Assimilation of AMSR-E Land Products into the NOAH LSM

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Outline

- Introduction
  - Ensemble Kalman Filter (EnKF)
  - LIS-based Noah LSM
  - AMSR_E soil moisture retrievals and CDF matching
  - SCAN in-situ observations
- Soil Moisture Data Assimilation (DA) Experiments
  - Assimilation of unscaled AMSR_E observations
  - Assimilation of scaled AMSR_E observations
  - Validation of model simulations without DA and with DA against satellite and ground observations
- Results and Discussion
  - Uncertainties and challenges in soil moisture estimation
  - Impact of DA on other land surface states and fluxes
- Current Work and Future Plans
  - Results of bias correction in Noah model within EnKF data assimilation
  - Preparing to assimilate global AMSR_E retrievals in T126/T382 spectral Noah operational model

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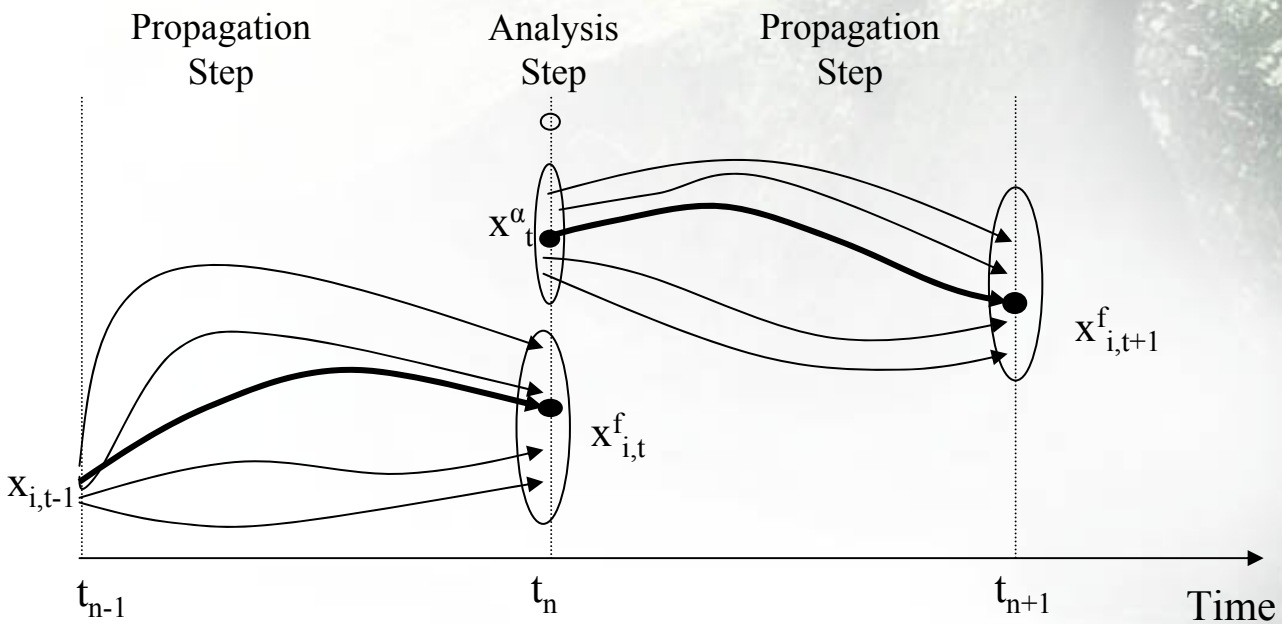
Data assimilation scheme-- Ensemble Kalman Filter (EnKF)

x - state vector

f - land surface model

y - observations



Propagation Step

$$x_{i,t}^{f} = f\left(x_{i,t-1}, u, \alpha, w\right)$$

$$P_t^{f} = \frac{1}{N-1} D_t D_t^{T}$$

$$D_t = [x_{1,t}^{f} - \bar{x}_t, x_{2,t}^{f} - \bar{x}_t, \ldots, x_{N,t}^{f} - \bar{x}_t]$$

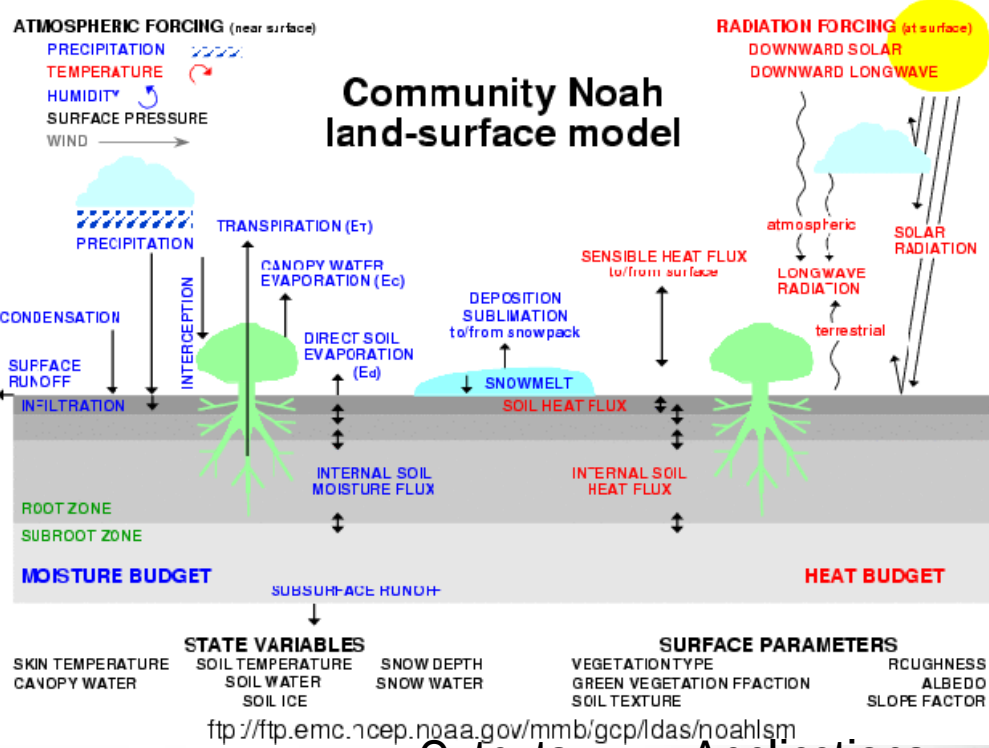
Analysis Step

$$x_{i,t}^{a} = x_{i,t}^{f} + K_t\left(y_t - Hx_{i,t}^{f} + v_i\right)$$

$$K_t = P_t^{f} H^{T}\left(HP_t^{f} H^{T} + R\right)^{-1}$$

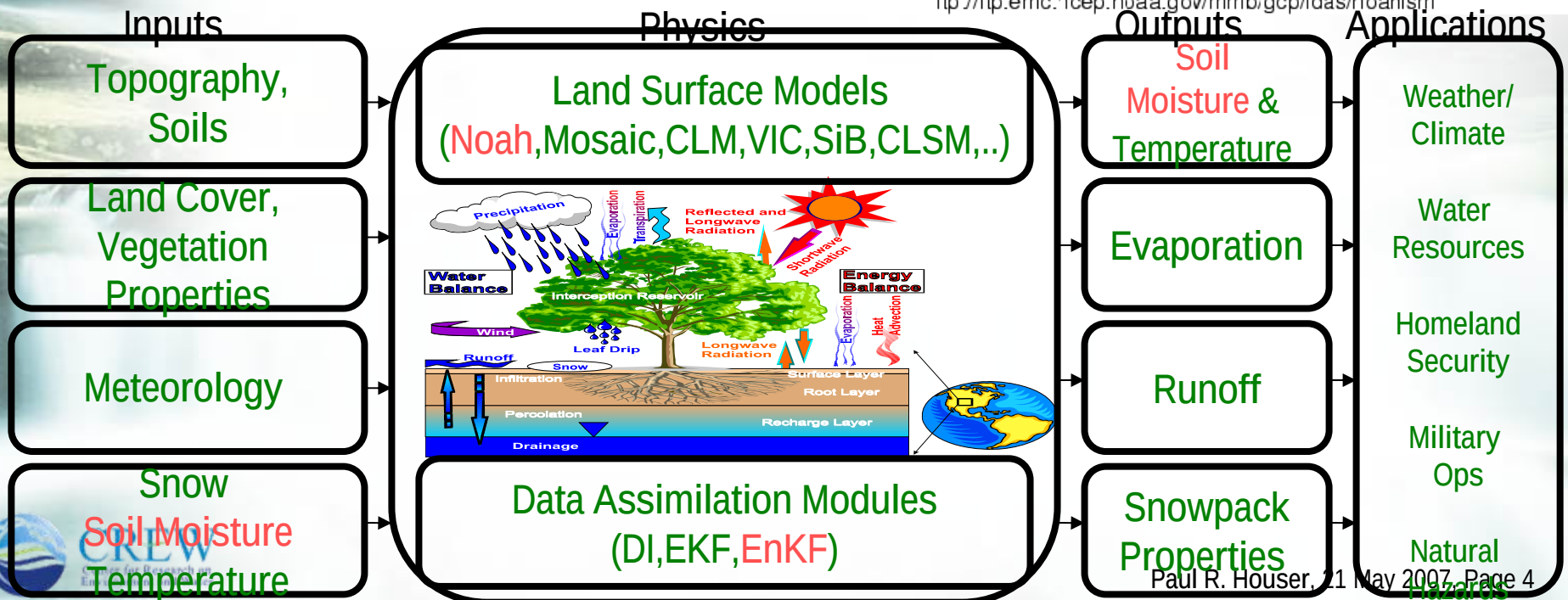
LIS-based Noah LSM

- **Noah** Land Surface Model (NOAH) Model results with observation-corrected meteorological forcing-NLDAS
- Upper 2cm, 1/8 degree, 30min
- Total 464x232 grid points on NLDAS domain



