Land Surface Data Assimilation

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http://ldas.gsfc.nasa.gov

Land Data Assimilation: Motivation

Quantification and prediction of hydrologic variability

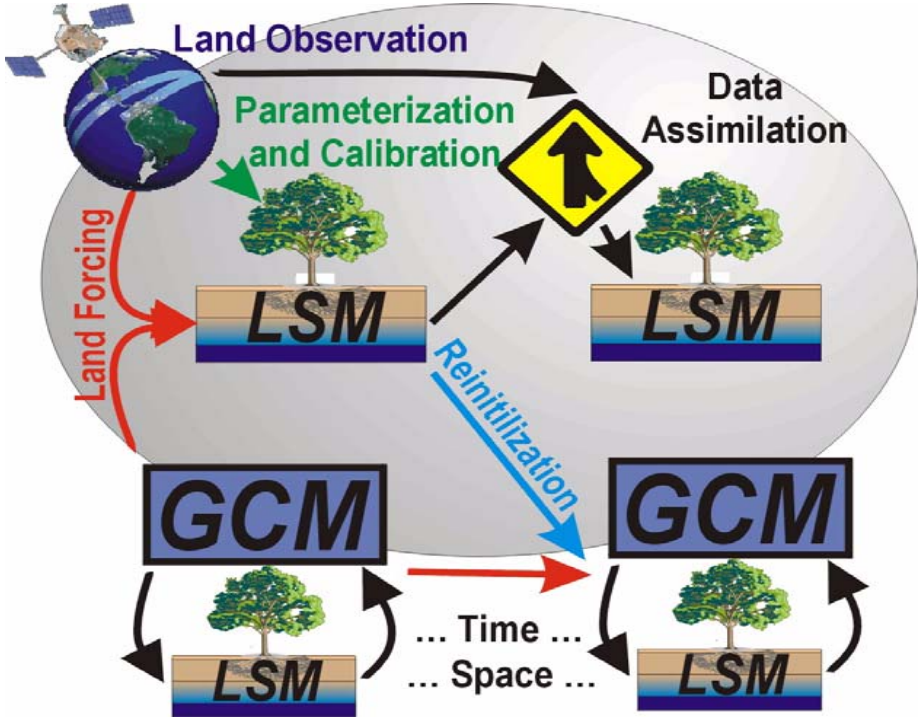
- Critical for initialization and improvement of weather/climate forecasts
- Critical for applications such as floods, agriculture, military operations, etc.

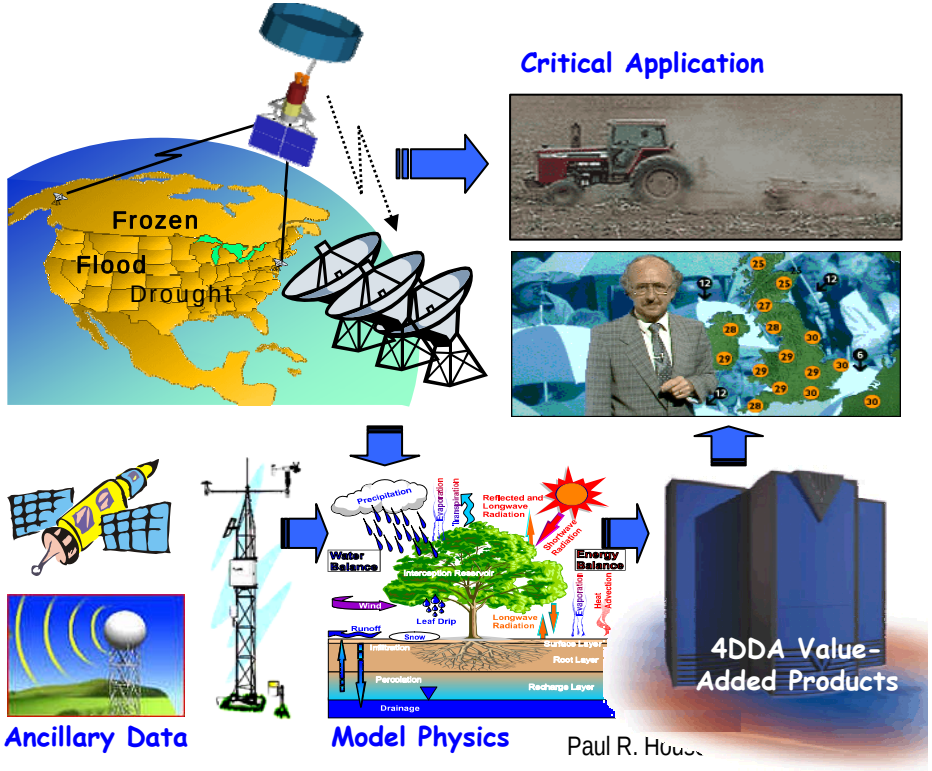
Maturing of hydrologic observation and prediction tools:

- Observation: Forcing, storages(states), fluxes, and parameters.
- Simulation: Land process models (Hydrology, Biogeochemistry, etc.).
- Assimilation: Short-term state constraints.

"LDAS" concept:

Bring state-of-the-art tools together to *operationally* obtain high quality land surface conditions and fluxes.



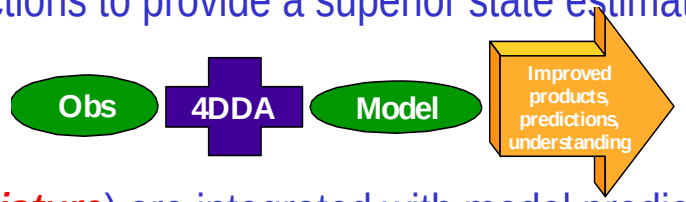


Paul R. Houser

Land Surface *Data Assimilation*

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

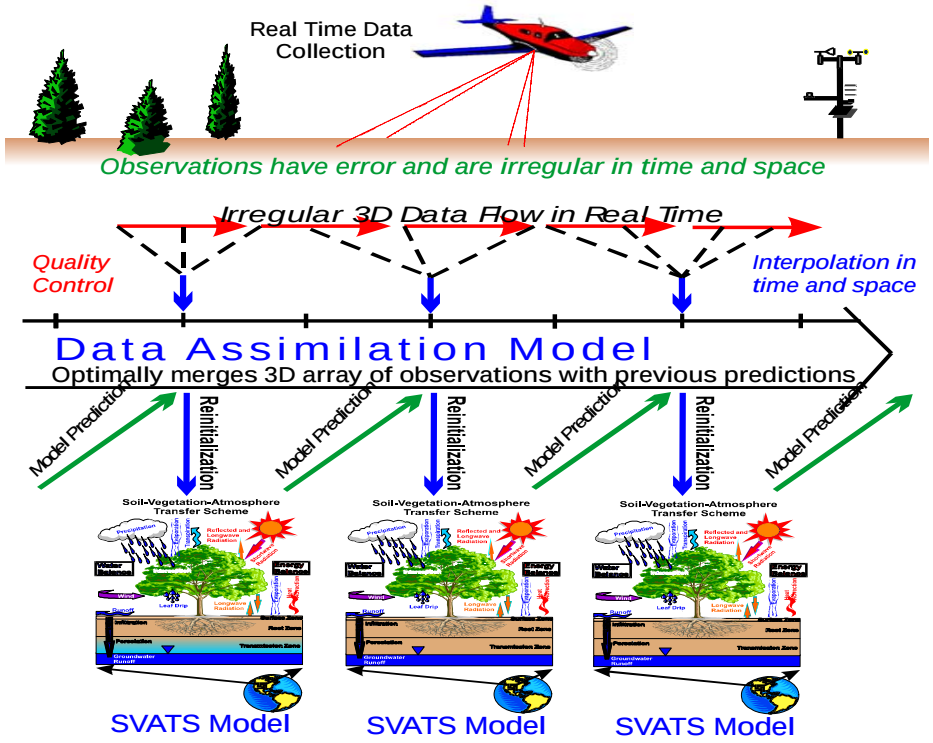
$$\partial x/\partial t = dynamics + physics + \Delta x$$



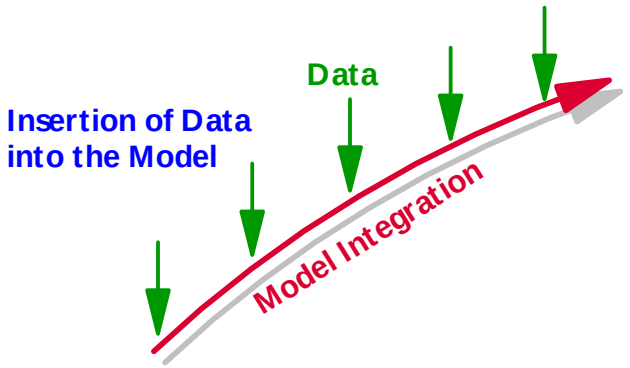
State or storage observations (*temperature, snow, moisture*) are integrated with model predictions.

Data Assimilation Methods: Numerical tools to combine disparate information.

1. Direct Insertion, Updating, or Dynamic Initialization:
2. Newtonian Nudging:
3. Optimal or Statistical Interpolation:
4. Kalman Filtering: EKF & EnKF
5. Variational Approaches - Adjoint:



- Errors in land model prediction result from:
  - Initialization error.
  - Errors in atmospheric forcing data.
  - Errors in LSM physics (model not perfect).
  - Errors in representation (sub-grid processes).
  - Errors in parameters (soil and vegetation).



Land Surface Observation

Off-line LDAS

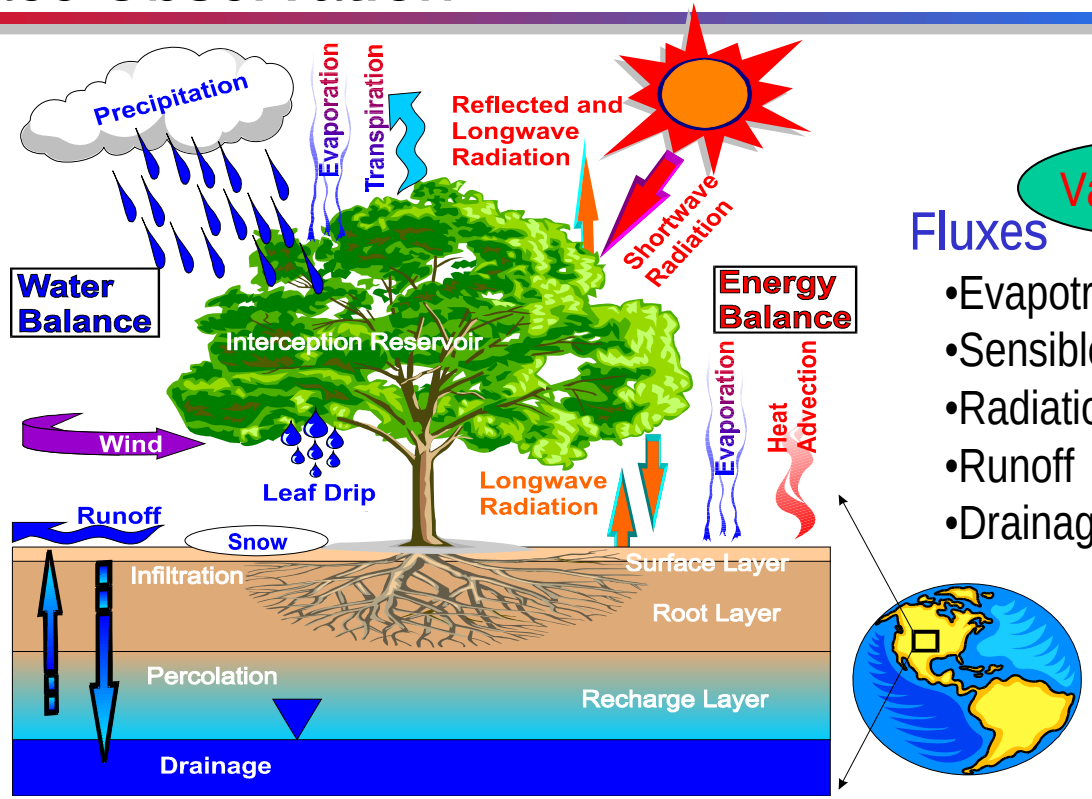
Forcing

- Precipitation
- Wind
- Humidity
- Radiation
- Air Temperature

Validation

Fluxes

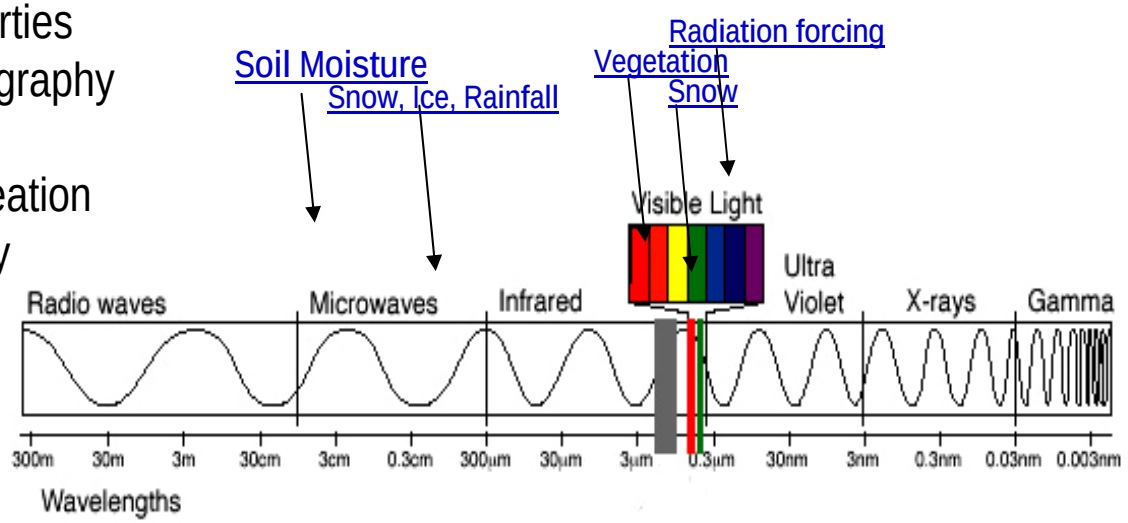
- Evapotranspiration
- Sensible Heat Flux
- Radiation
- Runoff
- Drainage



Calibration

Parameters

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



Assimilation

States

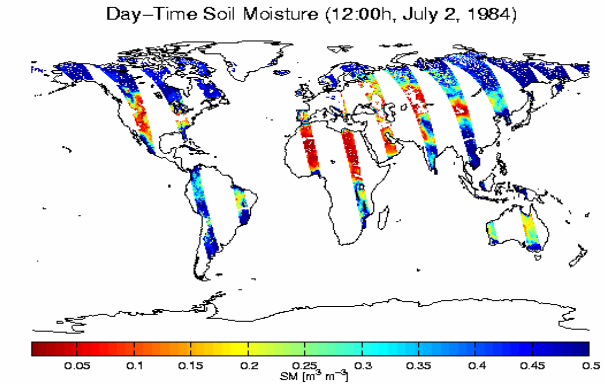
- Soil Moisture
- Temperature
- Snow
- Carbon
- Nitrogen
- Biomass

NASA-GSFC Land Surface Data Assimilation

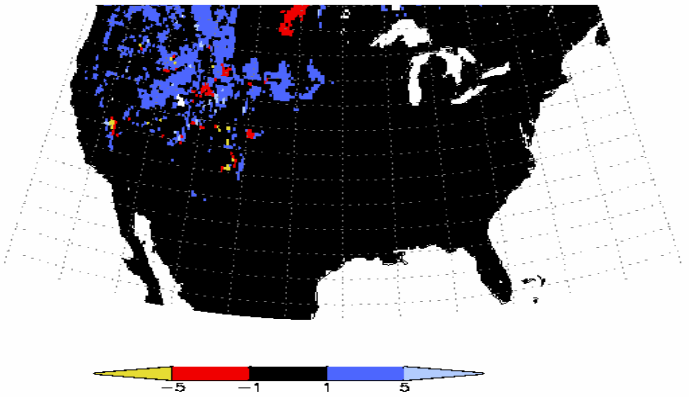
Data Assimilation merges observations & model predictions to provide a superior state estimate.

