Hydrologic Data Assimilation

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October 26, 2005

Acknowledging the NLDAS, GLDAS, LIS, and ELDAS teams and collaborators

Surface temperature, soil moisture, and snow, significantly influence Earth system processes and predictability at multiple scales

Improved knowledge of hydrologic conditions will promote better land resource management, natural hazard mitigation, and homeland security

Using a <u>systems engineering approach</u> we can merge advanced hydrologic <u>process understanding</u>, observing system <u>data</u>, and computing power to significantly improve Earth system prediction and critical water management applications

Hydrologic 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:

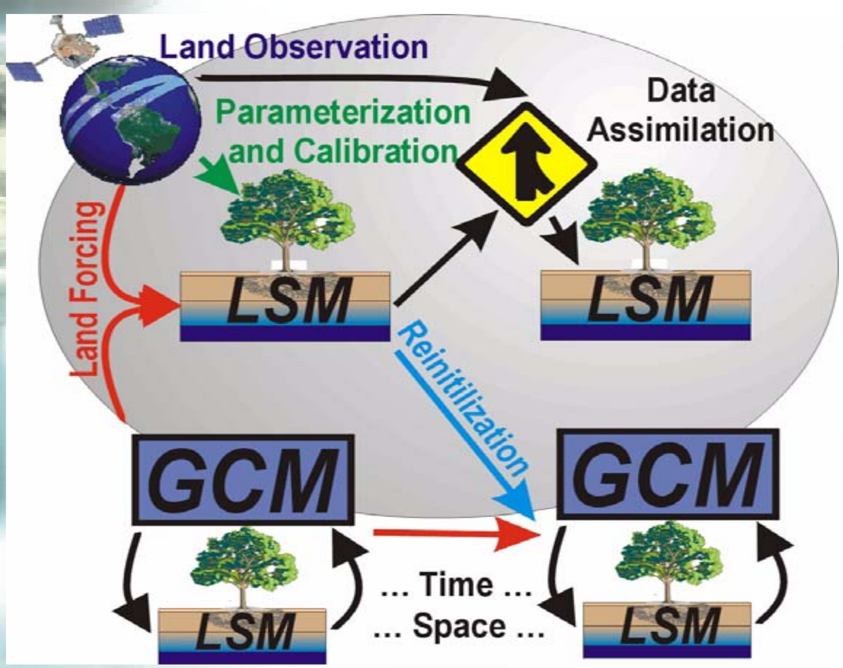
•Observation: Forcing, storages(states), fluxes, and parameters.

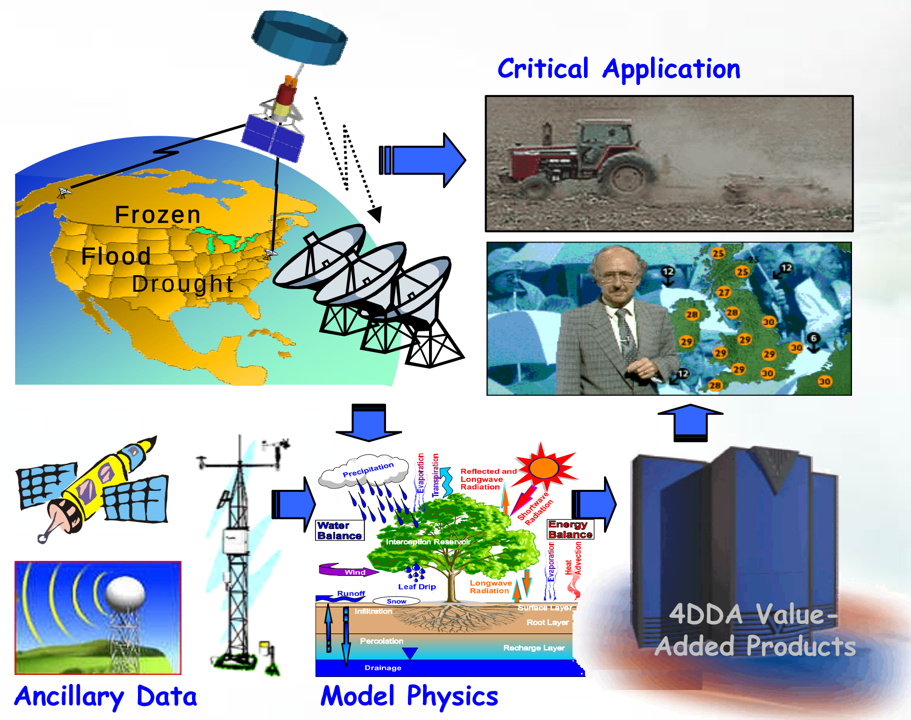
•Simulation: Land process models (Hydrology, Biogeochemistry, etc.).

•Assimilation: Short-term state constraints.

"LDAS" concept:

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





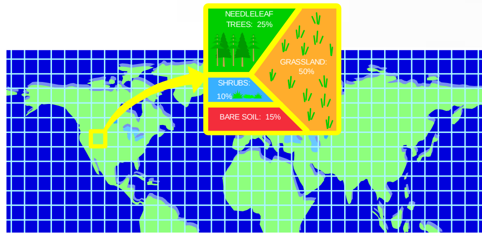
Background: Land Surface Modeling

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

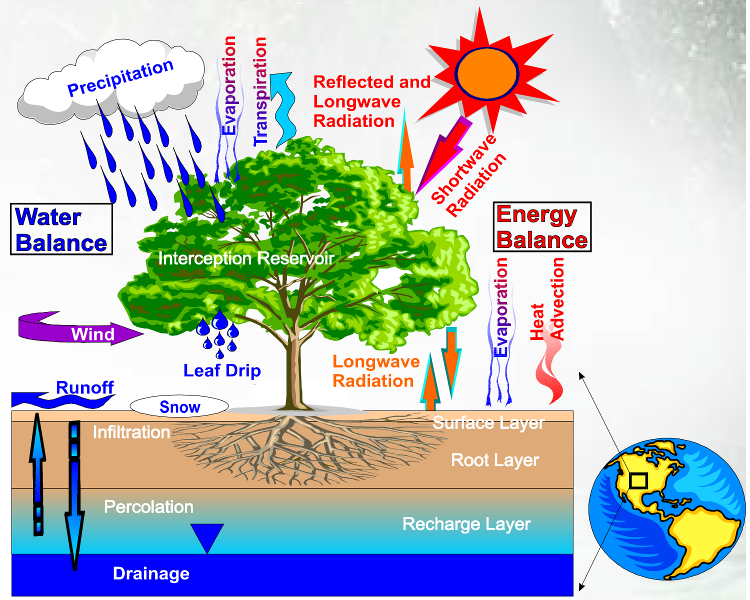
P + Gin –(Q + ET + Gout) = ΔS

Rn - G = Le + H



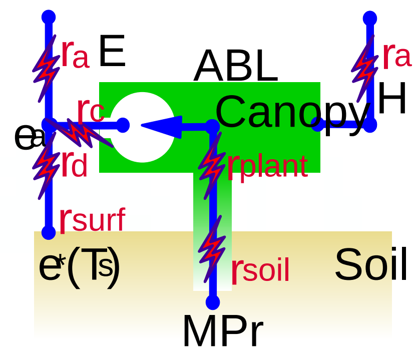
Mosaic (Koster, 1996):

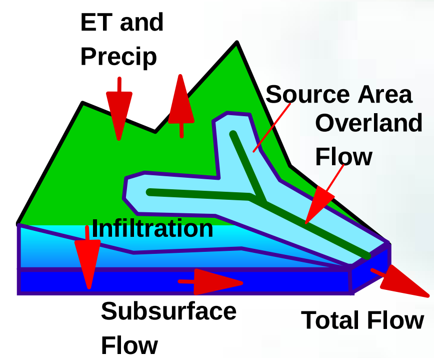
- Based on simple SiB physics.
- Subgrid scale "mosaic"



CLM (Community Land Model, ~2003):

- Community developed "open-source" model.
- 10 soil layers, 5 layer snow scheme.





Catchment Model (Koster et al., 2003):

- Models in catchment space rather than on grids.
- Uses Topmodel concepts to model groundwater

NOAA-NCEP-Noah Model (NCEP, ~2004):

- Operational Land Surface model.

Also: vic, bucket, SiB, etc.

