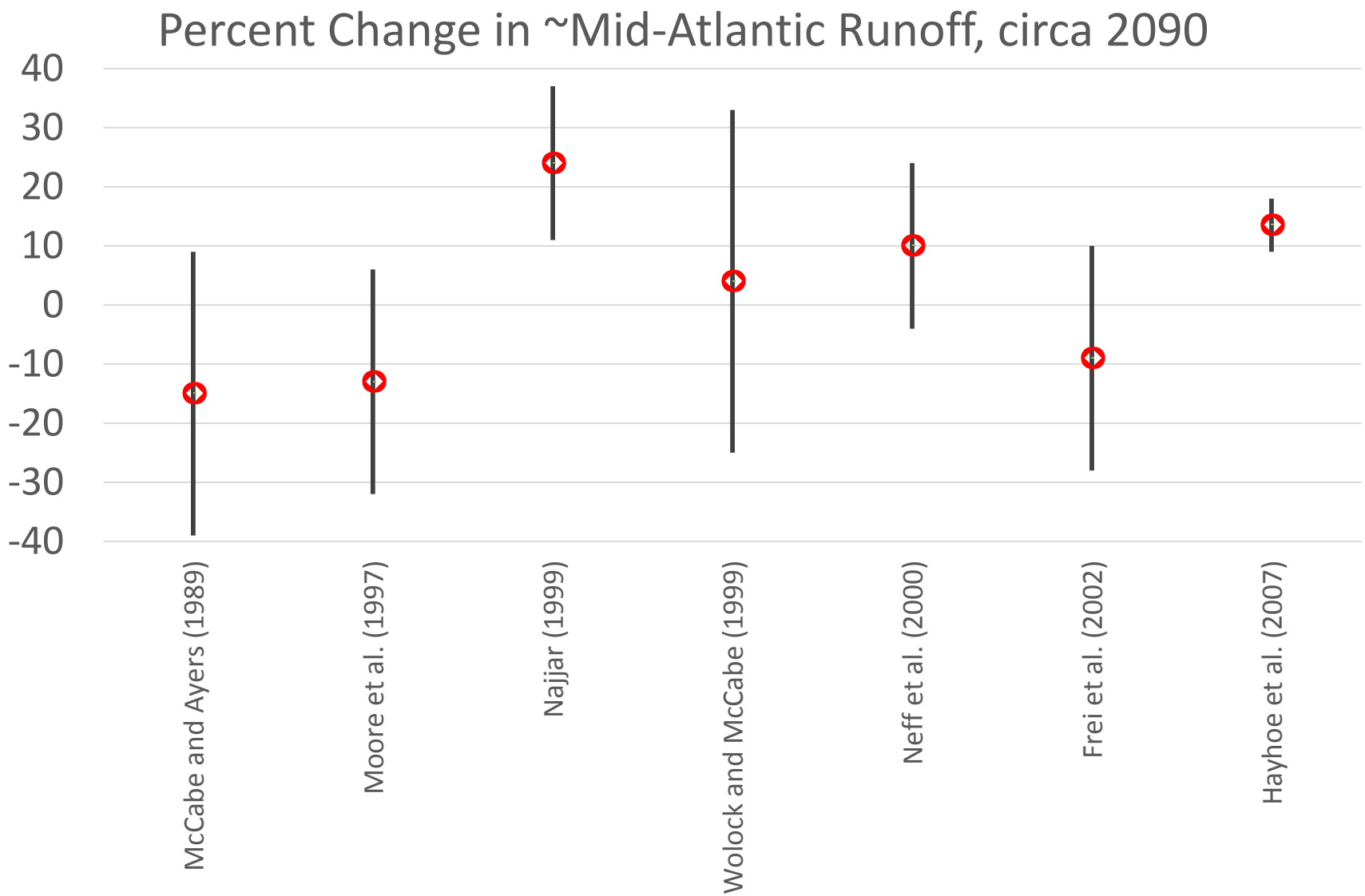
Runoff in a Changing Climate: Climate-Model Choice Matters, and So Does PET Choice

P. C. D. Milly, USGS

Workshop on
"The Development of Climate Projections for Use in Chesapeake Bay Program Assessments"
Scientific and Technical Advisory Committee, Chesapeake Bay Program

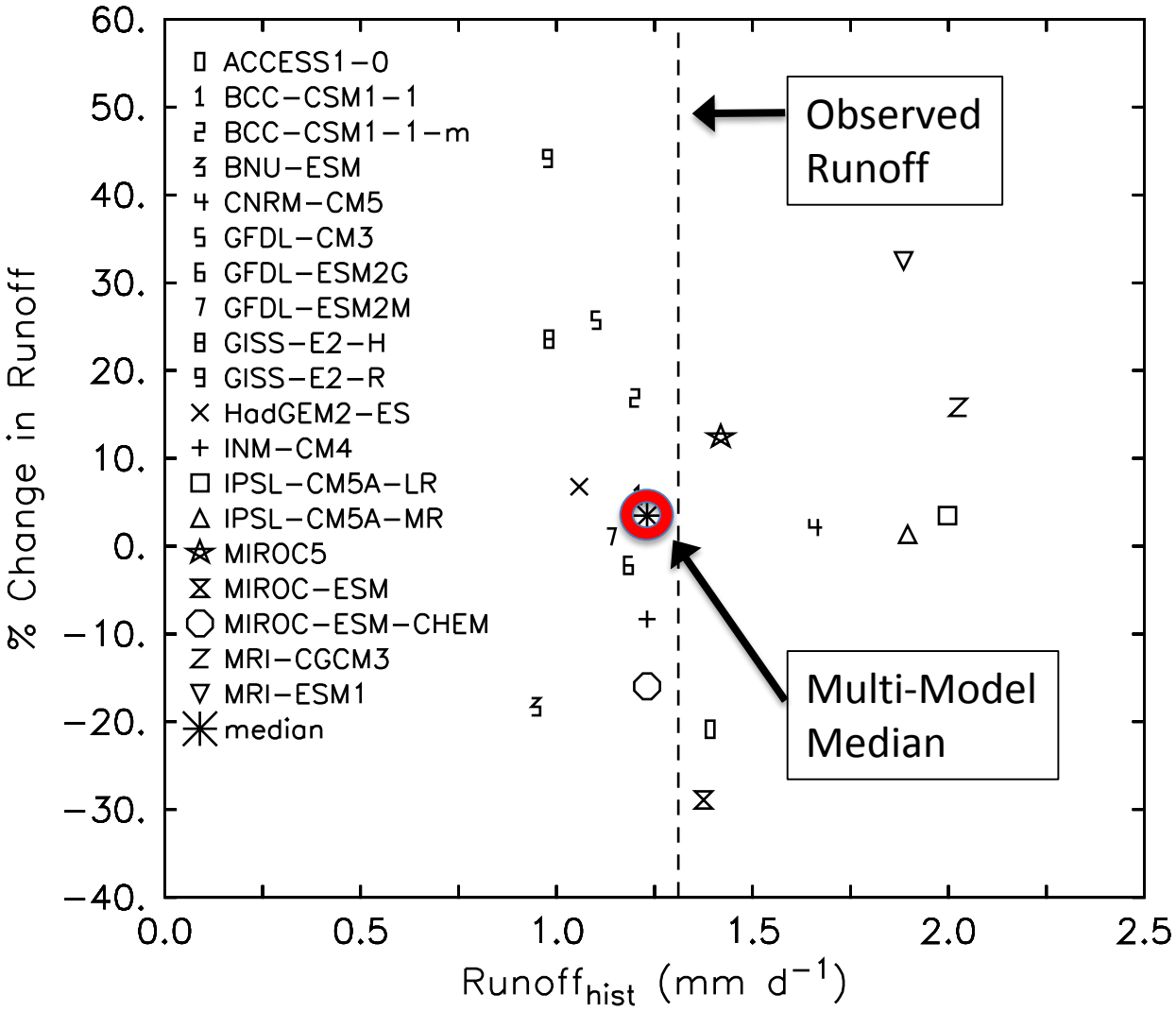
Annapolis, MD
7 March 2016



Based on Table 7 of Najjar et al. (2009)

