Land Data Assimilation

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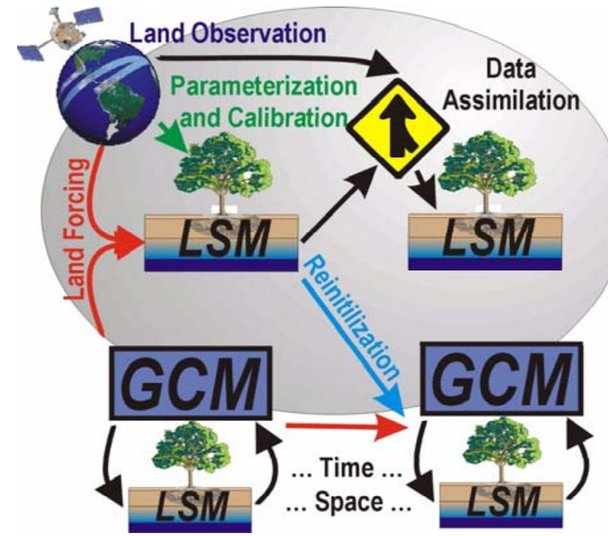
http://ldas.gsfc.nasa.gov

Land Data Assimilation Systems: Motivation

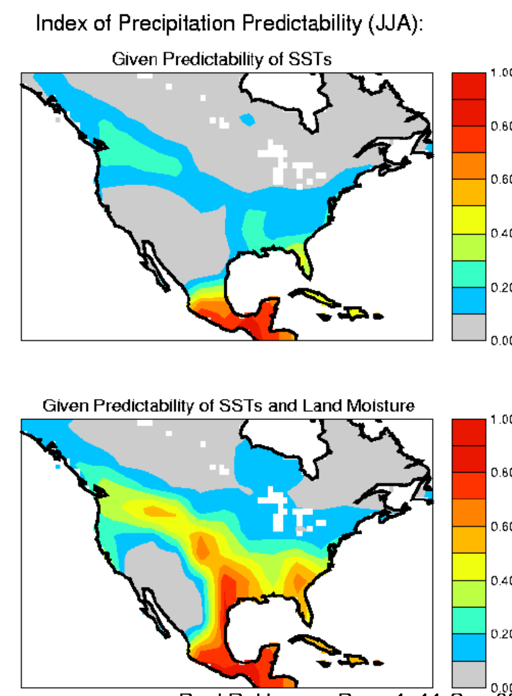


Quantification and prediction of hydrologic variability

- 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:

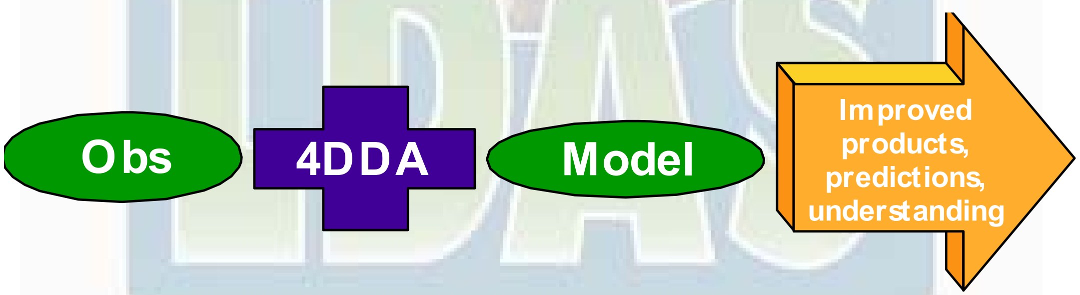
- Observation: Forcing, storages(states), fluxes, and parameters.
- Simulation: Land process models (Hydrology, Biogeochemistry, etc.).
- Assimilation: Short-term state constraints.



"LDAS" concept:

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

- Optimal integration of land surface observations and predictions.
- Continuous in time&space; multiple scales; retrospective, realtime, forecast



Background: Land Surface Modeling

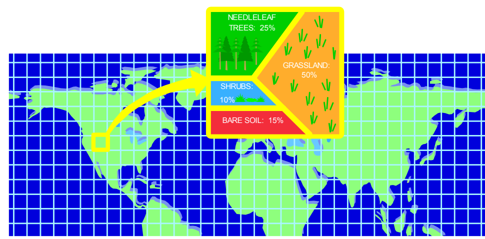
Land Surface Prediction: Accurate land model prediction is essential to enable data assimilation methods to propagate or extend scarce observations in time and space. Based on ***water and energy balance***.

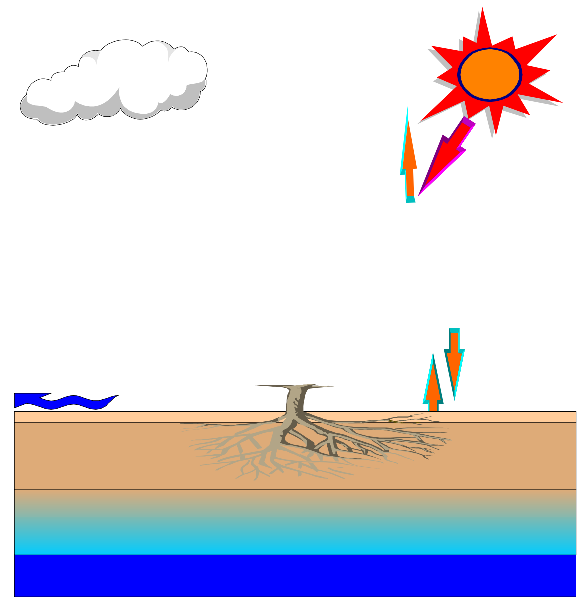
Input - Output = Storage Change

P + Gin –(Q + ET + Gout) = ΔS

Rn - G = Le + H

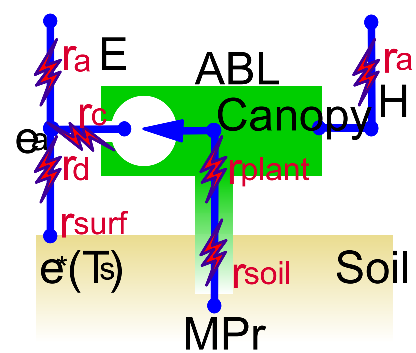
Mosaic (Koster, 1996):
- Based on simple SiB physics.
- Subgrid scale "mosaic"

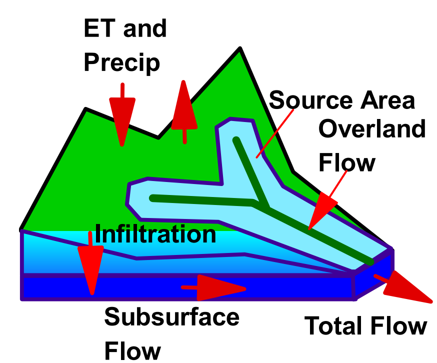




CLM (Community Land Model, ~2001):
- Community developed “open-source” model.
- 10 soil layers, 5 layer snow scheme.

Catchment Model (Koster et al., 2000):
- Models in catchment space rather than on grids.
- Uses Topmodel concepts to model groundwater





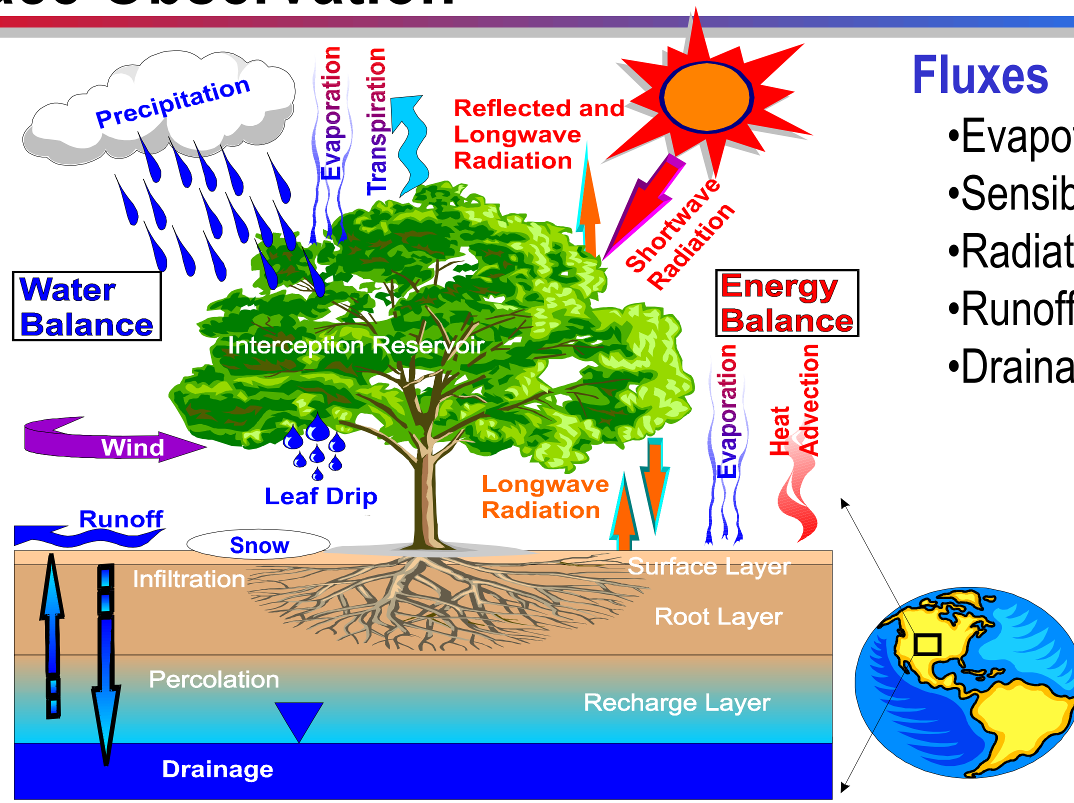
NOAA-NCEP-Noah Model (NCEP, ~2001):
- Operational Land Surface model.

Also: vic, bucket, SiB, etc.

Land Surface Observation

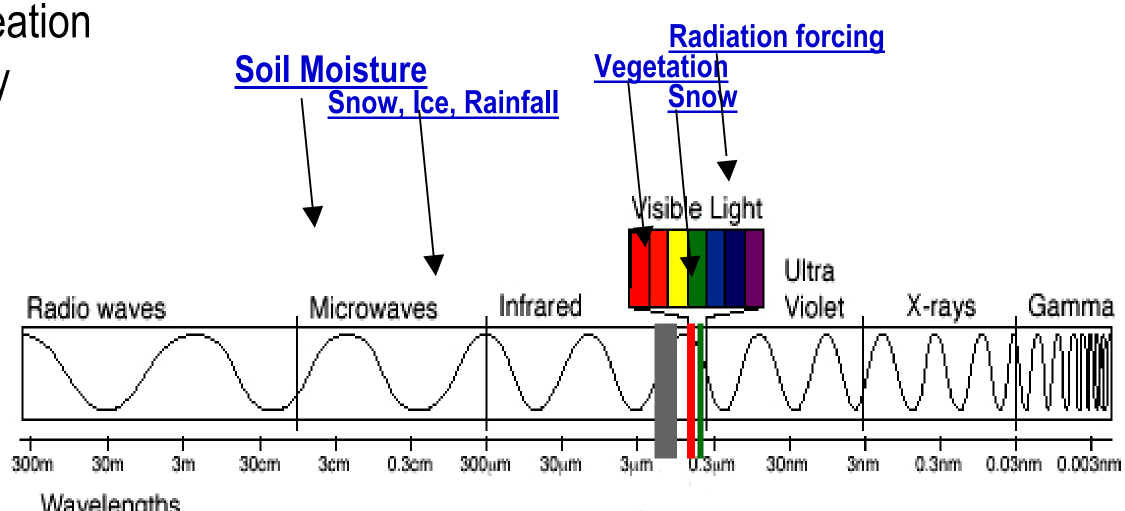
Forcing
- Precipitation
- Wind
- Humidity
- Radiation
- Air Temperature

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



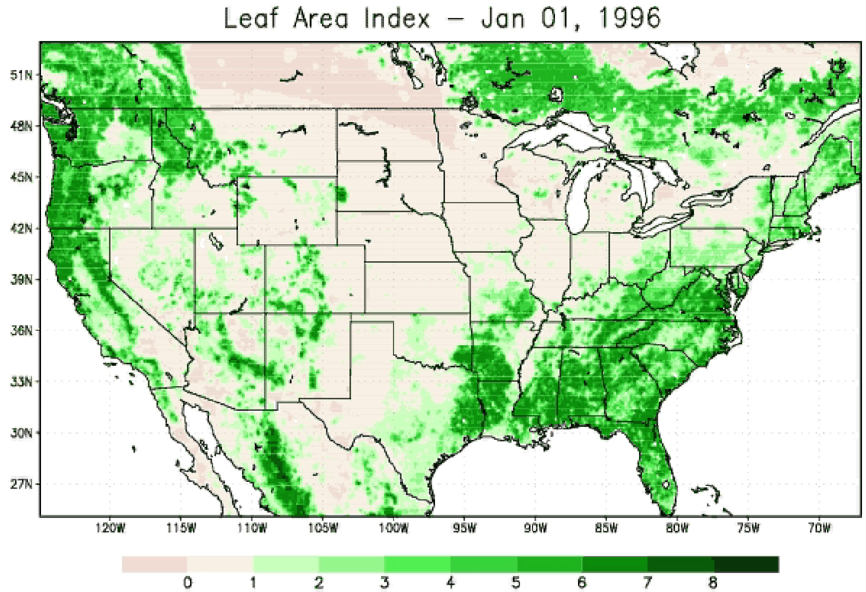
Fluxes
- Evapotranspiration
- Sensible Heat Flux
- Radiation
- Runoff
- Drainage

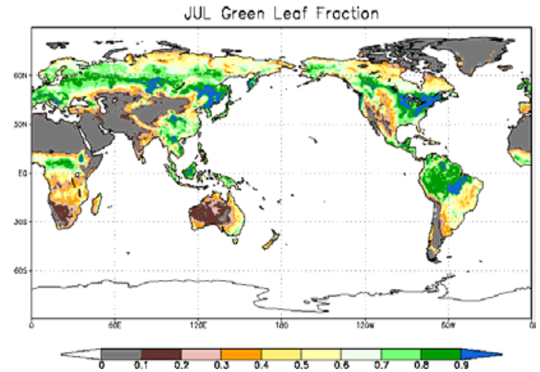
States
- Soil Moisture
- Temperature
- Snow
- Carbon
- Nitrogen
- Biomass

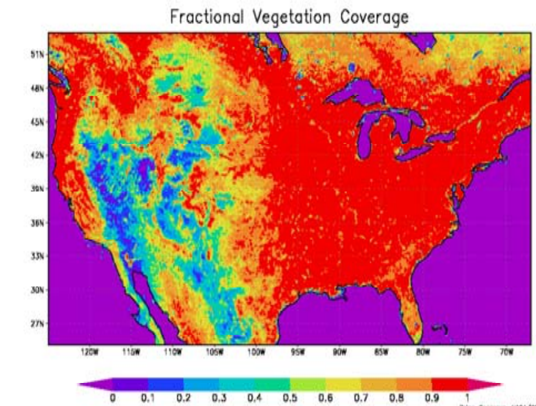


Land Parameter Observations

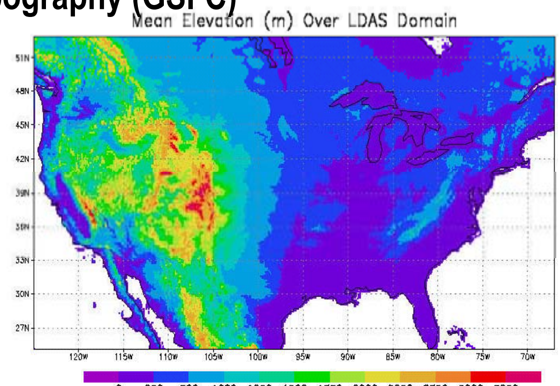
AVHRR/MODIS 1 km LAI -- July



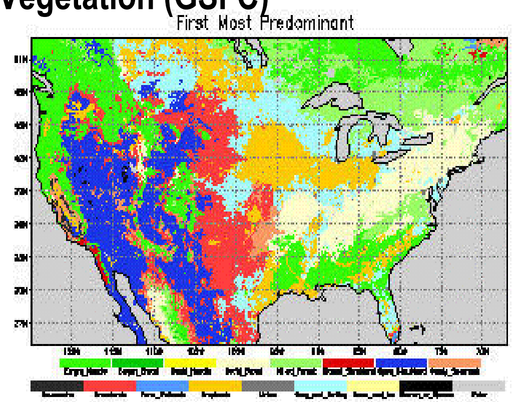




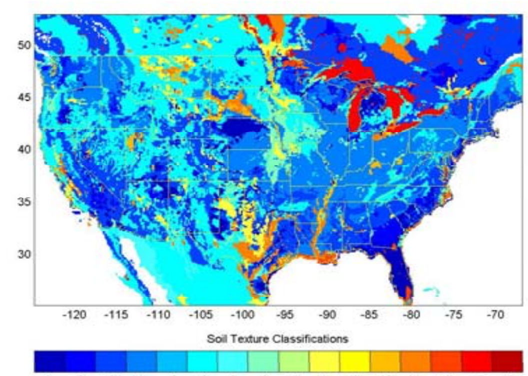
Topography (GSFC)



Vegetation (GSFC)

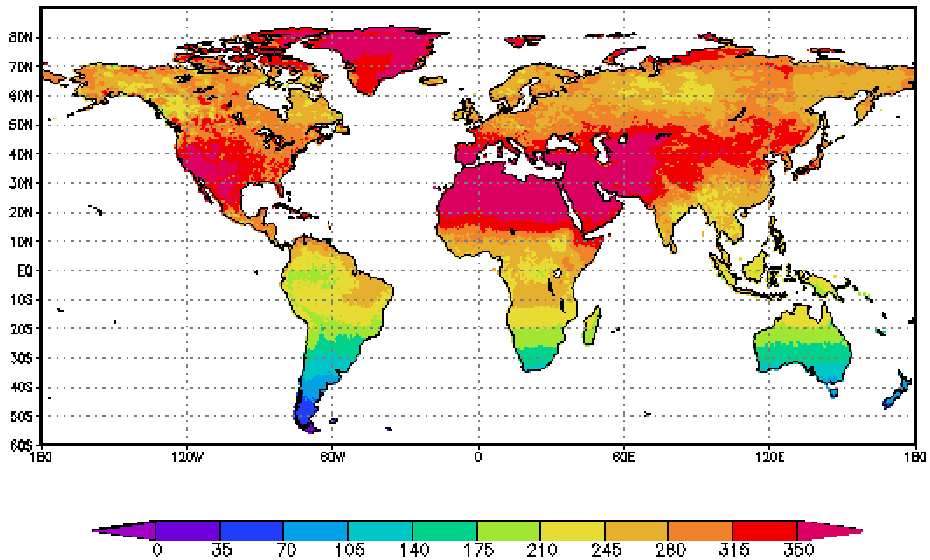


Soils (NWS-OH)

