The impact of assimilating terrestrial remote sensing observations on drought monitoring

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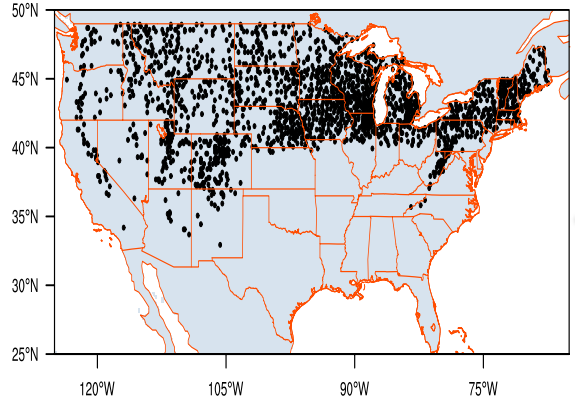
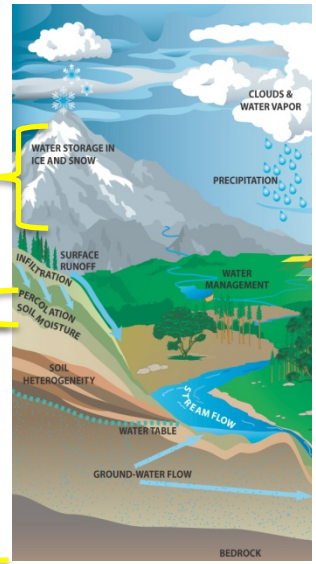
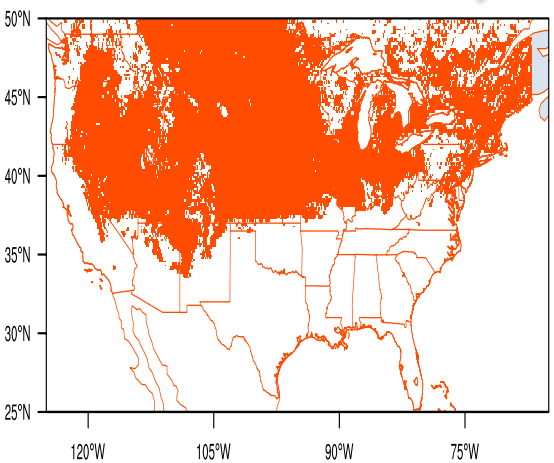
Reference: Kumar, S., C. Peters-Lidard, D. Mocko, R. Reichle, Y. Liu, K. Arsenault, Y. Xia, M. Ek, G. Riggs, B. Livneh, M. Cosh, 2014: Assimilation of passive microwave-based soil moisture and snow depth retrievals for drought estimation in press, J. Hydromet, (Special Collection on Advances in Drought Monitoring and Prediction)

NLDAS Land Data Assimilation Experiments

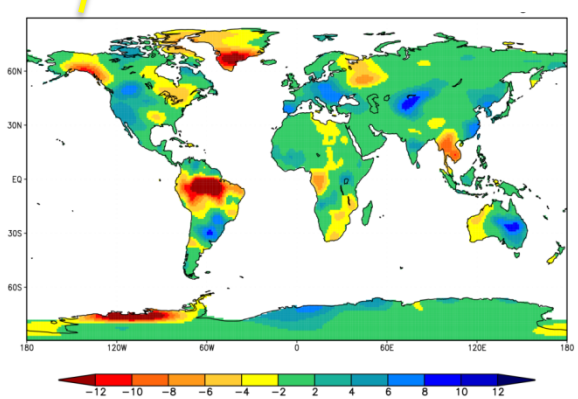


SNOW: Snow water equivalent (SWE) based on Aqua/AMSR-E with checks for MODIS and IMS SCA. The snow depth retrievals are corrected using the in-situ measurements from the Global Historical Climate Network (GHCN).





SOIL MOISTURE: Daily soil moisture based on Aqua/AMSR-E LPRM algorithm. Mask above shows where data assimilation occurs for at lesat one year due to masks for vegetation water content, precipitation, freeze/thaw, etc.



GRACE Terrestrial Water Storage: Gridded TWS Tellus data retrievals from (version RL05) is assimilated into the CLSM using a 3-d EnKS algorithm during the time period of 2003 -2012.

Domain : CONUS 1/8th degree

Forcing: NLDAS-2 forcing

LSMs: Noah 3.3 and CLSM

DA methods:

- 1-d Ensemble Kalman Filter (snow, soil moisture)
- 3-d Ensemble Kalman Smoother (GRACE TWS)

Time period: 1979-2012

Review: Soil moisture and Snow depth DA results

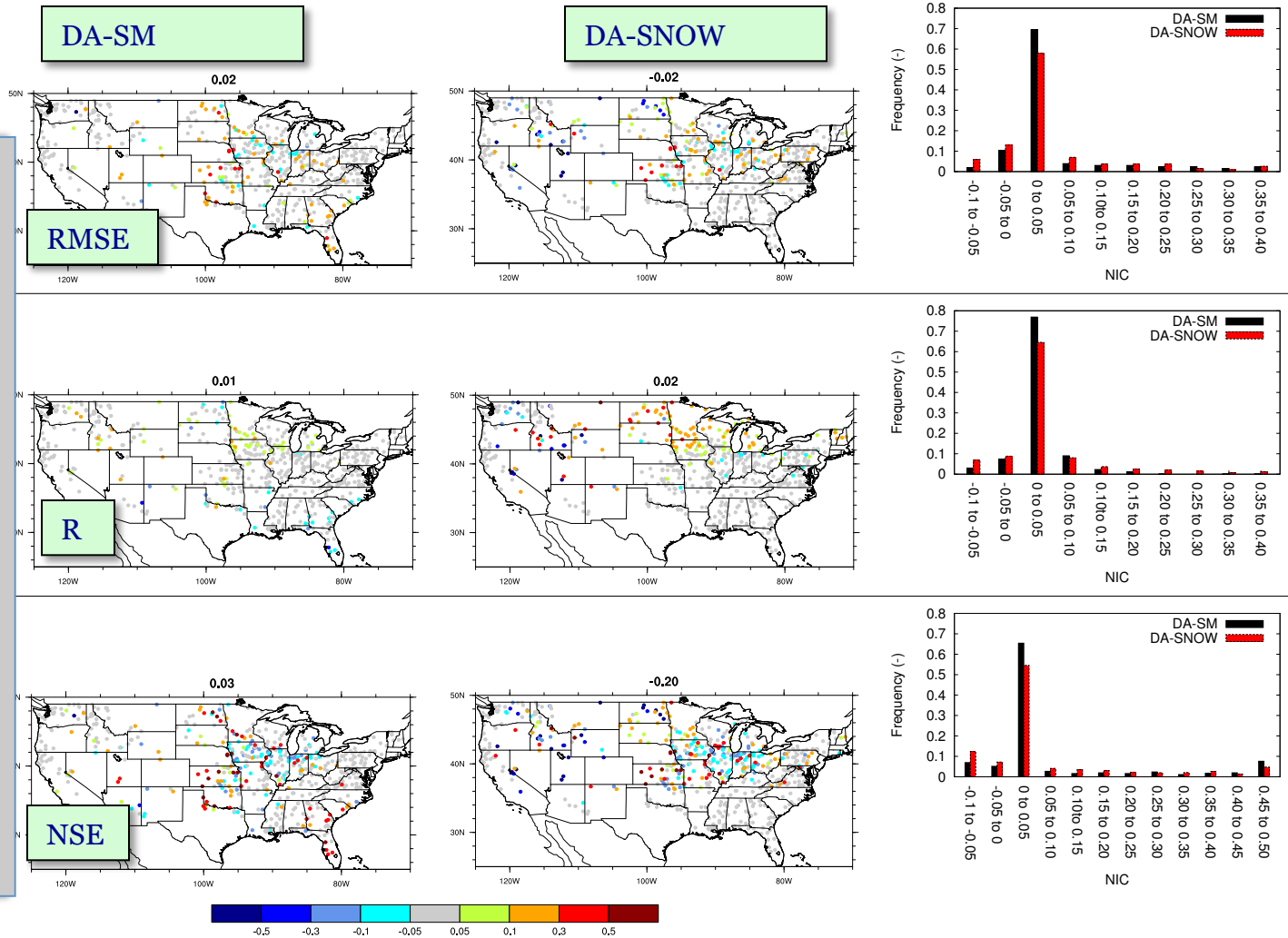
Evaluation of the improvements in streamflow simulation from soil moisture DA