Percent Change in Model Runoff v. Historical Runoff

Susquehanna River Basin at Harrisburg, PA



The global pattern of historical (20th century) runoff trends was reproduced skillfully by a multi-climate-model ensemble, more skillfully than by the most skillful single climate model (Milly et al., 2005).

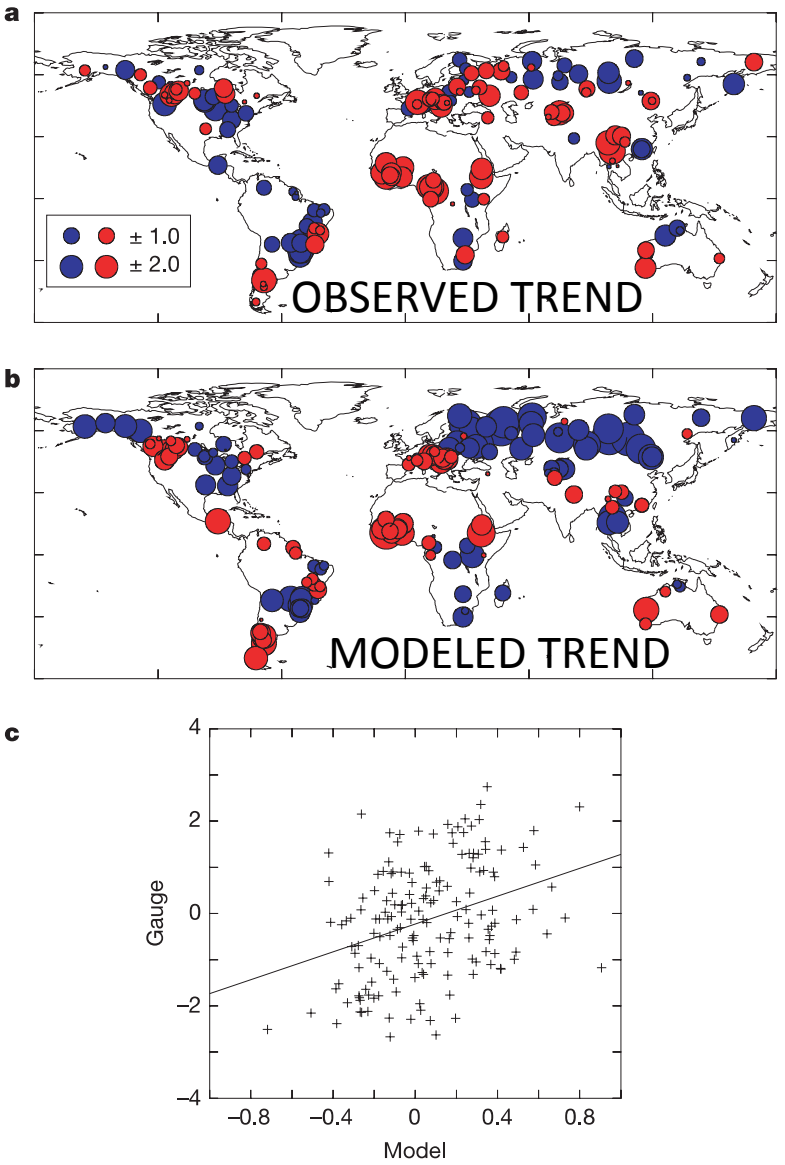
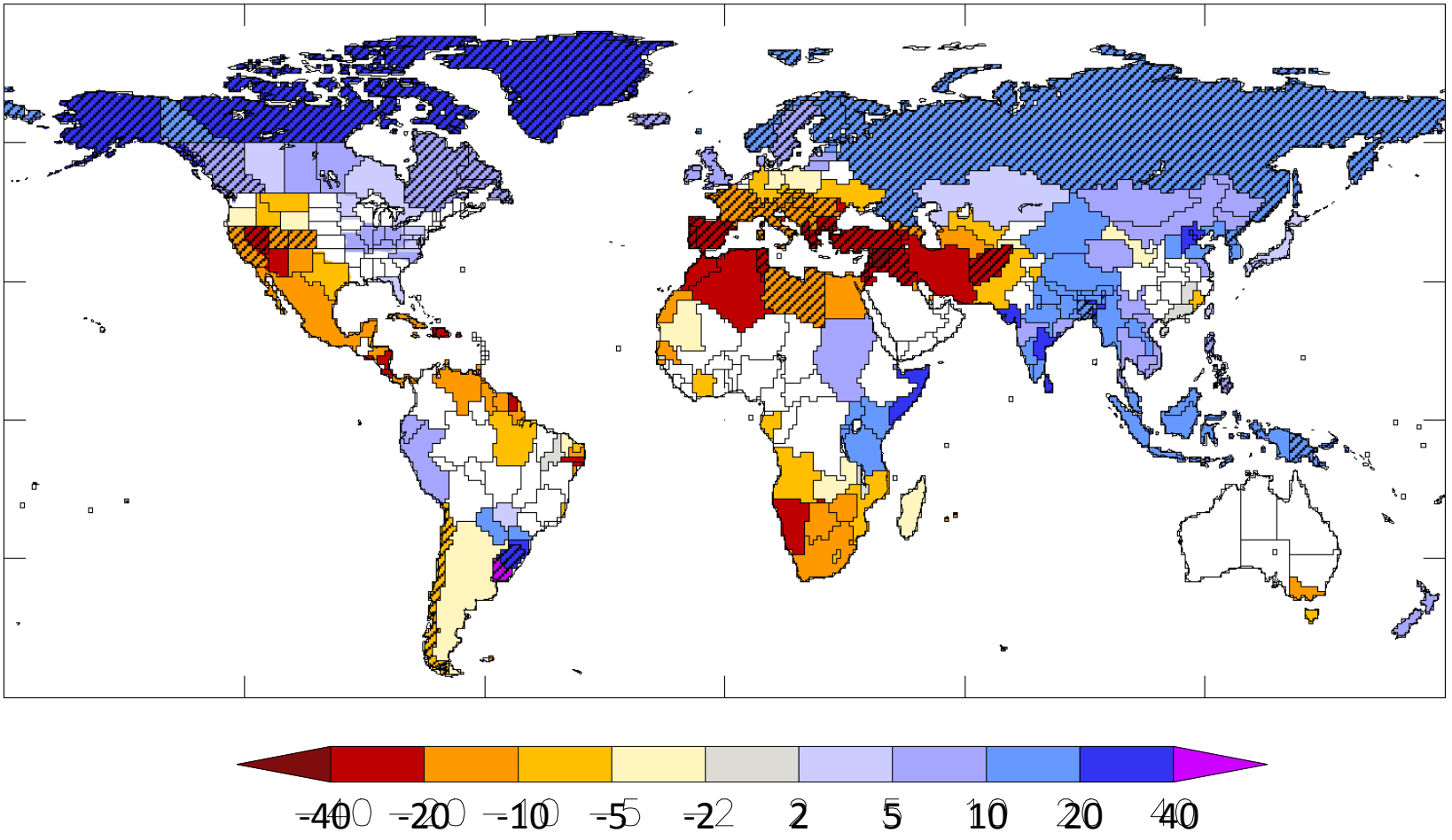