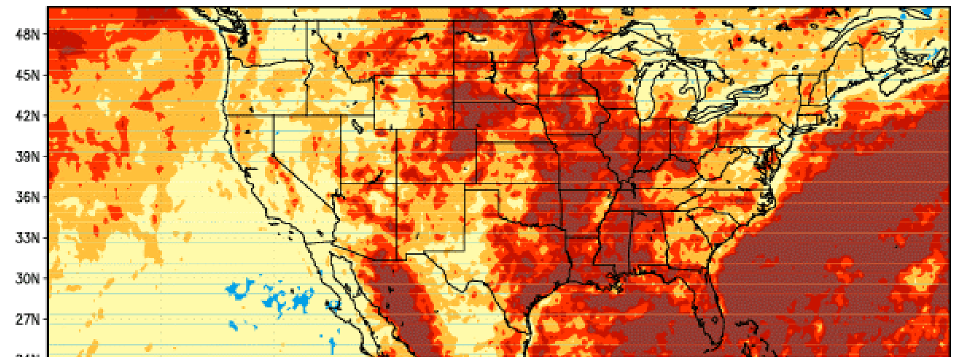


Land Forcing Observations

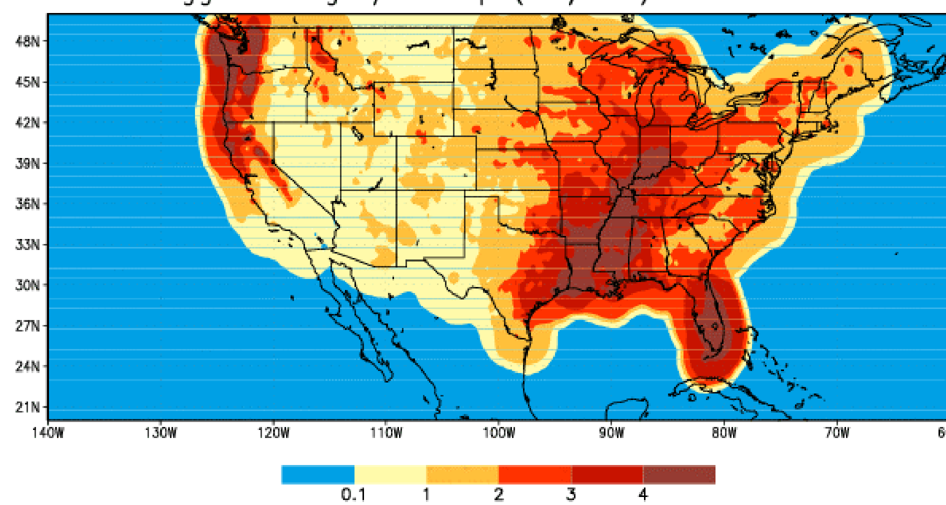
AGRMET daily-mean SW Flux [W/m^2], July 2001



NRL Microwave / Precip (MM/DAY) / Jul – Dec 2001



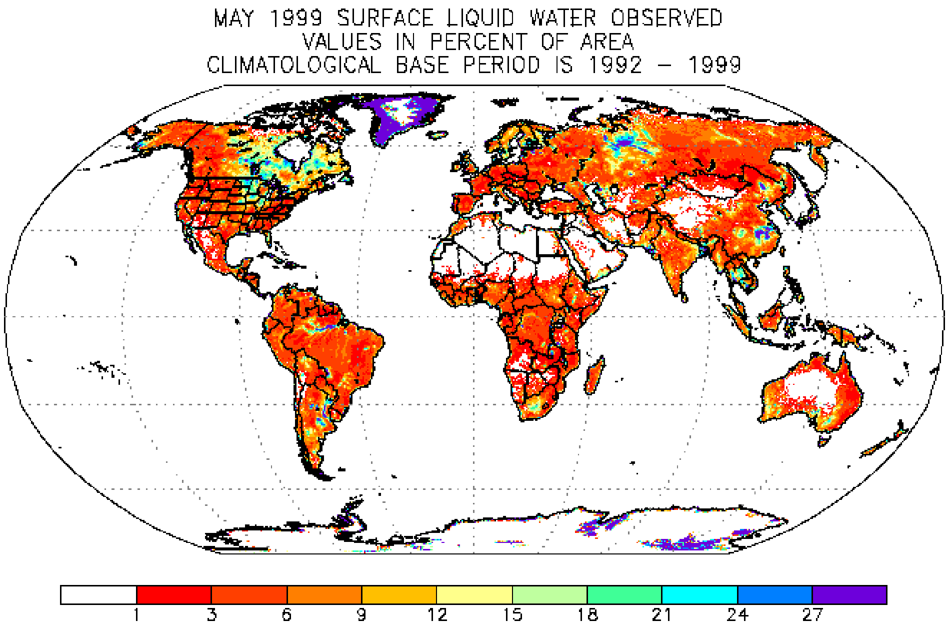
CPC Higgins Gauge / Precip (MM/DAY) Jul – Dec 2001

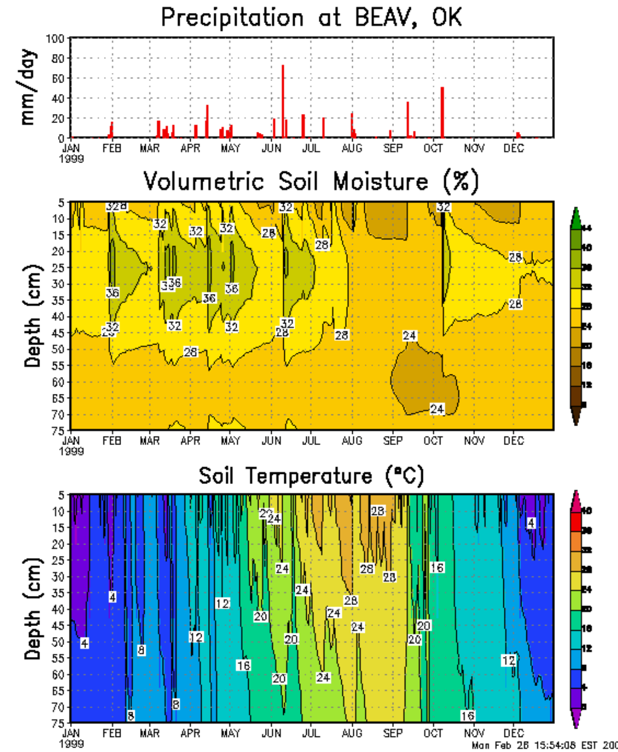


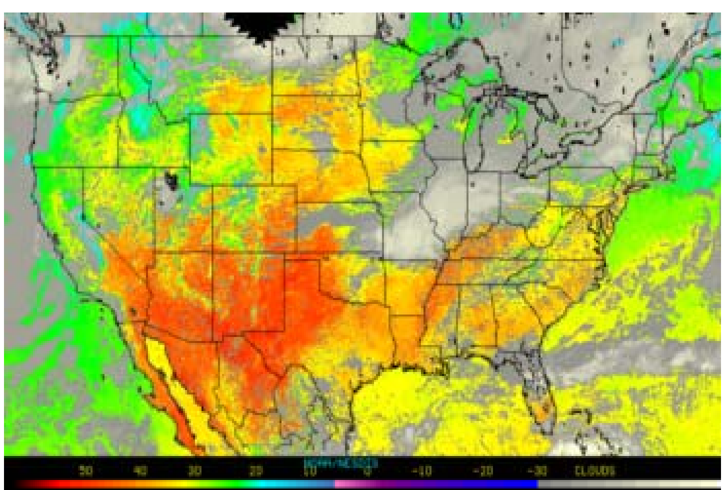
TRMM Precipitation

Land State Observations

Soil Moisture

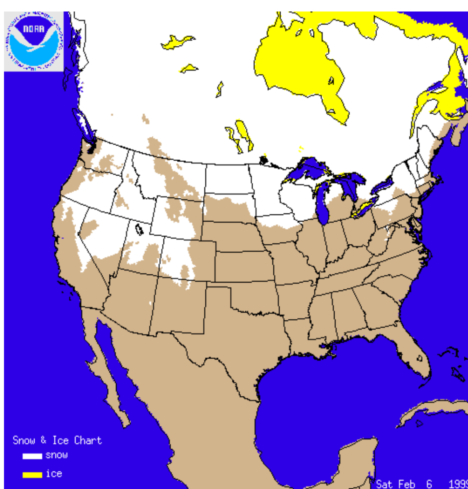






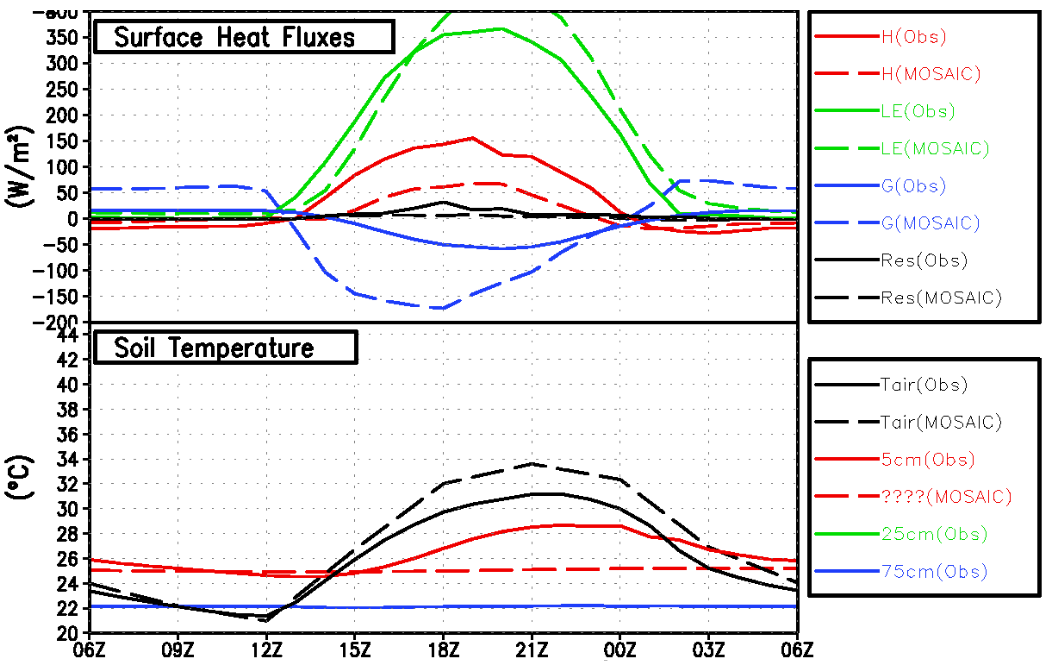
Skin temperature derived from NOAA/NESDIS GOES.

Snow Cover/Depth



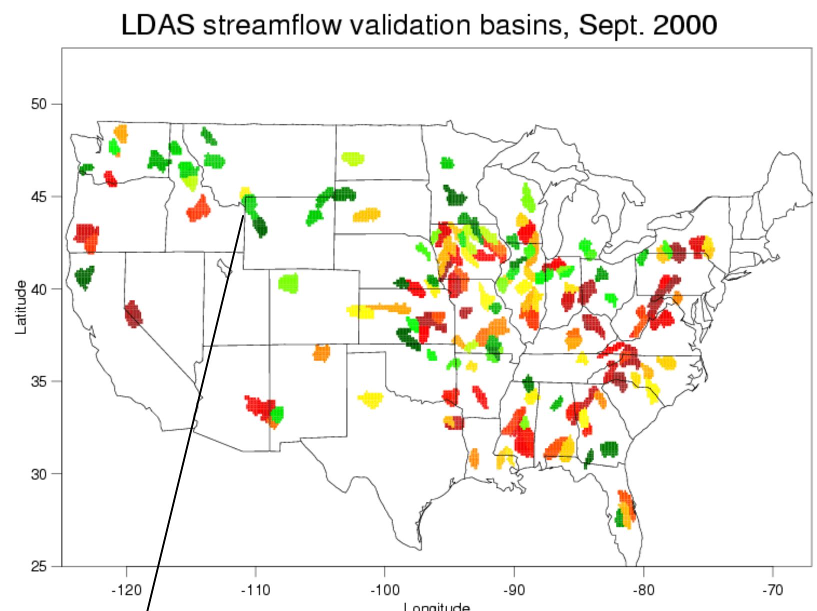
Land Flux Observations

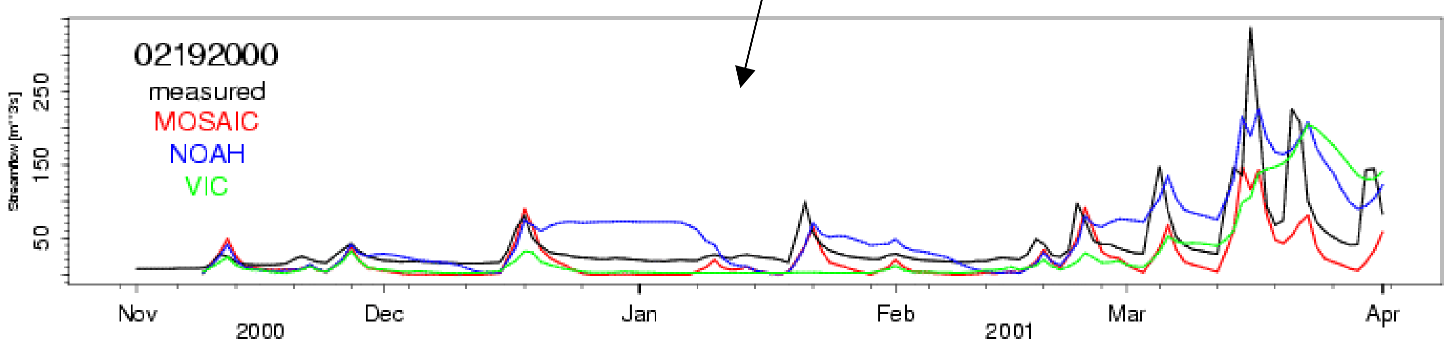
Surface Fluxes



Oklahoma ARM Site

Streamflow

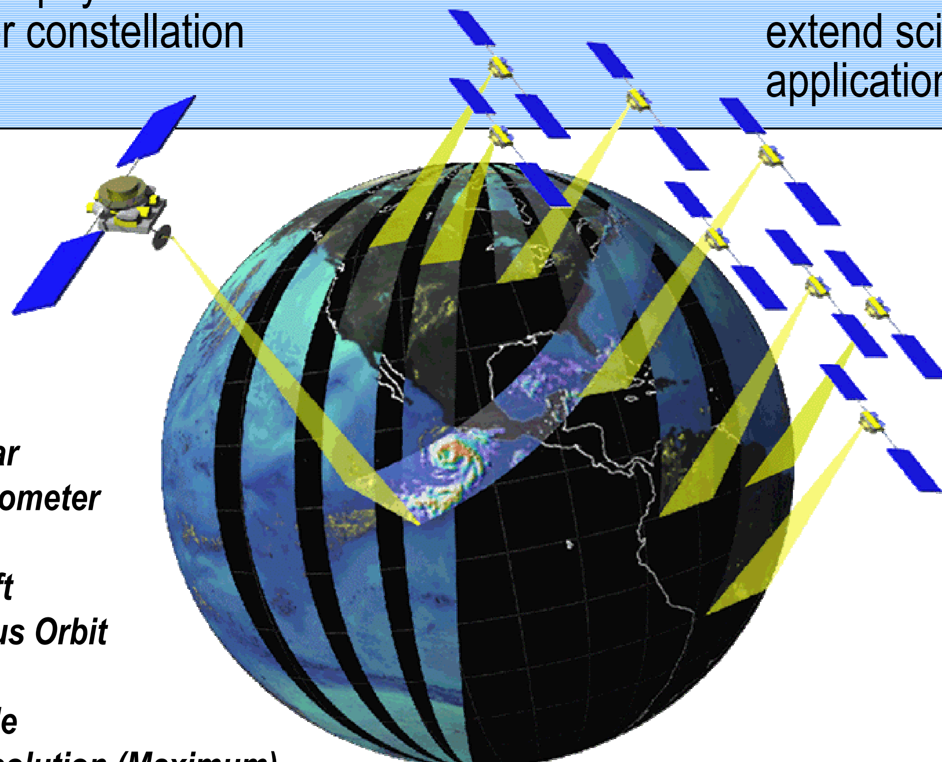




Global Precipitation Mission

OBJECTIVE: Understand the horizontal and vertical structure of rainfall and Its microphysical element. Provide training for constellation radiometers.

OBJECTIVE: Provide enough sampling to reduce uncertainty in short-term rainfall accumulations. extend scientific and societal applications.