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.

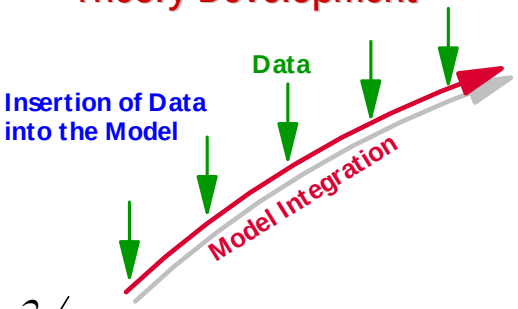
Soil Moisture Assimilation



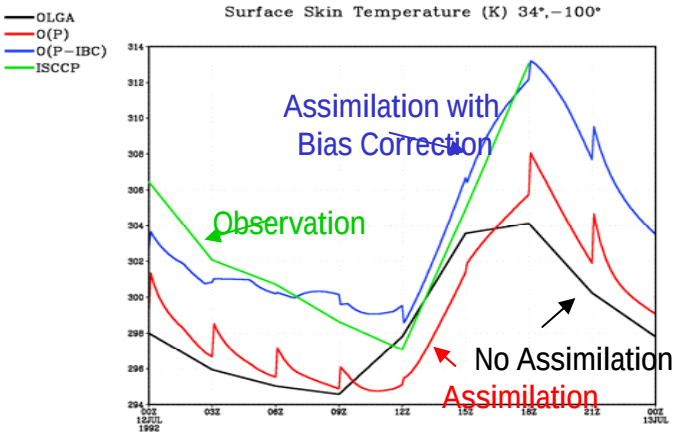
Snow Cover Assimilation



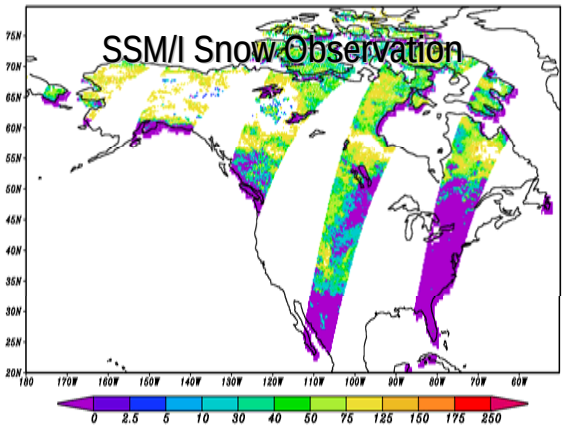
Theory Development

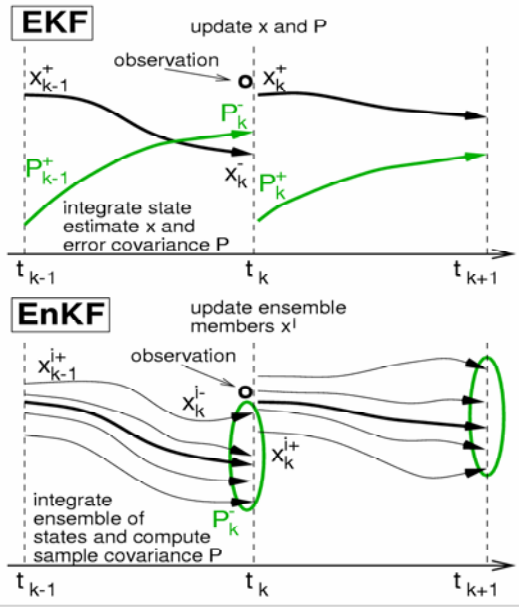


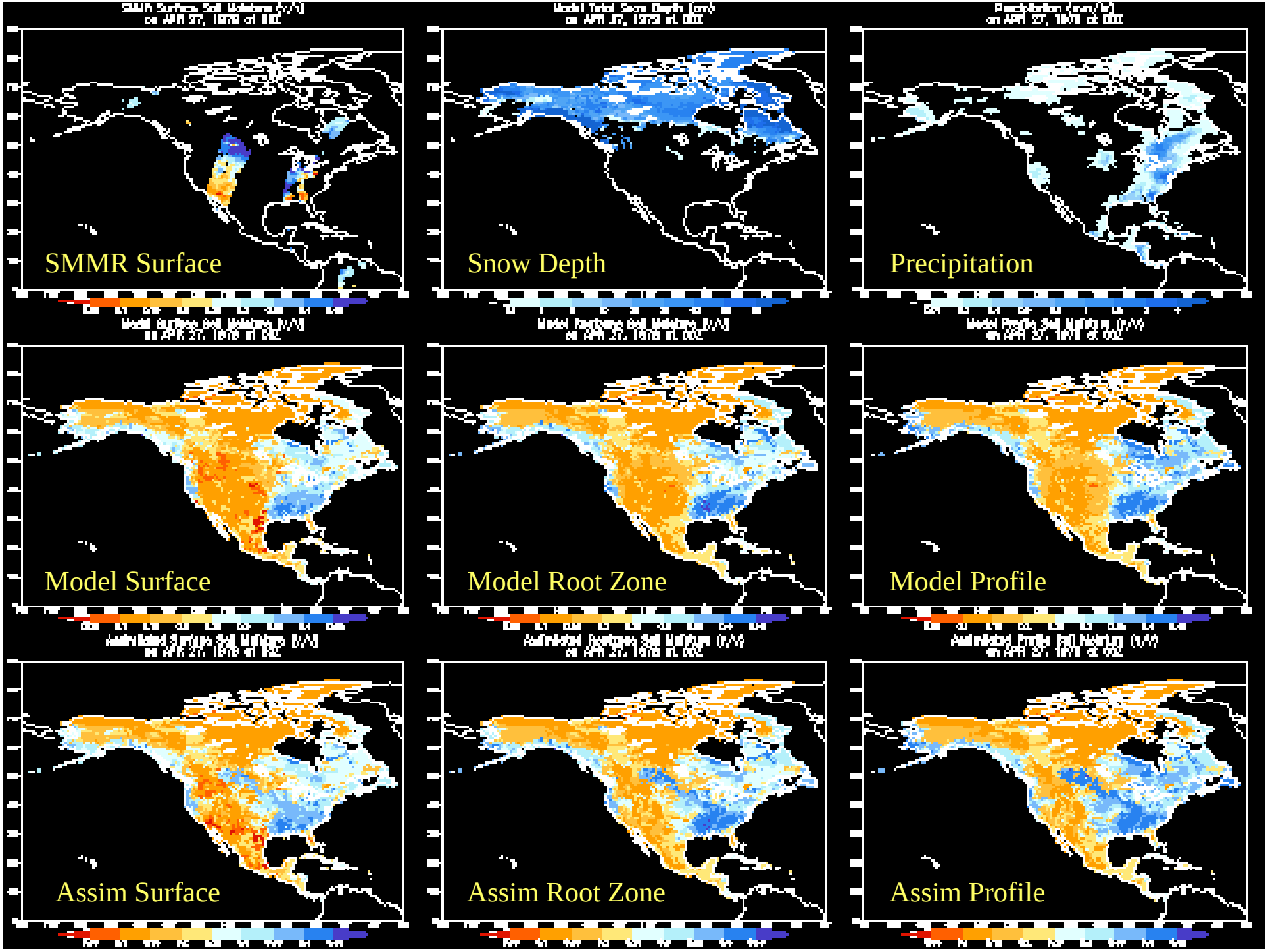
Skin Temperature Assimilation



Snow Water Assimilation

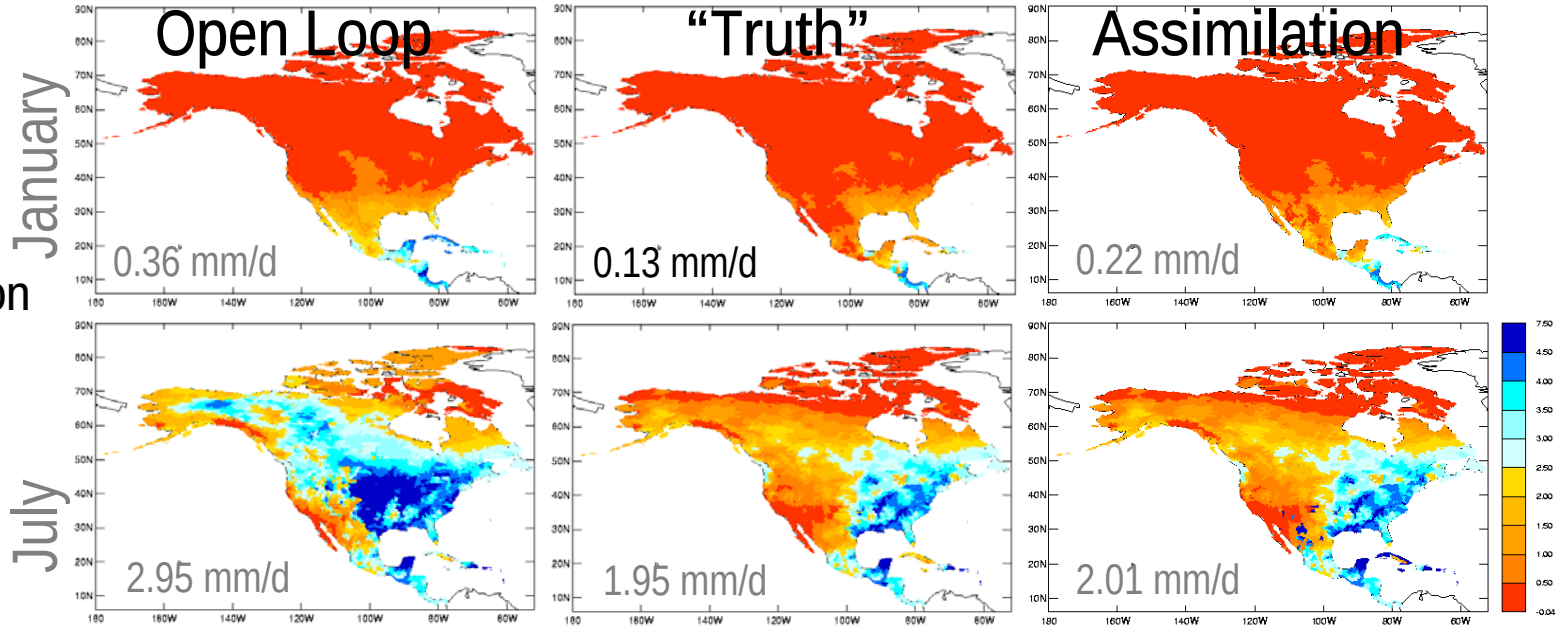




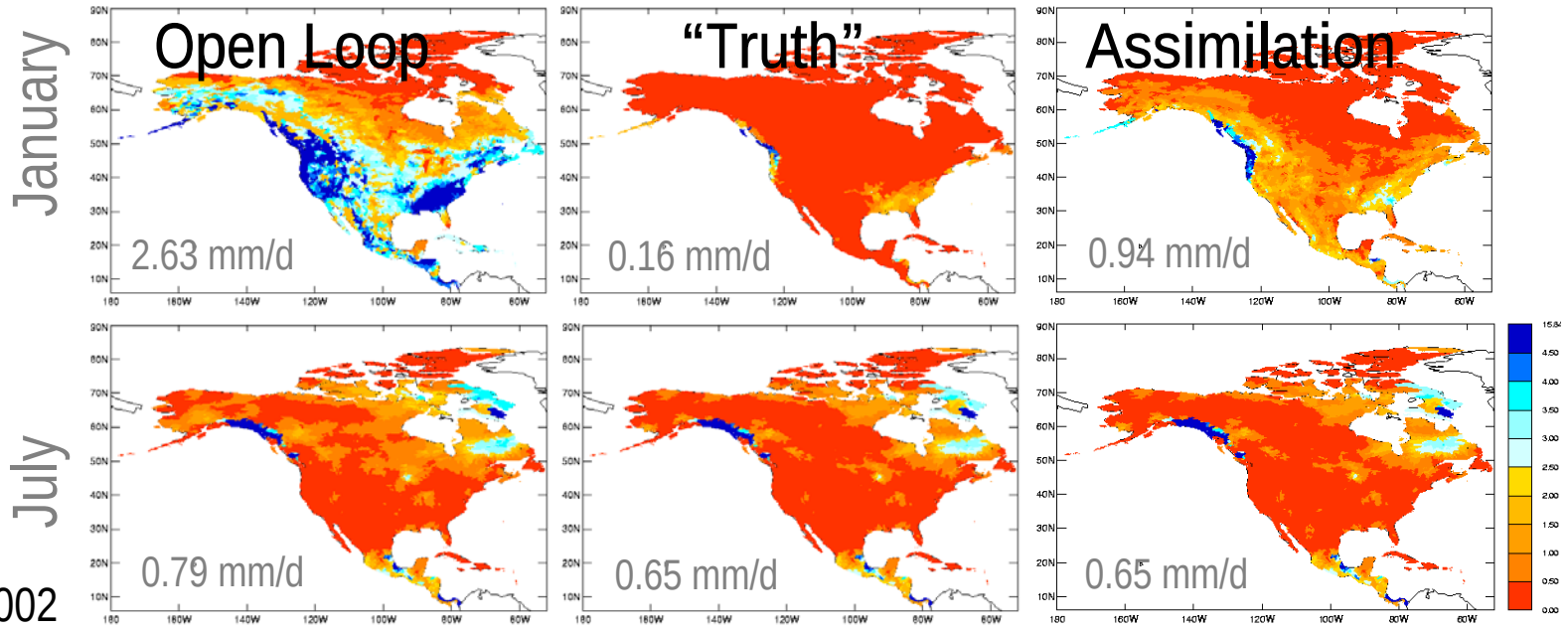

SMMR Surface
Snow Depth
Precipitation
Model Surface
Model Root Zone
Model Profile
Assim Surface
Assim Root Zone
Assim Profile