Figure 2 | Global distributions of trend (*Z*) in streamflow from 1900–70 to 1971–98. **a**, Stream-gauge observations. **b**, Ensemble (arithmetic) means of 35 model-run *Z* values, multiplied by $35^{1/2}$ to account for the reduction in variance caused by averaging. **c**, Plot of observations against means of 35 model-run *Z* values. The ordinary least-squares regression line shown has the equation gauge data = 1.51 × (model ensemble) − 0.23.

Model-Projected Changes in Annual Runoff, 2041-2060

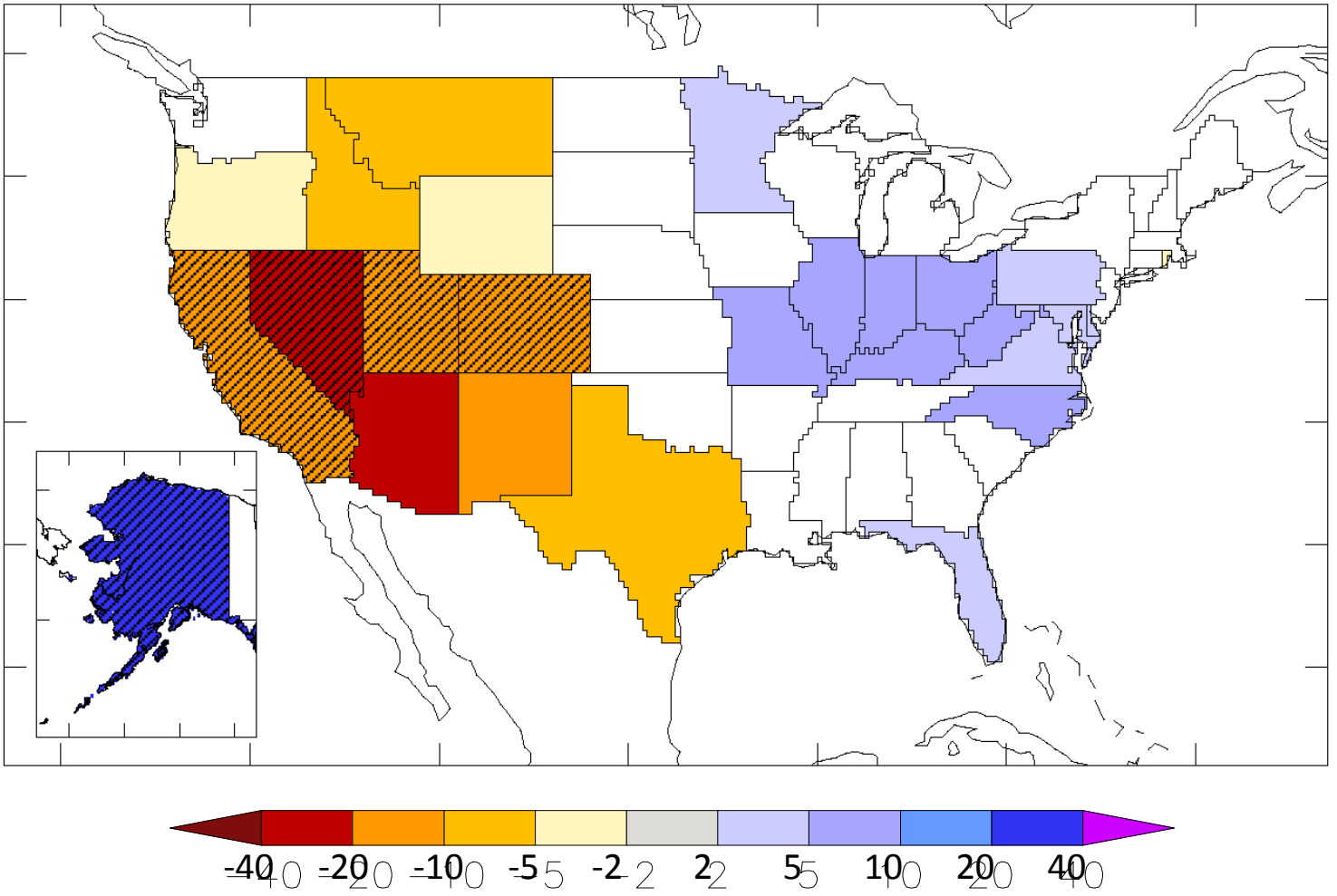
Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement.



