Improving Streamflow Prediction in Snow-fed River Basins via Satellite Snow Assimilation

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CAHMDA-DAFOH Joint Workshop

Austin, Texas

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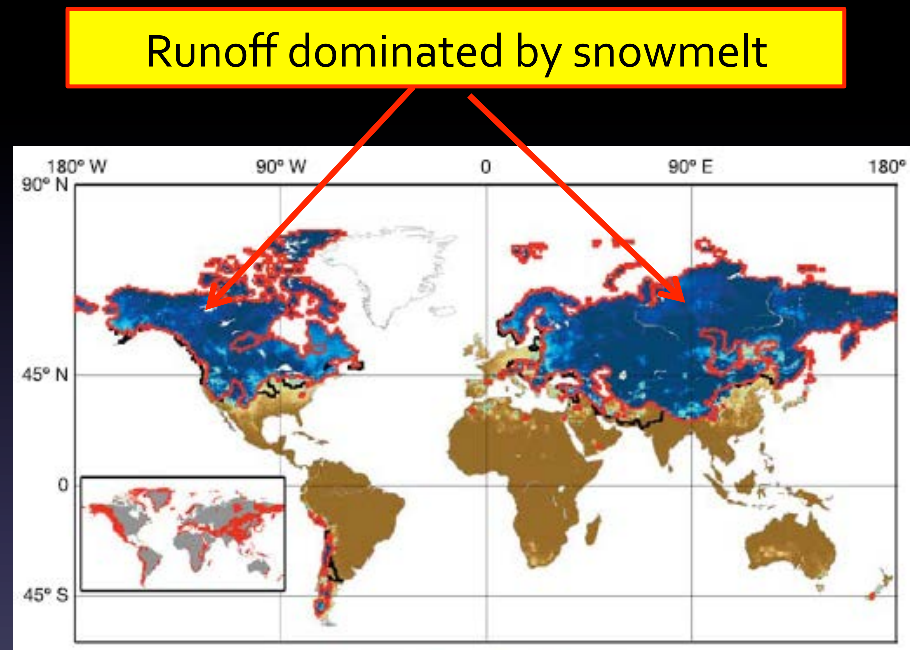
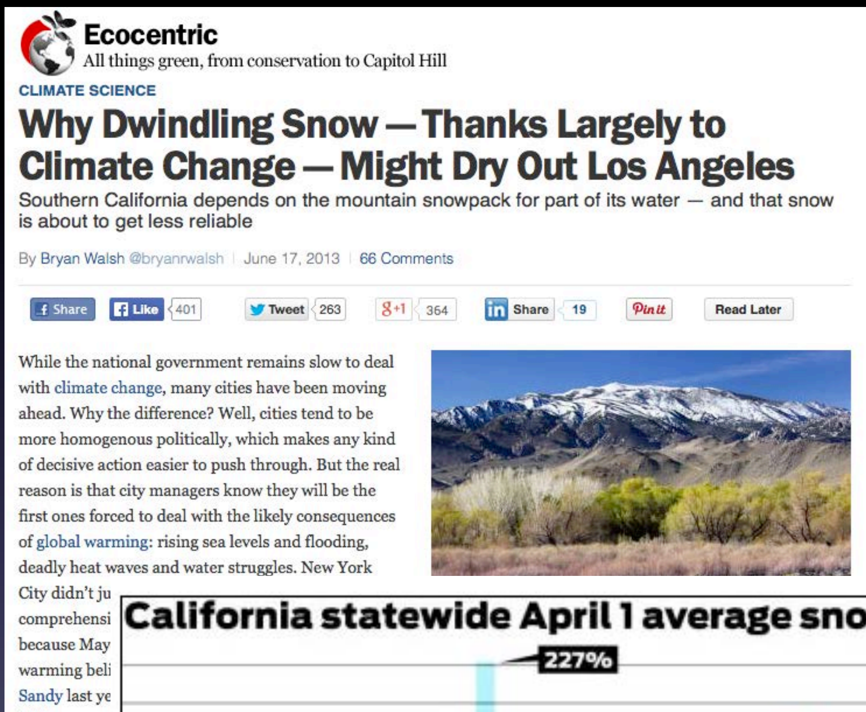
Importance of Snow

- 1/6 of world's population depends on snowmelt runoff for water supply
- Snow is a critical element of the hydrologic cycle
- Snow is a sensitive indicator of climate change
- Snow is an important initial condition for seasonal flow forecasting



Barnett et al., Nature, 2005

Snow and Drought



Ecocentric
All things green, from conservation to Capitol Hill

CLIMATE SCIENCE

Why Dwindling Snow — Thanks Largely to Climate Change — Might Dry Out Los Angeles

Southern California depends on the mountain snowpack for part of its water — and that snow is about to get less reliable

By Bryan Walsh @bryanrwalsh | June 17, 2013 | 66 Comments

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While the national government remains slow to deal with climate change, many cities have been moving ahead. Why the difference? Well, cities tend to be more homogenous politically, which makes any kind of decisive action easier to push through. But the real reason is that city managers know they will be the first ones forced to deal with the likely consequences of global warming: rising sea levels and flooding, deadly heat waves and water struggles. New York City didn't ju
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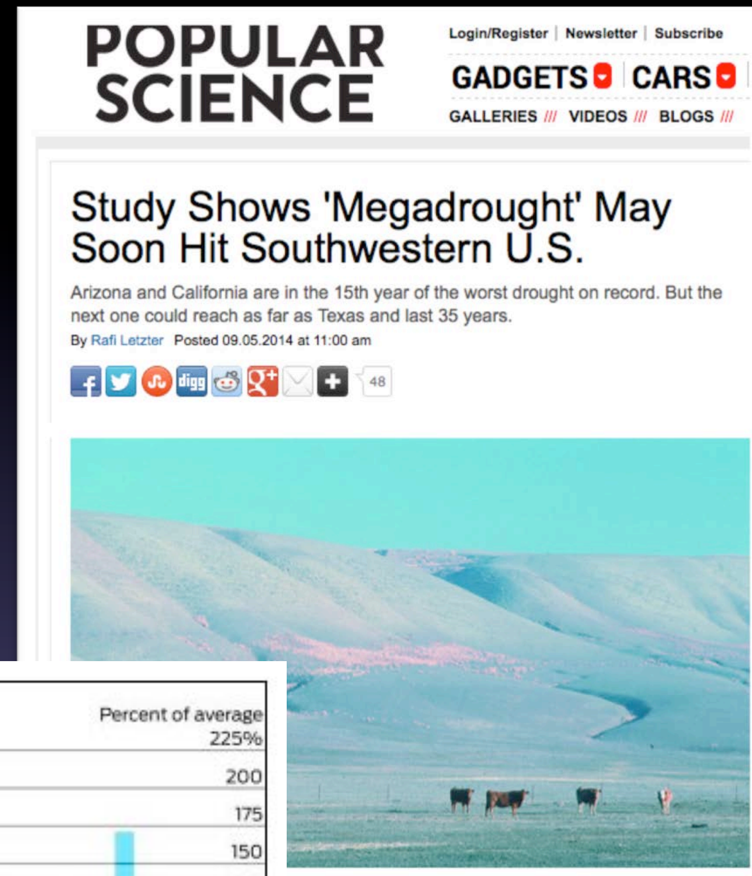

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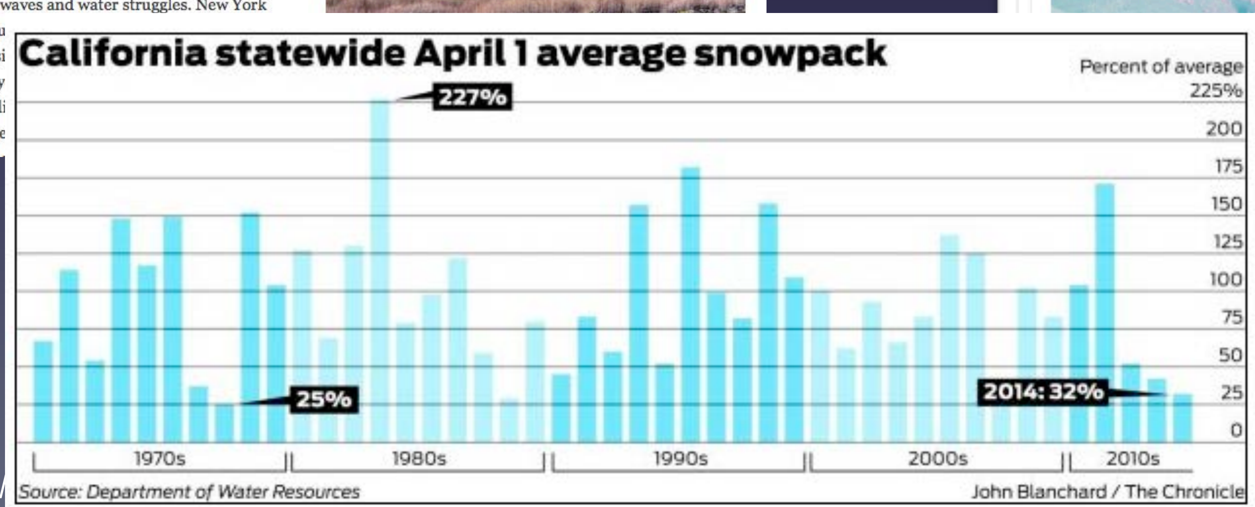
Study Shows 'Megadrought' May Soon Hit Southwestern U.S.

