Land Surface Data Assimilation

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CREW Center for Research on Environment and Water

GEORGE MASON UNIVERSITY

Water Cycle Research Making a Difference

Acknowledging:
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Land Data Assimilation: Overview

Ultimate Goal: Operationally **obtain high quality land surface conditions and fluxes.**

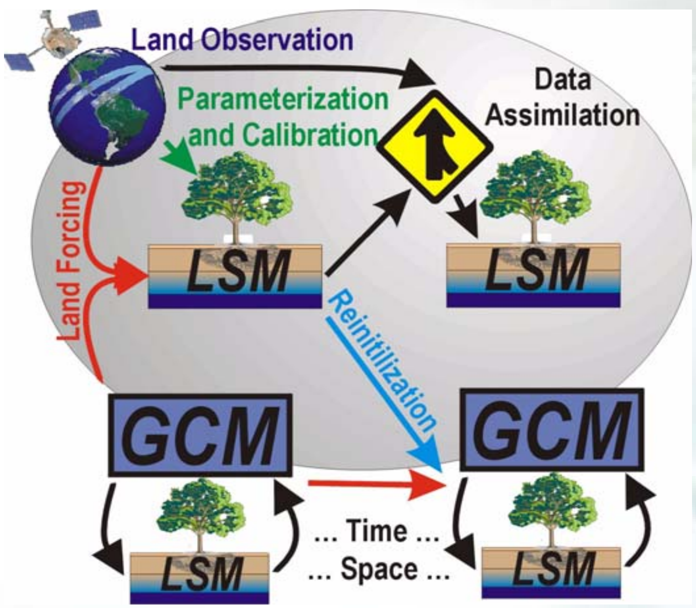
- Optimal integration of land surface observations and predictions.
- Continuous in time & space; local to global scales; retrospective, real-time, and forecasts.

Contributions:

- 4DDA Fields: 4DDA process and new merged data fields useful for research (**process understanding**), applications (**floods/agriculture/drought**), and **weather/climate prediction**.
- Model refinement: Constant confrontation with observations will force model improvements.
- Forecast improvement: Better initial conditions and improved models, predictions of weather, climate, and hydrologic phenomena on various timescales will improve.
- Observation needs: Define characteristics of most important observations, establish observation error criteria.

Components:

- **Observation**: Land surface forcing, storages(states), fluxes, and parameters (**calibration**).
- **Simulation:** Land system process models (Hydrology, Biogeochemistry, etc.).
- **Assimilation:** Short-term state constraints=Energy and Water Storage (Temperature, Snow, Soil Moisture).



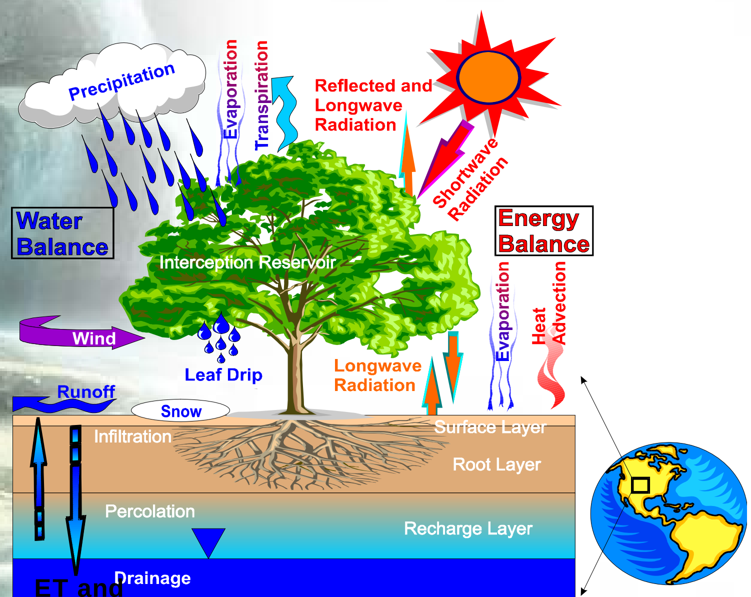
Background: Land Surface Modeling

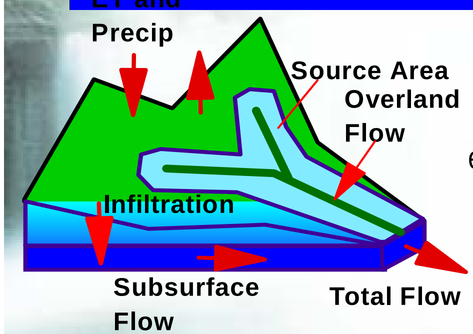
Land Surface Prediction: Accurate land model prediction is essential to enable data assimilation methods to propagate or extend scarce observations in time and space. Based on *water and energy balance*.

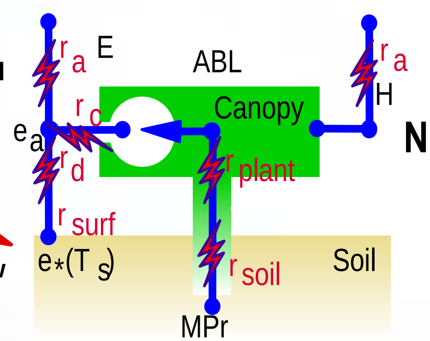
Input - Output = Storage Change

$P + Gin - (Q + ET + Gout) = \Delta S$

$Rn - G = Le + H$







Dominant land surface horizontal processes:

- Groundwater movement
- Horizontal temperature/water diffusion/advection
- Runoff

Assume 1-D Physics at mesoscales (greater than 100m)

- Gravity and gradient driven water & energy movement
- Horizontal processes very weak
- Observed horizontal correlations related to forcing
- Perturbation in state will not change neighbor

Ramifications of 1-D assumption:

- 1-D (vertical) assimilation very cheap
- No account for horizontal correlation in observation/model
- No “advection” of observation information horizontally

Land observations mostly at surface

- Surface skin temperature, soil moisture
- Snow cover
- Want to retrieve full root-zone profile; longer memory states

Nonlinear Processes

- Freeze/Thaw, Infiltration, Interception, Snow Cover, Leaf Fall
- Difficult to linearize, derive adjoint, etc.

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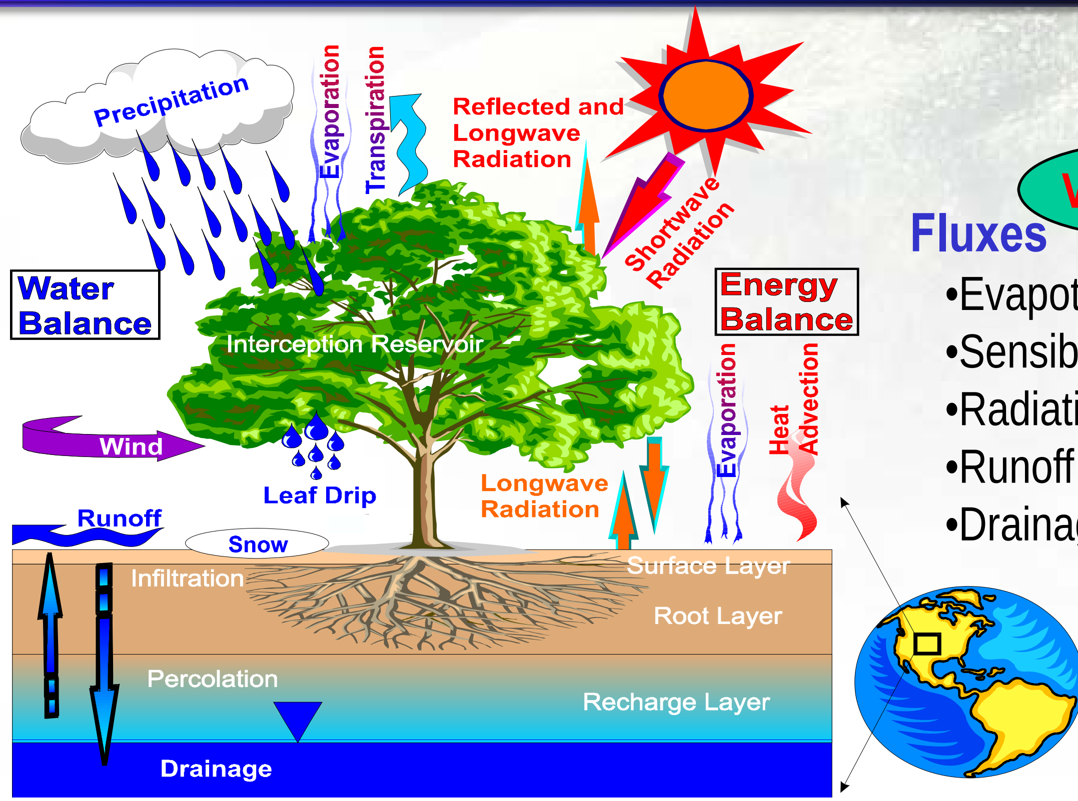
Land Surface Observation

Off-line LDAS

Forcing
- Precipitation
- Wind
- Humidity
- Radiation
- Air Temperature

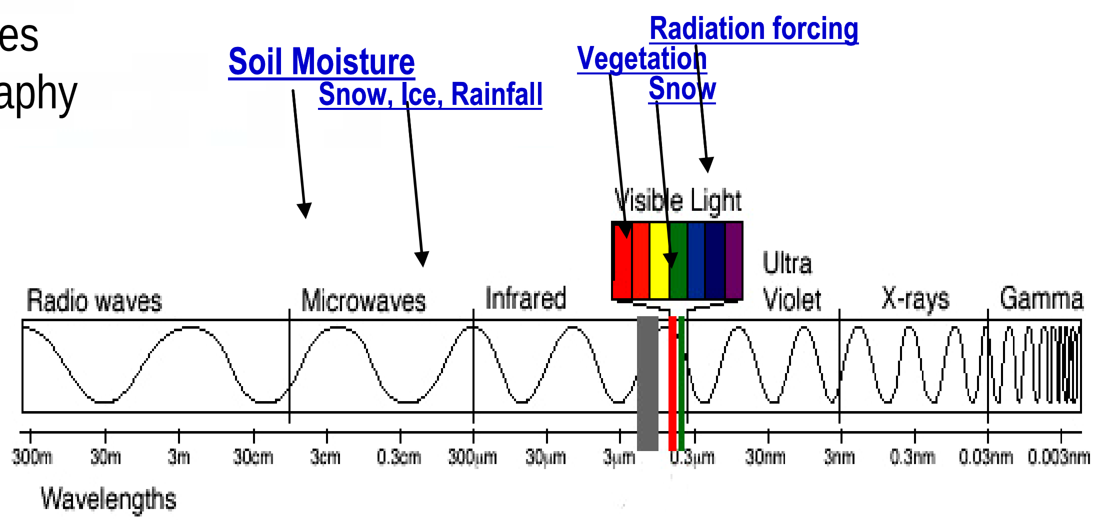
Calibration

Parameters
- Soil Properties
- Vegetation Properties
- Elevation & Topography
- Subgrid Variation
- Catchment Deline
- River Connectivity



Validation

Fluxes
- Evapotranspiration
- Sensible Heat Flux
- Radiation
- Runoff
- Drainage



Assimilation

States
- Soil Moisture
- Temperature
- Snow
- Carbon
- Nitrogen
- Biomass

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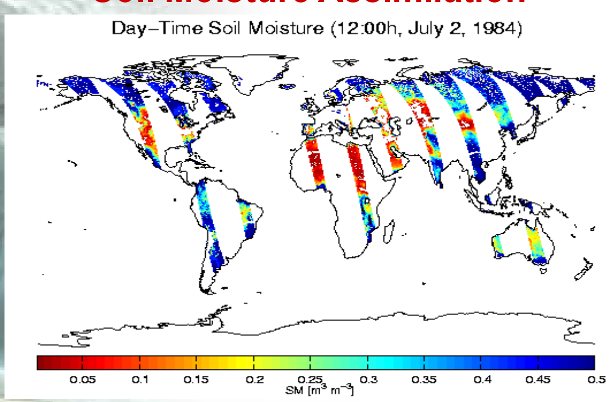
Land Surface Data Assimilation Summary

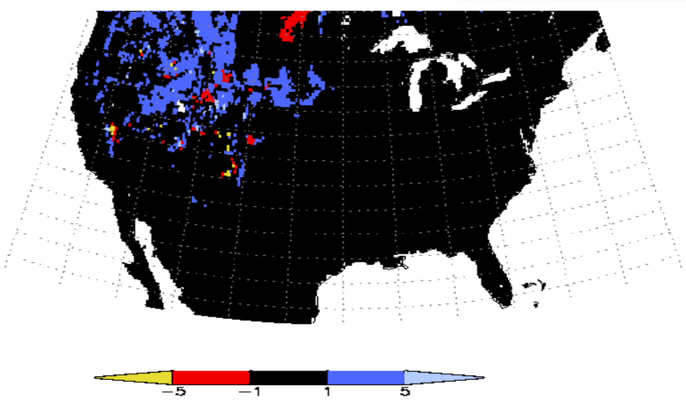
Data Assimilation merges observations & model predictions to provide a superior state estimate.

Remotely-sensed hydrologic **state** or storage observations (**temperature, snow, soil moisture**) are integrated into a hydrologic model to improve prediction, produce research-quality data sets, and to enhance understanding.