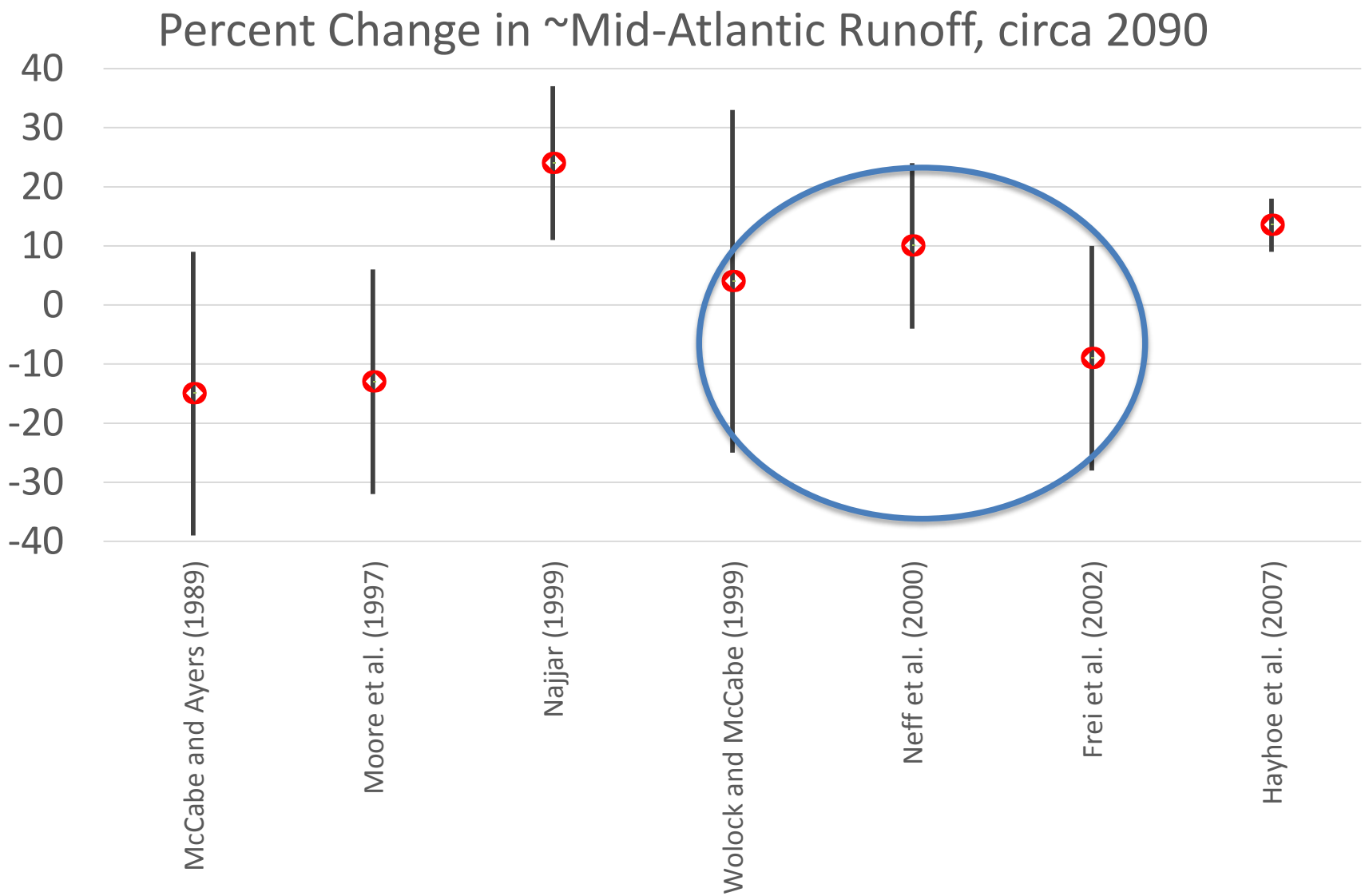
(After Milly, P.C.D., K.A. Dunne, A.V. Vecchia, Global pattern of trends in streamflow and water availability in a changing climate, *Nature*, **438**, 347-350, 2005.)

Model-Projected Changes in Annual Runoff, 2041-2060

Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement.

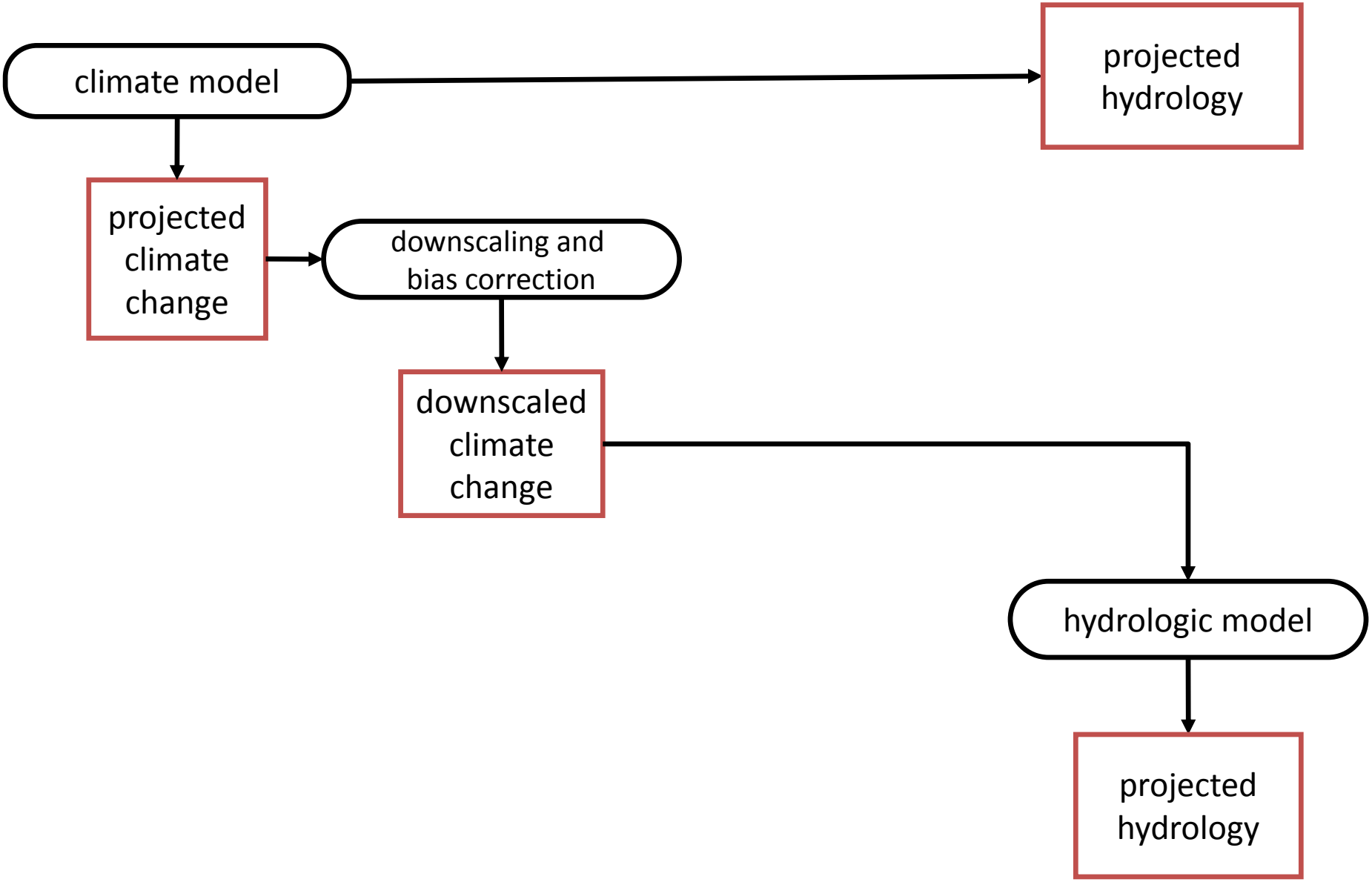


(After Milly, P.C.D., K.A. Dunne, A.V. Vecchia, Global pattern of trends in streamflow and water availability in a changing climate, *Nature*, **438**, 347-350, 2005.)