Arizona and California are in the 15th year of the worst drought on record. But the next one could reach as far as Texas and last 35 years.

By Rafi Letzter Posted 09.05.2014 at 11:00 am

48



Source: sfgate.com

Colorado River Basin Drought

Since 2004, the snowmelt-driven Colorado River Basin (which feeds California and six other states) lost nearly 53 million acre feet of freshwater. That's enough to submerge New York City beneath 344 feet of water.

(source: bloomberg.com)

Lake Mead

Photo: USBR

Snow and Flooding

In snow-dominated basins, heavy rainfall accompanied by rapid snowmelt (rain on snow – ROS) can cause severe/dangerous flooding in winter or spring!

Feb 1996 ROS Flooding in Oregon

Willamette River flooding Oregon City, Oregon, photos courtesy Lew Scholl

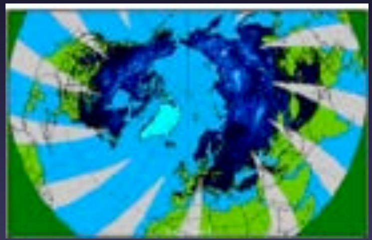
Existing snow information

✧Remote sensing products

- MODIS, Landsat, VIIRS, SMMR, SSMI, AMSR-E, AMSR-2, AVHRR, GRACE, GPS, Airborne snow observatory

✧Operational analysis products

- IMS, CMC, SNODAS, GlobSnow

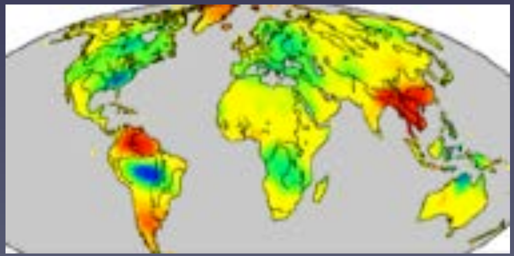


✧Model-based reanalyses

- ERA interim, MERRA-Land, GLDAS, NLDAS

✧Reconstruction products

- Liston and Hiemstra, 2011; Girotto et al., 2014



✧In-situ data

- SNOTEL, COOPS, GHCN, snow course, field campaigns (CLPX, C3VP, GCPEX)

Snowmelt-driven flow forecasting: Challenges & Opportunities

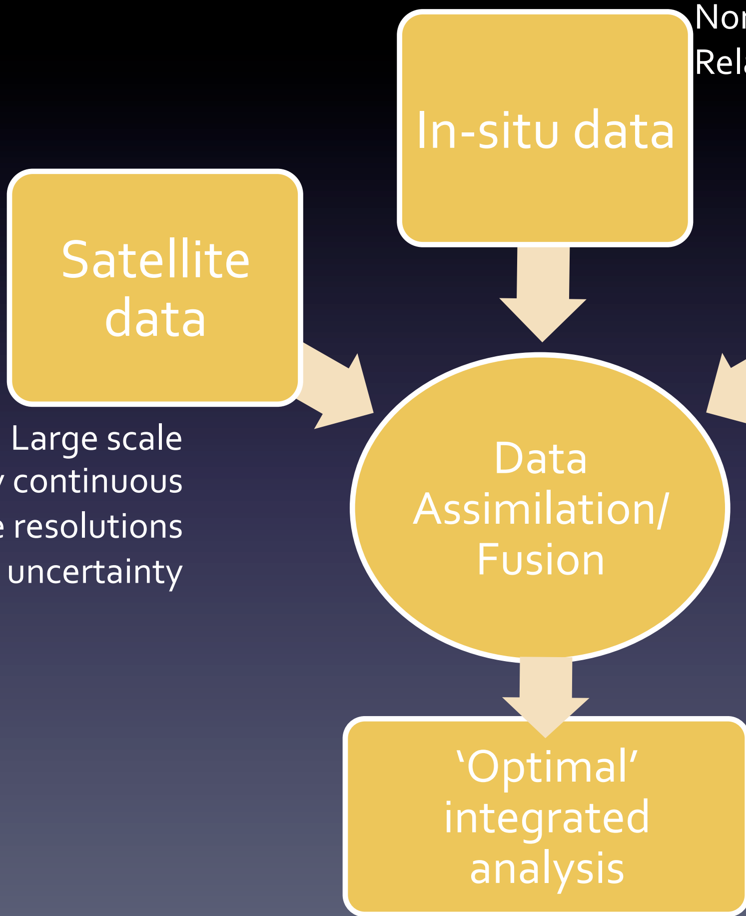
Challenges

- Large spatiotemporal variability, sparse in-situ snow observation network
- Remote sensing measurements subject to large bias and data gaps
- Large uncertainty snow models and reference snow datasets
- Improvement in snow does not always translate into improvement in flow forecasting

Opportunities

- Scale satellite products to model climatology and only assimilate anomalies
- Conduct radiance-based assimilation
- Adjust satellite products against in-situ observations to reduce bias prior to assimilation
- Assimilate integrated multi-sensor products (e.g., PMW + VIS)

Using satellite data for hydrologic prediction via data assimilation

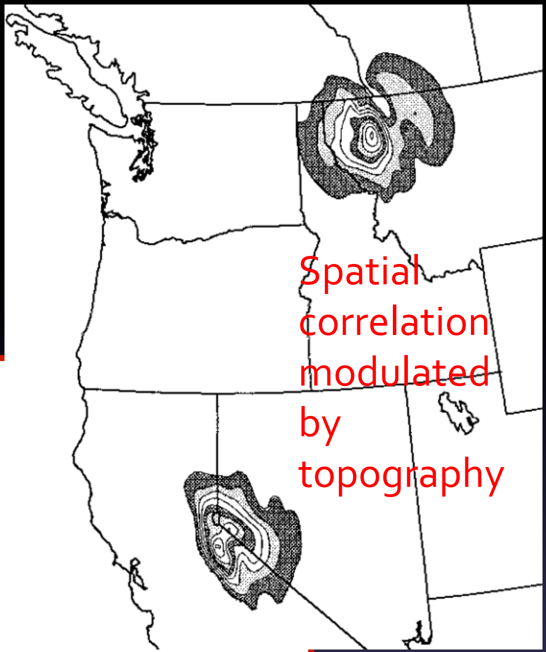


Advancing data assimilation in operational hydrologic forecasting: progresses, challenges, and emerging opportunities HESS 2012

Y. Liu[1,2], A. H. Weerts[3], M. Clark[4], H.-J. Hendricks Franssen[5], S. Kumar[6,2], H. Moradkhani[7], D.-J. Seo[8], D. Schwanenberg[3], P. Smith[9], A. I. J. M. van Dijk[10], N. van Velzen[11], M. He[12,13], H. Lee[12,14], S. J. Noh[15], O. Rakovec[16], and P. Restrepo[12]

Bias Correction Algorithm – Optimal Interpolation

$$x_g^a = x_g^b + \sum_{i=1}^{N} w_i (o_i - x_i^b)$$



Weight Calculation (Brasnett 1999)