Core Satellite

- *Dual Frequency Radar*
- *Multi-frequency Radiometer*
- *H2-A Launch*
- *TRMM-like Spacecraft*
- *Non-Sun Synchronous Orbit*
- *~65° Inclination*
- *~400 - 500 km Altitude*
- *~4 km Horizontal Resolution (Maximum)*
- *250 m Vertical Resolution*

Constellation Satellites

- *Multiple Satellites with Microwave Radiometers*
- *Aggregate Revisit Time, 3 Hour goal*
- *Sun-Synchronous Polar Orbits*
- *~600 km Altitude*

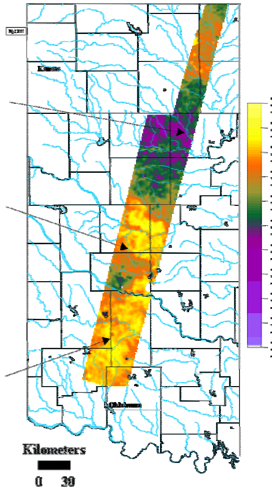
Precipitation Validation Sites

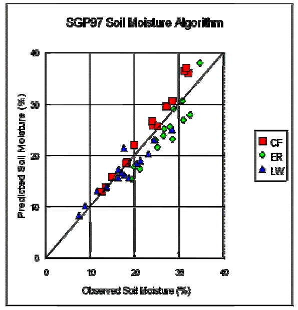
- *Global Ground Based Rain Measurement*

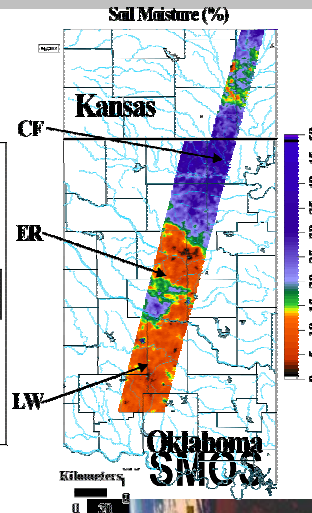
Global Precipitation Processing Center

- *Capable of Producing Global Precip Data Products as Defined by GPM Partners*

Evolution of Soil Moisture Mapping

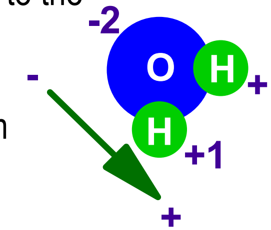




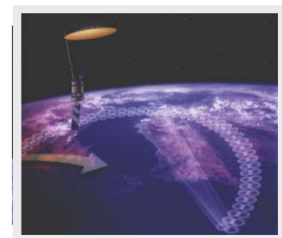


Dielectric constant: Dry soil~3.5, Water ~80

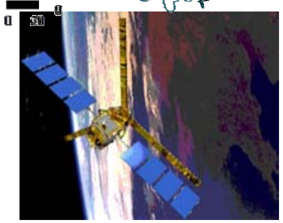
- Water molecule aligns itself to the microwave field
- Penetration depth: ~10 cm
- Measurement depth: ~5 cm

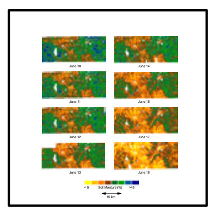


HYDROS



SMOS





Hydrologic Process Mission — Higher spatial resolution, (10 km) higher sensitivity

Hydroclimate Mission — Global mapping of soil moisture, operational feasibility (30 km)

ESTAR — Large scale mapping, hydrologic studies, first demonstration of STAR (1 km)

PBMR — Exporation of spatial and temporal concepts (100 m)

Field Experiments — Ground and aircraft development and verification of theory (1 m)

(AMSR-E)

Soil Moisture Sensing Technology

70 80 90 00

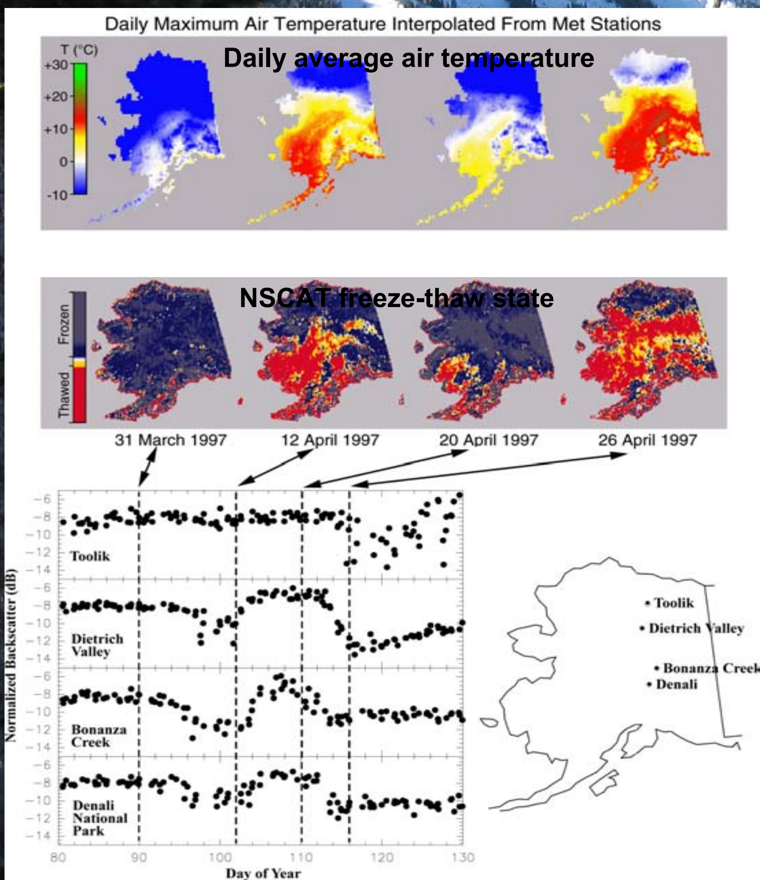
Time Period

Cold Seasons Experiment/Mission

Cold Seasons Hydrology Experiment

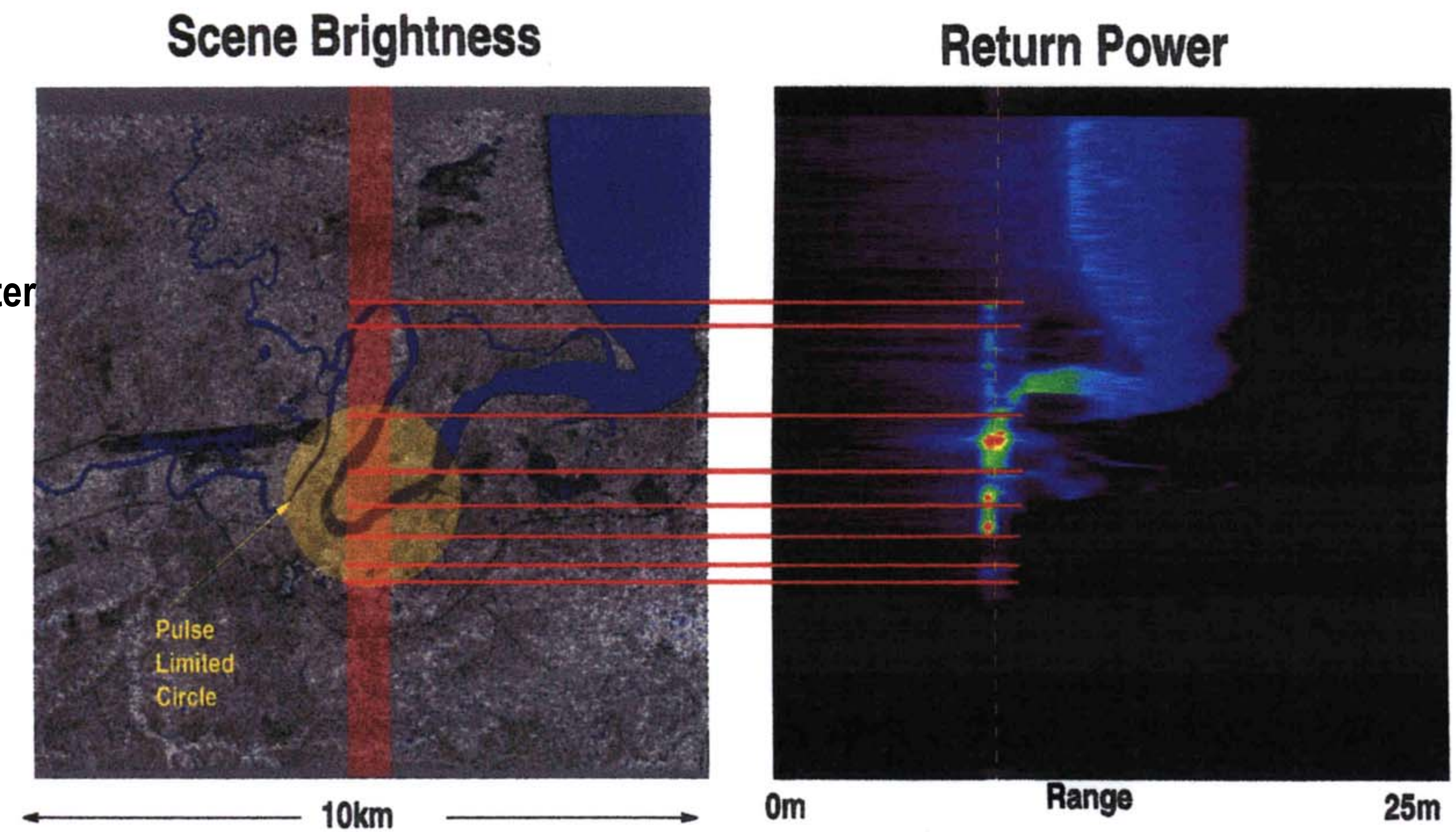
Colorado, 2002-2005

NASA, NOHRSC, USFC, BLM, etc.



Hydrologic Altimetry *"Streamflow AND inundation from Space"*

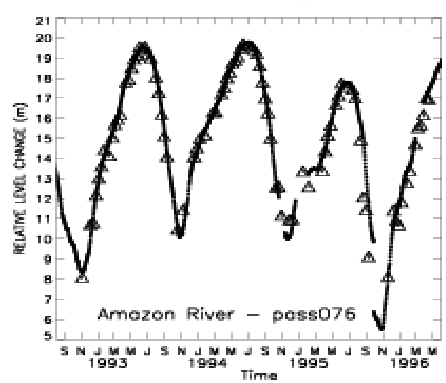
KU-Band Wide-Beam SAR-Altimeter

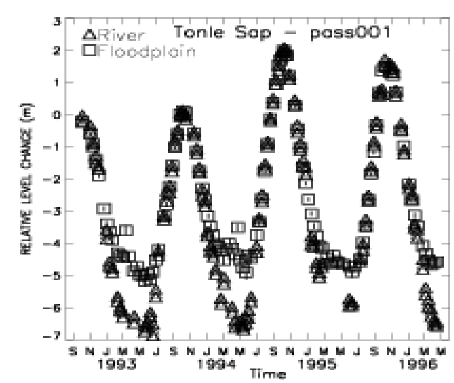


Floodplain, delta, braded, and ice flow streams are impossible to gage – perhaps remote sensing can help?

IDEA? Continuous river imaging from geostationary?

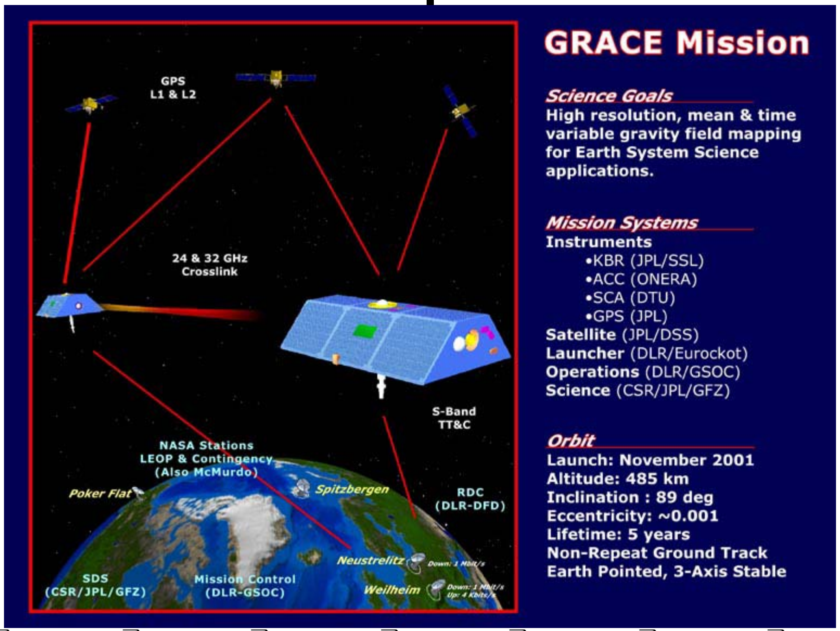
Potentially laser and/or radar altimetry

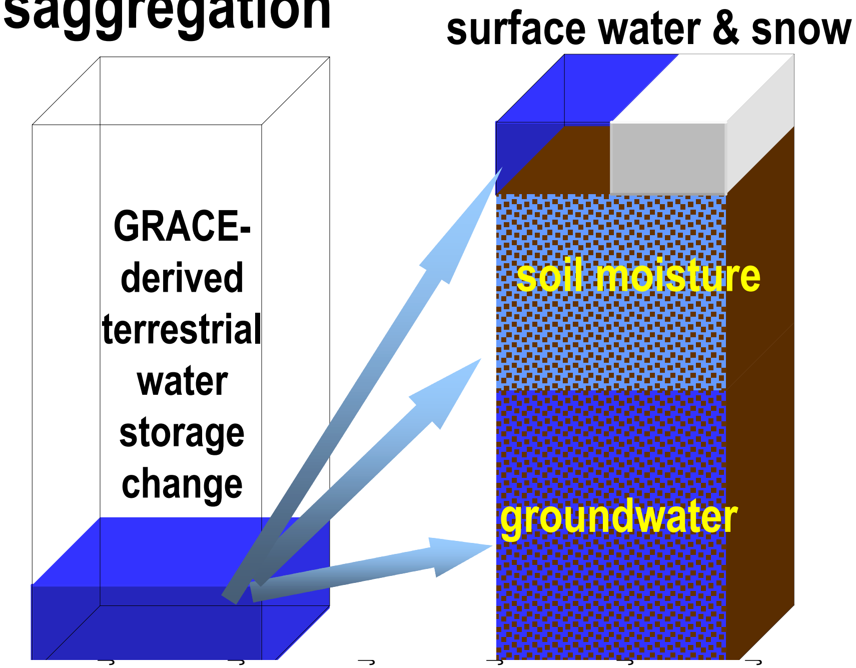


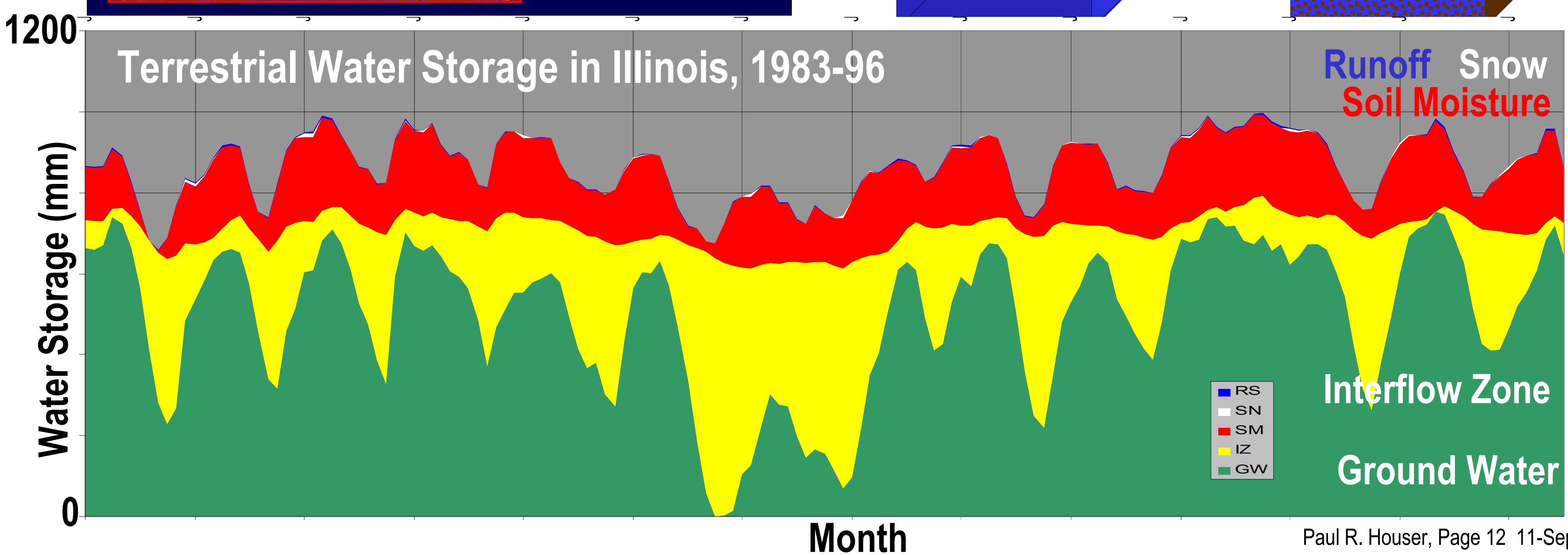


Gravity Observations – *Total Water Changes*

Temporal and Vertical Disaggregation



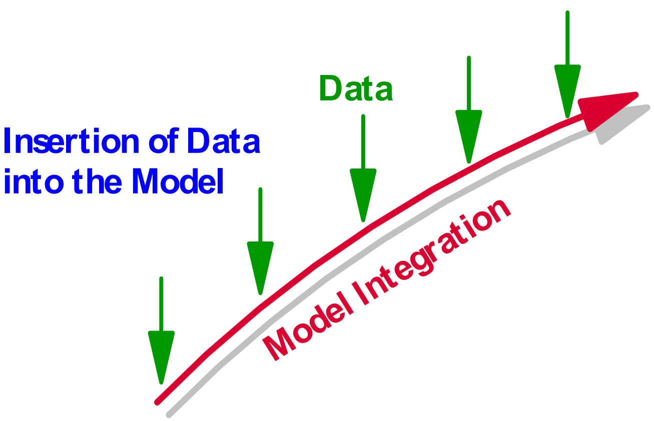




Problem of Observation Integration

Due to its importance, hydrologic data availability will increase.

Complete quantification of hydrologic variability requires innovative organization, comprehension, and integration of diverse hydrologic information due to disparity in observation type, scale, and error.



