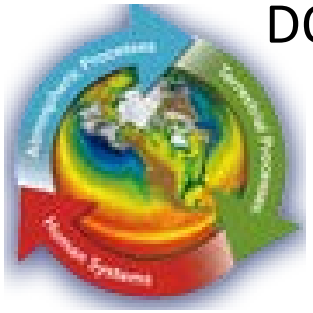
Model Prediction and Evaluation

Eric F. Wood
Princeton University



DOE Workshop on Community Modeling and Long-term Predictions of the Integrated Water Cycle

Washington, DC
September 24-26, 2012

Workshop focus

"(the workshop participants) will be discussing challenges in predicting the water cycle and evaluating models that are used to do the predictions."

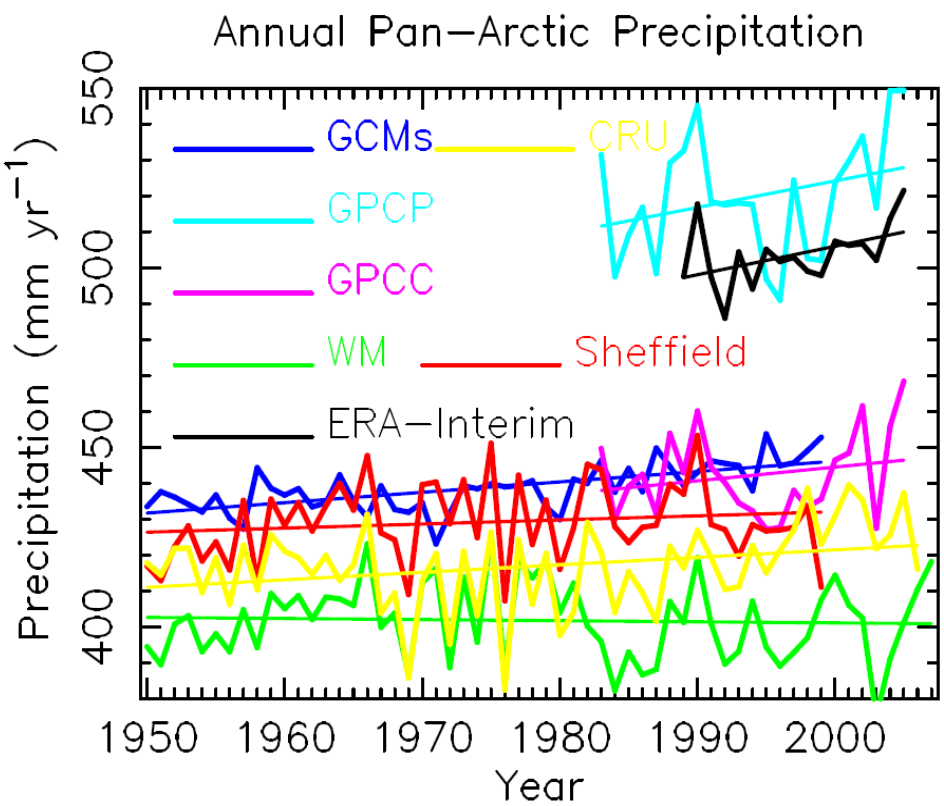
"what may be the most important obstacles or challenges in predicting water cycle changes in the future."

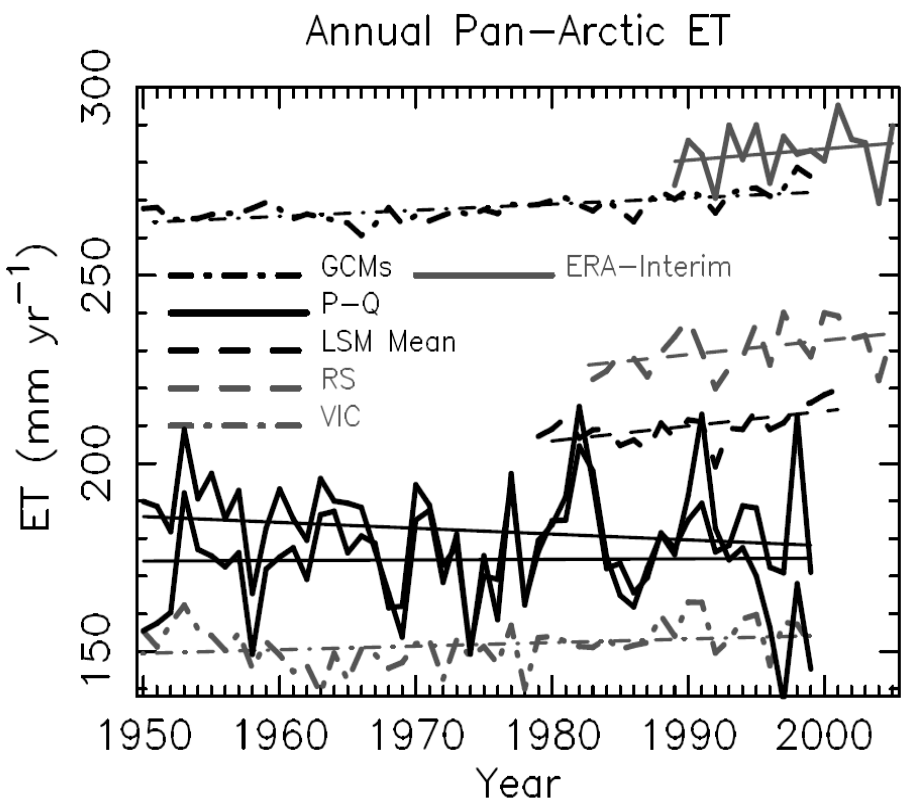
Questions relevant to this presentation

- What is the consistency among models in predicting the water cycle?
- Can a framework be developed for water and energy cycle model evaluation?
- Does adequate data exists for evaluating models, and if so where is it?
- Can we develop models with improved predictive capabilities?

Some representative examples
How consistent are predictions of water cycle variables?

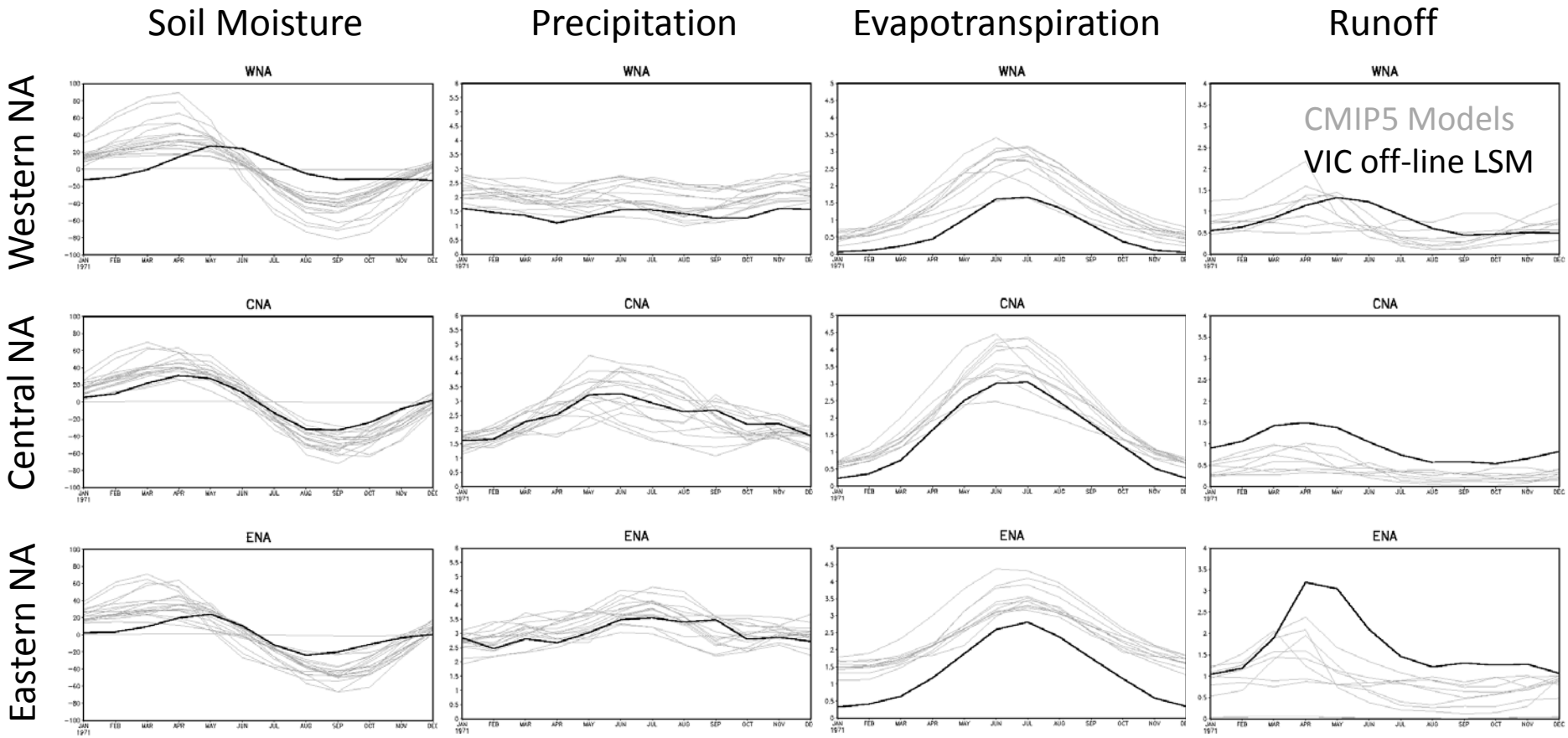
Estimates of water cycle variables over the pan-Arctic from observations, coupled GCMs, uncoupled LSMs, and remote sensing vary widely.

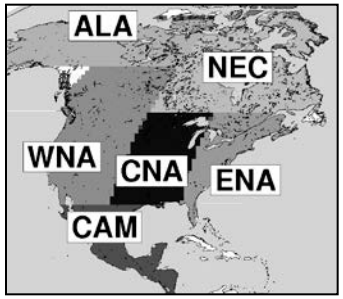




(from Rawlins, et al "Analysis of the Arctic System for Freshwater Cycle Intensification", in review)

Seasonal Water Budgets for N. American Regions from CMIP5





- Soil moisture tends to wet too early in CMIP5 models and has larger dynamic range (deeper soils, more P, more E)
- Precipitation is too high in the west
- Evapotranspiration is generally too high, regardless of precip
- Runoff is too low and spring melt peaks too early

Drought Monitoring and Hydrologic Forecasting with VIC

Nowcast/Forecast | Historical Droughts/Hindcast | Documentation | About the Project

As of 2012/05/01, CFS forecasts are switched to CFSv2. Hover mouse on items to see more info.

Product/Date/Variable (change on click)

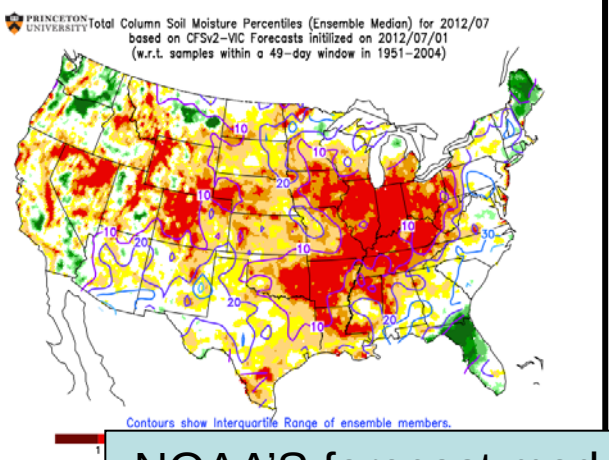
Monitoring validated < 2012/09/13 > for ○ Soil Moisture ○ Snow ○ Streamflow ○ Precipitation

Forecast initialized < 2012/08/01 > for ◉ Soil Moisture ○ Drought Probability

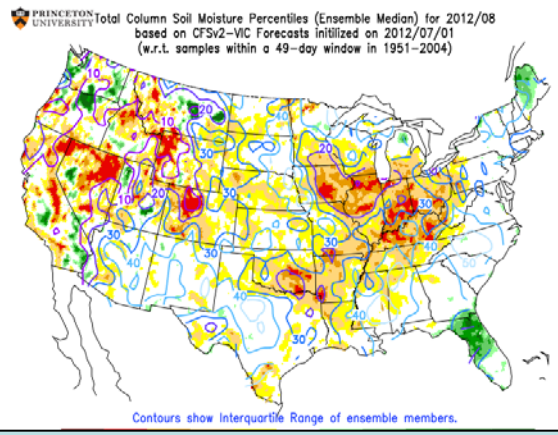
Timeline (change on hover)