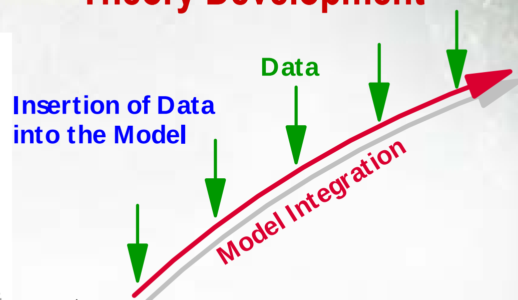
Soil Moisture Assimilation



Snow Cover Assimilation

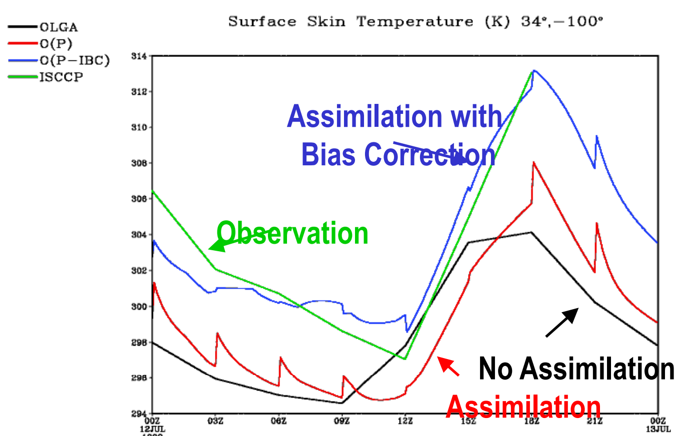


Theory Development

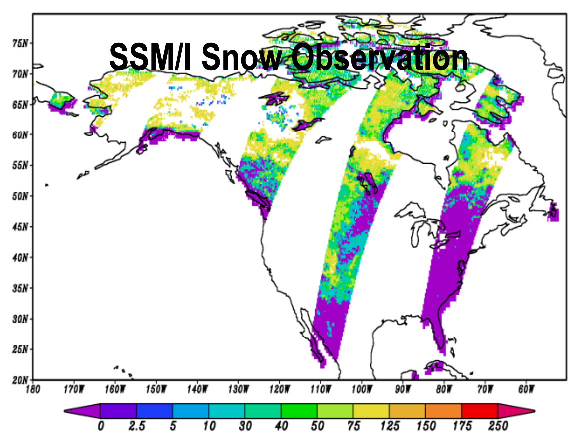


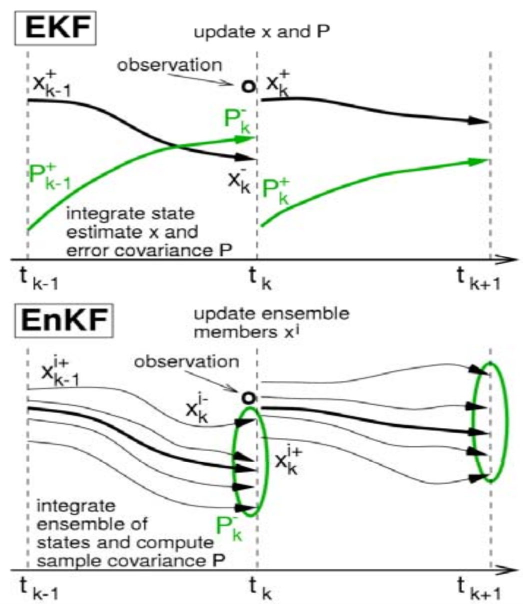
$$\partial x / \partial t = dynamics + physics + \Delta x$$

Skin Temperature Assimilation



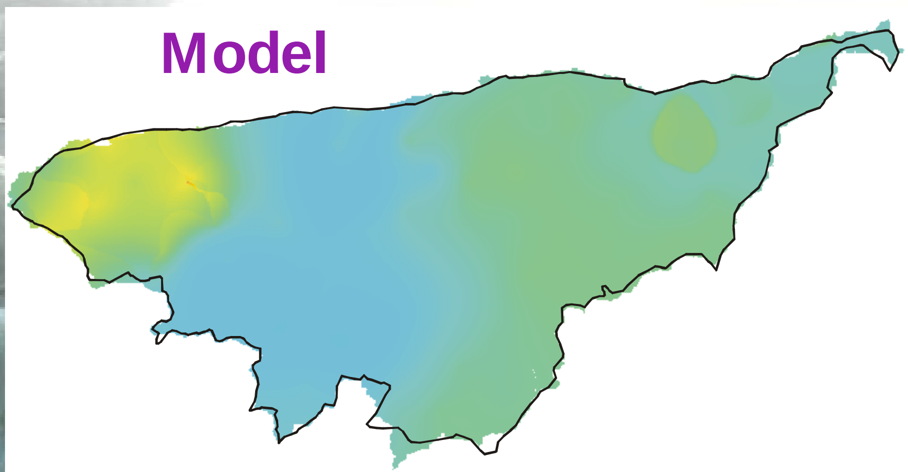
Snow Water Assimilation

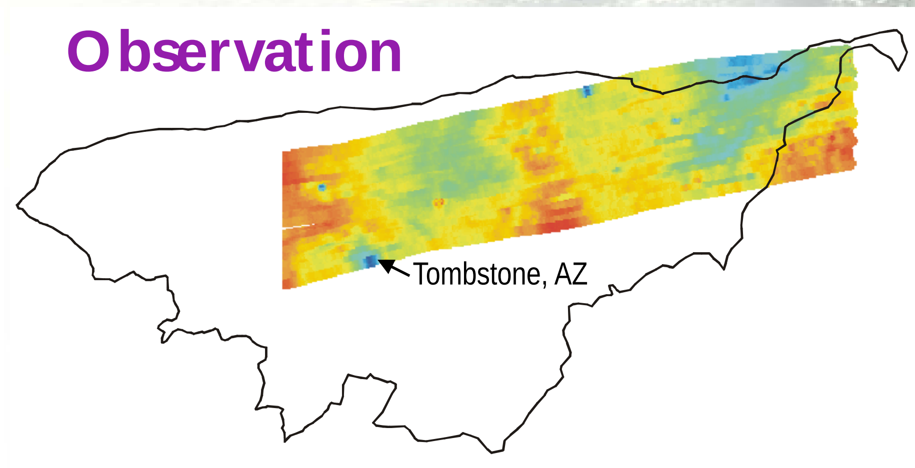


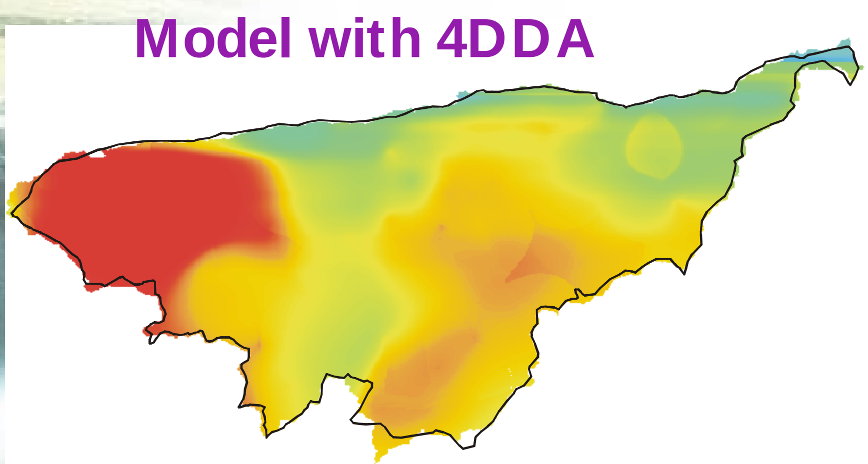


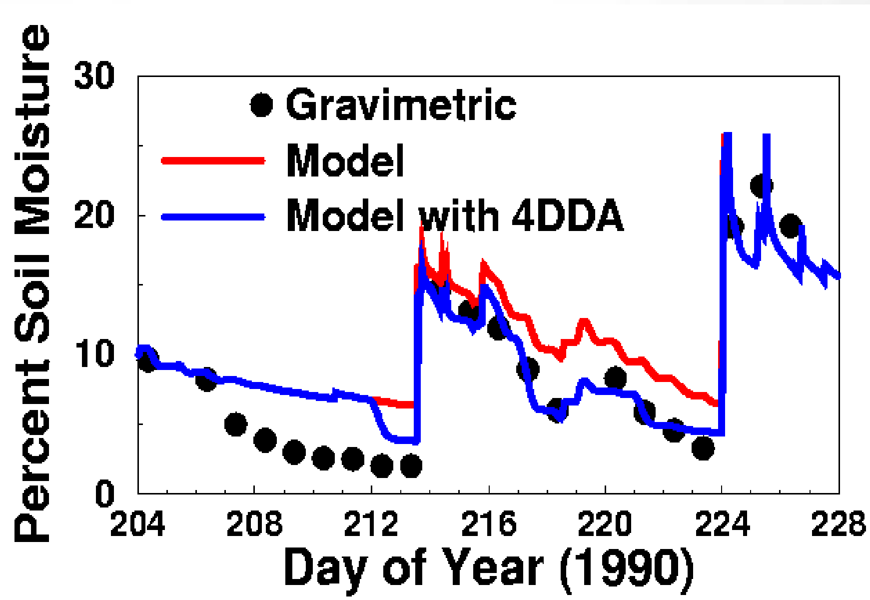
Also: Runoff, Evapotranspiration, groundwater (gravity), and Carbon Assimilation

Regional Scale: *Walnut Gulch (Monsoon 90)*









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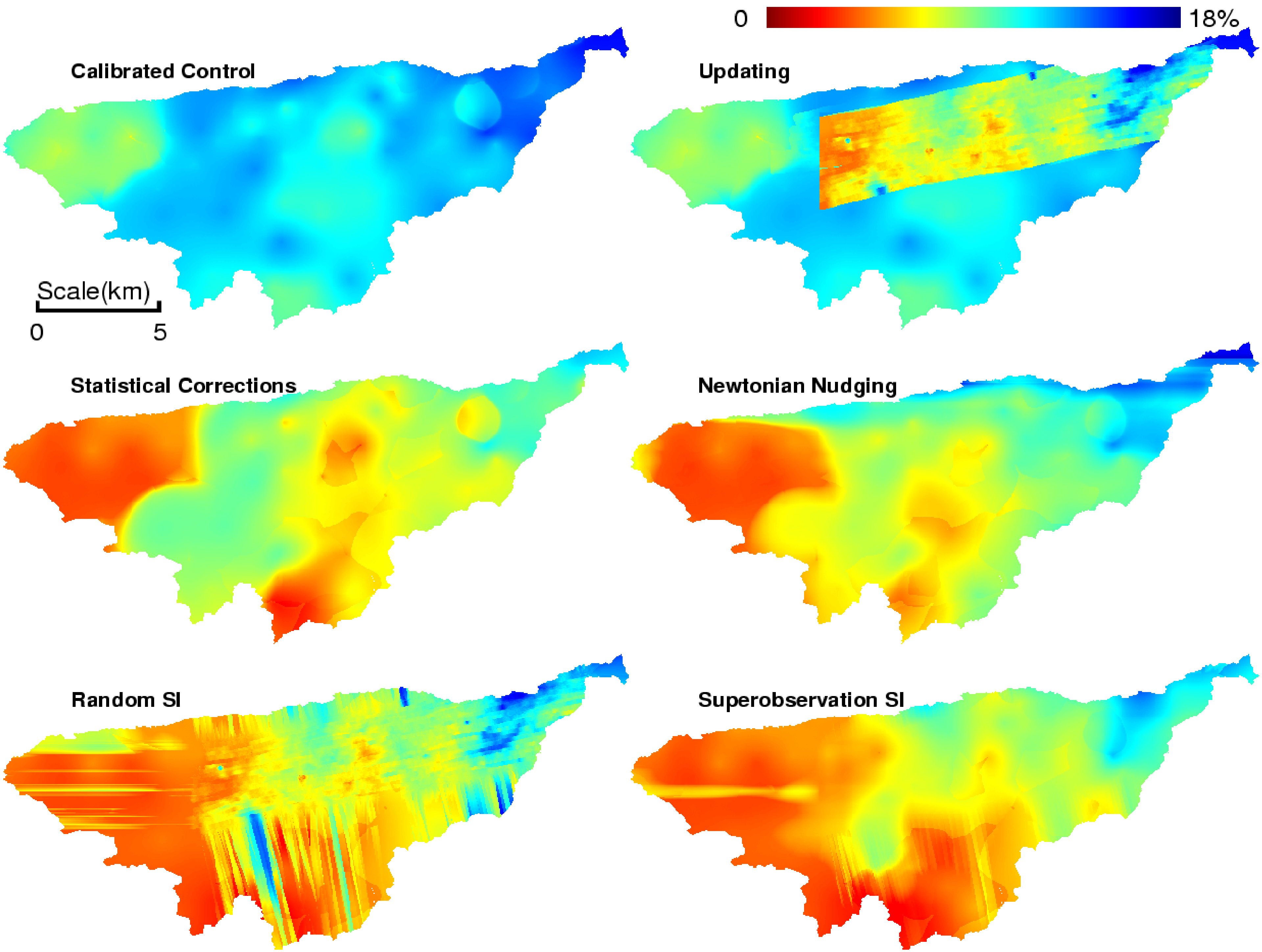
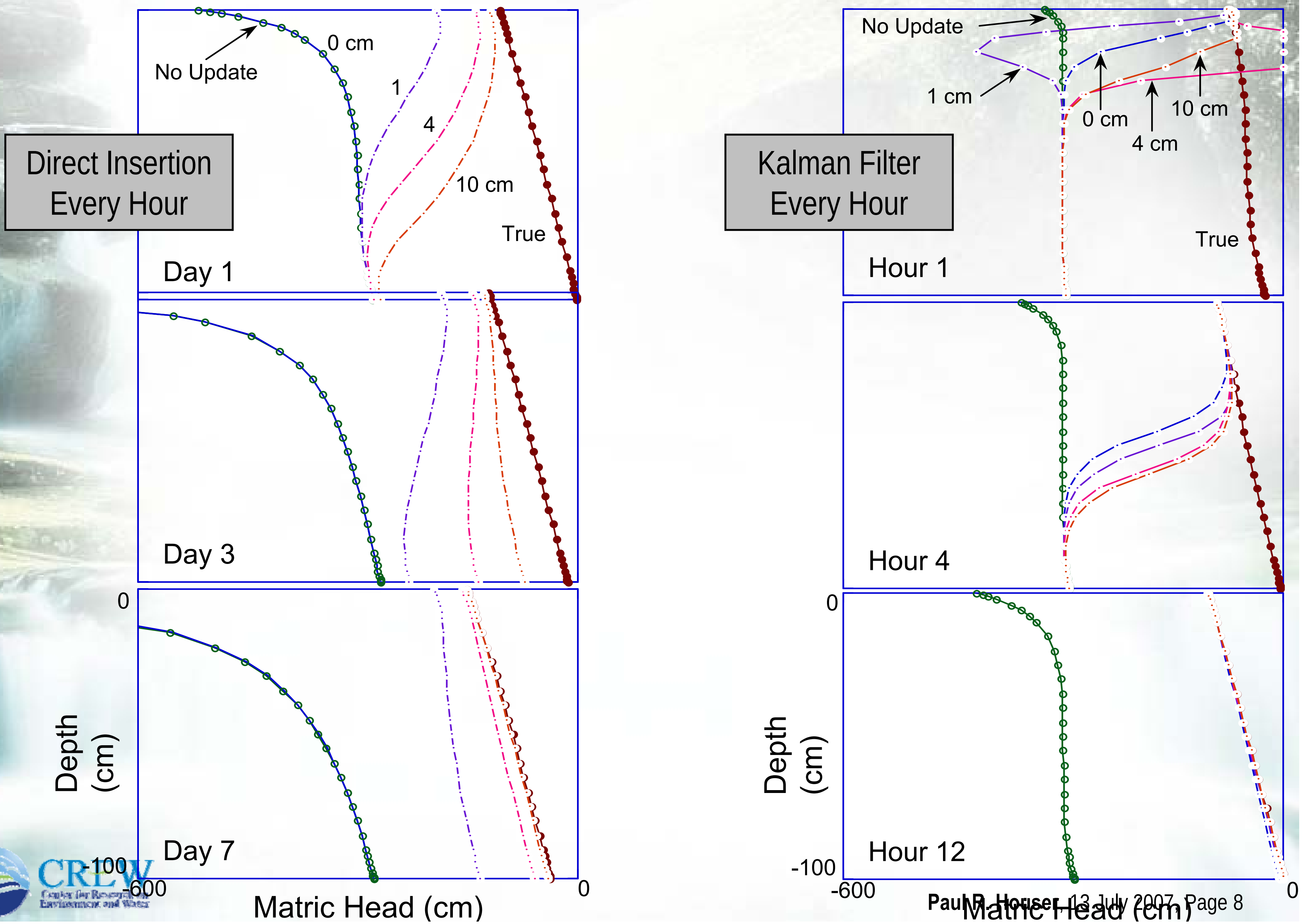
Houser et al., 1998