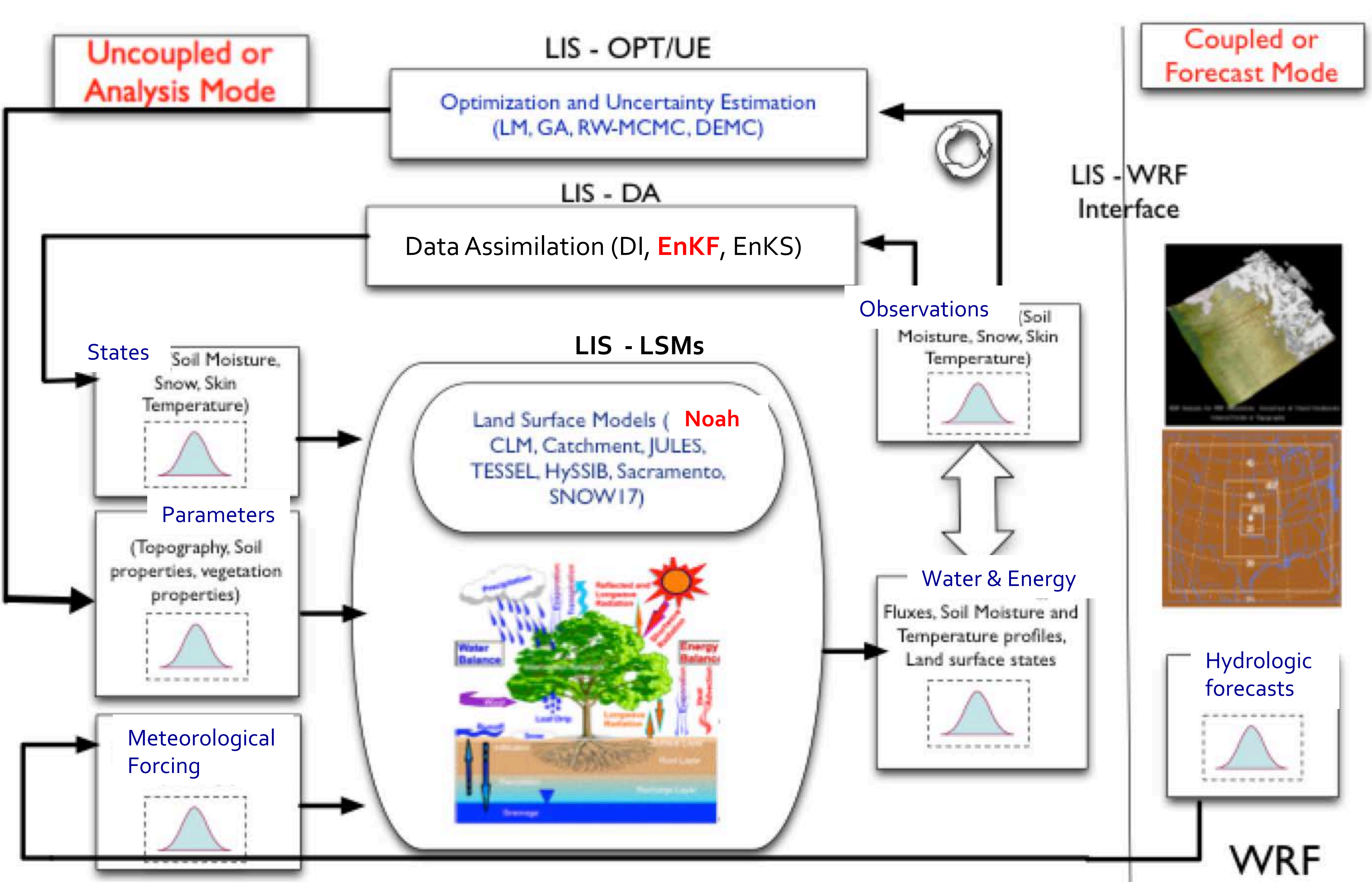
$$W = (P + O)^{-1} q$$

P: correlation of background error at obs. locations
q: correlation of background error between grid cell & observation
O: obs. error variance normalized by background error variance

Calculation of P and q: $\mu_{ij} = \alpha(r_{ij})\beta(\Delta z_{ij})$

$$\alpha(r_{ij}) = (1 + cr_{ij}) \exp(-cr_{ij}) \qquad \beta(\Delta z_{ij}) = \exp\left[-\left(\frac{\Delta z_{ij}}{h}\right)^2\right]$$

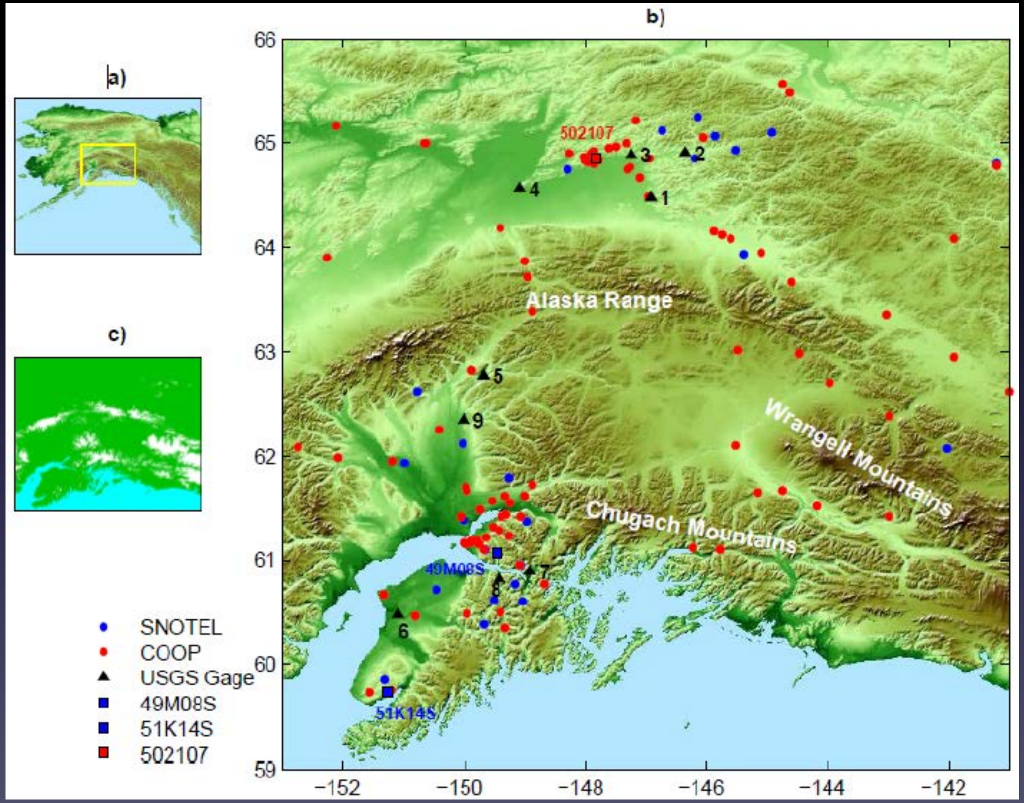
NASA Land Information System (LIS)



Case Study 1 - Alaska

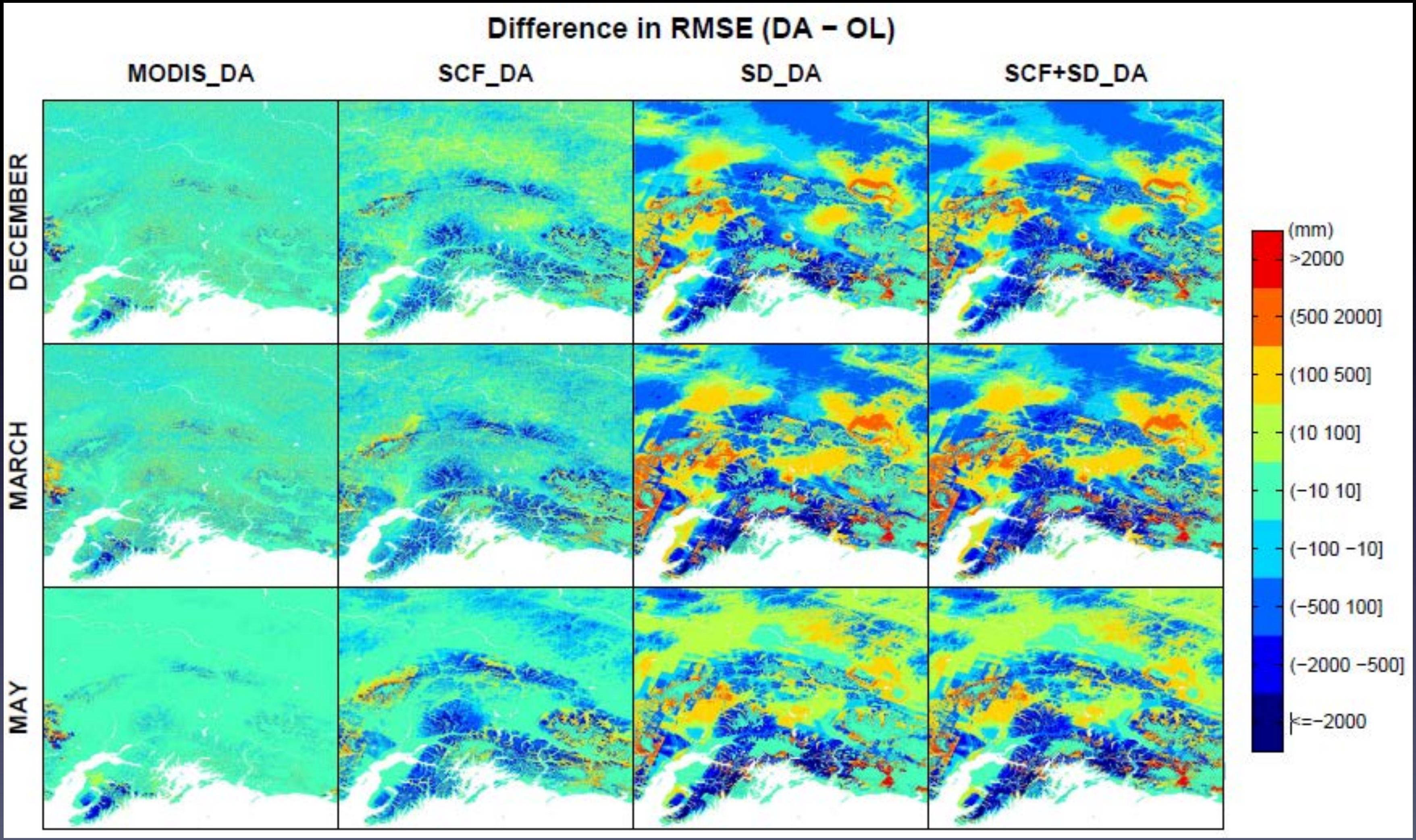
- Elevation: 0-6000 m
- Complex mountainous areas, discontinuous permafrost, seasonally frozen soils, extensive glaciation, distinctive climate zones
- Huge spatial variability in snow distribution, diverse snow classes
- 1-km spatial resolution (700*1200)
- Analysis period: 2002-2011
- Assimilate MODIS snow cover and AMSR-E snow depth
- 27 SNOTELs, 90 COOPs