2012/06/07
2012/06/14
2012/06/21

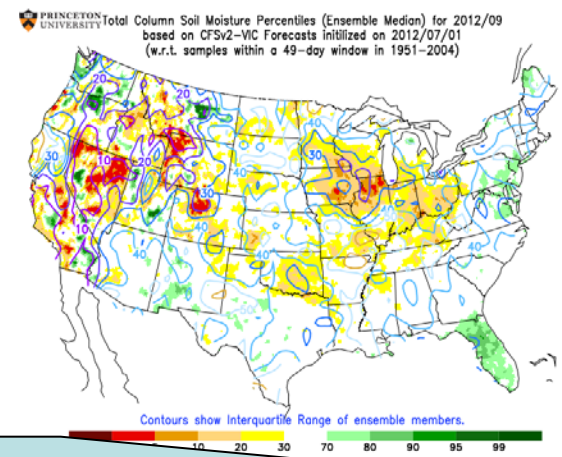
July 2012 initialized 7/1/2012



Aug. 2012 initialized 7/1/2012

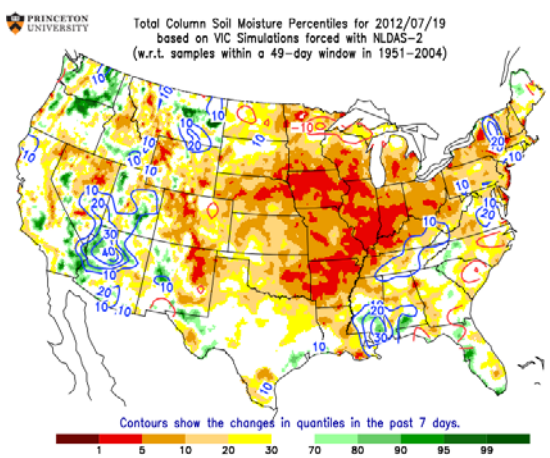


Sept. 2012 initialized 7/1/2012

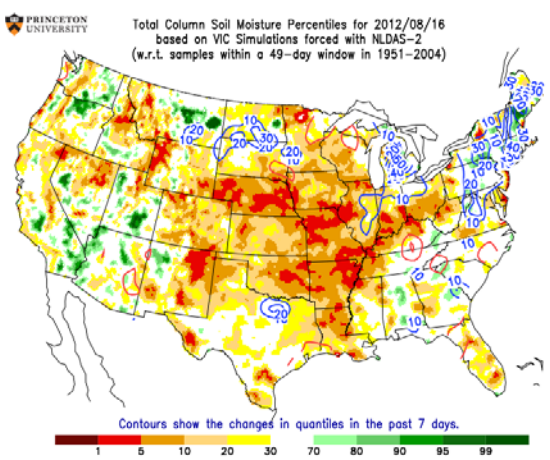


NOAA'S forecast model doesn't hold drought conditions. WHY?

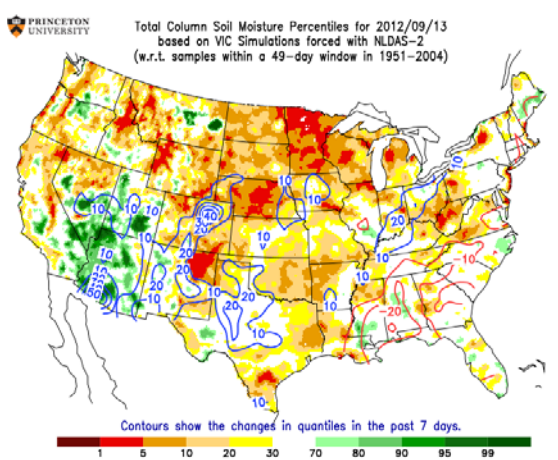
Verification of Jul. 2012 forecast



Verification of Aug. 2012 forecast



Verification of Sept. 2012 forecast

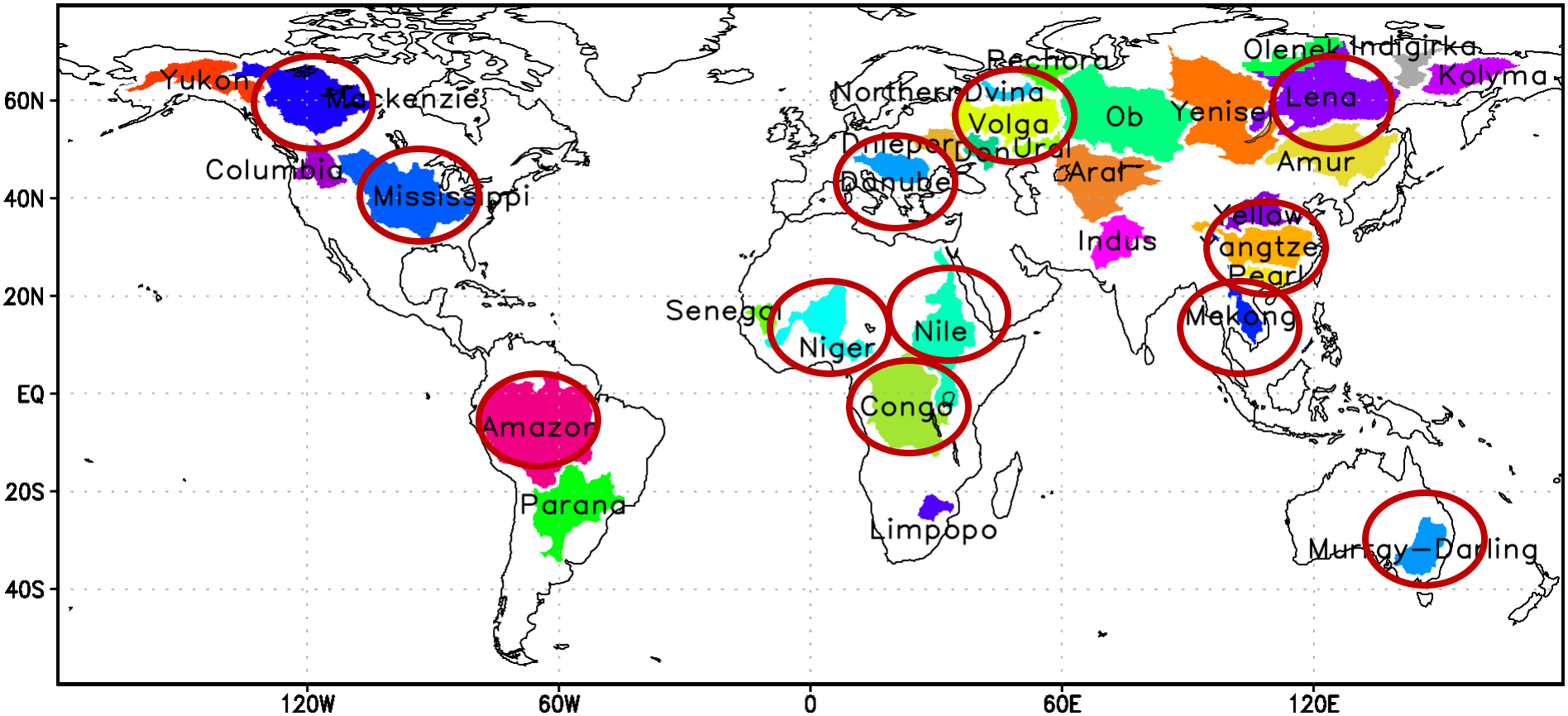


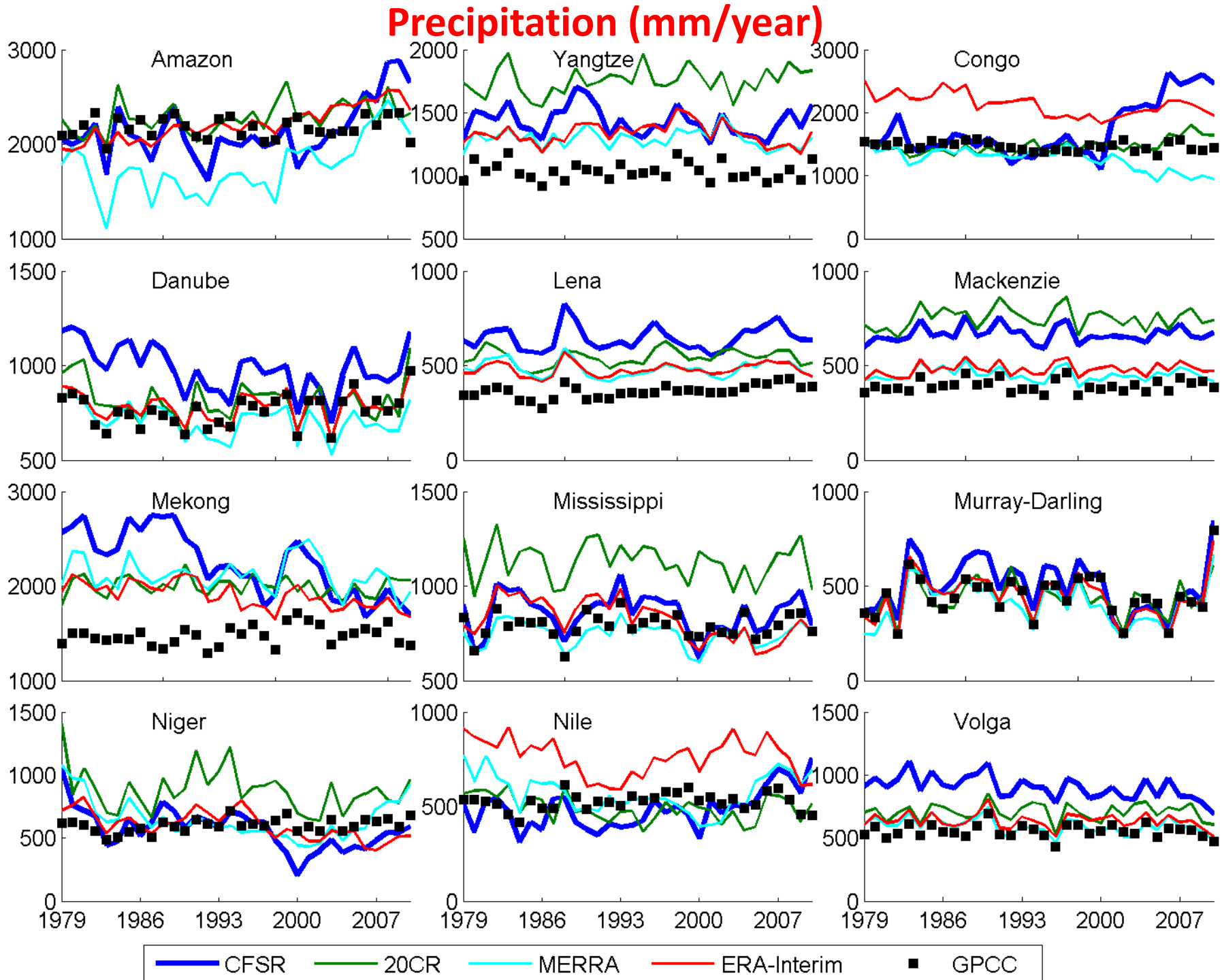
Comparisons of re-analysis derived, and observed, water cycle variables?

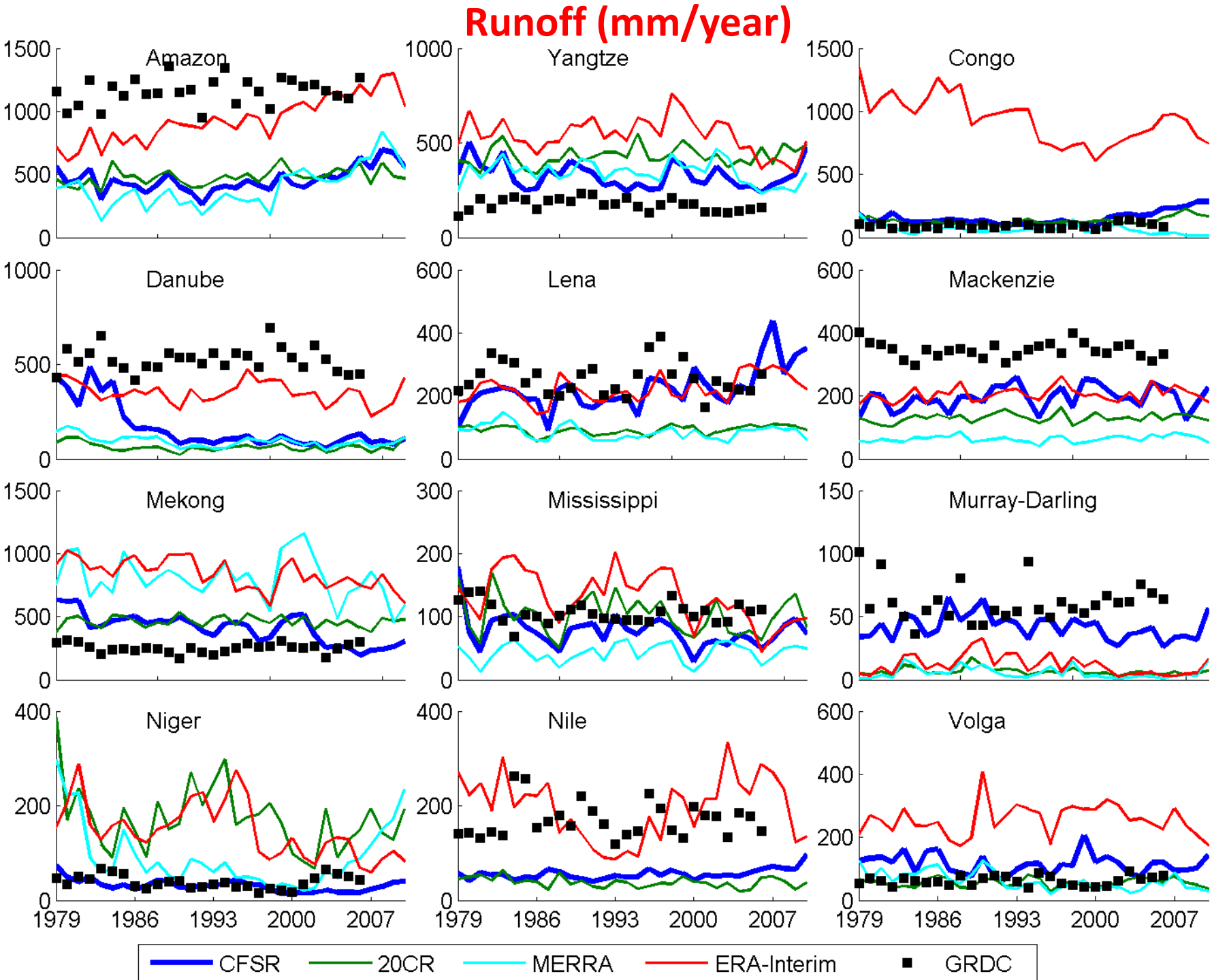
The community has the belief that re-analysis derived model outputs (data sets) should be skillful since they assimilate a wide suite of observations from which the models predict water and energy cycle fluxes and states.