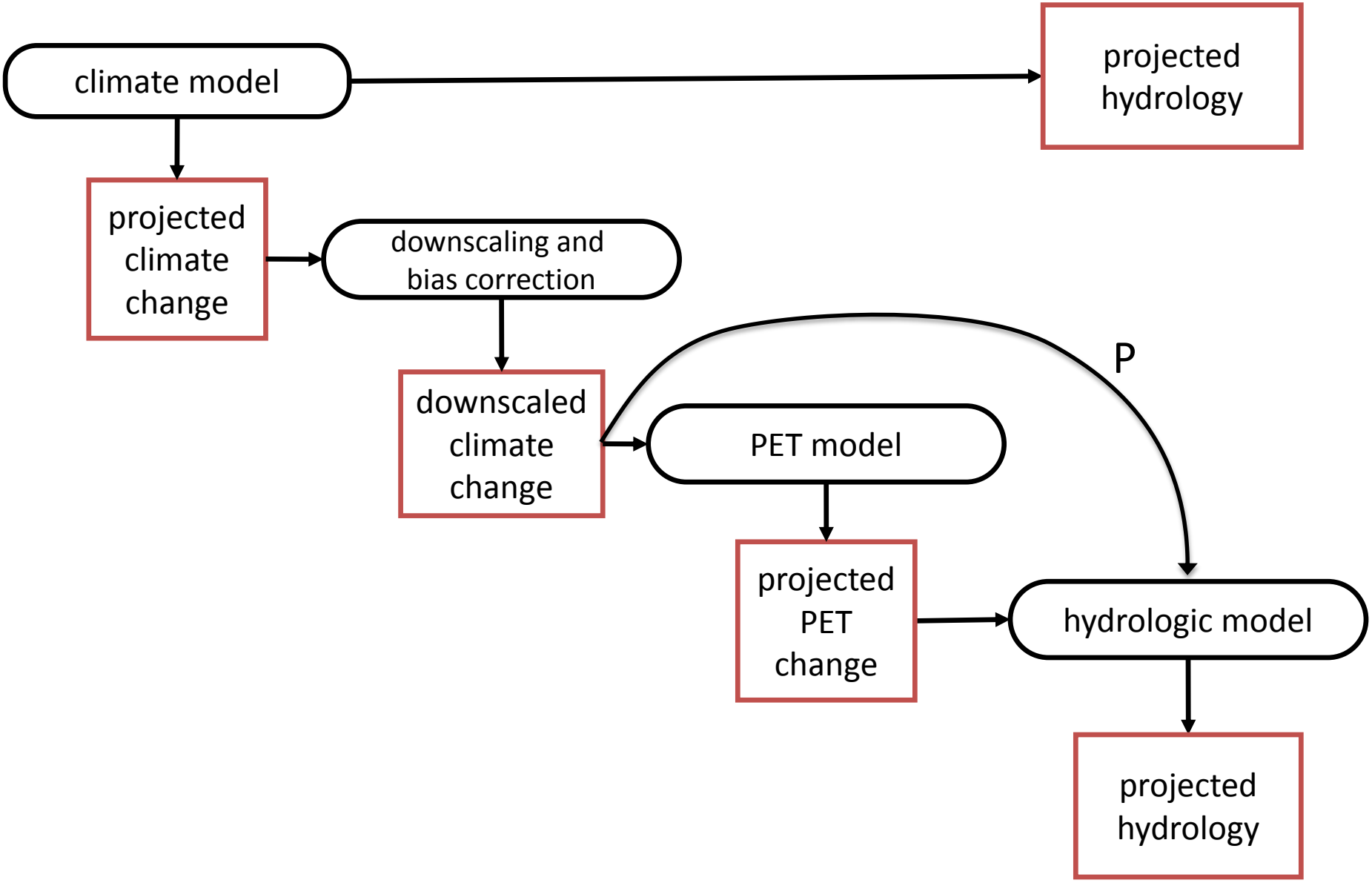


Based on Table 7 of Najjar et al. (2009)