The improvements are expressed using an Normalized Information Contribution (NIC) metric that measures the skill improvement from DA as a fraction of the maximum possible skill improvement

$$NIC_{RMSE} = \frac{(RMSE_o - RMSE_a)}{RMSE_o}$$

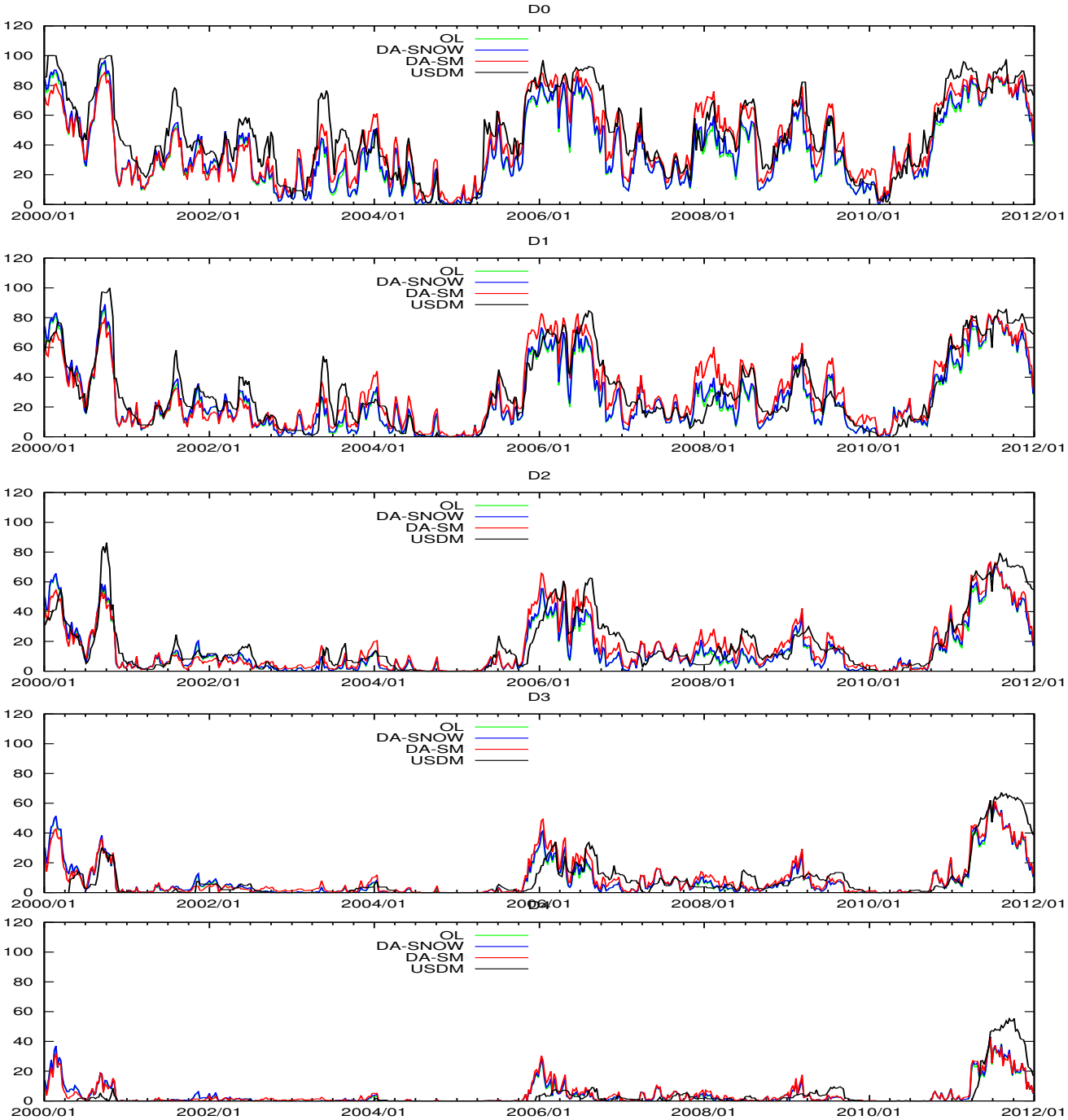
$$NIC_R = \frac{(R_a - R_o)}{(1 - R_o)}$$

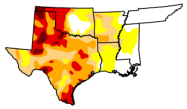
$$NIC_{NSE} = \frac{(NSE_a - NSE_o)}{(1 - NSE_o)}$$



Minor improvements in all skill metrics (RMSE, R and NSE) are observed in streamflow estimates with soil moisture data assimilation. Snow DA indicates a slight overall degradation.

Skill improvements from soil moisture assimilation are mostly over parts of the Mississippi, Missouri and Arkansas-Red basins and parts of Southeastern U.S. Notable degradations due to snow DA are observed over Colorado headwater region and over Northwest U.S.