Are these predictions consistent among models since most of the assimilated data sets are the same?

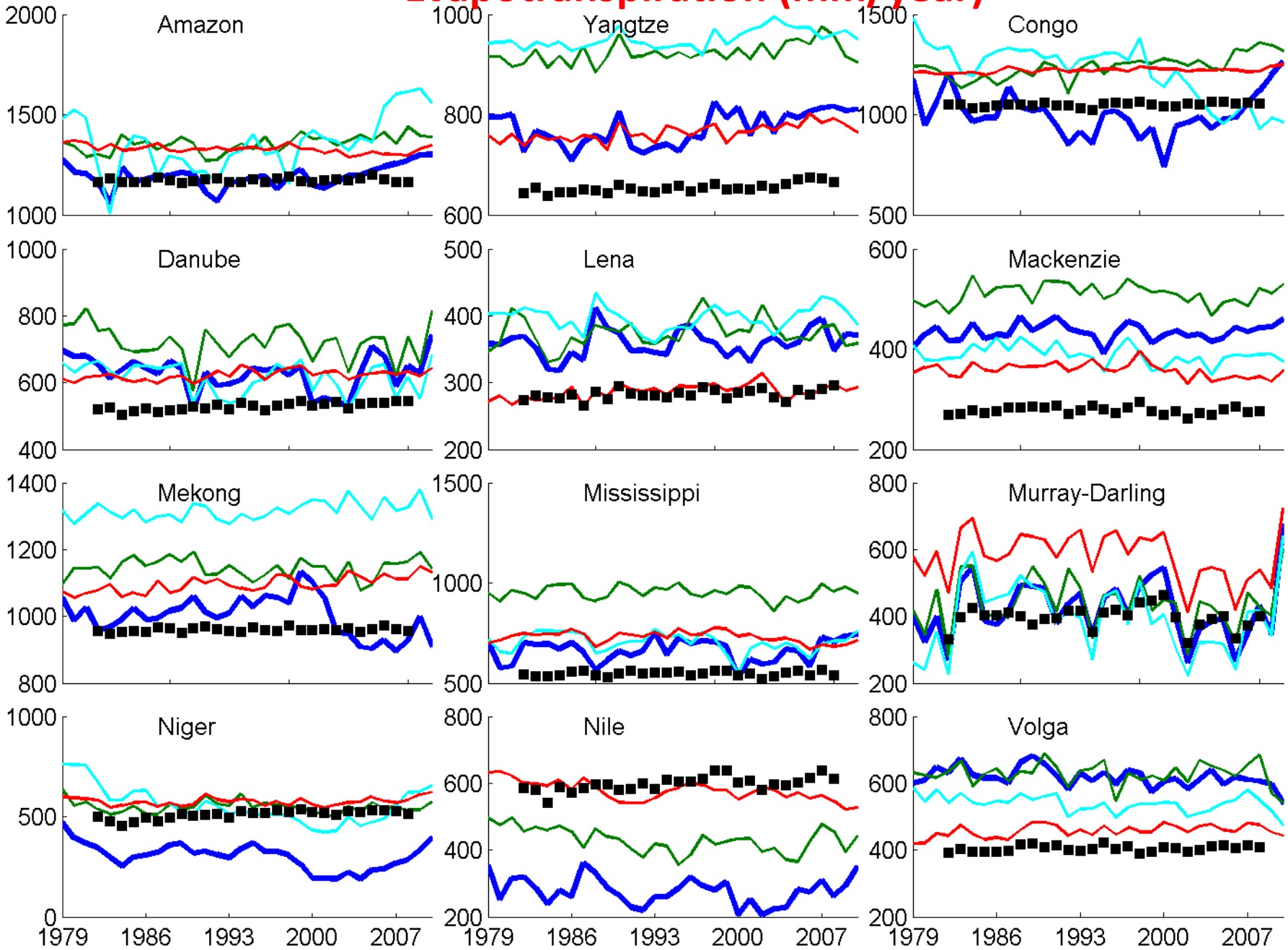
Basins where we have been focusing large-scale analysis of model performance.




Precipitation (mm/year)
Amazon
Yangtze
Congo
Danube
Lena
Mackenzie
Mekong
Mississippi
Murray-Darling
Niger
Nile
Volga
1979
1986
1993
2000
2007
CFSR
20CR
MERRA
ERA-Interim
GPCC


Runoff (mm/year)
Amazon
Yangtze
Congo
Danube
Lena
Mackenzie
Mekong
Mississippi
Murray-Darling
Niger
Nile
Volga
1979
1986
1993
2000
2007
CFSR
20CR
MERRA
ERA-Interim
GRDC

Evapotranspiration (mm/year)



How consistent are re-analysis derived, and observed, water cycle variables?

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Are these predictions consistent among models since most of the assimilated data sets are the same?

These results and MANY OTHER STUDIES indicate significant differences among model predictions, and significant differences with observations.
Is there a strategy for progress here?

How do atmosphere-land surface interactions operate and feed back onto the regional and larger scale climate system?

Recent papers:

Findell, K. L. & Eltahir, E. A. B. Atmospheric controls on soil moisture-boundary layer interactions. Part II: feedbacks within the continental United States. *J. Hydrometeorol*. 4, 570–583 (2003).

Koster, R. D. et al. Regions of strong coupling between soil moisture and precipitation. *Science* 305, 1138–1140 (2004).

Betts, AK 2004 Understanding hydrometeorology using global models" *BAMS*, 1673-1688, DOI:10.1175/BAMS-85-11-1673, November

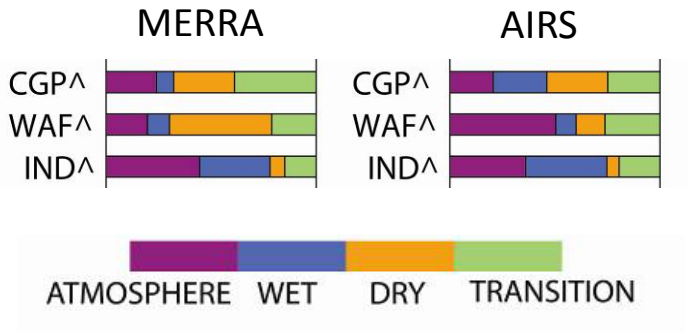
Ferguson, CR and Eric F Wood. 2011. Observed Land–Atmosphere Coupling from Satellite Remote Sensing and Reanalysis, *J Hydromet.* 12(6):1221-1254, DOI: 10.1175/2011JHM1380.1

Ferguson, C R; Wood, EF; Vinukollu, RK, 2012. A Global Intercomparison of Modeled and Observed Land-Atmosphere Coupling *J Hydromet.* 13(3):749-784. DOI: 10.1175/JHM-D-11-0119.1, June.

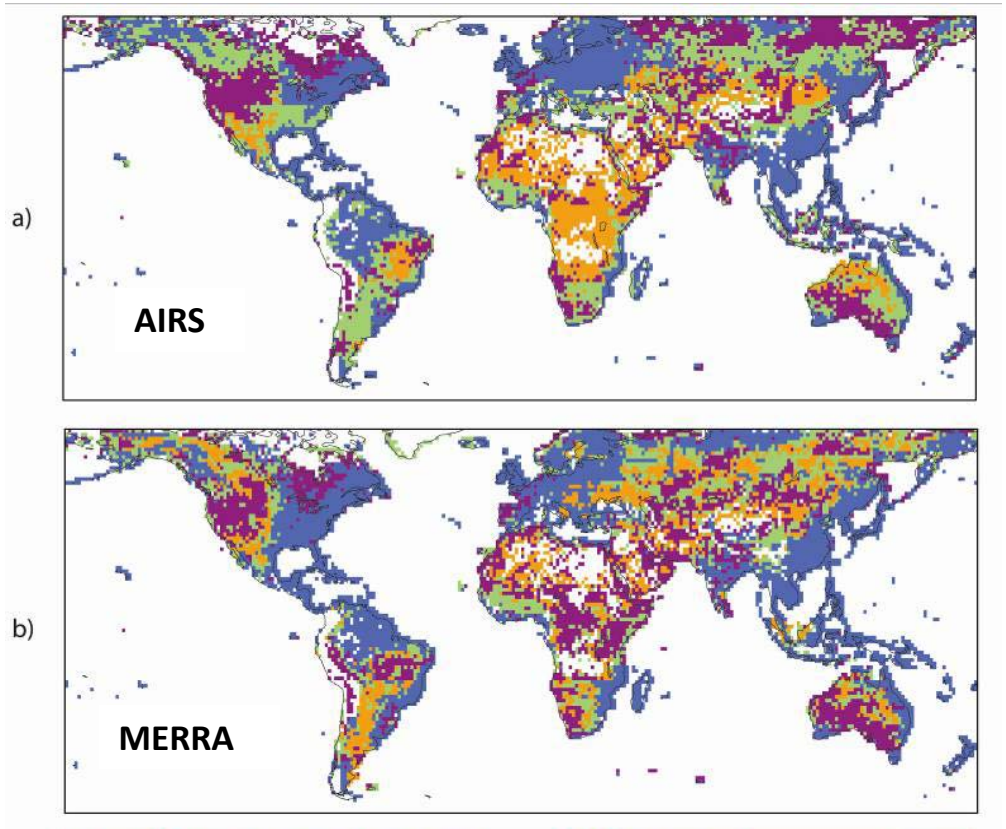
Taylor, CM et al. 2012 Afternoon rain more likely over drier soils, *Nature*, doi:10.1038/nature11377

What do “observations” say about land-atmospheric coupling and convection?

Fractional composition

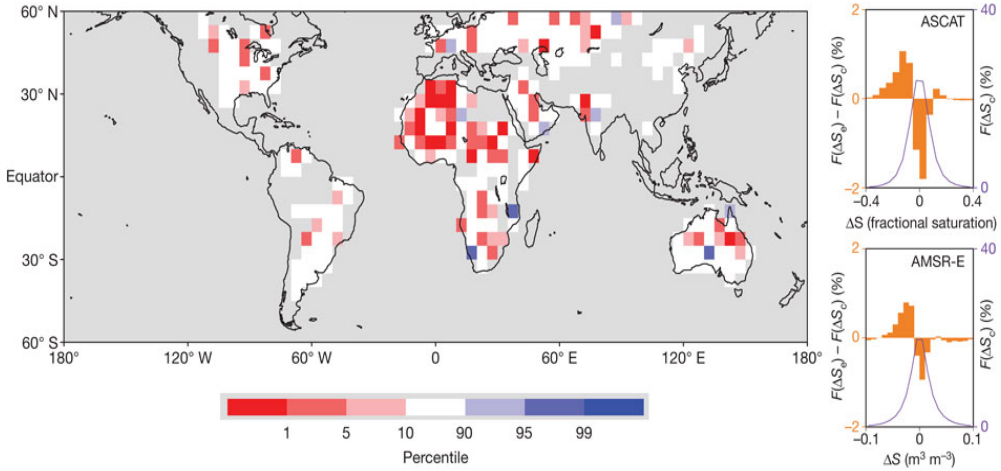


(from Ferguson and Wood, 2011)