Hydrologic Quantity	Remote-Sensing Technique	Time Scale	Space Scale	Accuracy Considerations
Precipitation	Infrared	1hr	4km	Tropical convective clouds only
	Passive microwave	3hr	10km	Land calibration problems
	Active Microwave	10day	10m	Land calibration problems
Surface Soil Moisture	C or L-band radar	10day	10m	Significant noise from vegetation and roughness
	C- or L- band radiometer	1-3day	10km	limited to sparse vegetation, low topographic relief
Surface Skin Temperature	infrared	1hr	10m	soil/vegetation average, cloud contamination
Snow Cover	visible/infrared	1hr	10m	Cloud contamination, vegetation masking, bright soil problems
Snow Water Equivalent	passive microwave	1-3day	10km	Limited depth penetration
	active microwave	10day	10m	
Water level/velocity	laser	10day		Cloud penetration problems
	radar	10day		
Total water storage changes	gravity changes	30day	1000km	Bulk water storage change
Evaporation	IR and Models	1hour	4km	Significant assumptions

Land Surface Data Assimilation

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

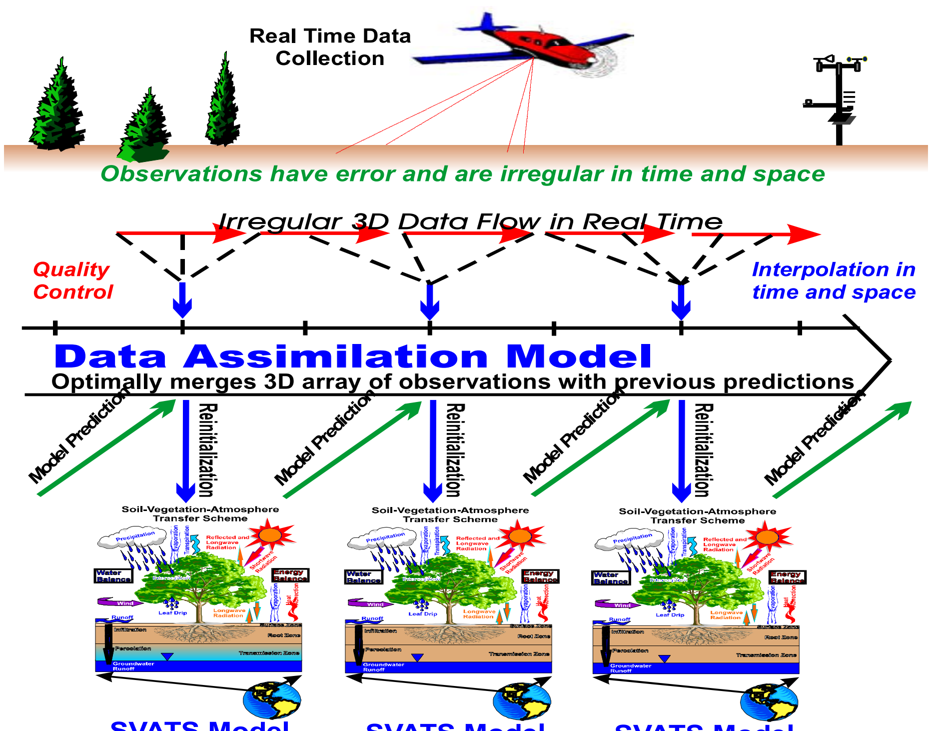
$$\partial x / \partial t = dynamics + physics + \Delta x \qquad A = B + \sum_{k=1}^{K} W_{ik}[O_k - B_k]$$

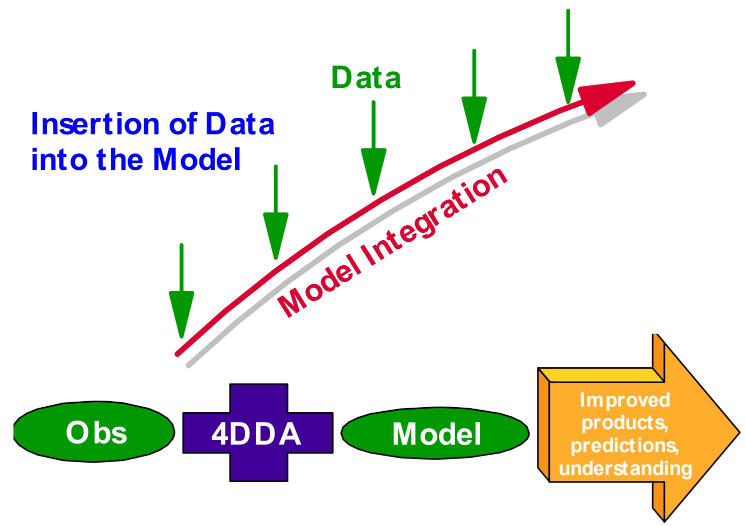
State or storage observations (***temperature, snow, moisture***) are integrated with model predictions

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).



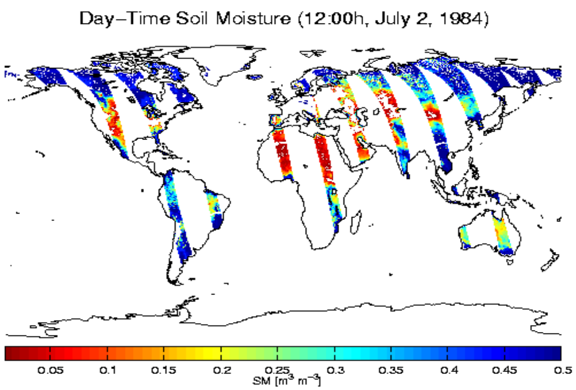


NASA-GSFC Land Surface Data Assimilation

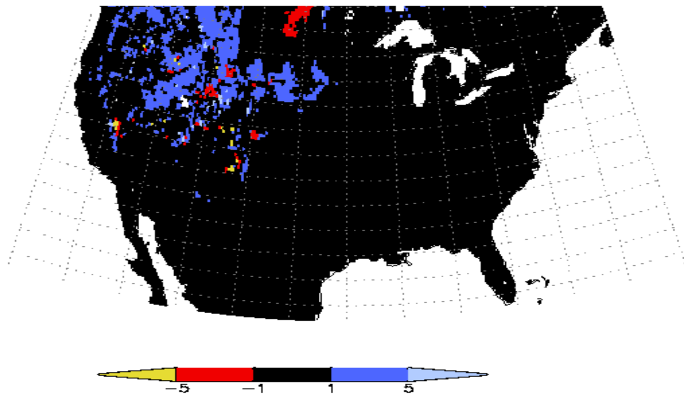
Data Assimilation merges observations & model predictions to provide a superior state estimate.

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.

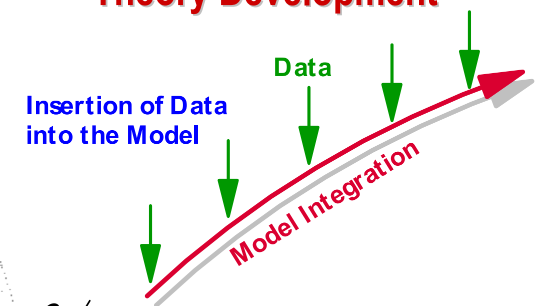
Soil Moisture Assimilation



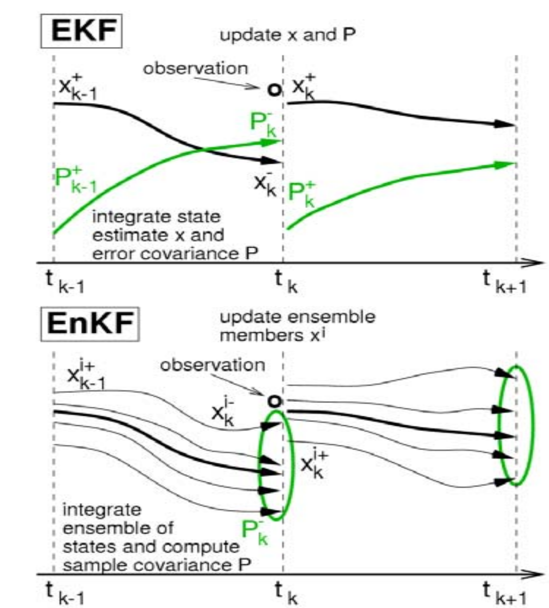
Snow Cover Assimilation



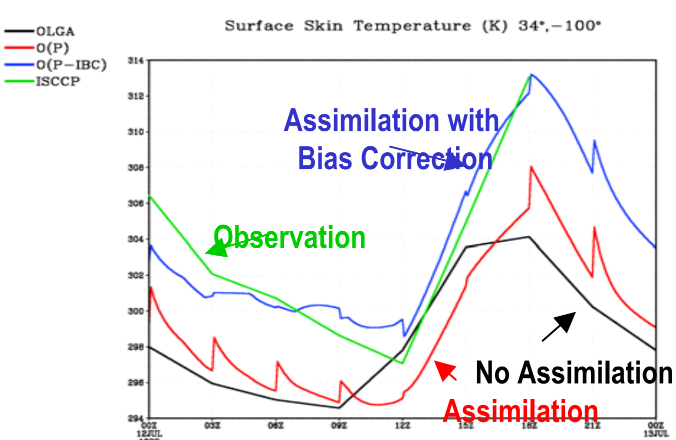
Theory Development



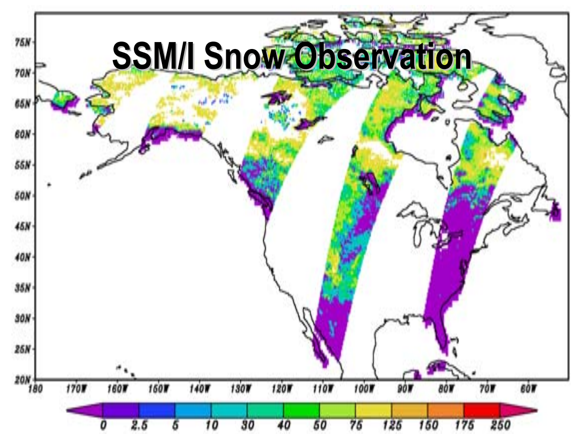
$$\partial x / \partial t = dynamics + physics + \Delta x$$



Skin Temperature Assimilation



Snow Water Assimilation



Land Data Assimilation

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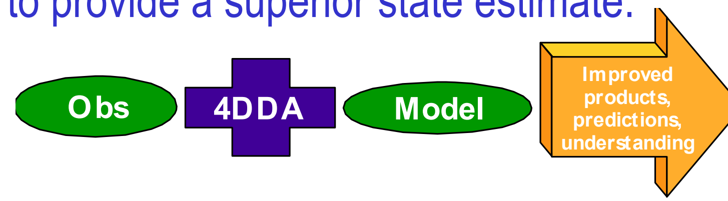
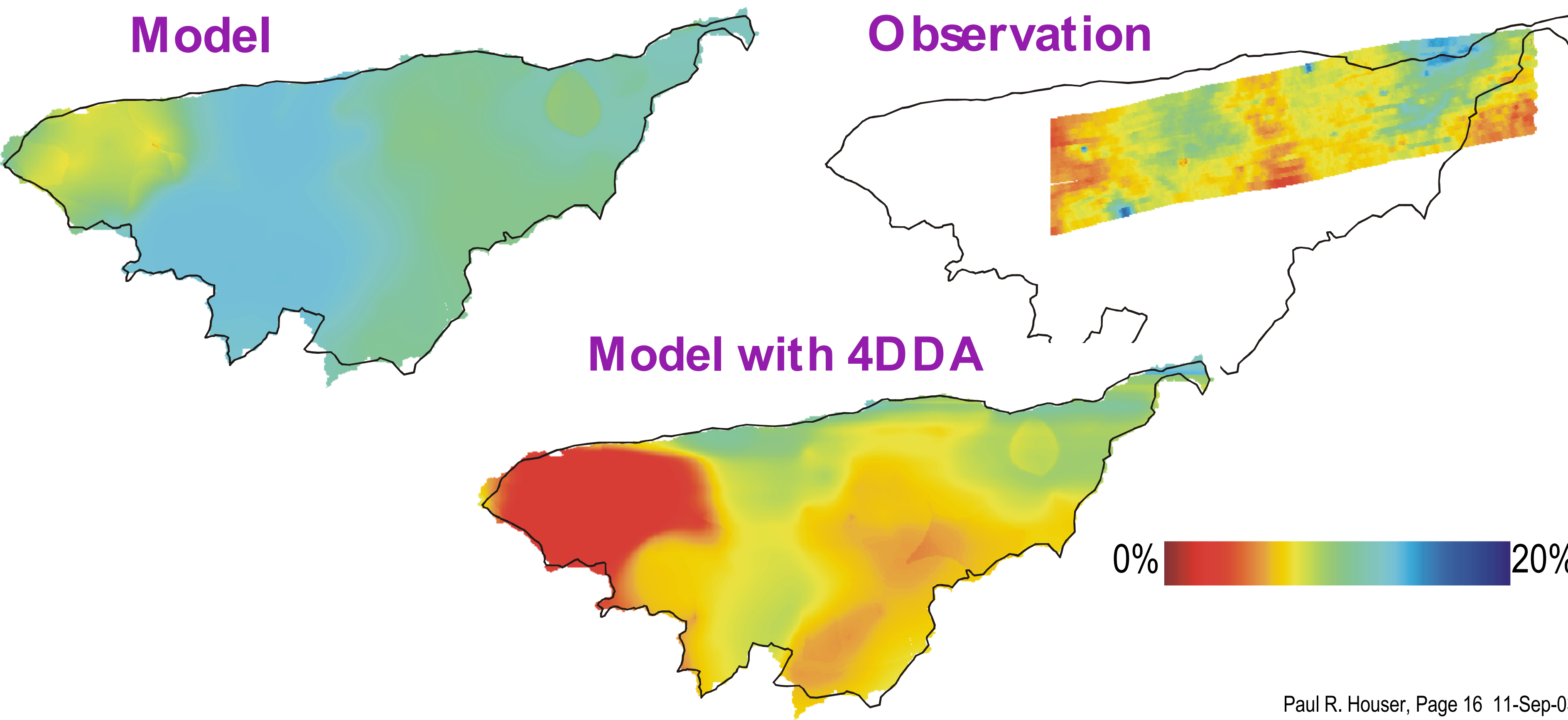
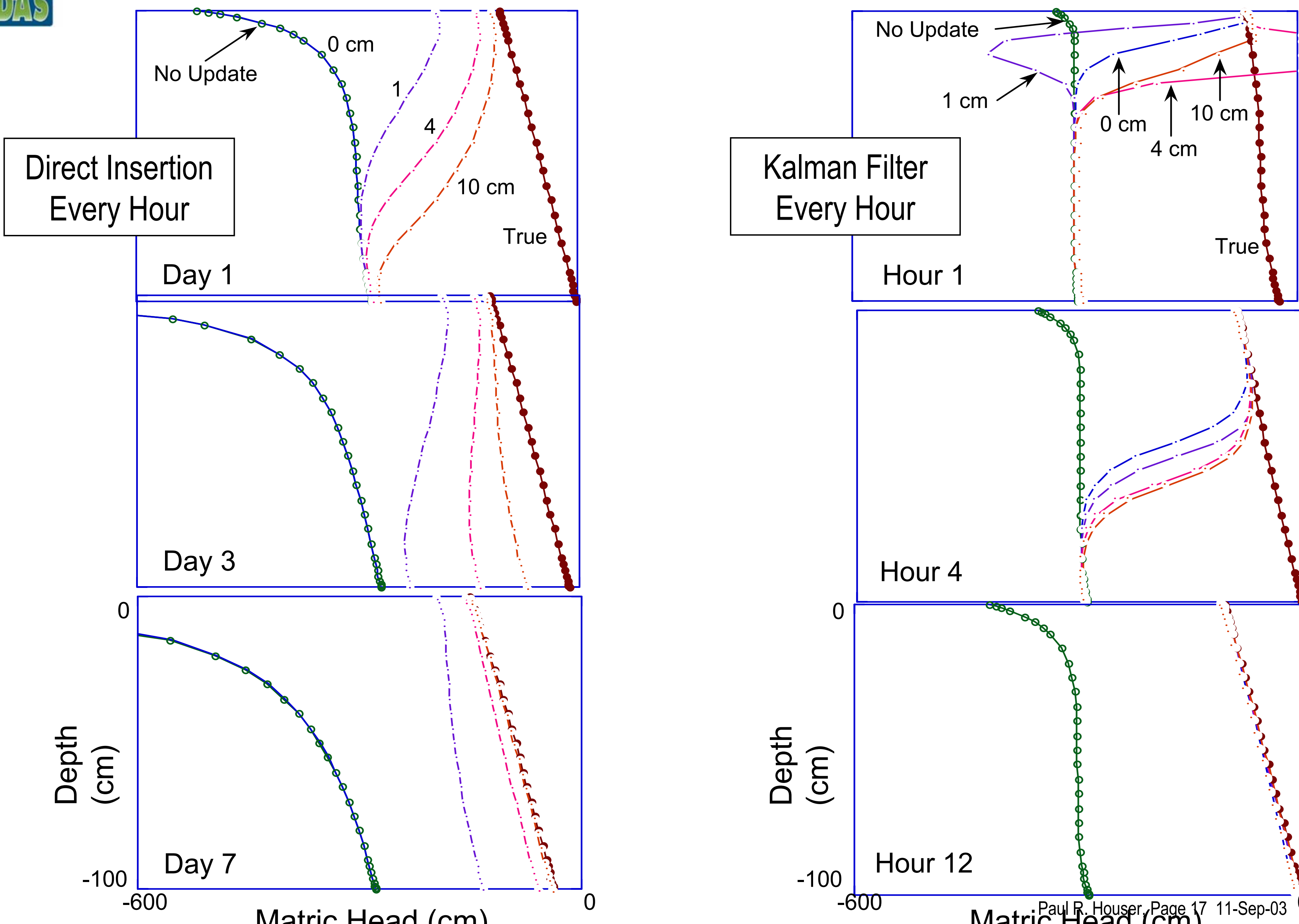
$$\partial x / \partial t = dynamics + physics + \Delta x$$



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 of complex hydrologic phenomenon.



Soil Moisture Profile Correction



Continental Scale: EKF Catchment Model

Kalman Filter:

•One-dimensional using linearized soil moisture forecasting equations, ignoring infiltration, evaporation, and transpiration.
•A linearization of the observation operator (relating surface soil moisture to the model surface excess, root-zone excess, and catchment deficit prognostics) using a Taylor series expansion.