Impact of Soil Moisture Assimilation on Fluxes

Monthly Evapotranspiration

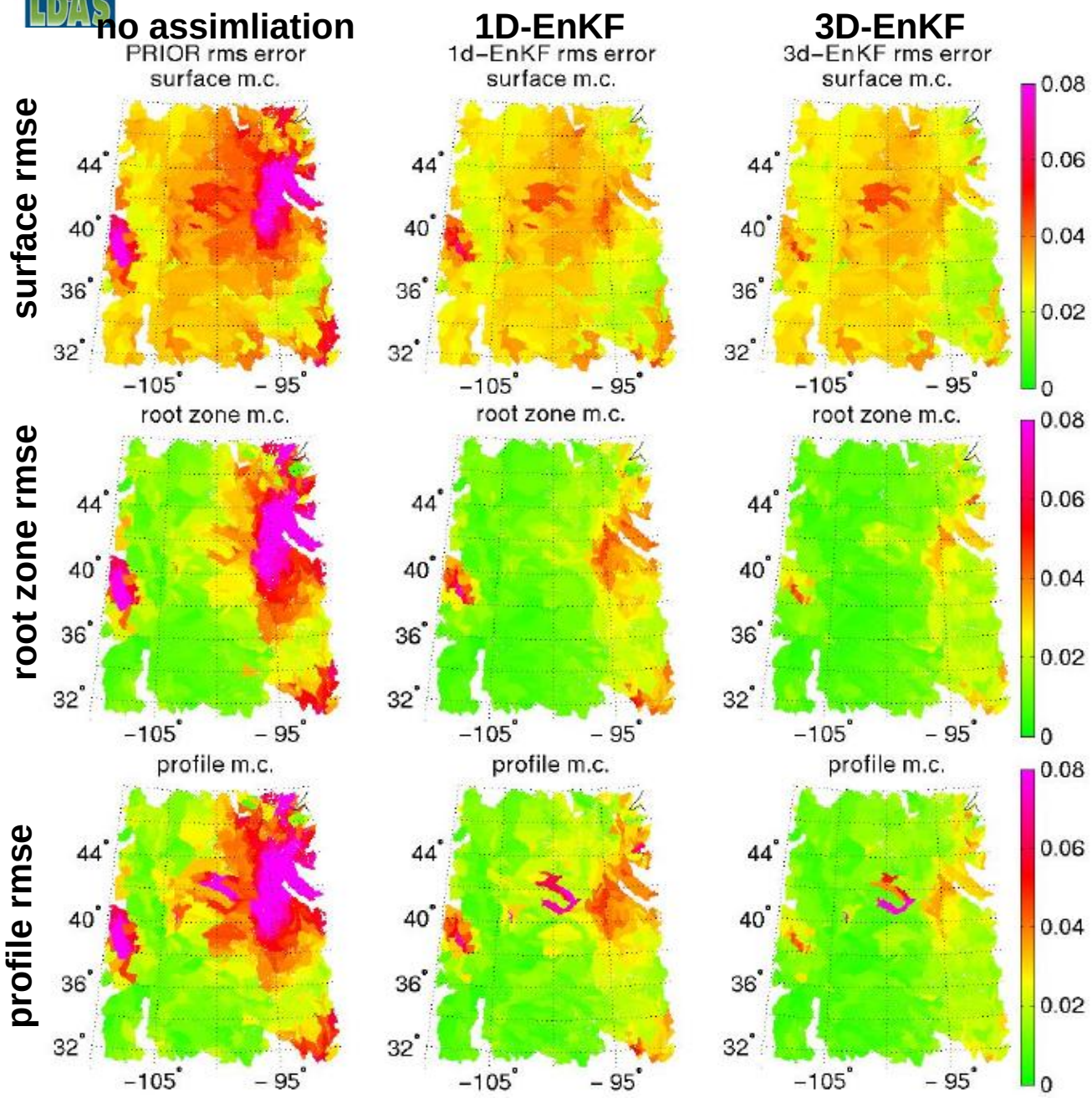


Monthly Runoff



Walker & Houser, 2002

Soil moisture assimilation: 1D-EnKF vs. 3D-EnKF



Reichle & Koster
JHM 4, 1229-1242, 2003.

Twin experiment:
- **US Great Plains**
- **1983-1986**
- **Control ("truth") uses gauge precipitation, assimilation uses re-analysis.**
- **Assimilate synthetic SMMR obs of surface soil moisture**

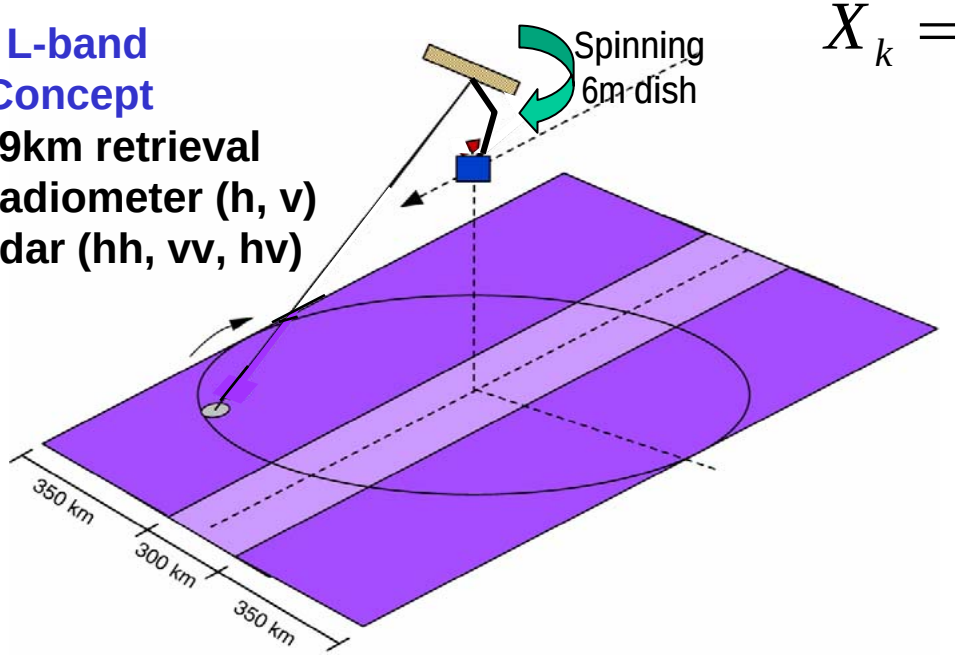
There are horizontal error correlations in the precipitation forcings.

3D filter yields more accurate soil moisture.

An *OSSE* for the *HYDROS* *soil moisture* mission

HYDROS L-band Mission Concept

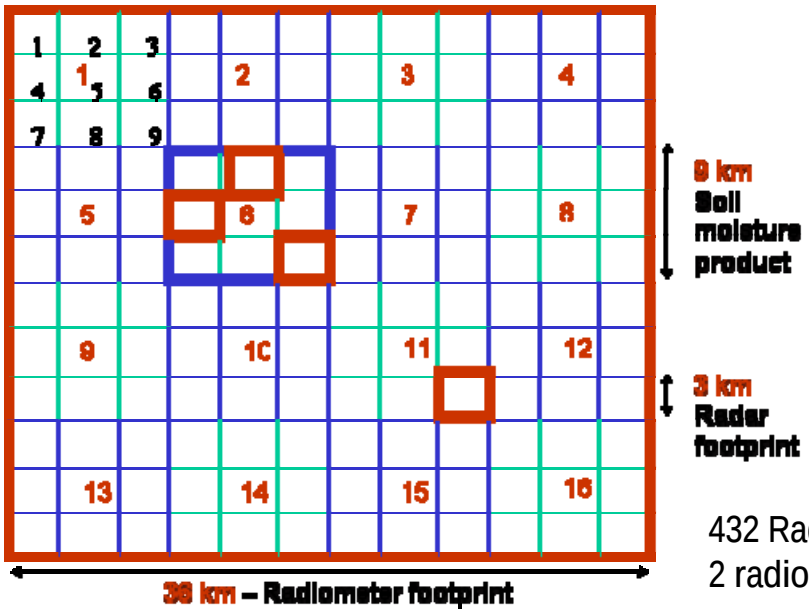
GOAL: 9km retrieval
~36km radiometer (h, v)
~3km radar (hh, vv, hv)



$$X_k = X_{b,k} + K_k[Z_k - h(X_{b,k},0)]$$

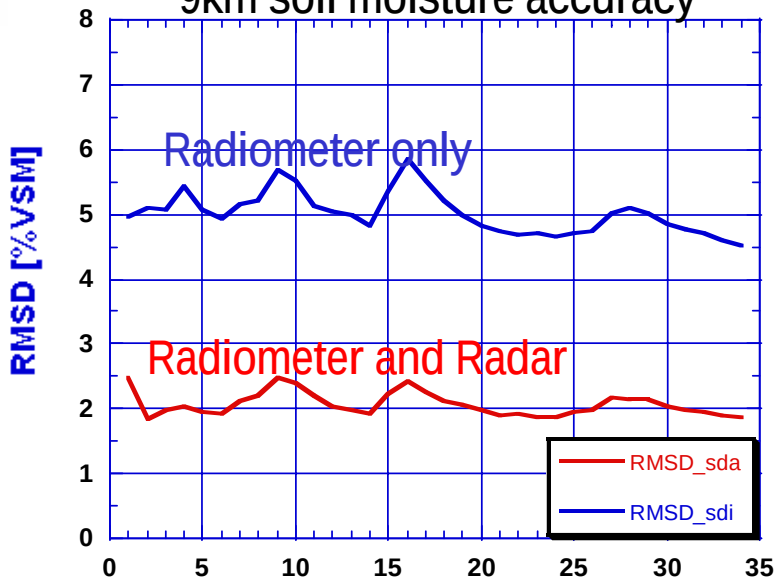
$$X_{b,k} = LSM$$

$$Z_k = \begin{pmatrix} T_{b_{v,f}} \\ T_{b_{h,f}} \\ \sigma_{vv,f} \\ \sigma_{hh,f} \\ \sigma_{vh,f} \end{pmatrix} \qquad H = \begin{pmatrix} \partial T_{b_{v,f}} / \partial x_f \\ \partial T_{b_{h,f}} / \partial x_f \\ \partial \sigma_{vv,f} / \partial x_f \\ \partial \sigma_{hh,f} / \partial x_f \\ \partial \sigma_{vh,f} / \partial x_f \end{pmatrix}$$