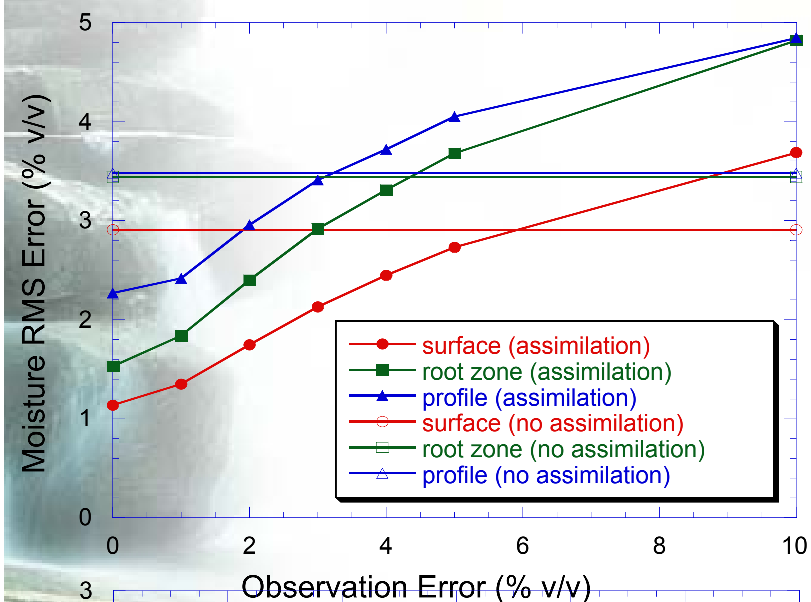


0
18%
Calibrated Control
Updating
Scale(km)
0
5
Statistical Corrections
Newtonian Nudging
Random SI
Superobservation SI

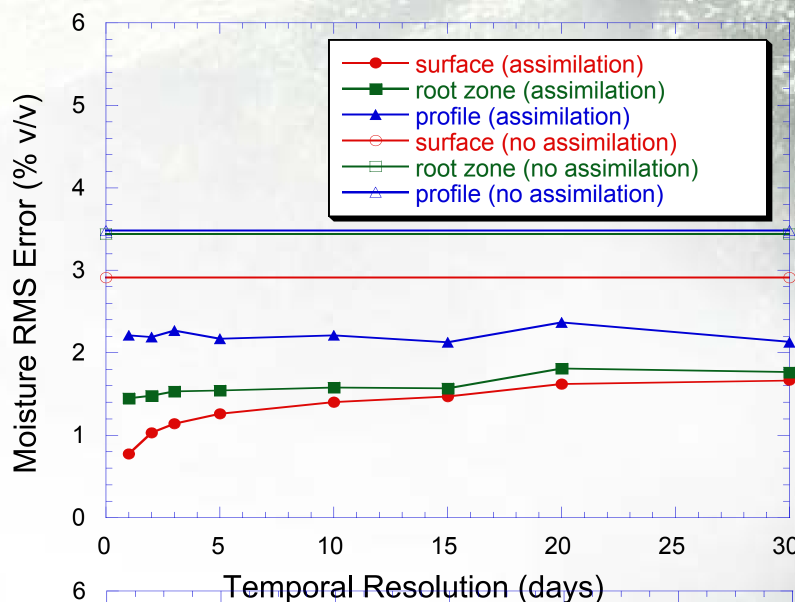
Soil Moisture Profile Correction

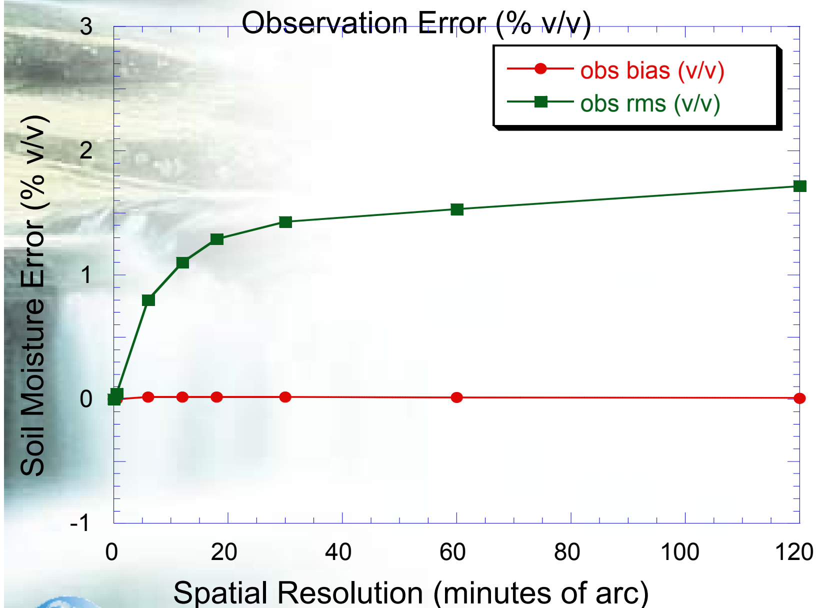


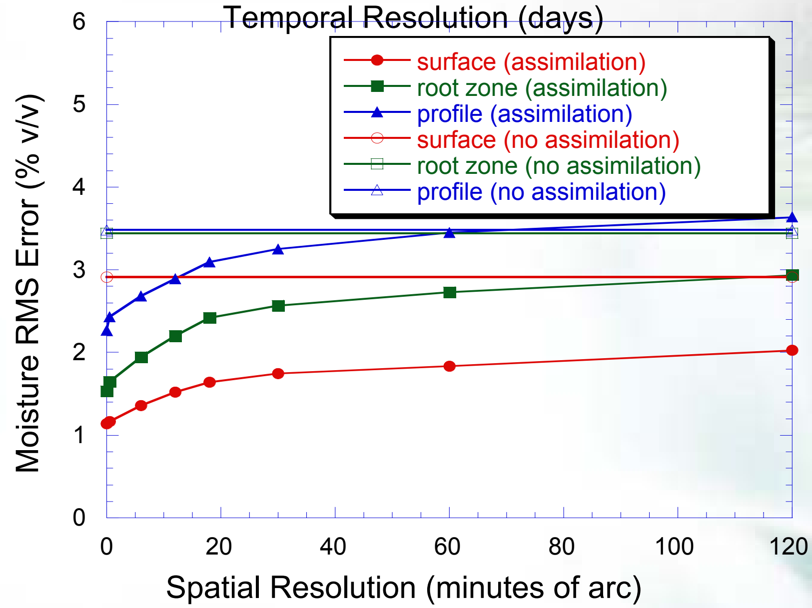
Soil Moisture Observation Error and Resolution Sensitivity:



NOTE: Assimilation of near-surface soil moisture can degrade profile soil moisture if errors are not known perfectly







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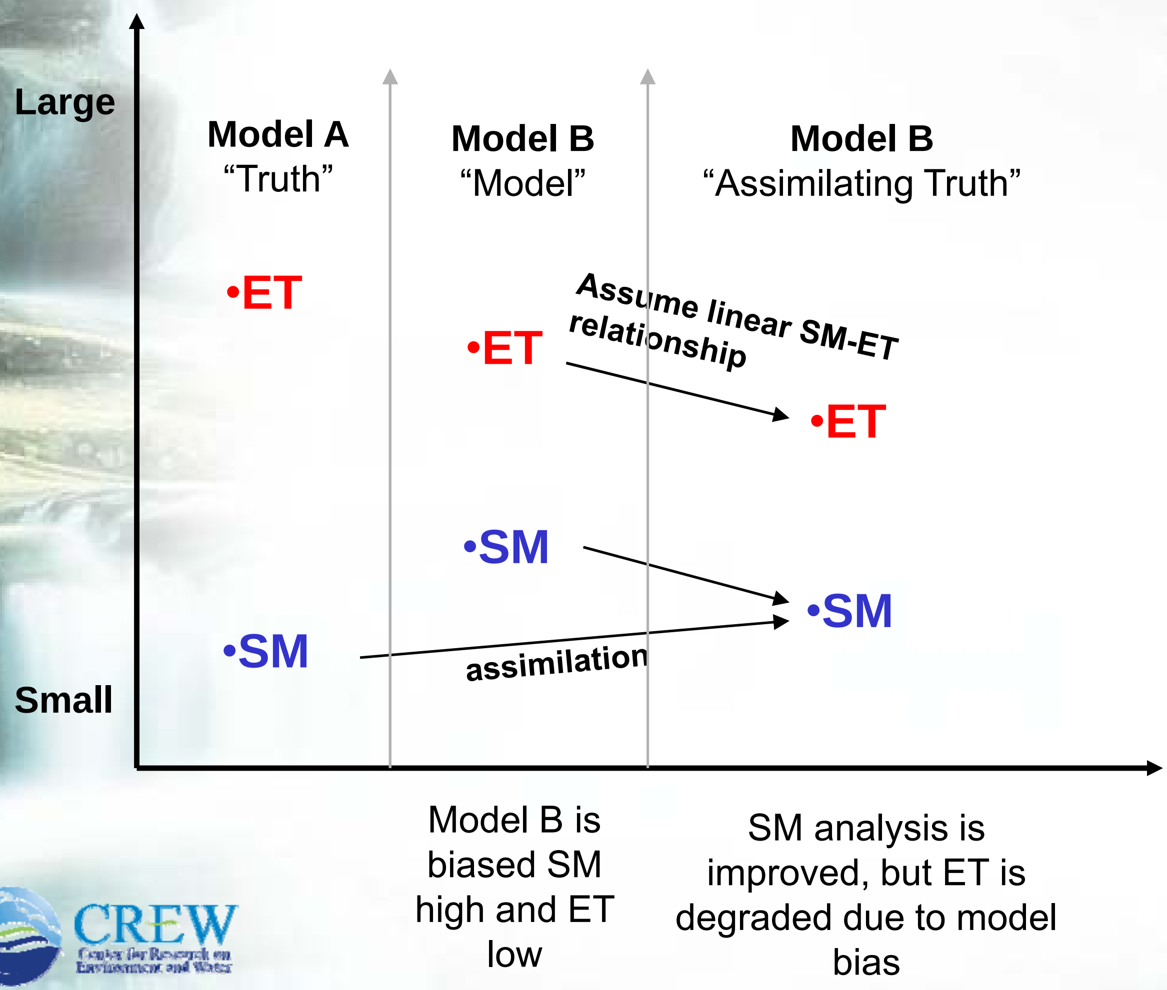
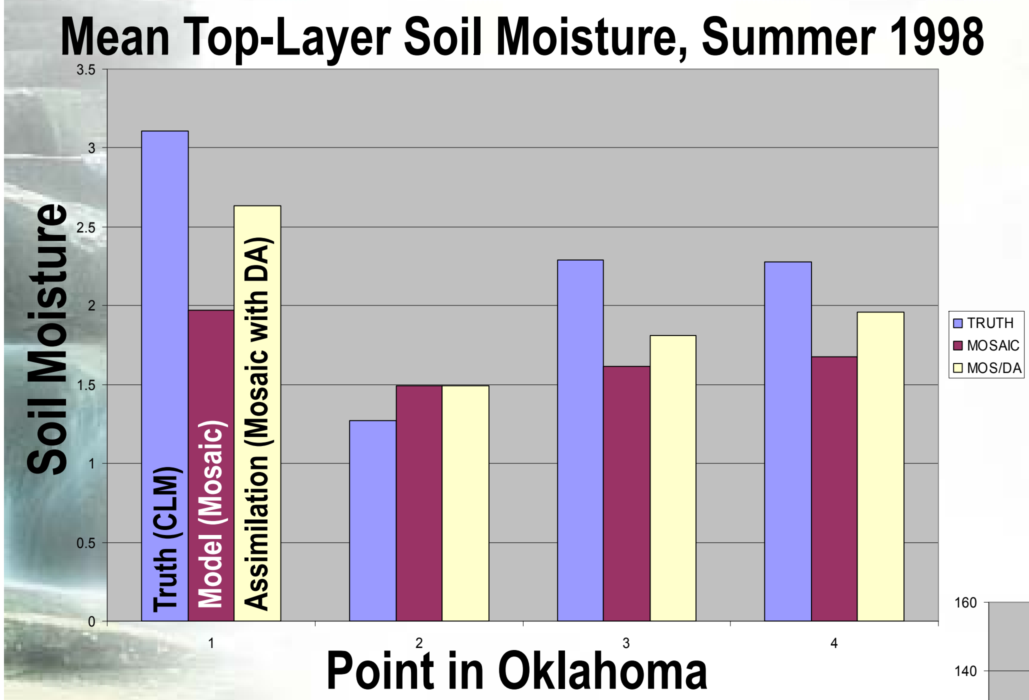
Fraternal Twin Studies

