneAGG

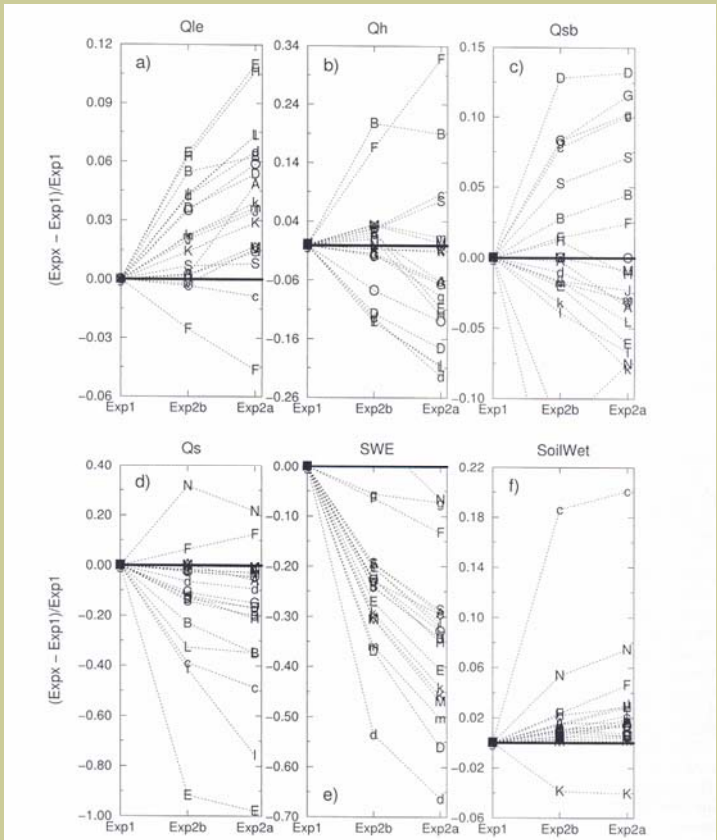


FIG. 12. The impact (as a relative difference) of scaling on selected LSS surface fluxes and hydrological components. The upscaled values are compared to the control, high-resolution results. Exp2b and Exp2a correspond with upscaling to 1/2° and 1° grids, respectively. Exp2c corresponds to using dominant surface parameters on a 1° grid.

Rhone-AGG Rhone AGGregation experiment

Results: RhoneAGG

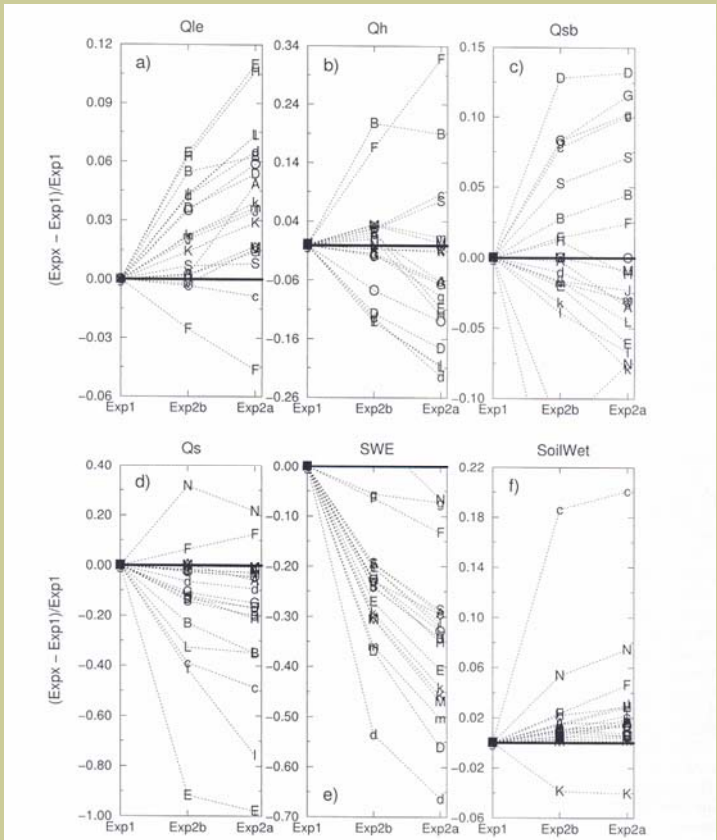


FIG. 12. The impact (as a relative difference) of scaling on selected LSS surface fluxes and hydrological components. The upscaled values are compared to the control, high-resolution results. Exp2b and Exp2a correspond with upscaling to 1/2° and 1° grids, respectively. Exp2c corresponds to using dominant surface parameters on a 1° grid.

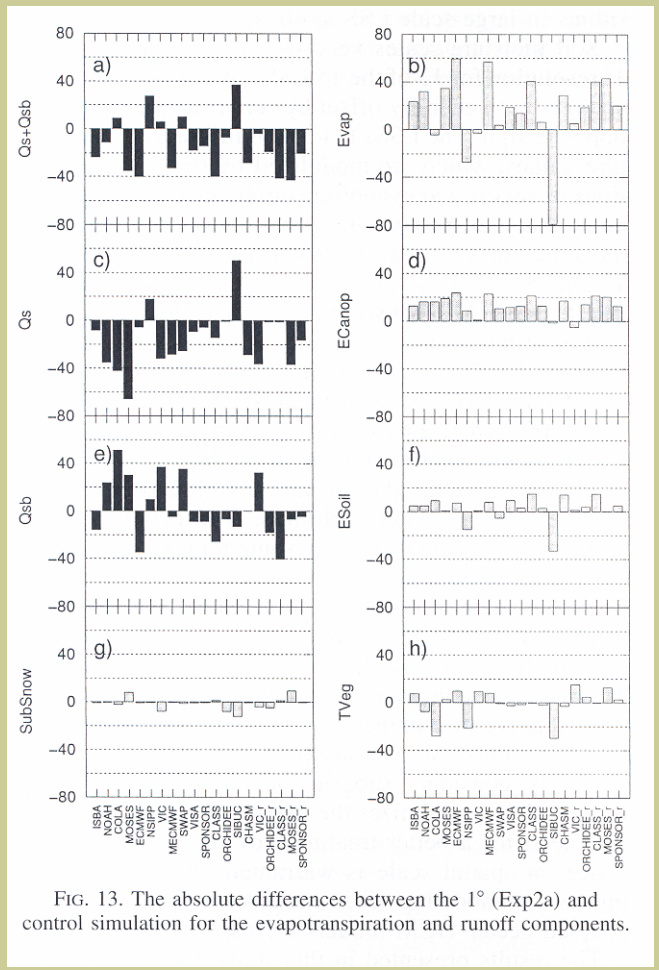
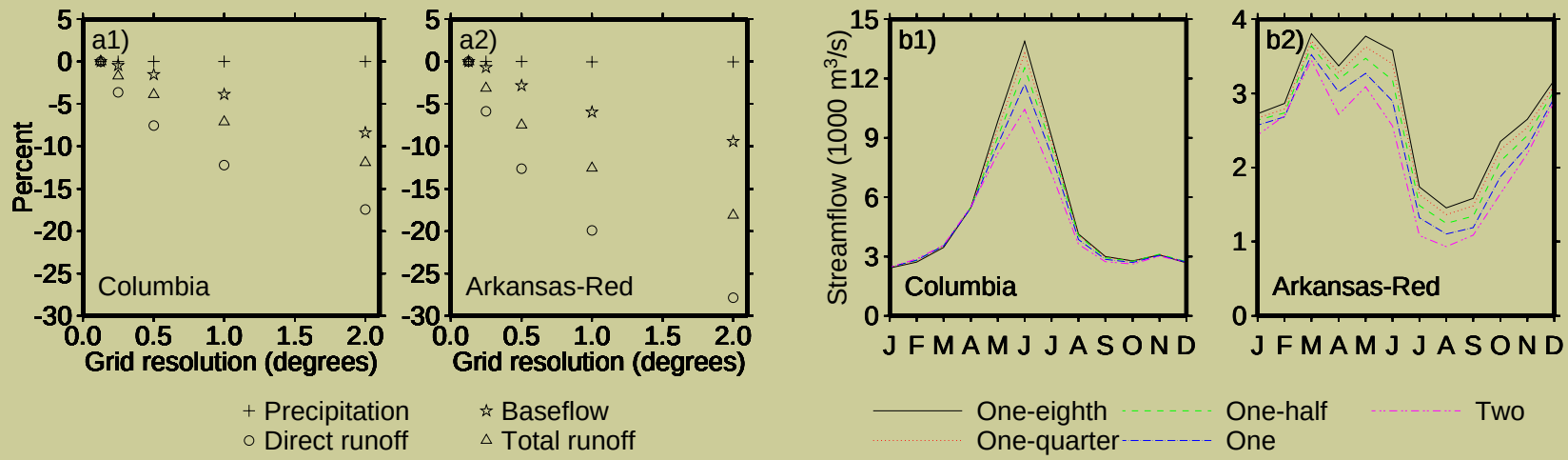


FIG. 13. The absolute differences between the 1° (Exp2a) and control simulation for the evapotranspiration and runoff components.