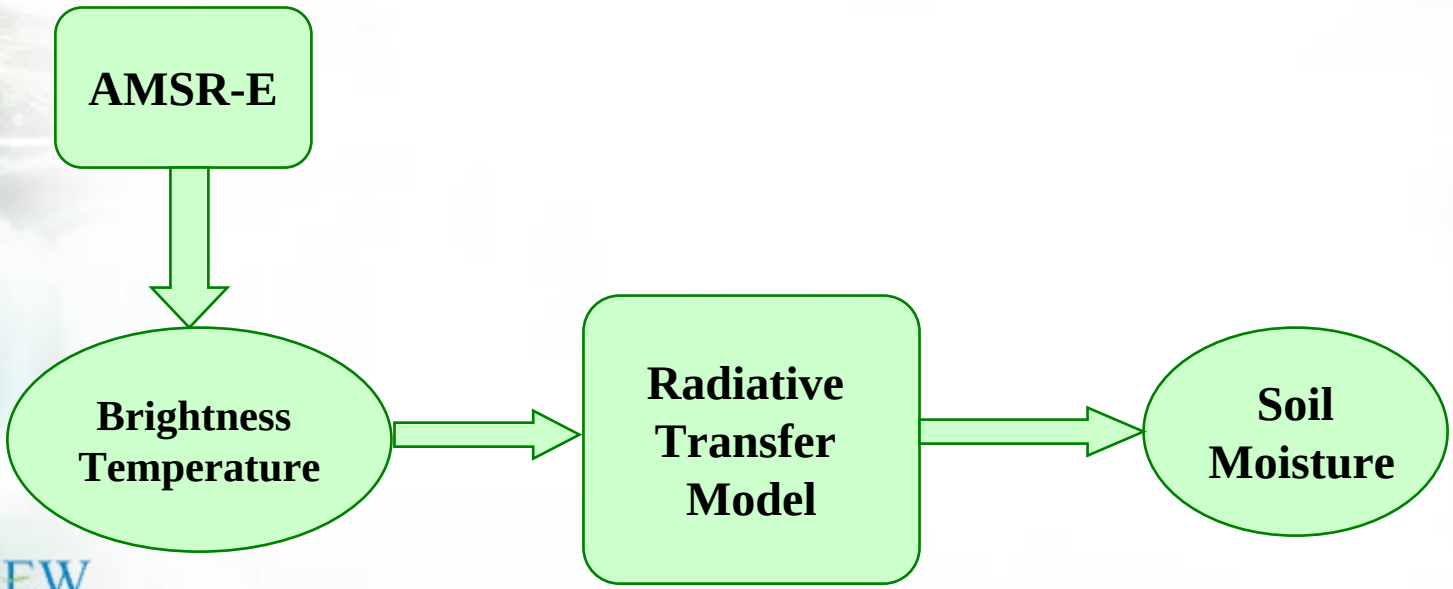
NASA Land Information System

ftp://ftp.emc.ncep.noaa.gov/mmb/gcp/ldas/noahlsm



AMSR_E soil moisture retrievals and CDF matching

- Advanced Microwave Scanning Radiometer (AMSR)
- Official AMSR-E Soil moisture dataset available since June 18, 2002
- Upper about 2cm, global, ~twice daily at 06Z, 12Z



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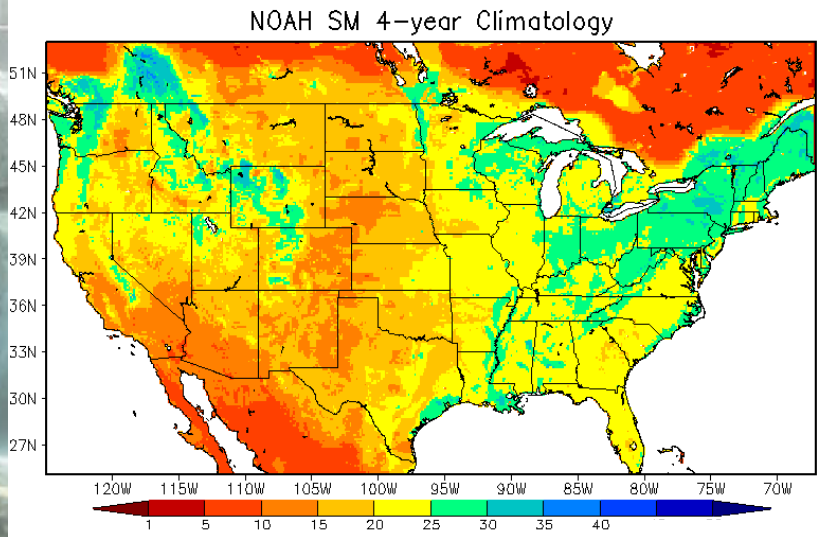
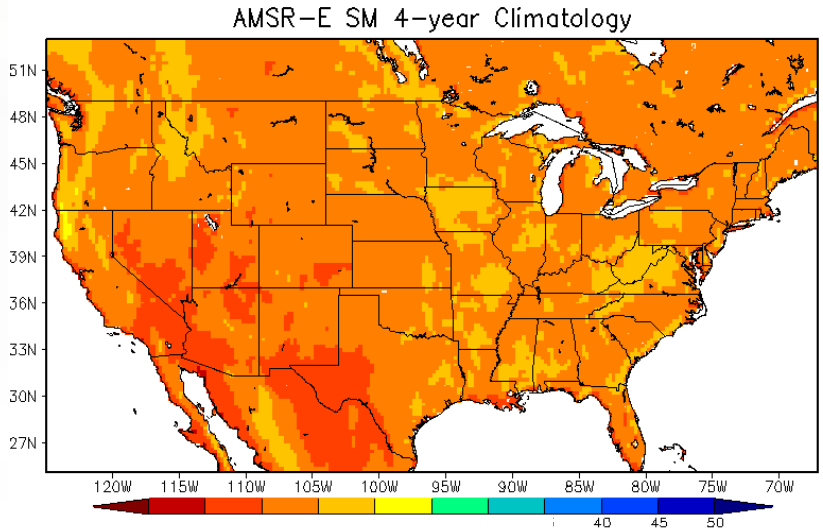
Surface Soil Moisture [v/v%] 4yr Climatology

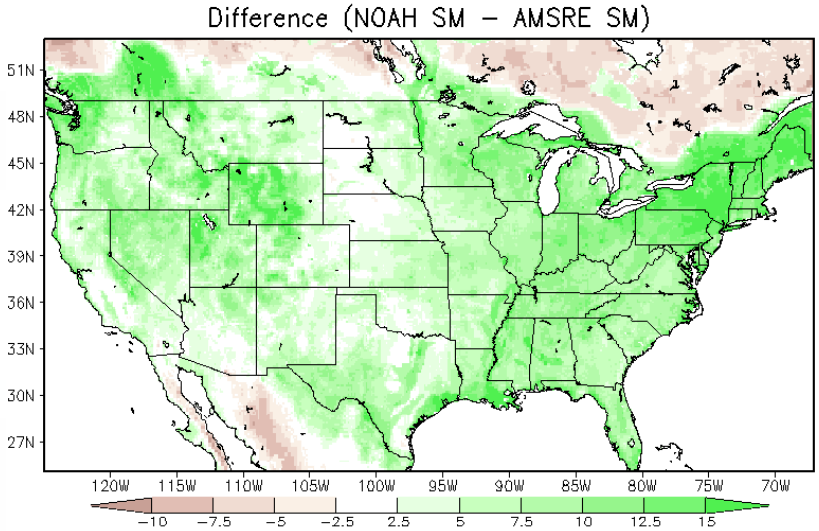
Noah



AMSRE

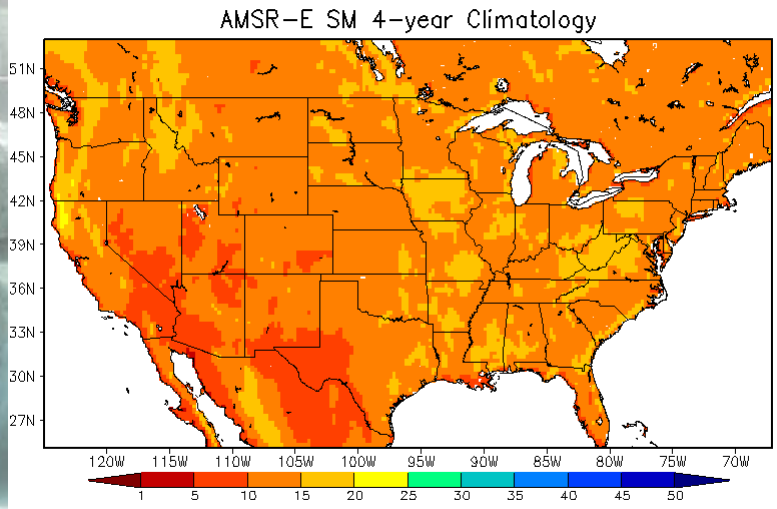


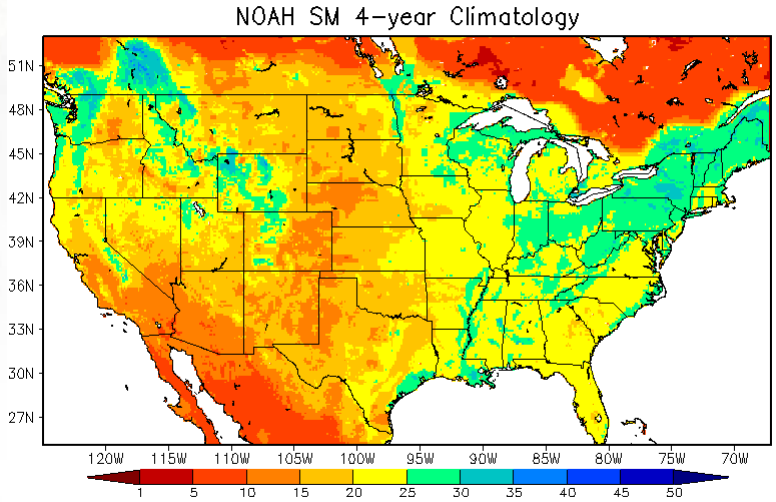
Noah - AMSRE



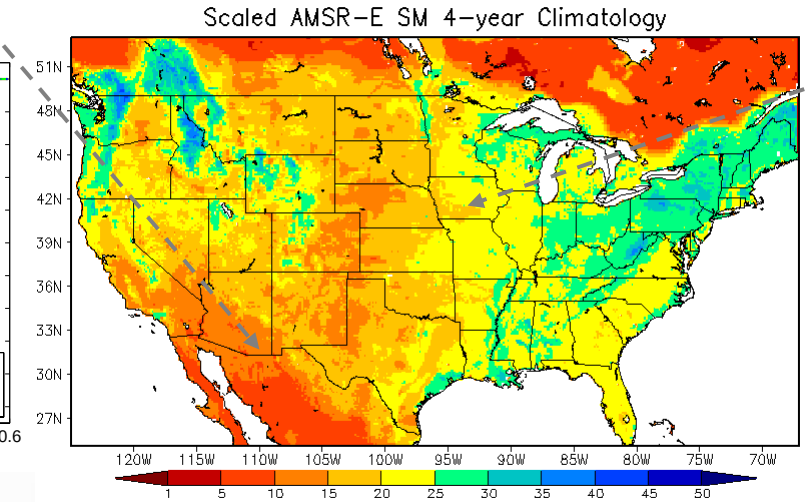
Noah is wetter.