- "Truth" from one model is assimilated into a second model with a biased parameterization
- The "truth" twin can be treated as a perfect observation to help illustrate conceptual problems beyond the assimilation procedure.



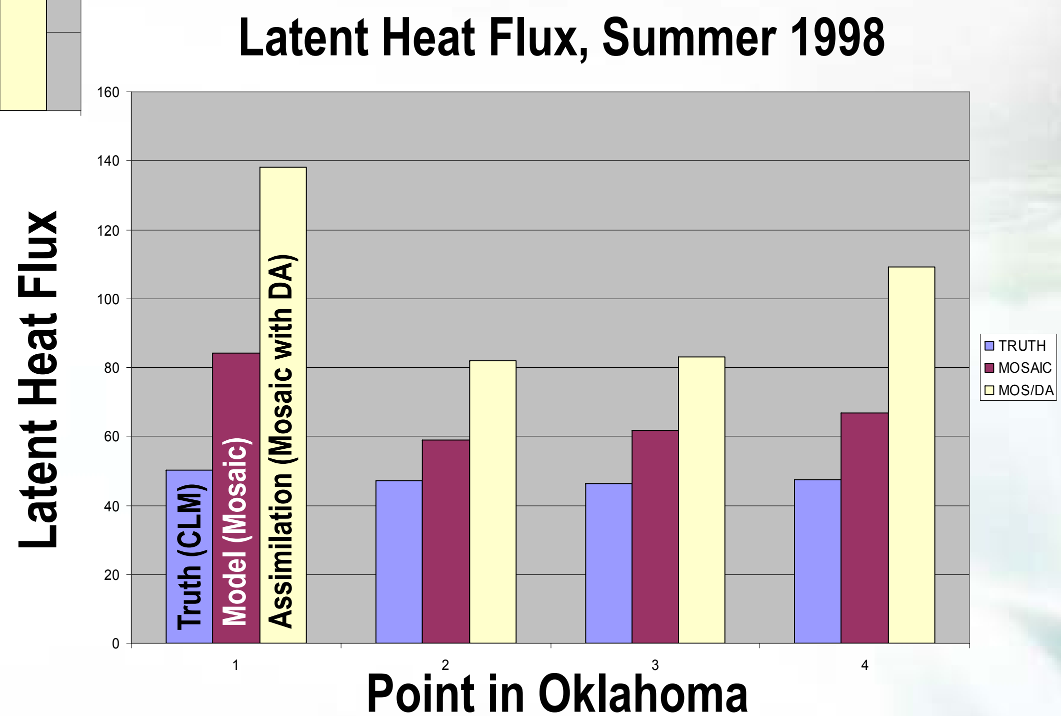
We must not only worry about obtaining an optimal model constraint, but also <u>understand the implications</u> of that constraint.

Fraternal Twin Demonstration



CLM=Truth

Mosaic=Faulty



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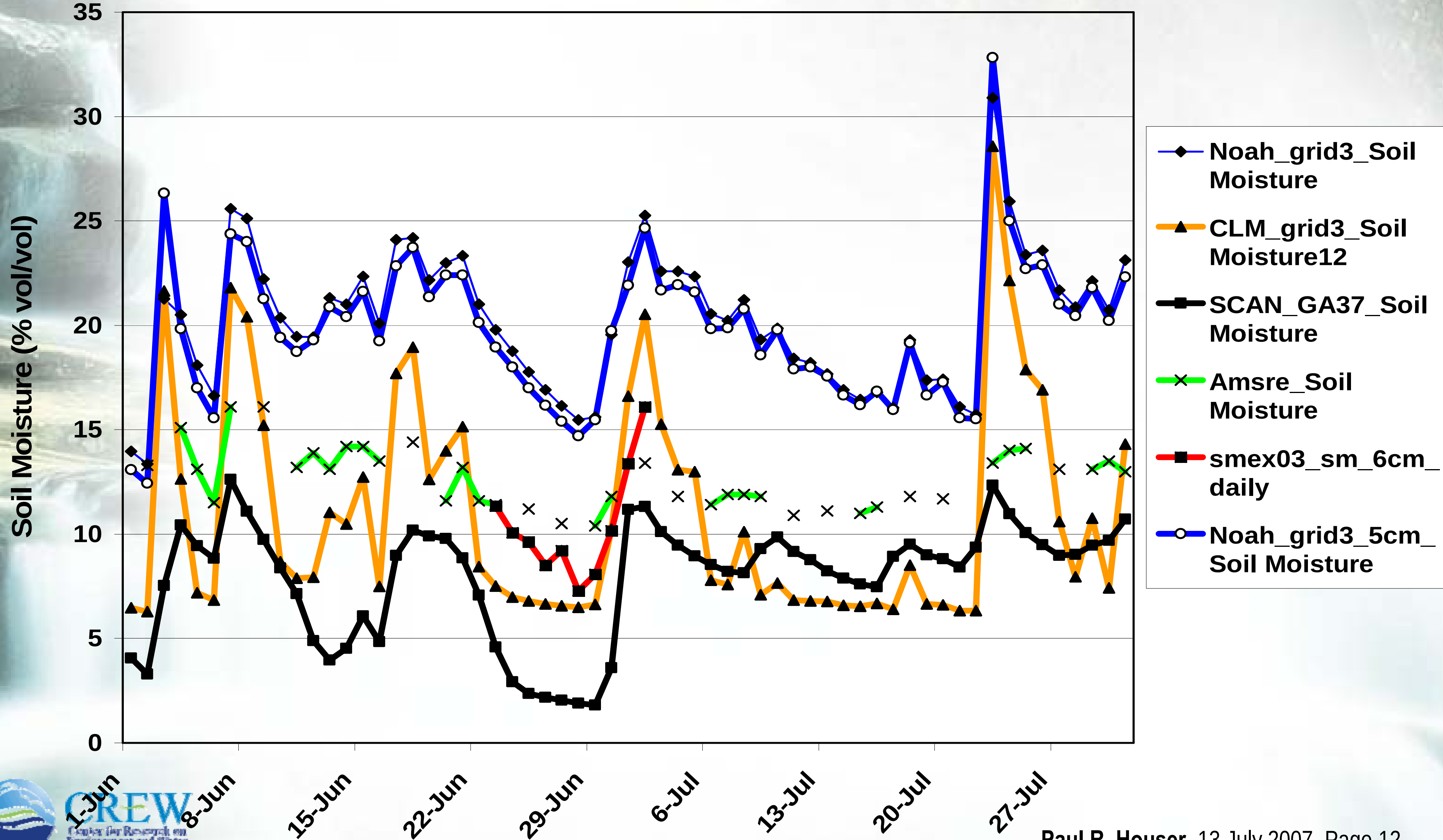
AMSR-E & Model Soil Moisture Evaluation

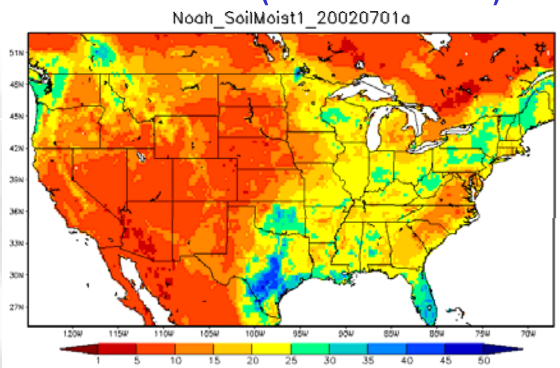
Averaged soil moisture plot from 17 sites (SMEX03-Georgia) over AMSR-E 1/4 degree grid. Noah (10 cm and 5 cm layer SM), CLM (4.5 cm layer, layer 1+ layer 2), SCAN (just one station, 5 cm), AMSR-E (2 cm layer), SMEX03 (6 cm layer).



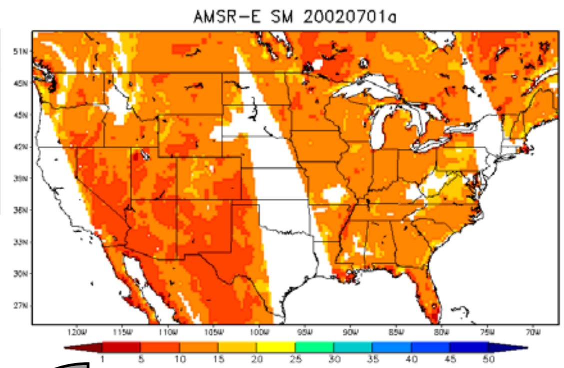
Assimilation of AMSR-E Land Products into the NOAH LSM

Paul Houser, Xiwu Zhan, Alok Sahoo, Kristi Arsenault, Brian Cosgrove

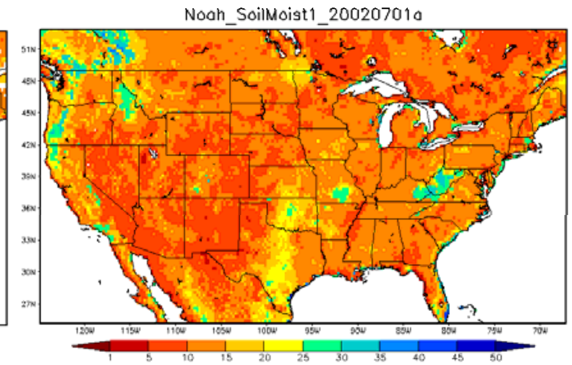
Noah Model (no assimilation)



Unscaled AMSR-E Soil Moisture



Unscaled AMSR-E SM Assimilation



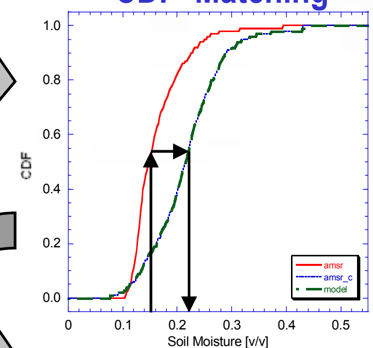
GOAL: Implement Kalman Filter to assimilate land satellite data products into the Noah land surface model installed in the Land Information System (LIS)

PROGRESS: Three data assimilation algorithms (DI, EKF, EnKF) have been implemented in LIS and has been tested with various soil moisture observations

FUTURE:

- Expand validation of assimilation results.
- Optimize ensemble perturbation procedures
- Finalize AMSR-E scaling philosophy
- Explore brightness temperature assimilation (CRTM)
- Expand to snow cover assimilation

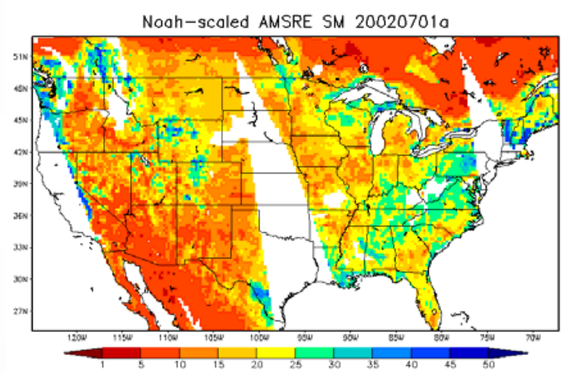
CDF Matching



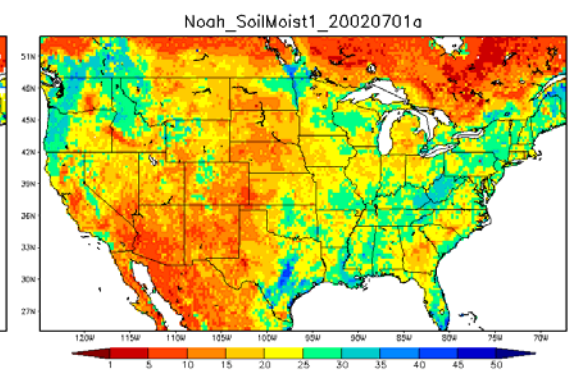
Quandary: Official AMSR-E soil moisture product has very low variability, wich produces an assimilated product with low variability