432 Radar Observations
2 radiometer observations

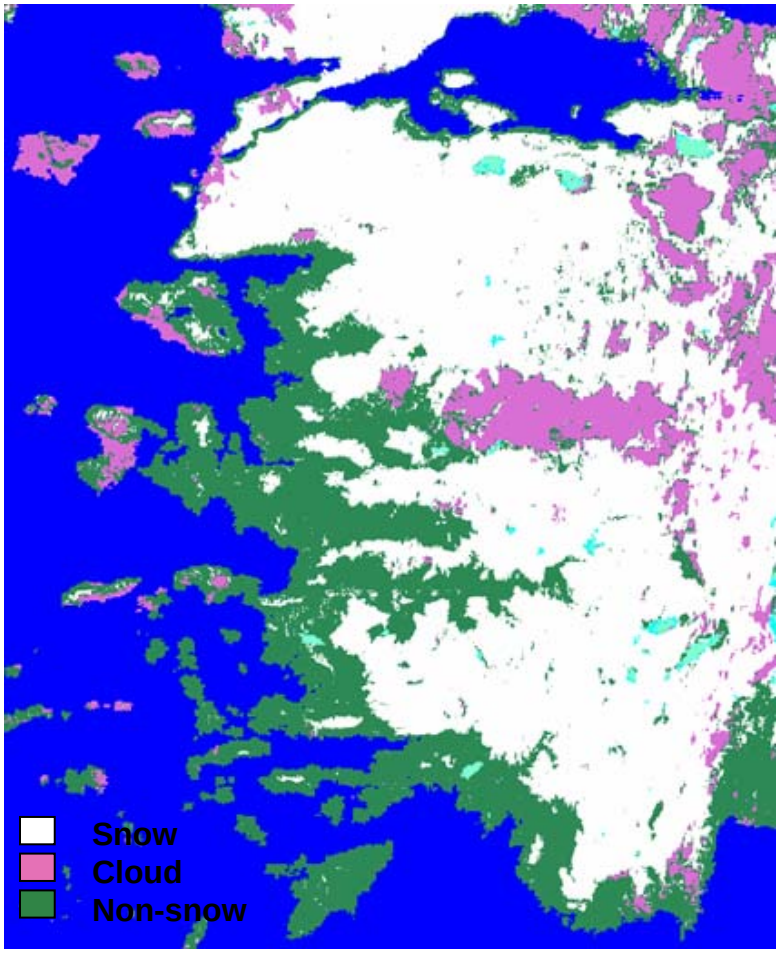
9km soil moisture accuracy



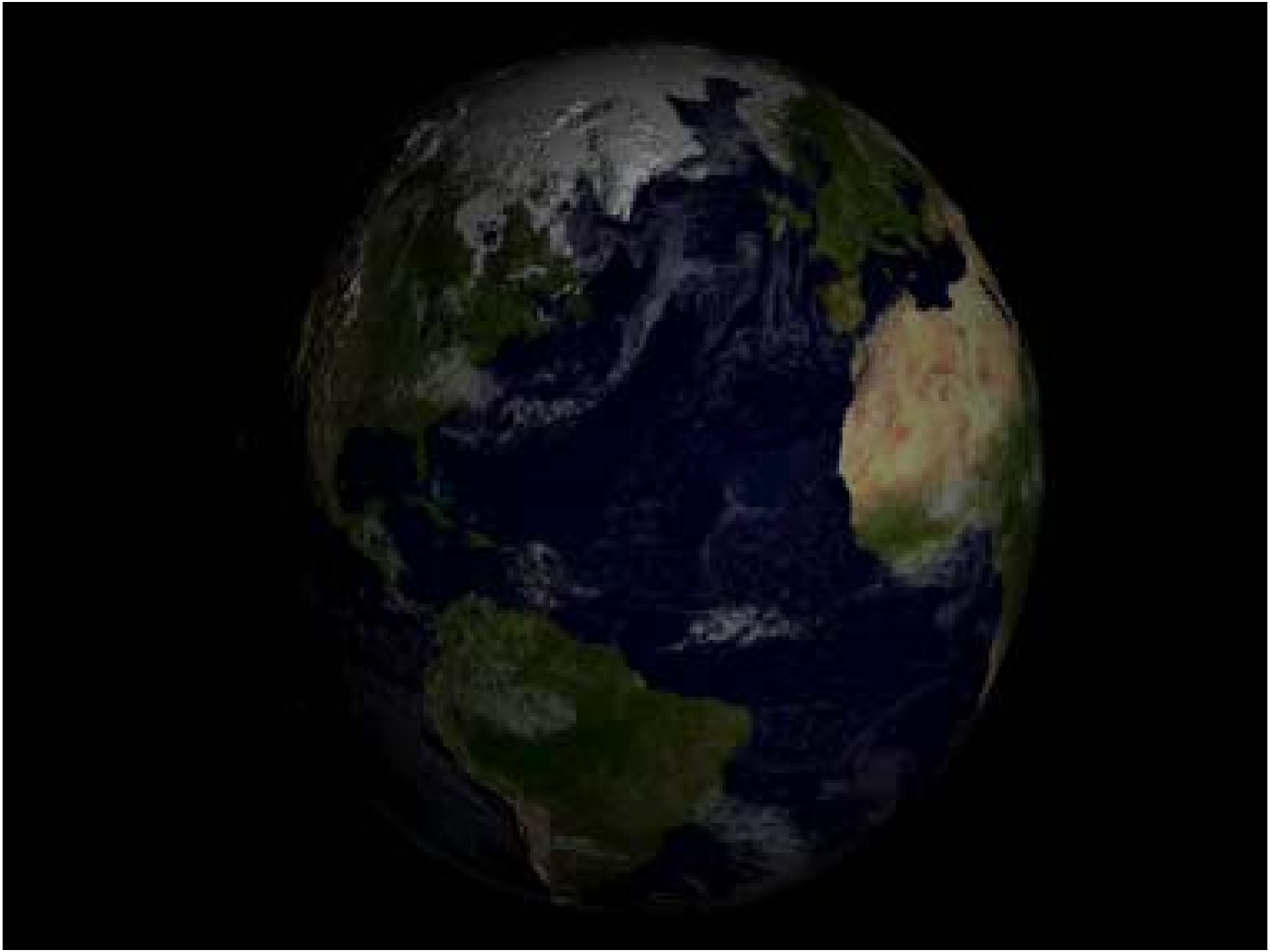
Zhan et al., 2004

MODIS Snow Cover

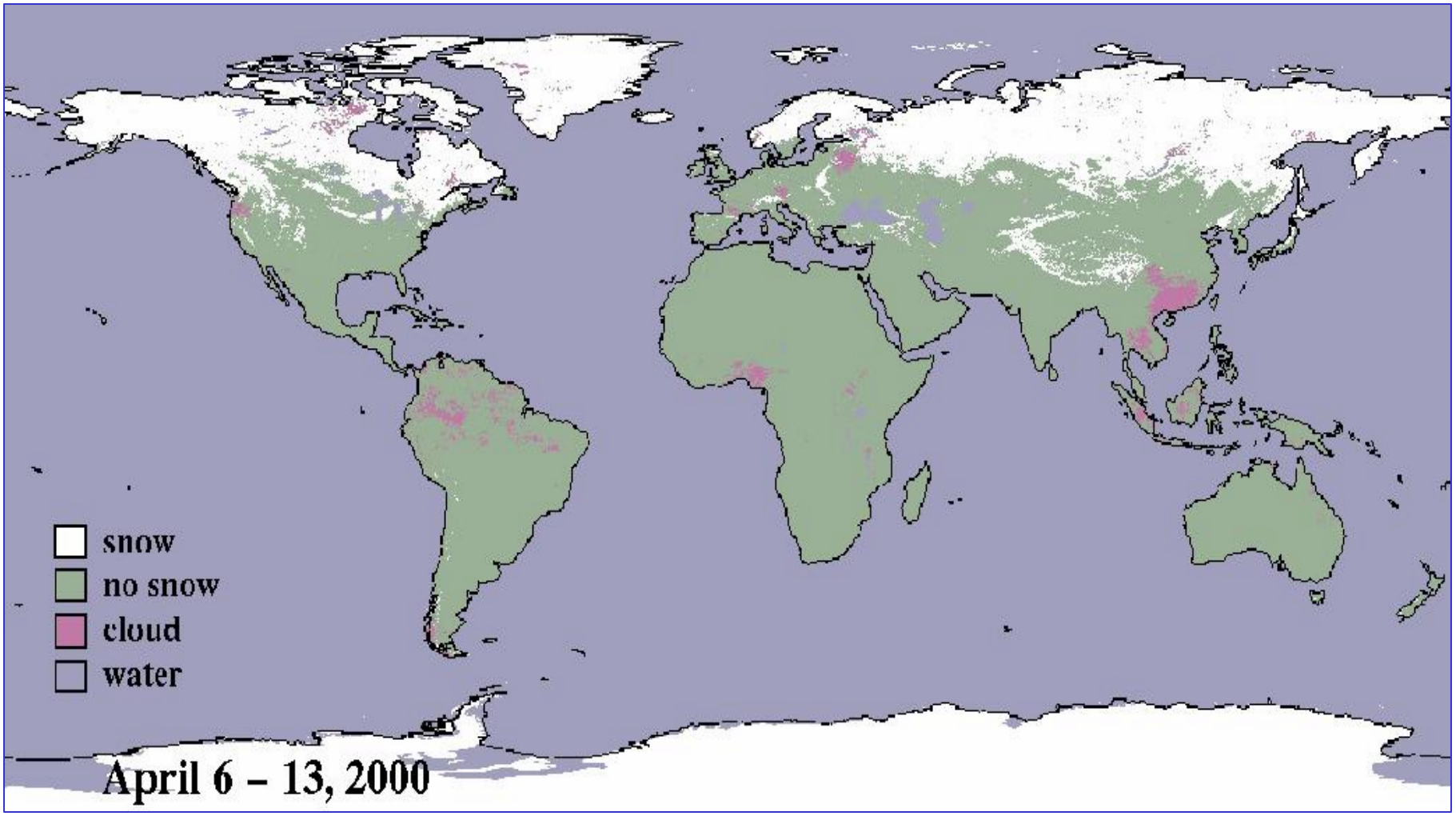
MODIS true color image and corresponding MOD10_L2 snow map of Western Turkey on January 27, 2004



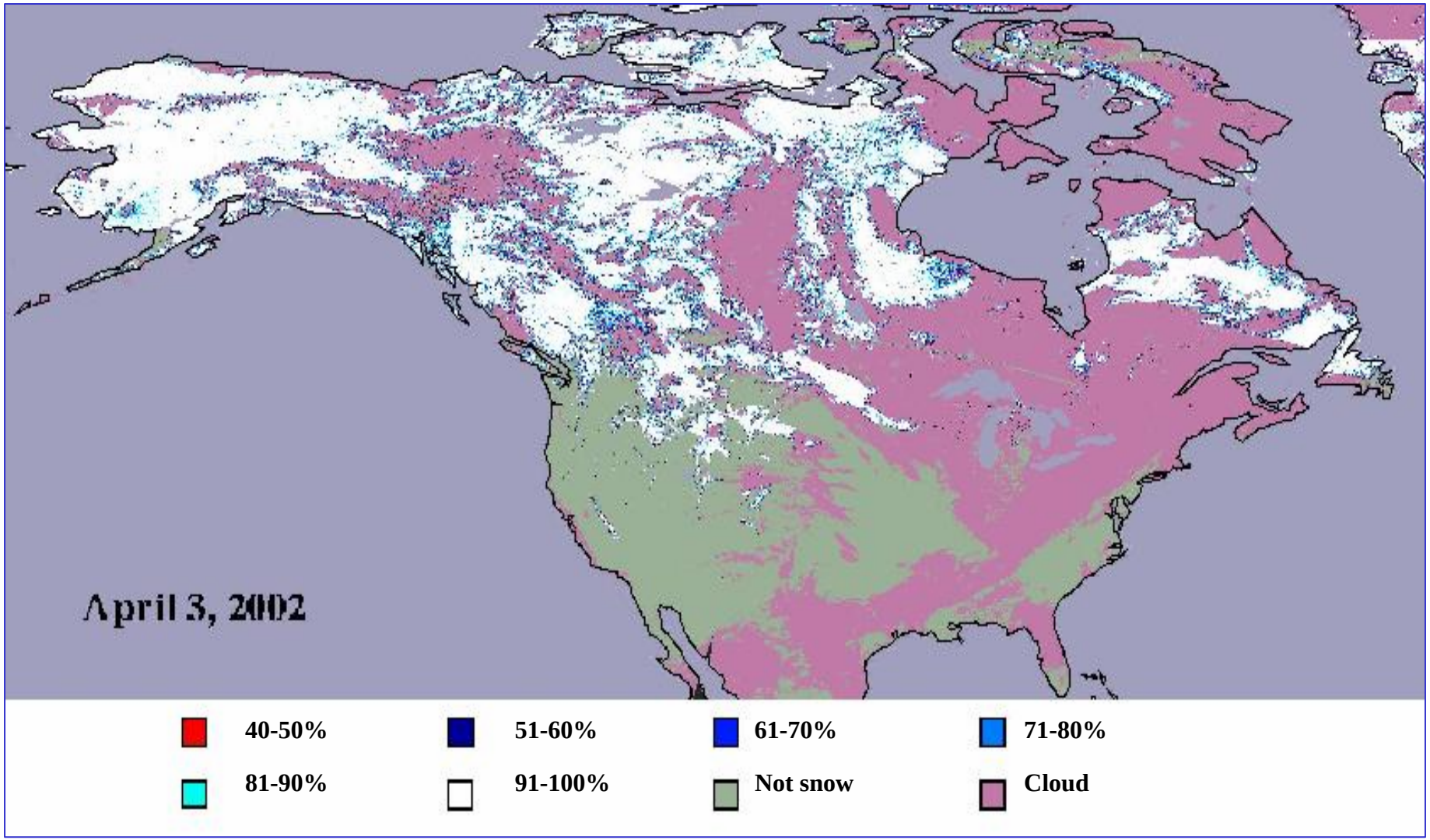
Large winter storms and sub-zero temperatures moved through the eastern Mediterranean during the last week of January 2004. The storms brought heavy snows to western Turkey.



Eight-day composite MODIS Climate-Modeling Grid (CMG) Snow Map at 0.05° resolution

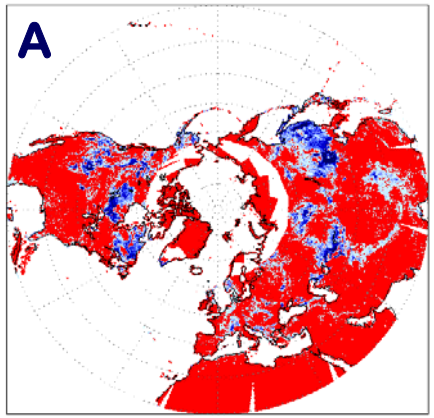


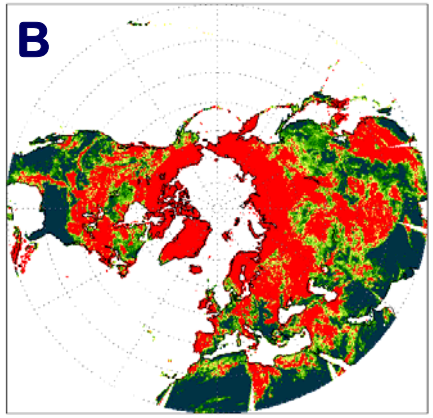
Daily CMG maps show fractional snow cover from 1 - 100% in each pixel*

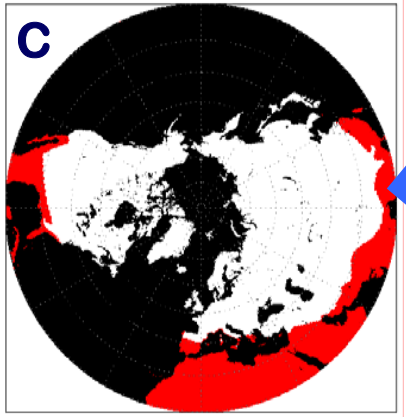


*** Only 40-100% shown here**

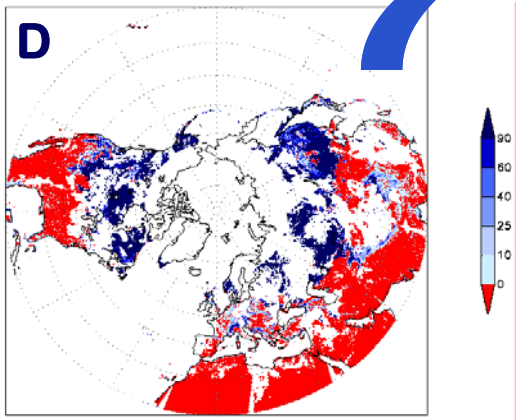
GLDAS Observation-based Snow Correction



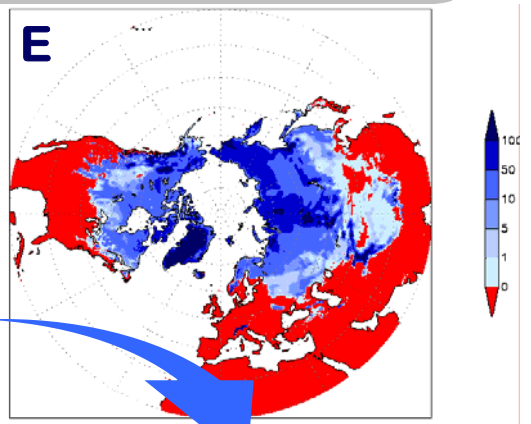


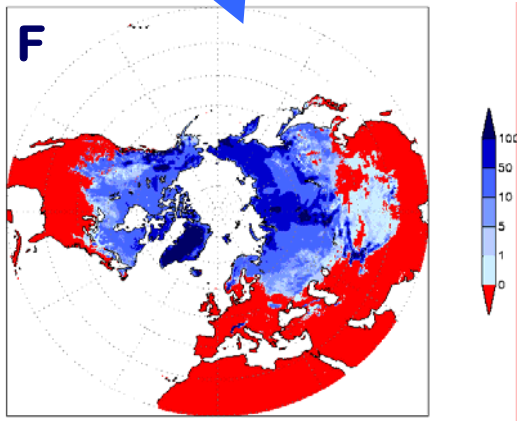


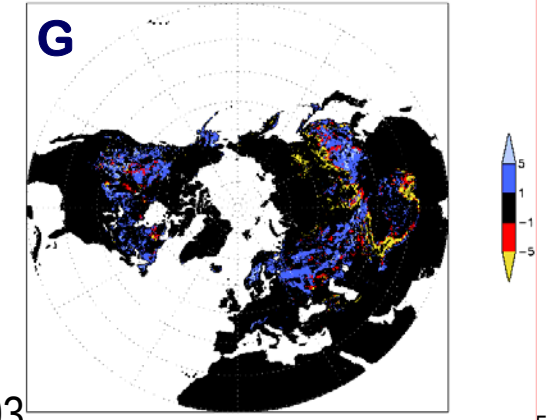
Original MODIS visible snow cover (%) ***A*** is modified using MODIS confidence index (total visibility; %) ***B*** and a snow impossible mask ***C*** in order to produce an enhanced snow field ***D***.



This is used to update the modeled snow on a daily basis. Output snow depth (mm H2O) is shown for 30 November 2000, after running the Mosaic LSM without ***E*** and with ***F*** the snow correction for 30 days. Map ***G*** shows the difference (mm H2O) between the two results.