Specifics:

Standard Kalman Filter Forecasting Equations:

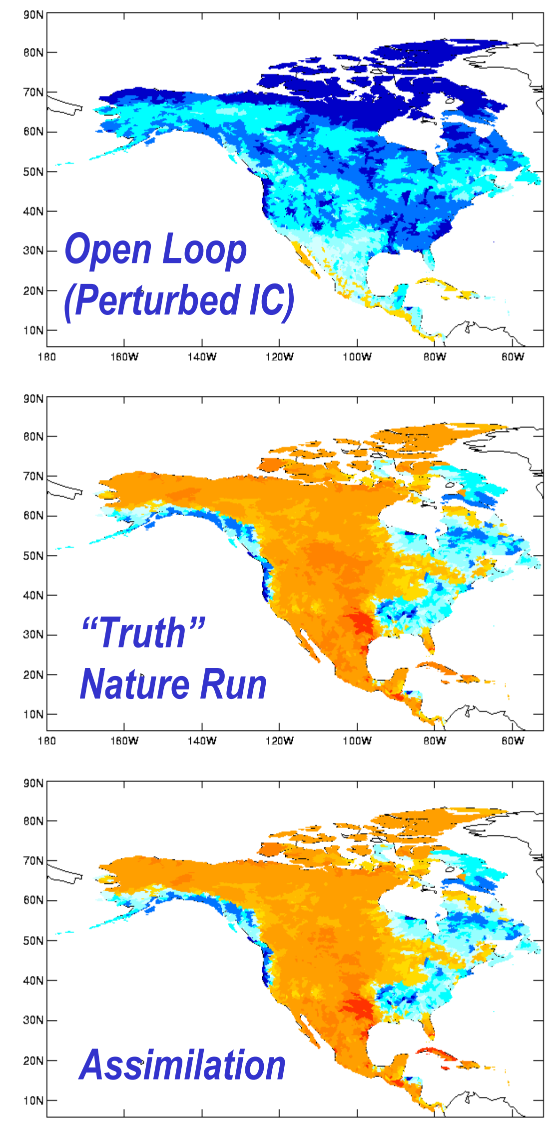
- •States: $X_{n+1/n}=A\bullet X_{n/n} + U_n+(w_n)$
- •Covariance: $\Sigma_{n+1/n} = A_n\bullet\Sigma_{n/n}AT+Q_n$

Observation Equation

$$Z=H\bullet X_n + (v)$$

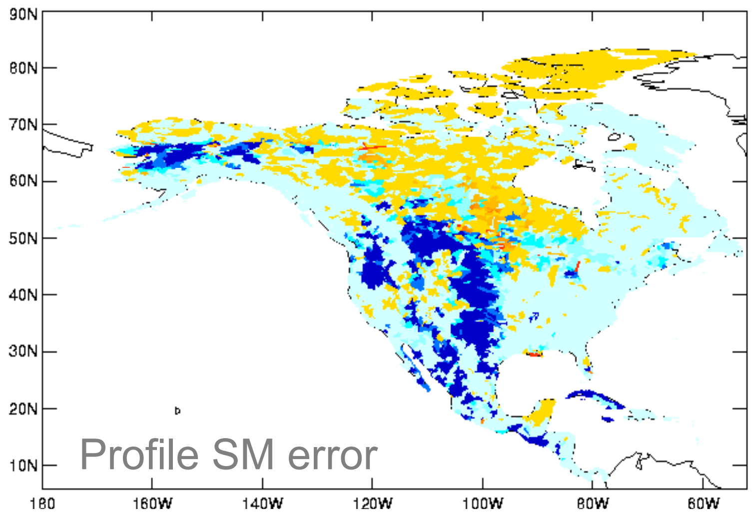
Updating Equations:

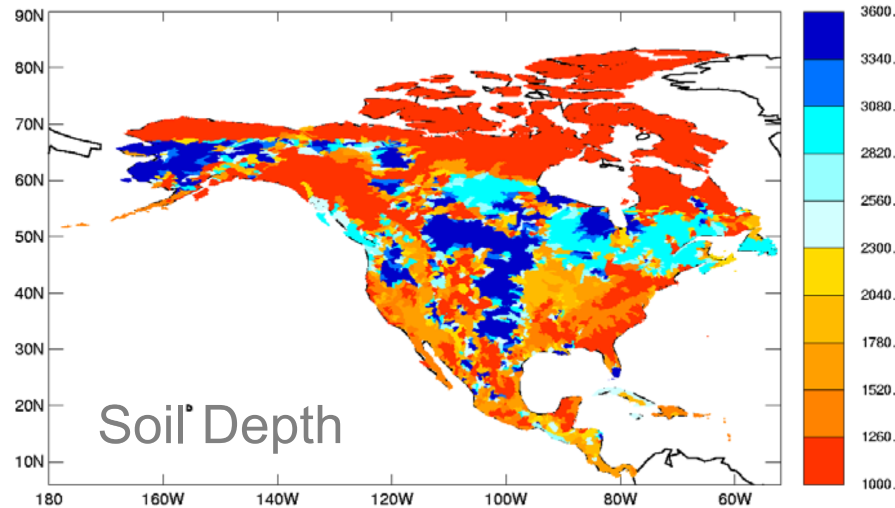
- •States: $X_{n+1/n+1}=X_{n+1/n}+K_{n+1}(Z_{n+1}-H_{n+1}\bullet X_{n+1/n})$
- •Covariance: $\Sigma_{n+1/n+1} = (I-K_{n+1}\bullet H_{n+1})\bullet\Sigma_{n+1/n}$

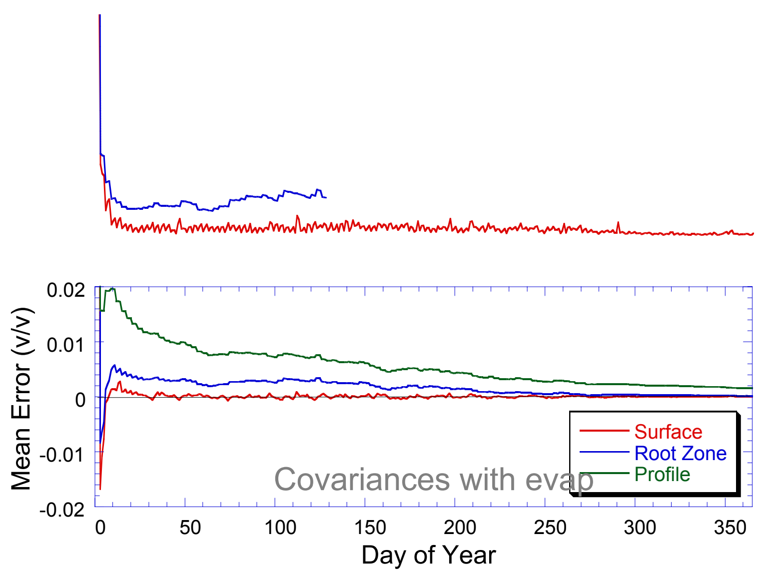


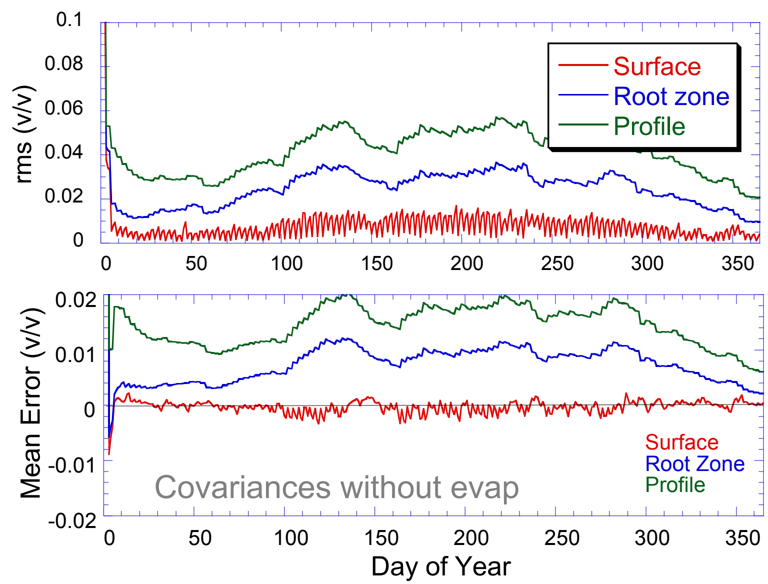
Walker and Houser, 2001

“Errors” in Assimilated Moisture



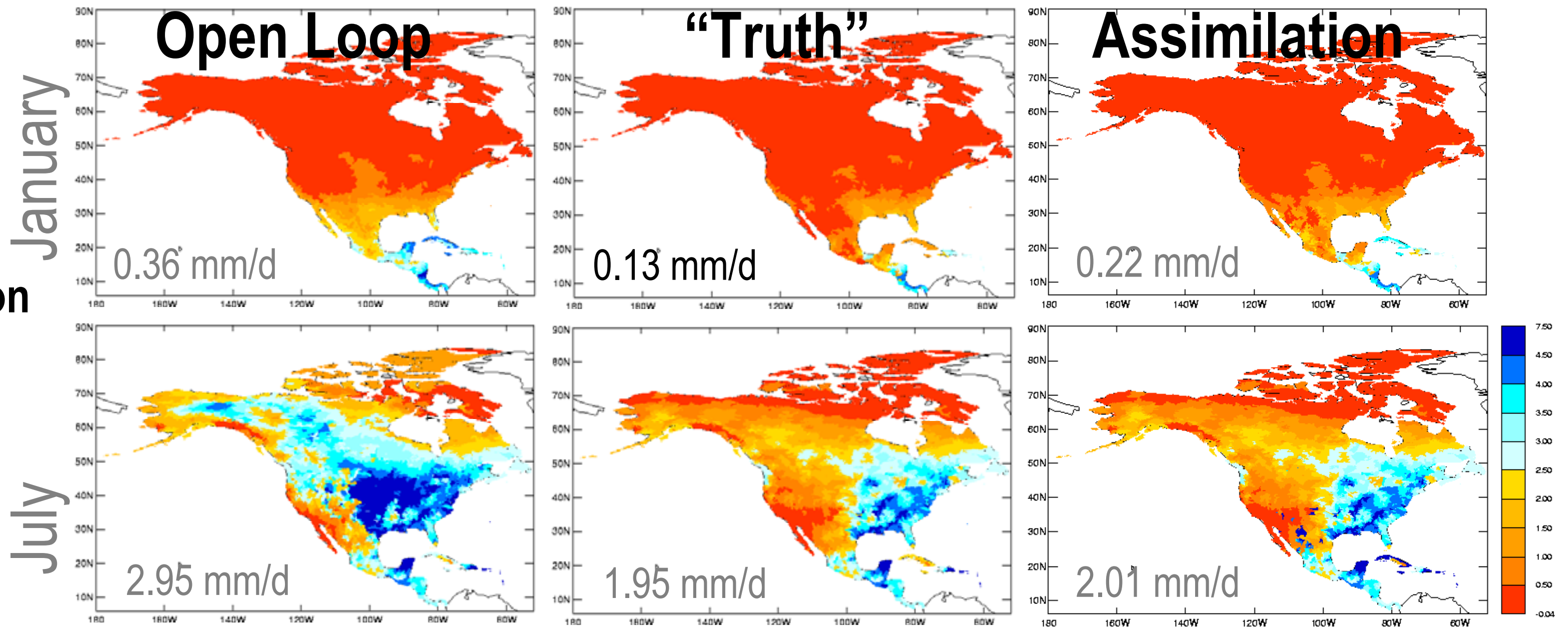




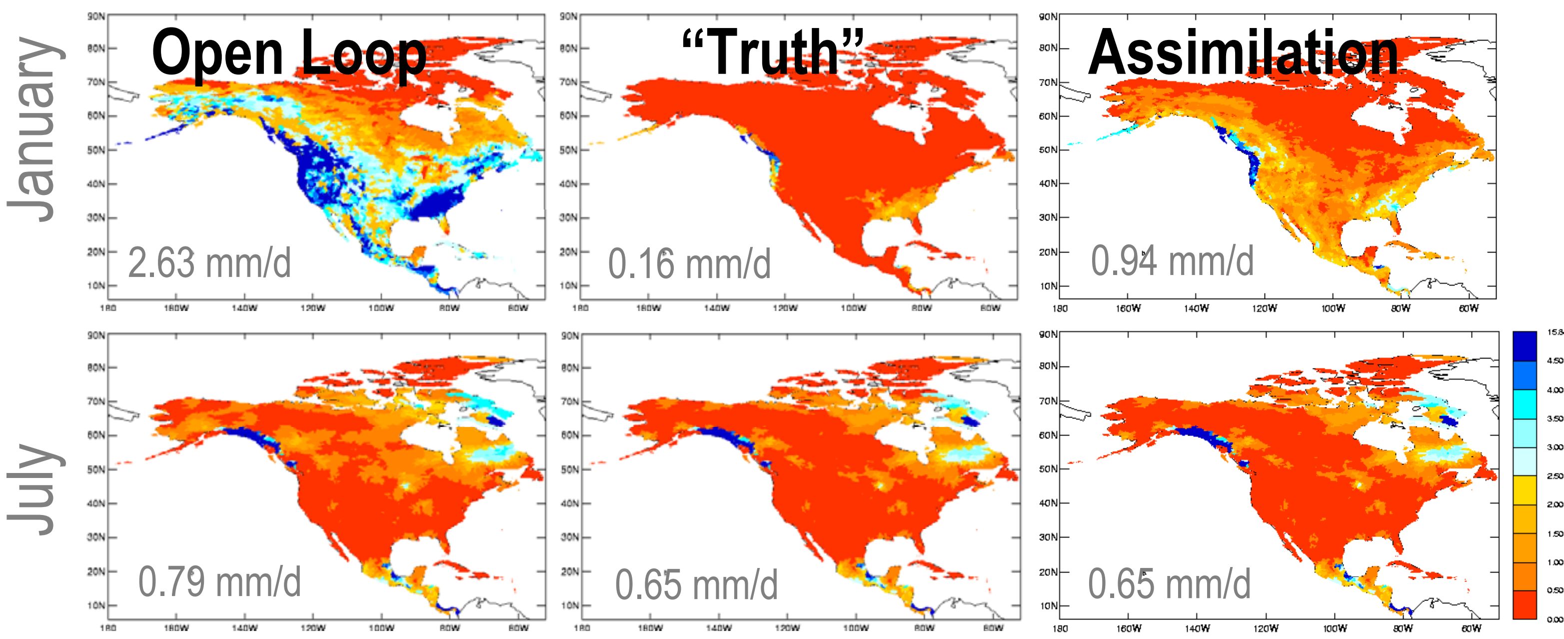


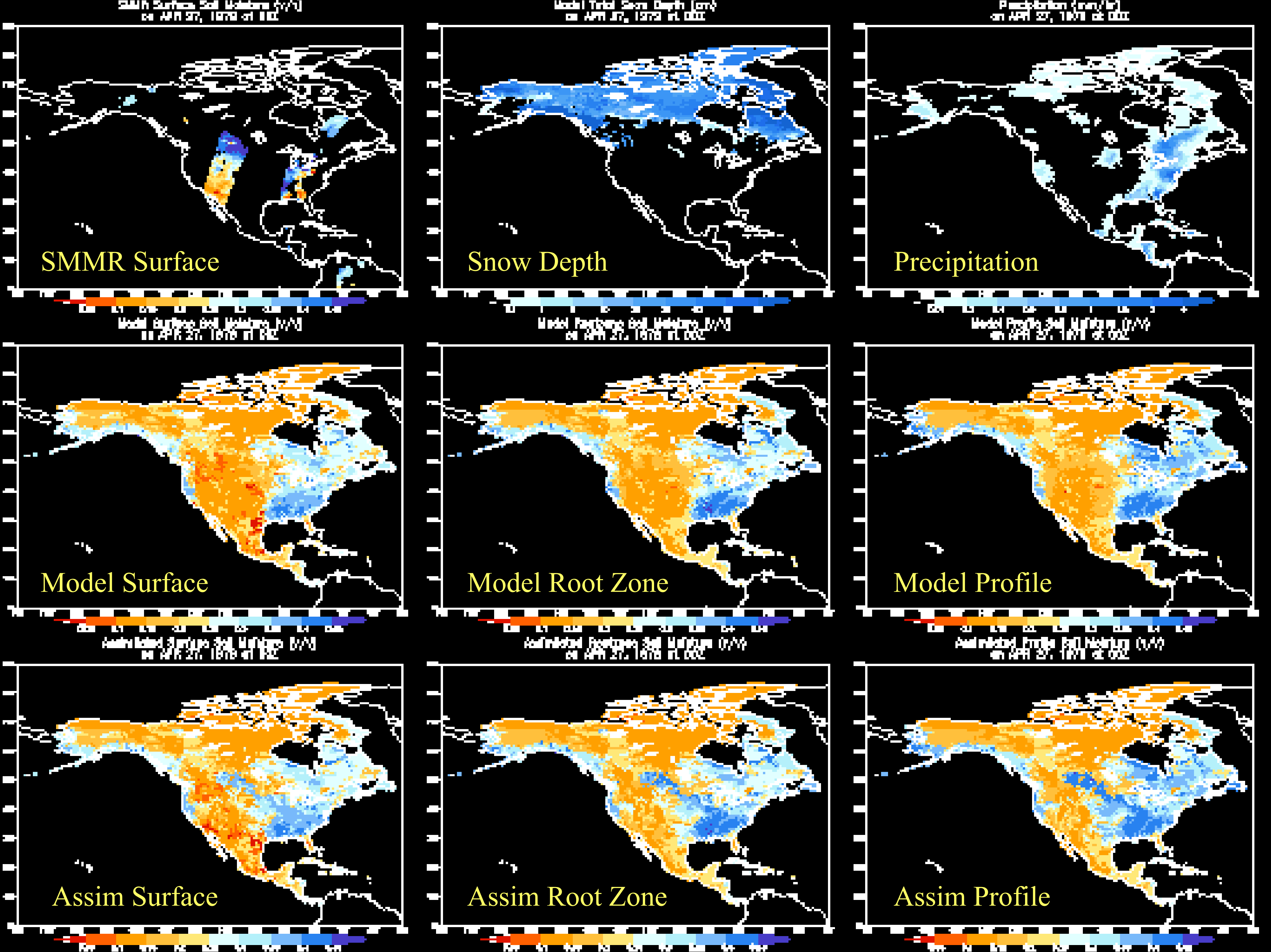
Impact of Soil Moisture Assimilation on Fluxes