CDF Matching: Scales AMSR-E to model climatology, erasing any real variability in AMSR-E

Scaled AMSR-E Soil Moisture



Scaled AMSR-E SM Assimilation



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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

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

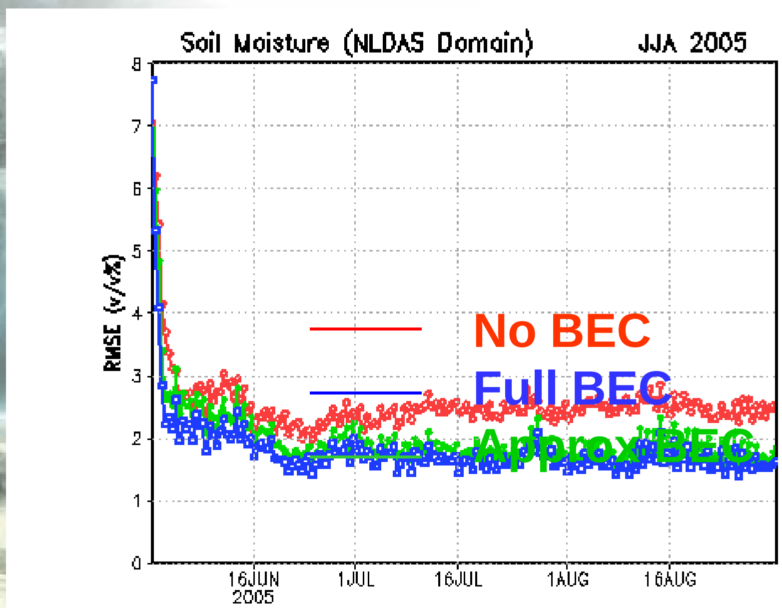
b. Approximate Scheme

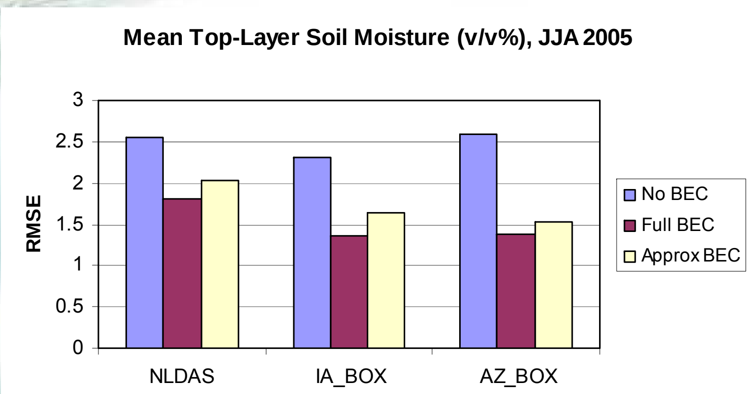
$$L = \alpha * K$$

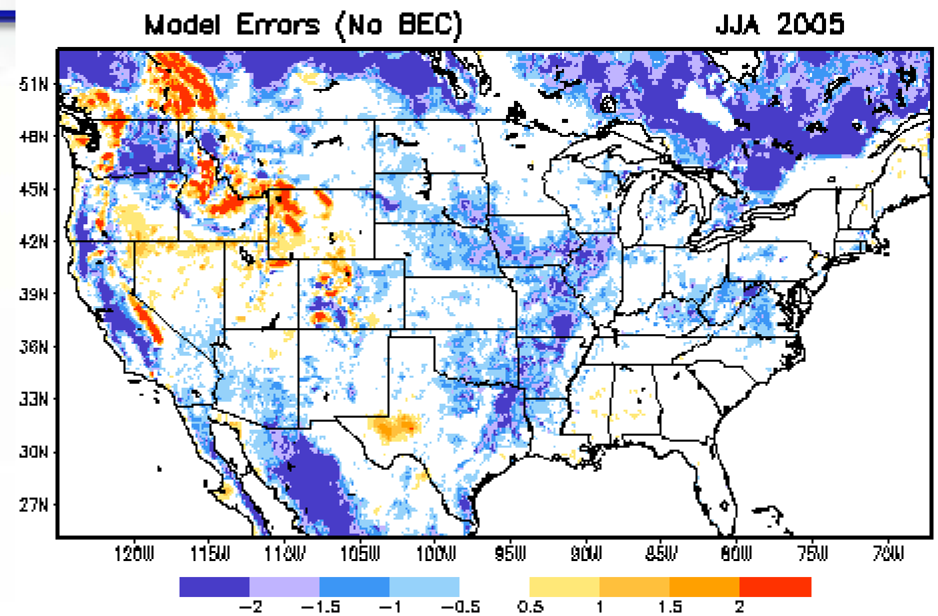
$0 < \mu, \gamma, \alpha \le 1$ tunable bias correction parameters

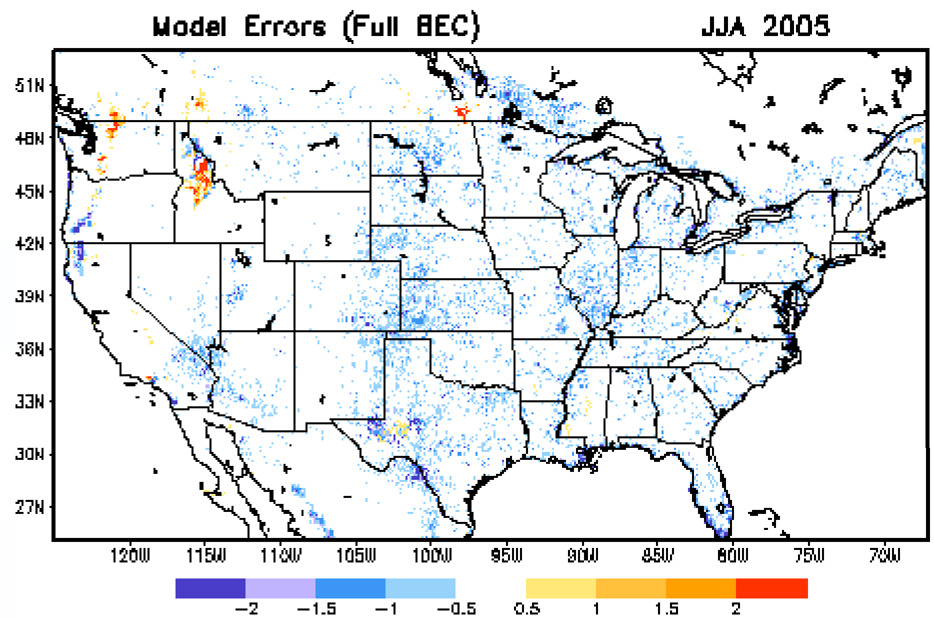
Bias correction comparison

- Model error ≈ Noah model forecast - AMSR_E retrieval









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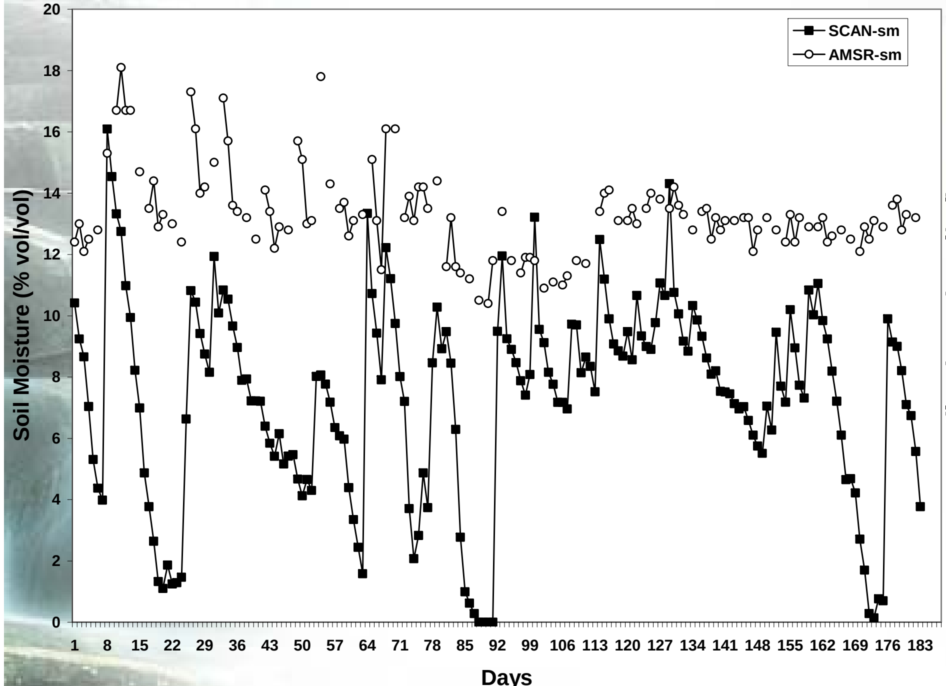
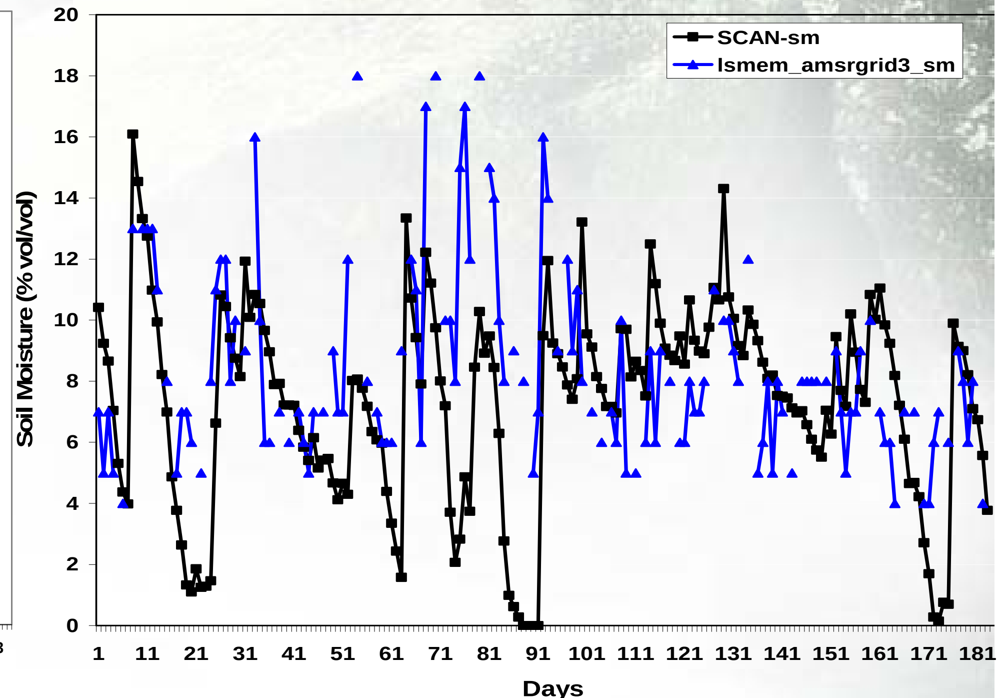
Initial Results (contd.)



Volumetric Soil Moisture Plot from SCAN and AMSR-E from April 1 to September 30, 2003

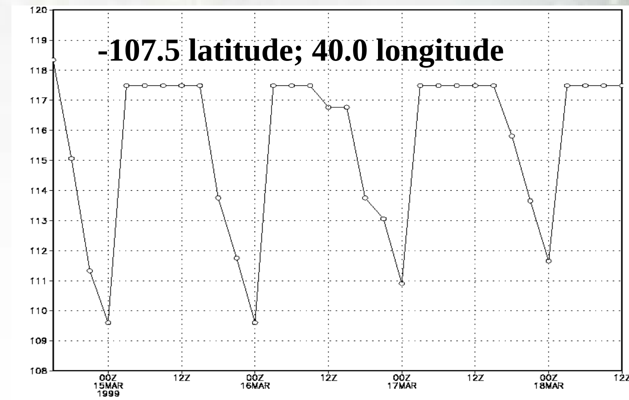


Volumetric Soil Moisture Plot from SCAN and LSMEM from April 1 to September 30, 2003

	SCAN SM (%)	NOAH 10 cm SM (%)	NOAH 2 cm SM (%)	CLM 5 cm SM (%)	CLM 2 cm SM (%)	SSiB 2cm SM (%)	AMSR-E SM (%)	AMSR-E SM (modified) (%)	LSMEM SM (%)
Mean	7.3778	20.2341	19.5564	10.9128	6.3228	22.5548	13.3272	7.3778	8.416
Standard Deviation	3.4093	3.3114	3.6245	5.3042	6.8852	6.0300	1.4467	3.4093	3.183
Range	0 - 16.0900	13.3672-30.9001	10.6563-33.4711	6.2920-28.5757	1.3677-28.1826	13.9912-39.3903	10.4 - 18.1	0.48 - 18.63	4-18
Correlation Coefficient (w.r.t. SCAN SM)	1.00	0.5721	0.5136	0.4681	0.4388	0.4079	0.3838	0.3838	0.59

Snow Assimilation: Background & Motivation

- In the northern hemisphere the snow cover ranges from 7% to 40% during the annual cycle.
- The high albedo, low thermal conductivity and large spatial/temporal variability impact energy/water budgets.
- Sno/bare soil interfaces cause wind circulations.
- Direct replacement does not account for model bias.