Land Surface Observation

Off-line LDAS

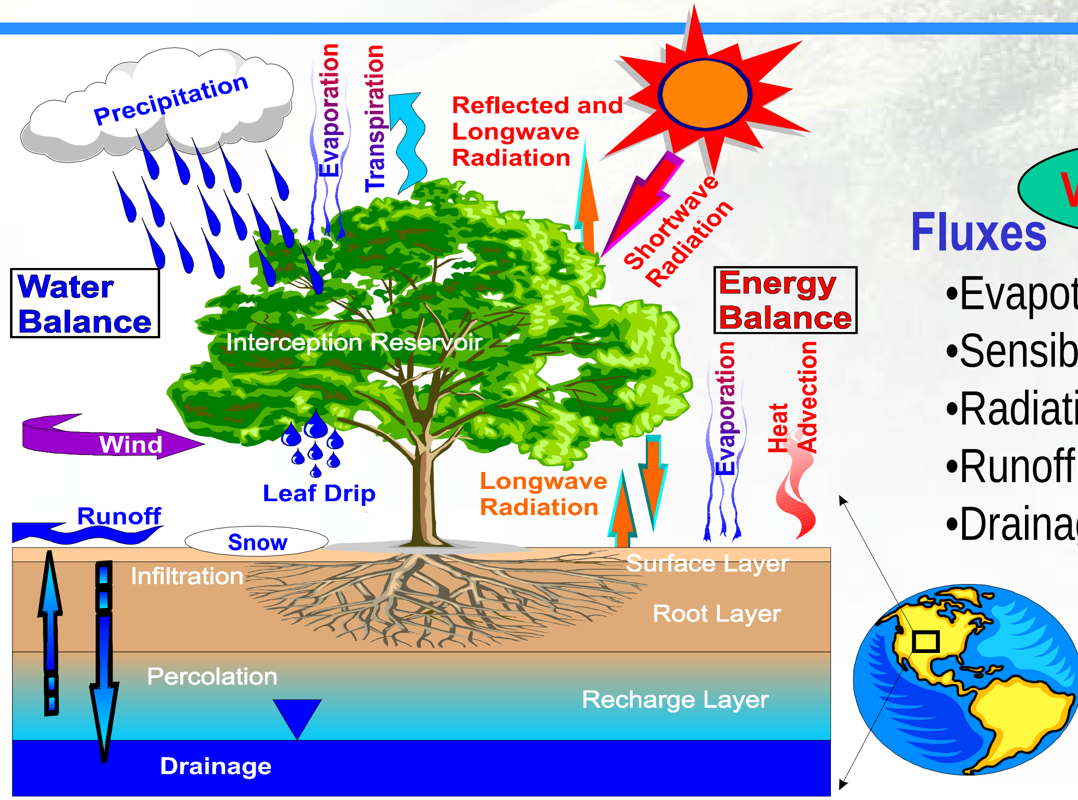
Forcing

- Precipitation
- Wind
- Humidity
- Radiation
- Air Temperature

Calibration

Parameters

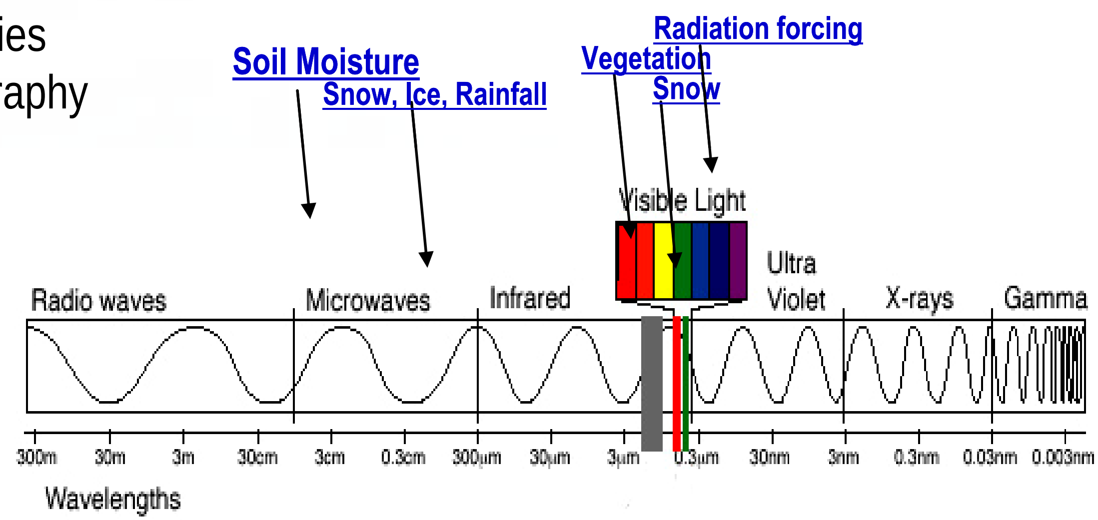
- Soil Properties
- Vegetation Properties
- Elevation & Topography
- Subgrid Variation
- Catchment Deline
- River Connectivity



Validation

Fluxes

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

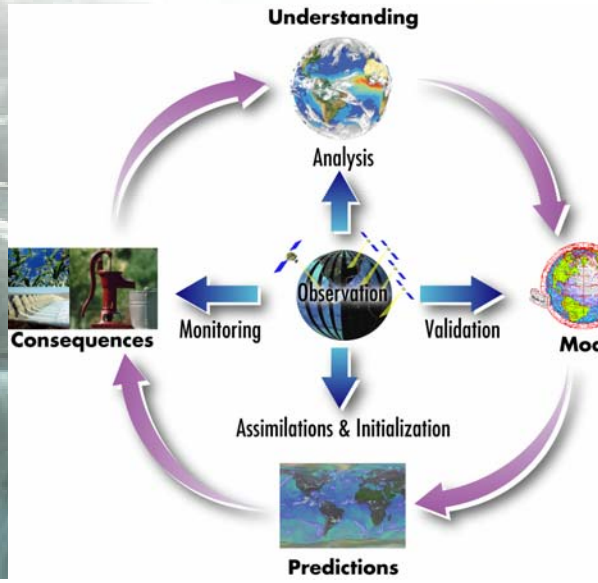


Assimilation

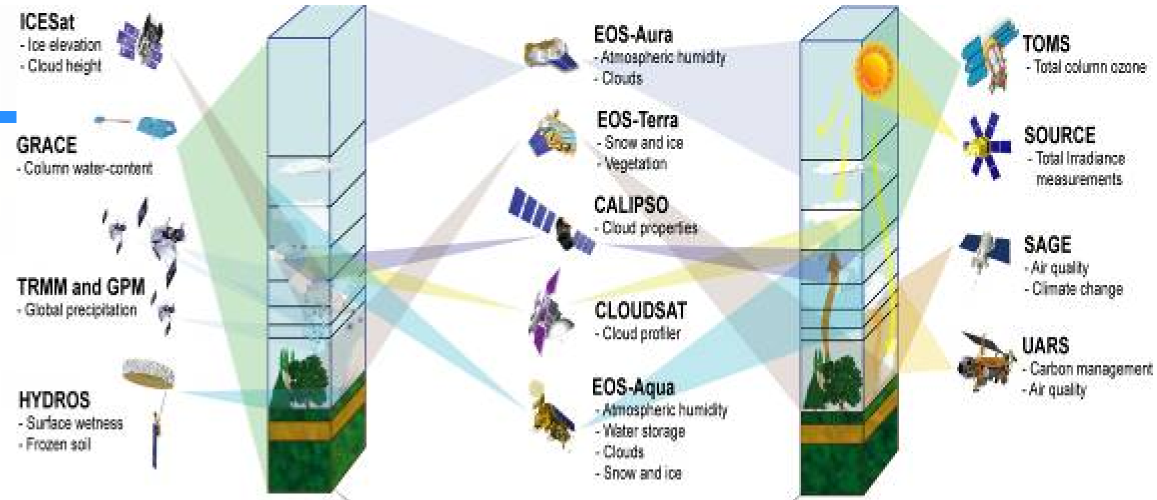
States

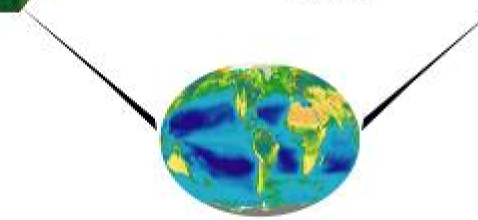
- Soil Moisture
- Temperature
- Snow
- Carbon
- Nitrogen
- Biomass

Tools: Observations



The availability of new *observations strongly motivates advances* in understanding, prediction, and application.



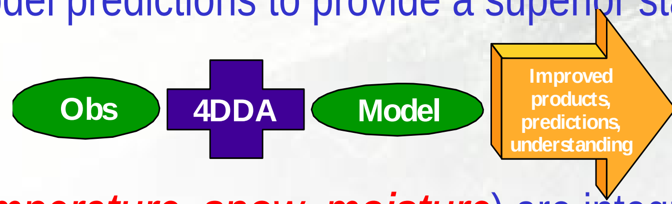


Class	Observation	Technique	Example Platform	Temporal	Spatial
Land Parameters	Leaf area and greenness	optical/IR	AVHRR, MODIS, NPOESS	weekly	1km
	Albedo	optical/IR	MODIS, NPOESS	weekly	1km
	Emissivity	optical/IR	MODIS, NPOESS	weekly	1km
	Vegetation structure	lidar	ICESAT, ESSP lidar mission	weekly-monthly	100m
	Topography	in-situ survey, radar	GTOPO30, SRTM	episodic	30m–1km
Land Forcings	Wind profile	radar			
	Air Humidity and temperature	IR, MW	TOVS, GOES, AVHRR, MODIS, AMSR	hourly-weekly	5 km
	Near- surface radiation	optical/IR	GOES, MODIS, CERES, ERBS, etc.	hourly-weekly	1km
	Precipitation	microwave/IR	TRMM, GPM, SSMI, GEO-IR, etc.	hourly-monthly	10km
Land States	Temperature	IR, in-situ	IR-GEO, MODIS, AVHRR, TOVS	hourly-monthly	10m-4km
	Thermal anomalies	IR, NIR, optical	AVHRR, MODIS, TRMM	daily-weekly	250m–1km
	Snow cover and water	optical, microwave	SSMI, TM, MODIS, AMSR, AVHRR, etc.	weekly-monthly	1km
	Freeze/thaw	radar	Quickscat, HYDROS, IceSAT, CryoSAT	weekly	3km
	Total water storage	gravity	GRACE	monthly	1000km
	Soil moisture	active/passive microwave	SSMI, AMSR, HYDROS, SMOS, etc.	3-30 day	10-100 km
Land Fluxes	Evapotranspiration	optical/IR, in-situ	MODIS, GOES	hourly-weekly	10m-4km
	Solar radiation	optical, IR	MODIS, GOES, CERES, ERBS	hourly-monthly	
	Longwave radiation	optical, IR	MODIS, GOES	hourly-monthly	10m-4km
	Sensible heat flux	IR	MODIS, ASTER, GOES	hourly-monthly	10m-4km

Hydrologic Data Assimilation

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

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

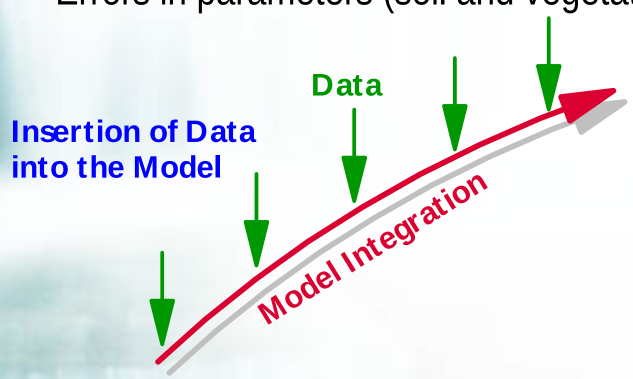


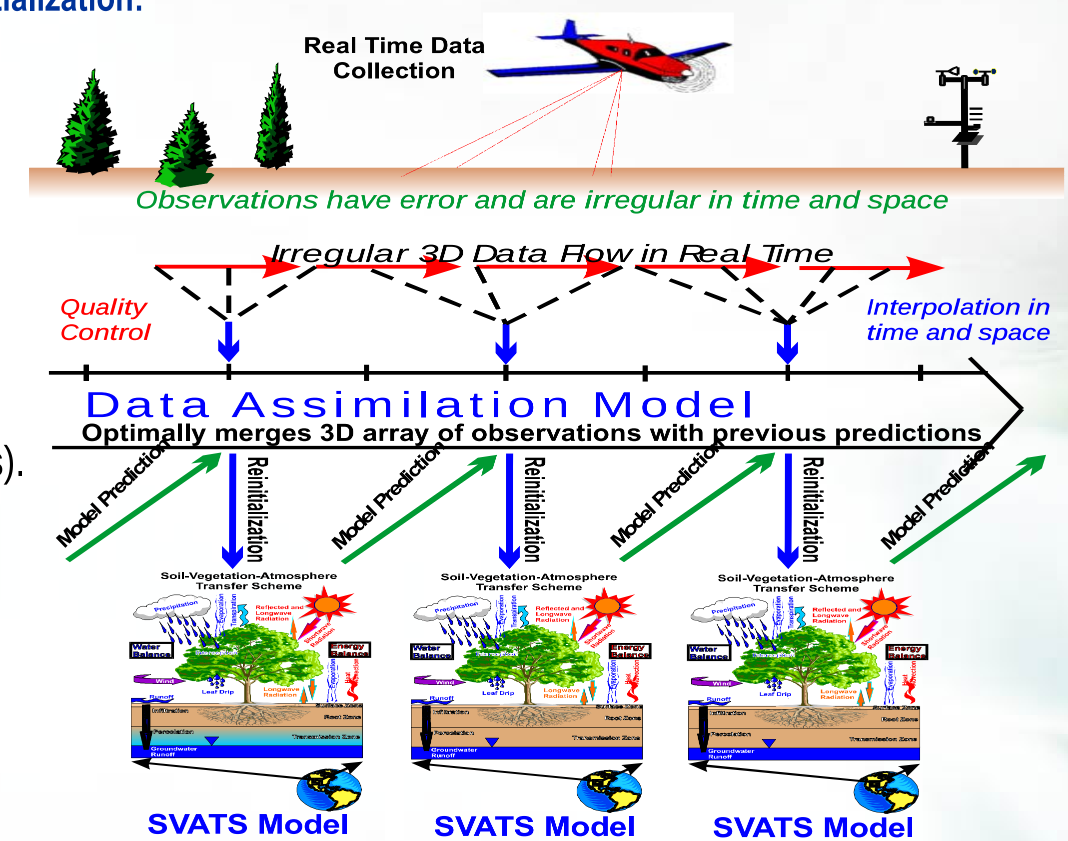
Hydrologic State or storage observations (*temperature, snow, moisture*) are integrated with models.