South (Noah)

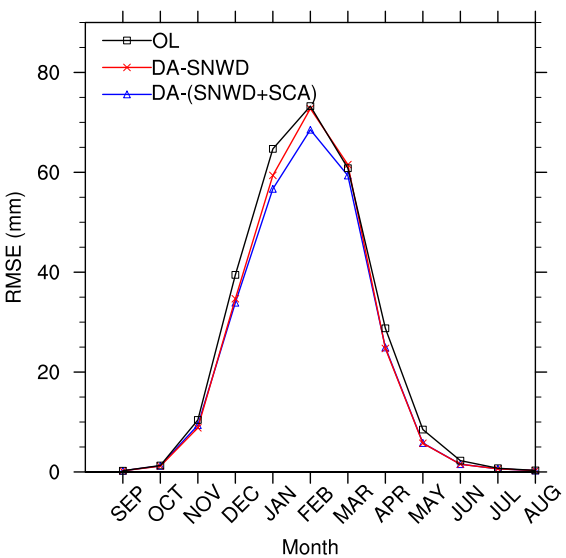
R	OL	DA-SM
D0	0.91	0.90
D1	0.91	0.89
D2	0.89	0.89
D3	0.78	0.80
D4	0.73	0.73

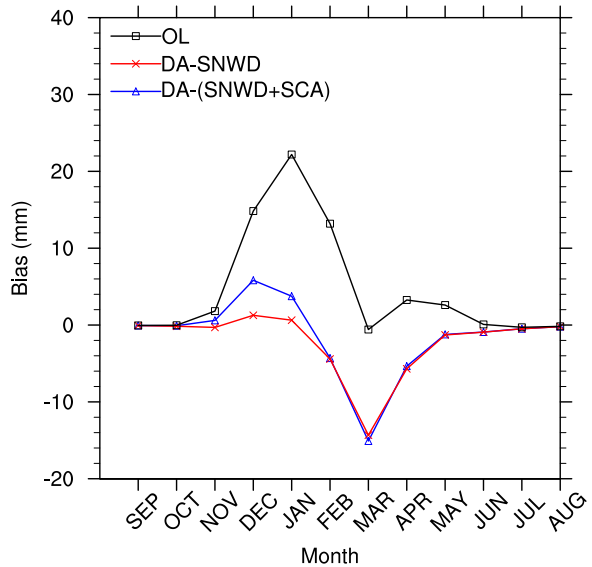
RMSE	OL	DA-SM
D0	15.7	12.8
D1	11.1	11.1
D2	9.9	9.2
D3	9.0	8.5
D4	6.7	6.7

Bias	OL	DA-SM
D0	11.2	5.0
D1	4.7	-0.1
D2	3.8	1.2
D3	0.5	-0.7
D4	-0.4	-0.8

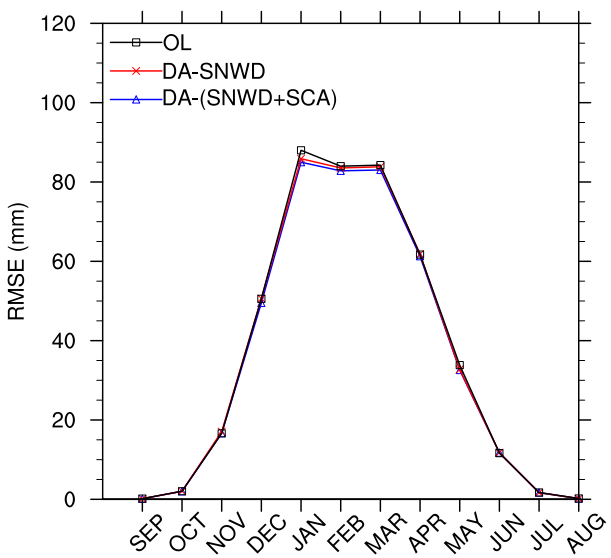
Refined Approach for Snow-DA: Use IMS/MODIS SCA

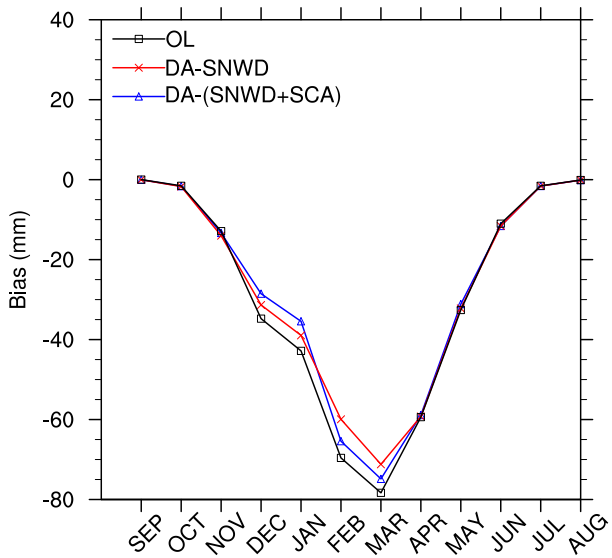
Vs. CMC





Vs. SNODAS

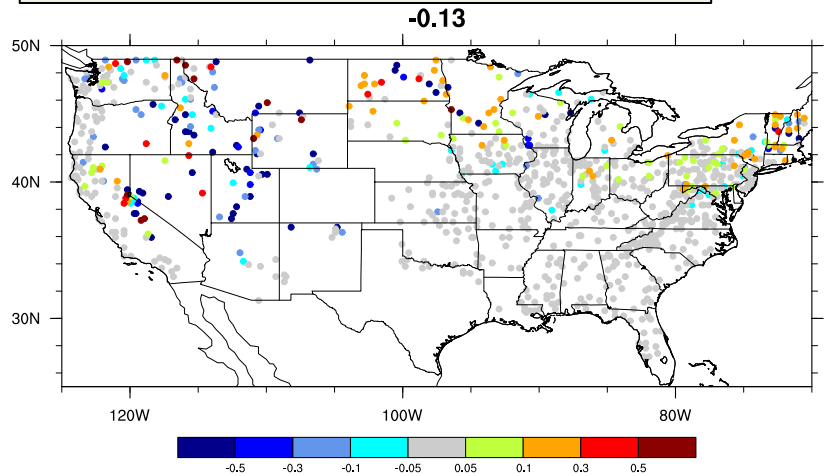




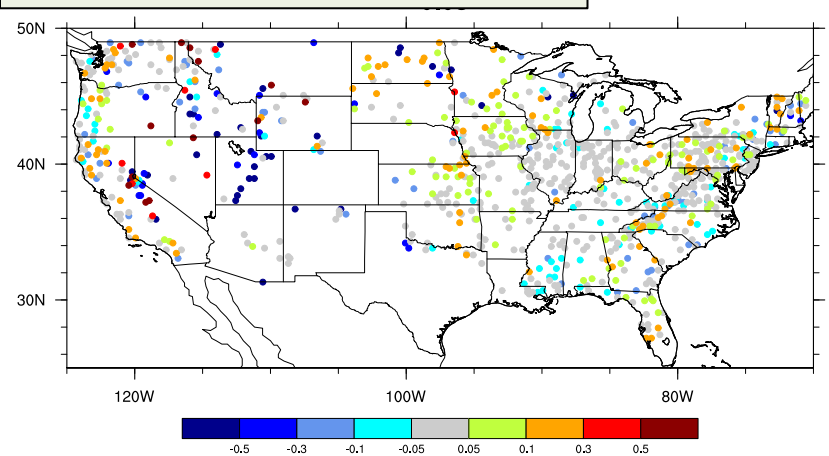
The added use of IMS and MODIS snow cover leads to improved RMSE, marginal improvements in Bias