Rhone-AGG Rhone AGGregation experiment

Results: Columbia and Arkansas-Red

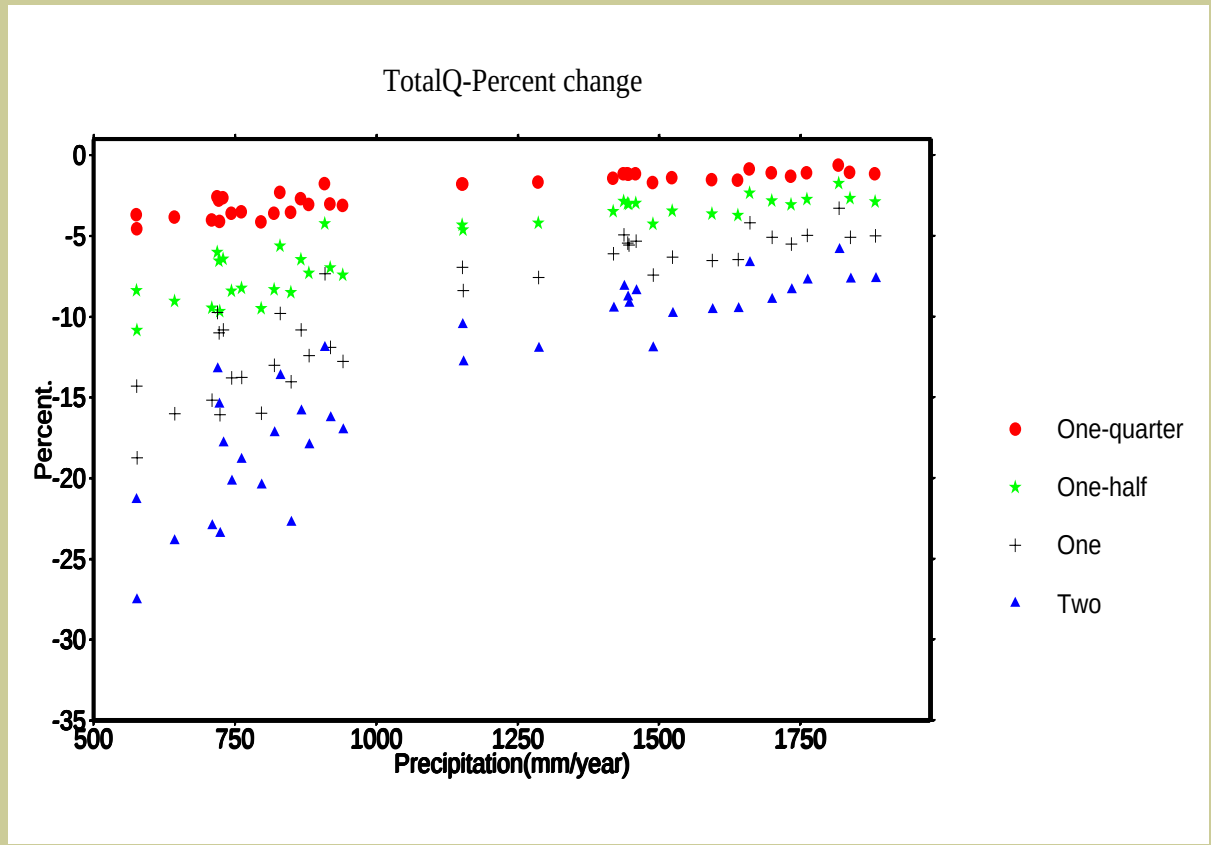
Spatially and temporally uniform precipitation, daily time steps



a) Percent changes in moisture fluxes, compared to the results at one-eighth degree spatial resolution, and b) Mean monthly streamflow at all spatial resolutions, for the 1) Columbia and 2) Arkansas-Red River basins, using spatially constant grid cell precipitation

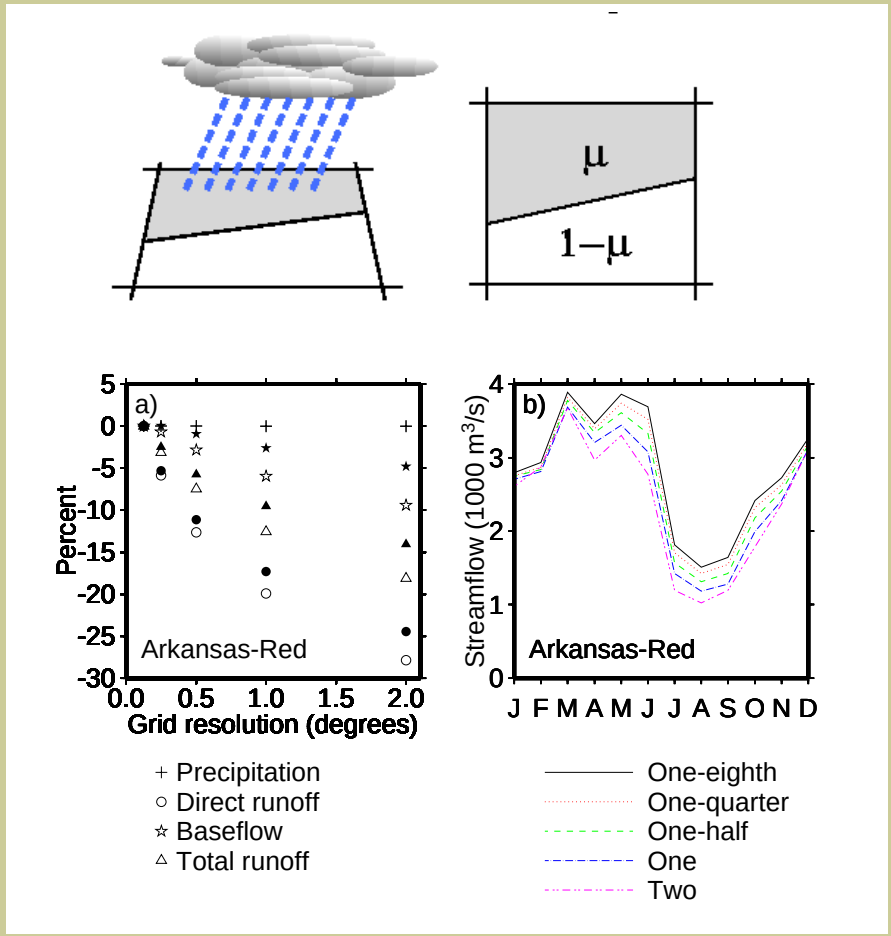
Results: Arkansas-Red

Scale sensitivity of total runoff for Arkansas-Red River basin as a function of water year precipitation



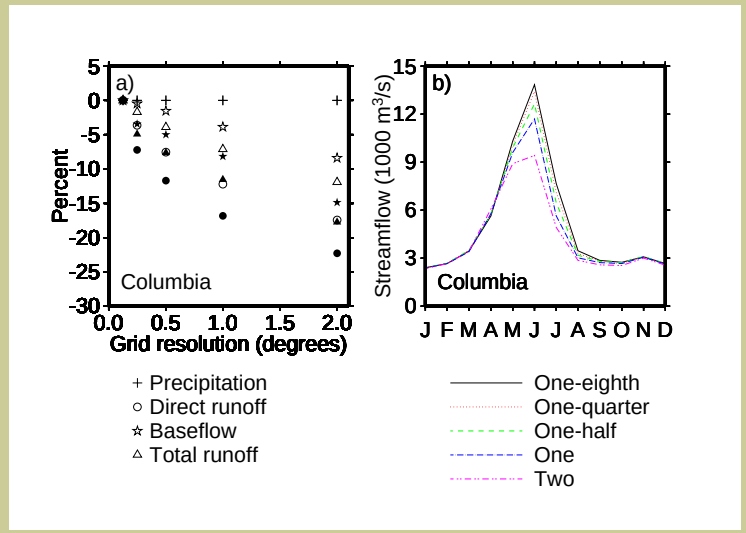
Results: Arkansas-Red

Effect of parameterization for spatial variability of precipitation (black) vs spatially uniform precipitation (open)