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:**

- **Model errors 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).



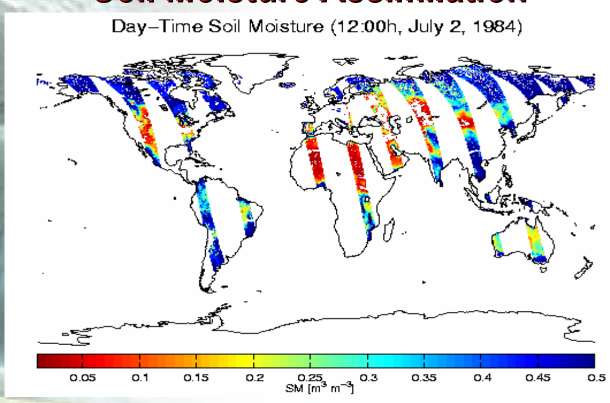


Land Surface Data Assimilation Summary

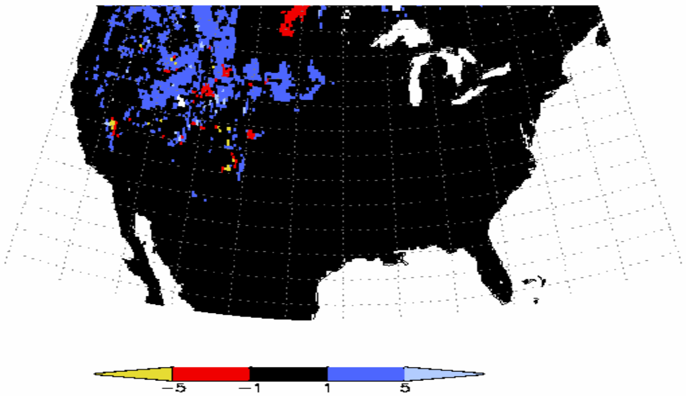
Data Assimilation merges observations & model predictions to provide a superior state estimate.

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.

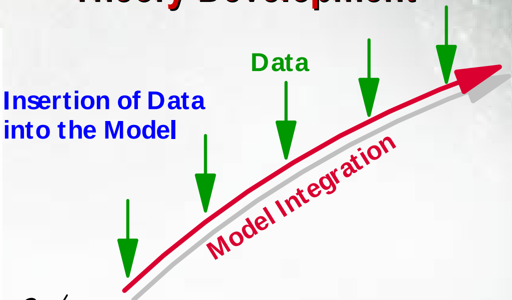
Soil Moisture Assimilation



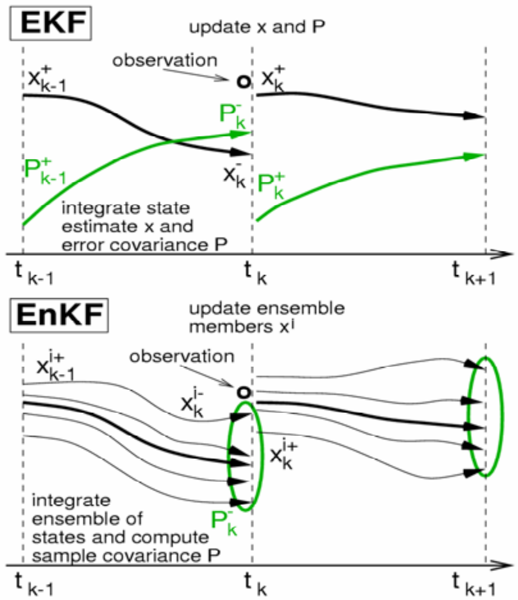
Snow Cover Assimilation



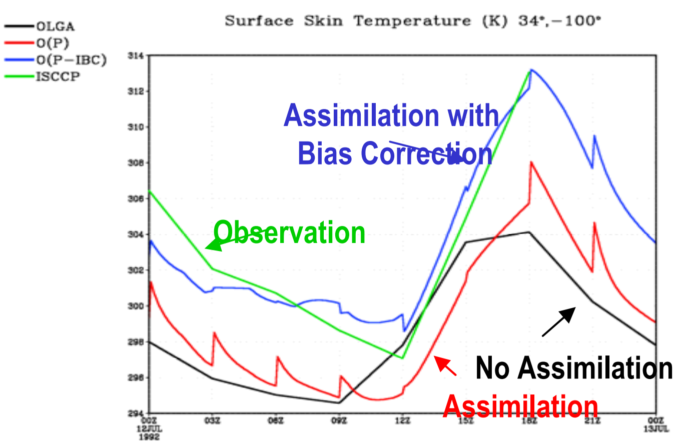
Theory Development



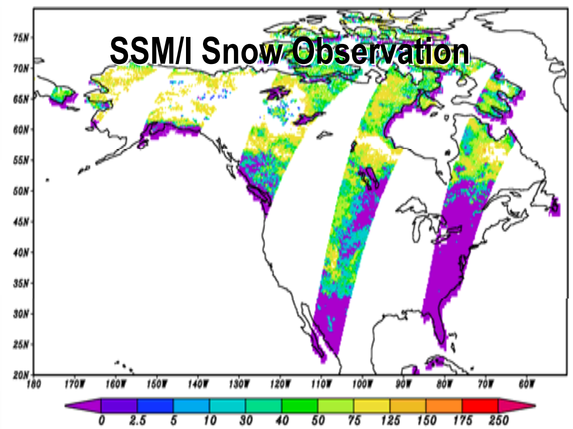
$$\partial x / \partial t = dynamics + physics + \Delta x$$