Impact of Refined Snow-DA on Streamflow

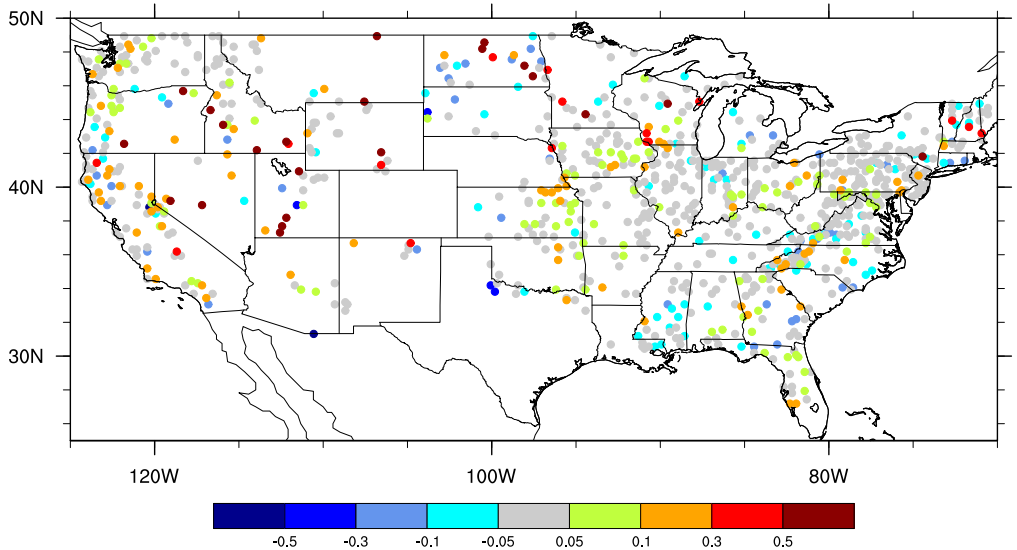
Passive microwave only **(DA1)**



Passive microwave + MODIS/IMS SCA **(DA2)**



NIC difference (DA2 – DA1)

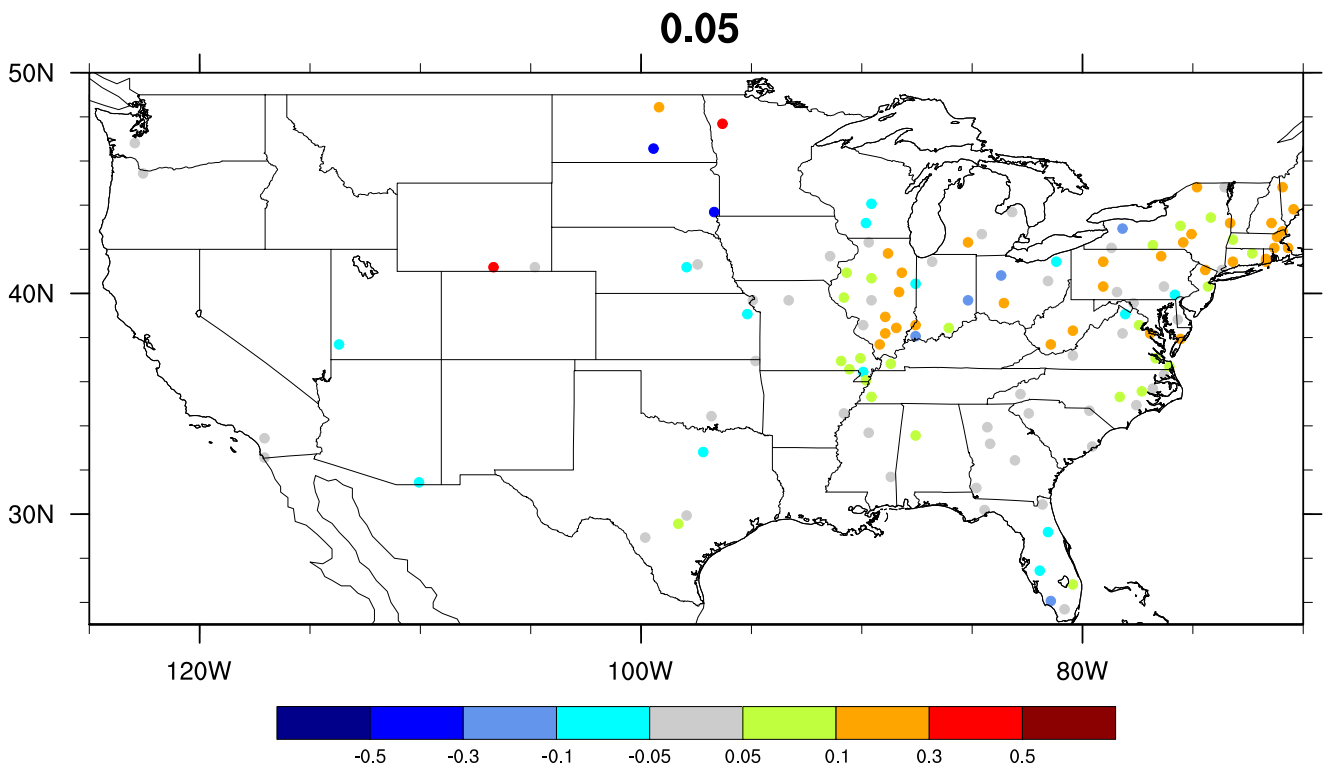


Warm colors indicate locations where the additional use of MODIS and IMS leads to improvement in streamflow over that of using passive microwave alone.

GRACE TWS DA results

- New NLDAS LSM:
  - Catchment LSM
- New DA:
  - 3-d EnKS

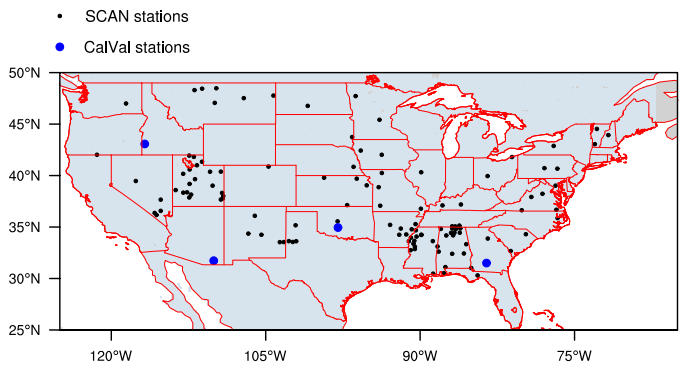
Ground Water (vs. USGS GW well data)



Statistically significant improvements in Anomaly R and Anomaly RMSE compared to USGS ground water well data.

	OL	DA-TWS
Anomaly R	0.64 +/- 0.02	**0.69 +/- 0.02**
Anomaly RMSE	0.048 +/- 0.002	**0.040 +/- 0.002**

Soil moisture evaluations (2003-2012)



DA-TWS provides statistically significant improvements in both surface and root zone anomaly R in comparisons to SCAN and ARS in-situ data.

The improvements noted in other metrics (anomaly RMSE and unbiased RMSE) are not always statistically significant.