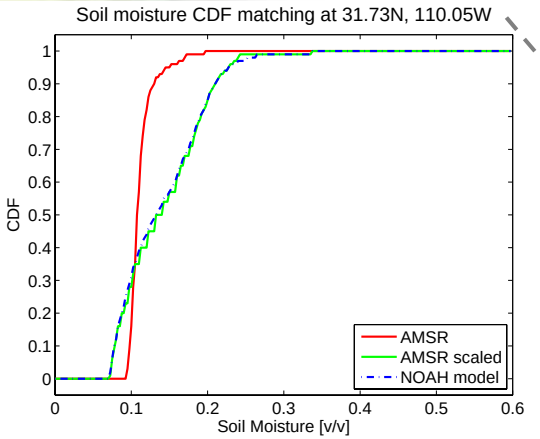
Bias correction-CDF matching

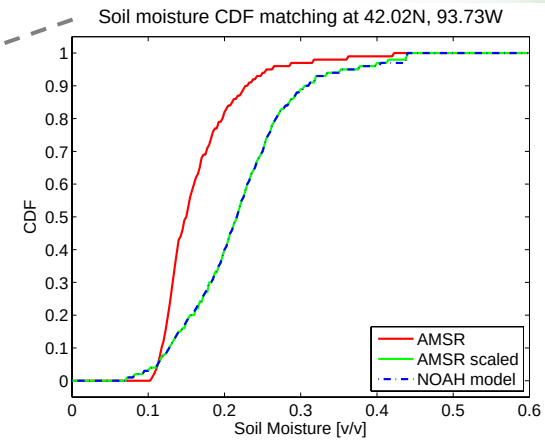




CDF matching



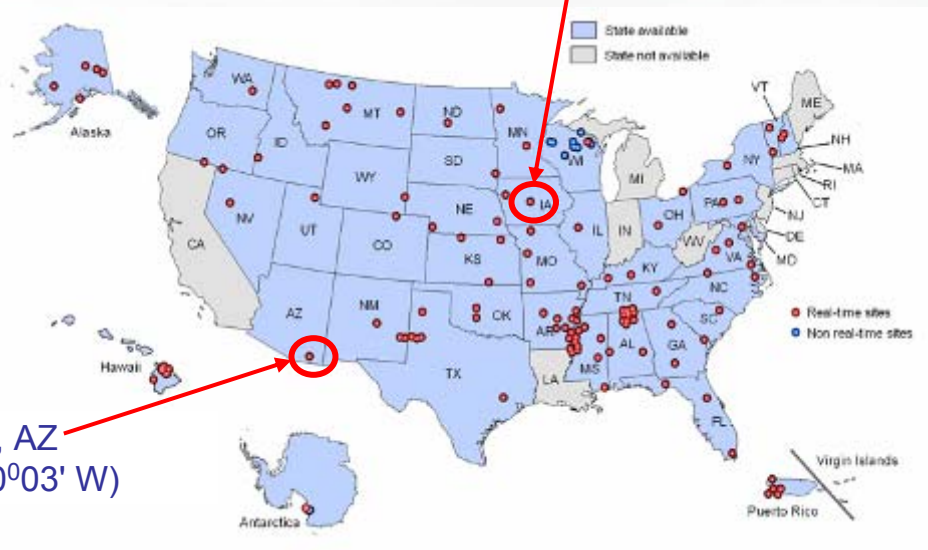




SCAN in-situ observations

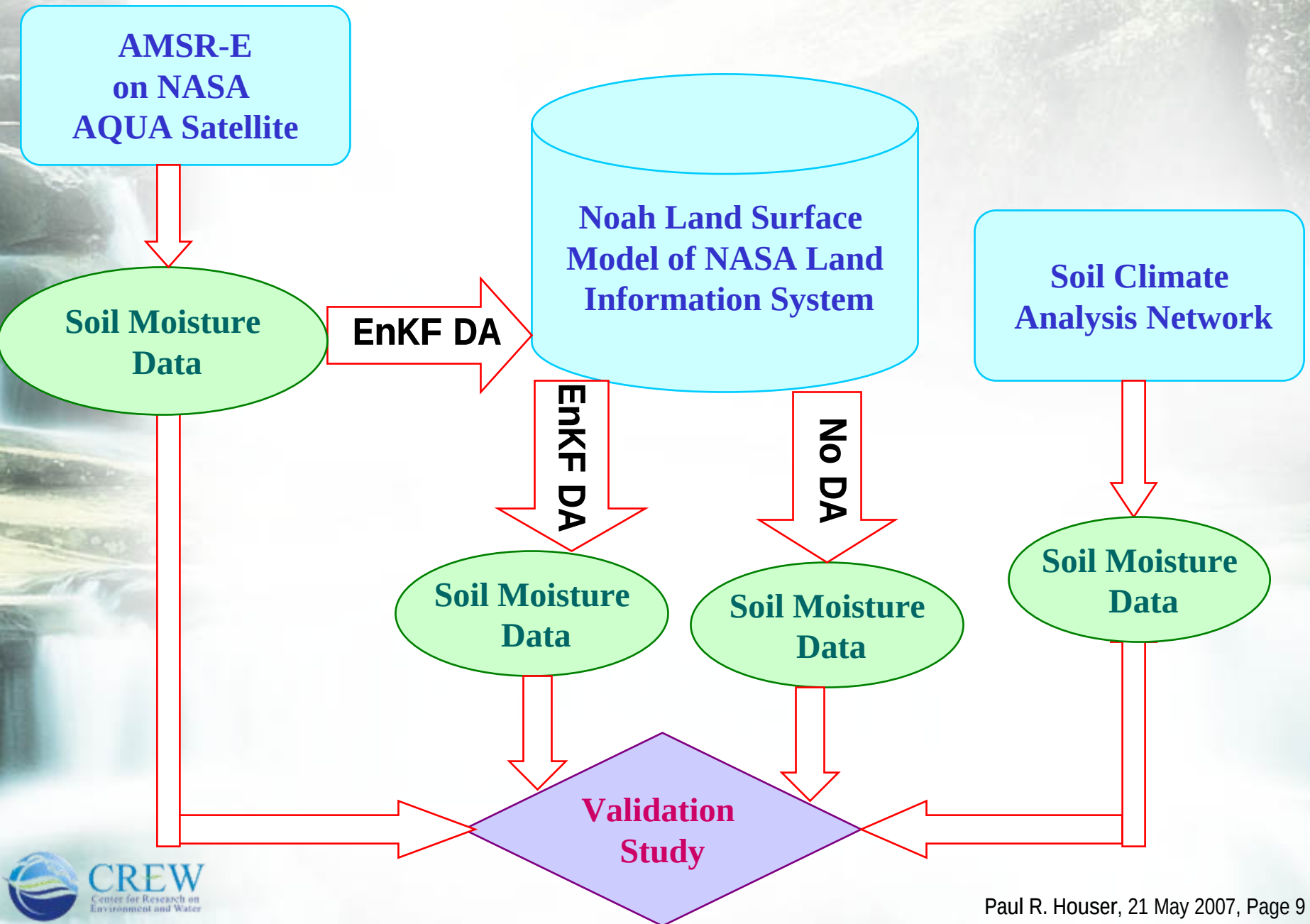
- Soil Climate Analysis Network (SCAN)
- Upper about 5cm, point scale, hourly

Ames, IA
(42^{0}01' N, 93^{0}44' W)



Walnut Gulch, AZ
(31^{0}44' N, 110^{0}03' W)

Soil Moisture Data Assimilation and Validation



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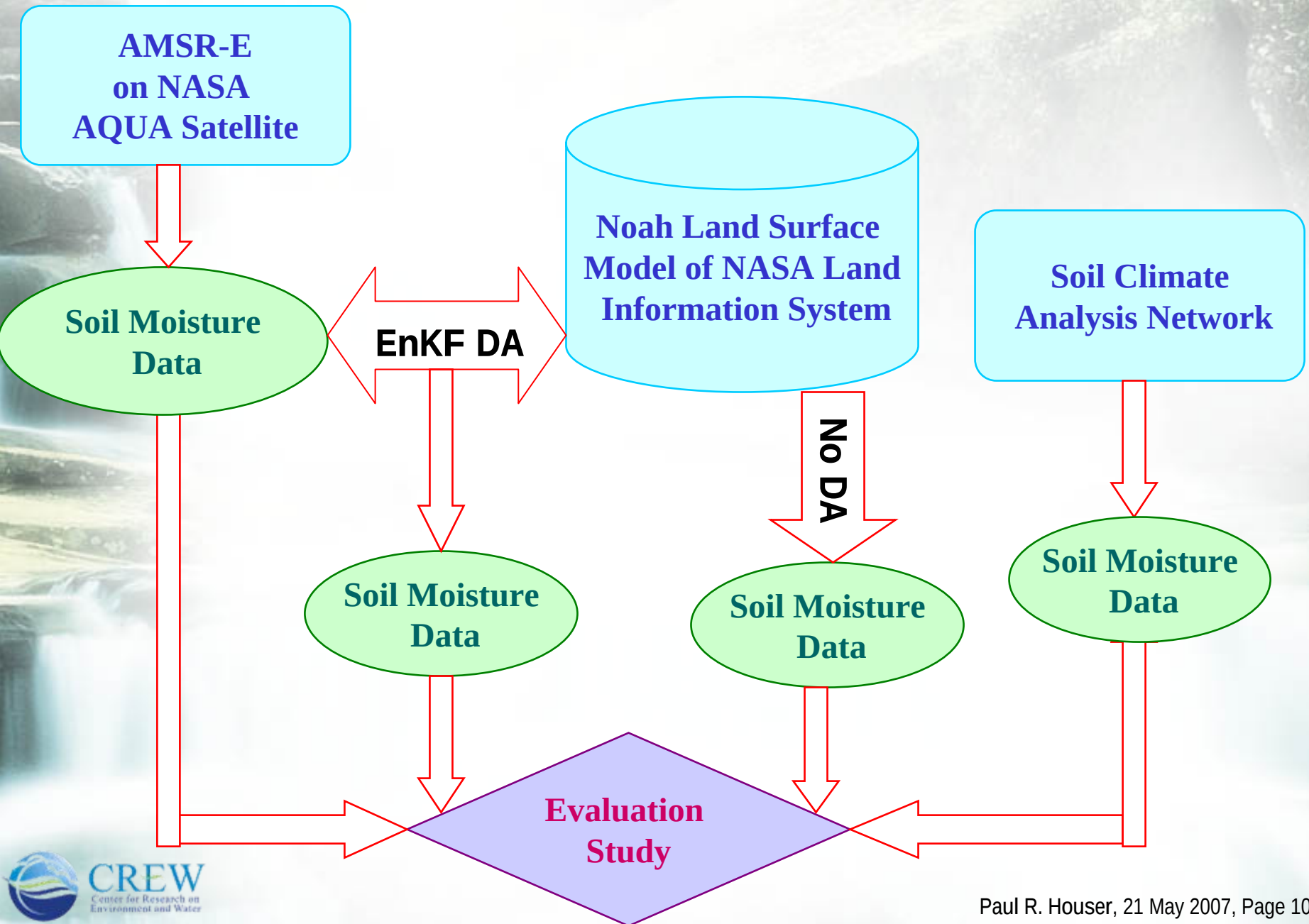
Soil Moisture Data Assimilation and Evaluation