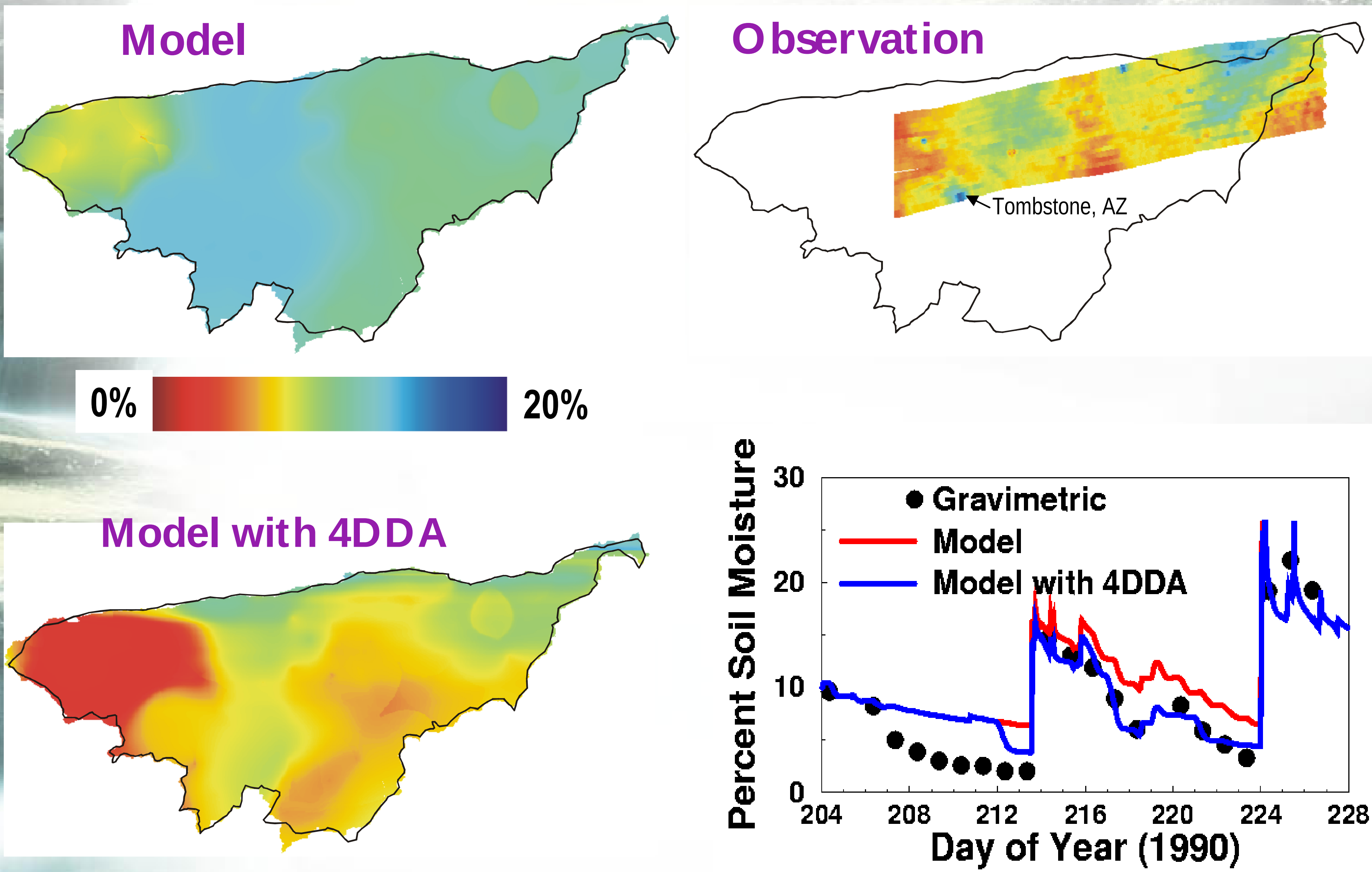
Skin Temperature Assimilation



Snow Water Assimilation

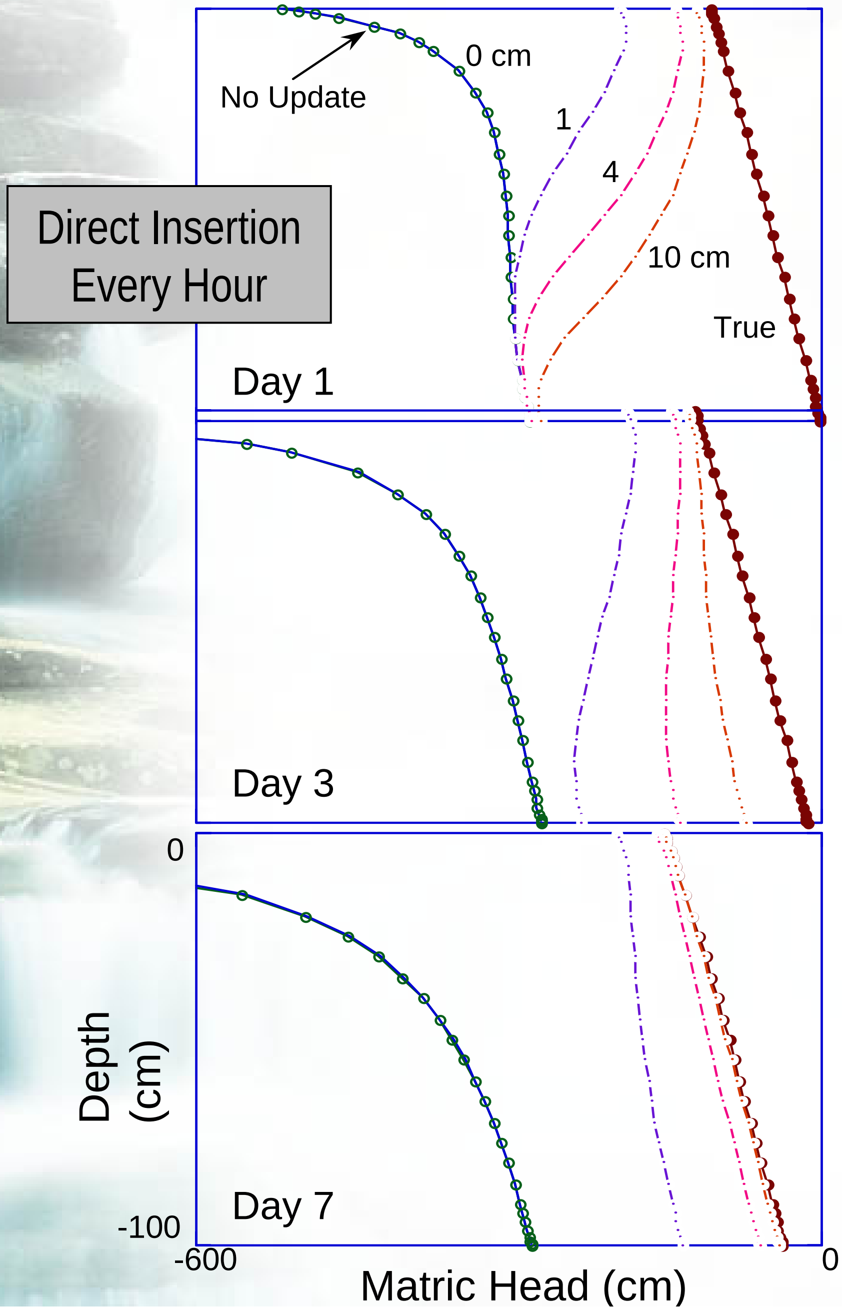


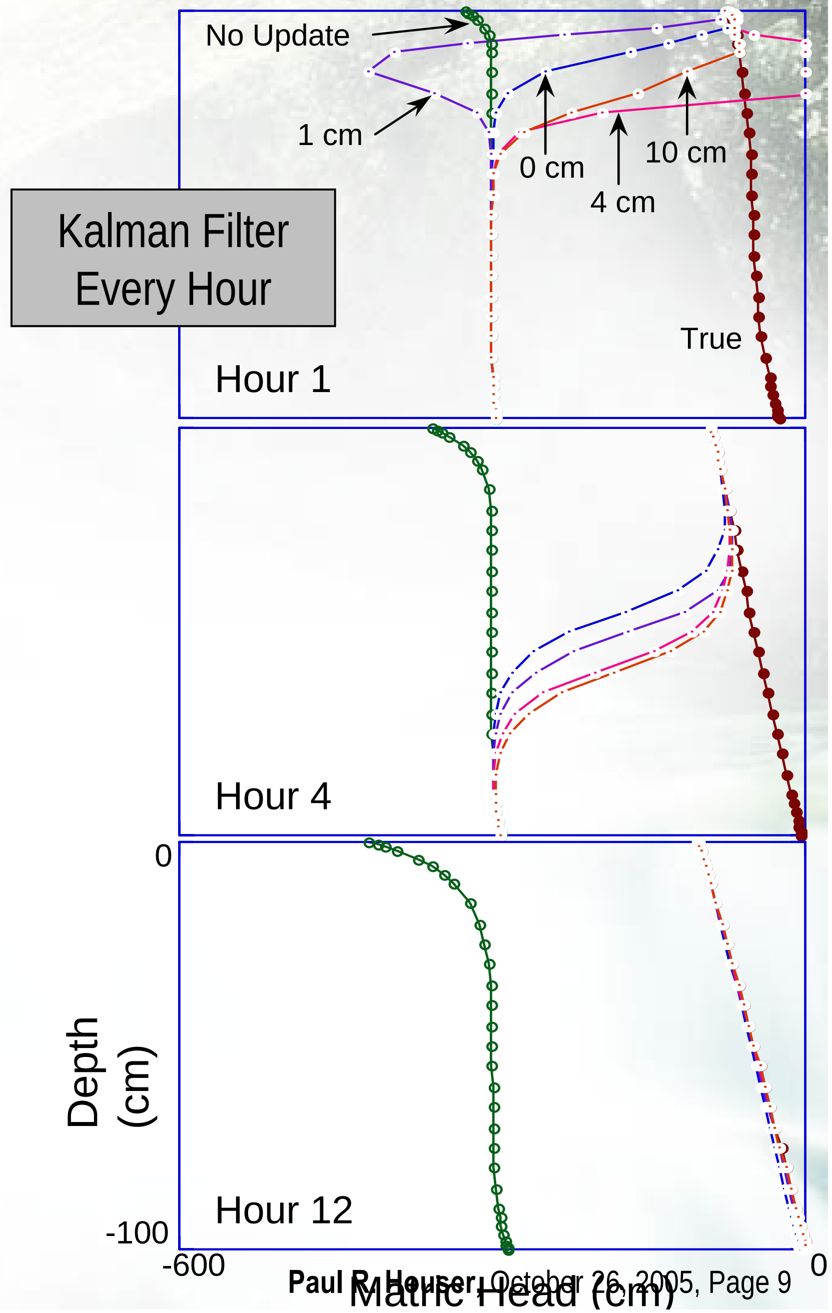
Soil Moisture Assimilation: *Walnut Gulch (Monsoon 90)*