“Offline” Hydrologic Modeling



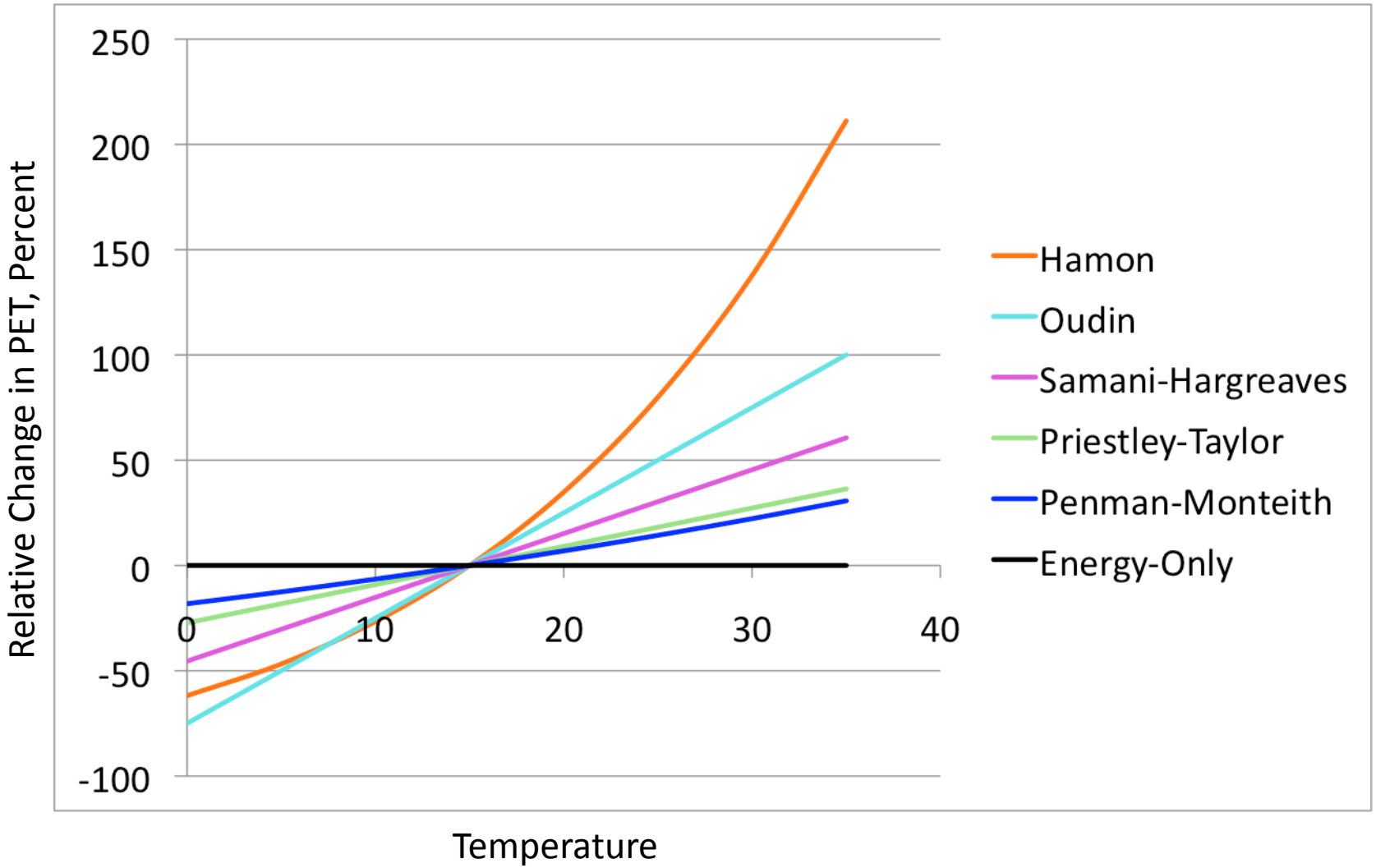
Downscaling and Bias Correction



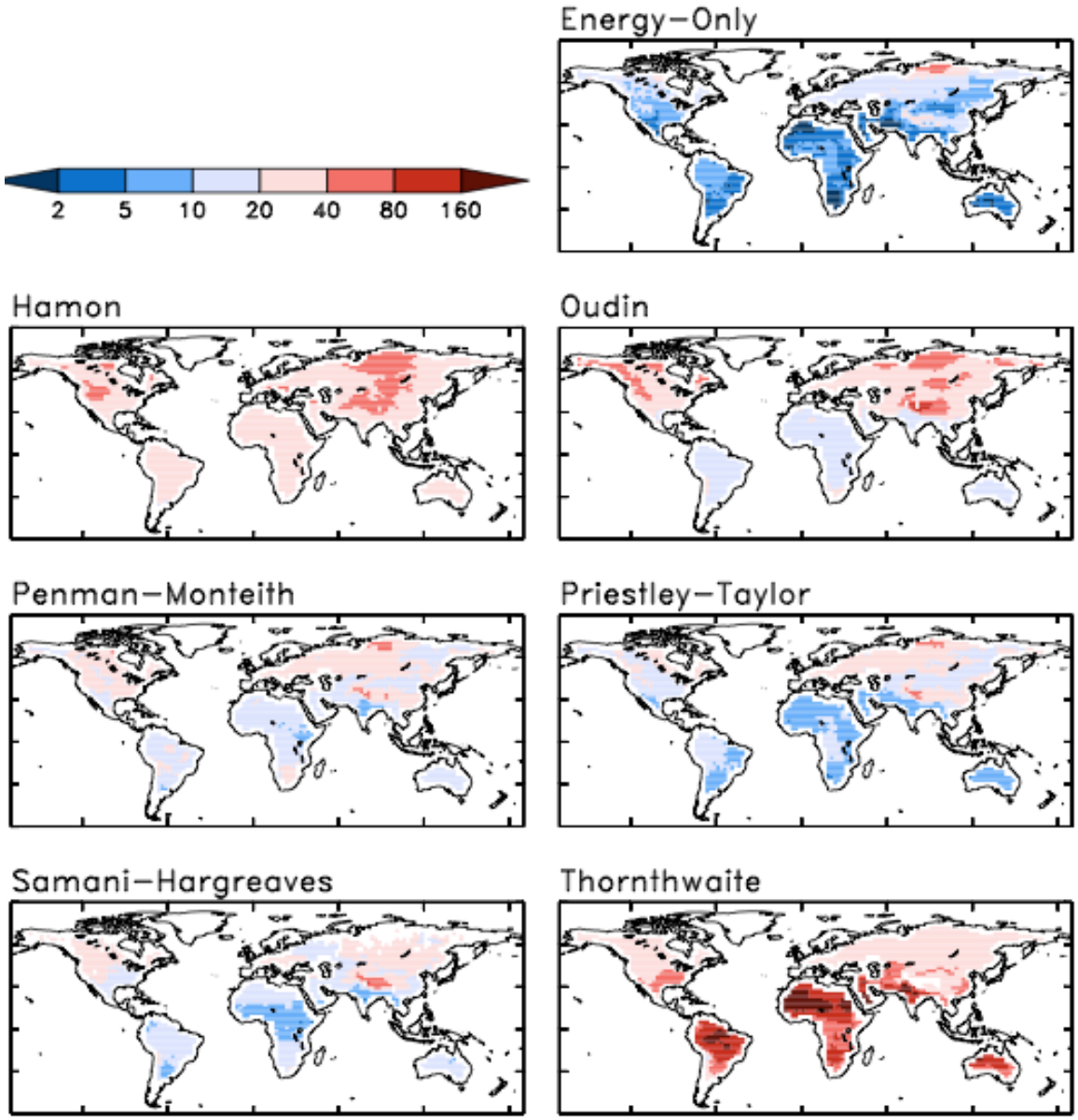
Some PET Methods Used in Offline Climate-Change Studies

Name	Equation
Penman-Monteith	$LE = \frac{\Delta\left(R_n - G\right) + \rho c_p \left[e_{sat}\left(T_a\right) - e_a\right] C_h u}{\Delta + \gamma\left(1 + r_s C_h u\right)}$
Priestley-Taylor	$LE = \frac{\alpha\Delta}{\Delta + \gamma}\left(R_n - G\right)$
"Energy-Only"	$LE \propto \left(R_n - G\right)$