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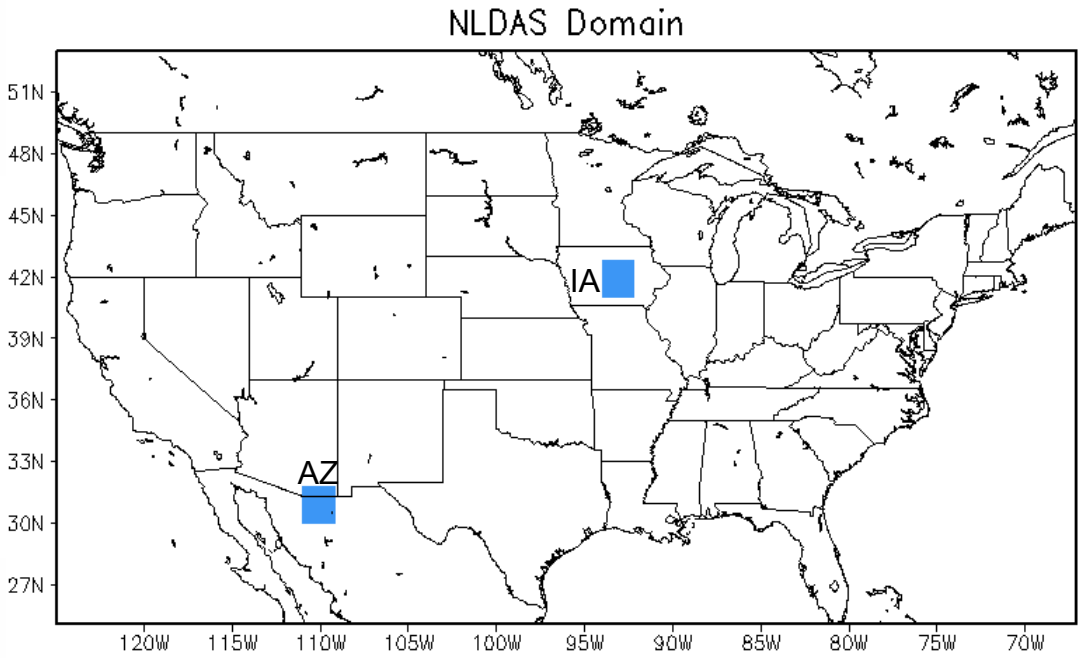
Experimental Design

Long-term data assimilation simulations



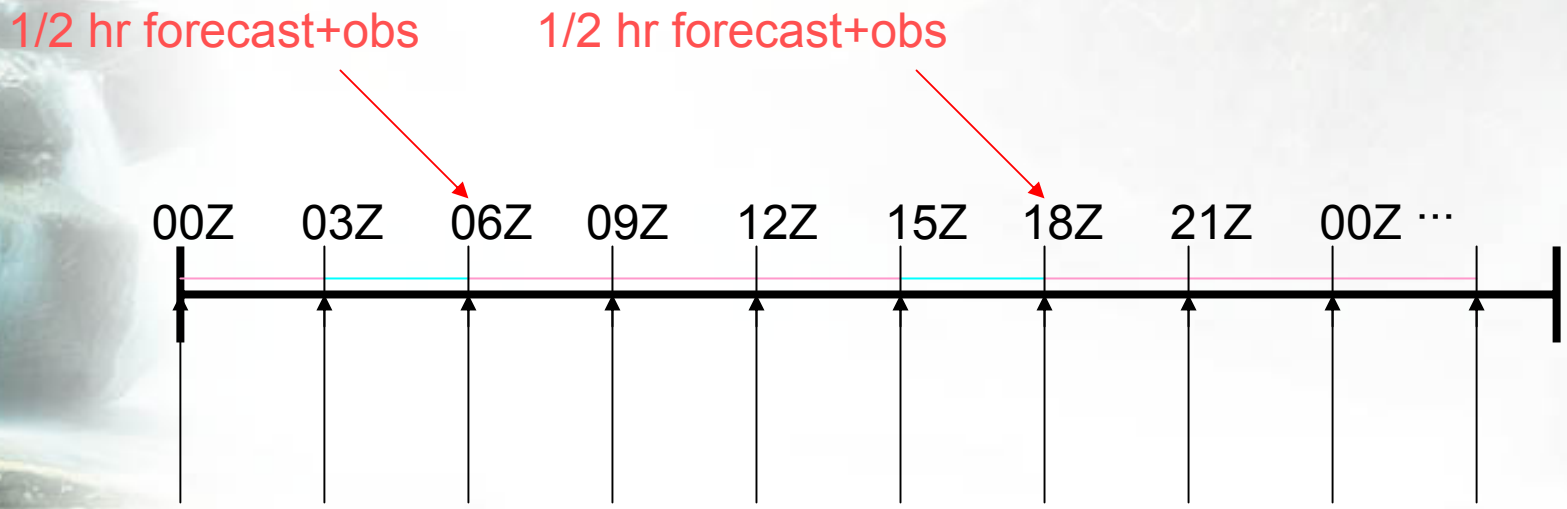
1/8th Degree (~15 km) over central North America

runs from 18 June 2002 to 17 June 2006

Three experiments:

1. Control run -- Noah LSM simulation
2. EnKF DA with unscaled AMSR-E SM (two boxes only)
3. EnKF DA with scaled AMSR-E SM (two boxes only)

Assimilation of AMSR-E soil moisture data

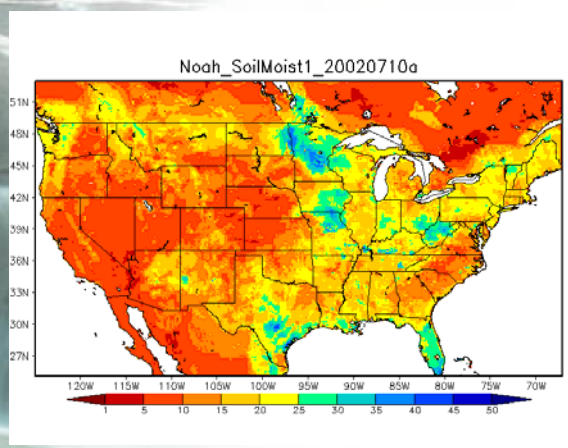


1/2 hour time step, 3 hourly output, and 5 ensemble members

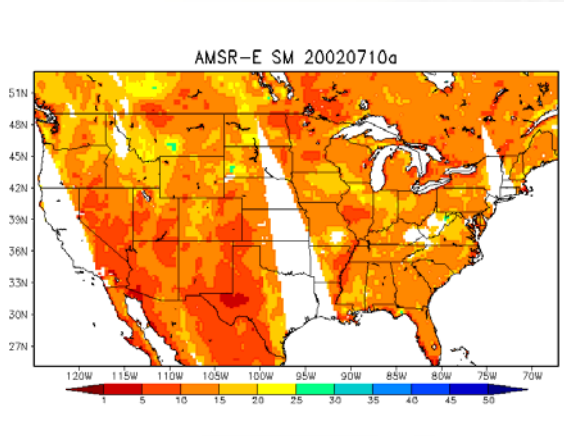
Data assimilation frequency is twice daily at 06Z and 18Z, with 2922 assimilation events over a fixed time period, from 18 June 2002 thru 17 June 2006. DA will not be “turned on” until observation is available we take the ensemble mean as first guess for next time step initial conditions

EnKF Assimilation of AMSR-E SM Retrievals

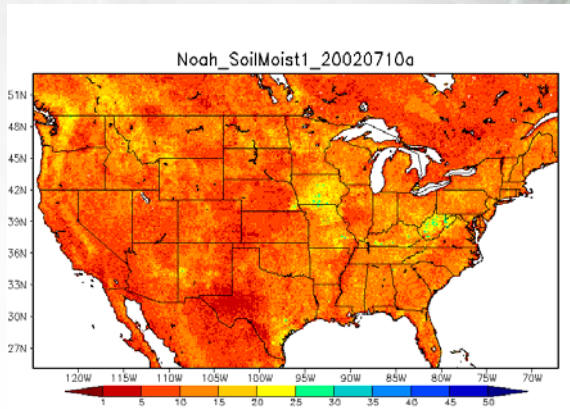
Noah LSM RUN



AMSR-E SM

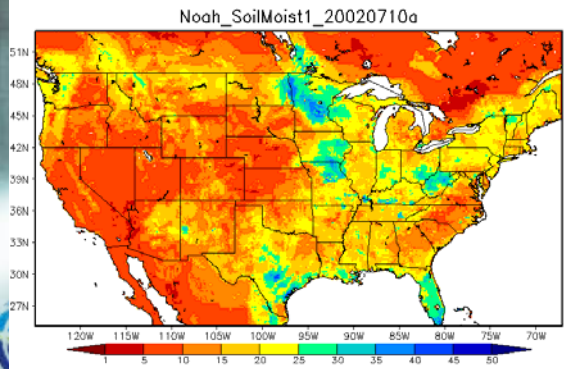


EnKF Assimilation(TEST2)

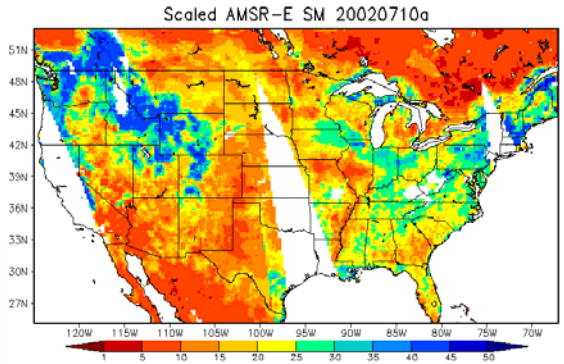


EnKF Assimilation of Scaled AMSR-E SM Retrievals

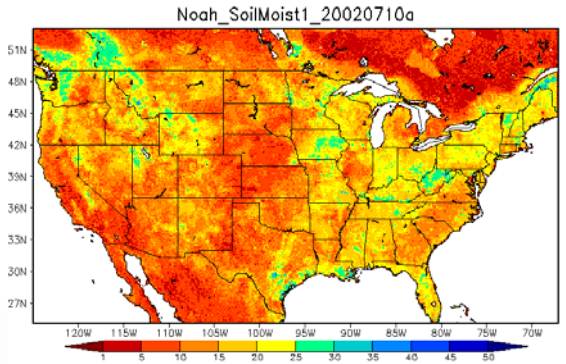
Noah LSM RUN



Scaled AMSR-E SM



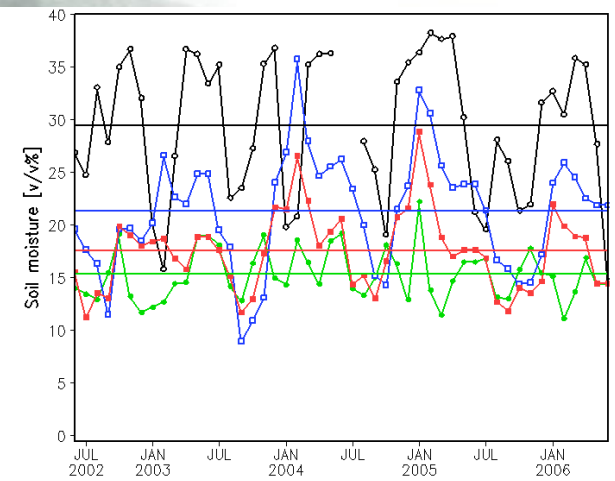
EnKF Assimilation (TEST2)