7^o X 12^o

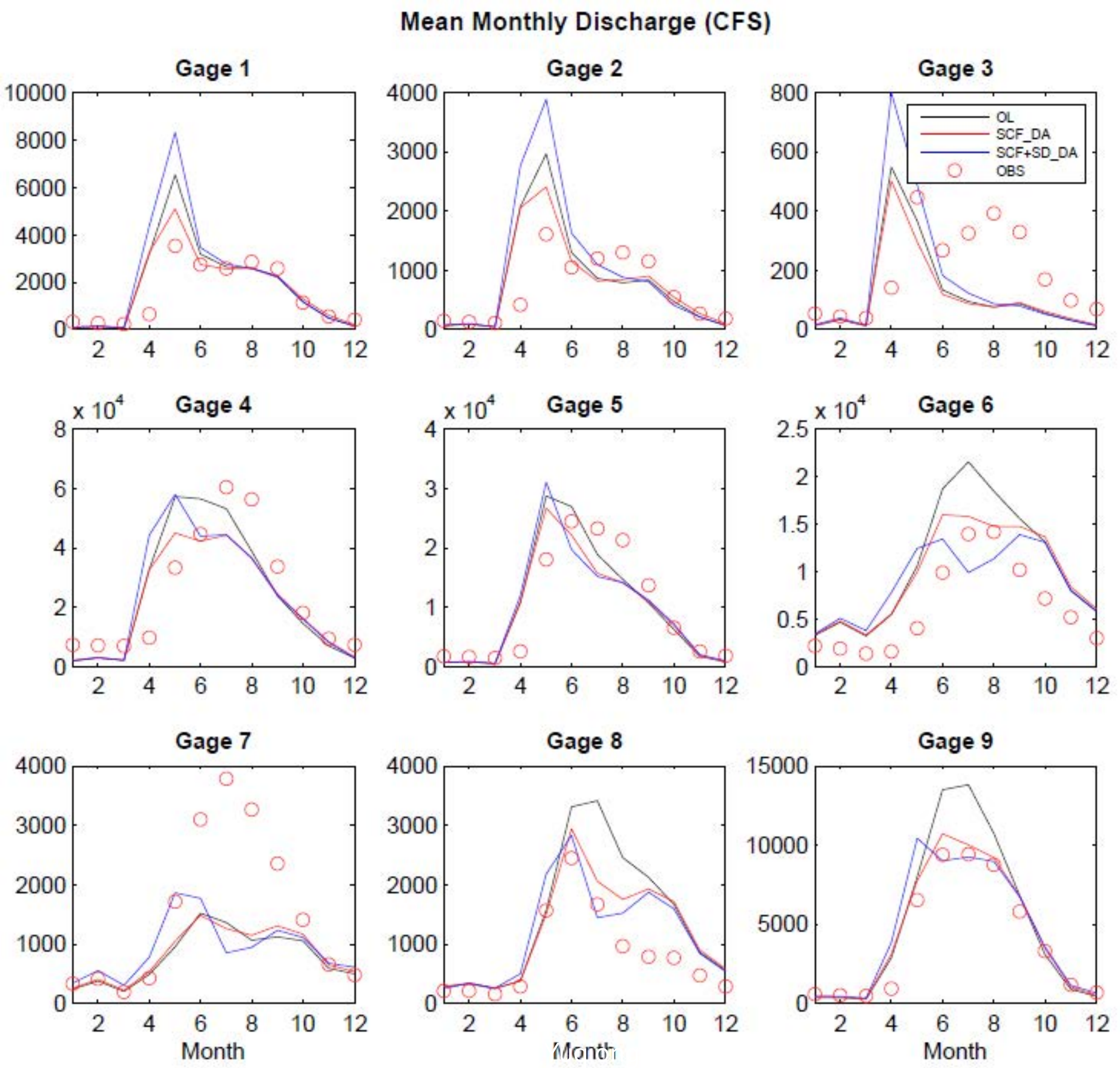


Liu et al., Advances in Water Resources, 2013

Evaluation Against CMC Daily SD - **RMSE**



Evaluation Against USGS Streamflow



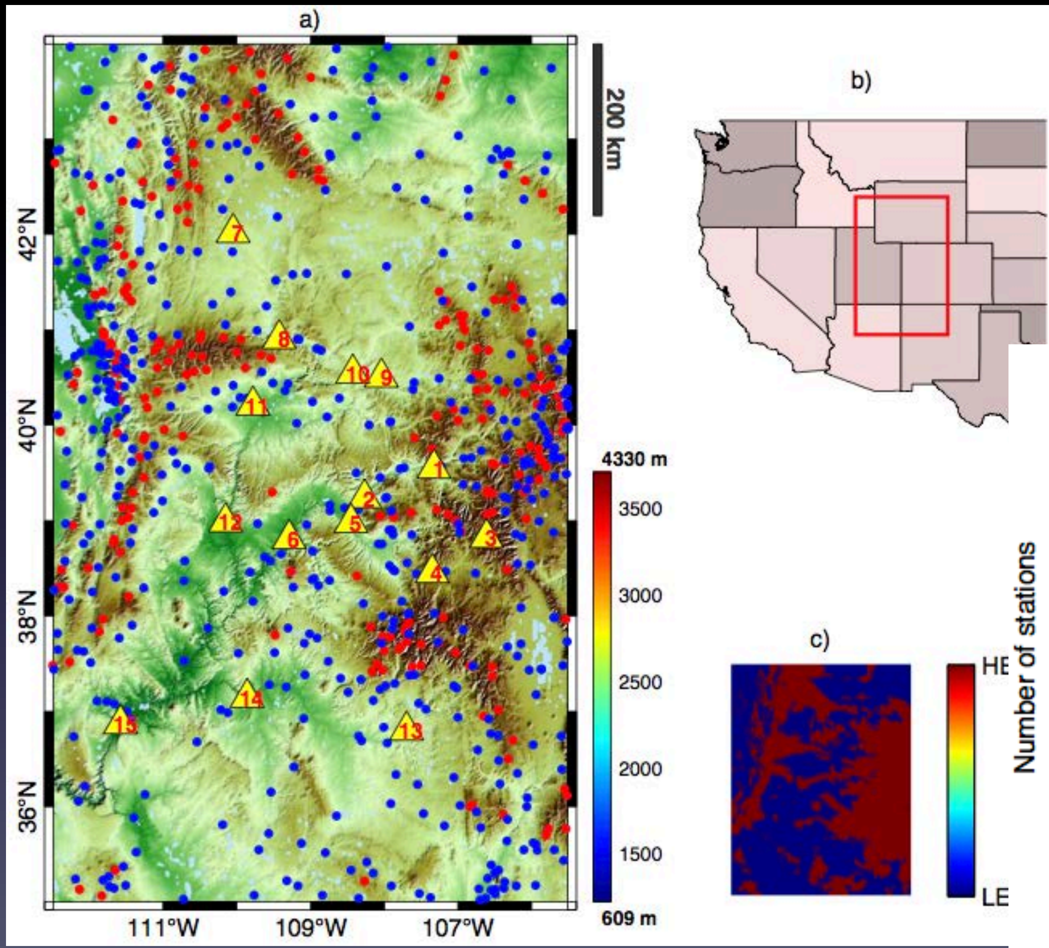
Basin area ranges from 140 to 25600 square miles

Improving Bias Correction of PMW Snow

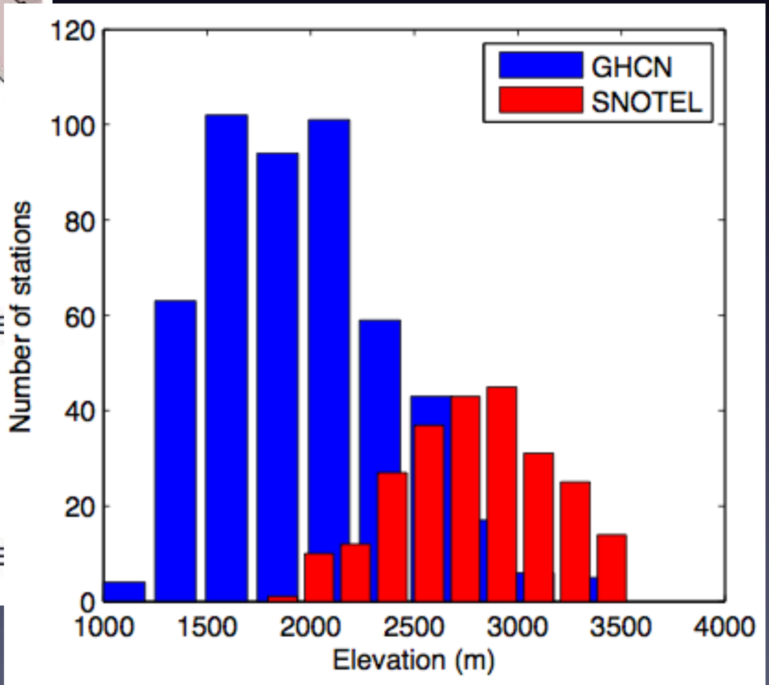
- Incorporating terrain aspect information
- Tuning algorithm parameters
- Using station data strategically
- Integrating MODIS snow cover for additional quality control
- Enabling spatial variability in PMW errors based on land cover
- Examining roles of spatial resolution
- Using additional quality checks and flags