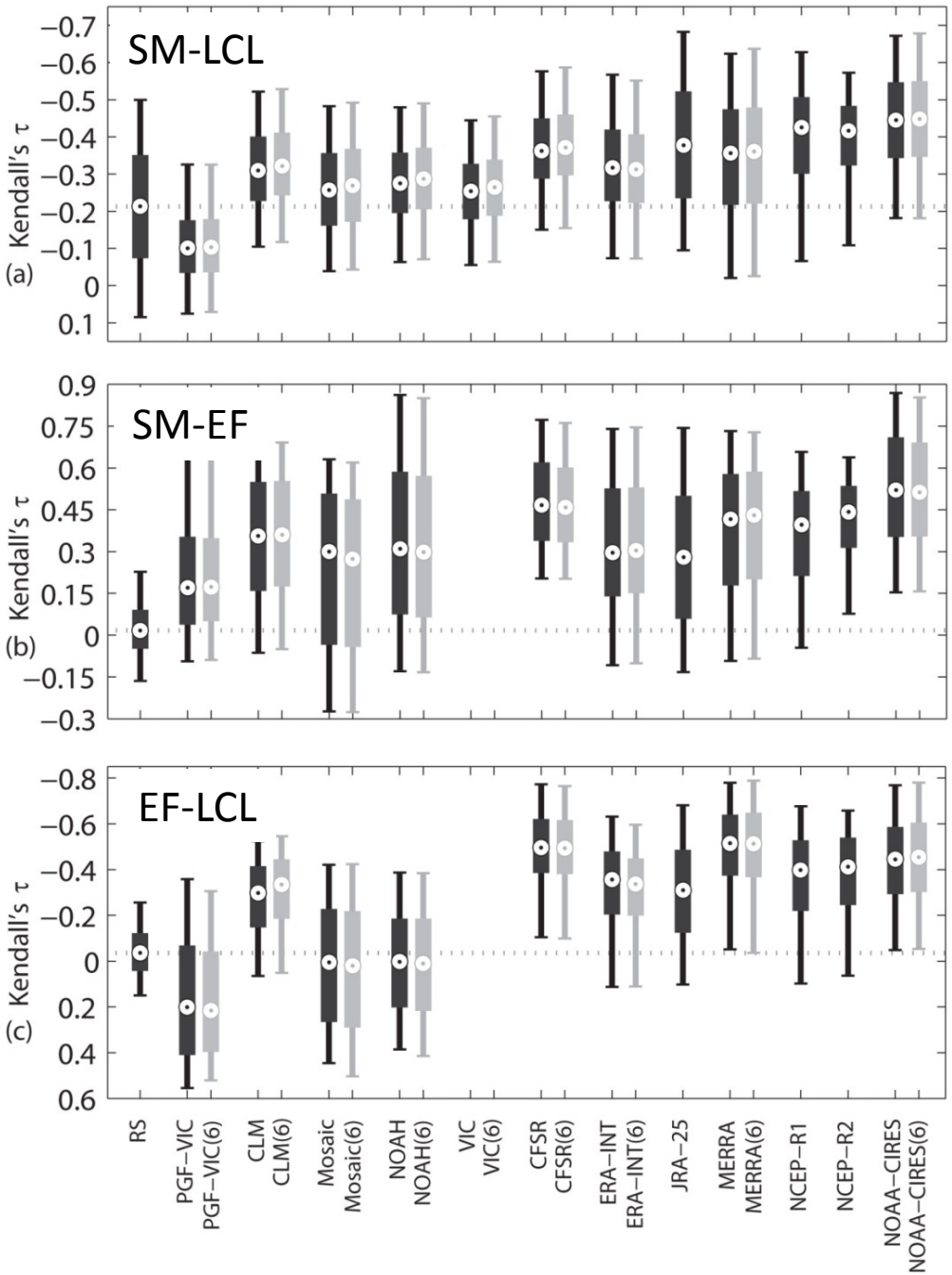


Afternoon convection over
dry soils
wet soils
Using ASCAT/AMSR-E/CMORPH

(from Taylor et al, 2012)

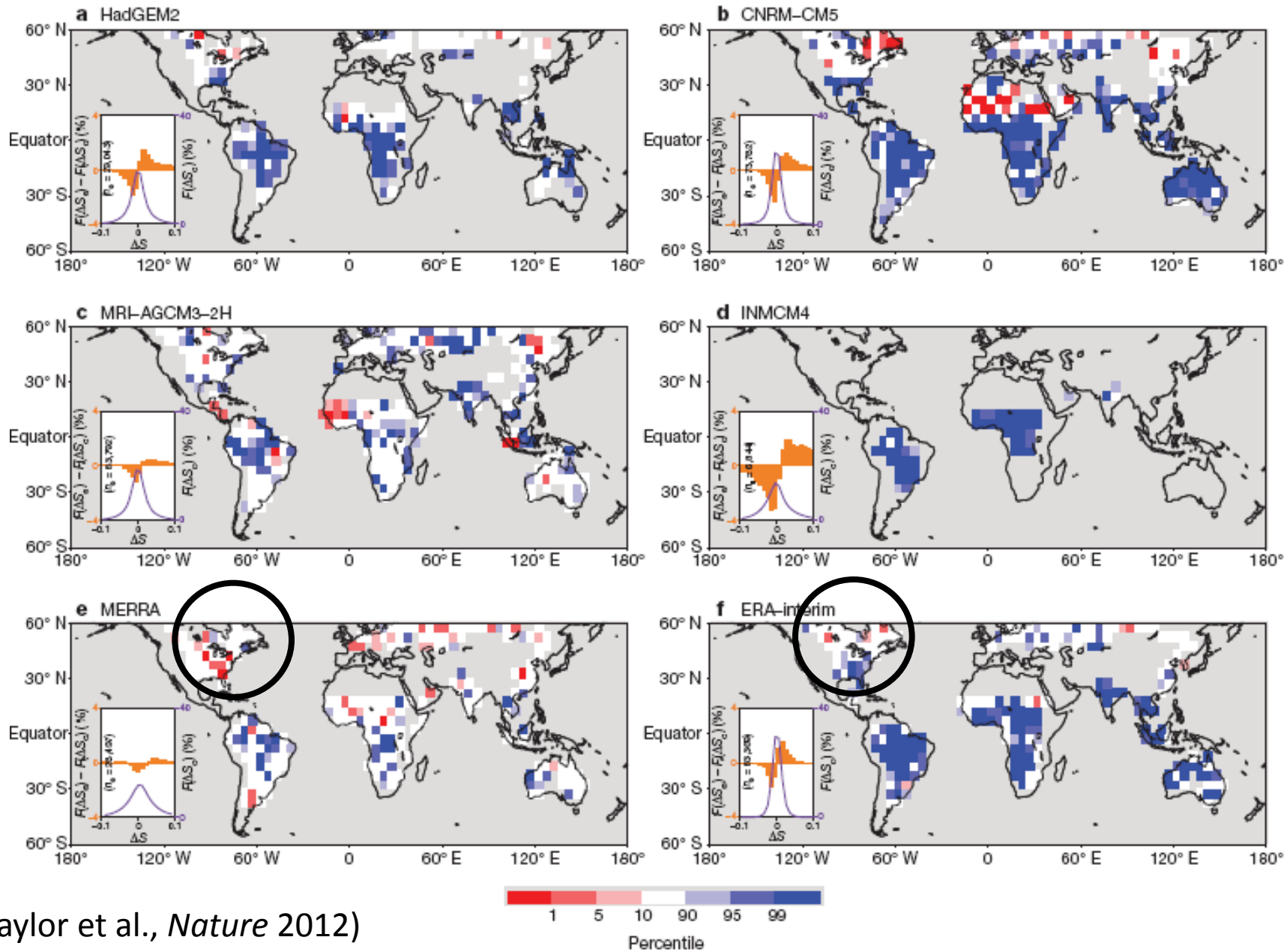


Comparisons among models of their (Kendall **τ)** correlation between land surface variables (SM: soil moisture; EF: Evaporative fraction) and measures of coupling (e.g. LCL: Lifting Condensation Level).



(Ferguson et al., 2012)

Differences in predictions of preferences for convection over wet or dry soils

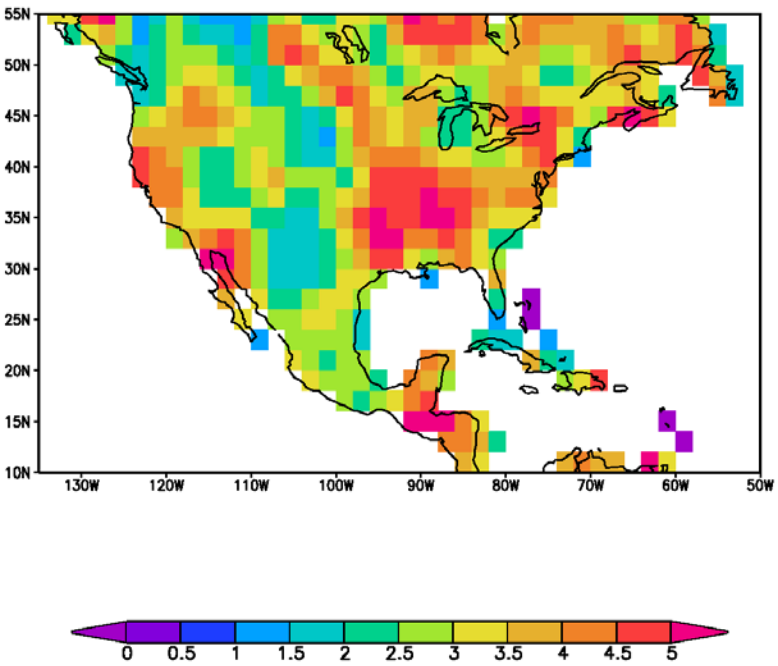


(Taylor et al., *Nature* 2012)

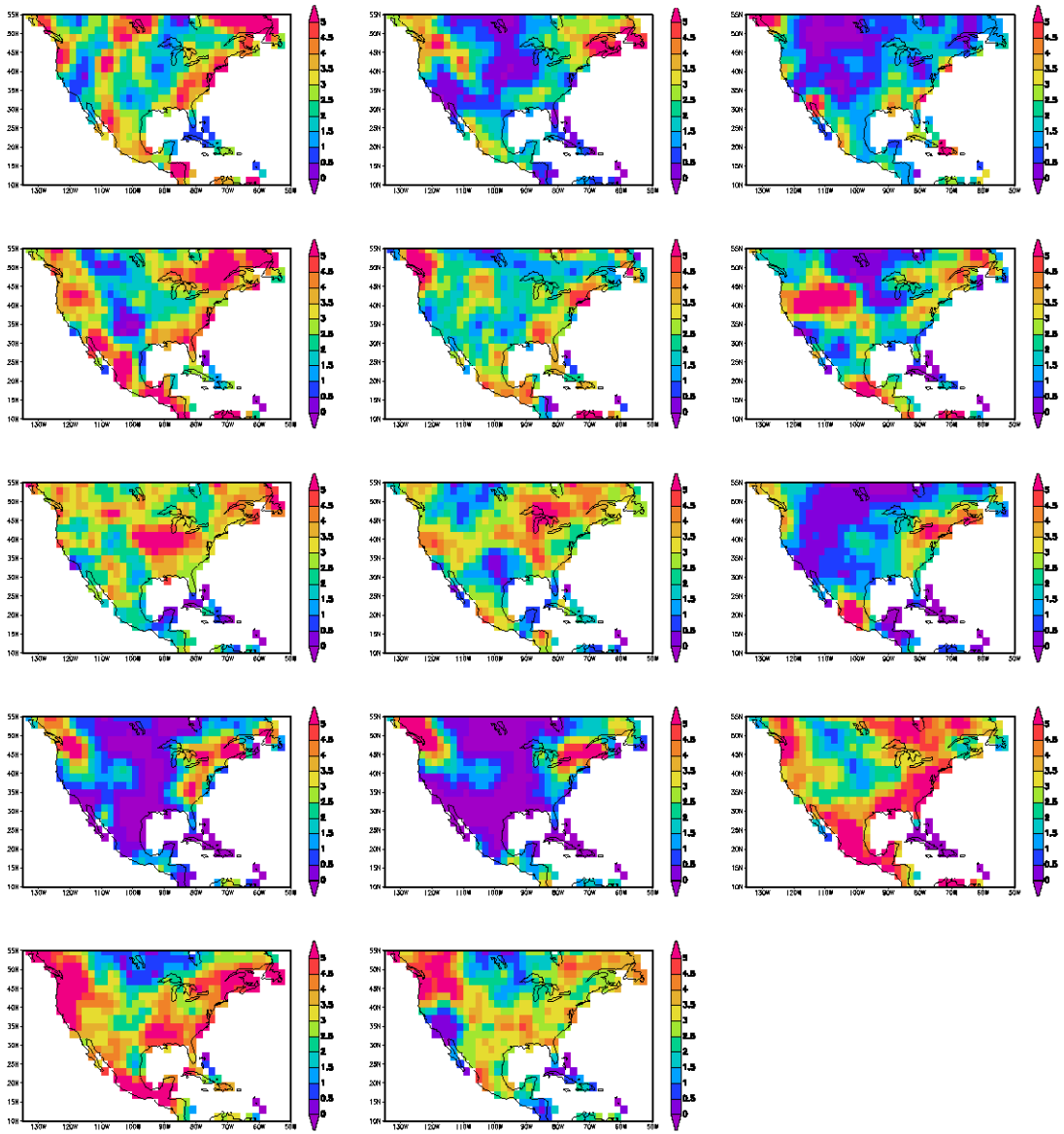
Is there consistency on projections of global and regional drought from CMIP5?