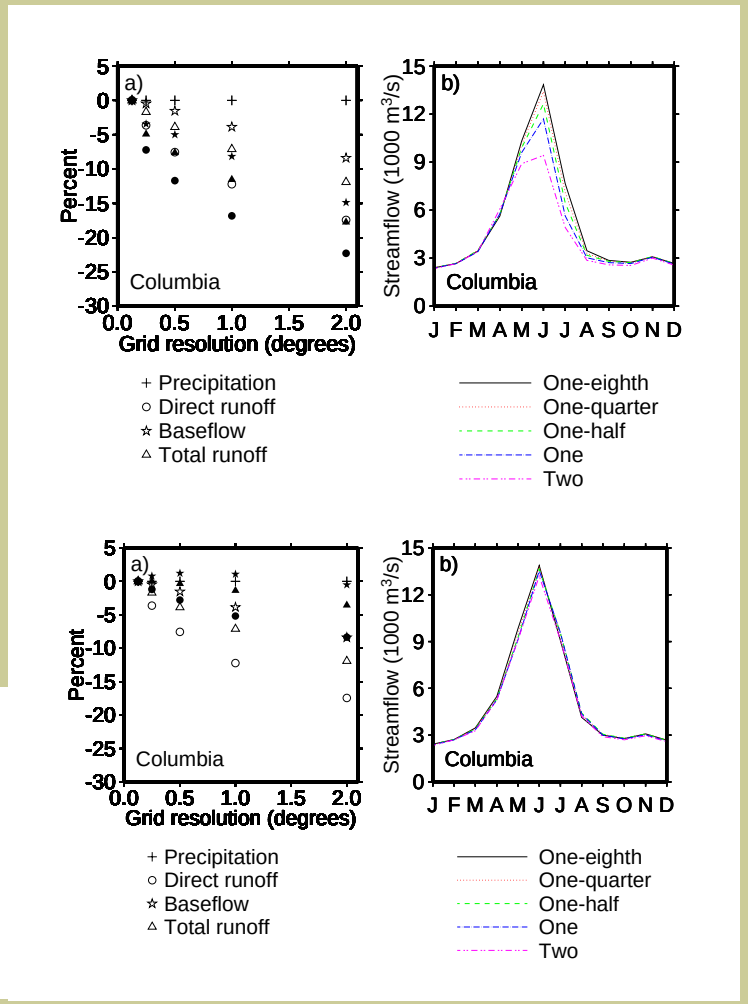
Results: Columbia

Effect of elevation bands (open symbols) vs no elevation bands (black symbols)

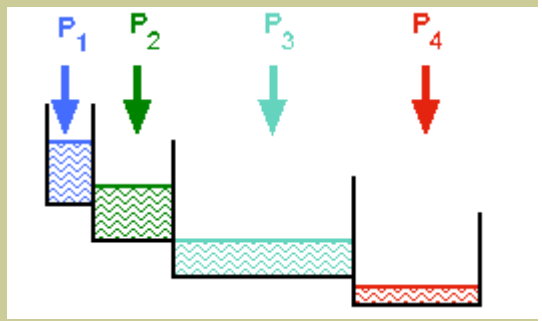


Results: Columbia

Effect of elevation bands (open symbols) vs no elevation bands (black symbols)



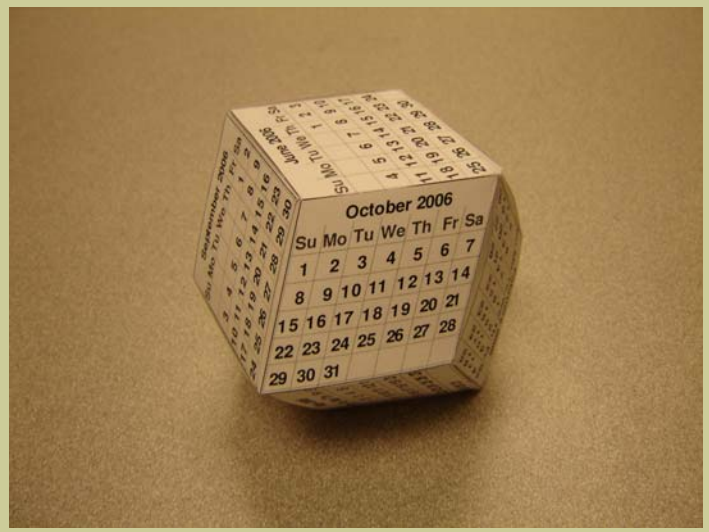
Effect of parameterization of precipitation as a function of elevation



Conclusions: Spatial aggregation

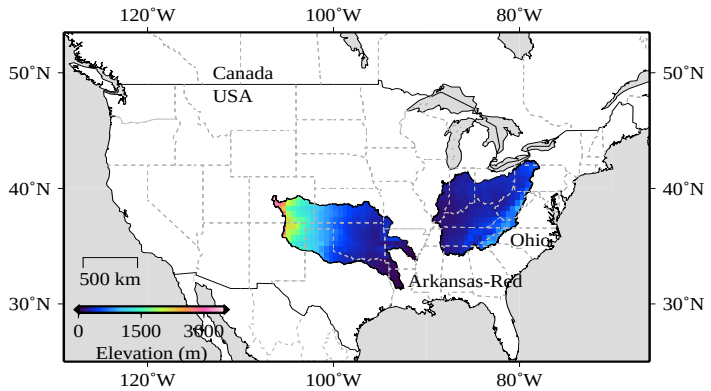
- In general: Form of hydrographs preserved, runoff decreases as spatial scale increases
- Snowmelt dominated areas: Interaction precipitation/temperature
  - Elevation bands
- Drier areas: Interaction precipitation/vegetation
  - Subgrid precipitation and soil moisture, canopy evaporation
- Wet areas: Decrease in direct runoff is compensated by an increase in baseflow

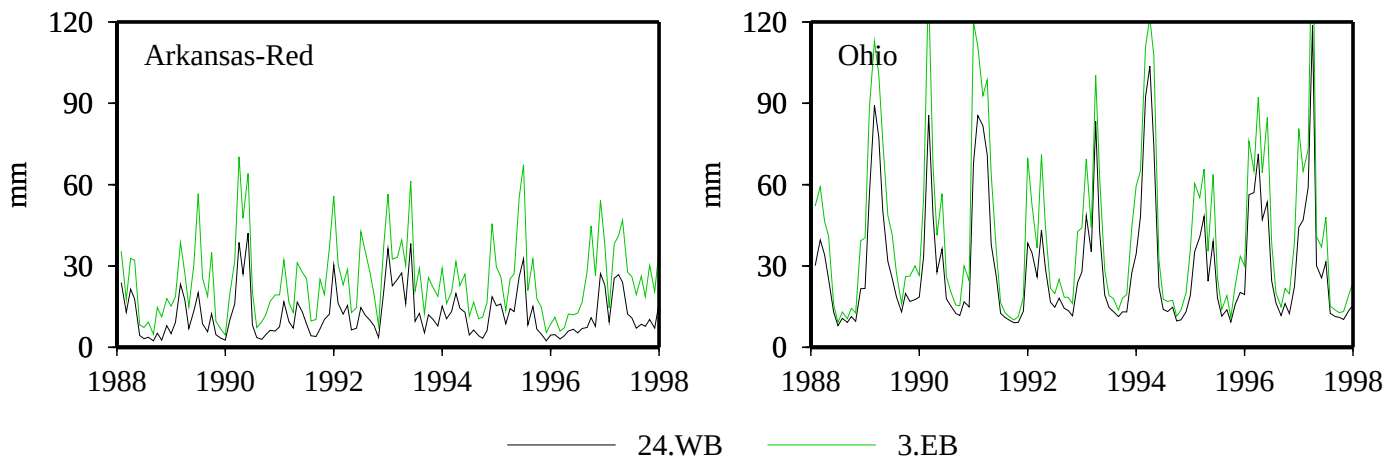
Temporal scale



Temporal scale: Background

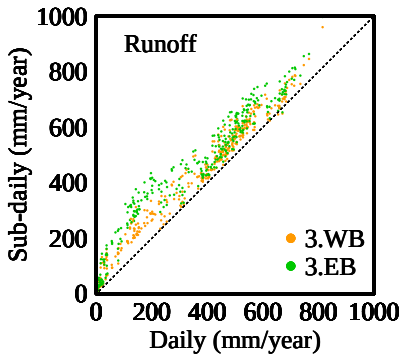
The backdrop: Models evaluated at one temporal scale (time step) may perform much differently at another

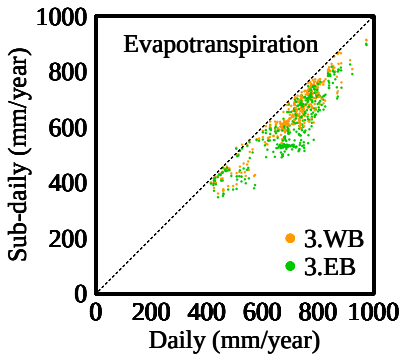


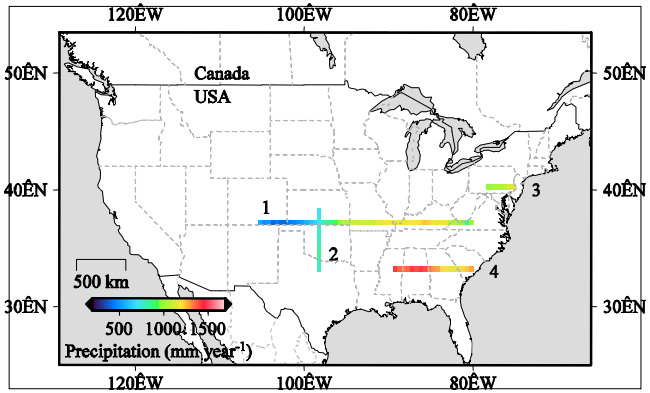


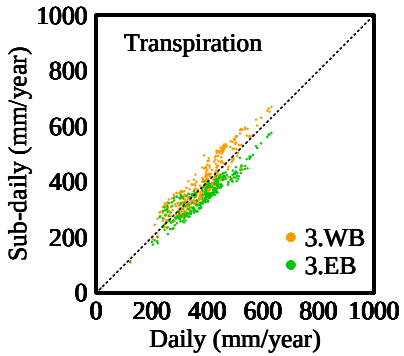
Mean annual runoff in the Arkansas-Red and Ohio River basins. Daily water balance mode (24.WB) and 3 hourly energy balance mode (3.EB)