Case Study 2 – Upper Colorado River Basin

DEM



Elevation distribution of stations

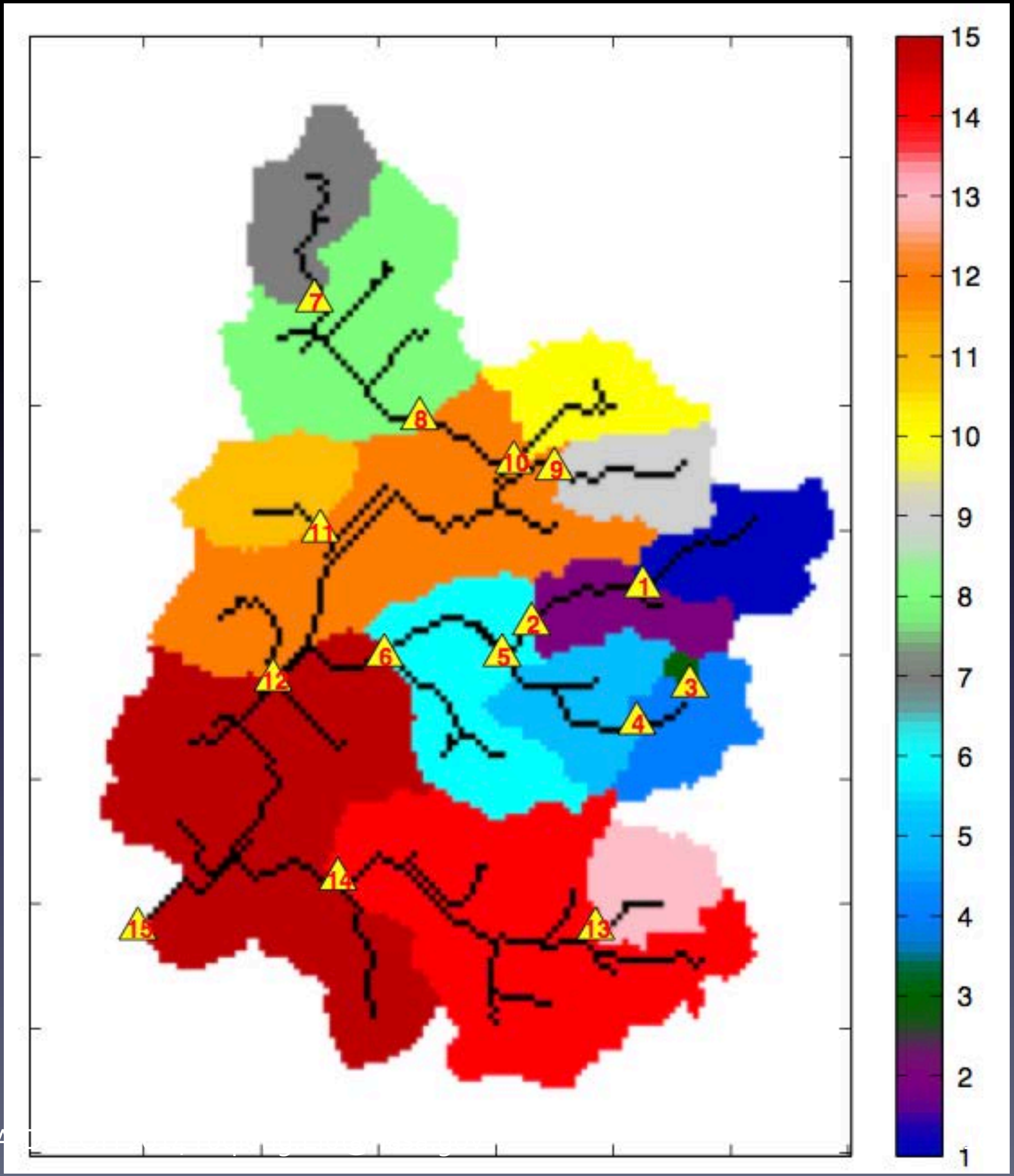


7° X 9°

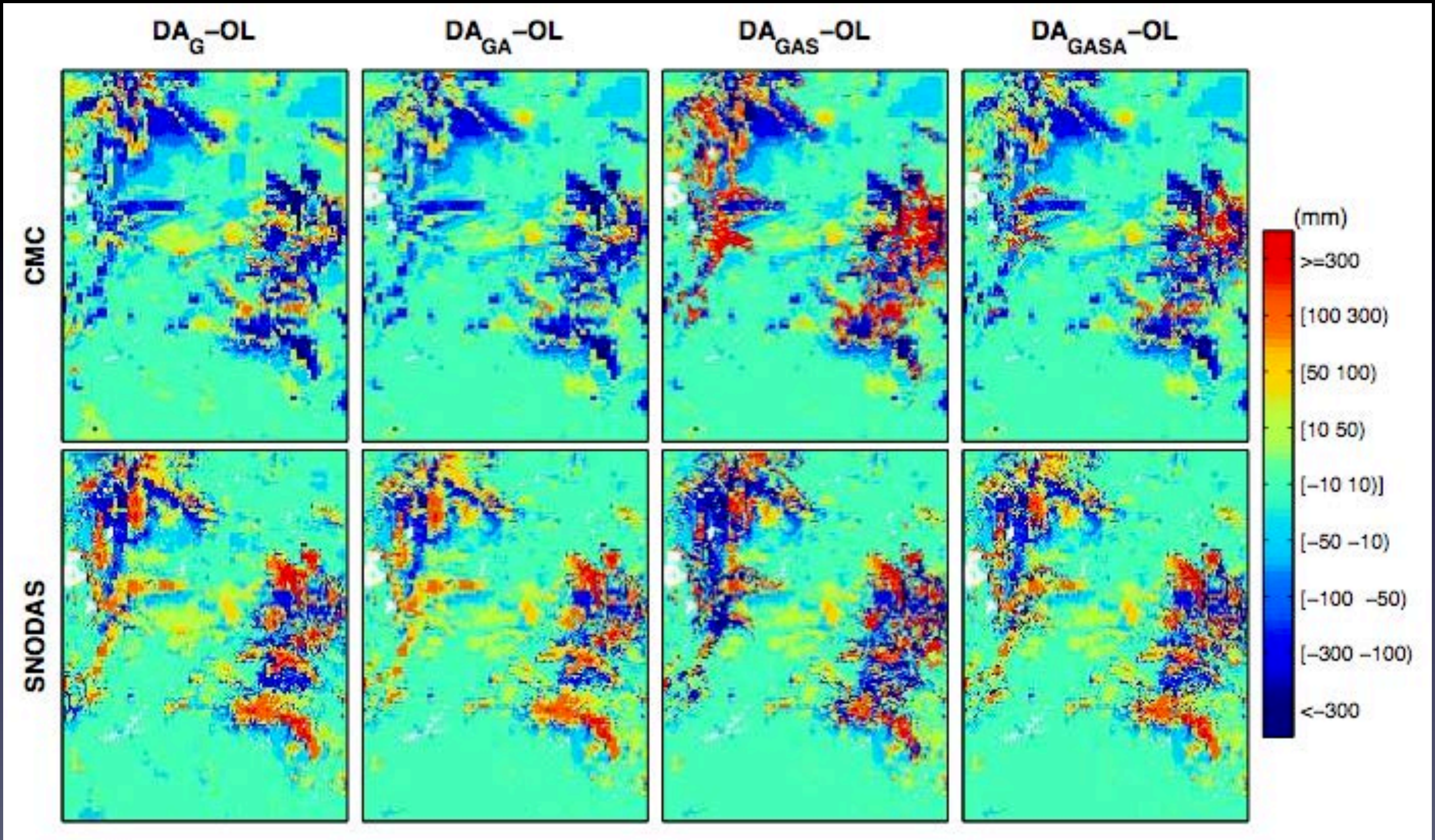
245 SNOTELs
494 GHCNs

Experimental Setup

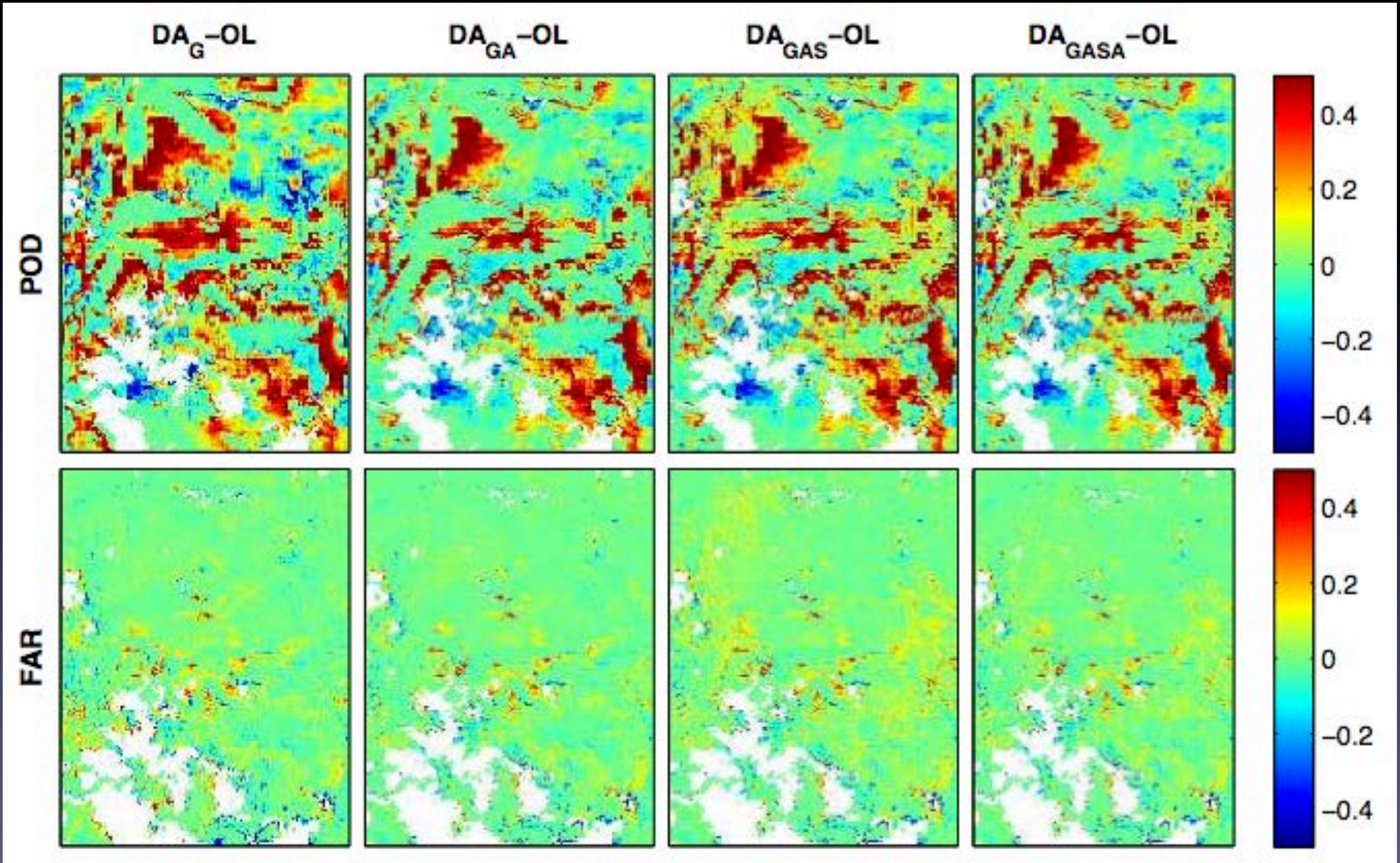
- Multiple DA runs assimilating different bias-corrected PMW snow depth datasets
- 5-km, 2002-2011