20C Evaluations:
Frequency of Short-Term (4-6 month) Drought

VIC Off-line LSM



CMIP5 Models

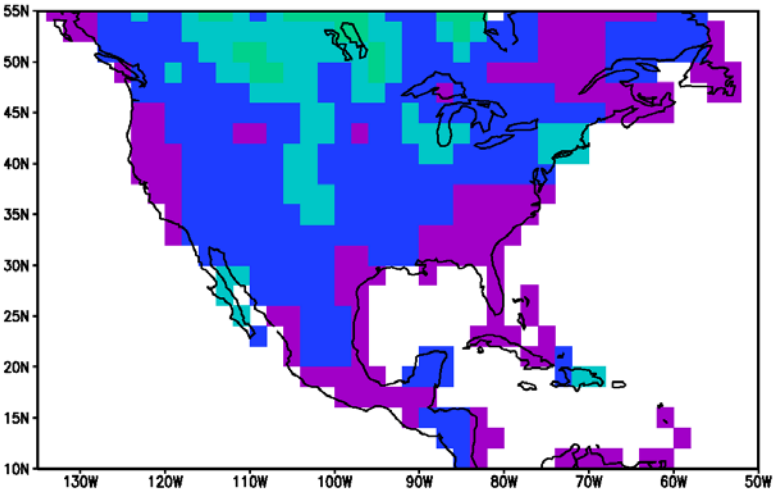


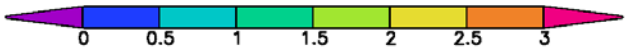
Is there consistency on projections of global and regional drought from CMIP5?

20C Evaluations:

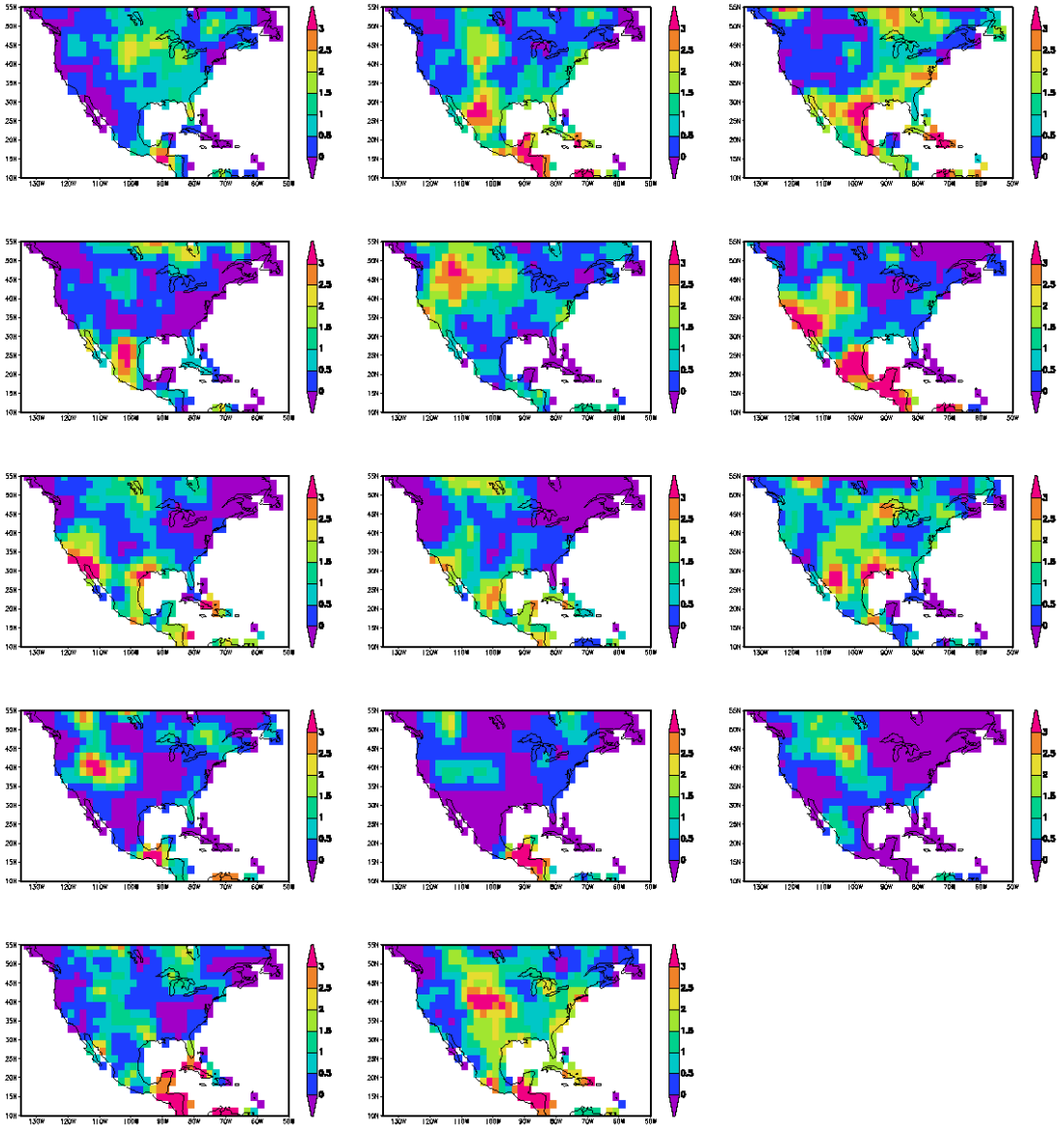
Frequency of Long-Term (> 12 months) Drought

VIC Off-line LSM

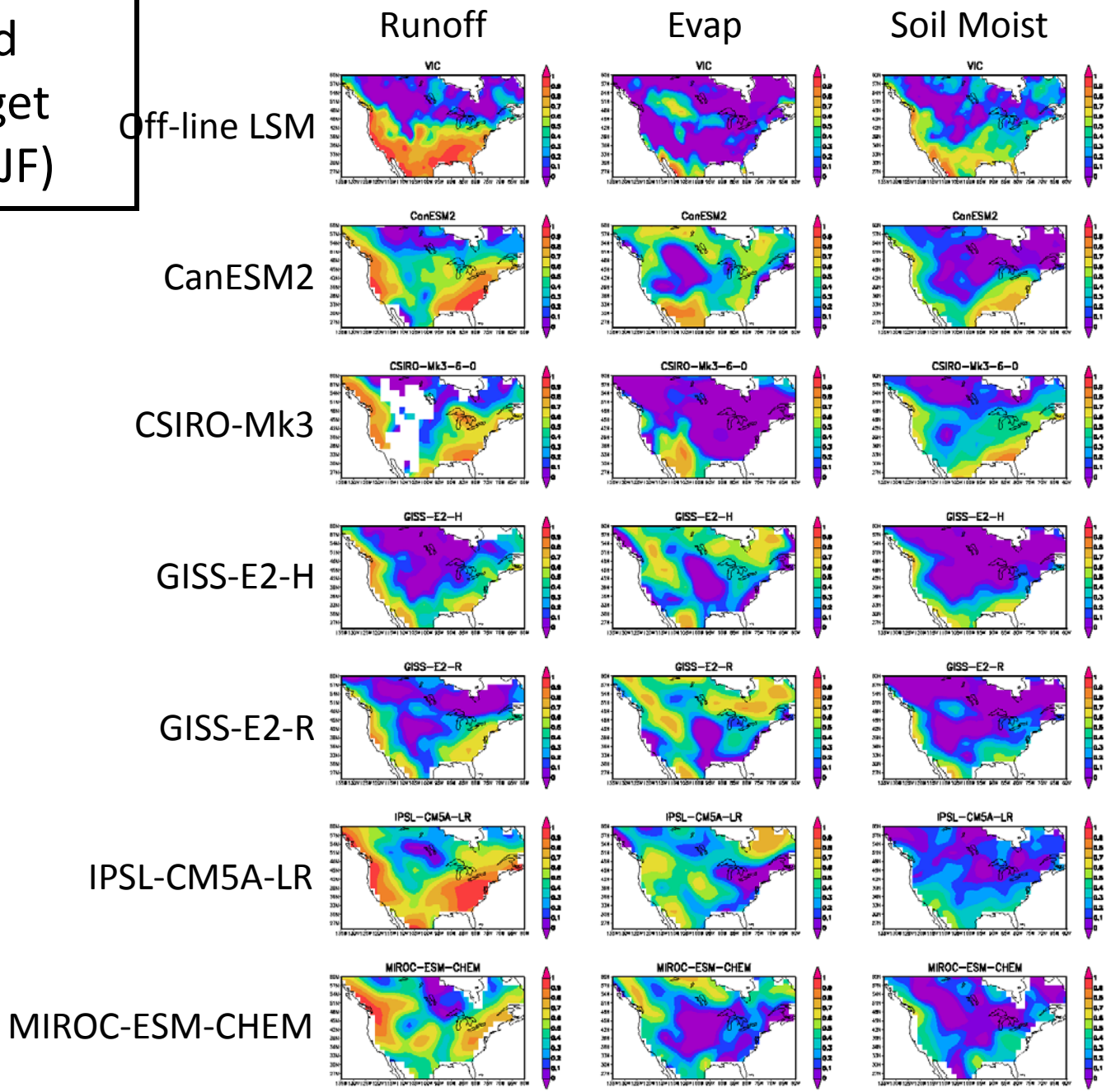




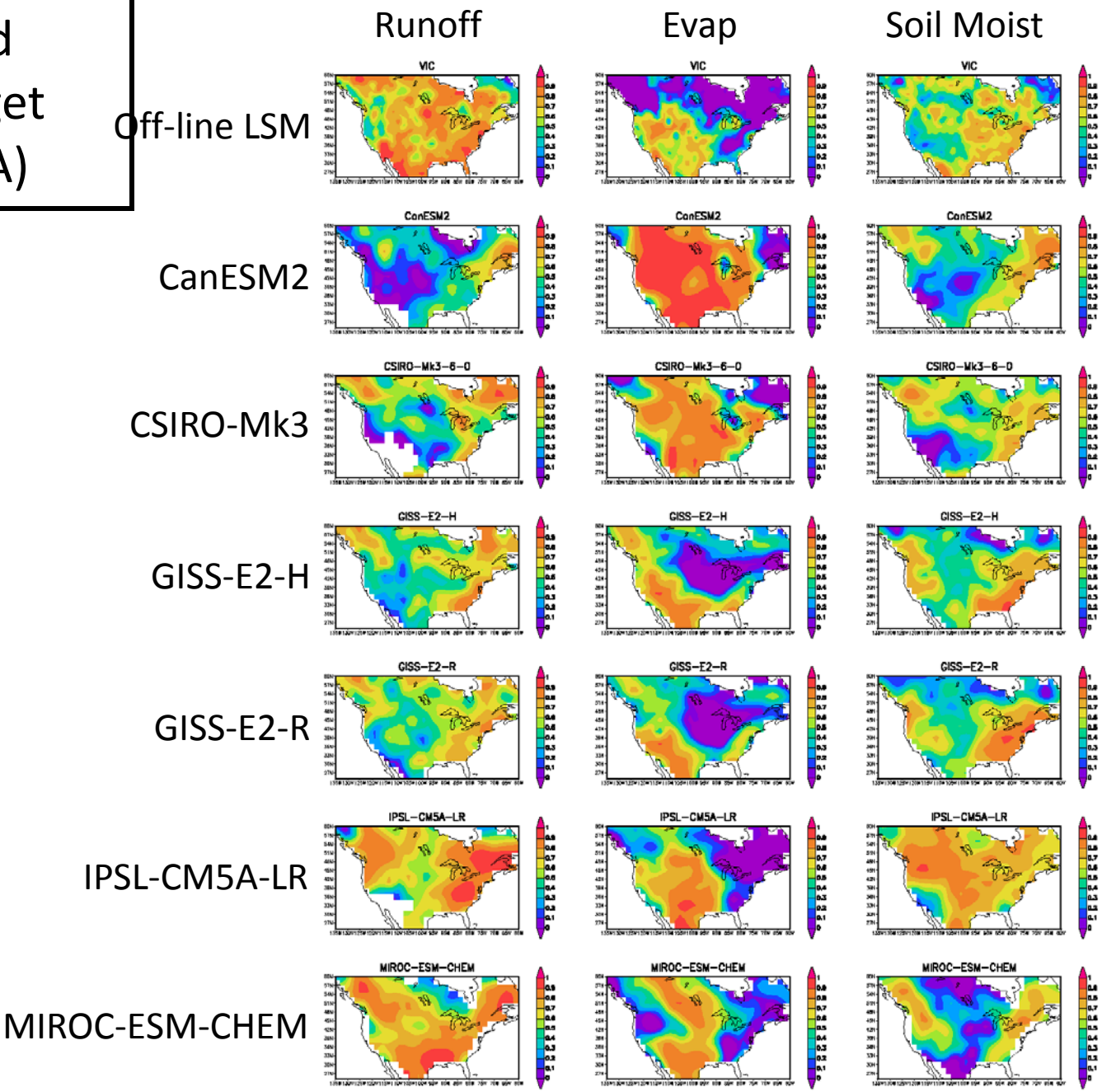
CMIP5 Models



Correlation between Precipitation and other Land Budget Components (DJF)