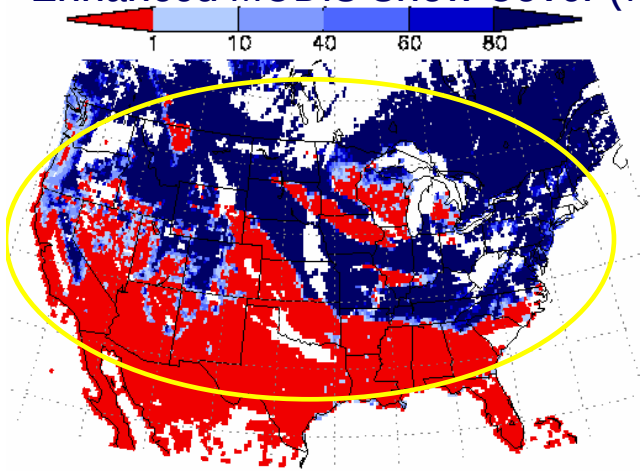
Rodell et al., 2003

GLDAS Snow Updates Using MODIS Data

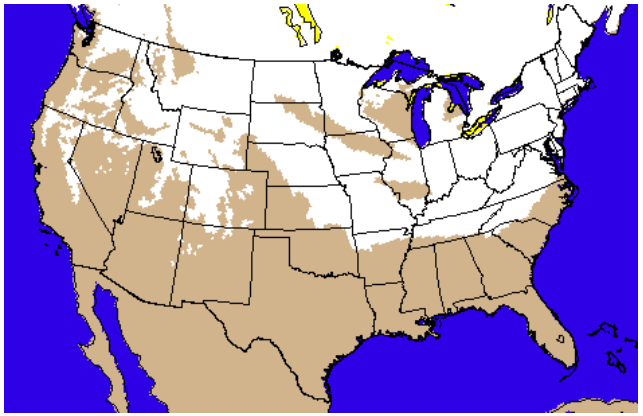
Land Surface Data Assimilation
Rodell et al., 2003

21Z 17 January 2003

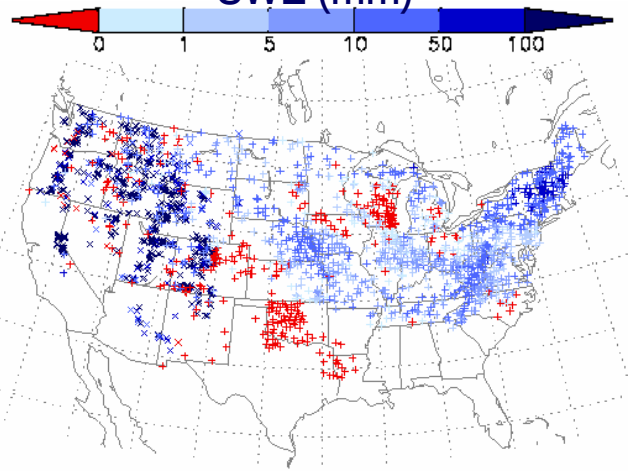
Enhanced MODIS Snow Cover (%)



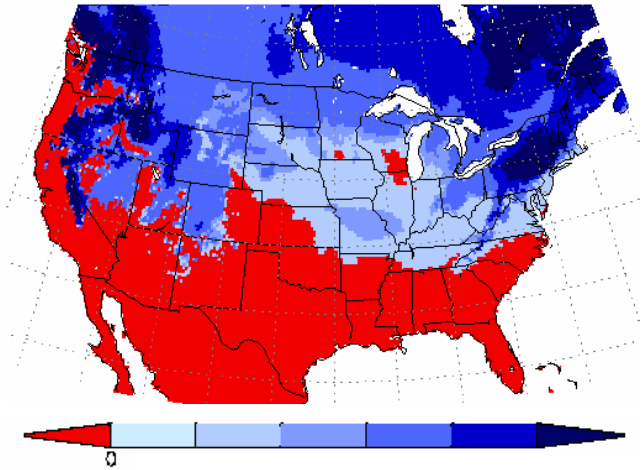
IMS Snow Cover



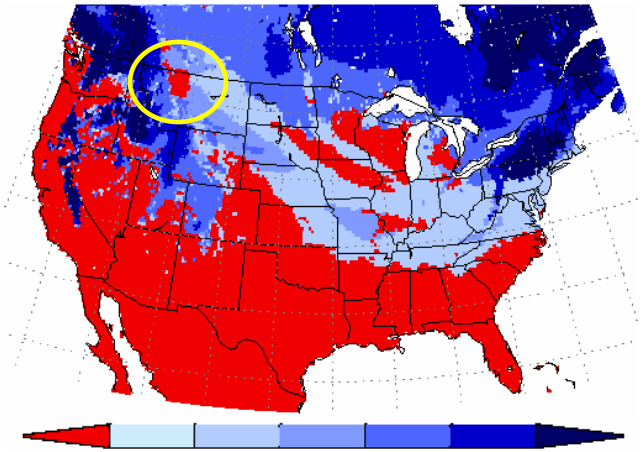
SNOTEL and Co-op Network SWE (mm)



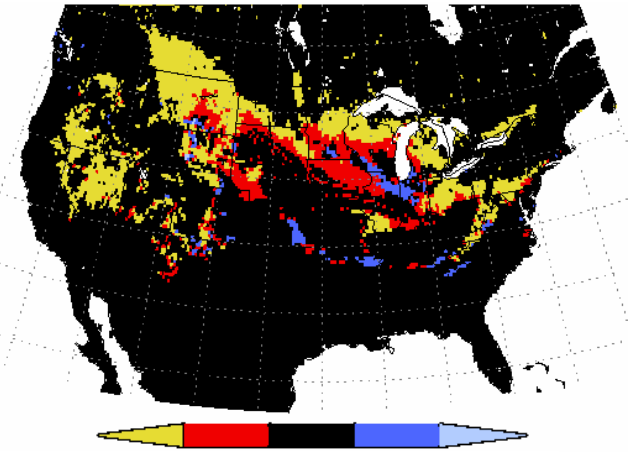
Control Run Mosaic SWE (mm)

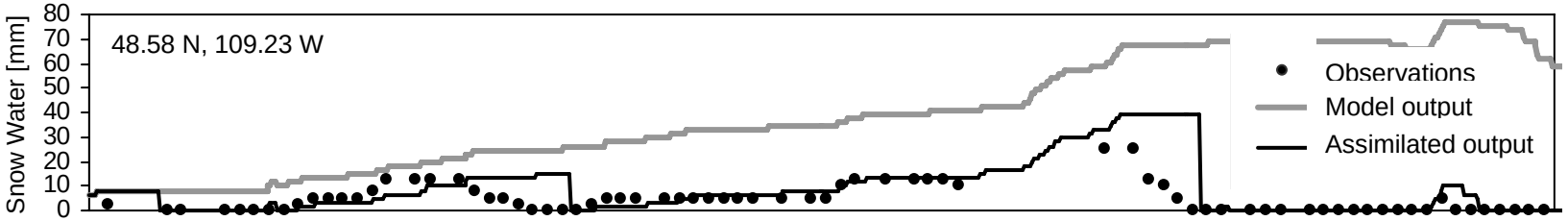


Assimilated Mosaic SWE (mm)



Mosaic SWE Difference (mm)





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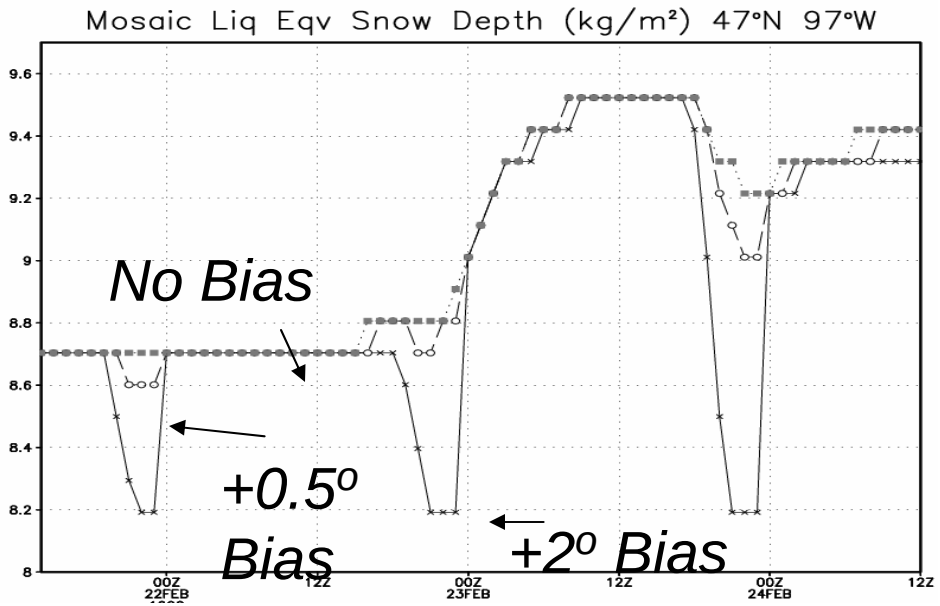
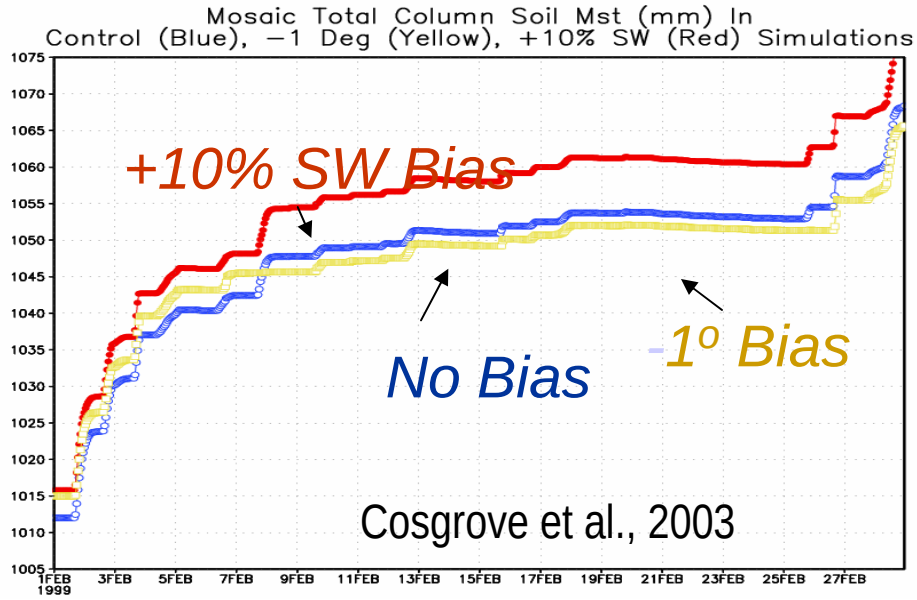
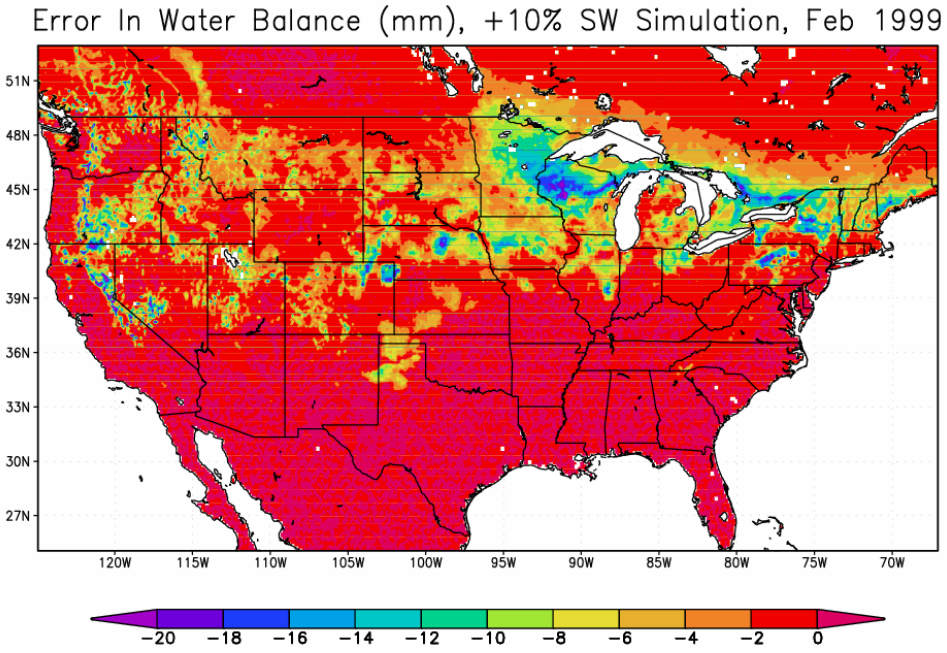
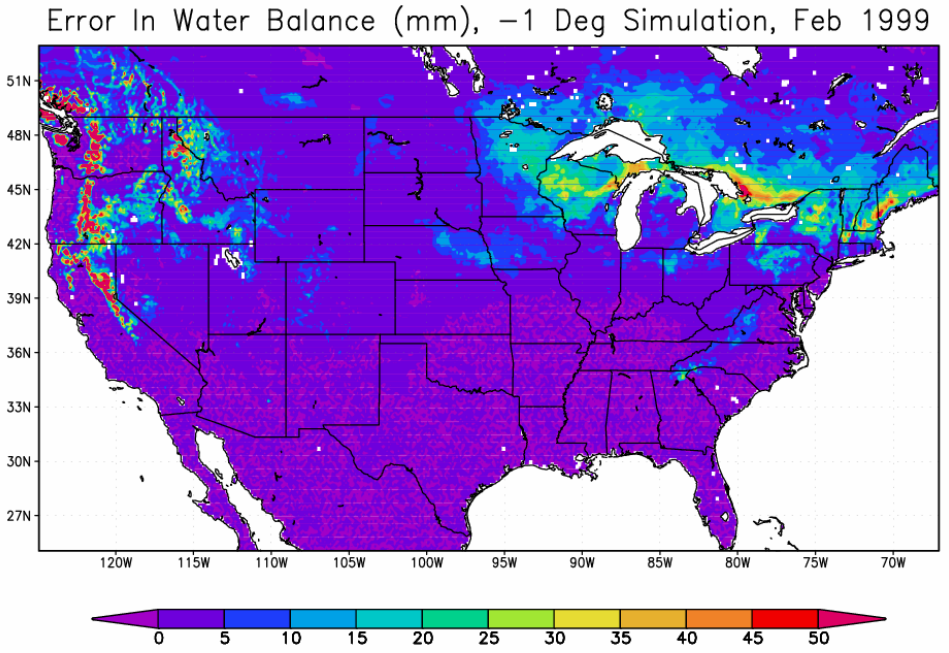
Snow Data Assimilation: Impact of bias