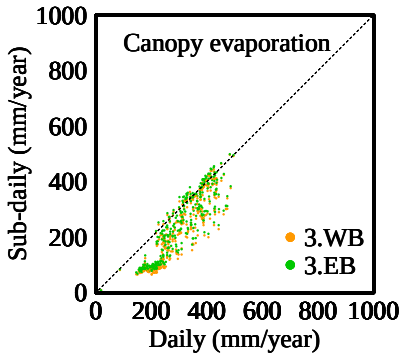
Temporal scale effects

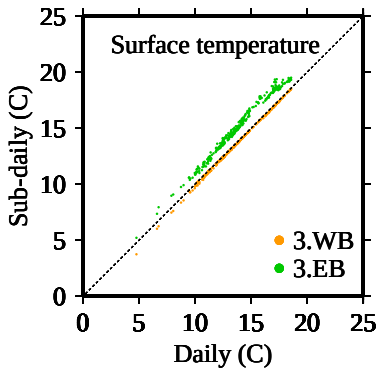


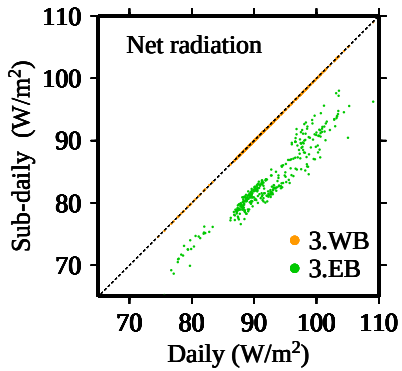






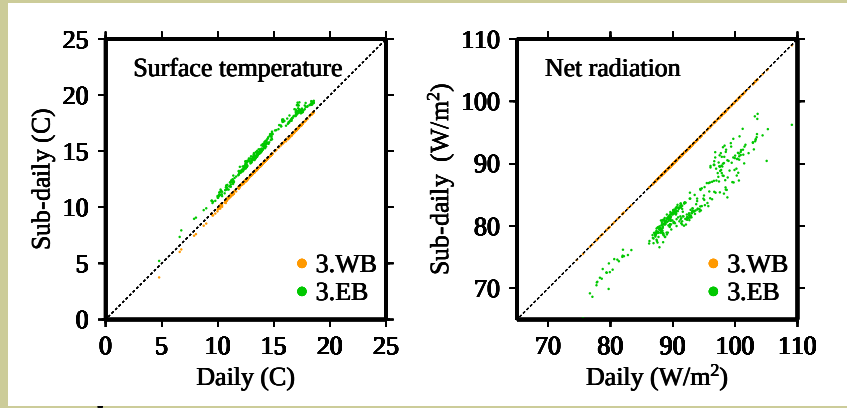






Spatially and temporally uniform precipitation. Daily water balance (24.WB) runs compared to 3 hourly water balance (3.WB) and 3 hourly energy balance (3.EB) runs.

Model differences: 24.WB – 3.EB



- Energy balance, water balance
  - Surface temperature
  - Net radiation
- Parameterization of canopy evaporation
  - Daily time steps: Evaporation *can* include current time step's precipitation
  - Sub-daily time steps: Evaporation *cannot* include current time step's precipitation
- So – how can we easily reconcile model simulations?

Rescaling parameters for time step differences

- Search for parameters (interception capacity factor and minimum stomatal resistance):

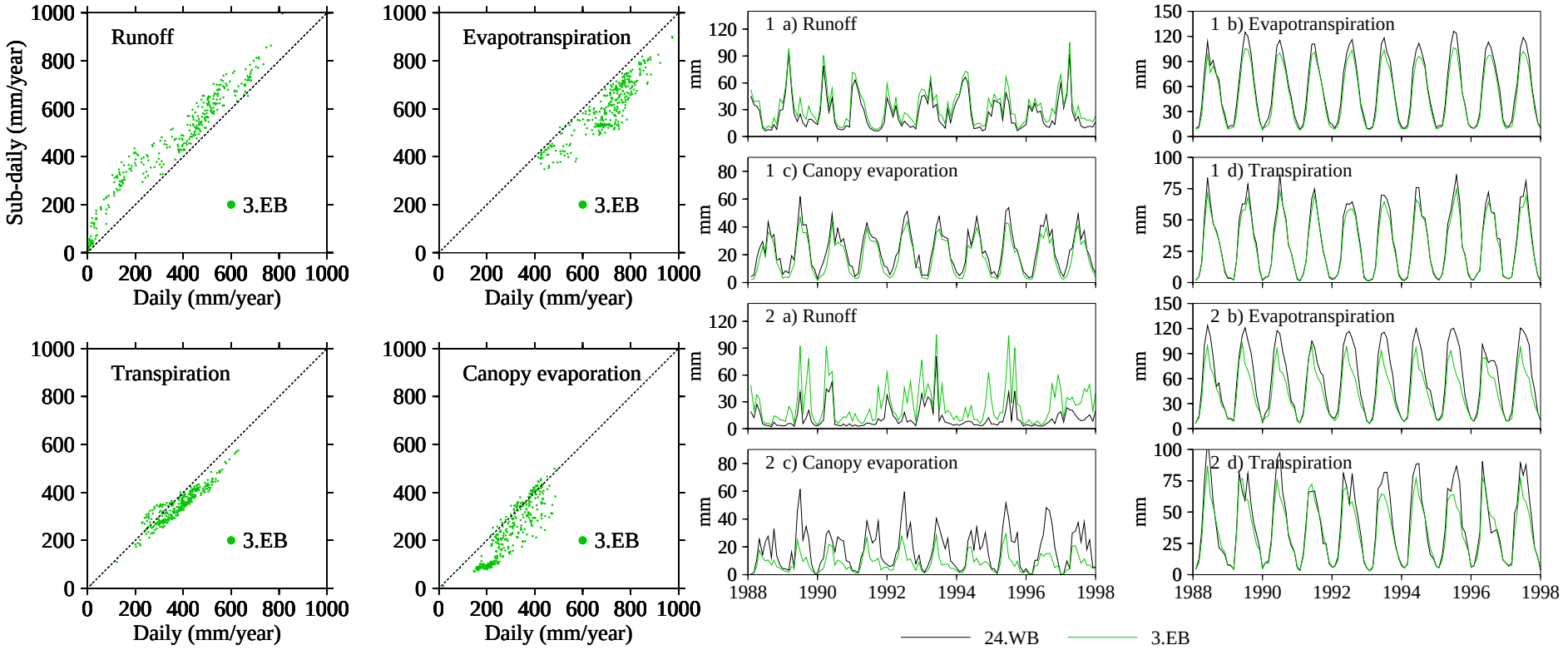
$$\left(R_{new}\right)_{n,i} = \left(R_{orig}\right)_{n,i} * k_{1,n} \qquad \left(C_{new}\right)_{n,i} = \left(C_{orig}\right)_{n,i} * k_{2,n}$$

$$\min \sum_{months} \left\{ \left(EC_{sub-daily} - EC_{24.WB}\right)^2 + \left(TV_{sub-daily} - TV_{24.WB}\right)^2 \right\}$$

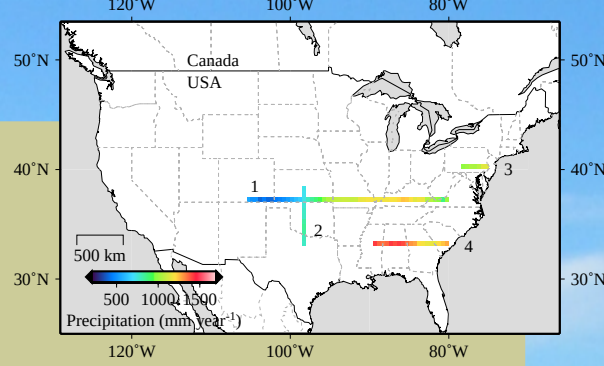
- SCEM-UA algorithm (Vrugt et al., *Water Resources Research*, 2003)
- Search done across transect at one degree interval, evaluation at 1/8 degree (parameters interpolated for intermediate grid cells)
- Reproduce daily water balance results from 3 hr energy balance runs