- 15 large sub-basins in the Upper Colorado Basin, ranging from 254 to 111800 square miles
- Monthly natural streamflow data from BOR



March Snow Depth RMSE (DA – OL)

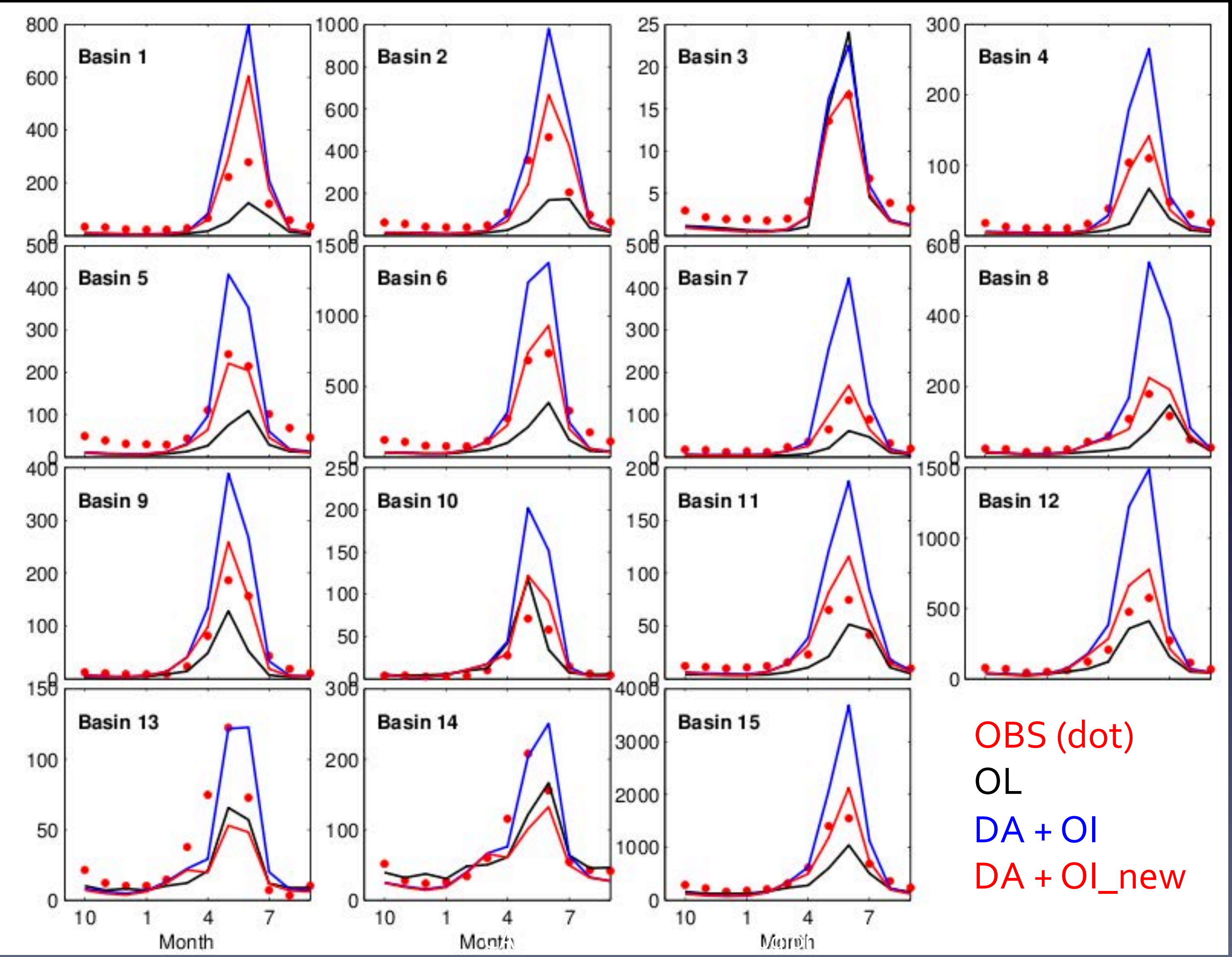


POD & FAR Against MODIS (DA – OL)



Evaluation Against Monthly Natural Flows (1)

Mean monthly flow (cms)



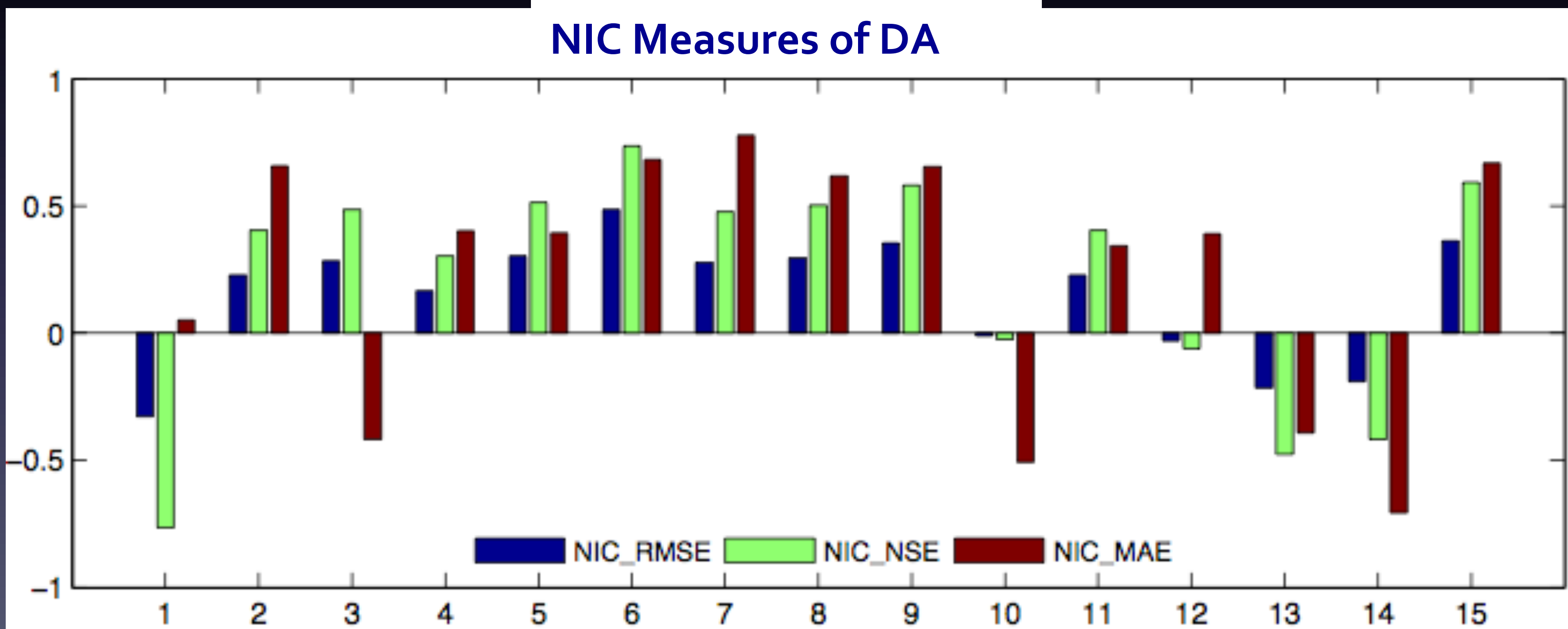
Evaluation Against Monthly Natural Flows (2)