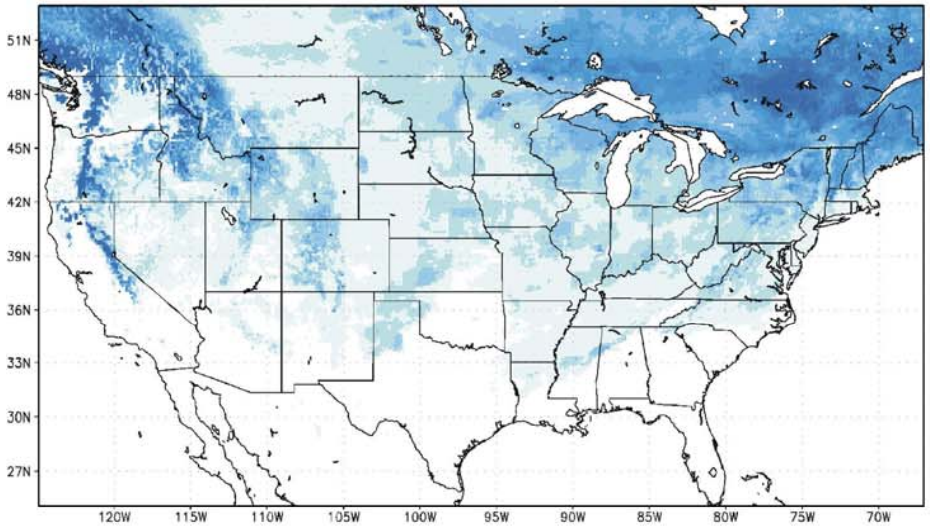




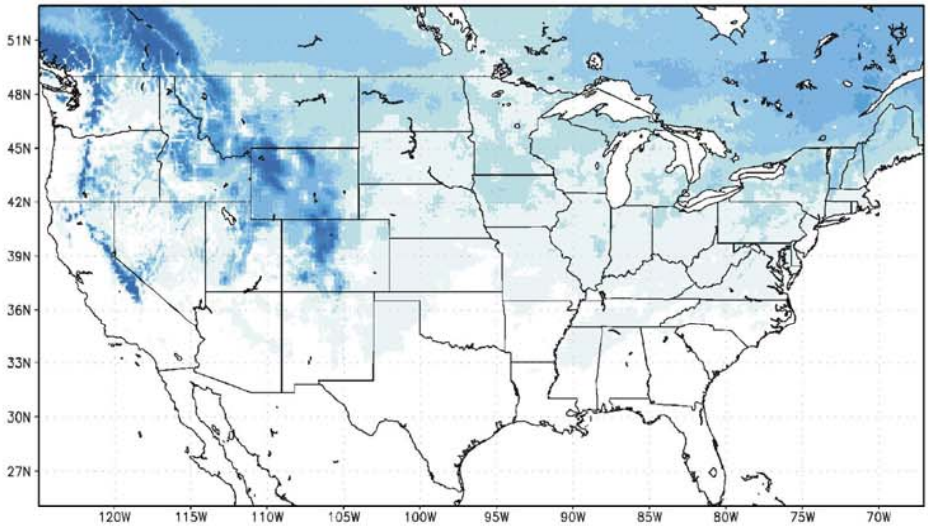


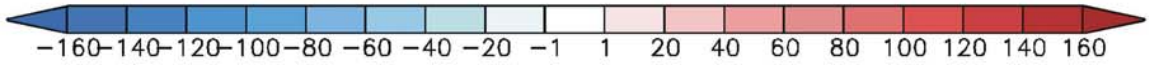
Snow Data Assimilation: Impact of bias

Assimilation Flux (kg/m^2) Sep 1998 to Aug 1999, Temp+1º

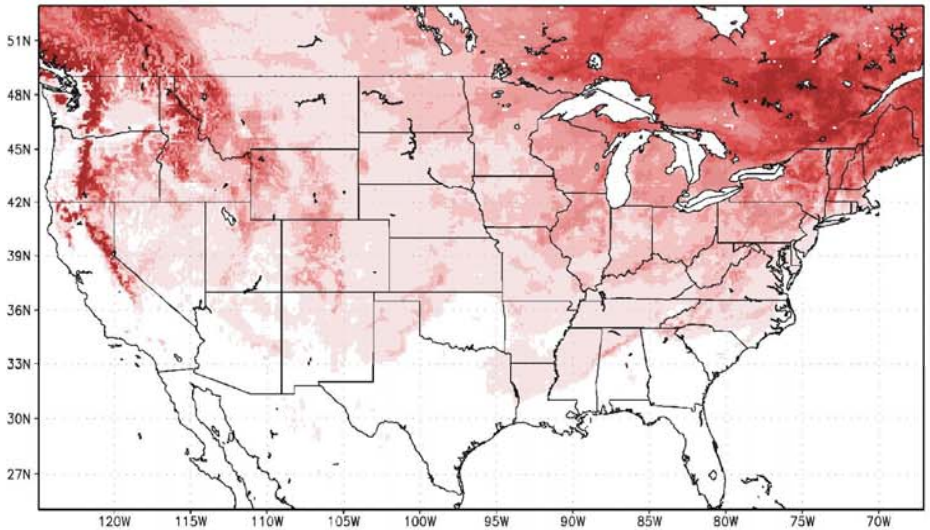


Assimilation Flux (kg/m^2) Sep 1998 to Aug 1999, SW+10%

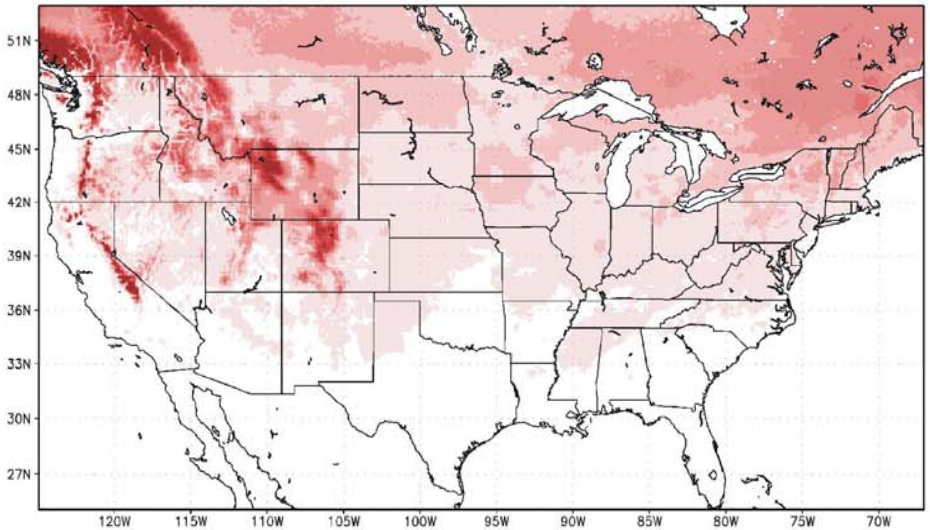




Assimilation Flux (kg/m^2) Sep 1998 to Aug 1999, Temp-1º



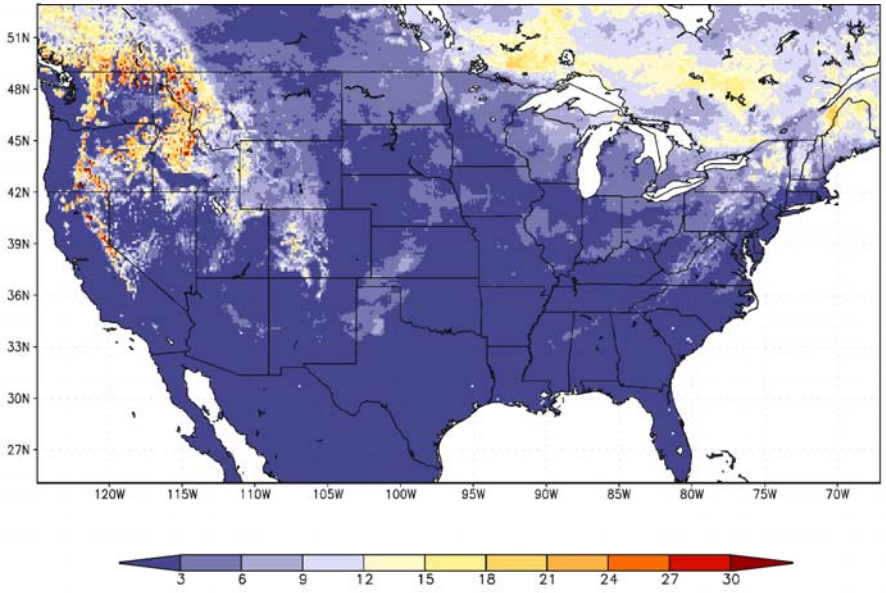
Assimilation Flux (kg/m^2) Sep 1998 to Aug 1999, SW-10%



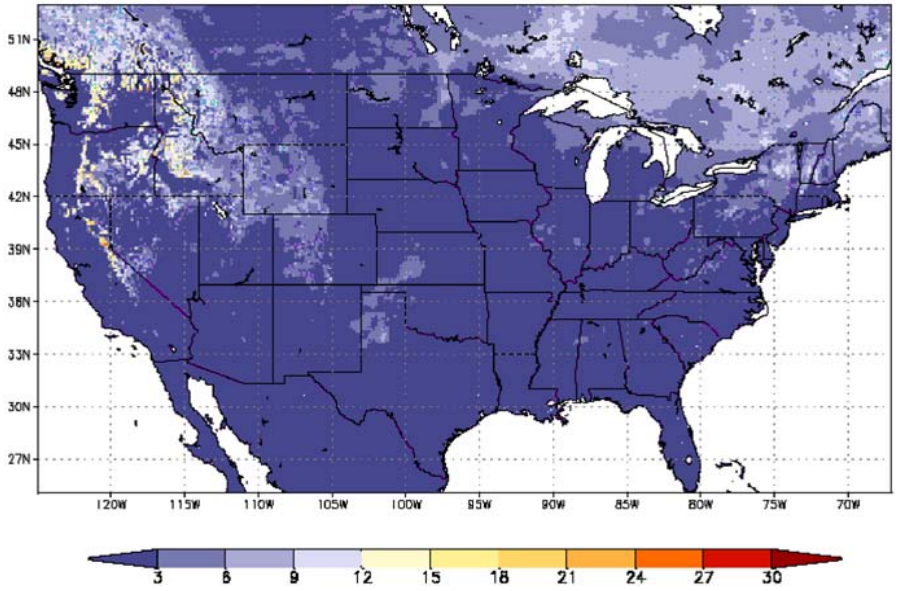
Snow Data Assimilation: Correcting Impact of bias

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

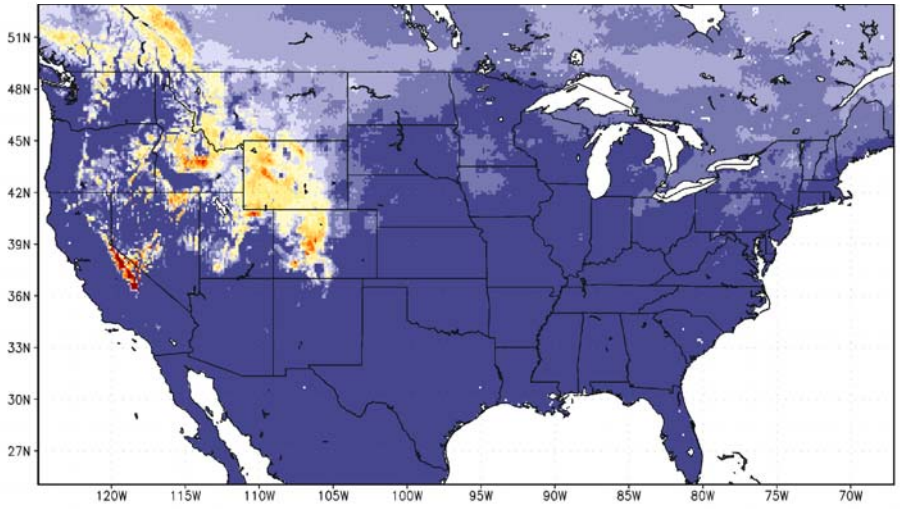
Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, Tmp+1º



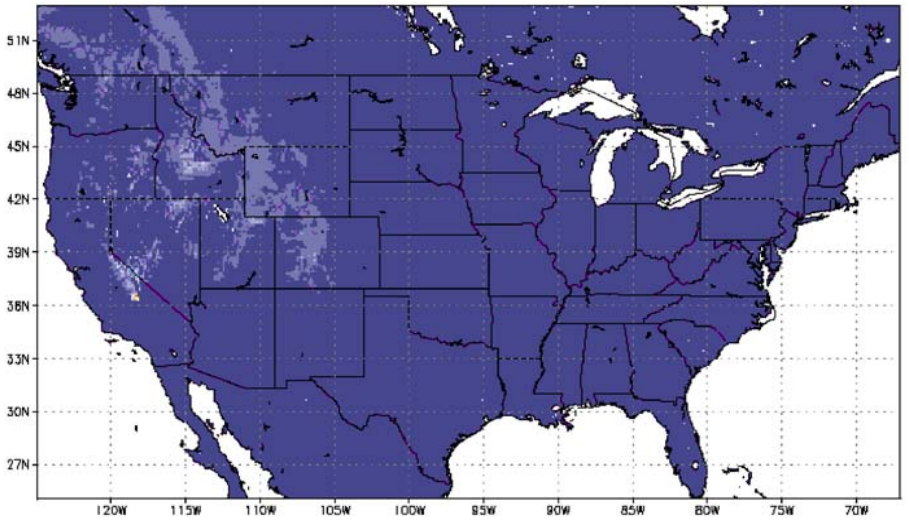
Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, Tmp+1º SMA