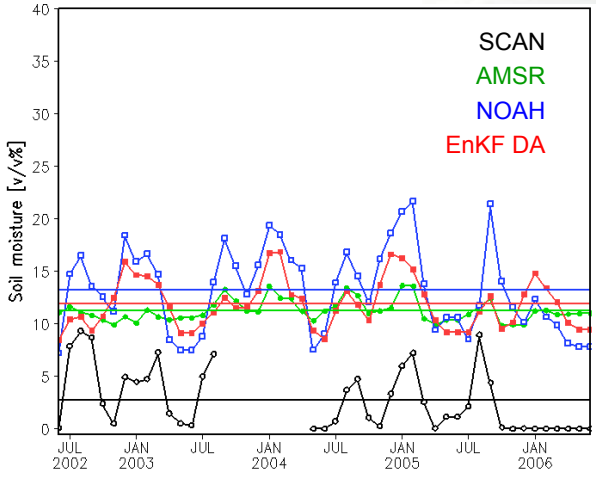
Data Assimilation Evaluation against Observations at Two SCAN Sites

Assimilation of Unscaled AMSR-E Soil Moisture

Ames, IA

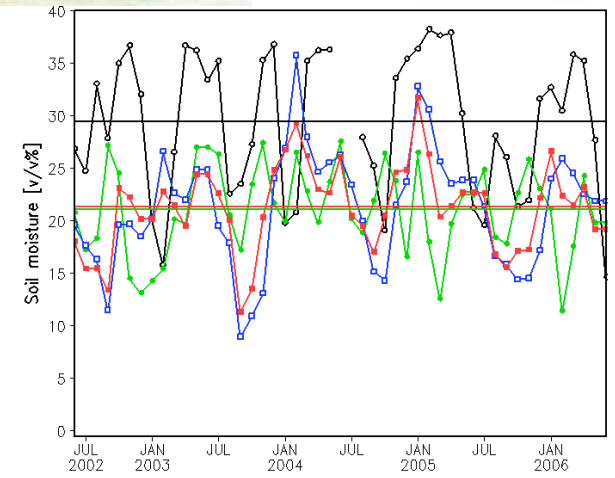


Walnut Gulch, AZ

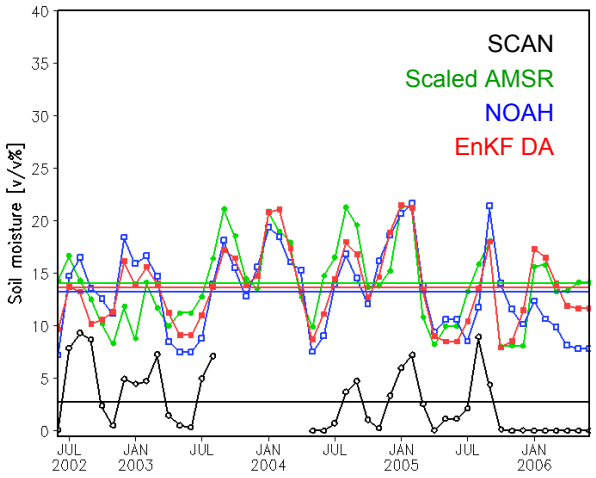


Assimilation of Scaled AMSR-E Soil moisture

Ames, IA



Walnut Gulch, AZ



- Model simulations, satellite and ground observations are significantly different from one another (much uncertainty in soil moisture estimation).
- CDF matching provides compatible/corrected AMSR-E soil moisture to Noah LSM soil moisture.
- Resulting estimates from EnKF are sensitive to observations applied in DA. Therefore, the accuracy of the resulting estimates would be limited by uncertainty in observations and model. In this study, the biased AMSR-E data degrade the performance of EnKF DA.
- EnKF DA validation and real application are challenging due to mismatched scales in model simulations, satellite observations and in situ observations.

Ames, Iowa

SM (%v/v) (6/18/2002 -6/17/2006)	SCAN SM ~5cm	AMSR-E ~2cm	Scaled AMSR-E 2cm	NOAH 2cm	AMSR-E SM DA ~2cm	Scaled AMSR-E SM DA ~2cm
Mean	29.42	15.35	21.11	21.33	17.57	21.32
Standard Deviation	6.74	2.45	4.24	5.40	3.77	4.11
Bias (wrt AMSR-E SM)	14.07	0	5.76	5.98	2.22	5.97
Correlation (wrt AMSR-E SM)	0.128	1.00	0.915	0.176	0.367	0.436
Bias (wrt SCAN SM)	0	-14.07	-8.31	-8.09	-11.85	-8.1
Correlation (wrt SCAN SM)	1.00	0.128	0.008	0.247	0.364	0.311

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Walnut Gulch, Arizona

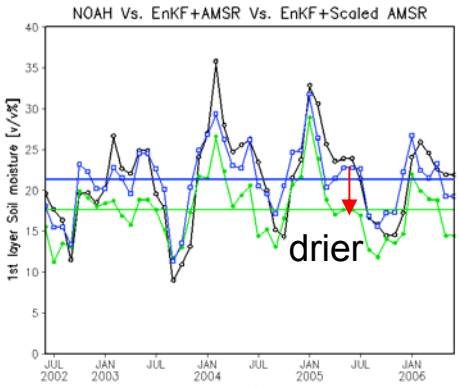
SM (%v/v) (6/18/2002 -6/17/2006)	SCAN SM ~5cm	AMSR-E ~2cm	Scaled AMSR-E 2cm	NOAH 2cm	AMSR-E SM DA ~2cm	Scaled AMSR-E SM DA ~2cm
Mean	2.73	11.27	14.04	13.24	11.90	13.65
Standard Deviation	3.04	1.04	3.88	4.06	2.36	3.71
Bias (wrt AMSR-E SM)	-8.54	0	2.77	1.97	0.63	2.38
Correlation (wrt AMSR-E SM)	0.46	1.00	0.98	0.66	0.49	0.83
Bias (wrt SCAN SM)	0	8.54	11.31	10.51	9.17	10.92
Correlation (wrt SCAN SM)	1.00	0.46	0.43	0.60	0.30	0.43

Impact of EnKF DA:

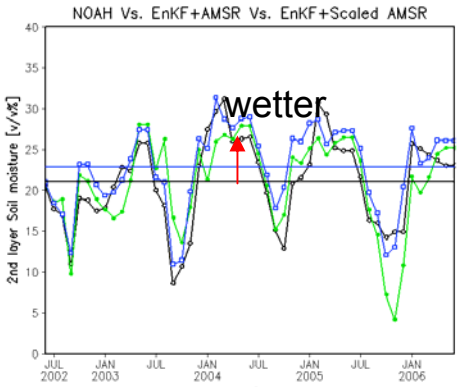
Corr1=corr(NOAH, EnKF+ Unscaled AMSR) Corr2=corr(NOAH, EnKF+ Scaled AMSR)