Samani-Hargreaves	$LE \propto \left(T_a + 18\right) R_{se} \left(T_{\max} - T_{\min}\right)^{1/2}$
Oudin	$LE \propto \left(T_a + 5\right) R_{se}$
Hamon	$LE \propto \left[e_{sat}\left(T_a\right)/T_a\right] D$
Thornthwaite	$E \propto \left(T/I\right)^a D \quad I = \sum_{j=1}^{12} \left(T_j/5\right)^{1.514}$ $a = 0.000000675 I^3 - 0.0000771 I^2 + 0.01792 I + 0.49239$

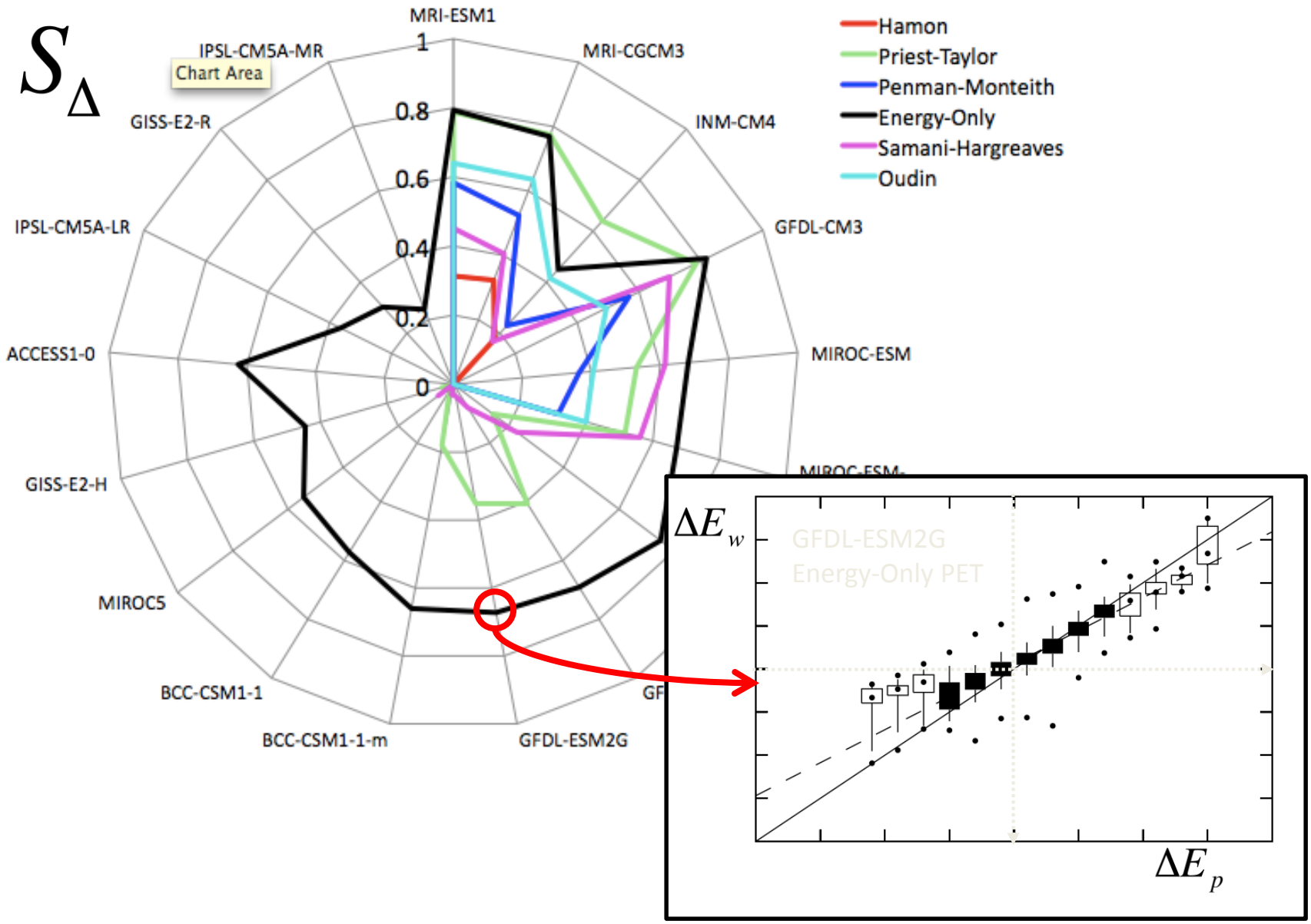
Typical Temperature Dependence of PET, Radiation Being Held Constant