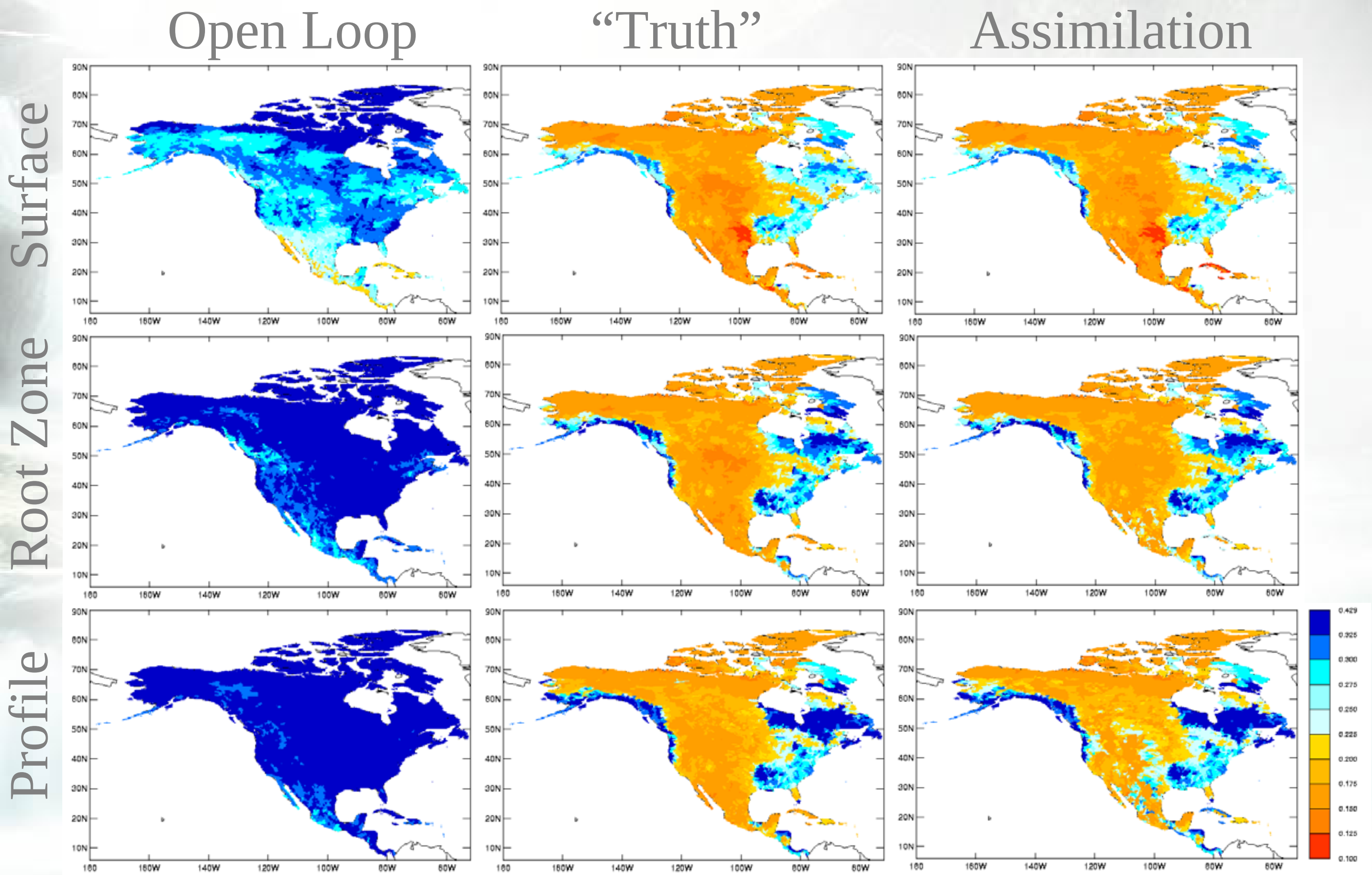
Houser et al., 1998

Soil Moisture Profile Correction





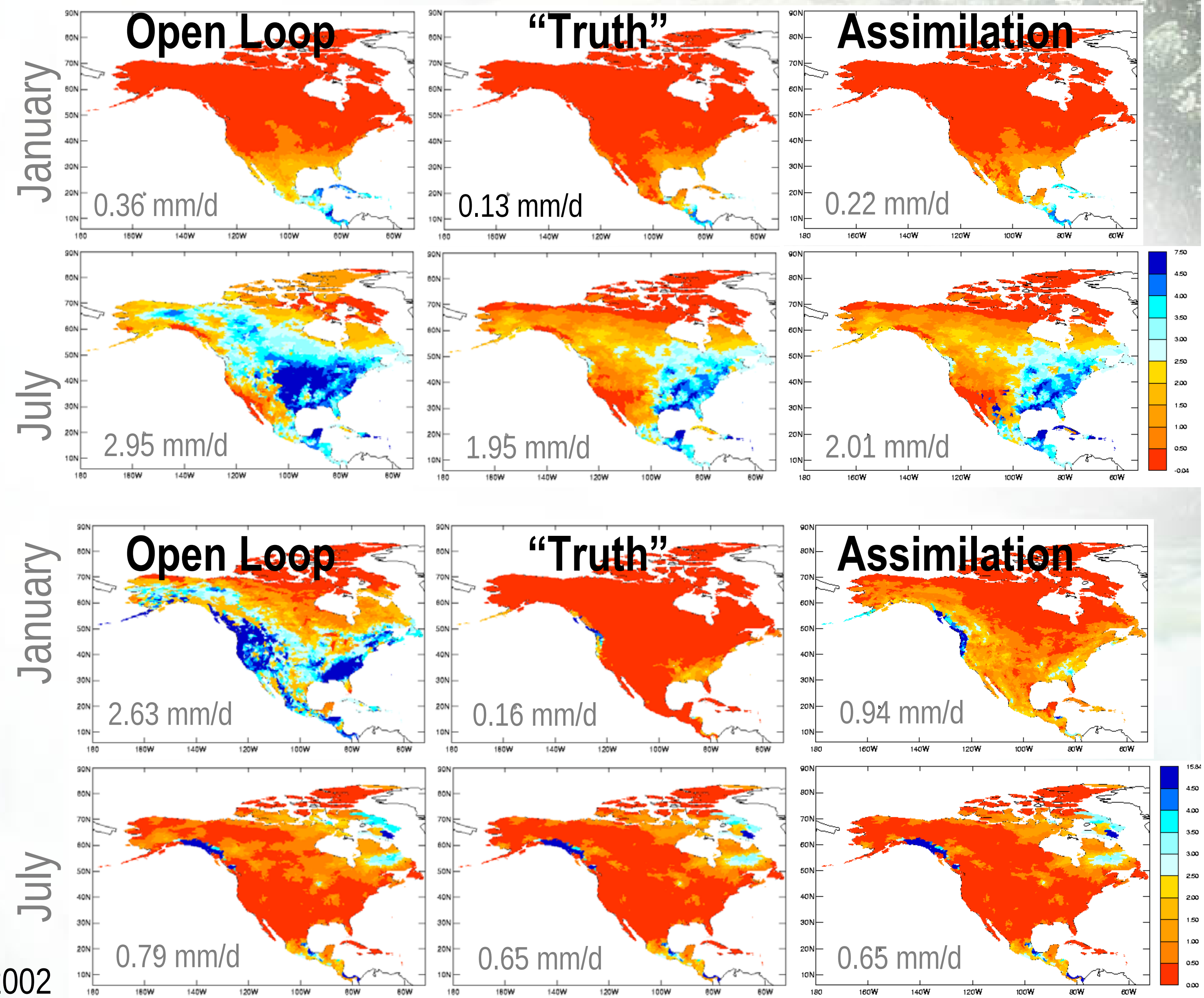
Synthetic Demonstration



Impact of Soil Moisture Assimilation on Fluxes

Monthly Evapotranspiration

Monthly Runoff



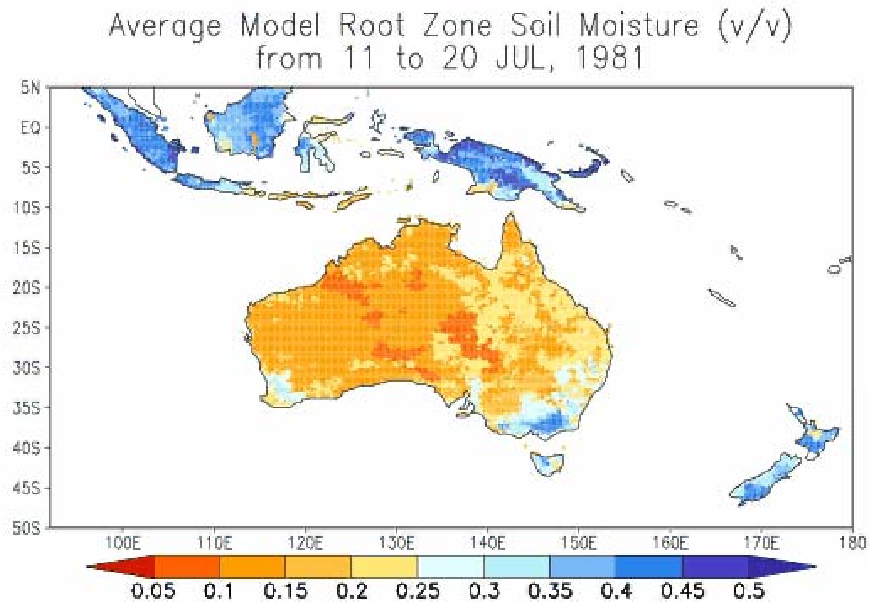
Walker & Houser, 2002

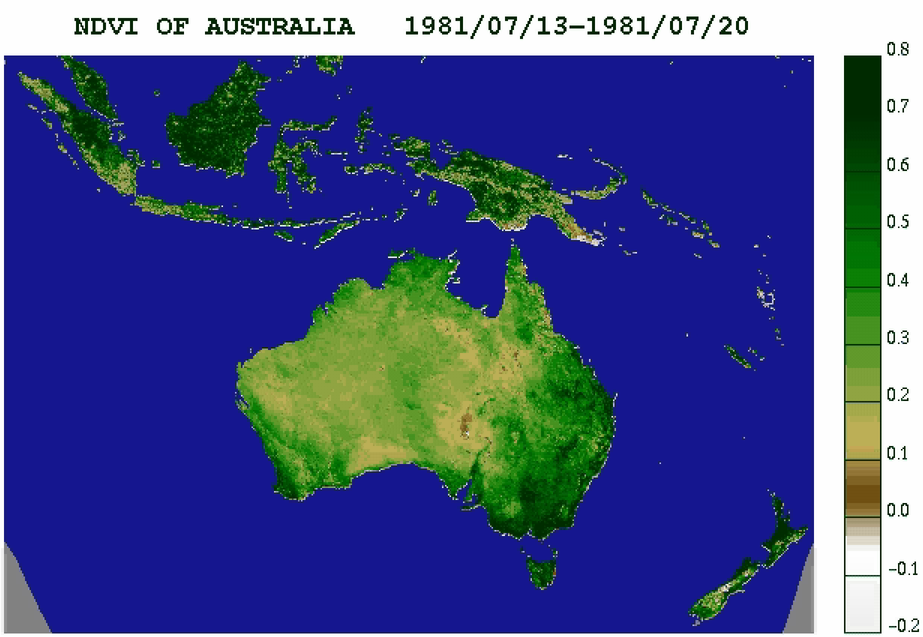
SMMR Soil Moisture Data Assimilation: EKF Catchment Model

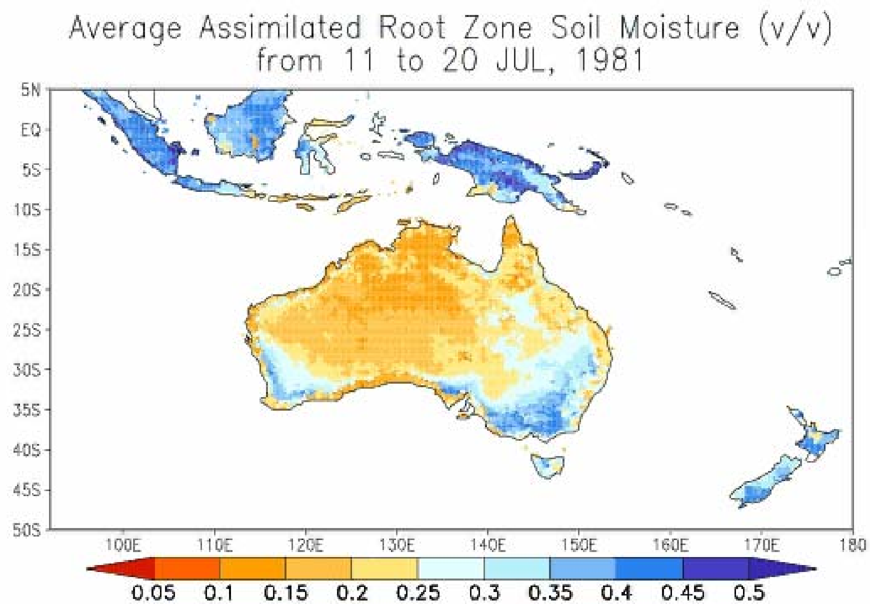
Summary:

- Assimilate SMMR derived soil moisture into the Catchment land surface model using a 1-D Extended Kalman Filter.
- Moisture anomalies compare favorably to NDVI and drought indexes.
- A similar analysis was performed over N. America with favorable results.

Walker, J. P., Ursino, N., Grayson, R. B., and Houser, P. R., 2003.