Ames, Iowa

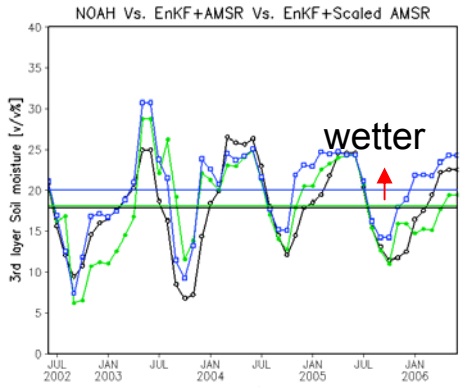
1st layer SM
Corr1=0.825,Corr2=0.862



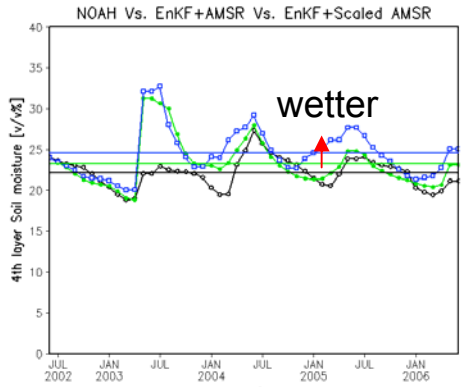
2nd layer SM
Corr1=0.773,Corr2=0.896



3rd layer SM
Corr1=0.735,Corr2=0.857

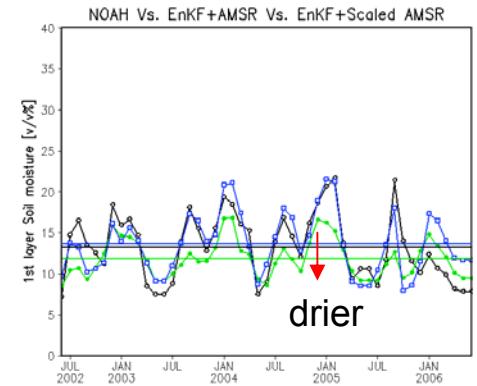


4th layer SM
Corr1=0.498,Corr2=0.450

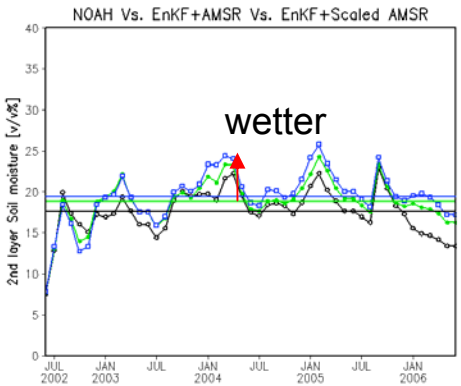


Walnut Gulch, Arizona

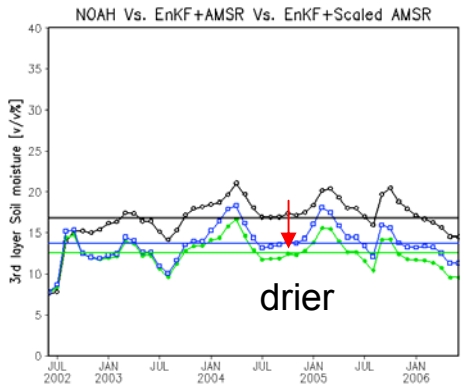
1st layer SM
Corr1=0.763,Corr2=0.809



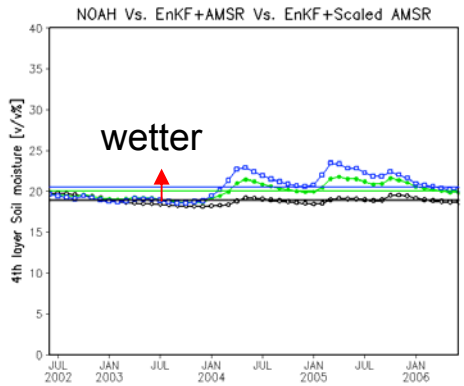
2nd layer SM
Corr1=0.913,Corr2=0.865



3rd layer SM
Corr1=0.807,Corr2=0.865



4th layer SM
Corr1=0.445,Corr2=0.287

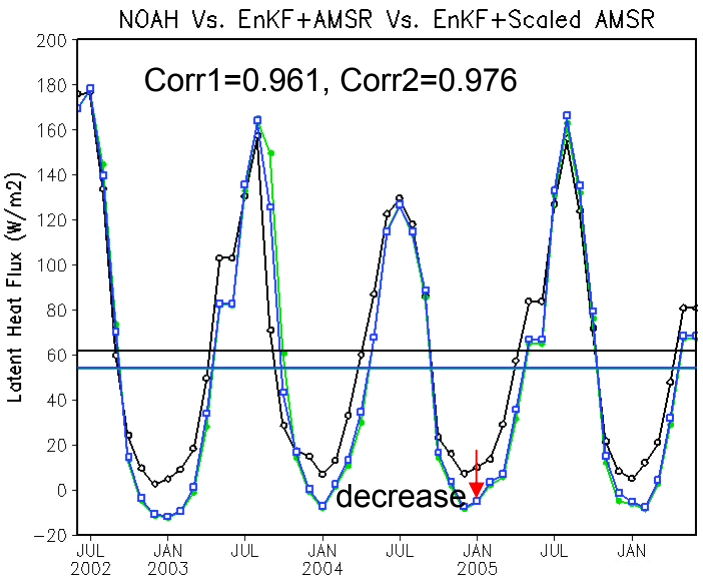


Impact of EnKF DA:

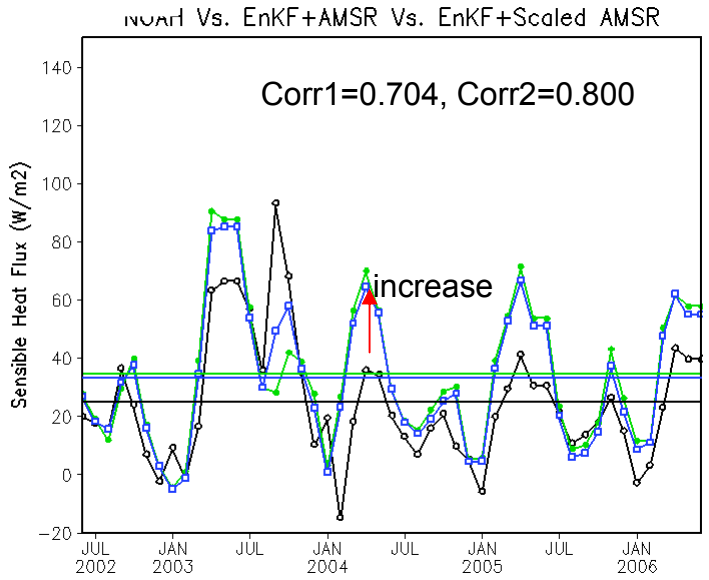
Corr1=corr(NOAH, EnKF+ Unscaled AMSR) Corr2=corr(NOAH, EnKF+ Scaled AMSR)

Ames, Iowa

LHF

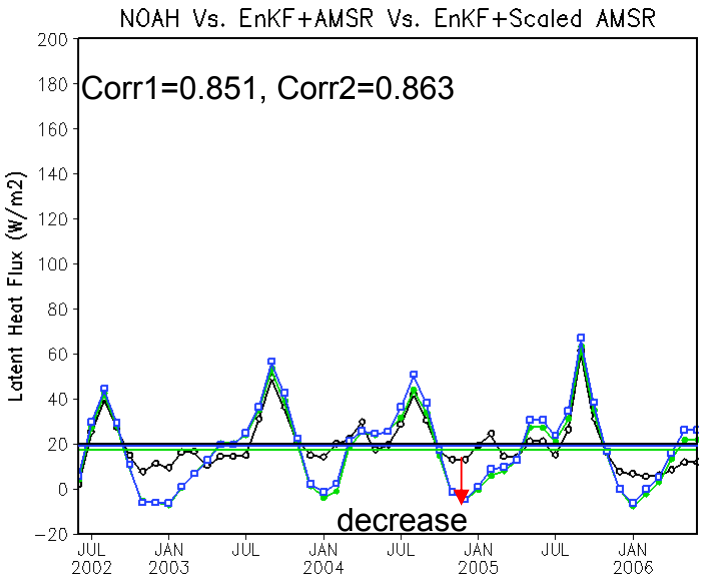


SHF

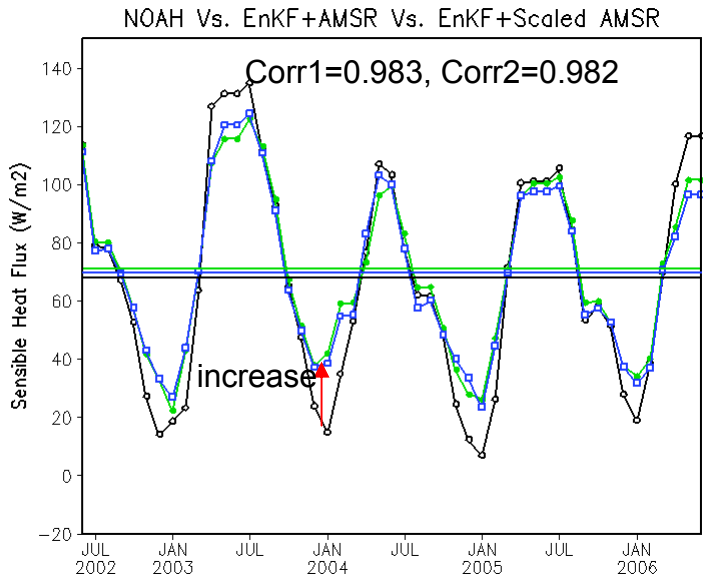


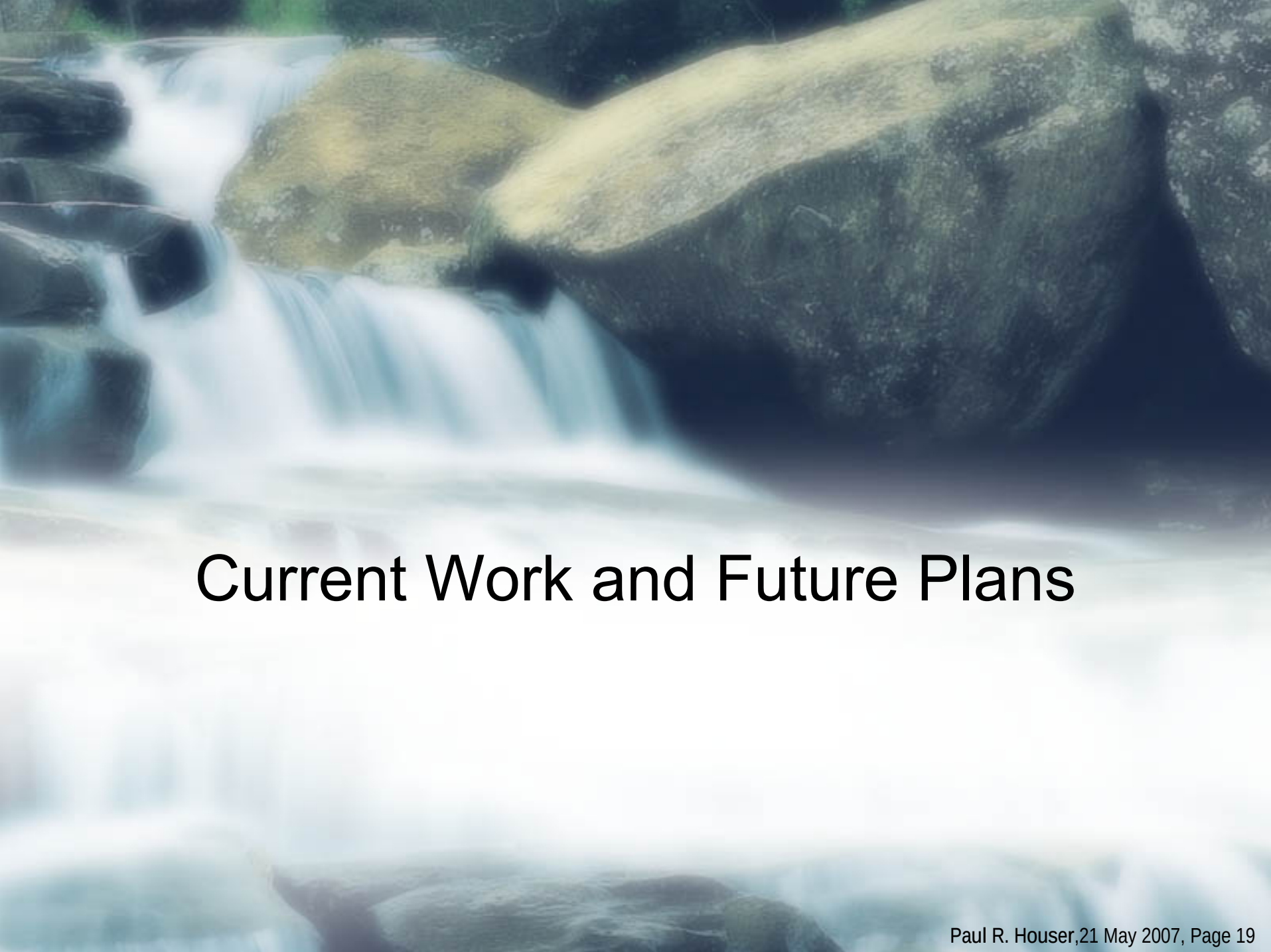
Walnut Gulch, Arizona

LHF



SHF





Current Work and Future Plans

Bias Correction Method (*Dee and Todling's, 1998, 2000*)