% Change in Annual PET, RCP8.5, 2081-2100

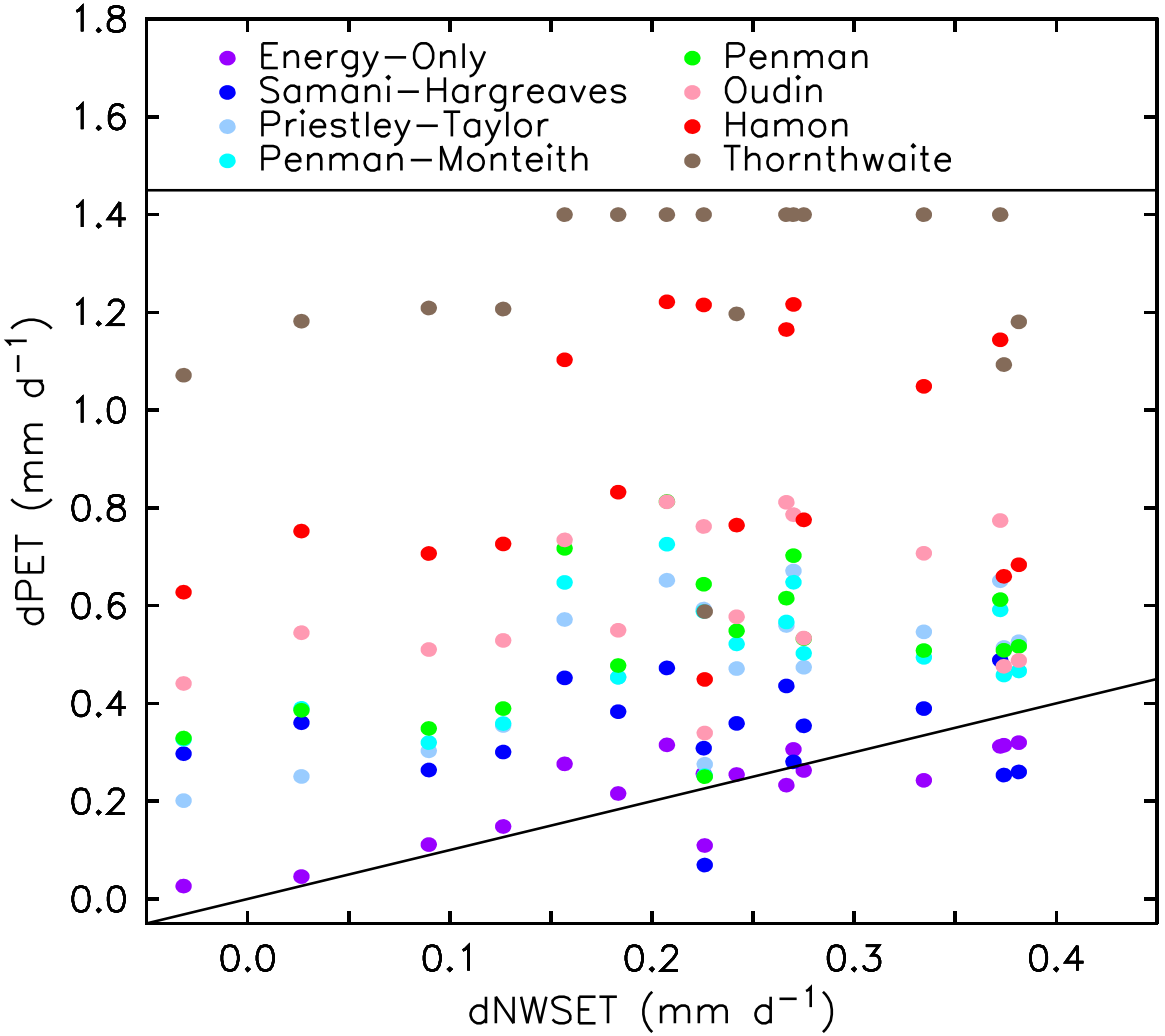


Skill for Change in PET

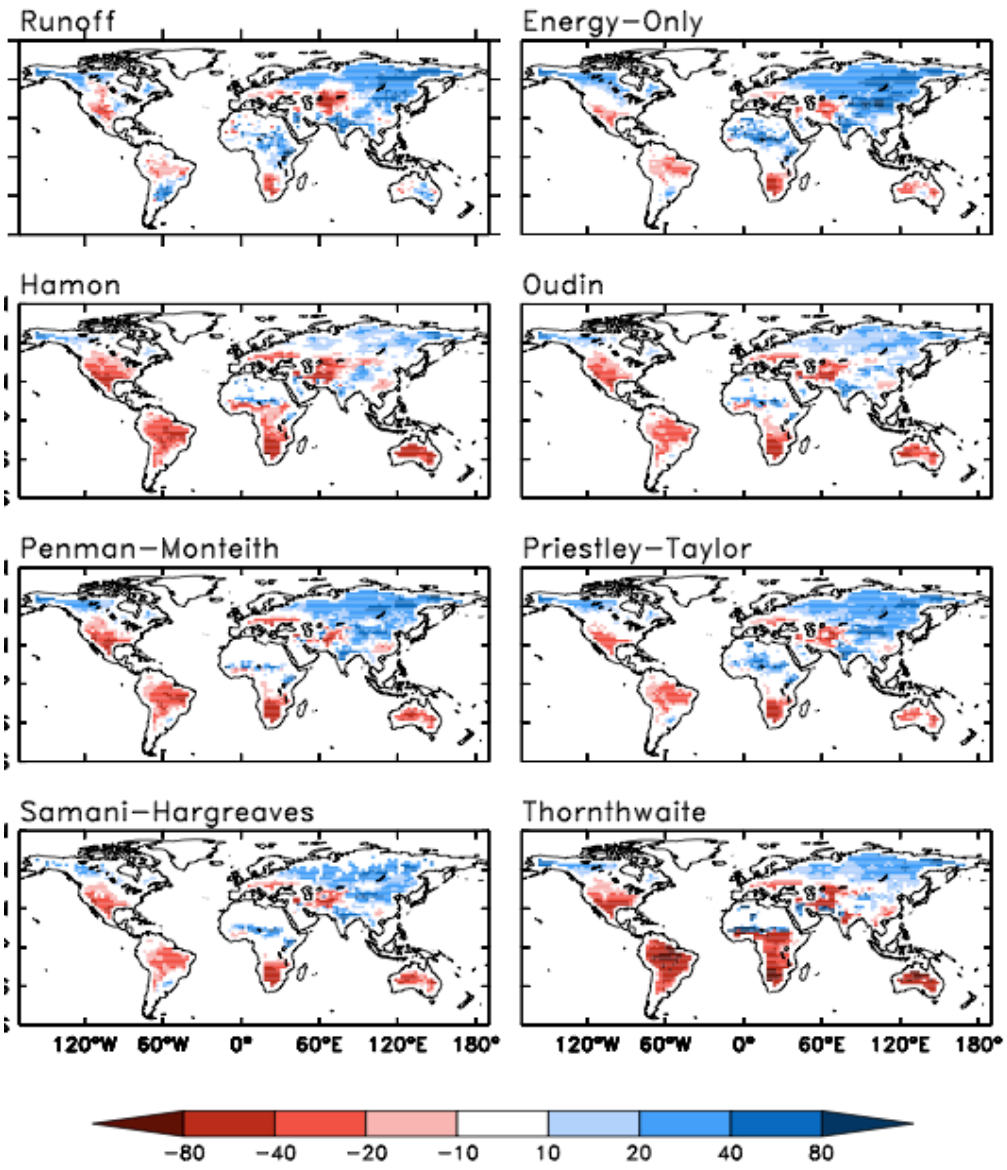


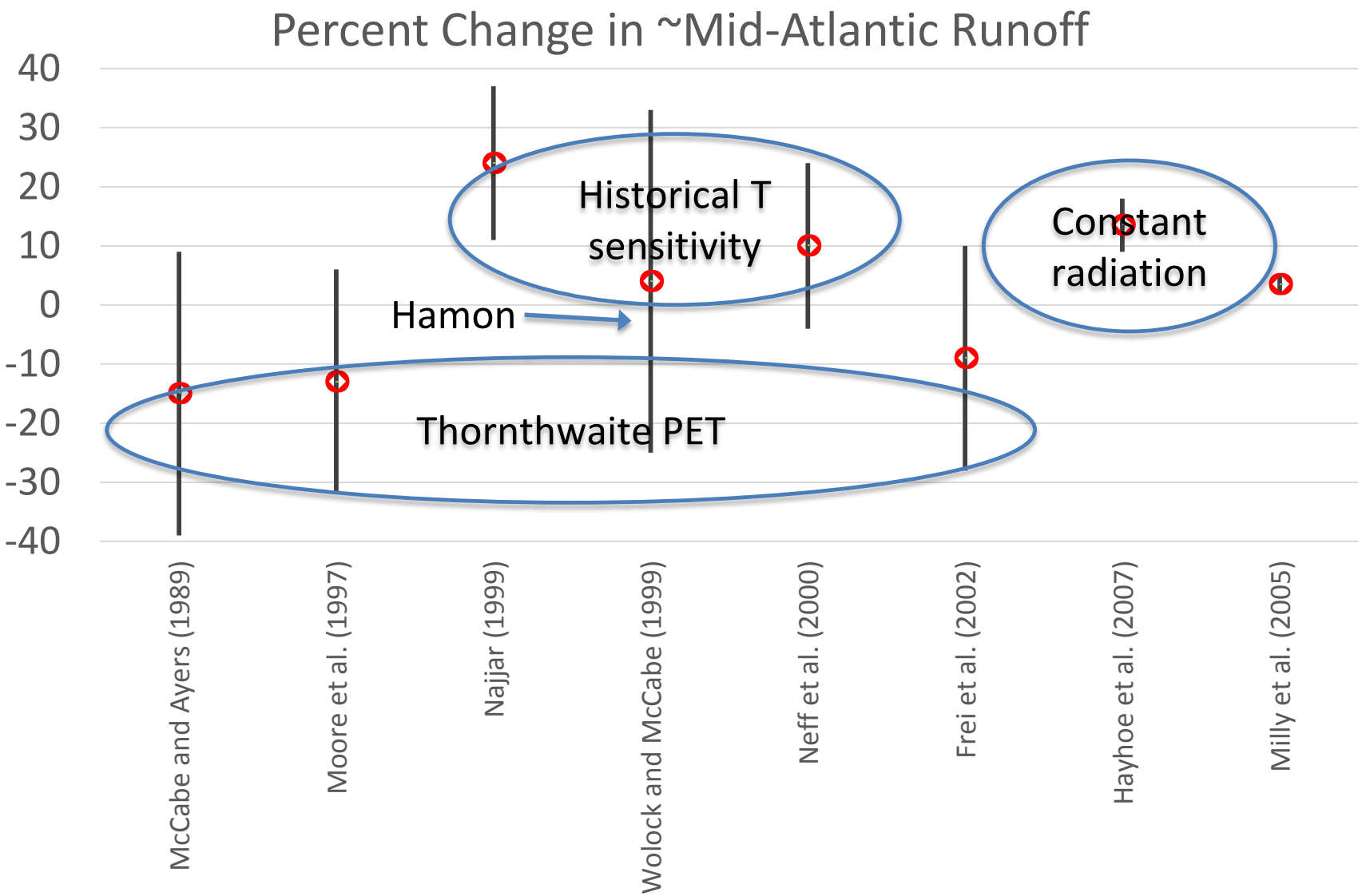
Exaggeration of Change in PET by Standard Methods

Average over all non-water-stressed gridcell-months



Change of Runoff: Climate Model and Budyko/PET Runoff (%)





Based on Table 7 of Najjar et al. (2009)

Summary

- To estimate **historical** Susquehanna R. basin (SRB) runoff, the use of the **median across many climate models is more accurate** than the use of most individual models or small collections thereof.
- Similarly, a **many-model ensemble was more skillful** than any single model in reproducing global pattern of 20th century streamflow **trends**.
- A **large number of climate models** is needed to obtain a stable estimate of future SRB runoff change.
- Variation in past estimates of SRB runoff change is significantly affected by at least two factors:
  - Use of **different climate models**.
  - Use of **different** hydrologic models, especially **PET formulations**.
- **Offline estimates of runoff change** based on empirical PET estimates are generally **biased low** relative to runoff changes in climate models themselves.
- Use of a more **process-based** approach to PET in "offline" hydrologic modeling of climate change requires surface **radiation**.
- **Climate models produce their own runoff**, and this is a useful source of climate-change information.