Monthly Evapotranspiration



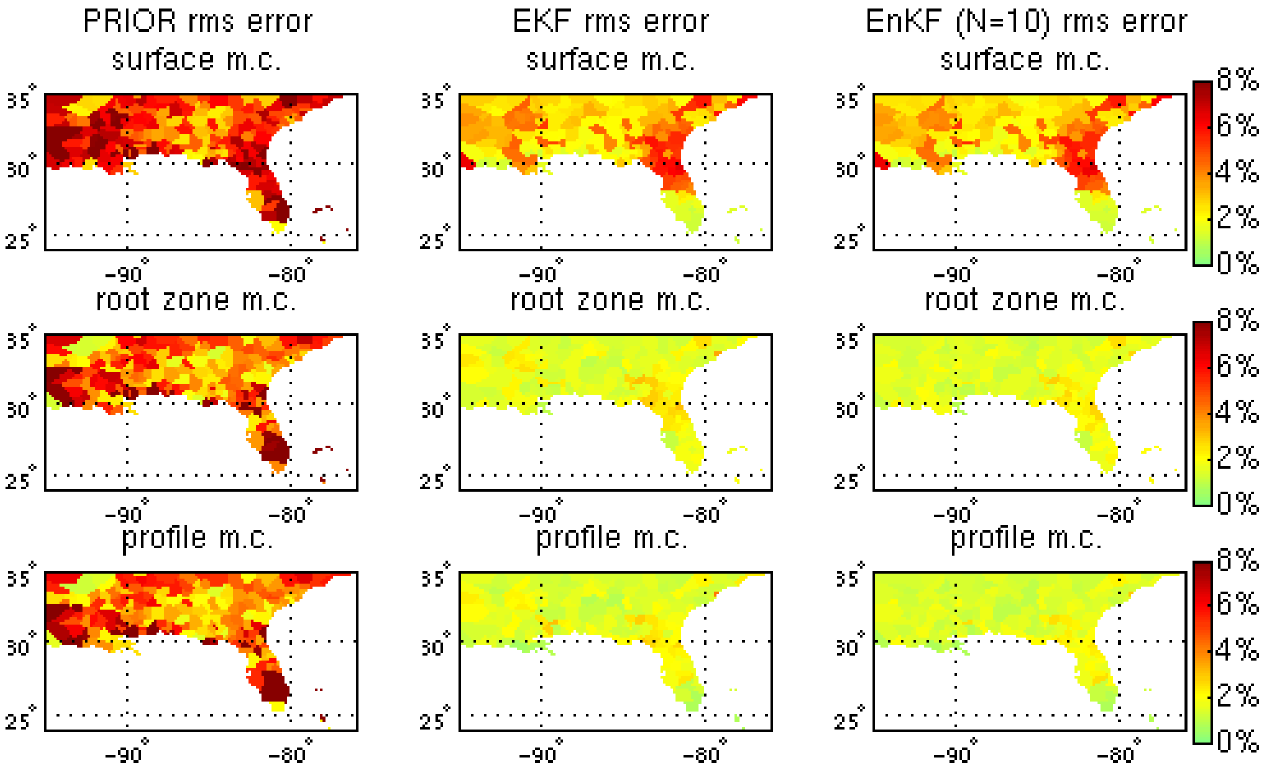
Monthly Runoff

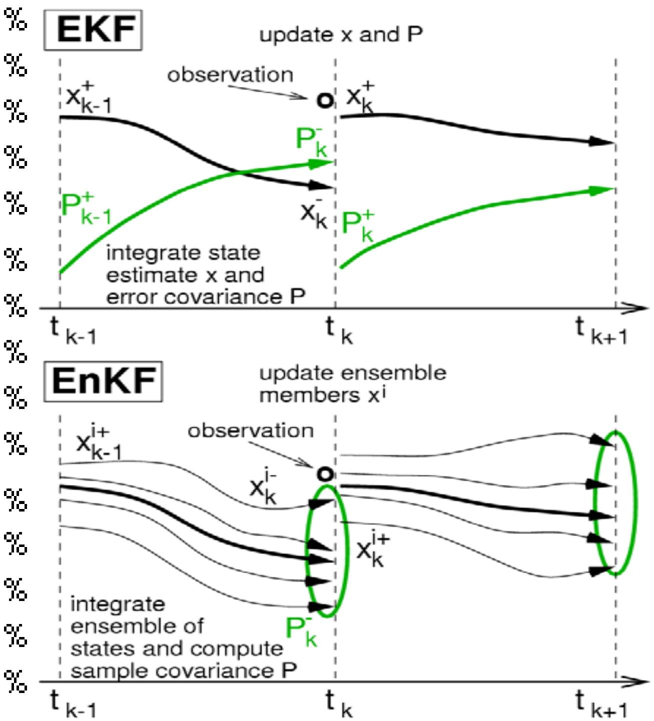


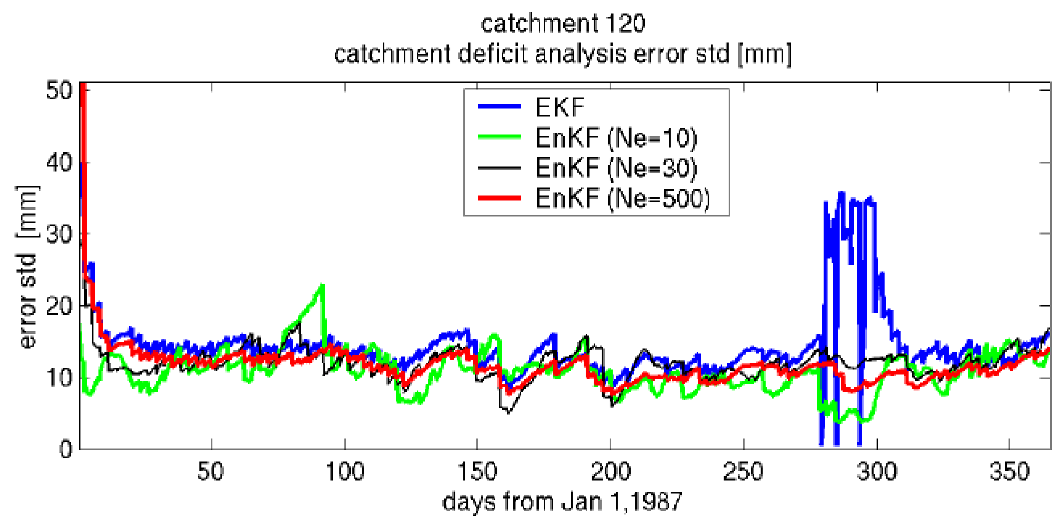


SMMR Surface
Snow Depth
Precipitation
Model Surface
Model Root Zone
Model Profile
Assim Surface
Assim Root Zone
Assim Profile

Extended or Ensemble KF?

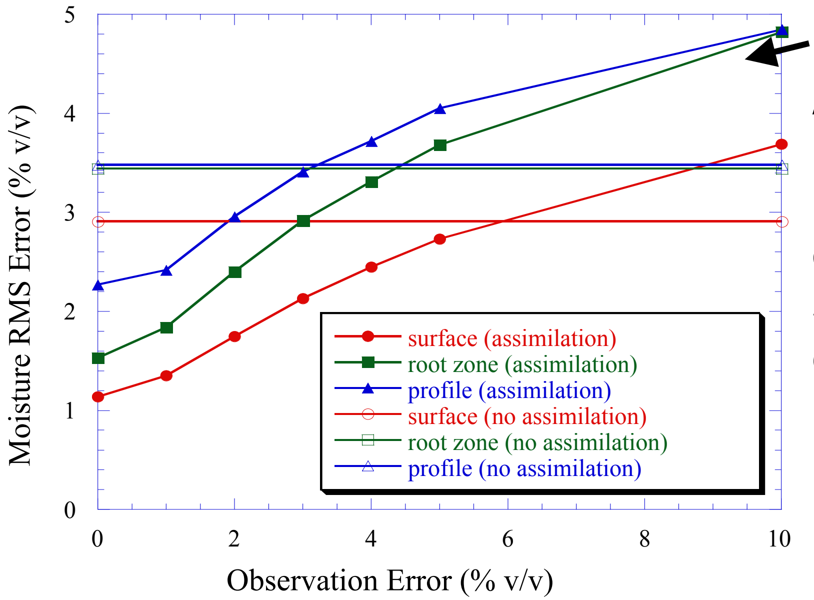




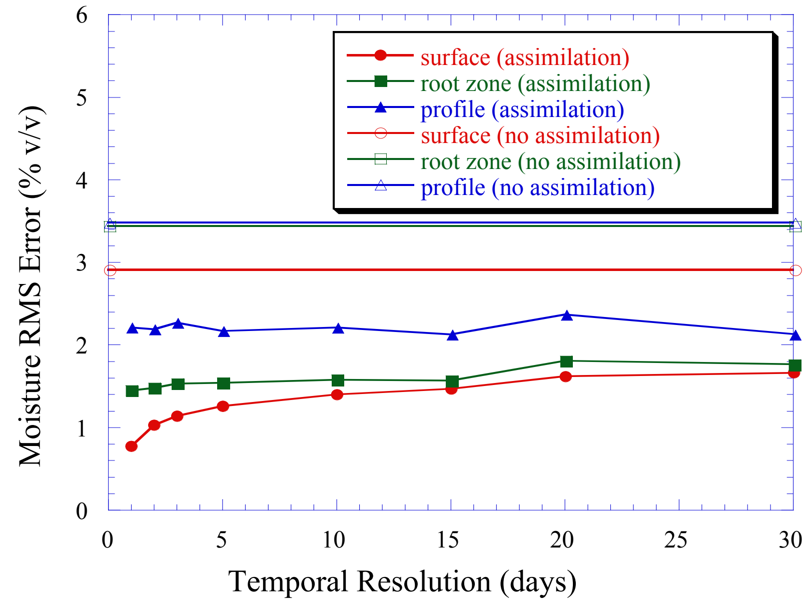


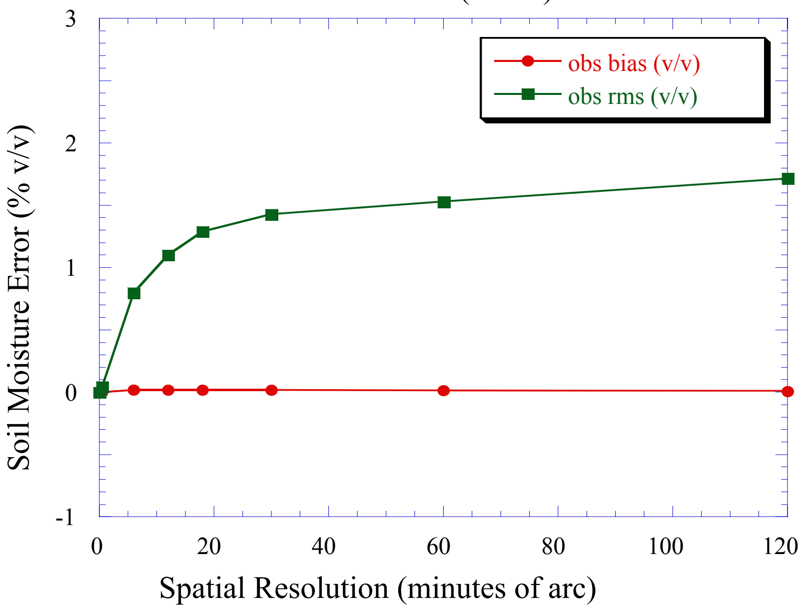
- EKF and EnKF provide satisfactory estimates of soil moisture.
- EKF cheaper, but EnKF more accurate for 6 (or more) ensemble members.
- EKF error estimates diverge occasionally.
- EnKF error estimates noisy for small ensemble (Ne=10).

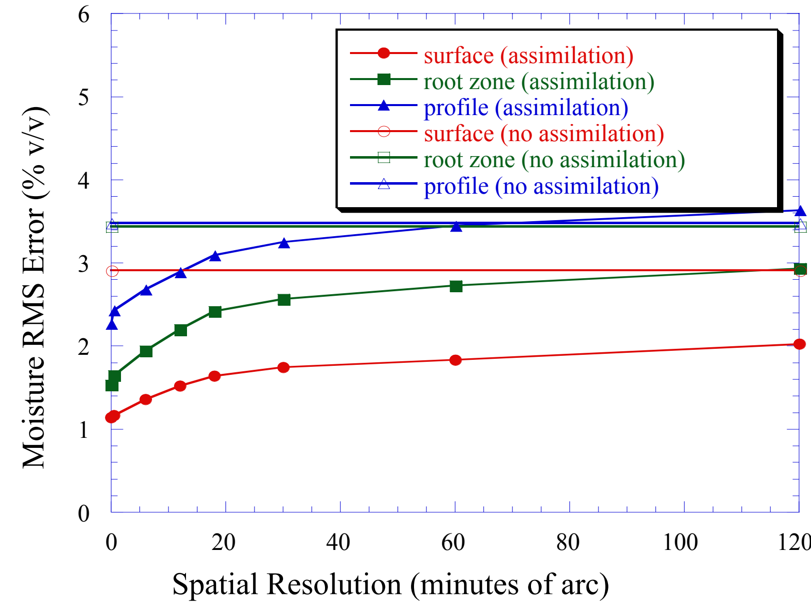
Soil Moisture Observation Error and Resolution Sensitivity:



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



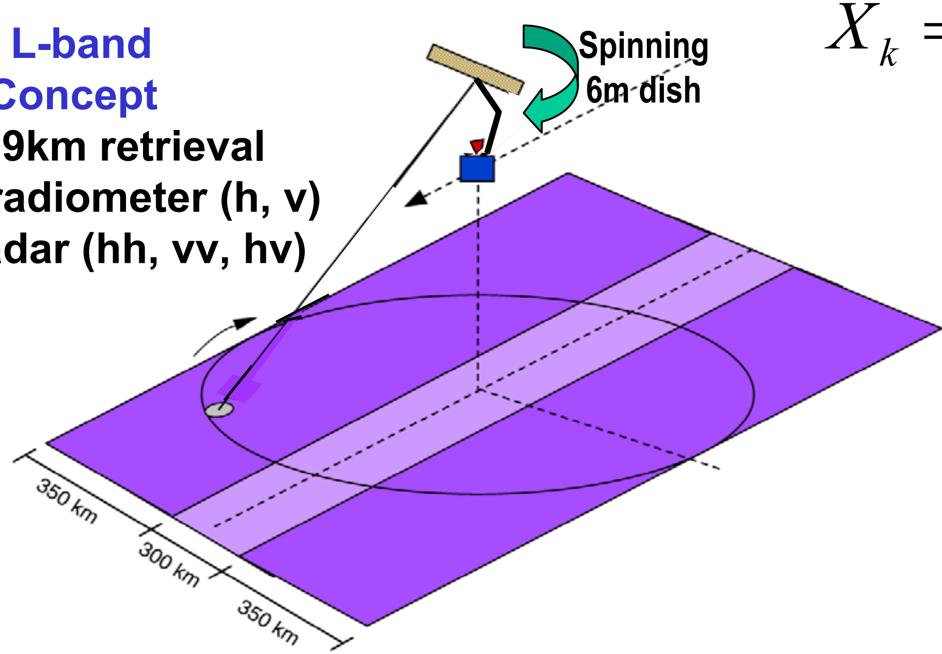




An *OSSE* for the *HYDROS* *soil moisture* mission concept

HYDROS L-band Mission Concept

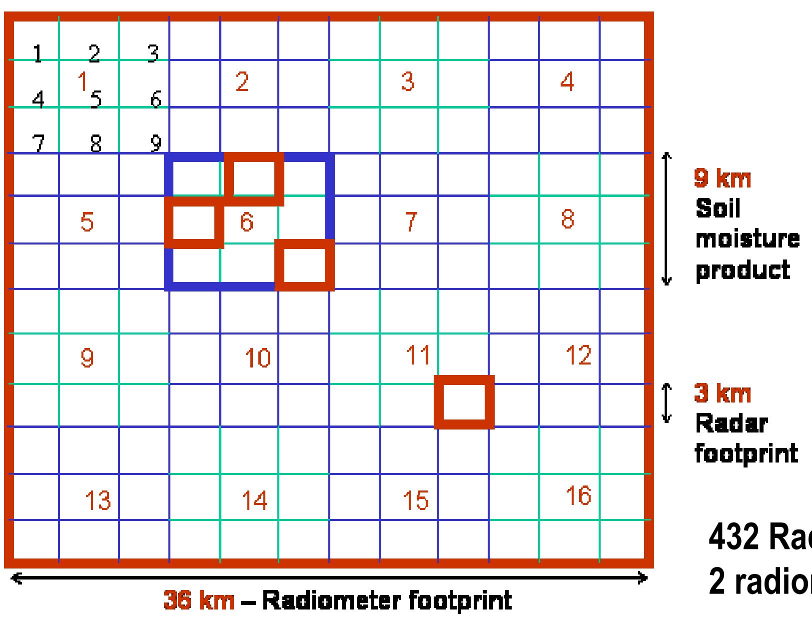
GOAL: 9km retrieval
~36km radiometer (h, v)
~3km radar (hh, vv, hv)



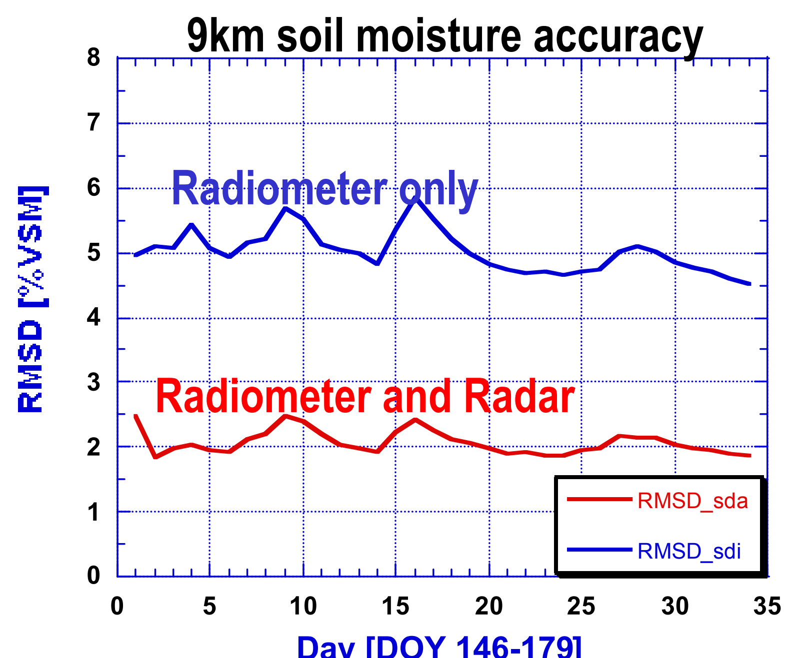
$$X_k = X_{b,k} + K_k[Z_k - h(X_{b,k},0)]$$

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

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

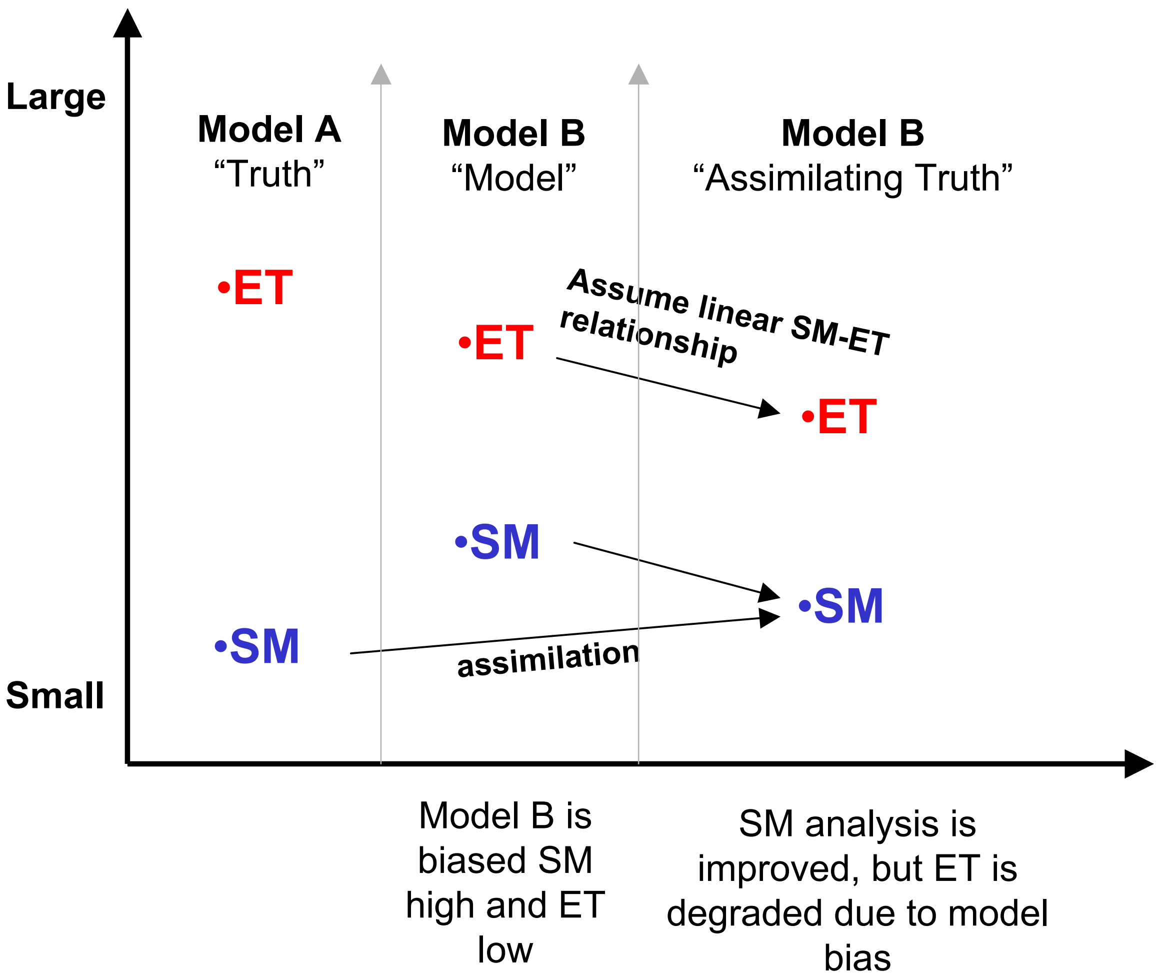


432 Radar Observations
2 radiometer observations



Fraternal Twin Studies

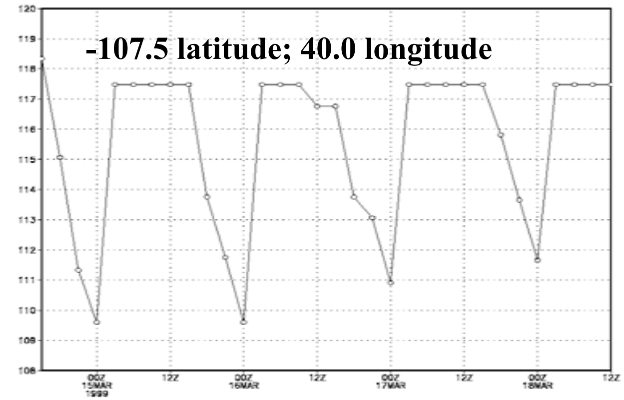
- "Truth" from one model is assimilated into a second model with a biased parameterization
- The "truth" twin can be treated as a perfect observation to help illustrate conceptual problems beyond the assimilation procedure.