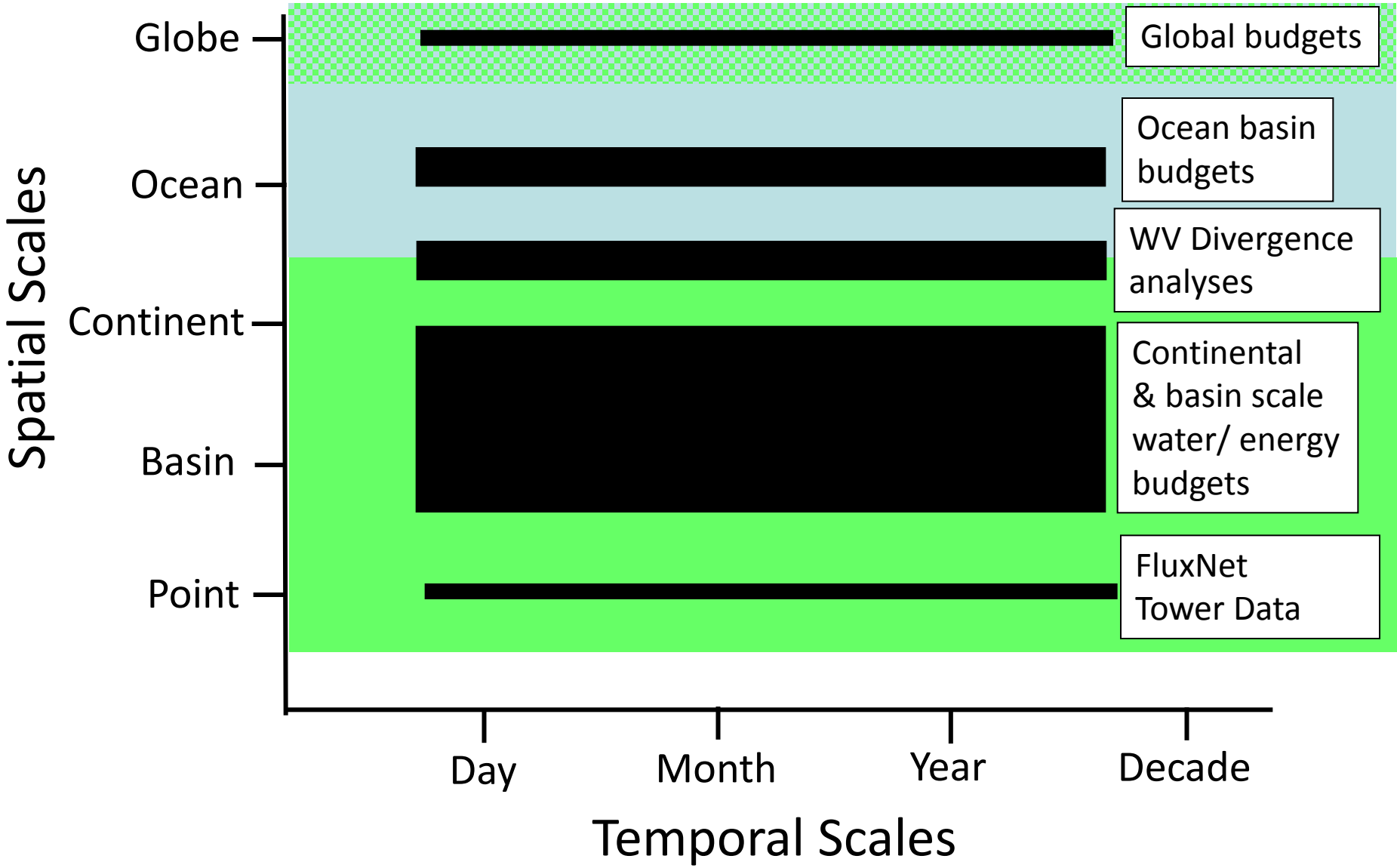


Correlation between Precipitation and other Land Budget Components (JJA)

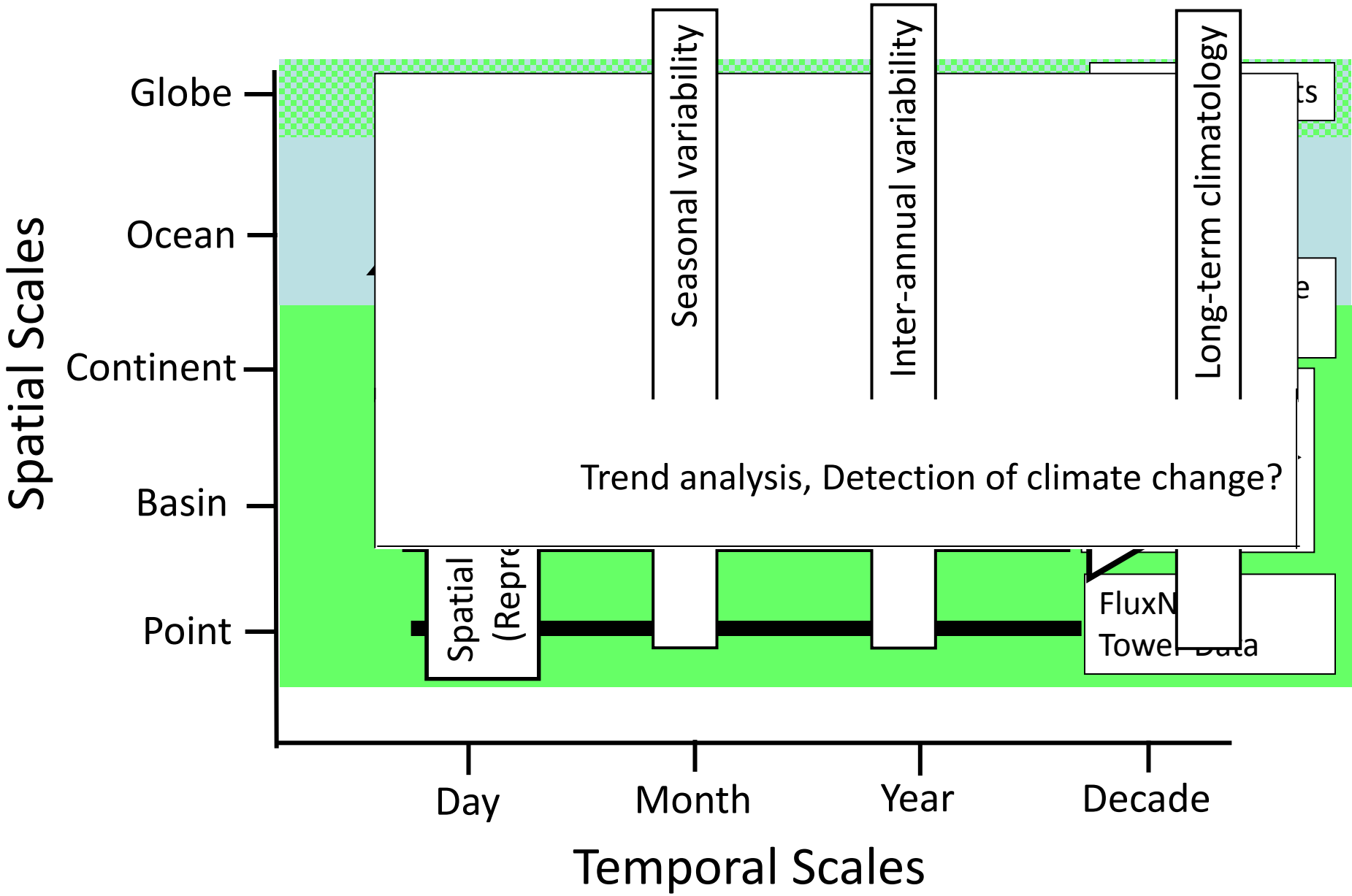


Can a framework be developed for water and energy cycle model evaluation?