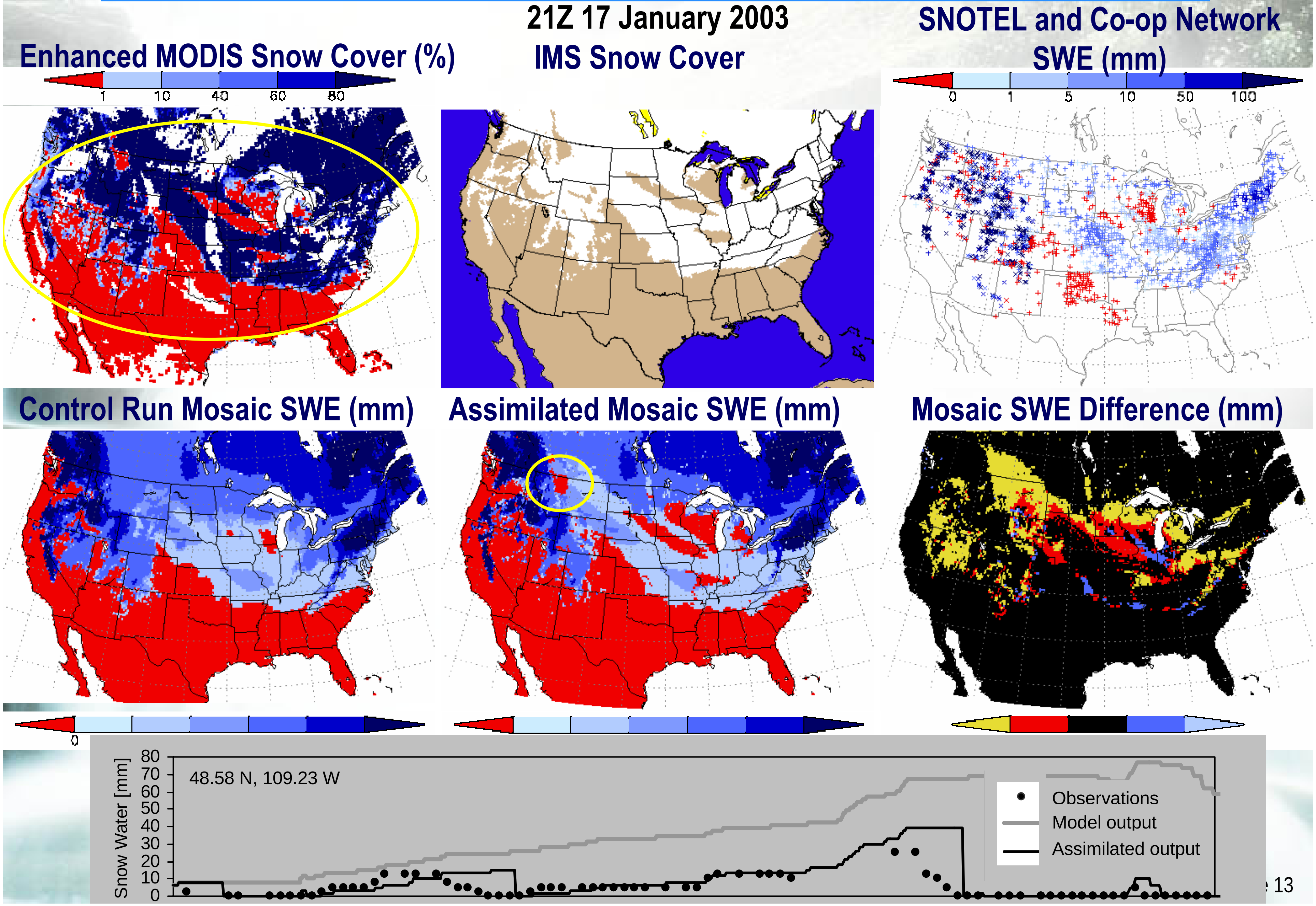






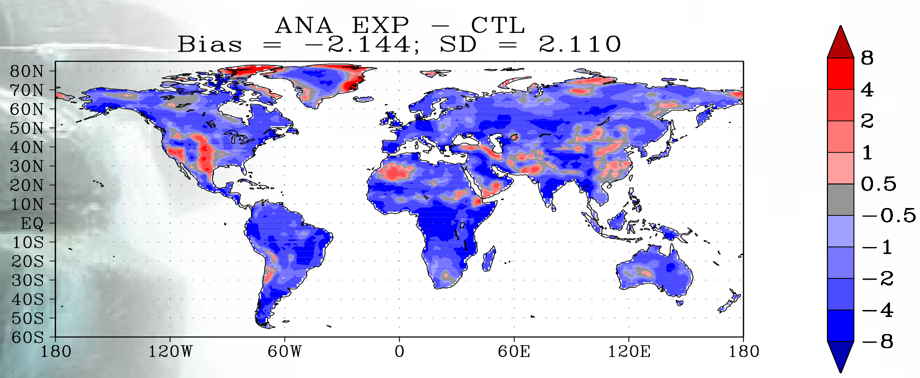
GLDAS Snow Updates Using MODIS Data

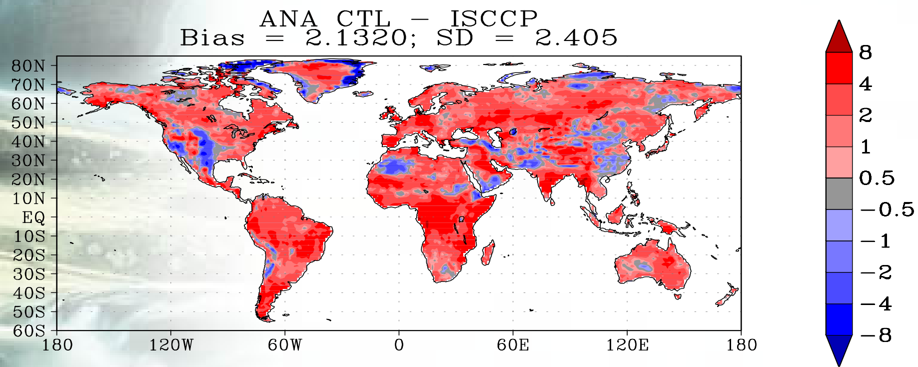
Rodell et al., 2003

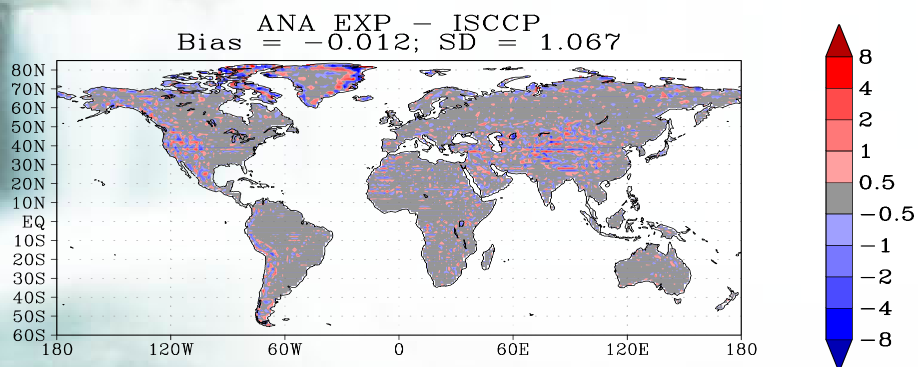


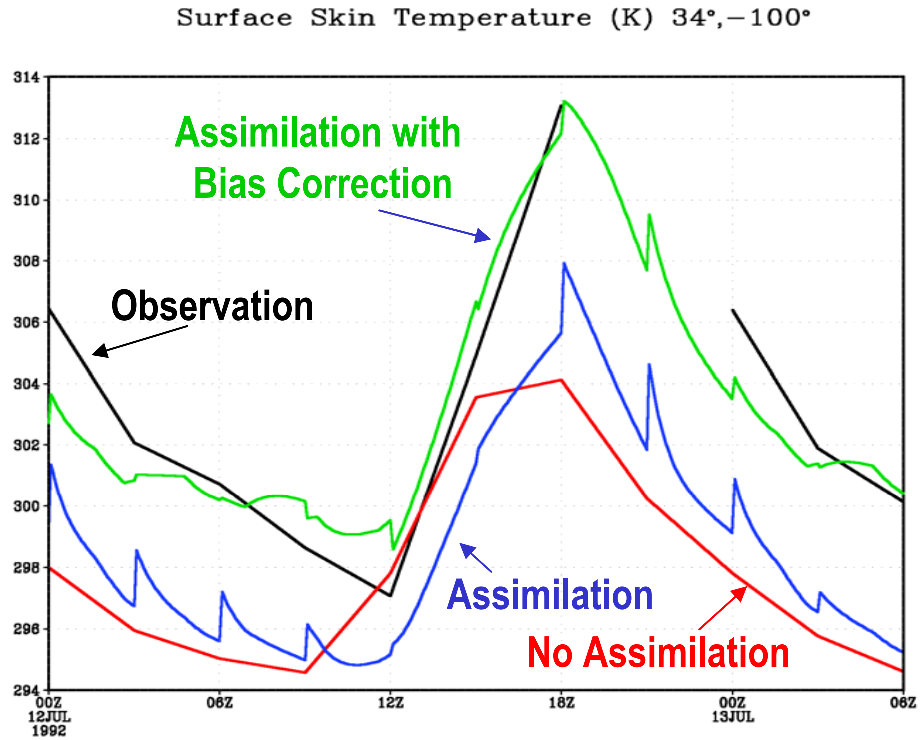
Data Assimilation: T_s Assimilation Results

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

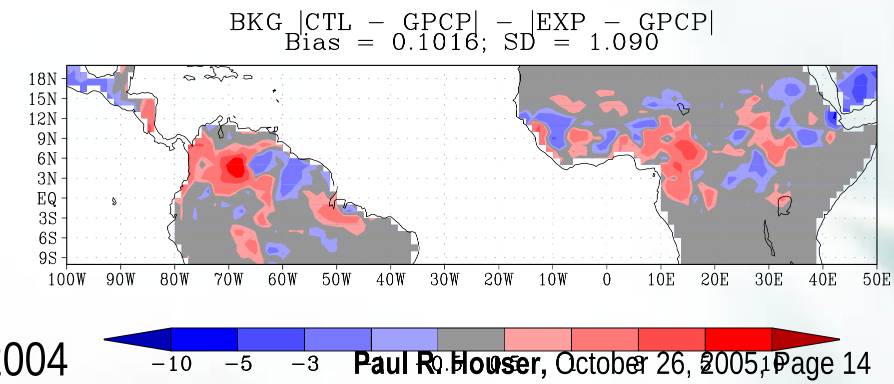








Surface temperature has **very little memory** or inertia, so without a continuous correction, it tends drift toward the control case very quickly.

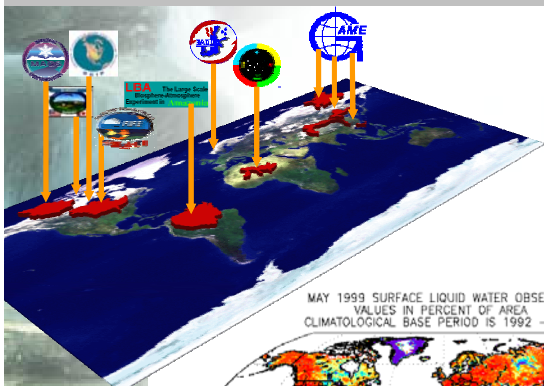


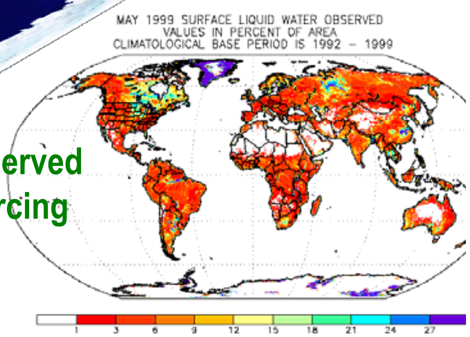
Radakovich et al., 2004

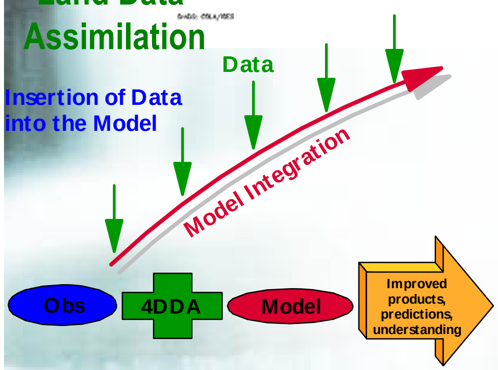
Global Land Data Assimilation System

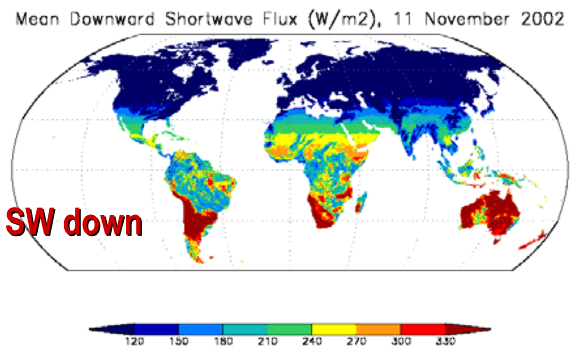
Objective: A 1/4 degree (and other) global land modeling and assimilation system that uses all relevant observed forcing, storages, and validation. Expand the current N. American LDAS to the globe. 1km global resolution goal