Unique Snow Data Assimilation Considerations:

- “Dissappearing” layers and states
- Arbitrary redistribution of mass between layers
- Lack of information in SWE about snow density or depth
- Lack of information in snow cover about snow mass & depth
- Biased forcing causing divergence between analysis steps
- **OBSERVATIONS:** Snow Cover, Snow Water Equiv., Tskin, Snow Fraction

Update Time

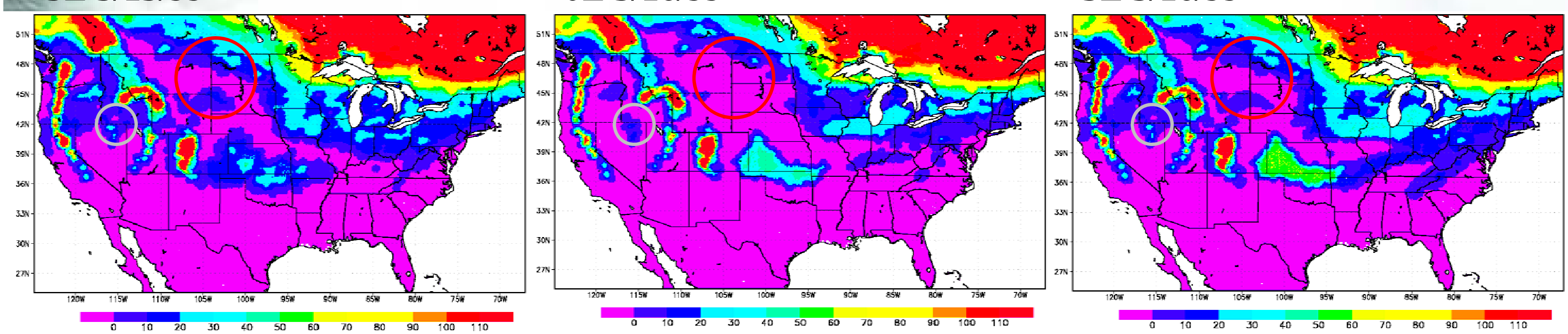
Melt

Update Time

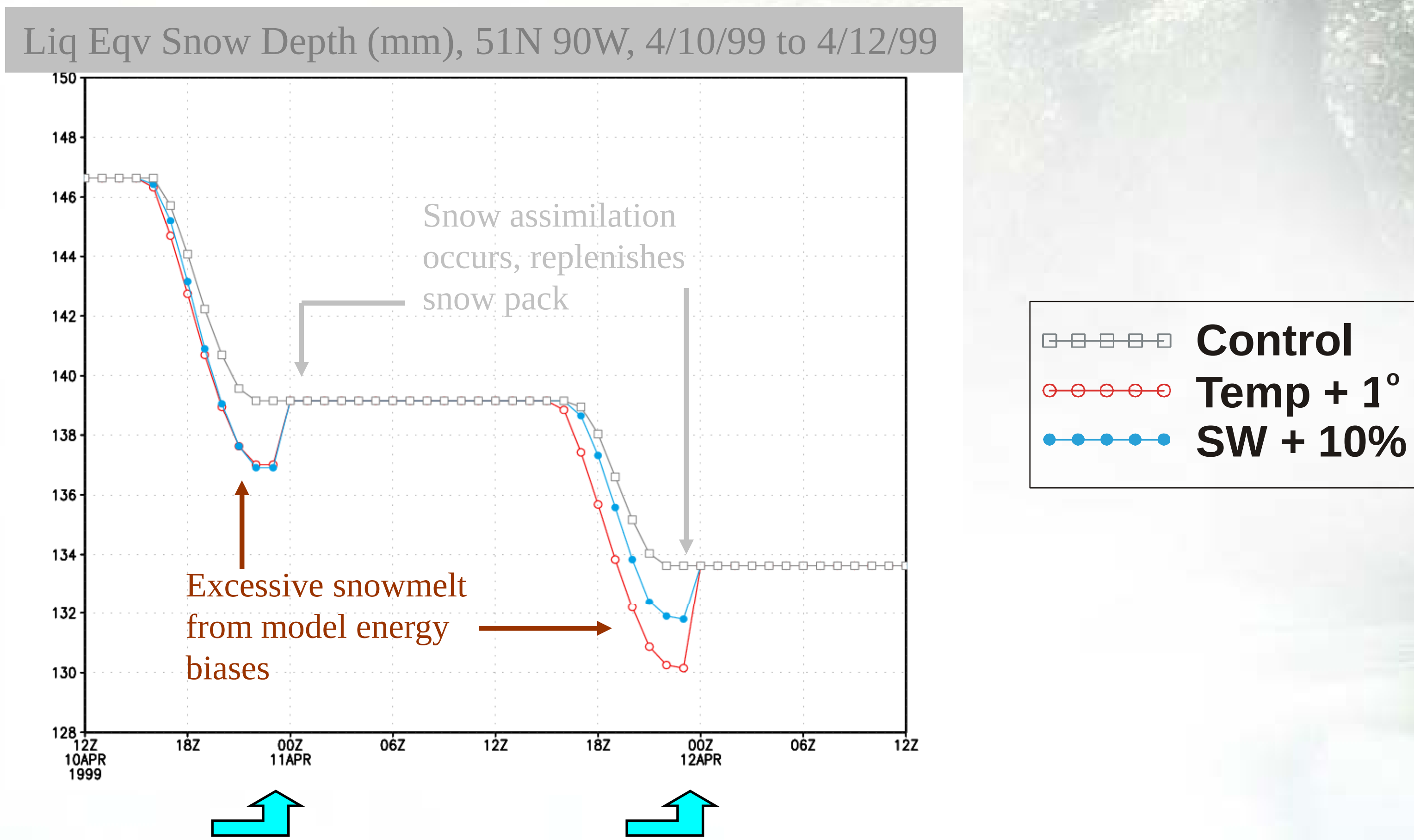
3Z 3/15/99

0Z 3/16/99

3Z 3/16/99

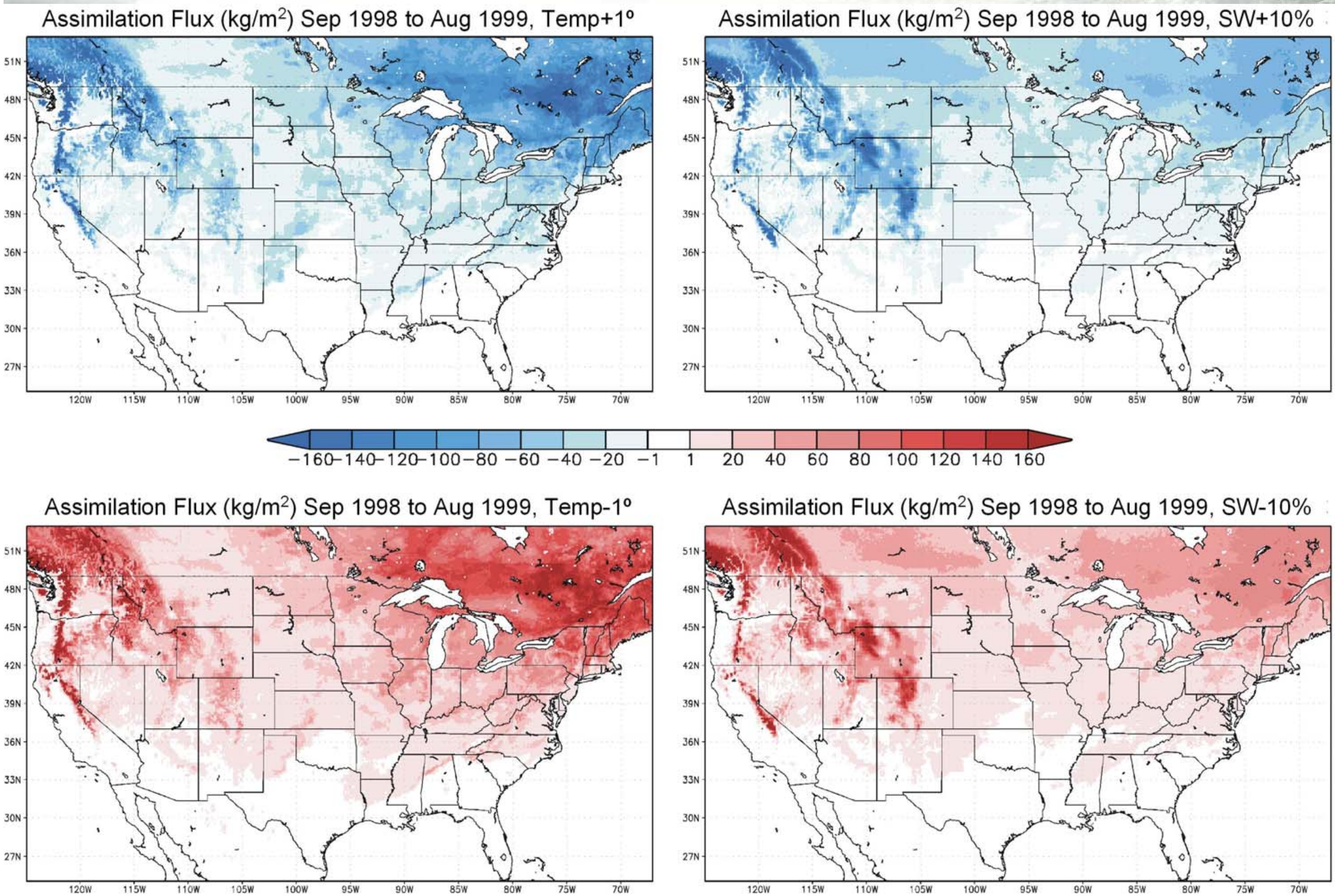


Mosaic LSM Experiments



- Excessive melting and replenishment of snow in experimental runs similar to that in the EDAS data

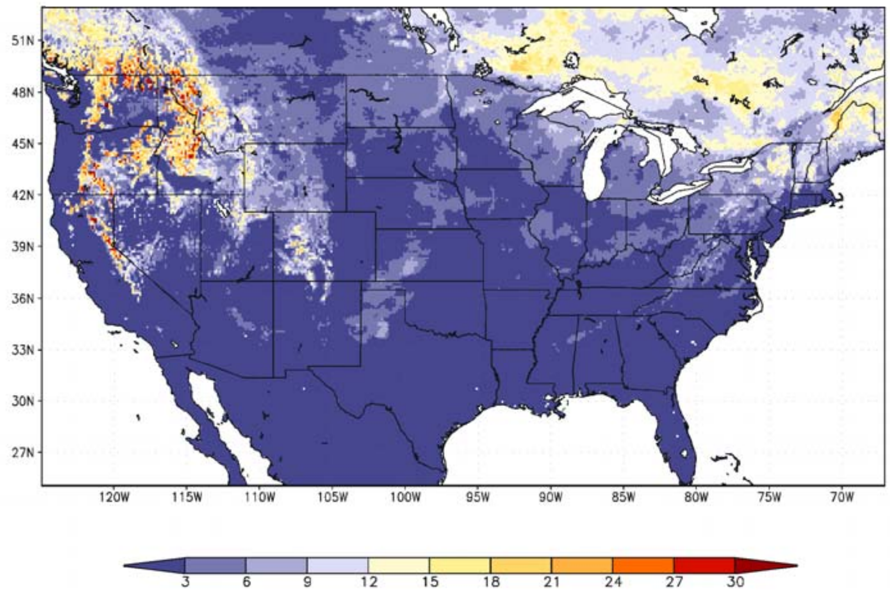
Snow Data Assimilation: Impact of bias



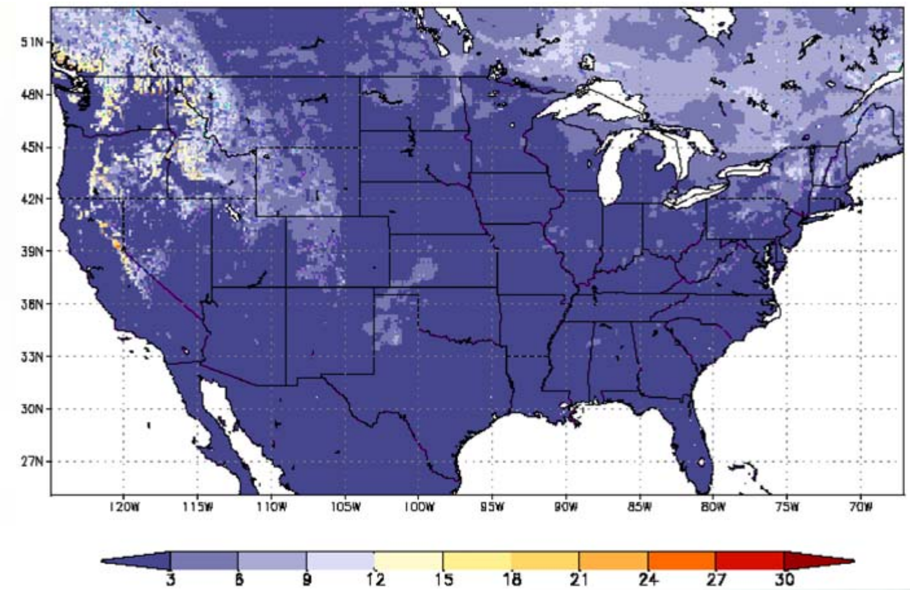
Snow Data Assimilation: Correcting Impact of bias