Results: Transects

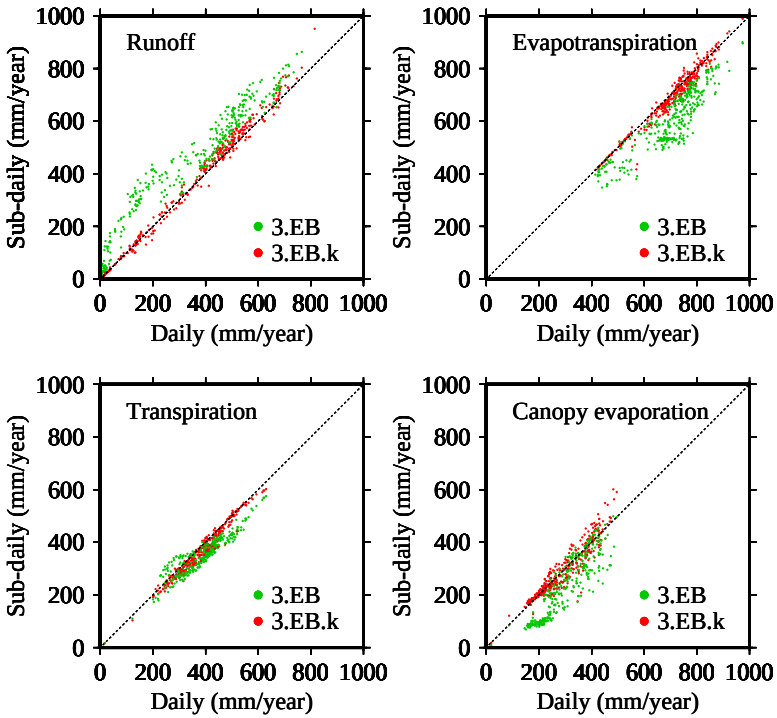
3 hourly energy balance compared to 24 hourly water balance runs

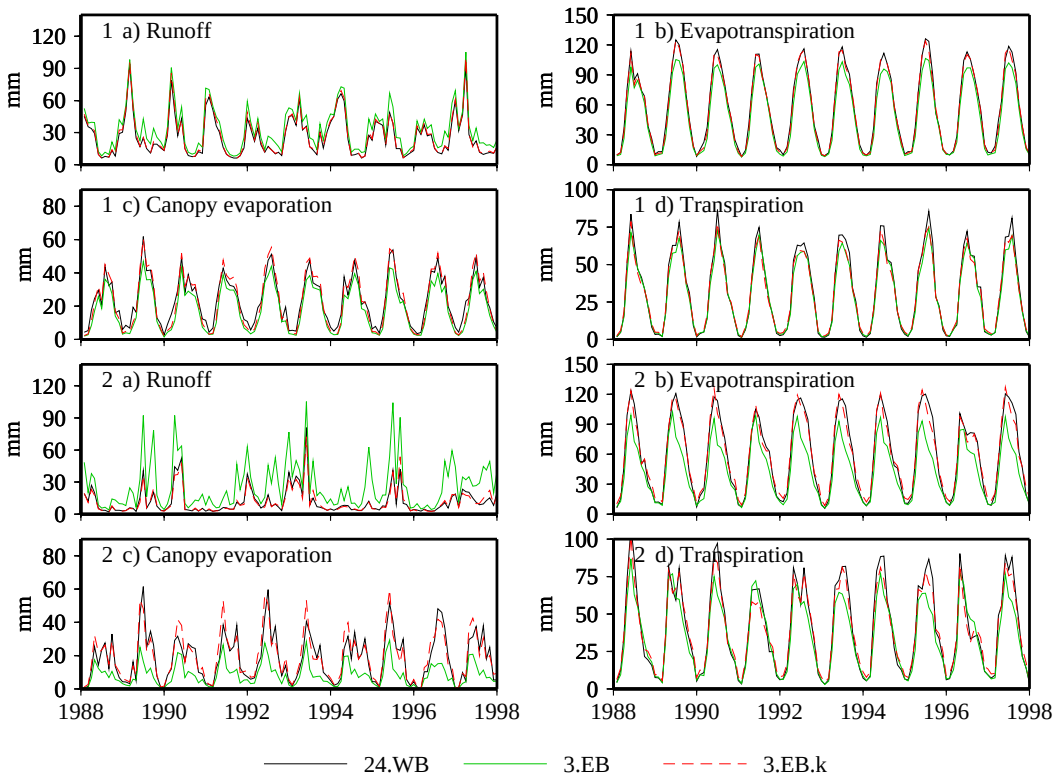


Results: Transects

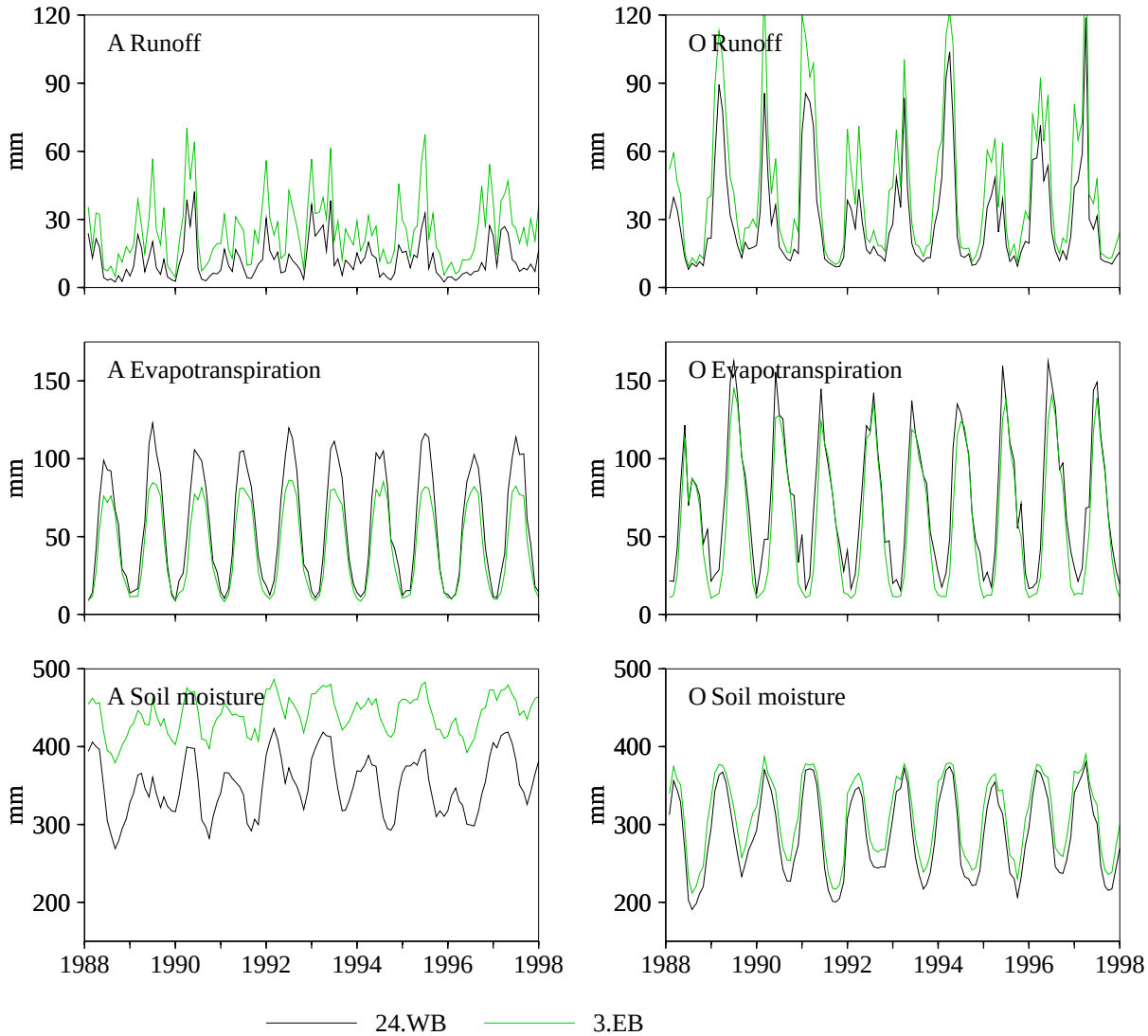


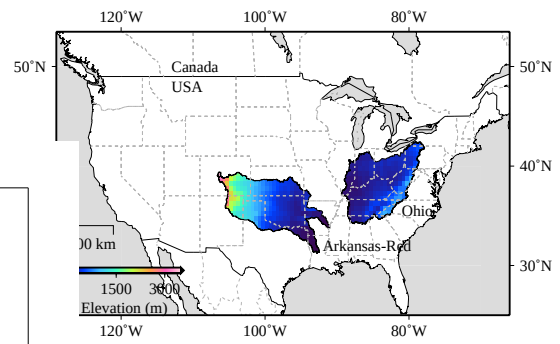
3 hourly energy balance runs matched to 24 hourly water balance runs