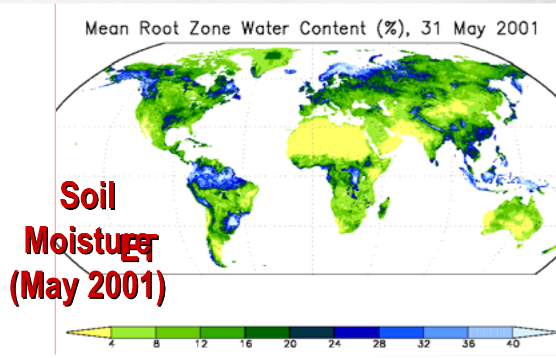
Consistent Global Intercomparison

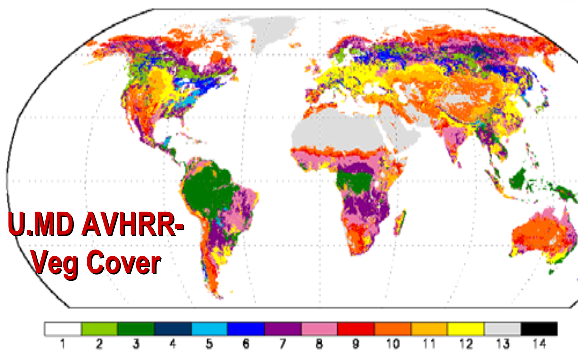


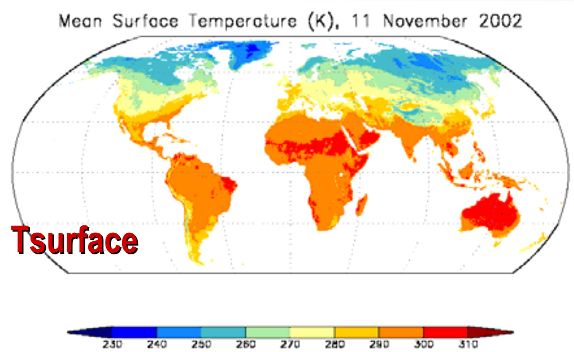


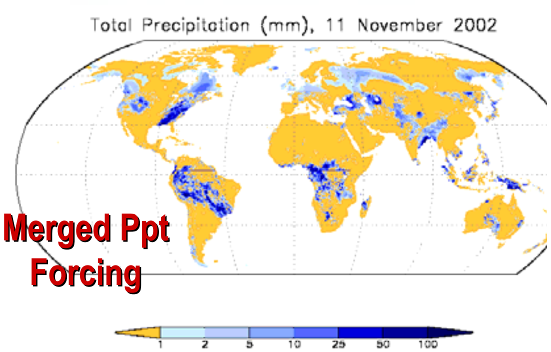


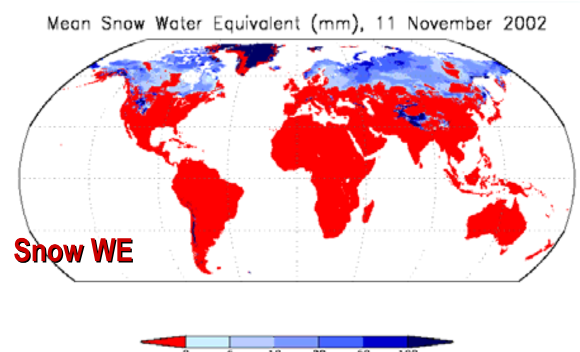










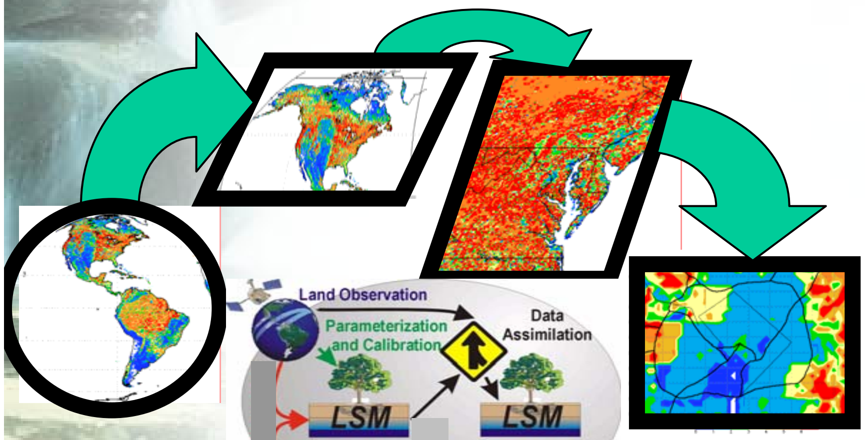


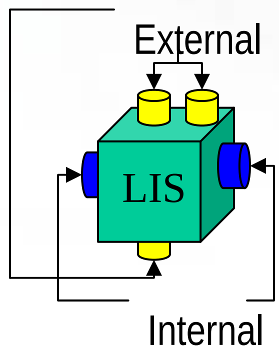
Land Information System http://lis.gsfc.nasa.gov

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

Summary: LIS is a high performance set of land surface modeling (LSM) assimilation tools.

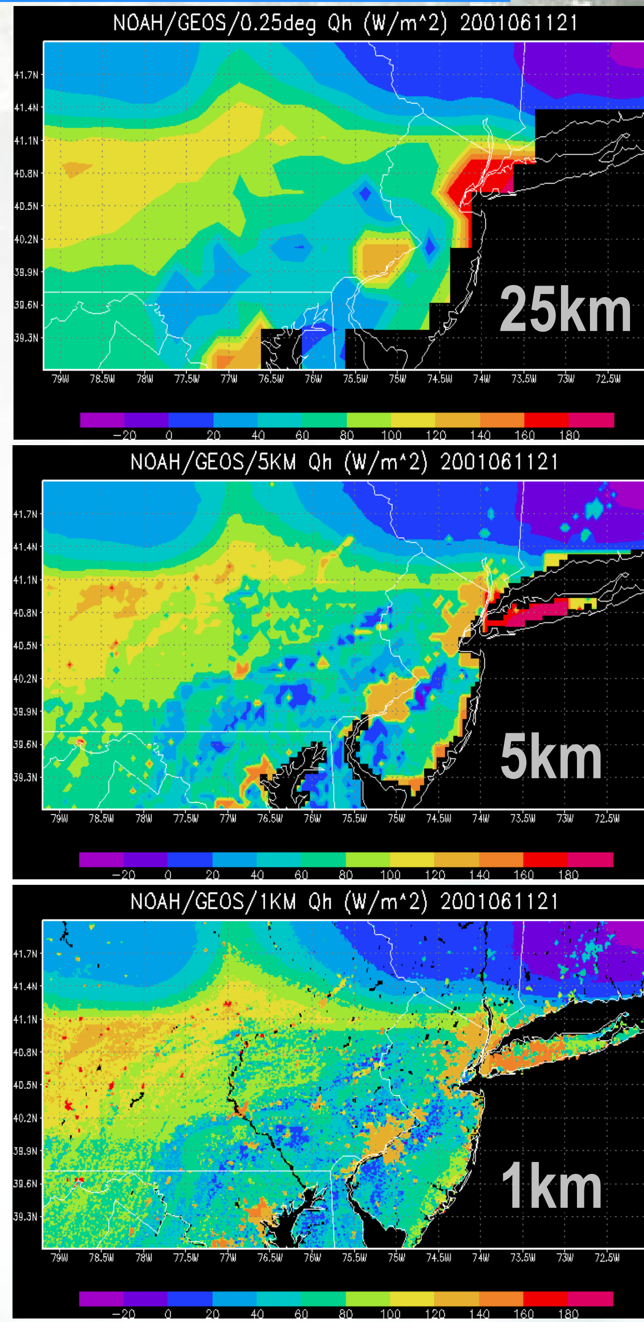
Applications: Weather and climate model initialization and coupled modeling, Flood and water resources, precision agriculture, Mobility assessment …