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

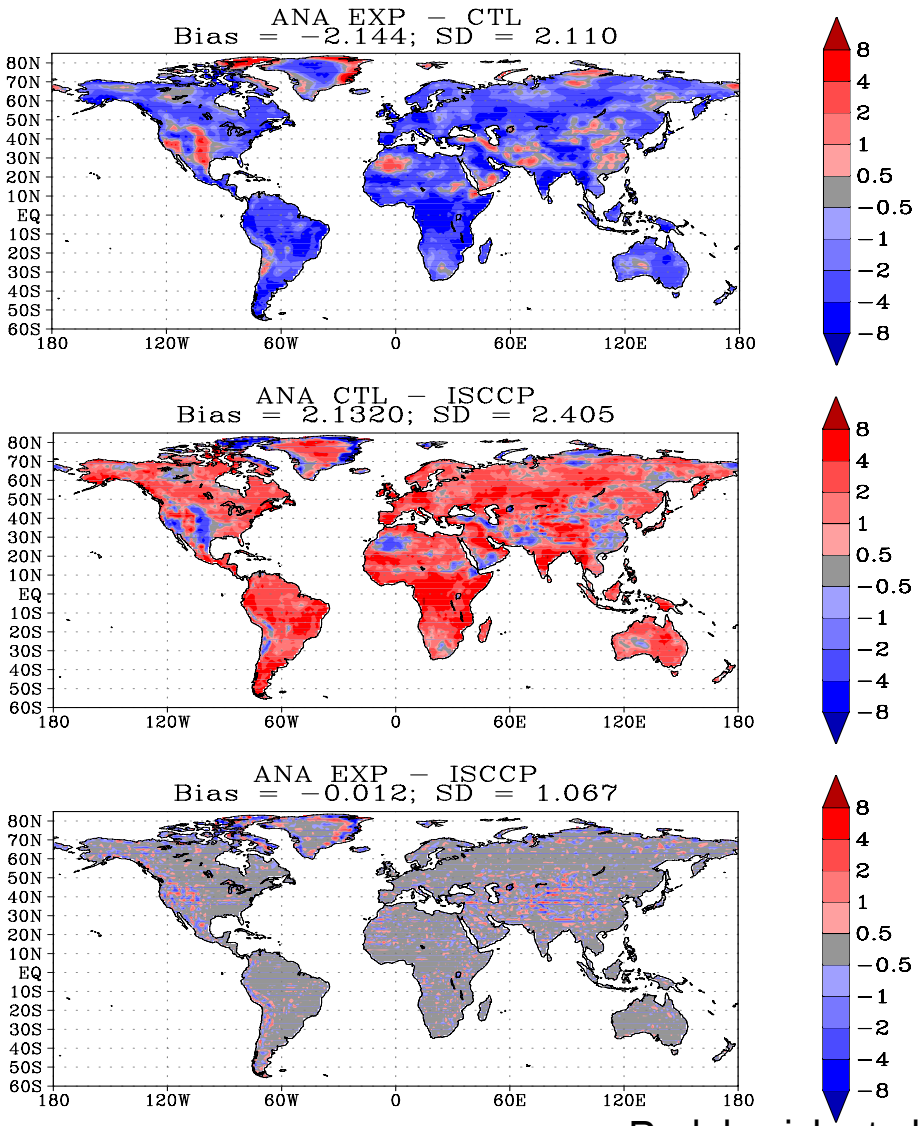


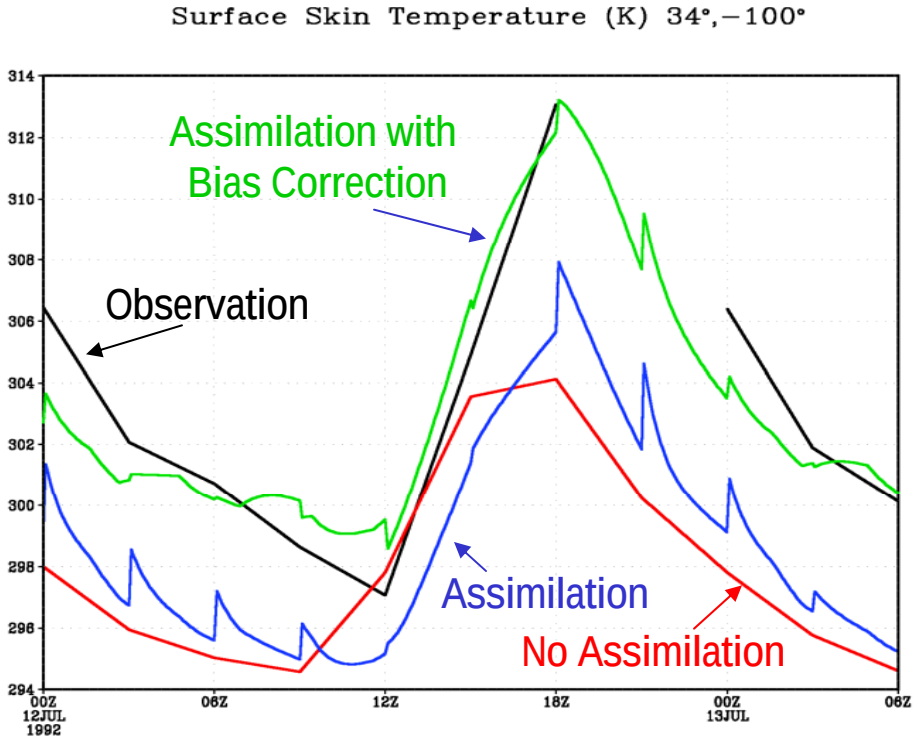
Assimilation Flux as % of Total Precipitation, 9/98 to 8/99, SW+10% SMA



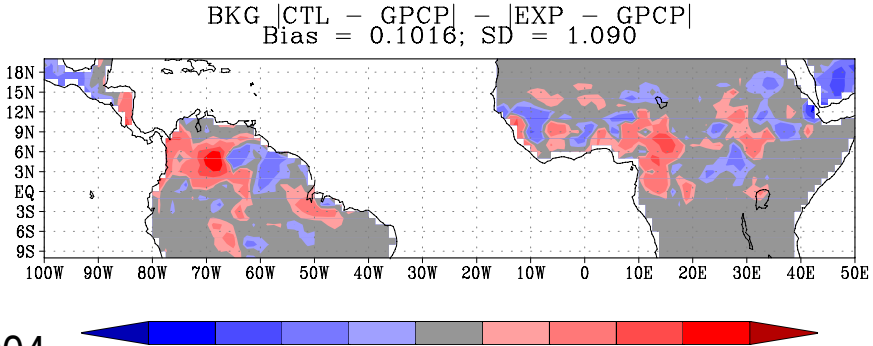
Data Assimilation: T_s Assimilation Results

FVDAS-CLM Assimilation of Remotely-Sensed Surface Skin Temperature.





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



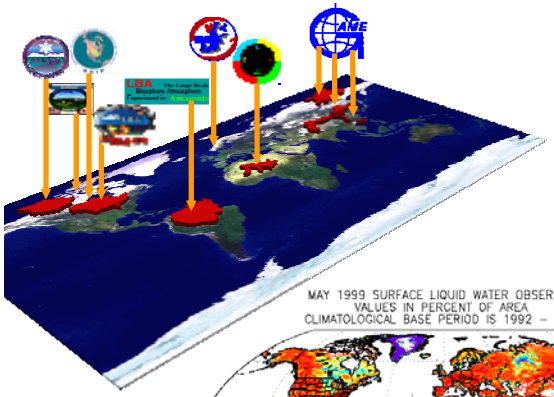
Radakovich et al., 2004

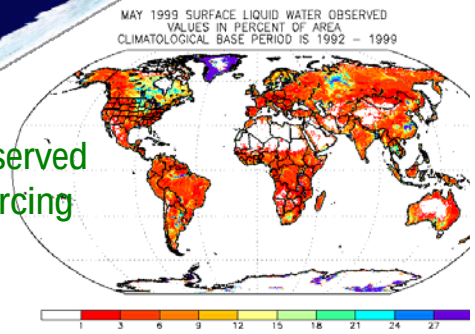
Paul R. Houser, *NASA/GSFC Hydrological Sciences*
Paul.Houser@gsfc.nasa.gov

Global Land Data Assimilation System

Objective: A 1/4 degree (and other) global land modeling and assimilation system that uses all relevant observed forcing, storages, and validation. Expand the current N. American LDAS to the globe. 1km global resolution goal

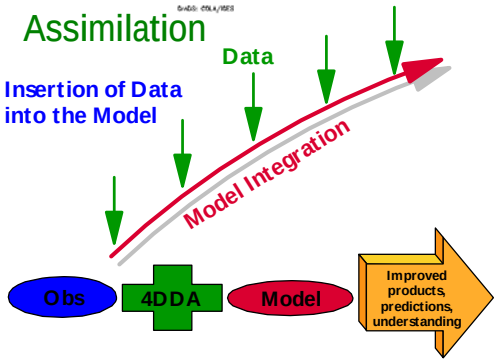
Consistent Global Intercomparison

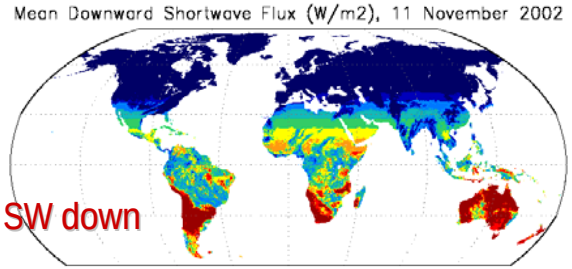




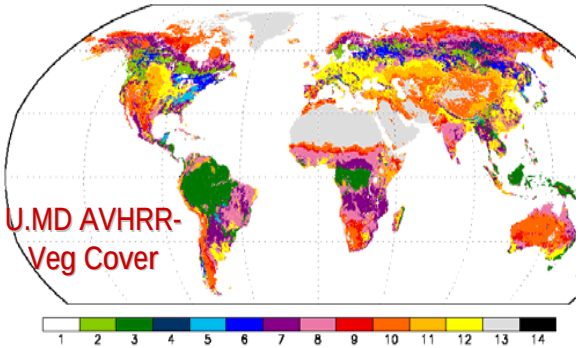
Observed Forcing

Land Data Assimilation

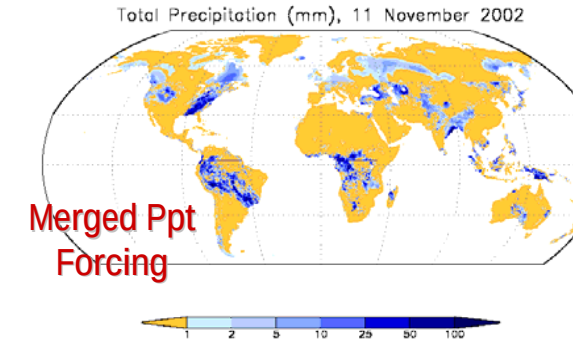




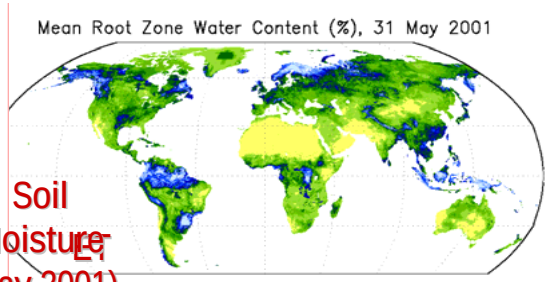
SW down



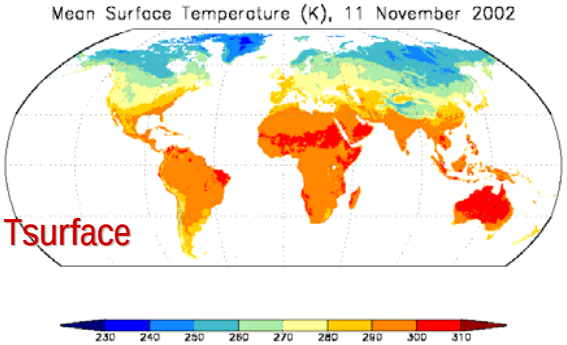
U.MD AVHRR-Veg Cover



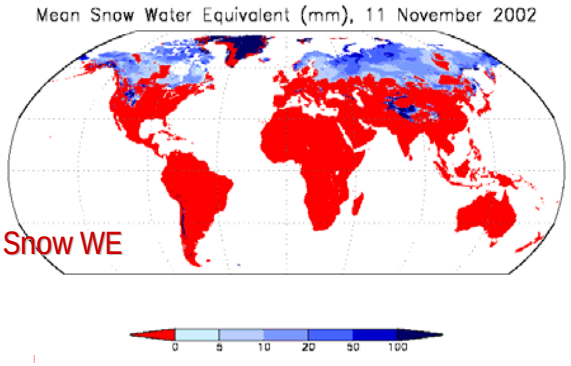
Merged Ppt Forcing



Soil Moisture, (May 2001)



Tsurface



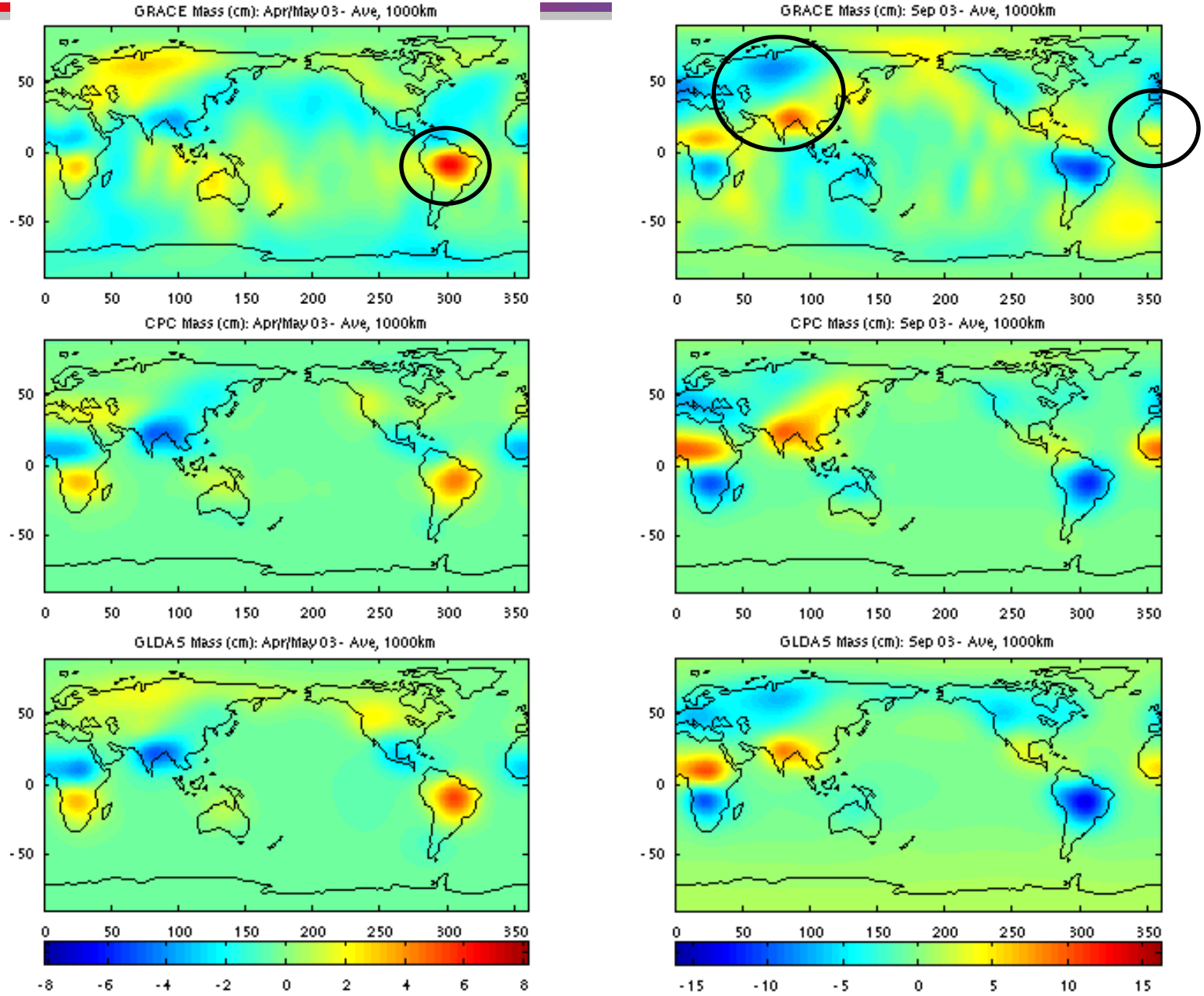
Snow WE

GRACE vs. Modeled TWS Anomalies (cm)