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

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.
- Snow/bare soil interfaces cause wind circulations.
- Direct replacement does not account for model bias.



Unique Snow Data Assimilation Considerations:

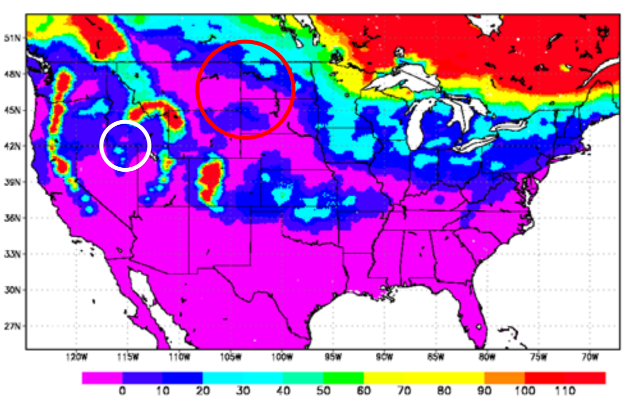
- “Disappearing” layers and states
- Arbitrary redistribution of mass between layers
- Lack of information in SWE about snow density or depth
- Lack of information in snow cover about snow mass & depth
- Biased forcing causing divergence between analysis steps
- **OBSERVATIONS:** Snow Cover, Snow Water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

Update Time

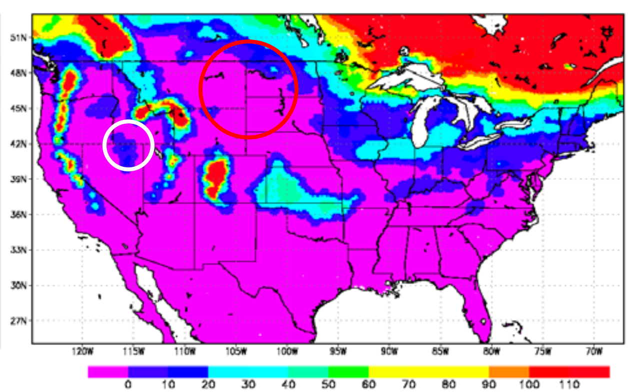
Melt

Update Time

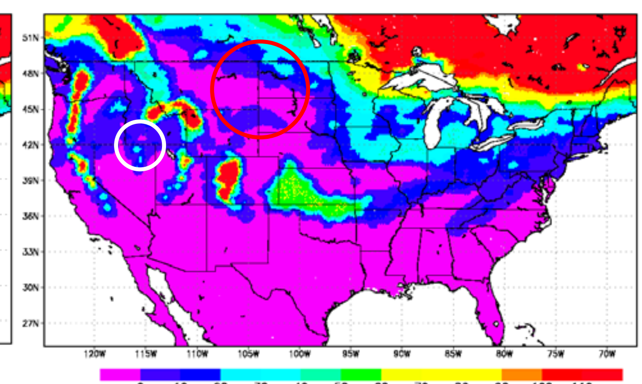
3Z 3/15/99



0Z 3/16/99



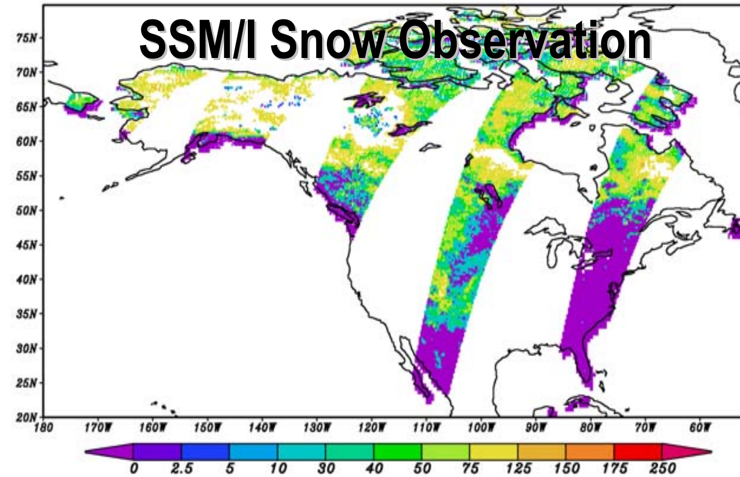
3Z 3/16/99



Snow Data Assimilation

Develop a Kalman filter snow assimilation to overcome current limitations with assimilation of snow water equivalent, snow depth, and snow cover.

- Investigate novel snow observation products such as snow melt signature and fractional snow cover.
- Provide a basis for global implementation.



Unique Snow Data Assimilation Considerations:

- "Disappearing" layers and states
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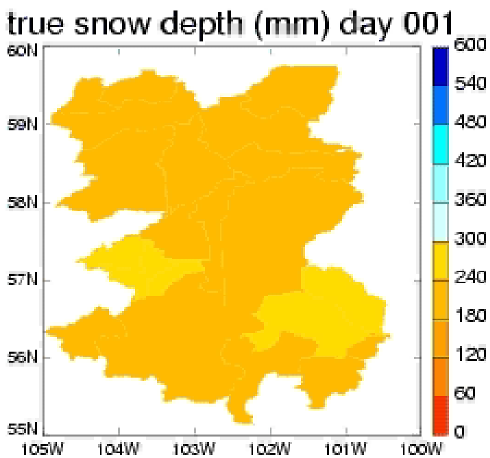
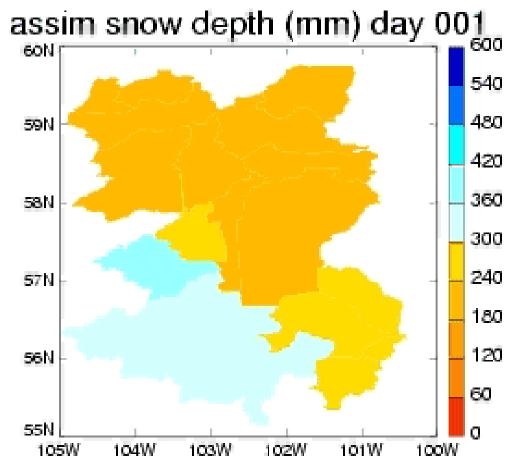
- Lack of information in SWE about snow density or depth
- Lack of information in snow cover about snow mass & depth
- Biased forcing causing divergence between analysis steps

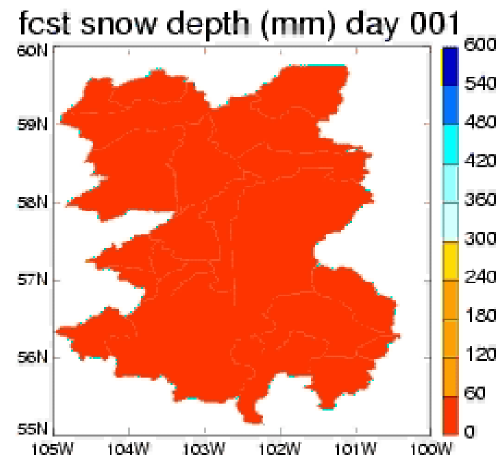
Truth run



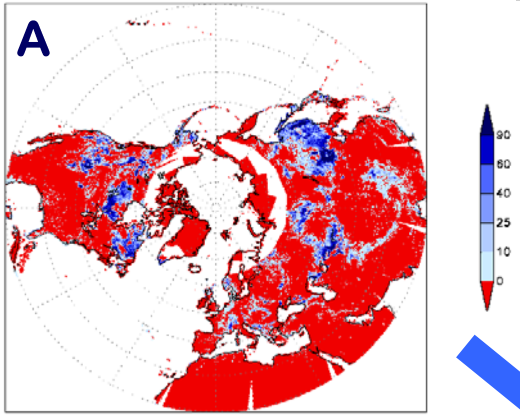
Assimilation run

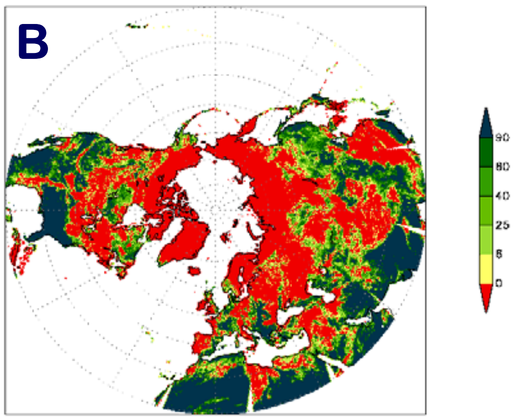


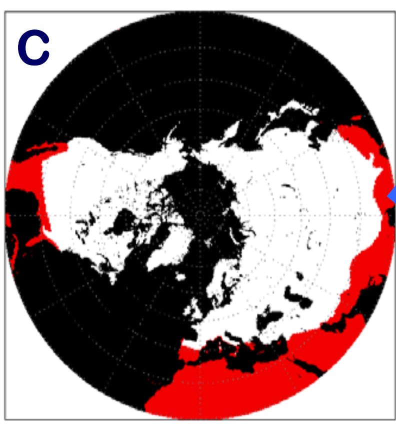
Control run



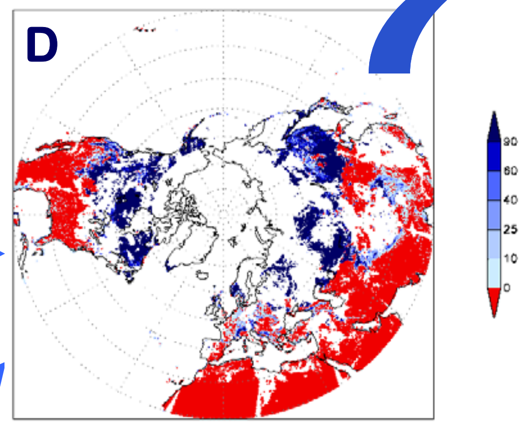
GLDAS Observation-based Snow Correction



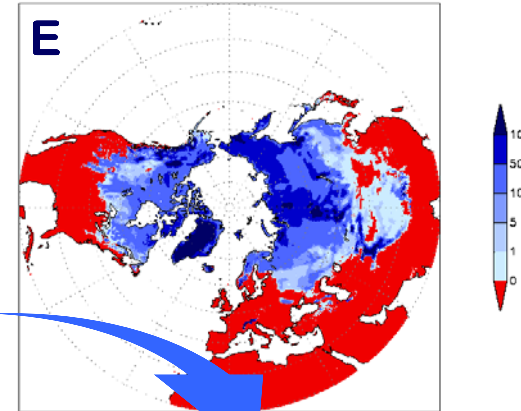


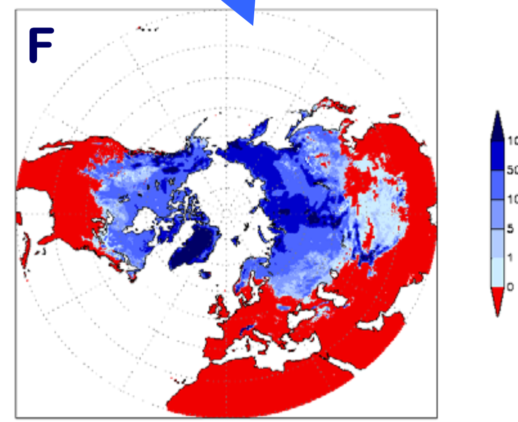


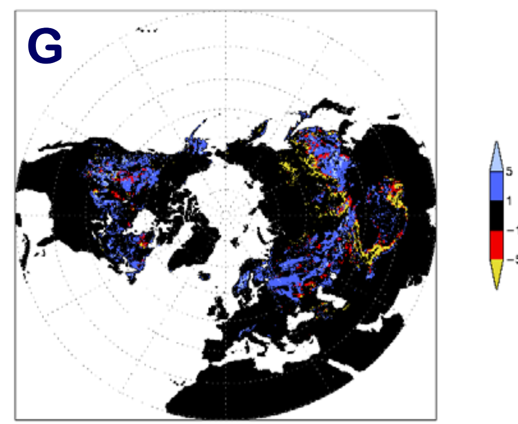
Original MODIS visible snow cover (%) *A* is modified using MODIS confidence index (total visibility; %) *B* and a snow impossible mask *C* in order to produce an enhanced snow field *D*.



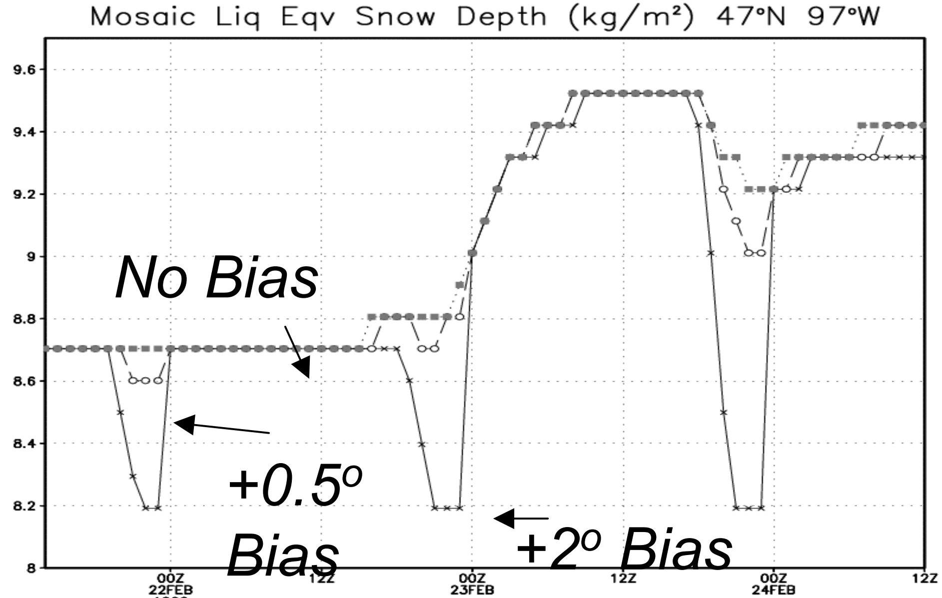
This is used to update the modeled snow on a daily basis. Output snow depth (mm H2O) is shown for 30 November 2000, after running the Mosaic LSM without *E* and with *F* the snow correction for 30 days. Map *G* shows the difference (mm H2O) between the two results.