Normalized Information Contribution (NIC) Measures

$$NIC_{RMSE} = (RMSE_{OL} - RMSE_{DA}) / RMSE_{OL}$$

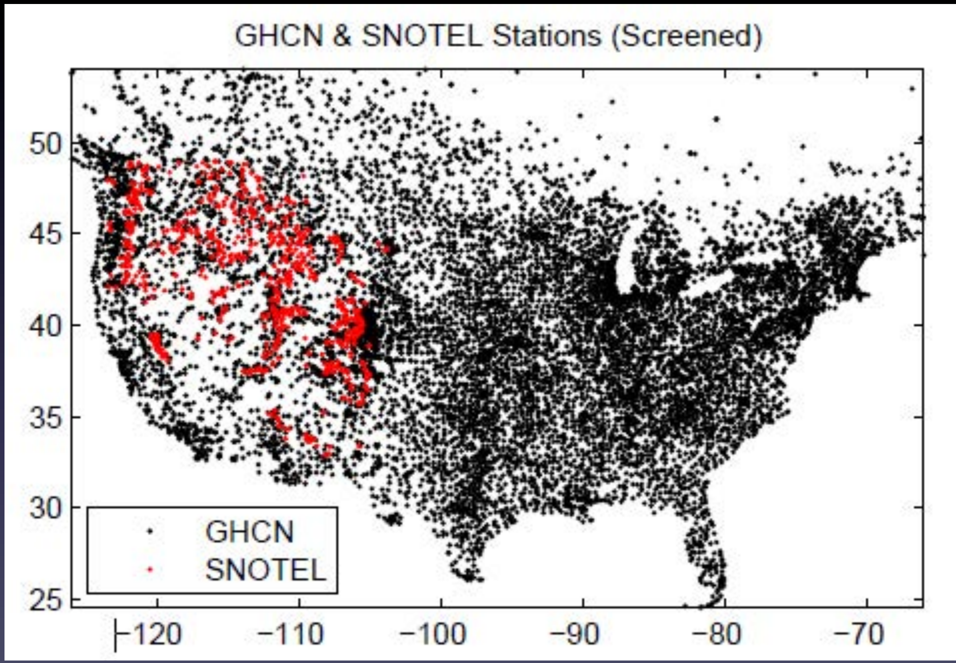
$$NIC_{MAE} = (MAE_{OL} - MAE_{DA}) / MAE_{OL}$$

$$NIC_{NSE} = (NSE_{DA} - NSE_{OL}) / (1 - NSE_{OL})$$



Case Study 3 - CONUS

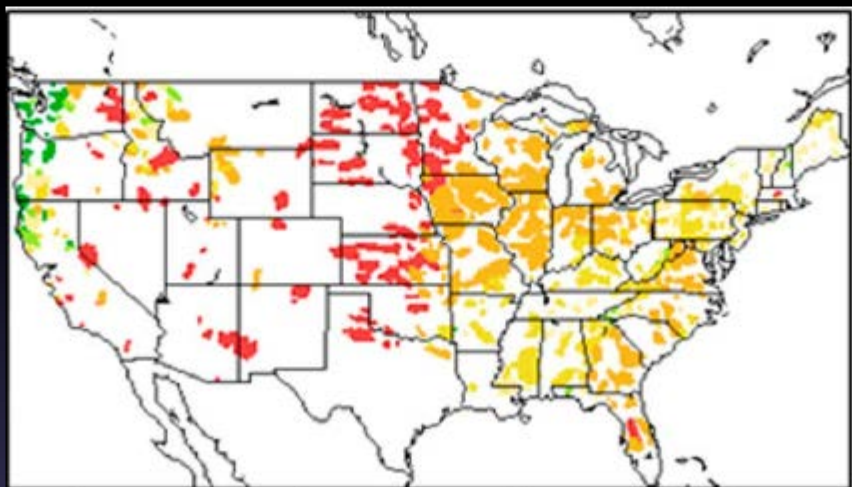
- 12.5km (NLDAS2 domain)
- 1980-2011 (31 years)
- PMW snow products
  - SMMR (1980-1987)
  - SSMI (1987-2002)
  - AMSR-E (2002-2011)



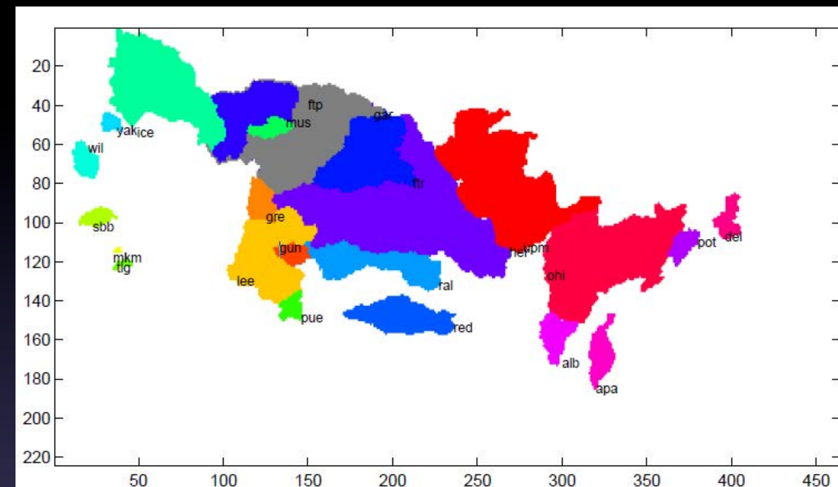
9106 GHCN stations
669 SNOTEL stations

Streamflow Data for Evaluation

USGS streamflow for 947 small NLDAS basins (Xia et al. 2012)



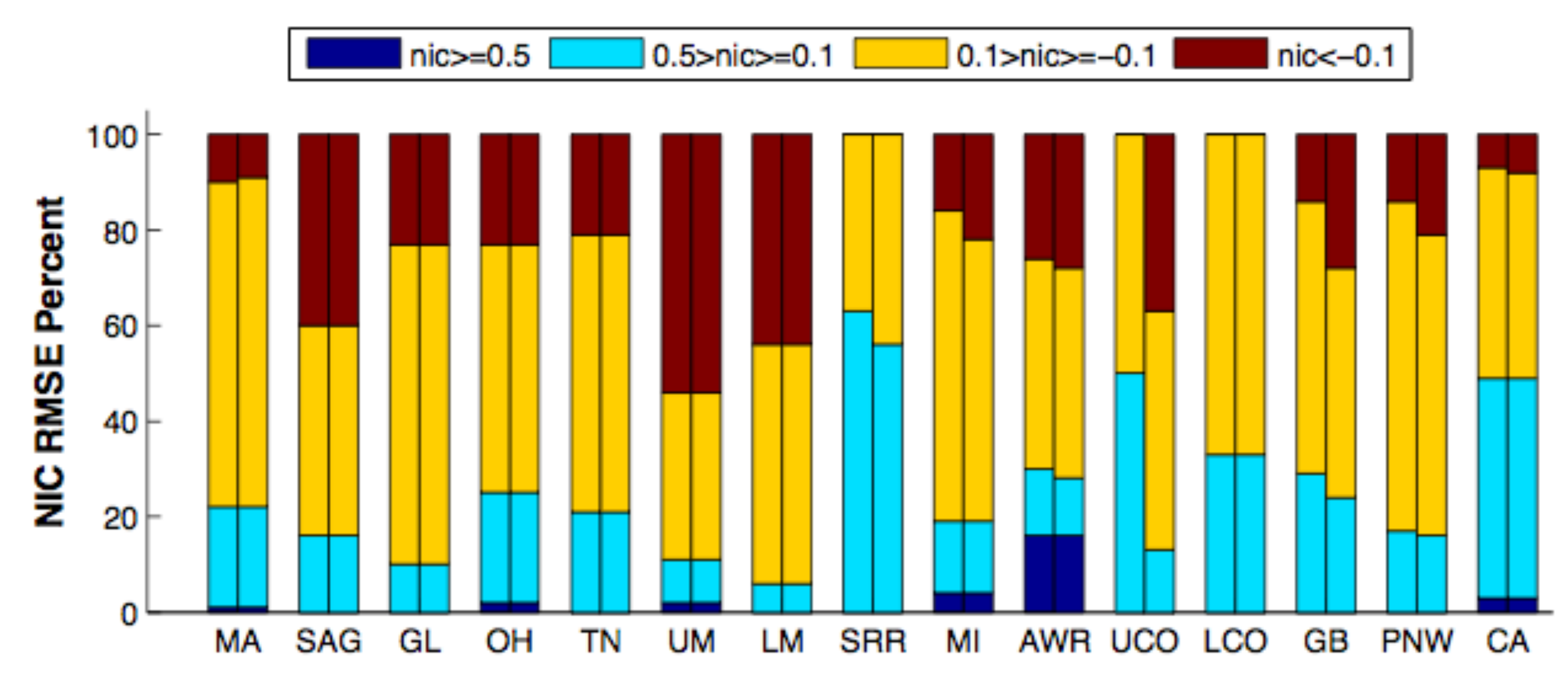
Natural flow river basins (Mahanama et al., 2012)