Results: River basins

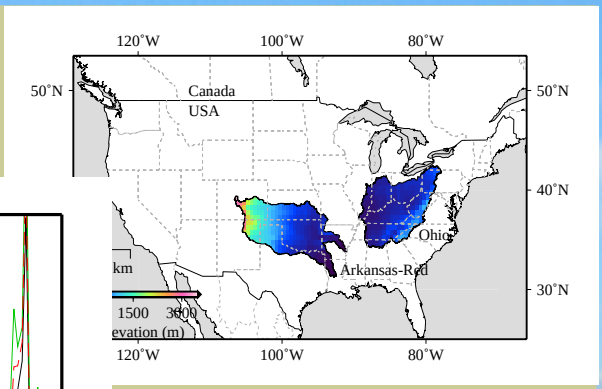


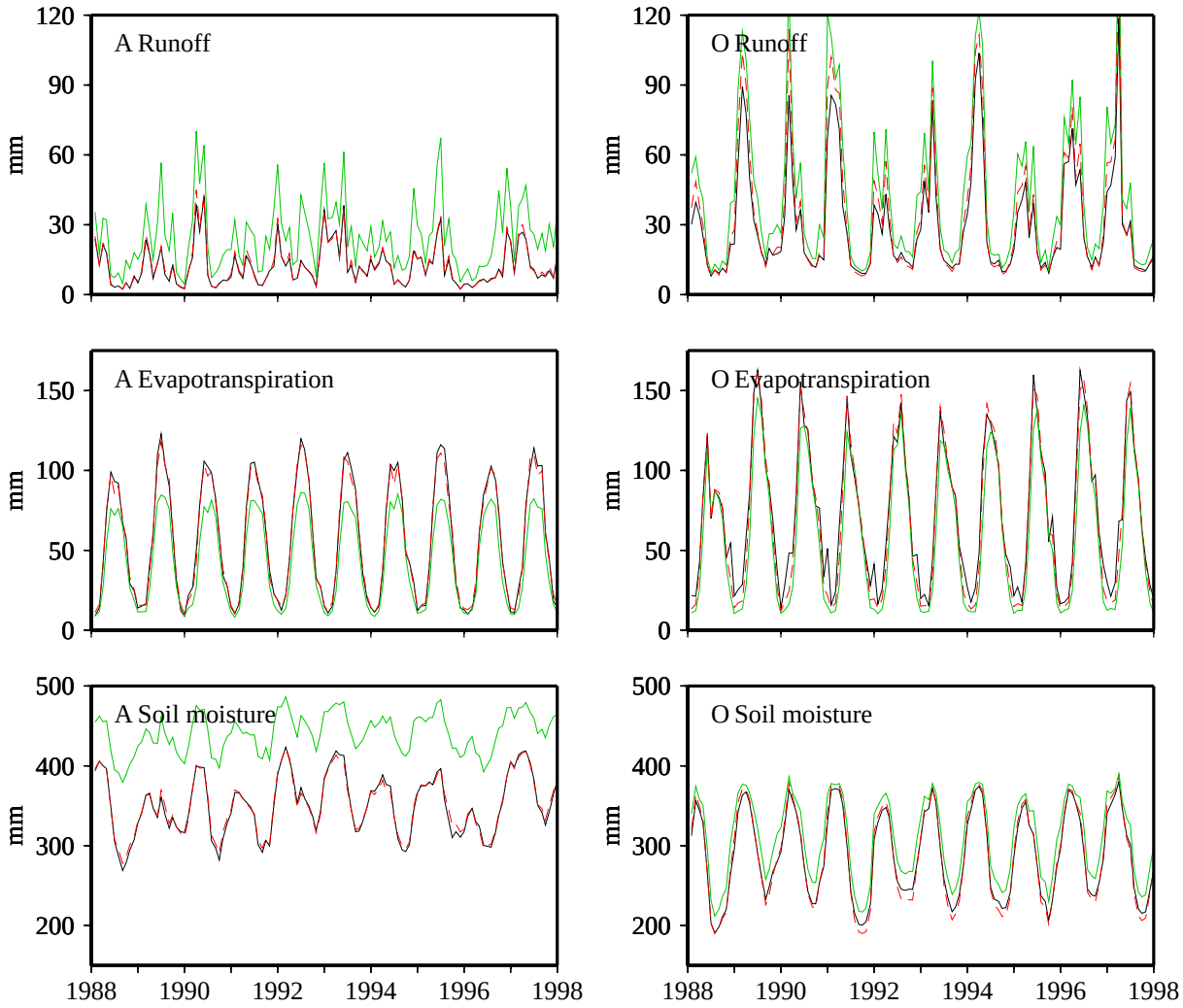


A: Arkansas-Red
O: Ohio

3 hourly energy balance runs and 24 hourly water balance runs

Results: River basins





A: Arkansas-Red
O: Ohio

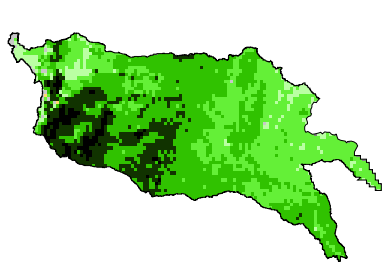
3 hourly energy balance runs matched to 24 hourly water balance runs

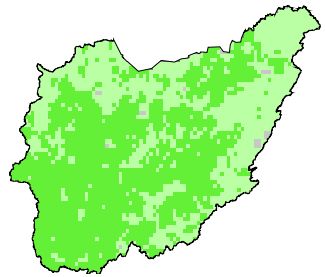
Results: Spatial images

3 hourly energy balance runs compared to 24 hourly water balance runs

a) Runoff

Original results



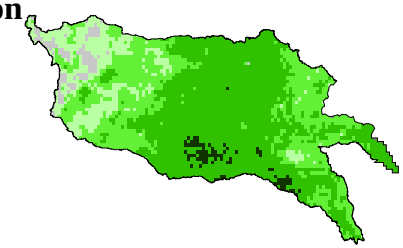


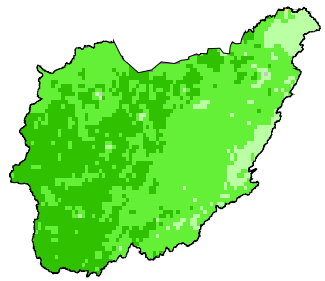
Corrected results

3.EB/24.WB

b) Evapotranspiration

Original results





Corrected results

3.EB/24.WB

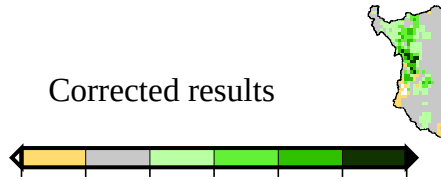
Results: Spatial images

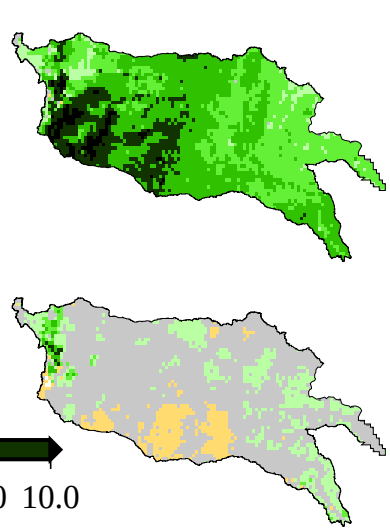
3 hourly energy balance runs matched to 24 hourly water balance runs