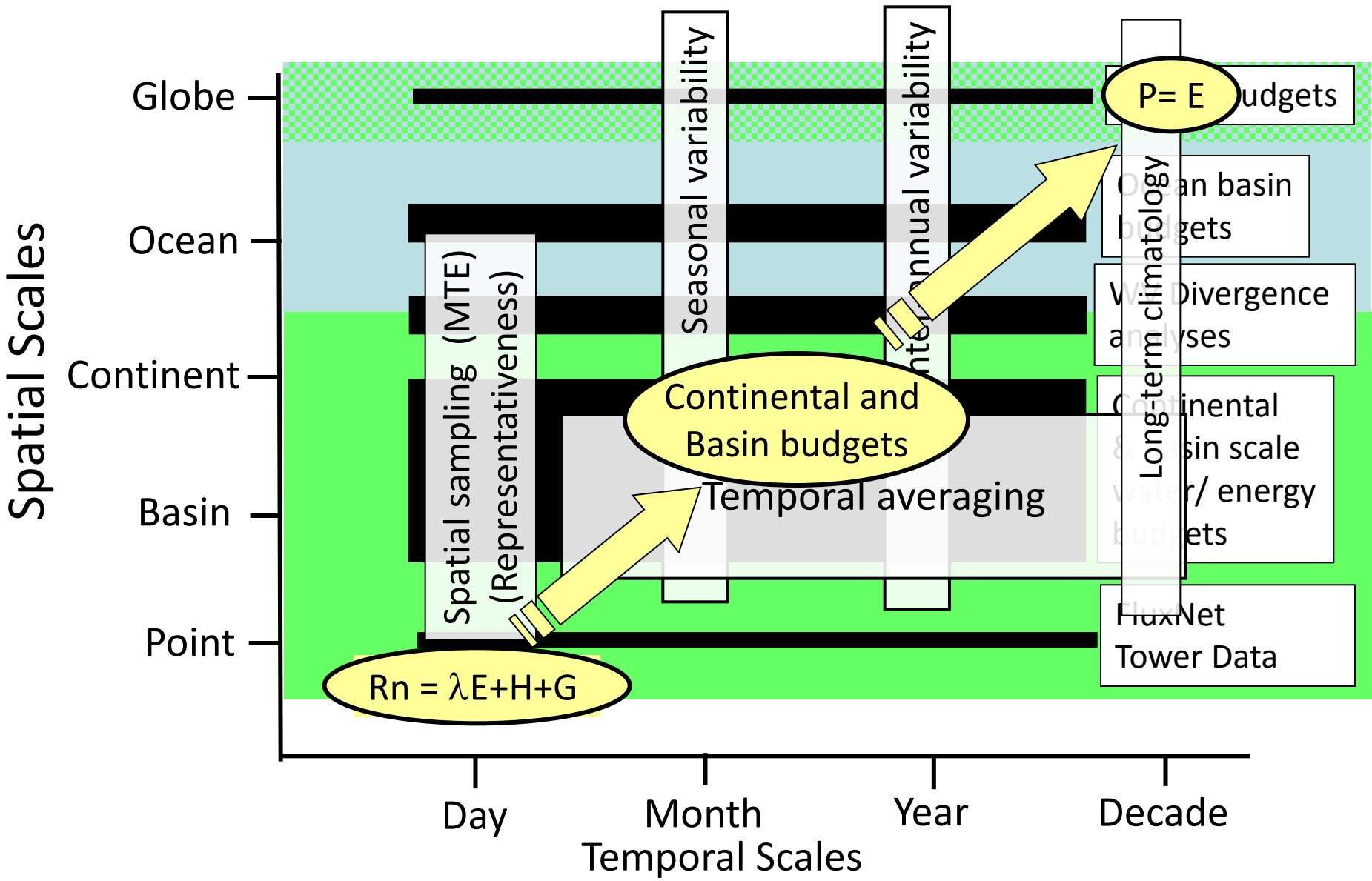
Potential data sets and approaches



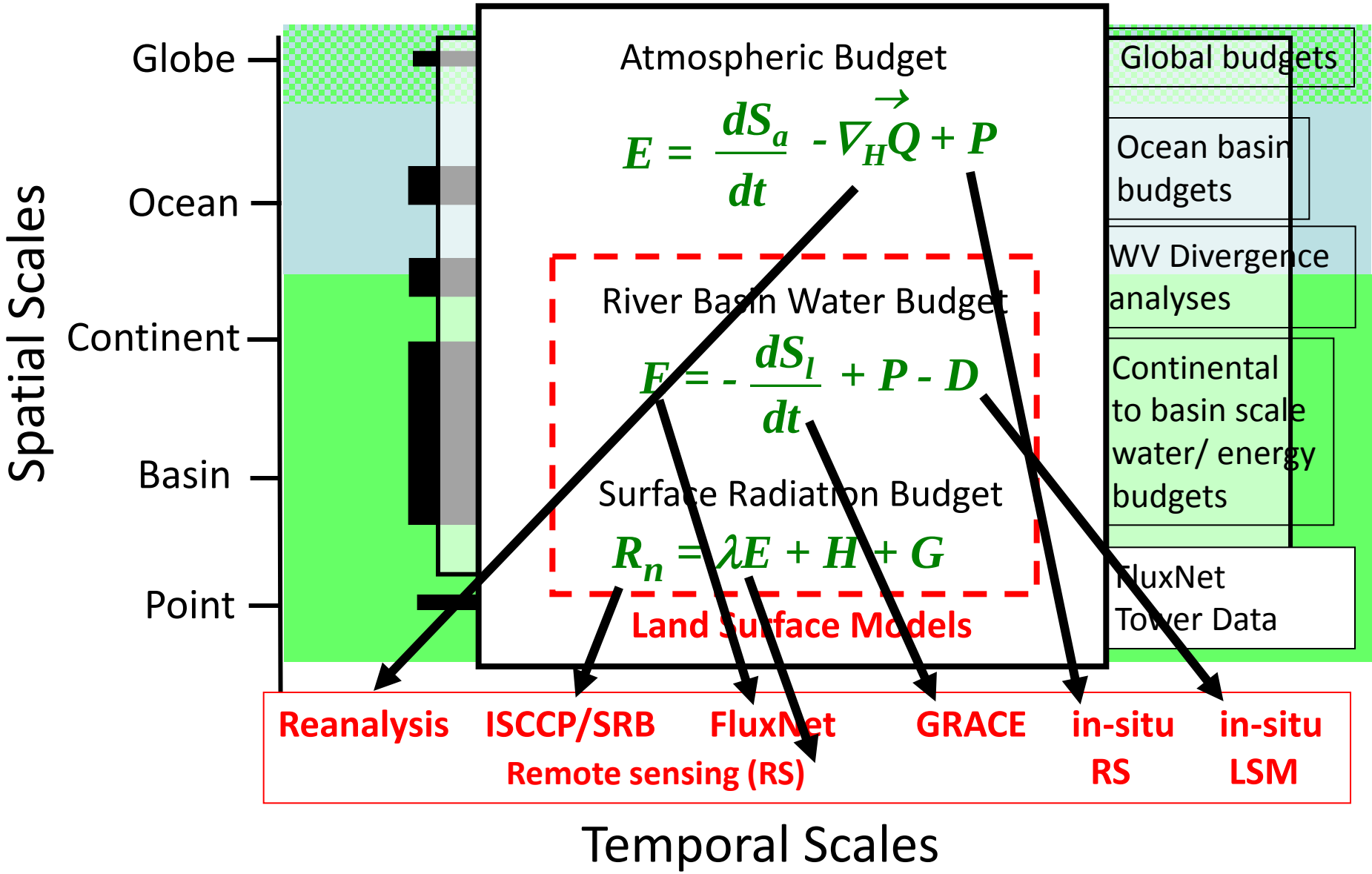
Product validation: Some statistical issues



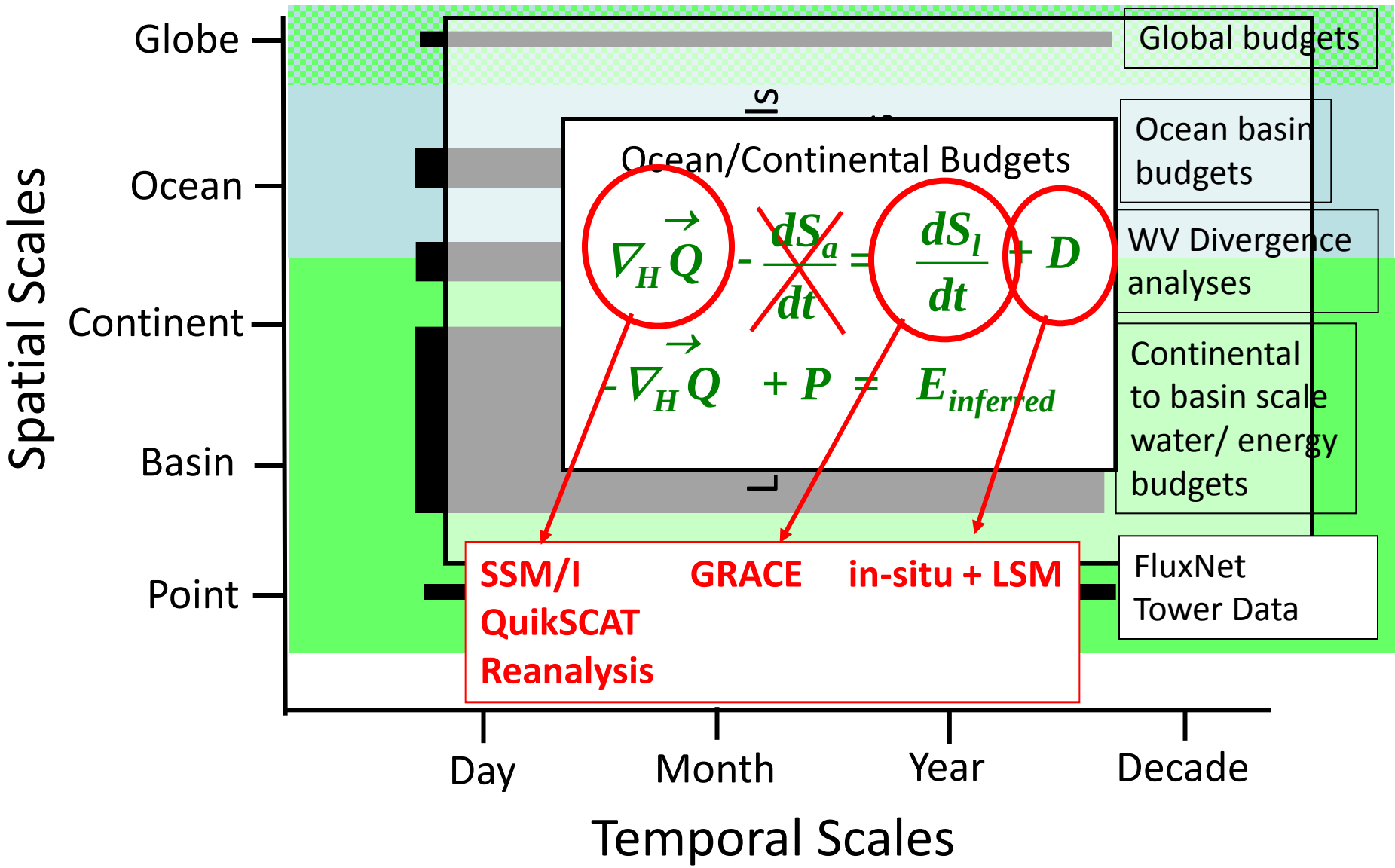
Product validation: Some scaling challenges



Can we use basin water budgets to constrain ET?



Can we use continental water budgets to constrain ET?



Major strategic issues for evaluating climate models

- Need to develop consistent, global time series of water budget variables for the evaluation of global models i.e. Climate Data Records (GCOS/NOAA) or Earth System Data Records (NASA).

Some Evaluation issues:

- How can we best assess the uncertainty among model predictions/projections of the same variable?
- What constraints can be applied to limit the uncertainty in the water budget variables?
- Can we develop a merged water budget, with budget closure? (Yes, see Pan et al, *J Climate,* 25(9): 3191-3206 , May, 2012)

To what extent can we improve process representation to improve predictive skill?

Hyper-Resolution, Global Land Surface Modeling: Are there pathways for addressing this need and will such models improve predictive capabilities?

WATER RESOURCES RESEARCH, VOL. 47, W05301, doi:10.1029/2010WR010090, 2011

Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water

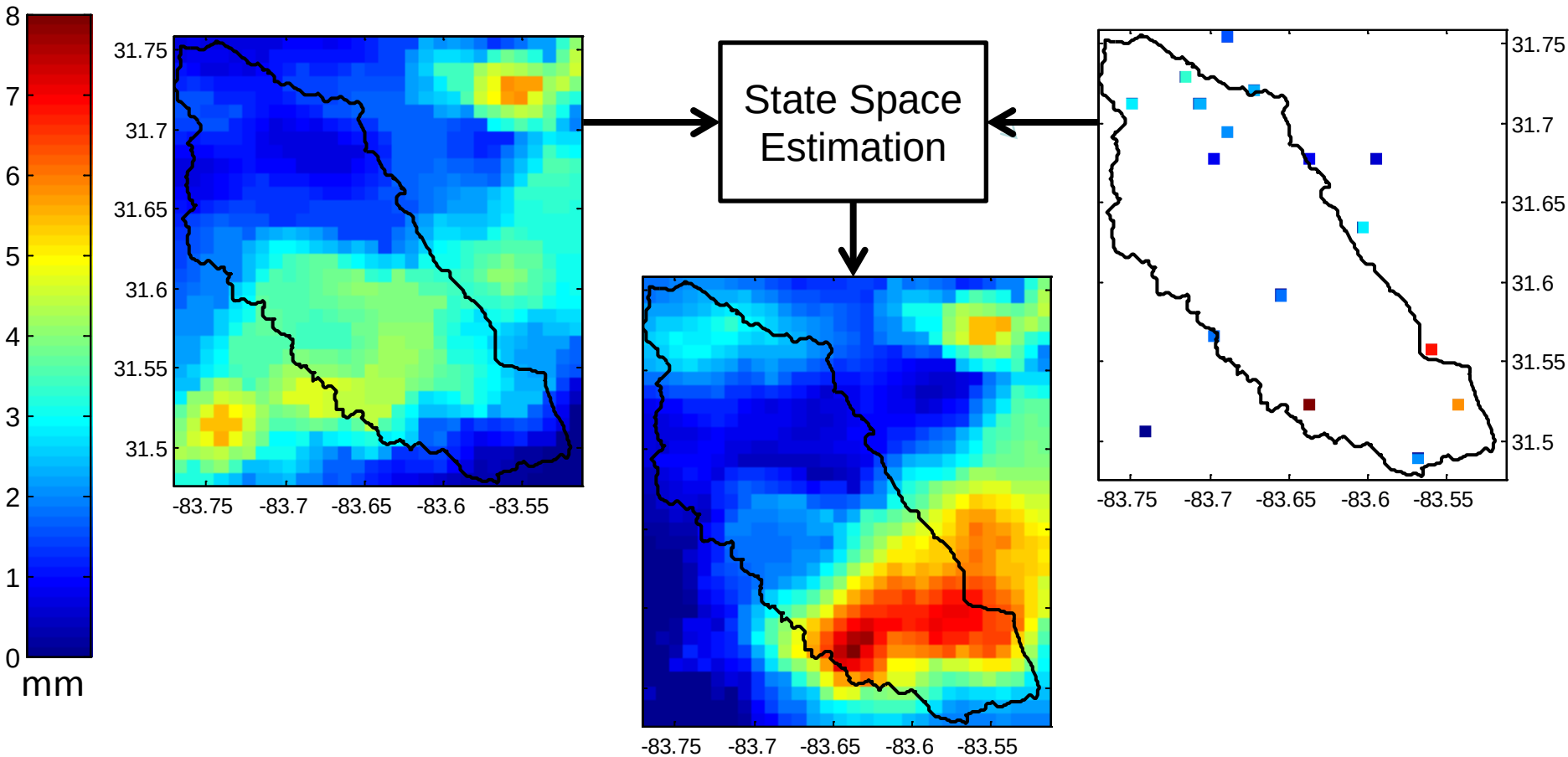
Eric F. Wood,[1] Joshua K. Roundy,[1] Tara J. Troy,[1] L. P. H. van Beek,[2] Marc F. P. Bierkens,[2,3] Eleanor Blyth,[4] Ad de Roo,[5] Petra Döll,[6] Mike Ek,[7] James Famiglietti,[8] David Gochis,[9] Nick van de Giesen,[10] Paul Houser,[11] Peter R. Jaffé,[1] Stefan Kollet,[12] Bernhard Lehner,[13] Dennis P. Lettenmaier,[14] Christa Peters-Lidard,[15] Murugesu Sivapalan,[16] Justin Sheffield,[1] Andrew Wade,[17] and Paul Whitehead[18]

Received 6 October 2010; revised 21 January 2011; accepted 24 February 2011; published 6 May 2011.