Estimating Bias:

$$b_t^f = \mu b_{t-1}^a$$

$$b^a = b^f - L[y^o - (Hx^f - Hb^f)]$$

$$L = P^{bias} H^T (HP^{bias} H^T + HP^f H^T + R)^{-1}$$

Correcting Bias:

$$\tilde{x}^f = x^f - b^a$$

$$x^a = \tilde{x}^f + K[y^o - H\tilde{x}^f]$$

$$K = P^f H^T (HP^f H^T + R)^{-1}$$

a. Full Scheme

b. Approximate Scheme

$$P^{bias} = \gamma * P^f$$

$$L = \alpha * K$$

$0 < \mu, \gamma, \alpha \leq 1$ tunable bias correction parameters

Bias correction experiment

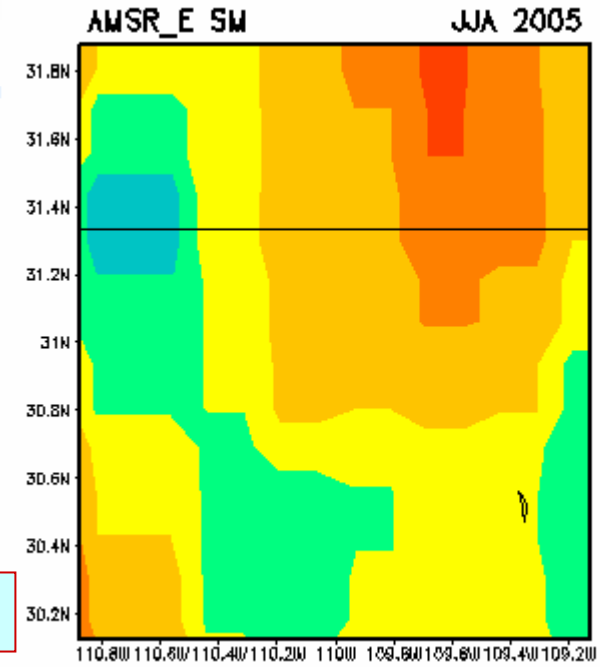
- Implement the bias estimation and correction scheme in LIS-Noah and assimilate AMSR-E data
- Assume that AMSR-E soil moisture observations are unbiased and represent the real land surface conditions, whereas the Noah has its own biased climatology.
- Assimilation period: 6/1/2005–8/31/2005. Spin up from 1/1/2000 till 6/1/2005, and restart from 6/1/2005 and start data assimilation
- Running over the NLDAS domain
- 20 ensemble members
- Experiments:
  - DA runs without bias correction scheme (No BEC)
  - DA runs with Full bias correction scheme (Full BEC)
  - DA runs with Approximate correction scheme (Approx BEC)

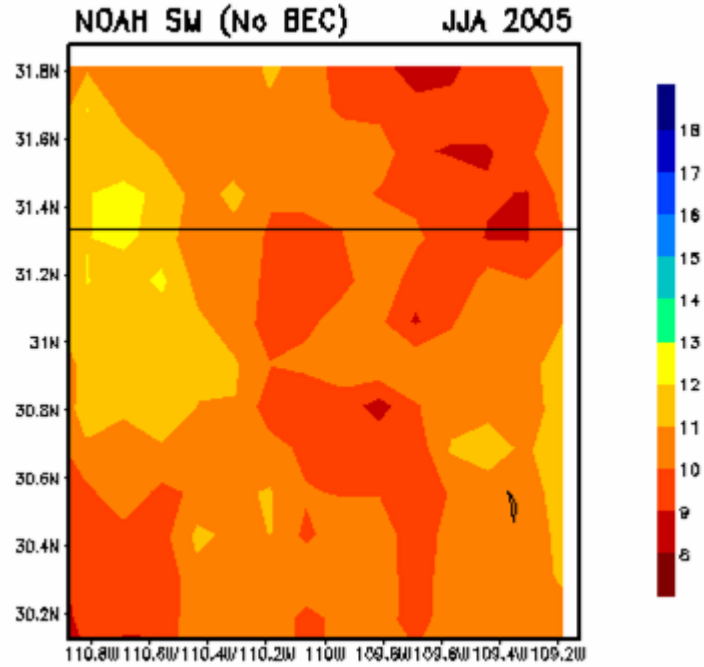
Assume:

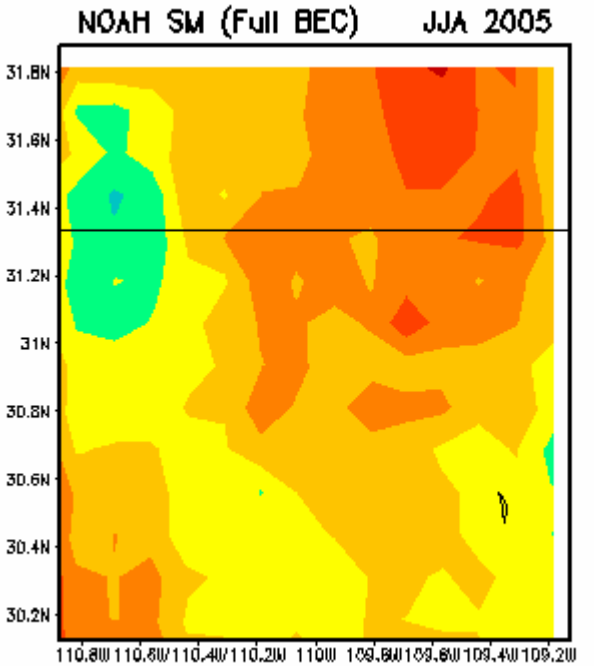
AMSR_E=Truth

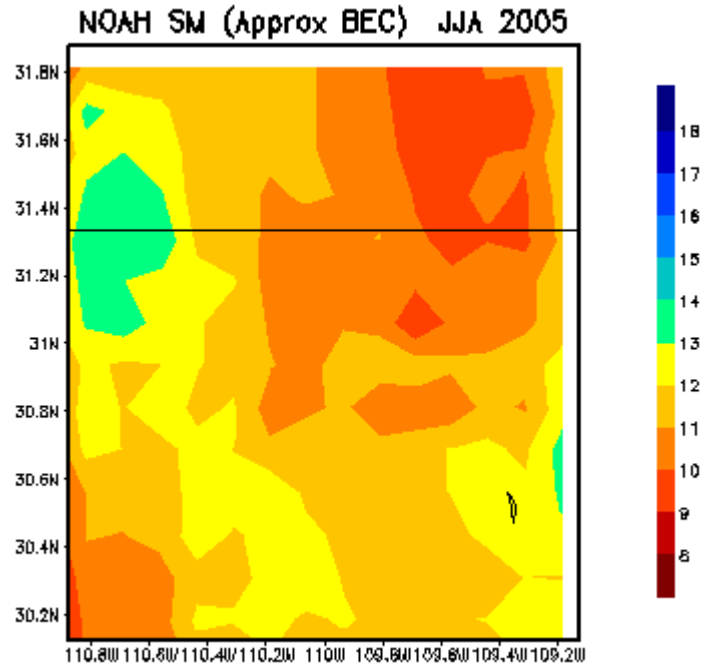
NOAH=Faulty

AZ BOX









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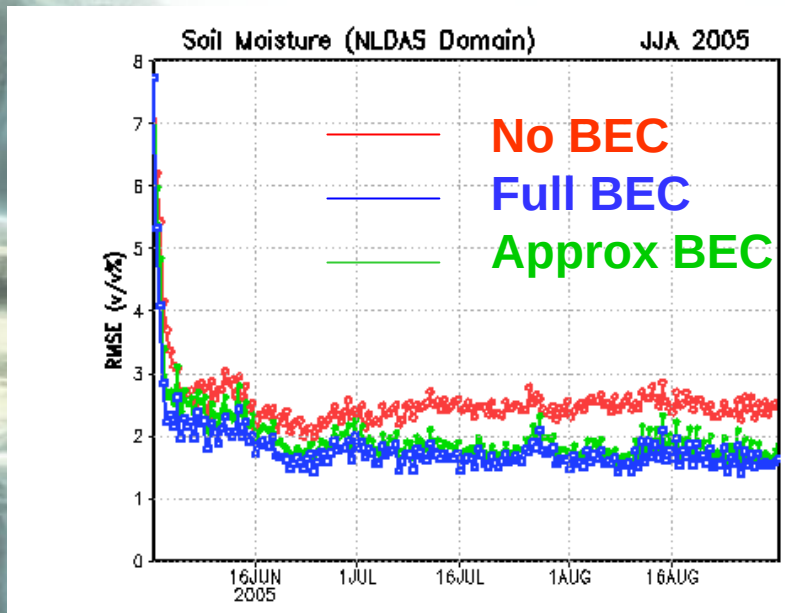
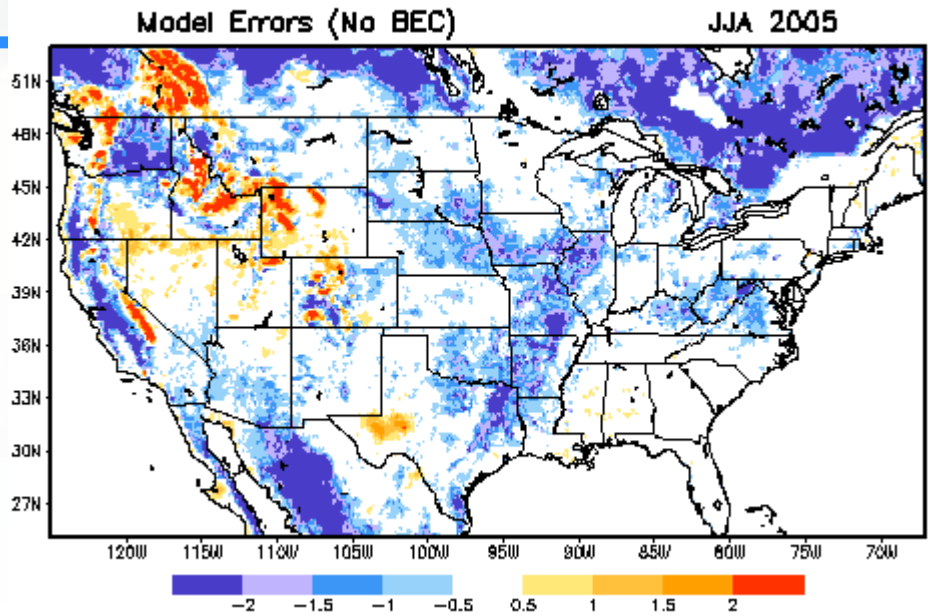
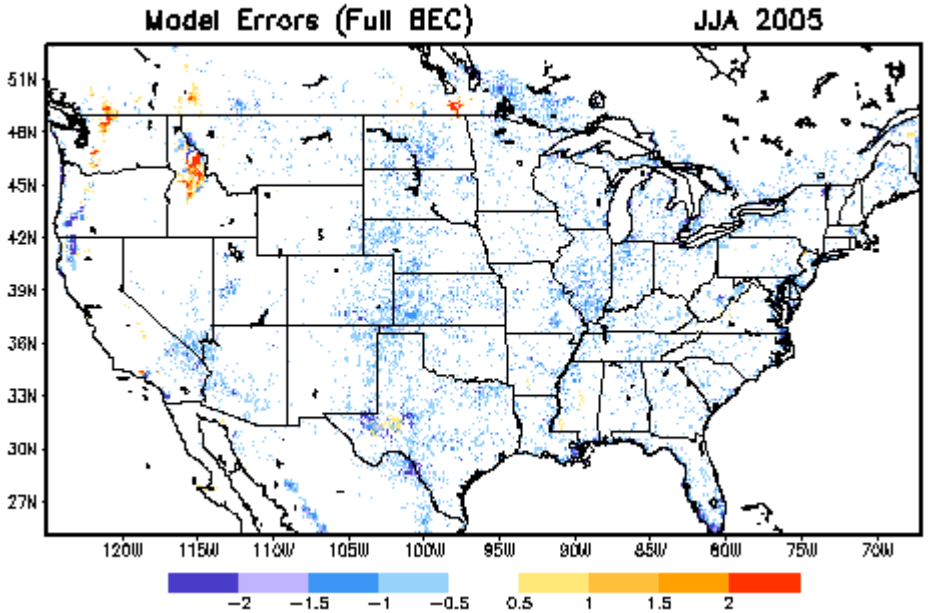
Bias correction comparison