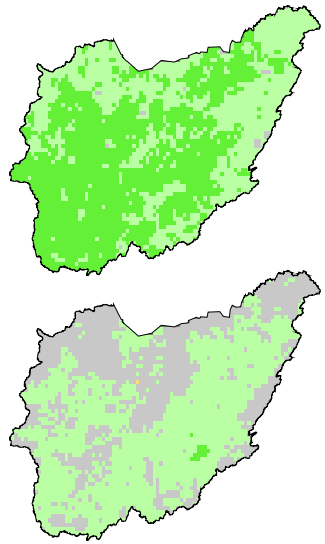
a) Runoff

Original results

Corrected results



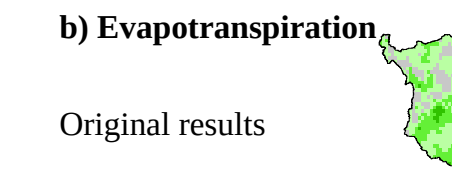


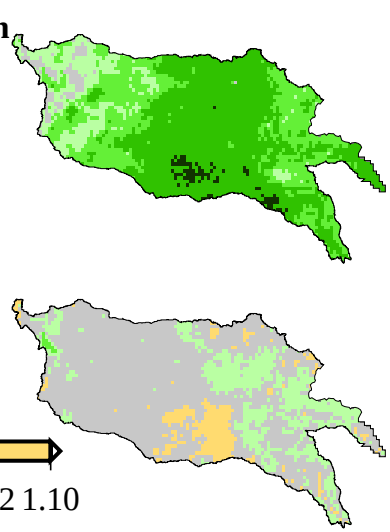


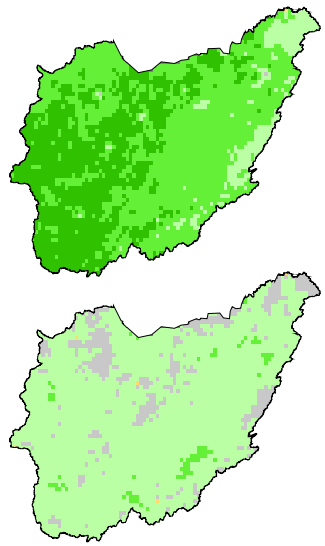
b) Evapotranspiration

Original results

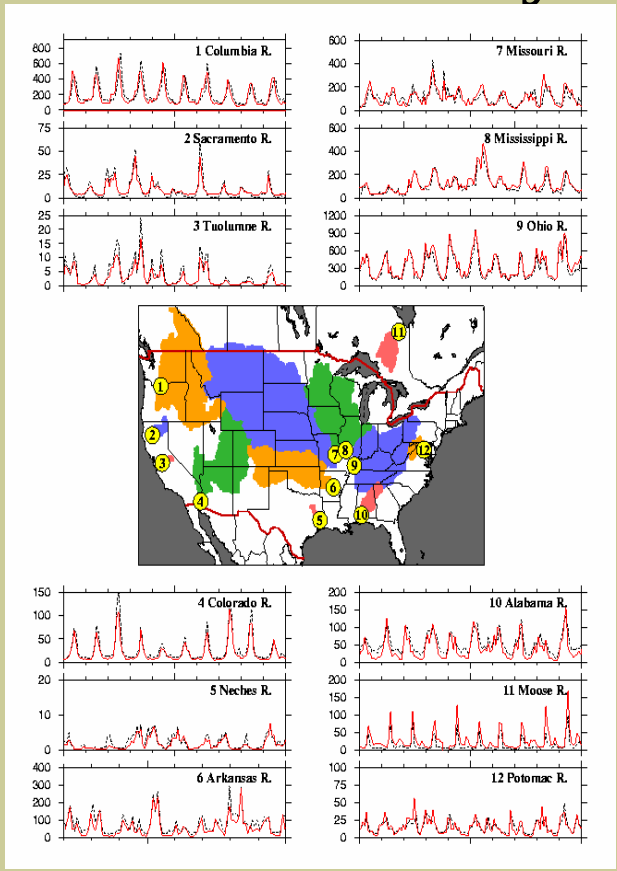
Corrected results



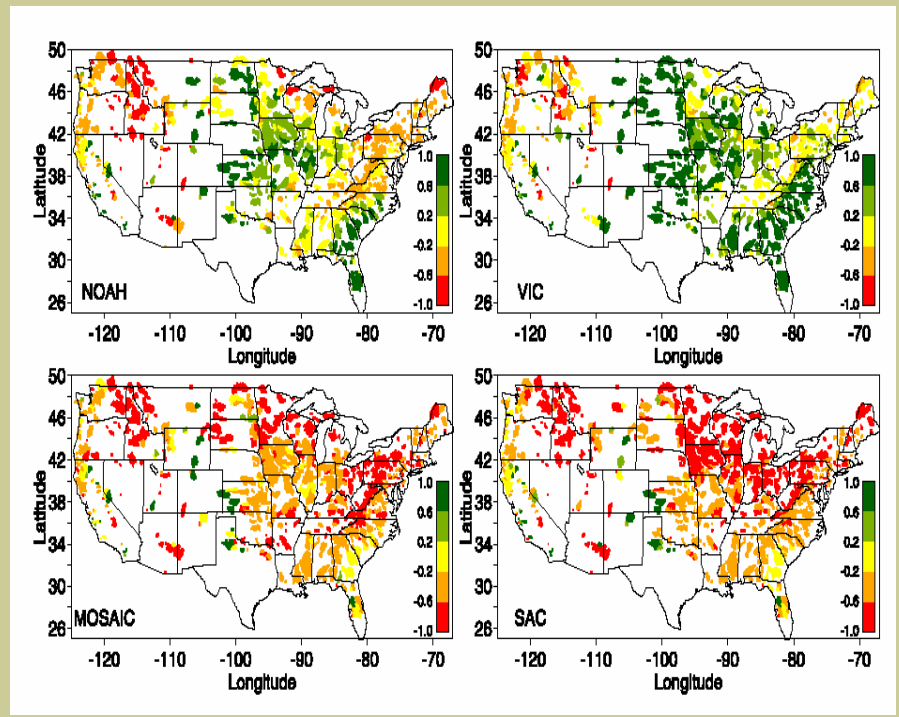




NLDAS (North American Data Assimilation System)



Maurer et al., 2002: A long-term hydrologically-based data set of land surface fluxes and states for the conterminous United States, *J. Climate*, **15**, 3237-3251.



Relative runoff bias WY 1998-99, evaluated at USGS gauges with minimal management effects.

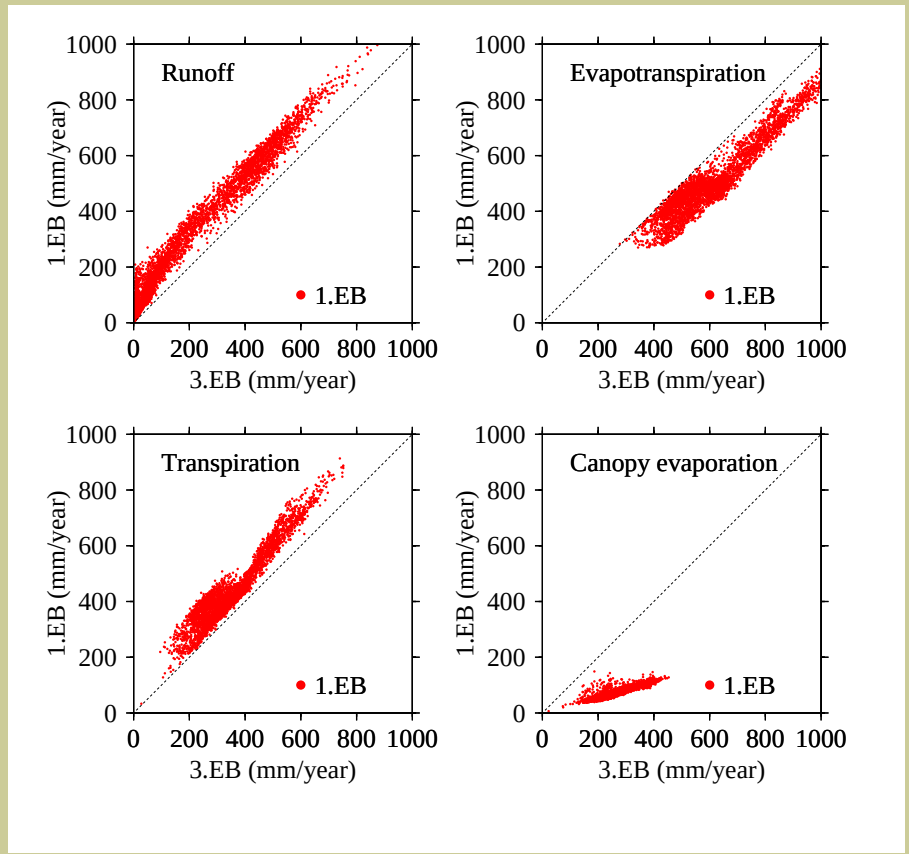
Lohmann et al., 2004: Streamflow and water balance intercomparisons of four land surface models in the North American Land Data Assimilation System project, *J. Geophys. Res.*, **109**, D07S91, doi:10.1029/2003JD003517

NLDAS: Arkansas-Red

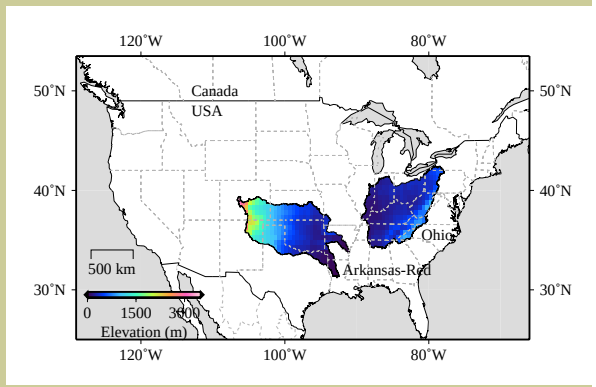
Arkansas-Red results Lohmann et al. (1.EB), vs Maurer et al. (3.EB)

3.EB: 3 hr energy balance results (no spatial or temporal disaggregation of precipitation)