Snowmelt adjustment (SMA) uses observed depth change to limit melt or accumulation

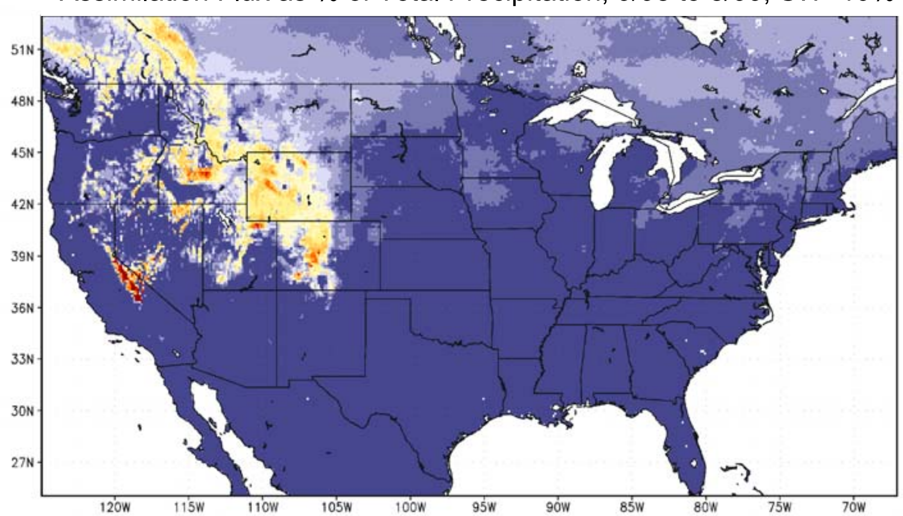
Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, Tmp+1º



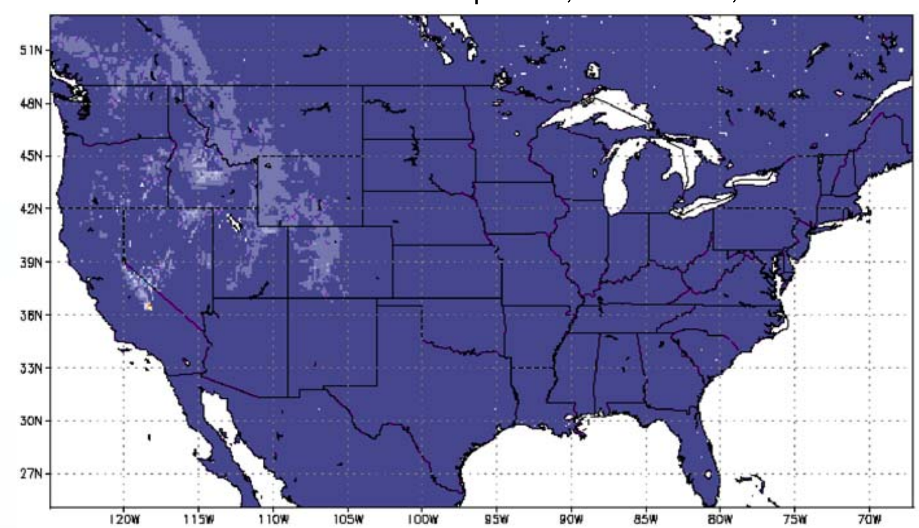
Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, Tmp+1º SMA



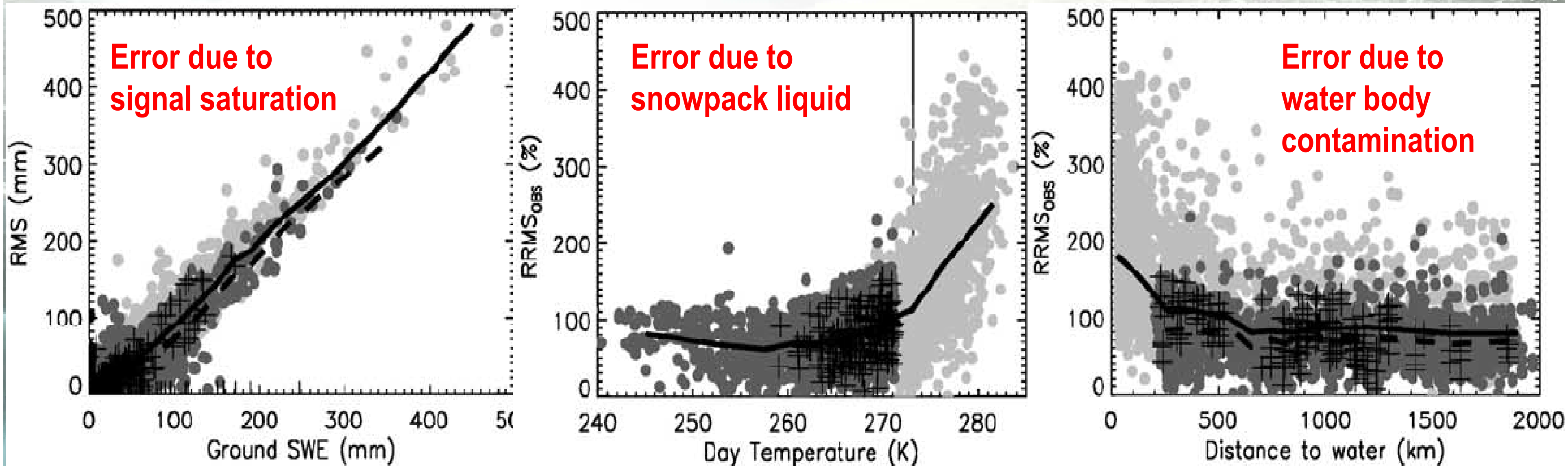
Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, SW+10%

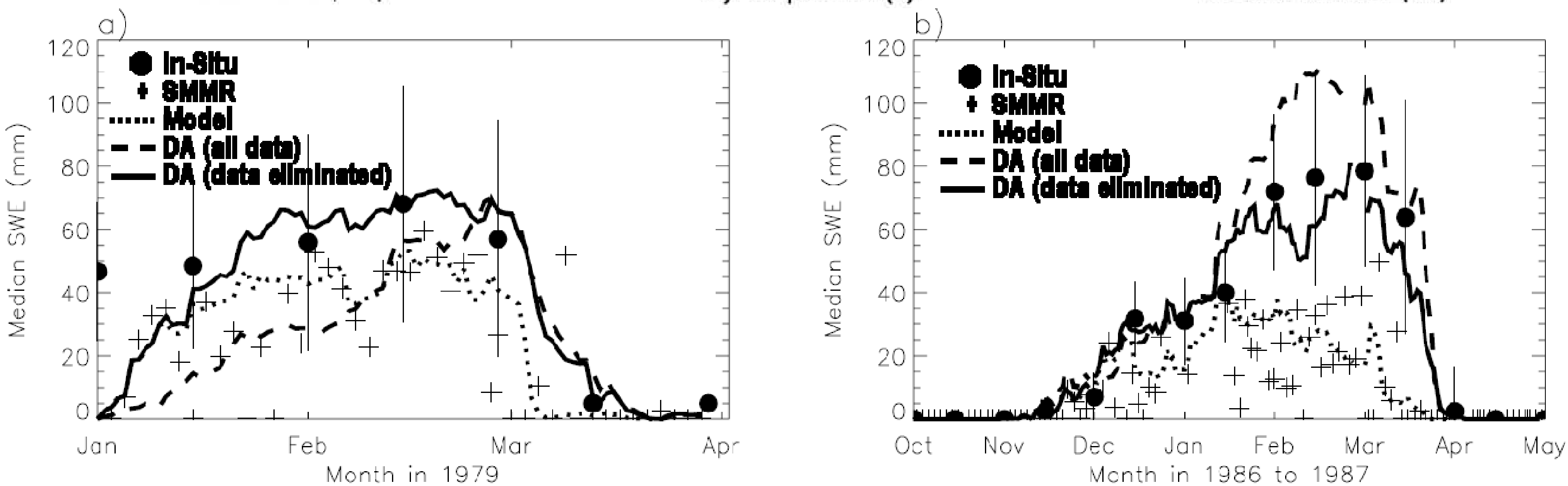


Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, SW+10% SMA



SMMR Snow Retrieval Error & Assimilation Impact





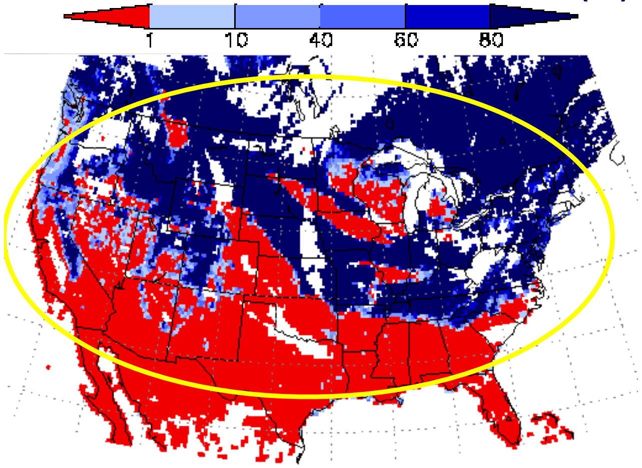
Dong et al., 2005, 2006

GLDAS Snow Updates Using MODIS Data

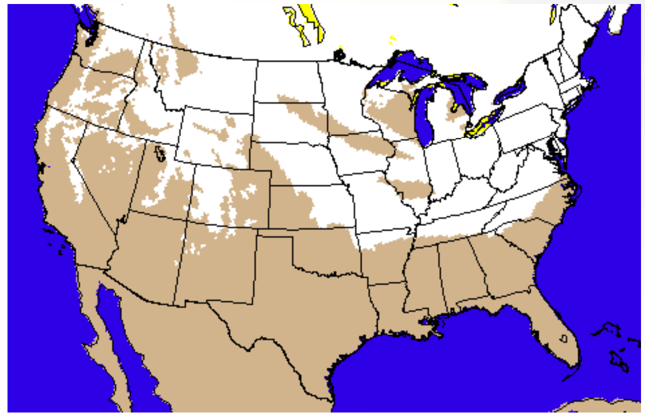
Rodell & Houser, 2004

21Z 17 January 2003

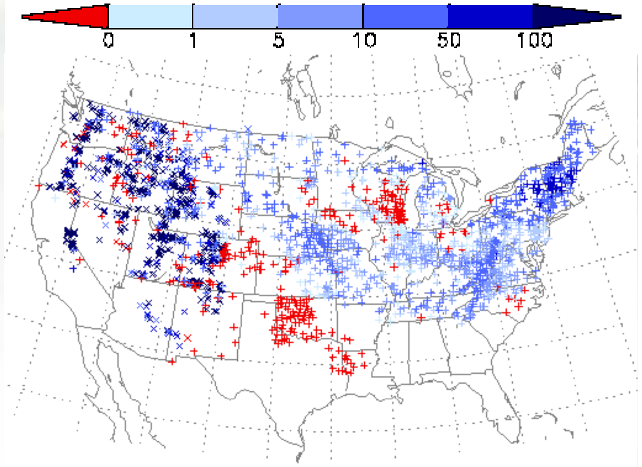
Enhanced MODIS Snow Cover (%)



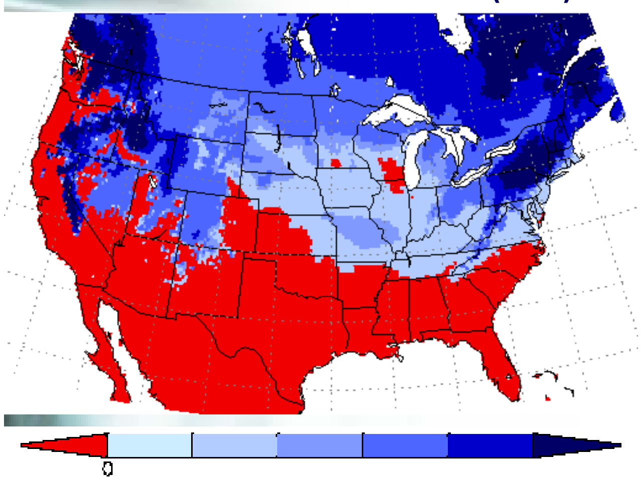
IMS Snow Cover



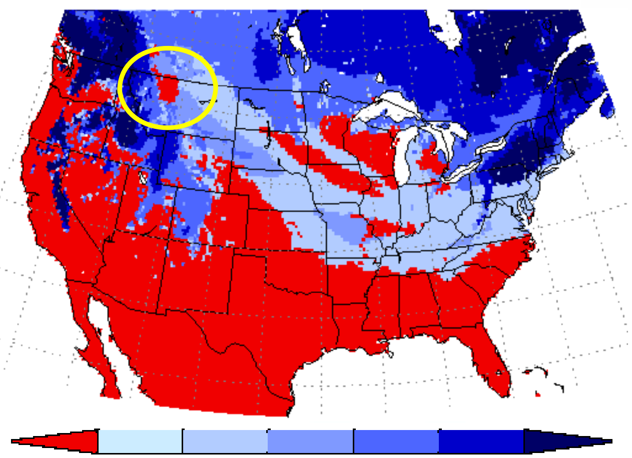
SNOTEL and Co-op Network SWE (mm)