Surface (SCAN)	OL	DA-TWS
Anomaly R	0.44 +/- 0.02	**0.59 +/- 0.02**
Anomaly RMSE	0.052 +/- 0.002	0.048 +/- 0.002
Unbiased RMSE	0.061 +/- 0.002	0.057 +/- 0.002

Root zone (SCAN)	OL	DA-TWS
Anomaly R	0.48 +/- 0.02	**0.53 +/- 0.02**
Anomaly RMSE	0.036 +/- 0.002	0.035 +/- 0.002
Unbiased RMSE	0.047 +/- 0.002	0.046 +/- 0.002

Surface (ARS)	OL	DA-TWS
Anomaly R	0.62 +/- 0.02	**0.75 +/- 0.02**
Anomaly RMSE	0.032 +/- 0.002	0.026 +/- 0.002
Unbiased RMSE	0.038 +/- 0.002	**0.033 +/- 0.002**

Streamflow evaluations (2003-2012)

The improvements are expressed using an Normalized Information Contribution (NIC) metric that measures the skill improvement from DA as a fraction of the maximum possible skill improvement

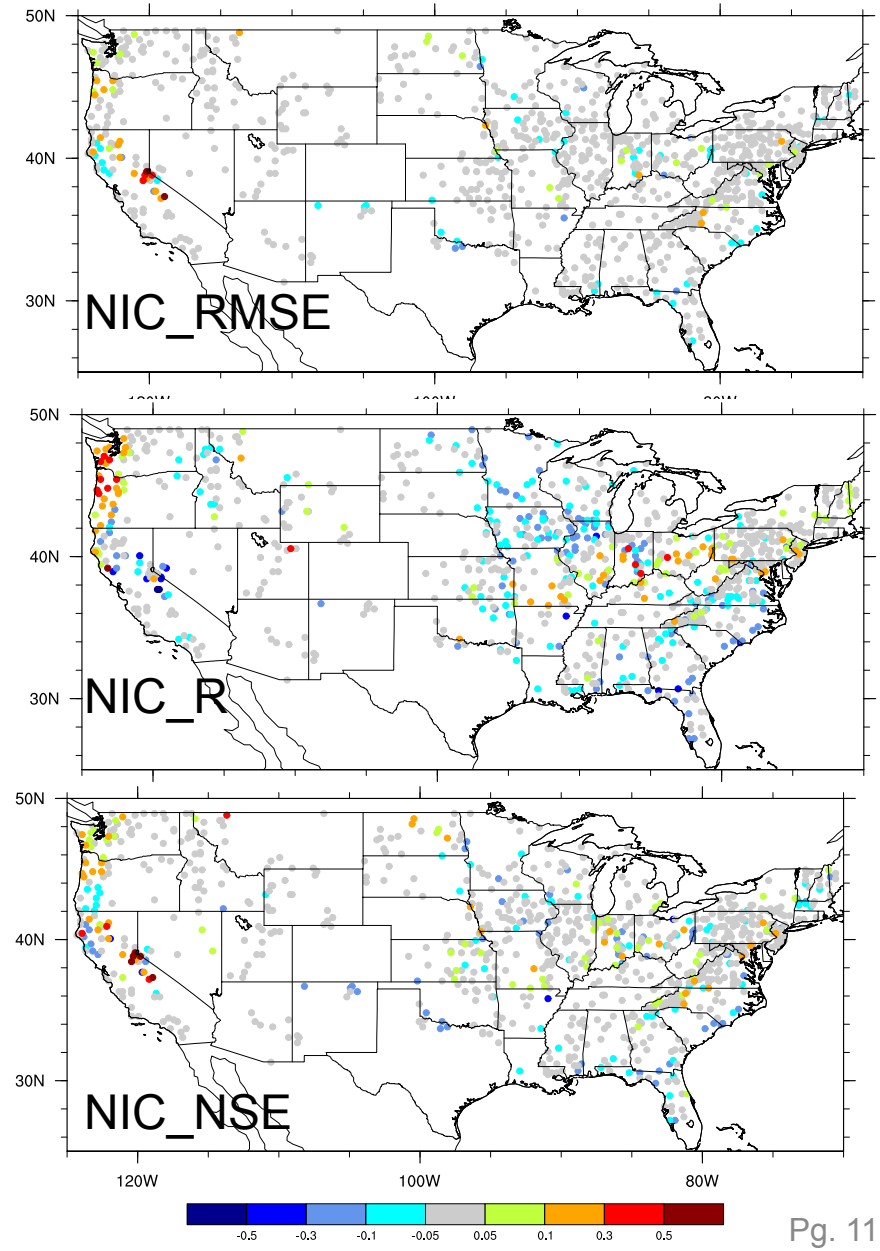
$$NIC_{RMSE} = \frac{(RMSE_o - RMSE_a)}{RMSE_o}$$

$$NIC_R = \frac{(R_a - R_o)}{(1 - R_o)}$$

$$NIC_{NSE} = \frac{(NSE_a - NSE_o)}{(1 - NSE_o)}$$

Improvements in West coast, Upper Mississippi, North east

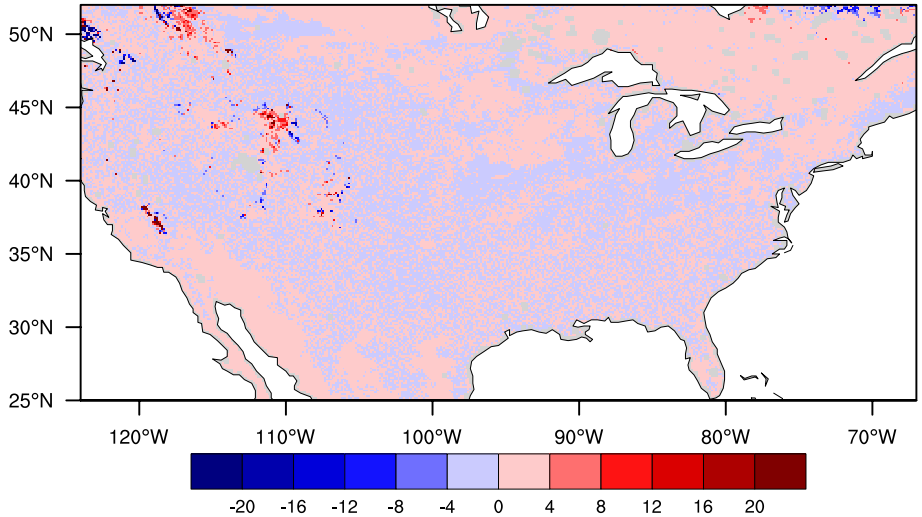
Degradations in South east, Lower mississippi, Texas



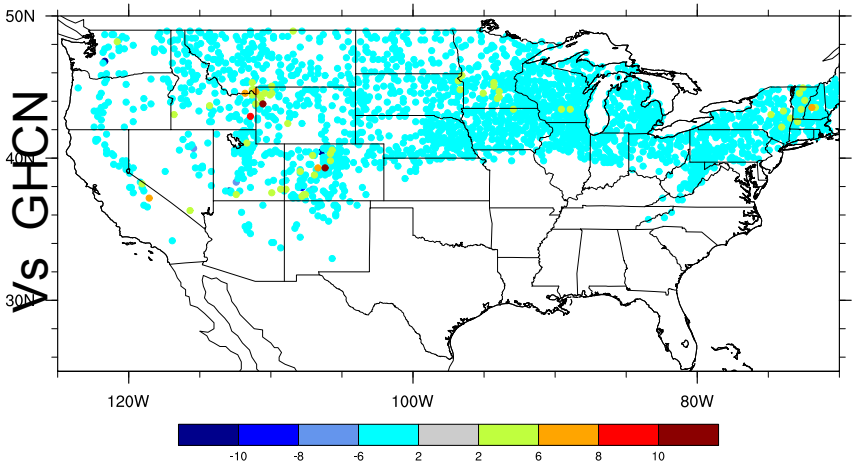
Snow depth evaluations

RMSE difference (RMSE(OL) – RMSE (DA)) plots from comparisons with (Blue colors indicate degradations, Red/warm colors indicate improvements)