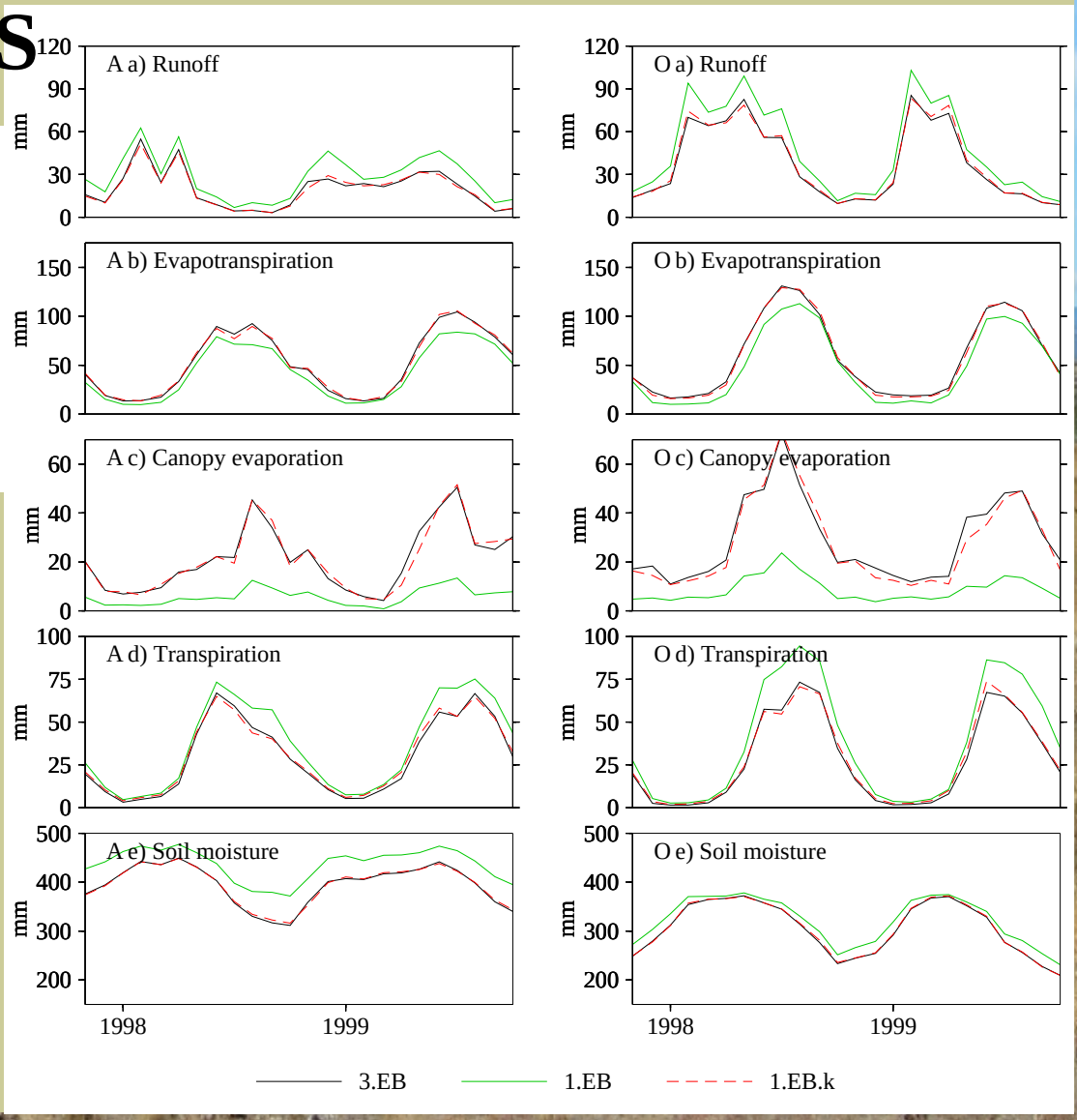
1.EB: 1 hr energy balance runs (spatially and temporally disaggregated precipitation)



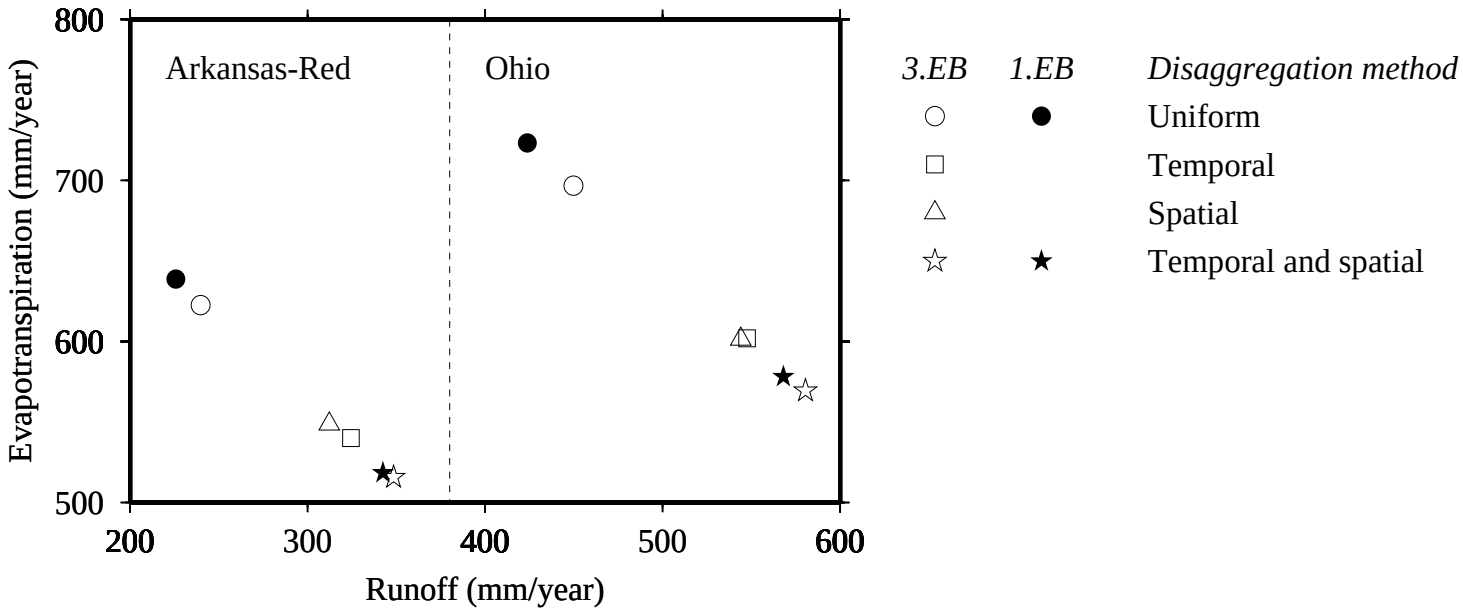
Results: NLDAS



1 hourly energy balance runs, spatially and temporally disaggregated precipitation, matched to 3 hourly energy balance runs, temporally and spatially uniform precipitation



Results: NLDAS



Conclusions – temporal aggregation

- Moisture fluxes simulated by the VIC model are sensitive to the time step used, to the assumptions made regarding closure of the surface energy budget, and to the method of temporal and spatial disaggregation of precipitation.
- Simulated canopy evaporation differences are the main reason for the discrepancies between simulated model results.
- Sensitivity analyses performed at sub-daily time steps (3 hours and 1 hour) indicate that temporal disaggregation of precipitation is the most significant factor controlling canopy evaporation at sub-daily time steps.
- Simulation results at different model setups can to a large extent be reconciled by introducing correction factors that adjust the canopy interception capacity and canopy resistance.
- It is possible to calibrate the model in the computationally efficient daily water balance mode and thereafter introduce correction factors to the sub-daily energy balance simulations without having to recalibrate the model.

References

- Boone, A., F. Habets, J. Noilhan, E. Blyth, D. Clark, P. Dirmeyer, S. Fox, Y. Gusev, I. Haddeland, R. Koster, D. Lohmann, S. Mahanama, K. Mitchell, O. Nasanova, G.-Y. Niu, A. Pitman, J. Polcher, A.B. Shmakin, K. Tanaka, B. van den Hurk, S. Verant, D. Verseghy, P. Viterbo, and Z.-L. Yang, 2004, The Rhone-Aggregation Land Surface Scheme Intercomparison Project: An Overview, *Journal of Climate* 17(1), 187-208

- Haddeland, I., B.V. Matheussen, and D.P. Lettenmaier, 2002, Influence of spatial resolution in a macroscale hydrologic model, *Water Resources Research*, 38(7), doi:10.1029/2001WR000854

- Haddeland, I., D.P. Lettenmaier, and T. Skaugen, 2006, Reconciling simulated moisture fluxes resulting from alternate hydrologic model time steps and energy balance closure assumptions, *Journal of Hydrometeorology* (in press)