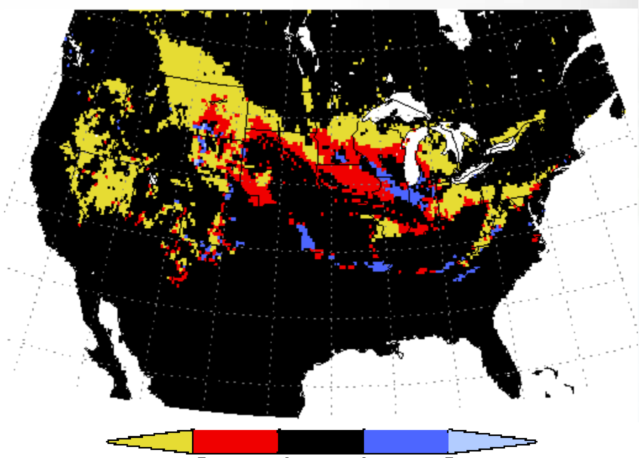
Control Run Mosaic SWE (mm)

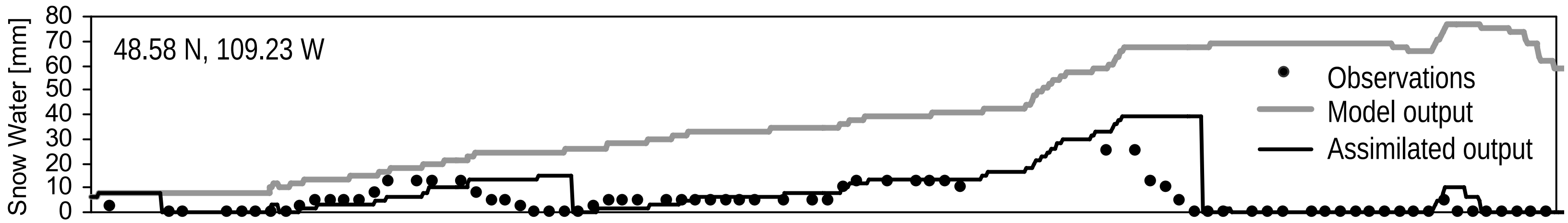


Assimilated Mosaic SWE (mm)



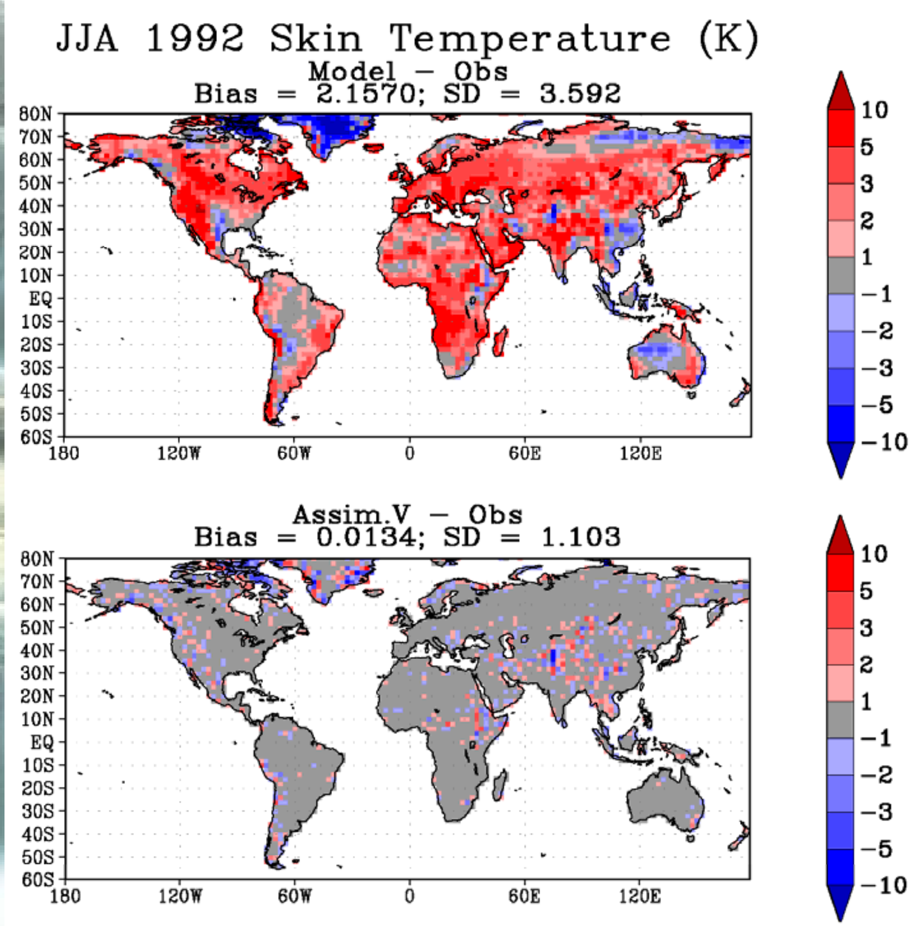
Mosaic SWE Difference (mm)

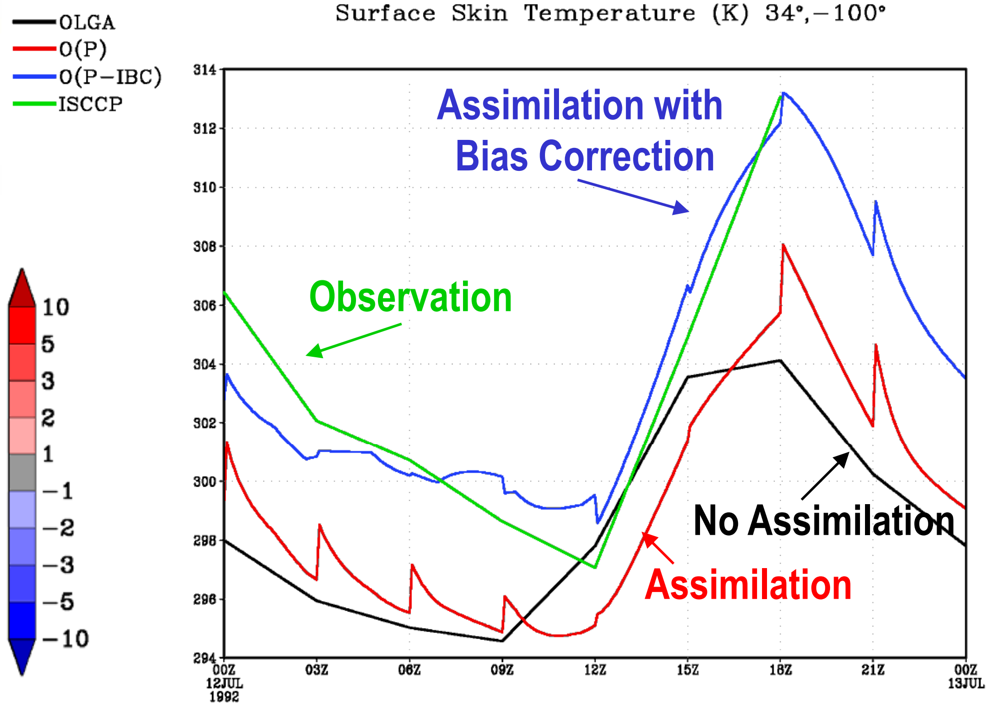




Data Assimilation: T_s Assimilation Results

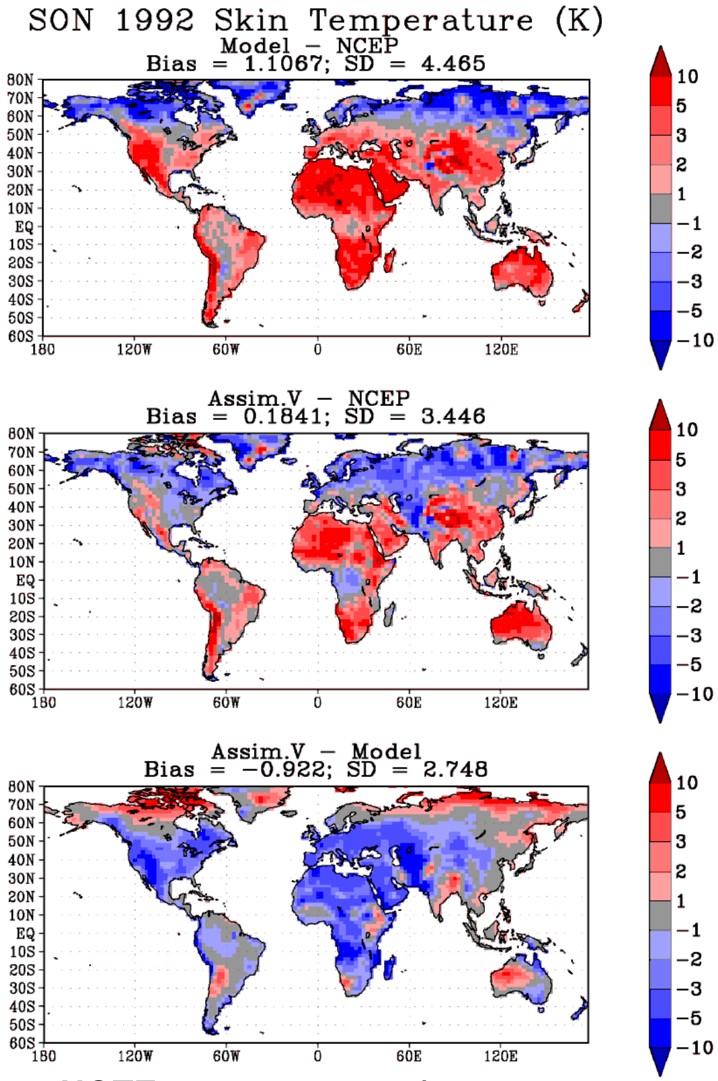
DAO-PSAS **Assimilation** of **ISCCP (IR based) Surface Skin Temperature** into a global 2 degree uncoupled land model.





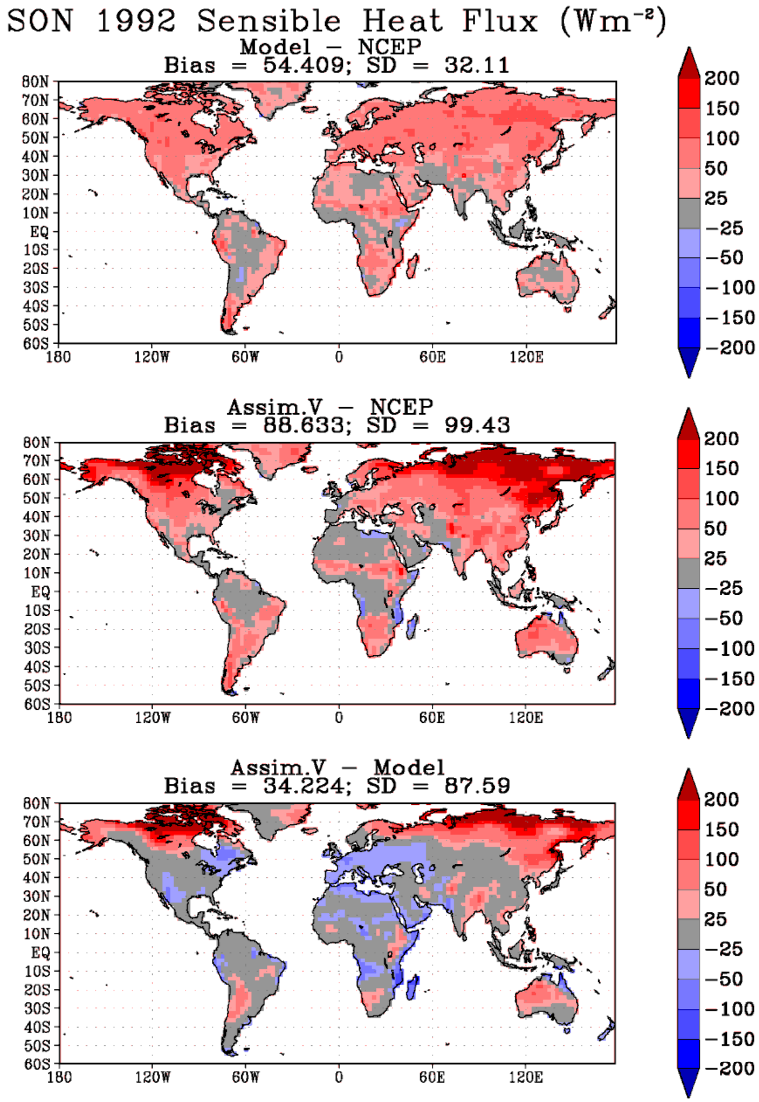
Surface temperature has **very little memory** or inertia, so without a continuous correction, it tends drift toward the control case very quickly.

Data Assimilation: T_s Assimilation Results



Comparison with NCEP Reanalysis

- Skin temperature improves significantly
- Sensible heat flux degrades due to modified near-atmosphere temperature gradient



NOTE: NCEP not equal to TRUTH

CREW Center for Research on Environment and Water

Land Surface Data Assimilation: Summary

Progress:

•Soil moisture, skin temperature, and snow assimilation have been demonstrated.
•Evapotranspiration, runoff, groundwater (gravity), and carbon assimilation are underway

Lessons Learned:

•We need to pay attention to the *consequences of assimilation*, not just the optimum assimilation technique. i.e. does the model do silly things as a result of assimilation, as in snow assimilation example.
•Land model physics can be biased, leading to incorrect fluxes, given correct states.
•Most land observations are only available at the surface, meaning that biased differences in surface observations and predictions can be improperly propagated to depth.
•Assimilation does not always make everything in the model better. In the case of skin temperature assimilation into an uncoupled model, biased air temperatures caused unreasonable near surface gradients to occur using assimilation that lead to questionable surface fluxes.

Near Future Directions:

•Methods to address simultaneous model and observation bias.
•New observations (SMOS, Aquarius, SMAP, etc.).
•Coupled Assimilation (to avoid uncoupled biases).
•Mass/Energy conserving data assimilation techniques?