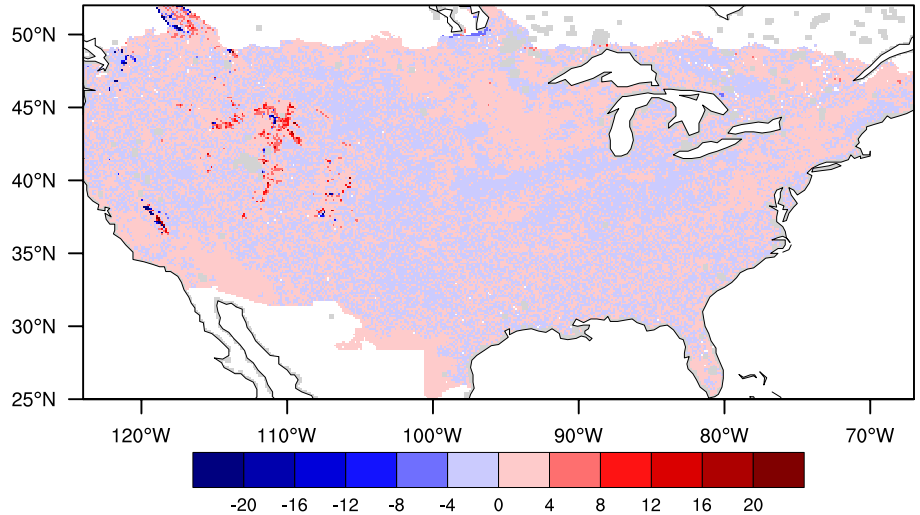
Vs CMC



Vs GHCN



Vs SNODAS



Flux evaluations (2003-2012)

RMSE difference (RMSE(OL) – RMSE (DA)) plots from comparisons with (Blue colors indicate degradations, Red colors indicate improvements)

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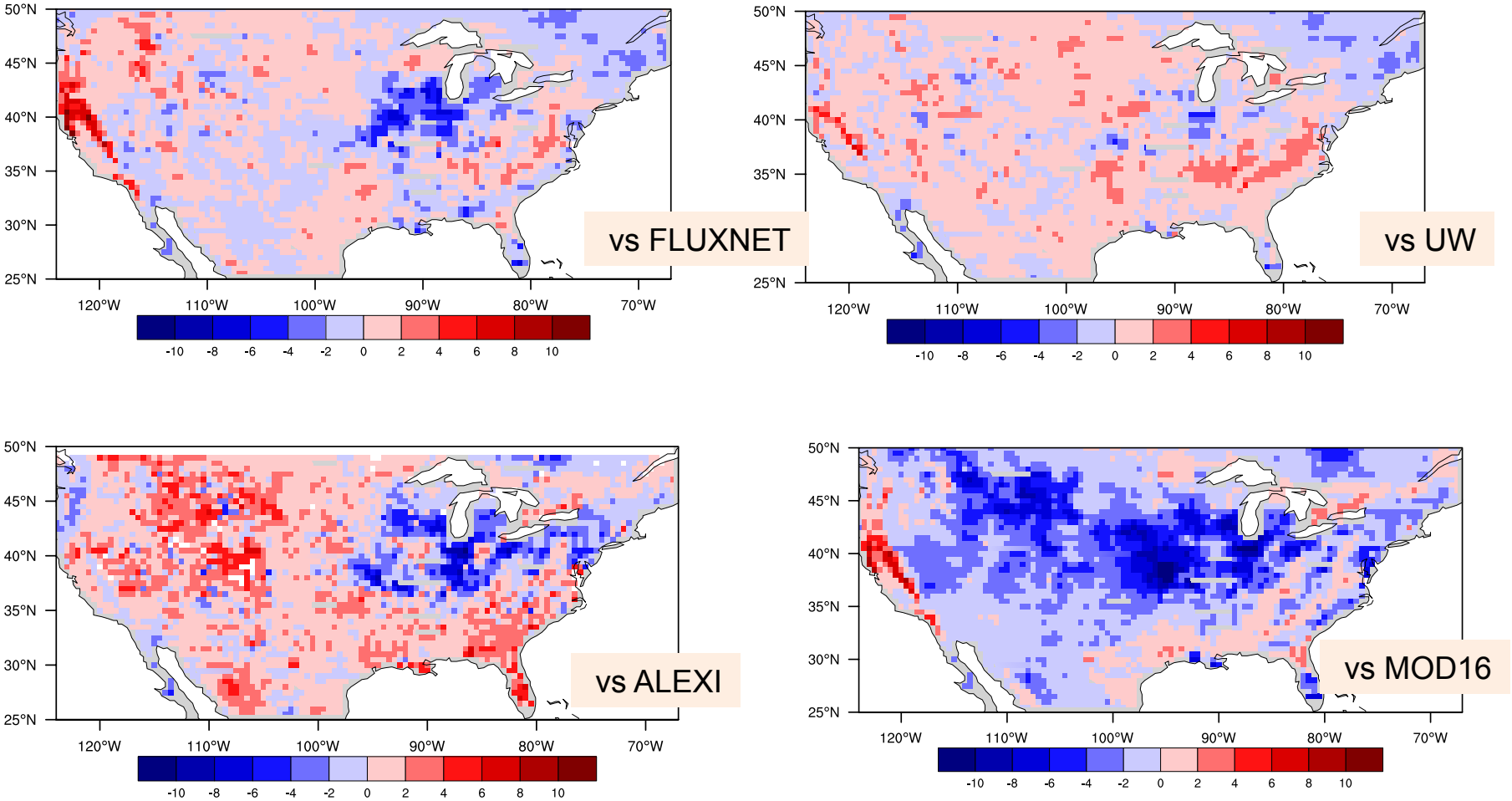
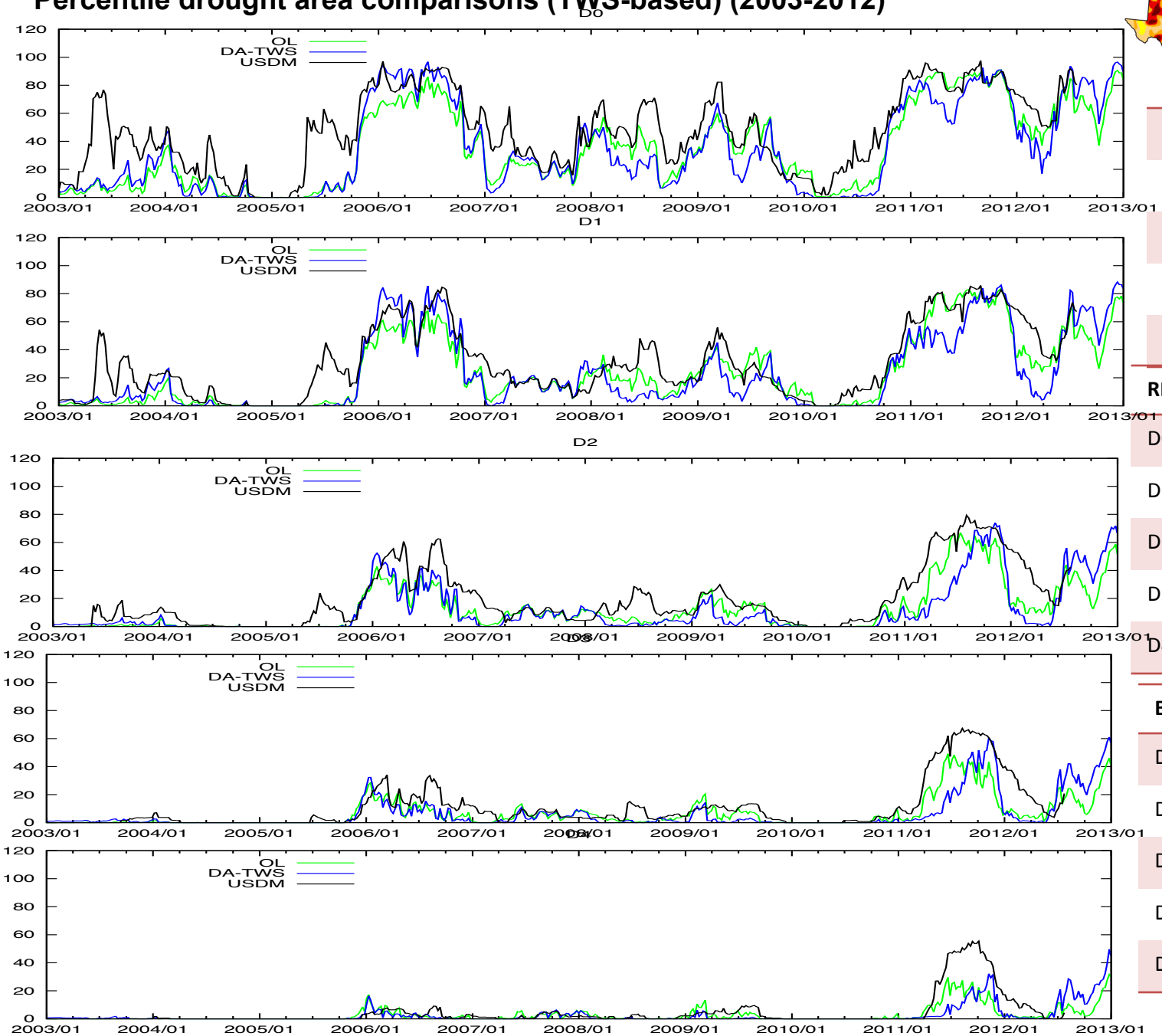
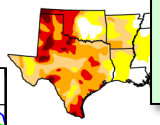