- Model error ≈ Noah model forecast - AMSR_E retrieval







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Bias correction comparison

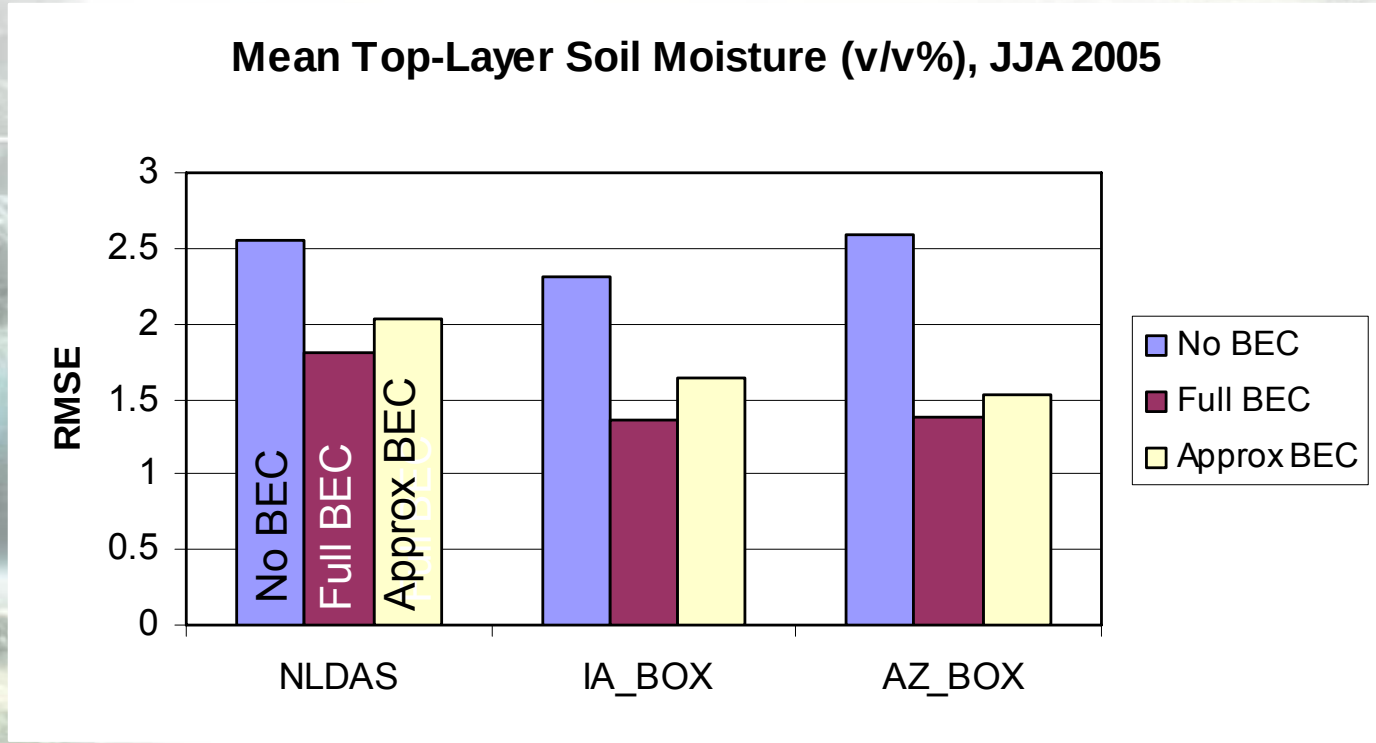
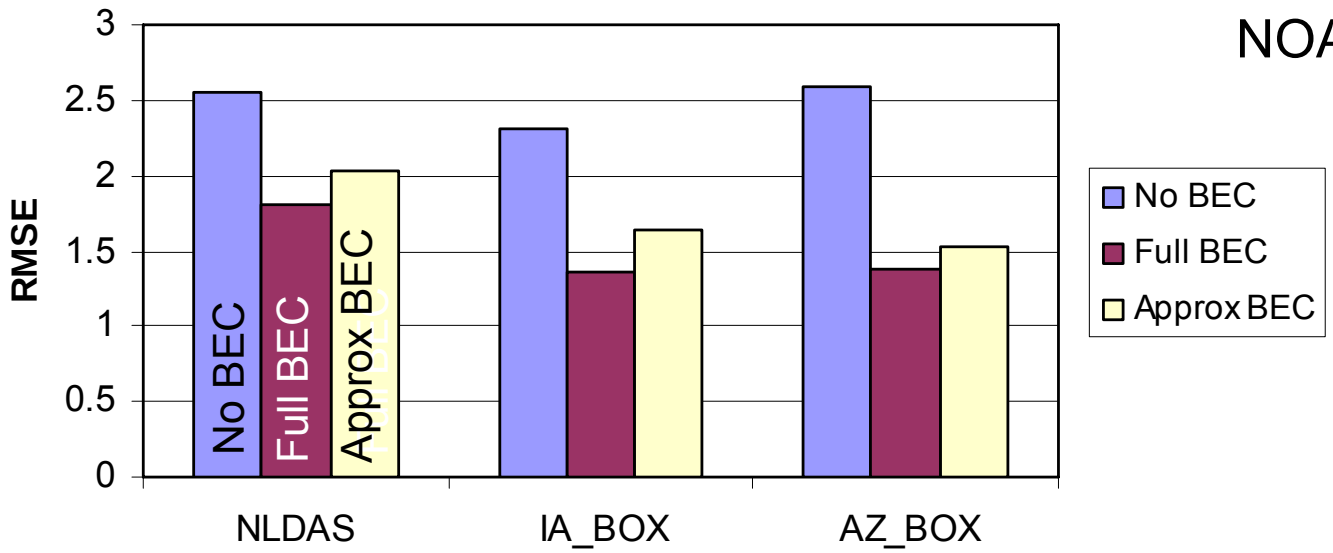


Table. Model Error Comparison of Surface Soil Moisture (Units: v/v%).

Experiments	Model Error			RMSE		
	NLDAS	IA_BOX	AZ_BOX	NLDAS	IA_BOX	AZ_BOX
No bias correction	-0.6684	-0.9782	-1.9523	2.5493	2.3058	2.5953
Full bias correction	-0.4279	-0.4098	-0.5683	1.8033	1.3582	1.3733
Approximate bias correction	-0.5556	-0.5742	-0.6538	2.0257	1.6398	1.5266

Bias correction comparison



Assume:

AMSR_E=Truth

NOAH=Faulty

Table. Model Error Comparison of Surface Soil Moisture (Units: v/v%).

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Summary of Results

- This bias correction algorithm can statistically estimate and correct Noah model errors without changing model itself.
- Our results have shown that bias correction at every analysis cycle has a significant positive impact on the EnKF.
- Additional computational cost is insignificant when the this simplified bias estimation and correction procedure are added in the EnKF DA procedures. Approximated BC scheme should be more efficient.

Future Plans

- Prepare for global data assimilation: testing in an operational testbed-Expand to assimilate Global AMSR_E retrievals intoT126/T382 spectral Noah LSM
- Improve the performance of the ensemble Kalman Filter application
  - Expand AMSR-E scaling philosophy using the Copula statistical tool
  - Optimize initial perturbations for EnKF assimilation
- Directly assimilate SCAN soil moisture as a supplement of current study

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Current LIS-Noah-EnKF

- ✓ NLDAS domain
- ✓ 0.125 lat/lon resolution (464, 224)
- ✓ Noah LSM
- ✓ Bias correction to observed AMSR with CDF matching
- ✓ Bias correction to model errors

Anticipated in Future LIS-Noah-ENKF

- ➢ Global
- ➢ T126 CFS/T382GFS
- ➢ Noah LSM
- ➢ Include above implementations

** Not yet available

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Global Data Assimilation

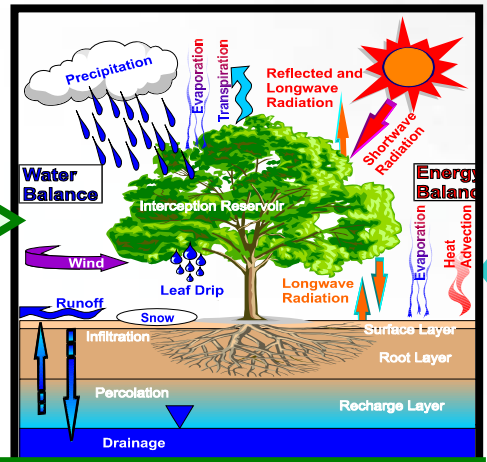
Uncoupled Mode

Coupled Mode

Global Reanalysis (GR Forcing)

AMSR_E Soil Moisture

EnKF DA



LIS -based T382/T126 Noah LSM

ESMF

WRF

LSM Initial Conditions (Assimilated SM, etc)

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