[1] Monitoring Earth's terrestrial water conditions is critically important to many hydrological applications such as global food production; assessing water resources sustainability; and flood, drought, and climate change prediction. These needs have motivated the development of pilot monitoring and prediction systems for terrestrial hydrologic and vegetative states, but to date only at the rather coarse spatial resolutions (~10–100 km) over continental to global domains. Adequately addressing critical water cycle science questions and applications requires systems that are implemented globally at much higher resolutions, on the order of 1 km, resolutions referred to as hyperresolution in the context of global land surface models. This opinion paper sets forth the needs and benefits for a system that would monitor and predict the Earth's terrestrial water, energy

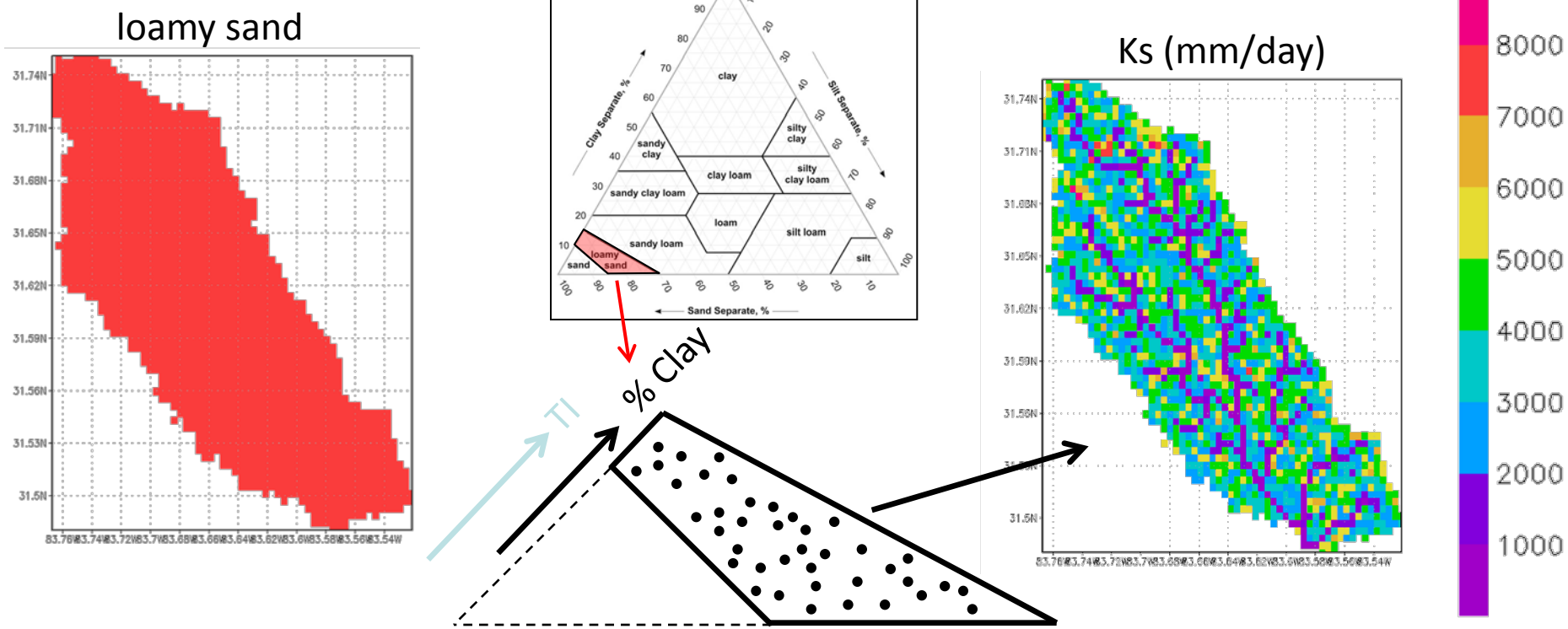
High Resolution Precipitation is needed

- Combine the spatial variability of NEXRAD radar data with the local accuracy of rain gauges.
  - Use the state – space linear estimation to correct the radar data with rain gauges (*Chirlin G. R. and Wood E. F., 1982)*.



High Resolution Soil Properties are needed

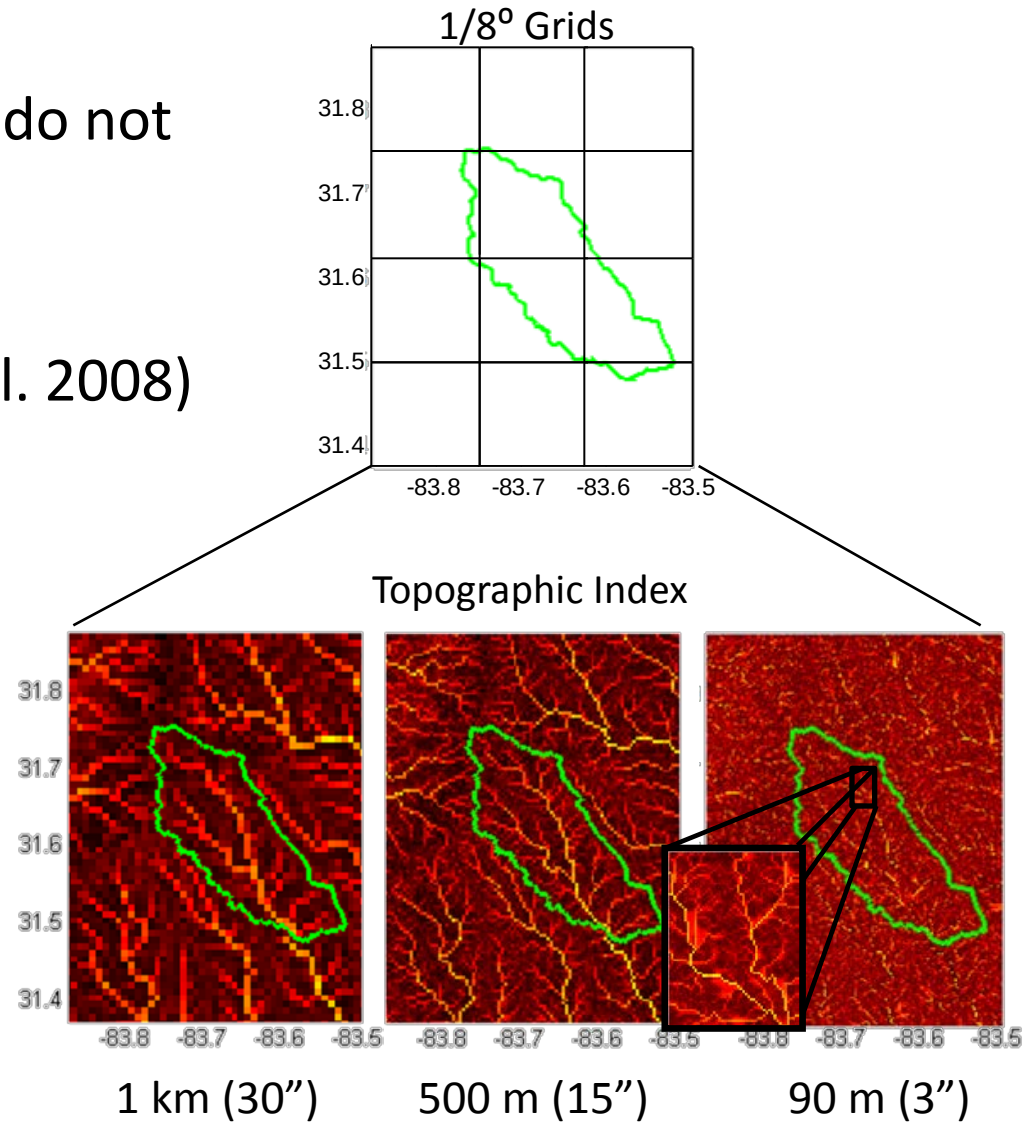
- No data exists at high resolution
  - Average properties of different soil types
- Variability estimation
  - Define a linear relationship between Topographic index and % clay
  - Randomly sample % silt and sand
  - Use pedotransfer functions, to calculate hydraulic properties per grid cell.



High Resolution Topography

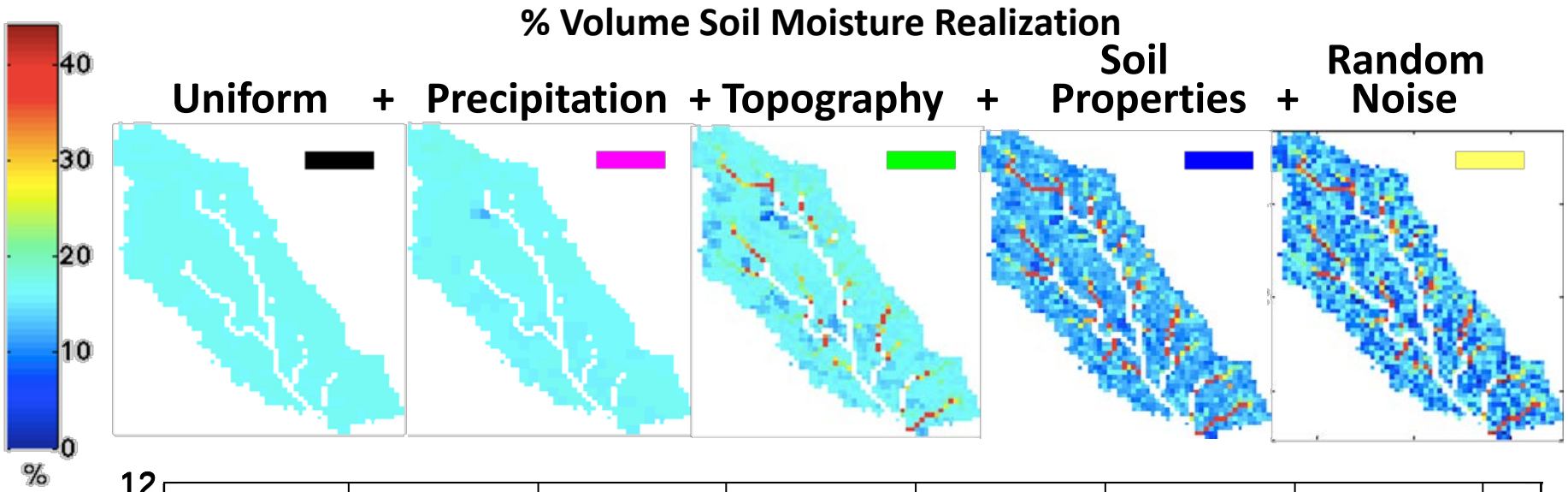
- Current resolutions models do not account for topography
- Data is available Globally
  - Hydrosheds (Lehner et al. 2008)

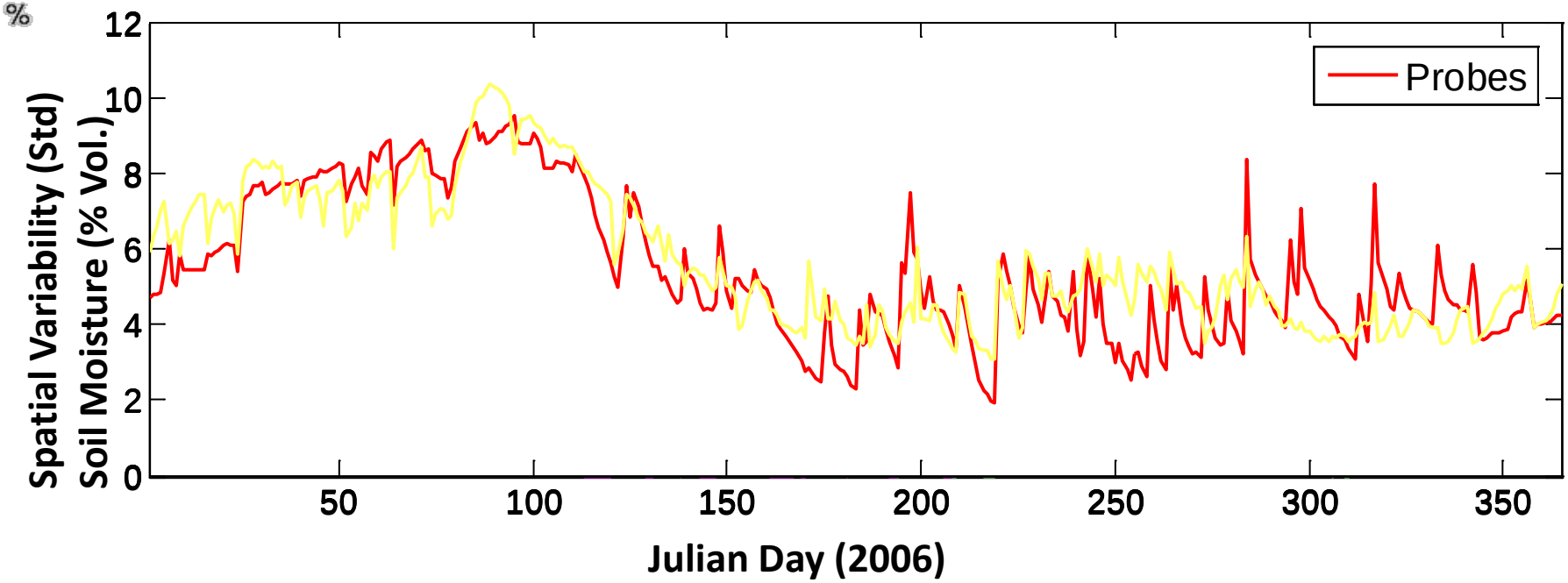
- TOPLATS
  - Only model to account for topography
  - Use it to see what variables account for the most variability



Impact on including spatial variability in predicting soil moisture

(from Assessment of large scale and regional scale models for application to a high resolution global land surface model (Roundy, Chaney and Wood, AGU Fall Meeting, 2011)





Summary

Needs and challenges:

The community must continue working with the space and data agencies (NASA, ESA, EUMETSAT, JAXA, NOAA, etc) to development of “validation” quality data records. They’ve done a pretty good job.

International programs and data centers **must** work harder to provide in-situ sets that are critical to assessment and validation (i.e. for “benchmarking”) or for merging with other data. They’ve done a poor job.

Alternative representations and algorithms for hydrologic process must get evaluated – more validation (“benchmarking”) and analysis activities are needed by the community – NEWS is making progress in this area but more $$ are needed.