Percentile drought area comparisons (TWS-based) (2003-2012)



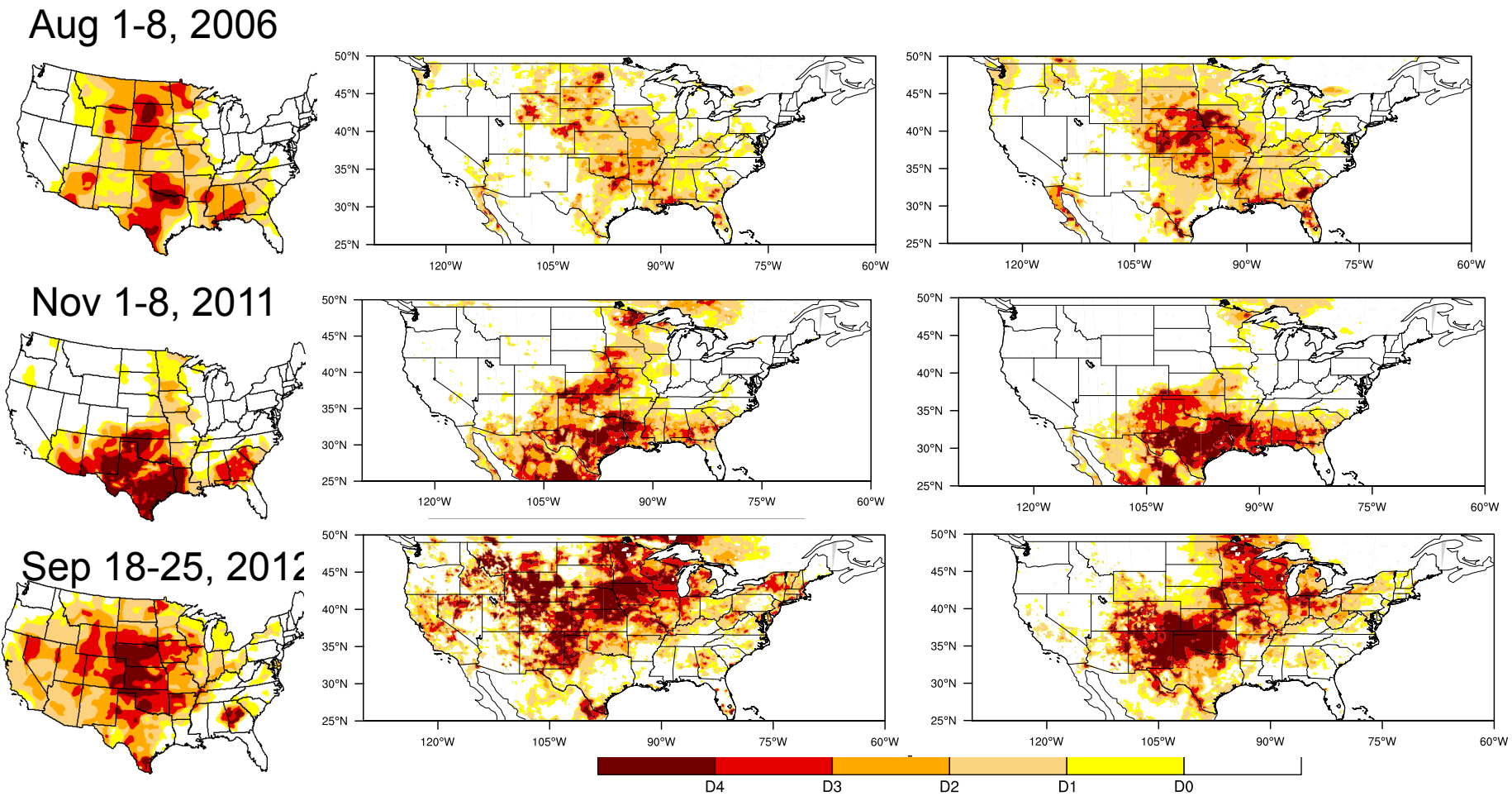


USDM south region

R	OL	DA-TWS
D0	0.87	0.88
D1	0.85	0.83
D2	0.81	0.76
D3	0.67	0.56
D4	0.55	0.36

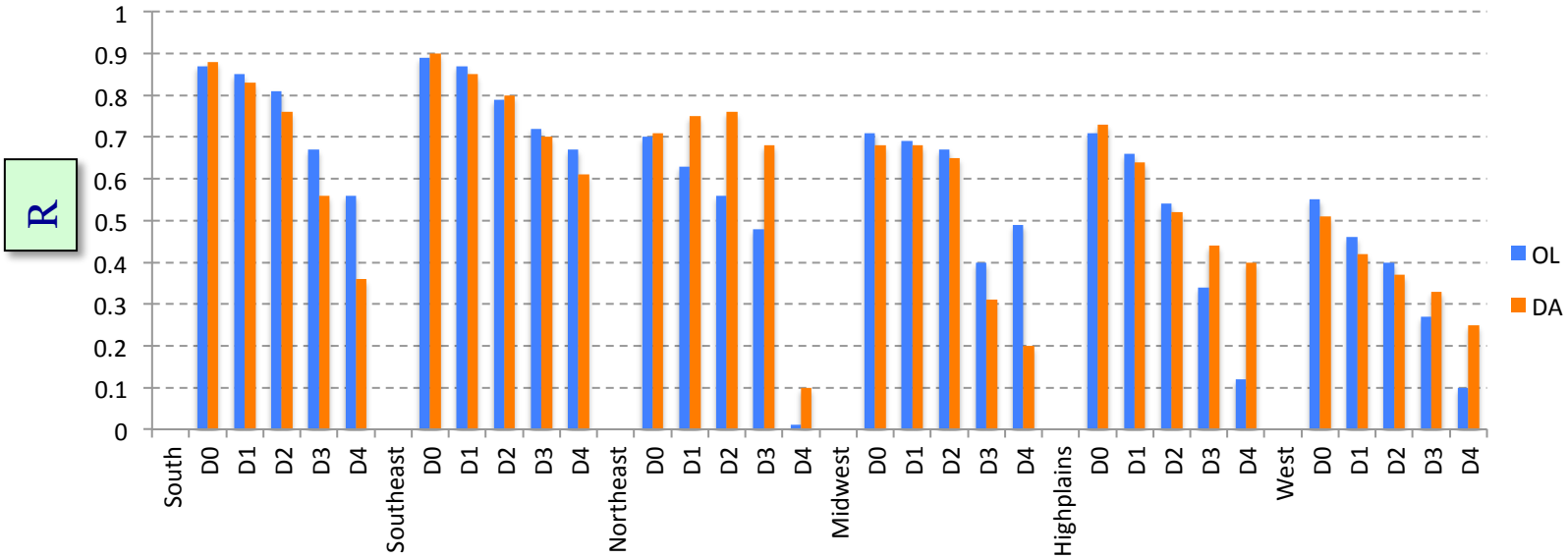
RMSE	OL	DA-TWS
D0	17.1	16.4
D1	14.3	15.2
D2	12.5	13.8
D3	11.0	12.5
D4	8.0	9.2

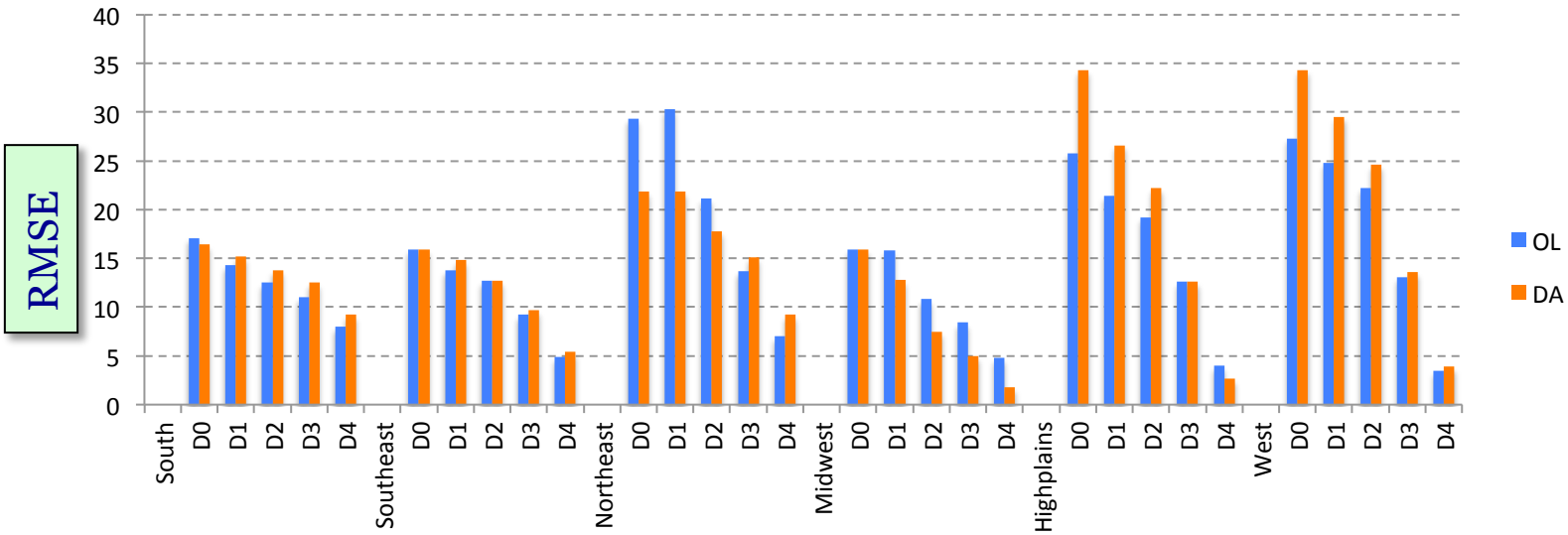
Bias	OL	DA-TWS
D0	9.7	7.9
D1	4.1	3.8
D2	4.0	4.7
D3	1.5	2.2
D4	0.7	1.0



Aug 1-8, 2006: DA improves drought severity estimates over parts of Nebraska, Texas, Alabama; Overestimates severity over Georgia.
Nov 1-8, 2011: DA correctly improves the severity estimates over Texas, Alabama; Reduces severity of drought over Minnesota; Misses drought over Iowa
Sep 18-25, 2012: DA improves the drought estimates over Oklahoma, Kansas, Texas; Misses drought over Western U.S.

Comparison of percentage drought areas vs USDM estimate





Marginal improvements in D0 over South, Southeast, Highplains

Improvements in all categories in Northeast

Improvements in severe drought categories in Highplains, Northeast and West

Summary

- AMSR-E soil moisture and bias-corrected AMSR-E snow depth assimilation improves soil moisture, snow depth and generally improves streamflow, with some improvements in drought area, as shown in Kumar et al., 2014, JHM.

- Newer snow DA shows some potential for MODIS and IMS SCA to further improve snow. The impact on drought is TBD.

- New results with Catchment LSM show that GRACE TWS DA improves groundwater, soil moisture, snow, as well as streamflow. Drought area is very sensitive to the GRACE DA, with
  - Marginal improvements in D0 over South, Southeast, Highplains
  - Improvements in all categories in Northeast
  - Improvements in severe drought categories in Highplains, Northeast and West