GRACE

CPC

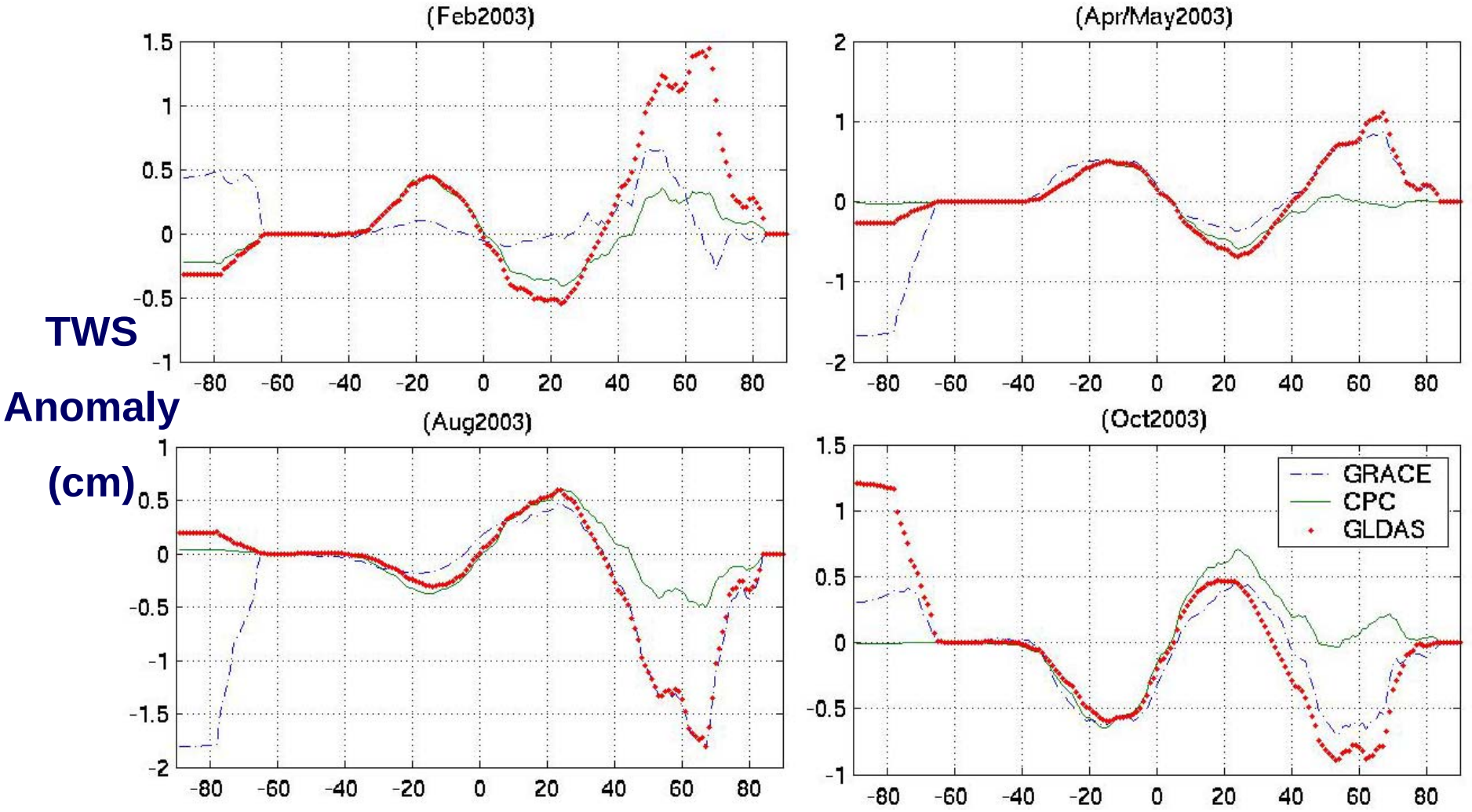
GLDAS



April/May 2003

September 2003

GRACE vs. Modeled TWS Anomalies



Land Information System

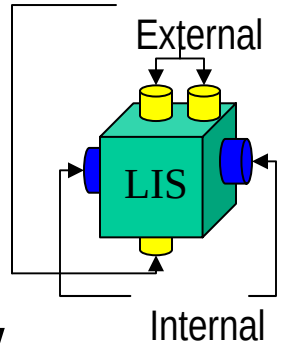
ESTO-CT Round-3 Grand Challenge Team

http://lis.gsfc.nasa.gov

Co-PIs: P. Houser, C. Peters-Lidard

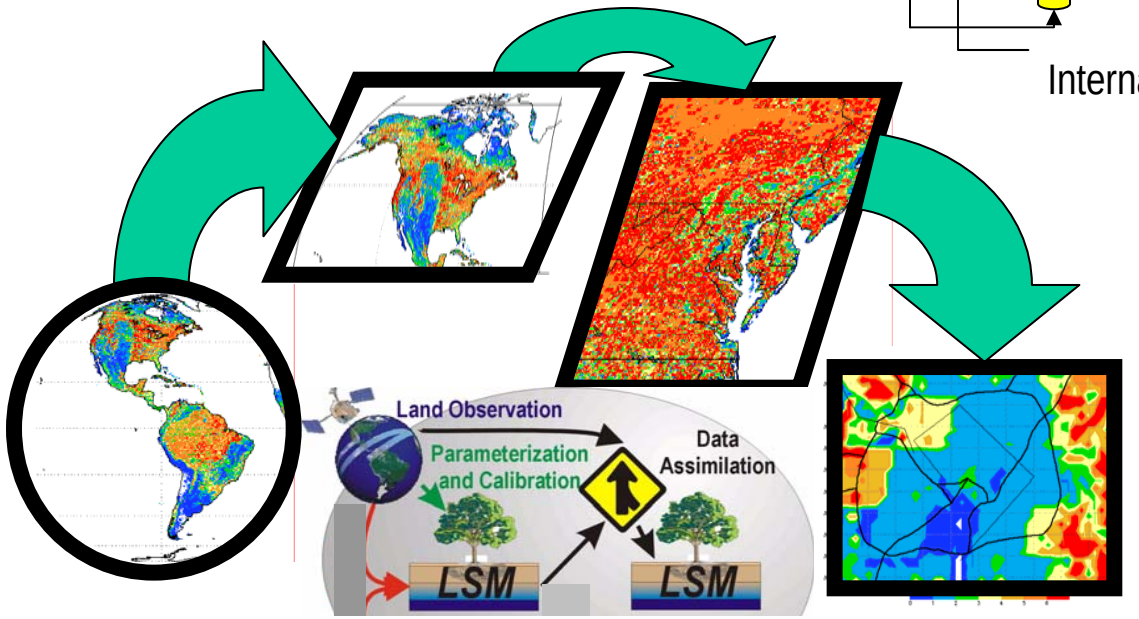
Hydrological Sciences Branch, Code 974

NASA Goddard Space Flight Center (GSFC), Greenbelt, MD

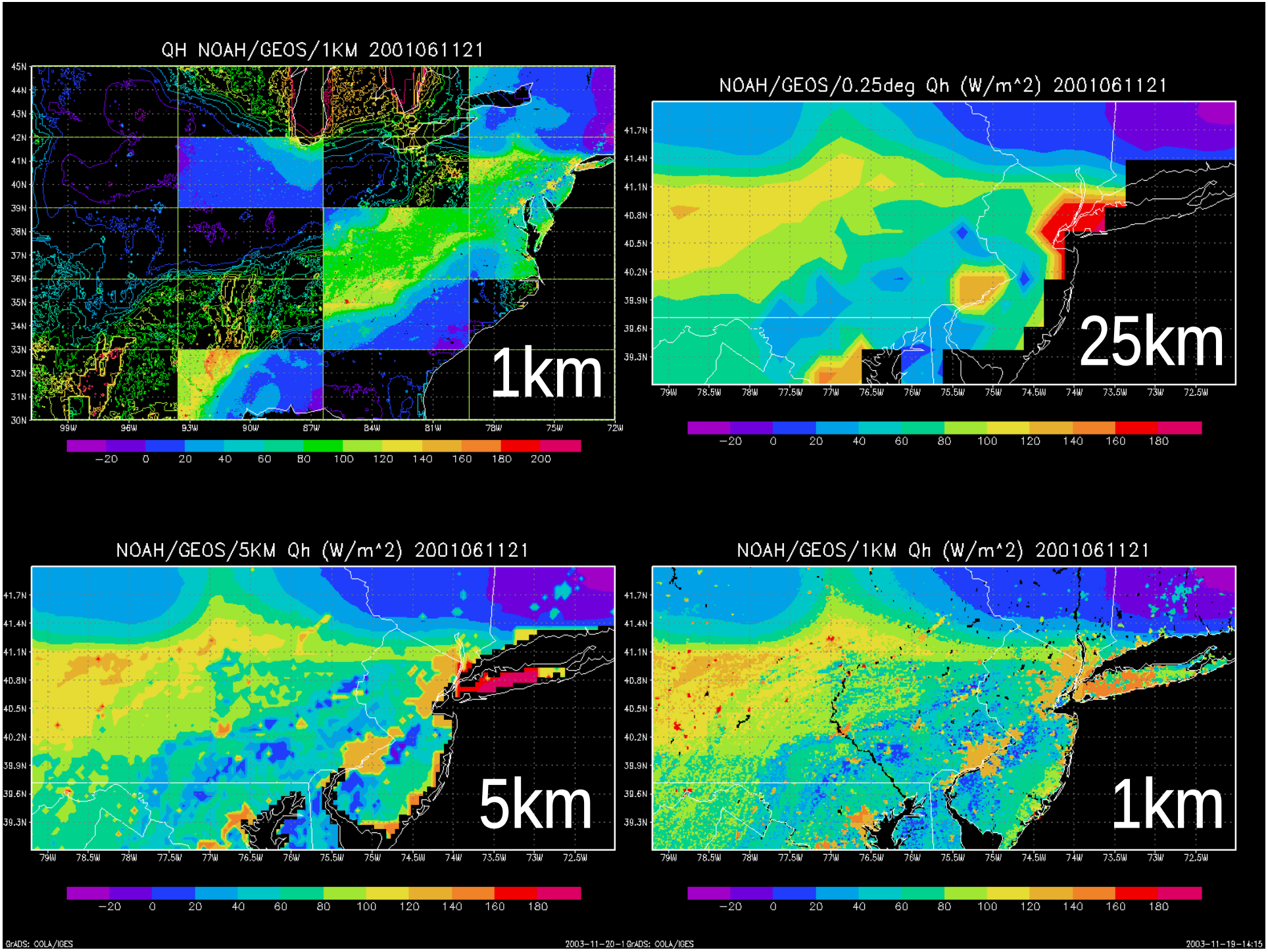


Summary: A high performance, high resolution (1 km) global land surface modeling (LSM) and data assimilation system demonstrating low-cost, Beowulf cluster computing and distributed data analysis (GrADS/DODS Server).

Applications: Weather and climate model initialization and coupled modeling, Flood and water resources forecasting, Precision agriculture, Mobility assessment, etc.

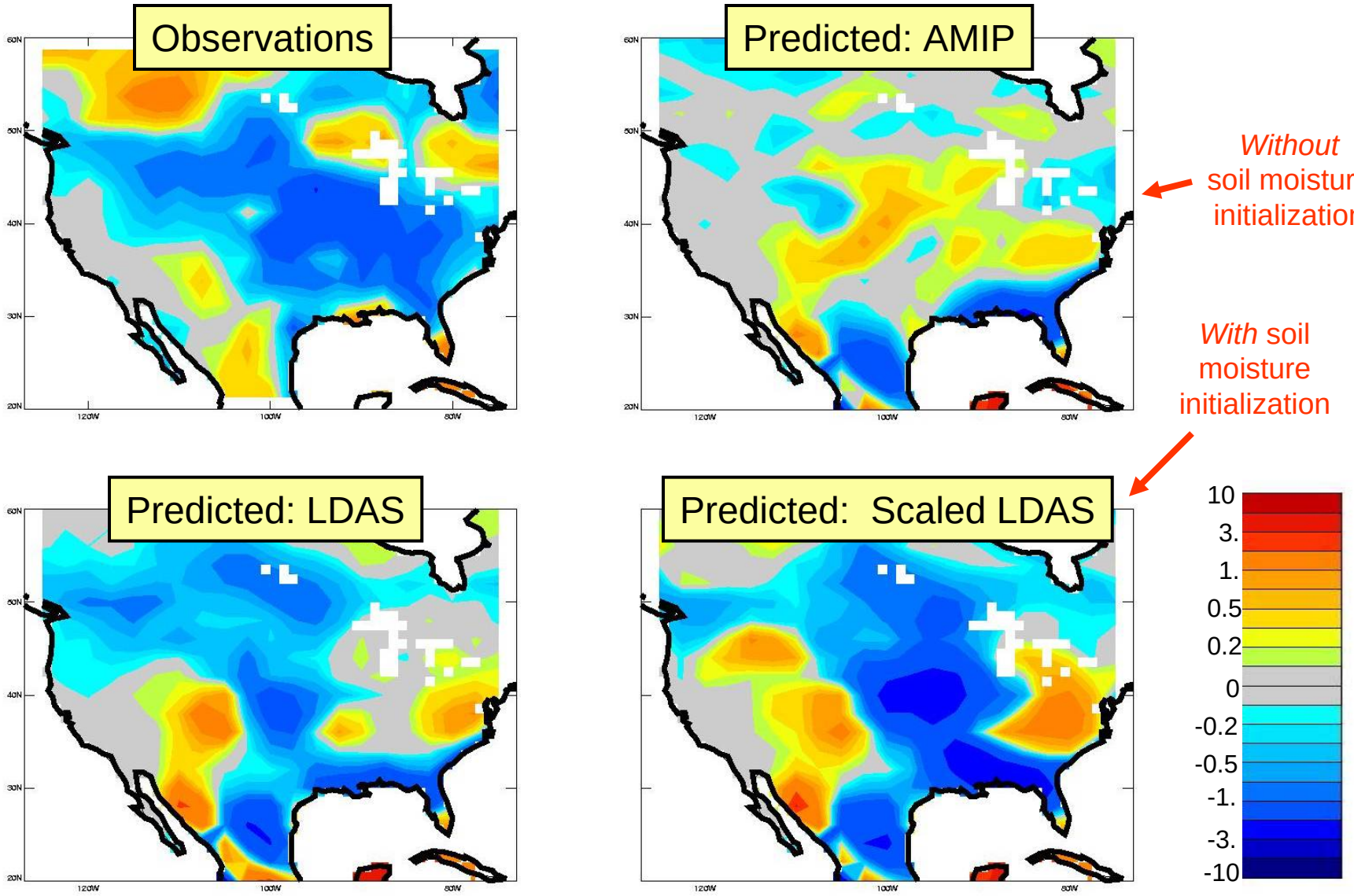


Resolution	1/4 deg	5 km	1 km
Land Grid Points	2.43E+05	5.73E+06	1.44E+08
Disk Space/Day (Gb)	1	28	694
Memory (Gb)	3	62	1561


QH NOAH/GEOS/1KM 2001061121
1km
NOAH/GEOS/0.25deg Qh (W/m^2) 2001061121
25km
NOAH/GEOS/5KM Qh (W/m^2) 2001061121
5km
NOAH/GEOS/1KM Qh (W/m^2) 2001061121
1km
−20 0 20 40 60 80 100 120 140 160 180 200
GrADS: COLA/IGES
2003-11-20-1 GrADS: COLA/IGES
2003-11-19-14:15

1988 Midwestern U.S. Drought

(JJA precipitation anomalies, in mm/day)



Koster et al., 2004

Land Assimilation: Progress

Current Status:

- Soil moisture, skin temperature, and snow assimilation are underway.
- Operational LDAS systems are developing and show promise for forecast improvement.

Land Surface Data Assimilation Realities

- Large-scale land data assimilation is severely limited by a lack of observations.
- 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.
- 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.

Data Assimilation Algorithm Development:

- Land models are highly nonlinear -> push for *model independent assimilation algorithms*.
- *Radiance Assimilation* – use forward models in the assimilation to assimilate brightness temperatures directly.
- *Link calibration and assimilation* in a logical and mutually beneficial way.
- Understand the potential of data *assimilation downscaling*

Land Modeling:

- Better *correlation* of land model states with observations
- Advanced processes: *River runoff/routing*, *vegetation and carbon dynamics, groundwater interaction*
- Parallel development of land model and their *adjoints*

Assimilate new types of data:

- Streamflow, Vegetation dynamics, and Groundwater/total water storage (Gravity)
- Boundary layer structures/evapotranspiration

Coupled feedbacks:

- Understand the impact of land assimilation feedbacks on coupled system predictions.