USGS Water Resources Regions (MA, SGA, GL, OH, TN, UM, LM, SRR, MI, AWR, UCO, LCO, GB, PNW,CA)

Evaluation Against Daily USGS Streamflow for 947 NLDAS Basins (1)

$$NIC\_RMSE = (RMSE(DA) - RMSE(OL)) / RMSE(OL)$$



East

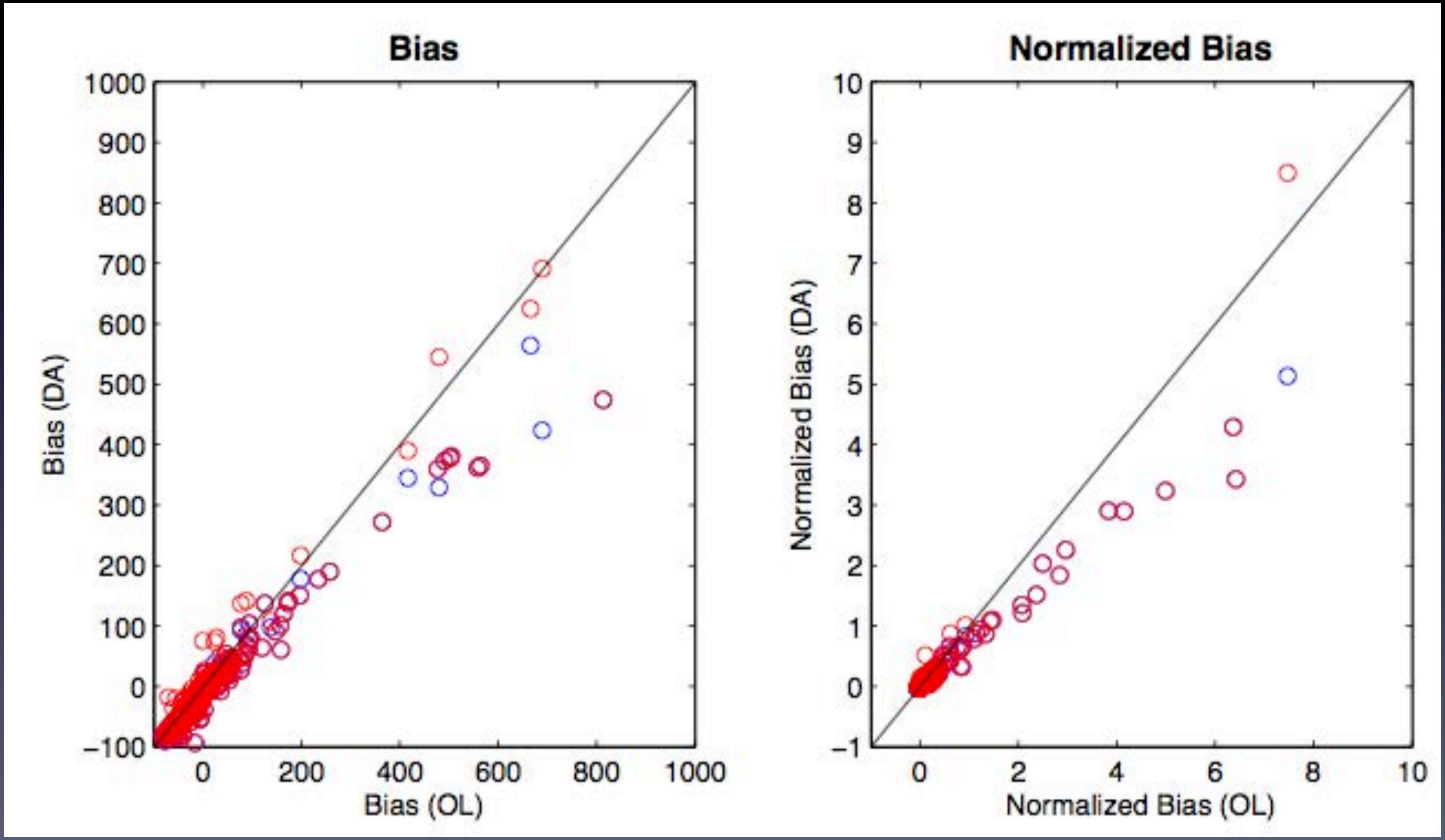
West

USGS Water Resources Regions

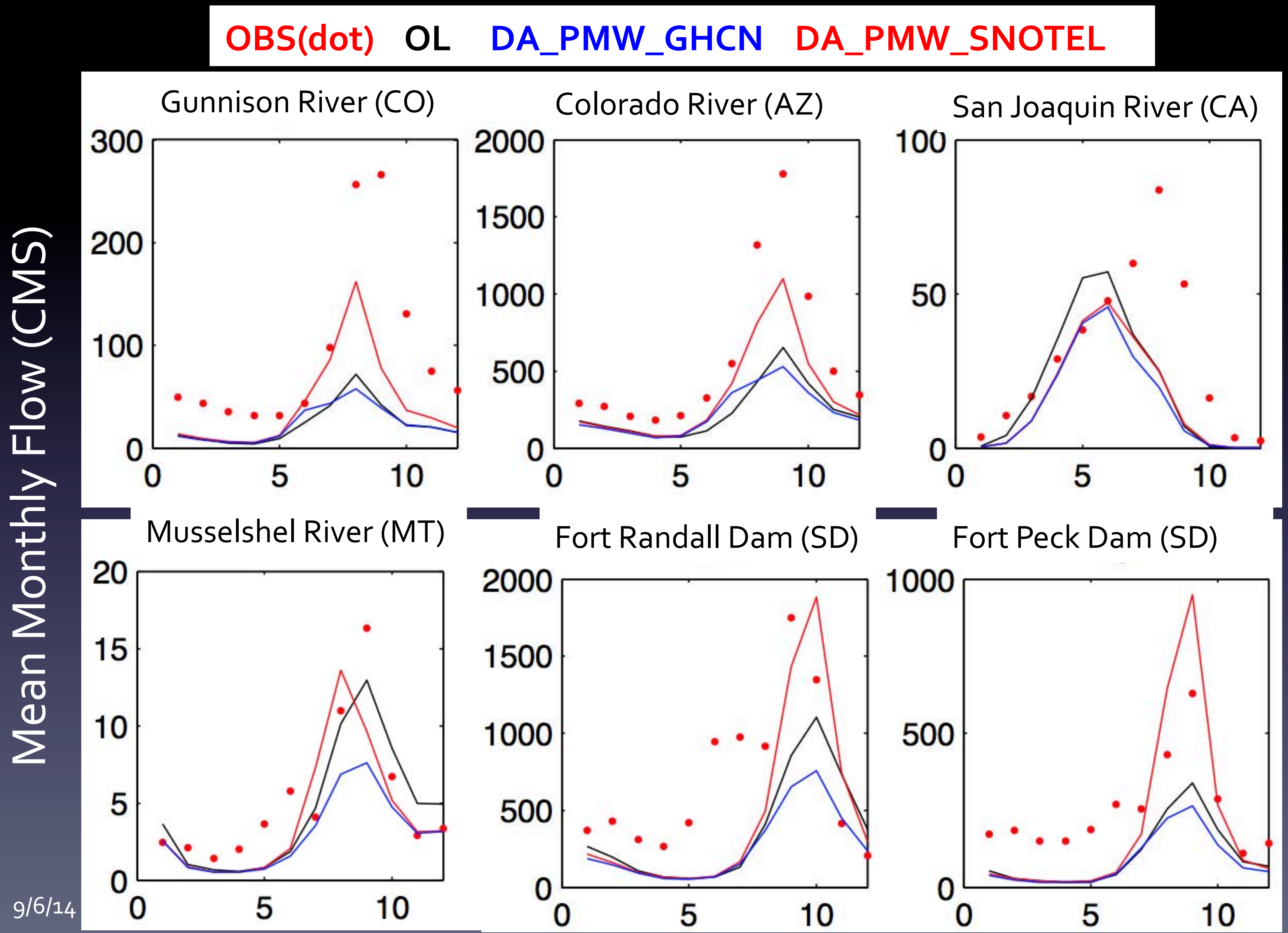
1st bar: DA_PMW_GHCN
2nd bar: DA_PMW_SNOTEL

Evaluation Against Daily USGS Streamflow for 947 NLDAS Basins (2)

Bias (Mean Error, CMS) Bias normalized by mean daily flow



Evaluation Against Monthly Natural Flow Data



Concluding Remarks

- Successful data assimilation requires good model and good data
- Blending satellite snow data with in-situ observations shows potential for streamflow forecasting in snow-driven basins
- Greater success with large basins but still considerable room for improvement with small basins
- *Snowmelt-driven streamflow prediction* session AGU 2014

"Yesterday is history. Tomorrow is mystery. Today is a gift. That's why it is called the present."

- Master Wugui, Kongfu Panda