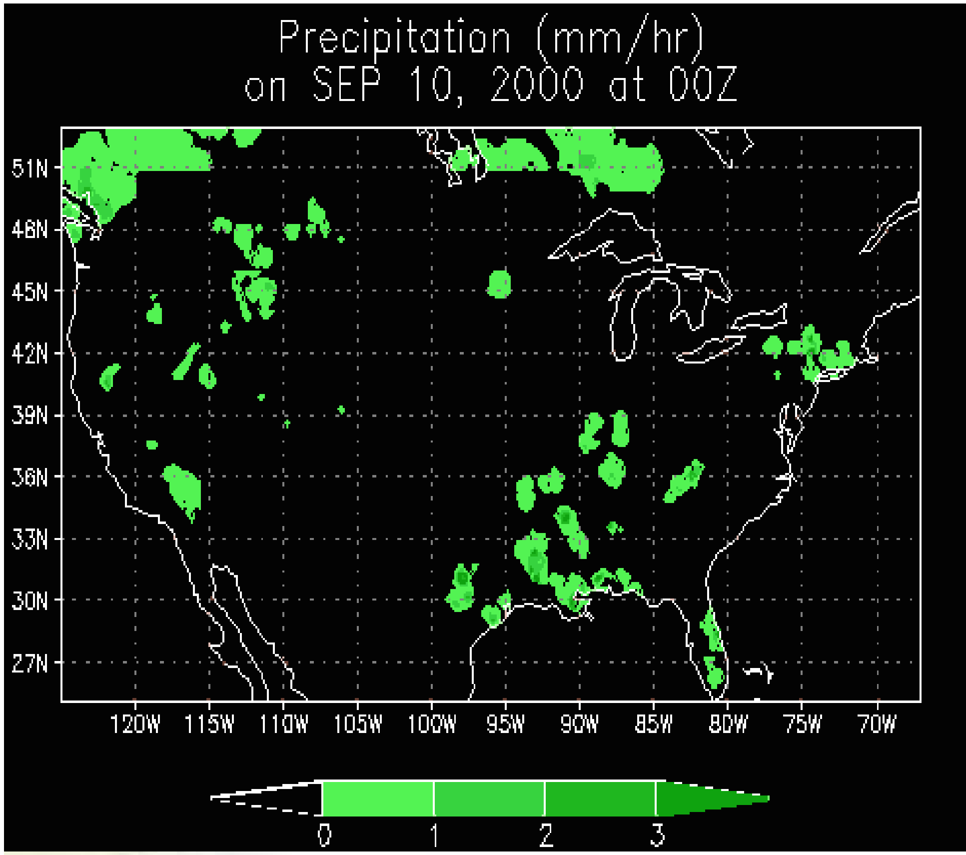


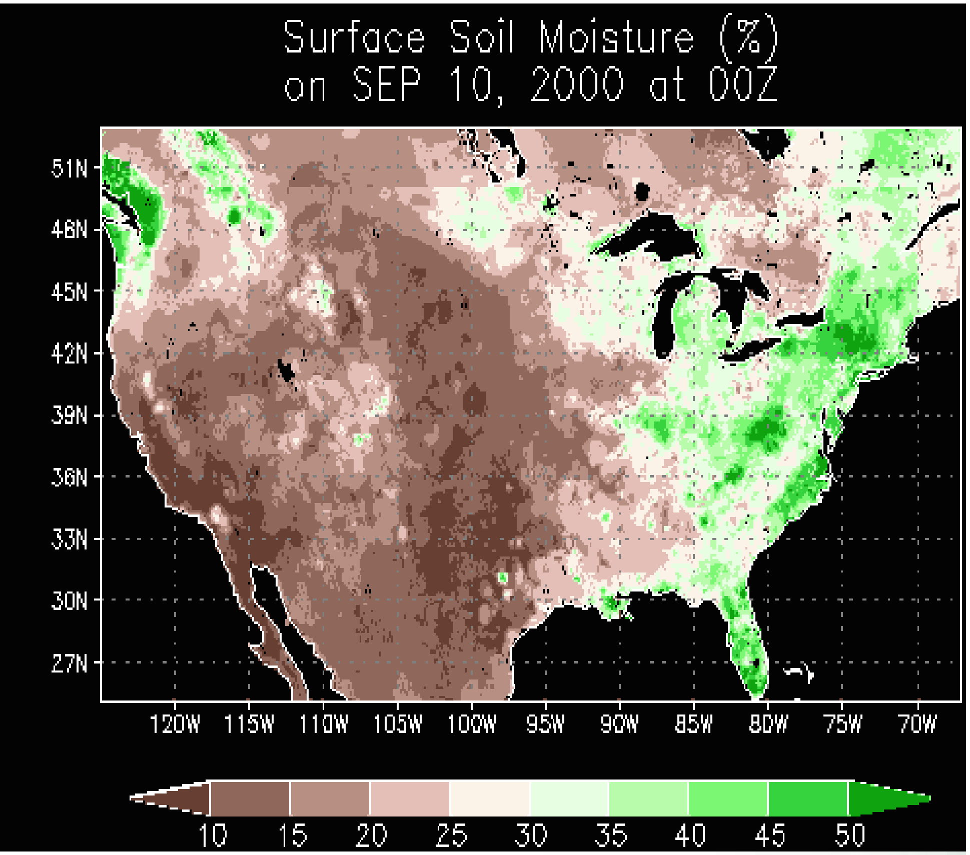


200 Node "LIS" Cluster
Optimized I/O, GDS Servers

	Memory (MB)	Wallclock time (minutes)	CPU time (minutes)
LDAS	3169	116.7	115.8
LIS	313	22	21.8
reduction factor	10.12	5.3	5.3



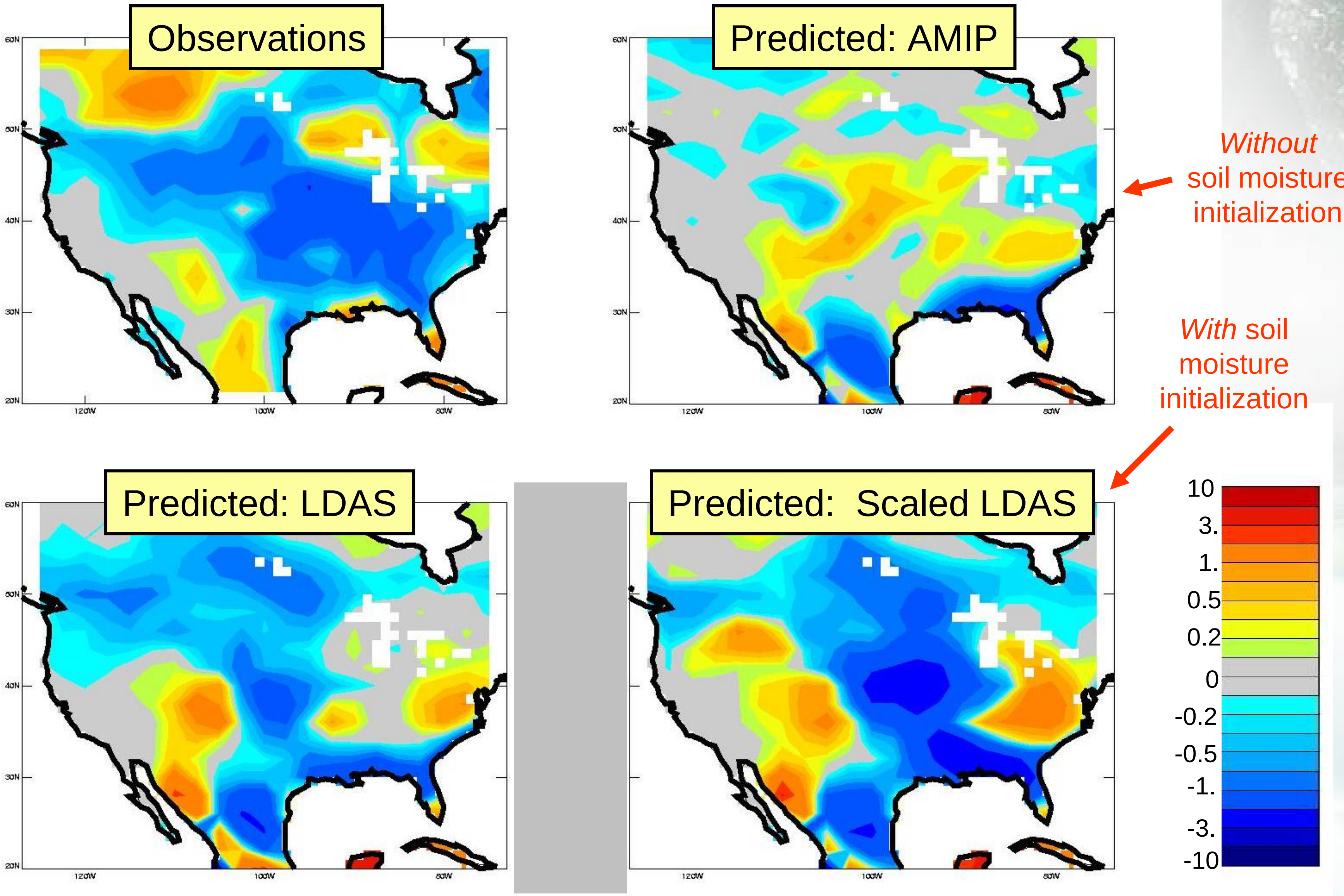




LDAS Predictions: Hourly Sept. 2000 Precipitation and Soil Moisture

Coupled Model Forecast: 1988 Midwestern U.S. Drought

(JJA precipitation anomalies, in mm/day)

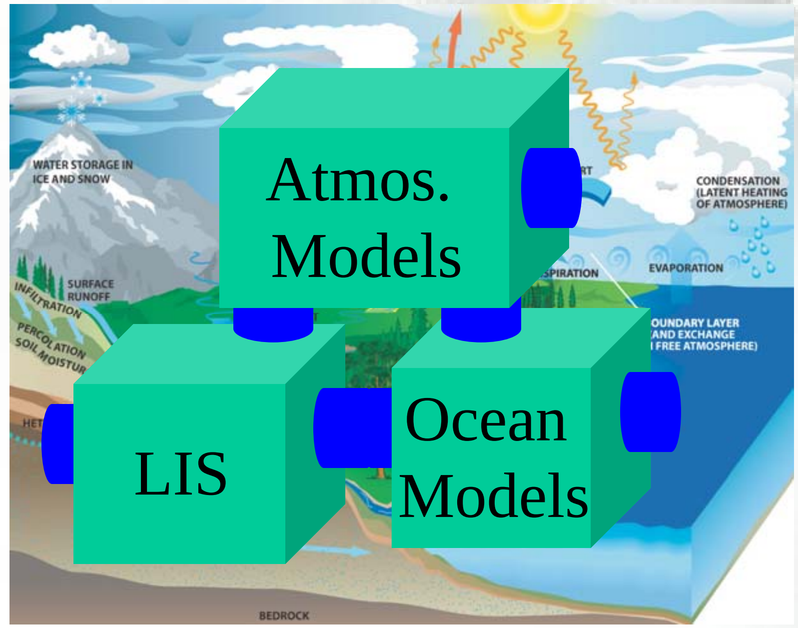


Koster et al., 2004

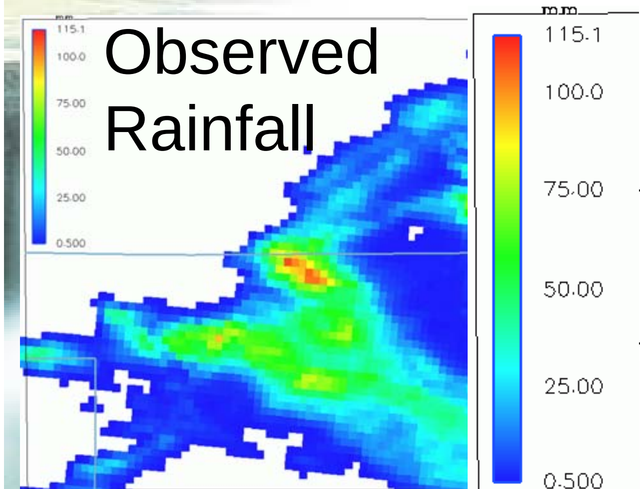
Impact: Coupled Earth System Modeling

Interoperability with standards:

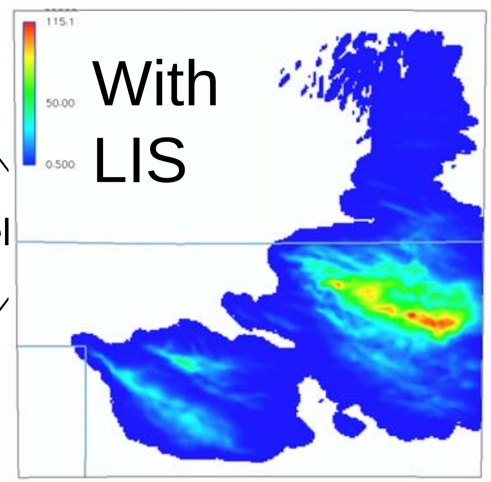
- The Earth System Modeling Framework (ESMF)
- Assistance for Land Modeling Activities (ALMA)

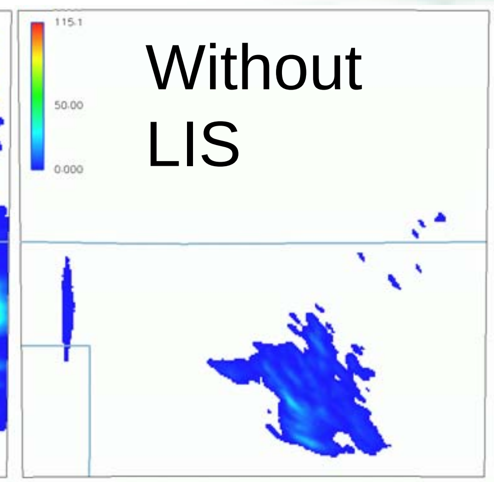


LIS Impact Example: Coupling to a Weather Model



12-Hours Ahead Atmospheric Model Forecasts





Land Data Assimilation System: Summary

Current Status:

- The LIS code provides the backbone tools that are used in various applications: NLDAS, GLDAS, etc..
- Operational LDAS systems are developing and show promise for forecast improvement.
- Research supporting the LDAS concept are actively being pursued.
  - Observation-driven model and driver development
  - Ensemble physics (multi-model framework)
  - Data assimilation development, mostly based on EnKF's
  - Innovative boundary layer coupling towards true global CRM's
  - Collaboration and partnering for end-user benefits
- The LDAS teams are committed to making their tools useful beyond the research realm.

Future Directions

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.