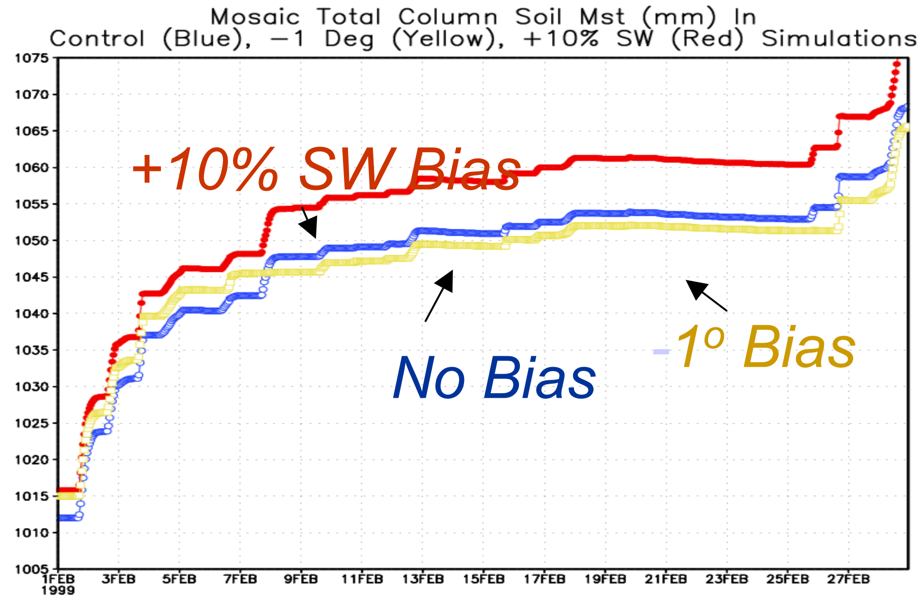


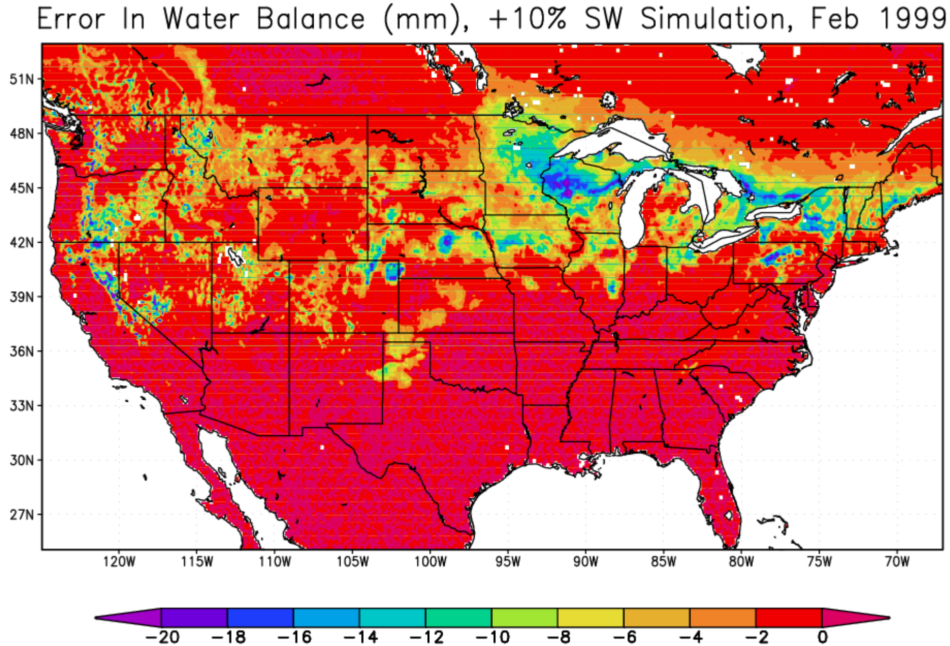


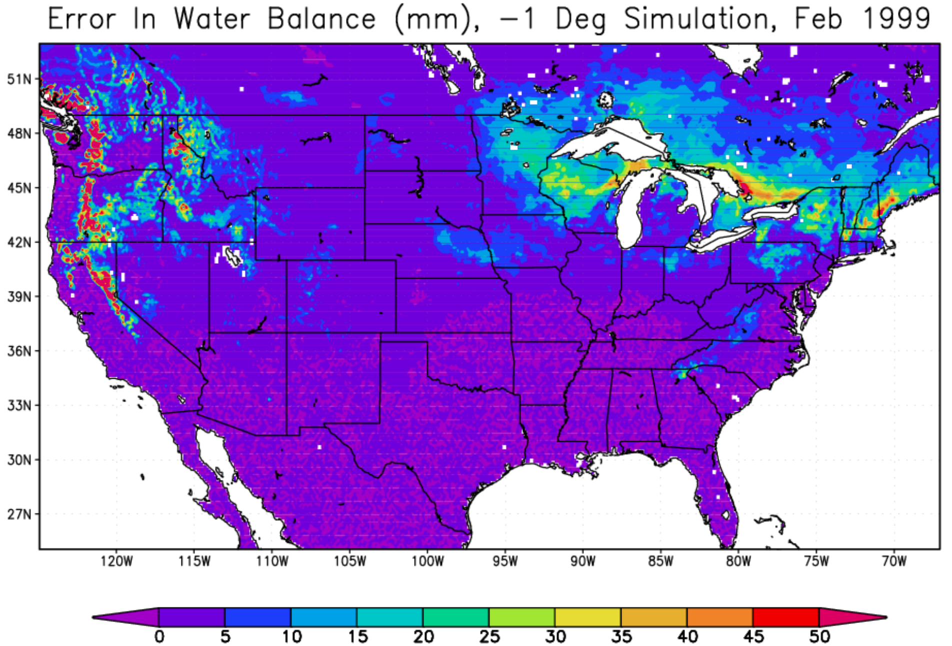


Snow Data Assimilation: Impact of temperature bias



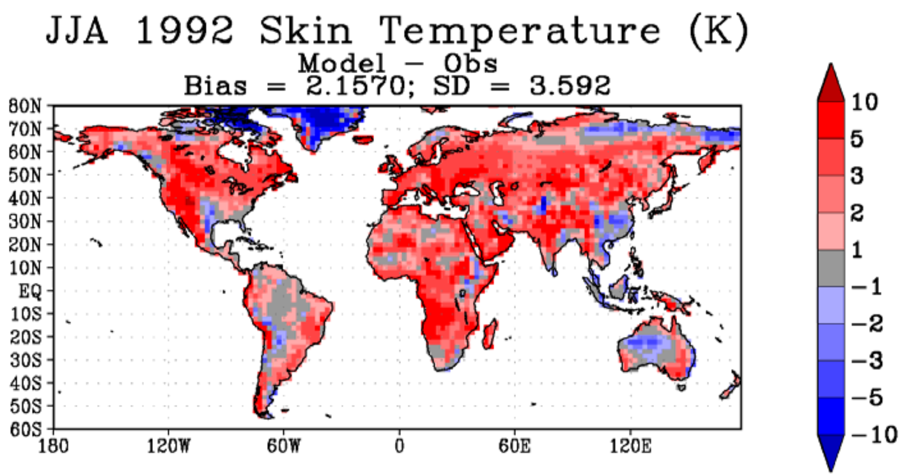


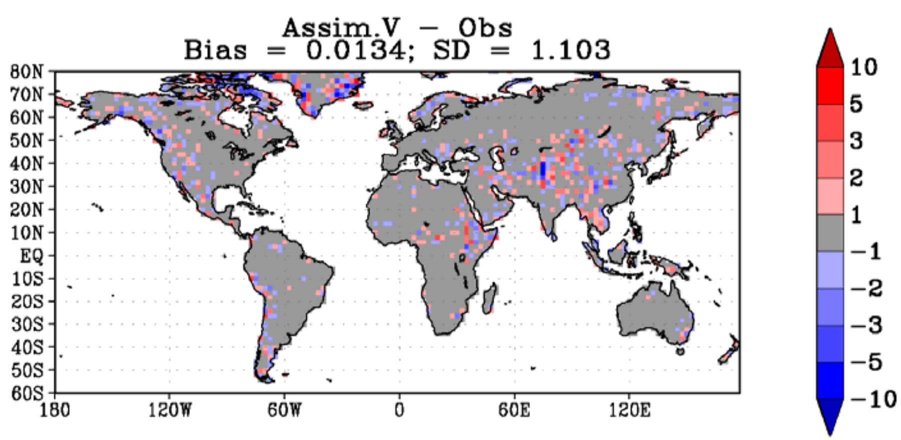


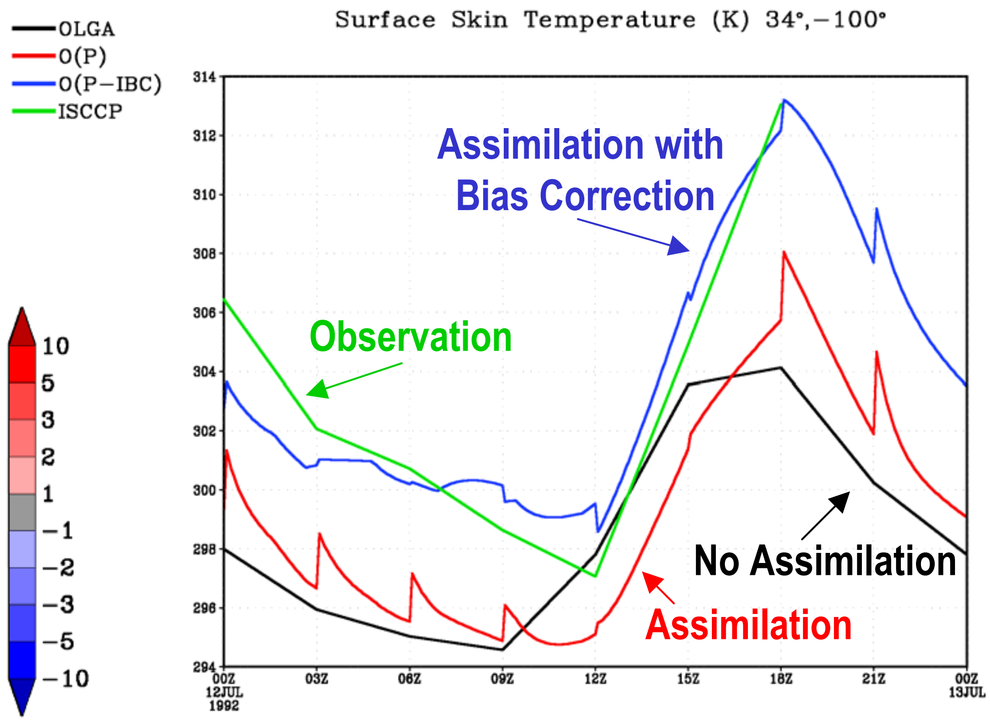


Data Assimilation: T_s Assimilation Results

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

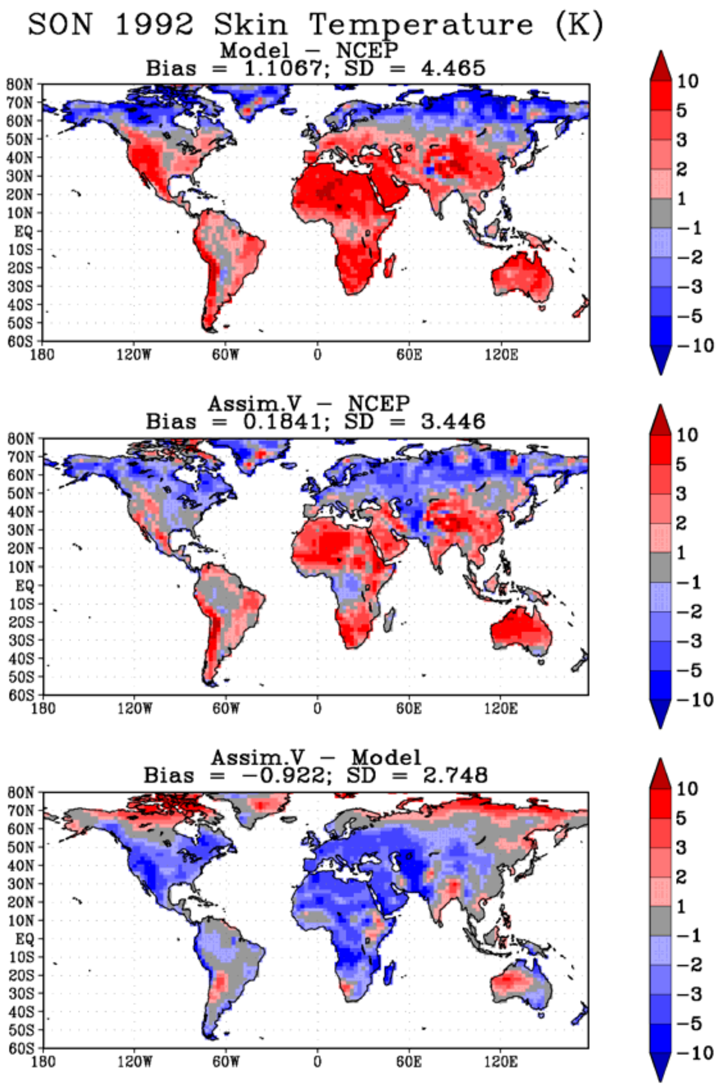






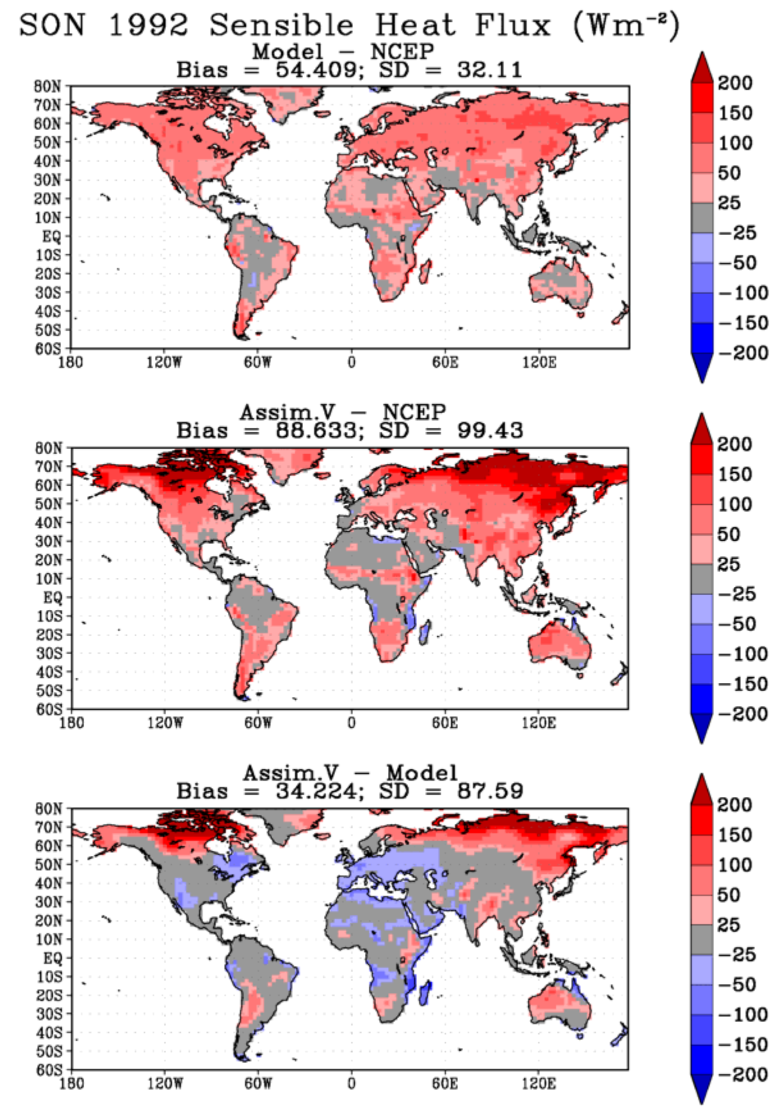
Surface temperature has **very little memory** or inertia, so without a continuous correction, it tends drift toward the control case very quickly.

Data Assimilation: T_s Assimilation Results



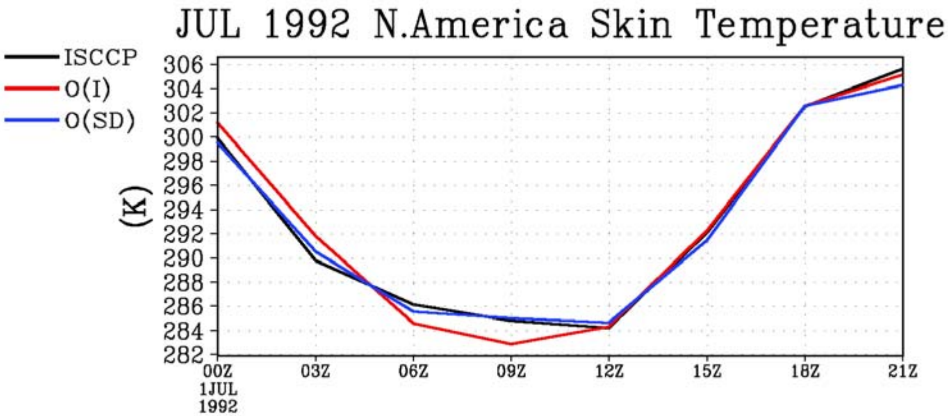
Comparison with NCEP Reanalysis

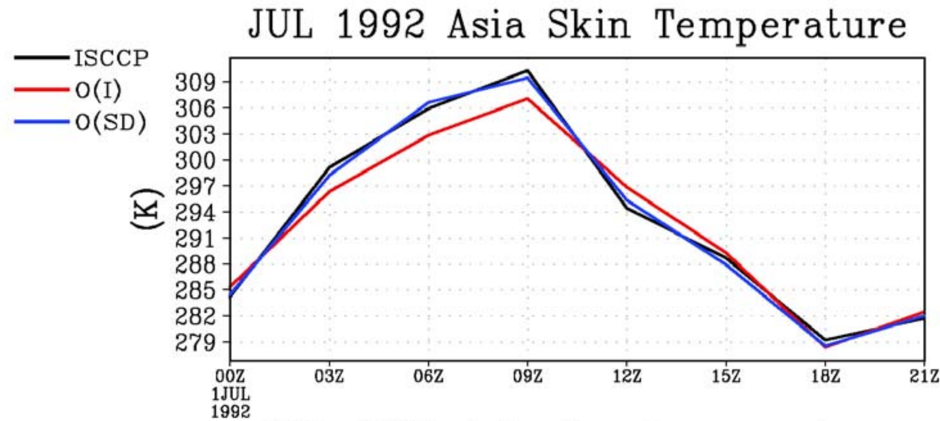
- Skin temperature improves significantly
- Sensible heat flux degrades due to modified near-atmosphere temperature gradient

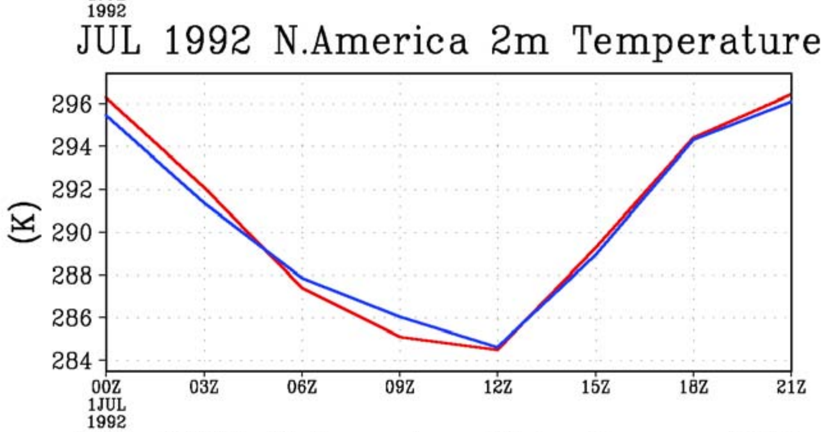


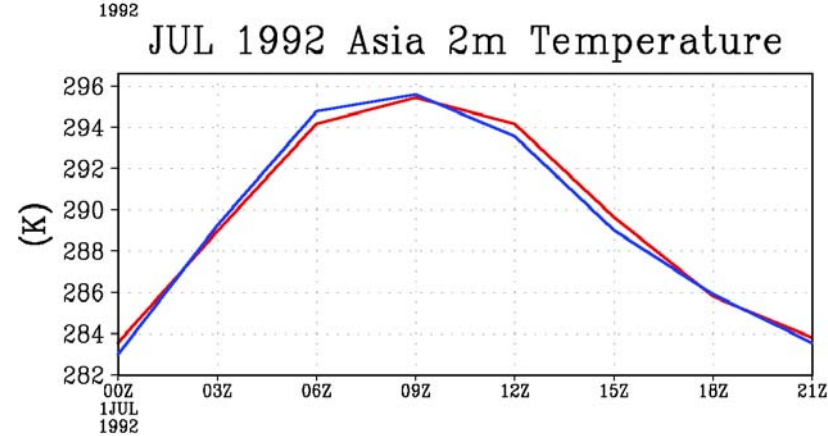
NOTE: NCEP not equal to TRUTH

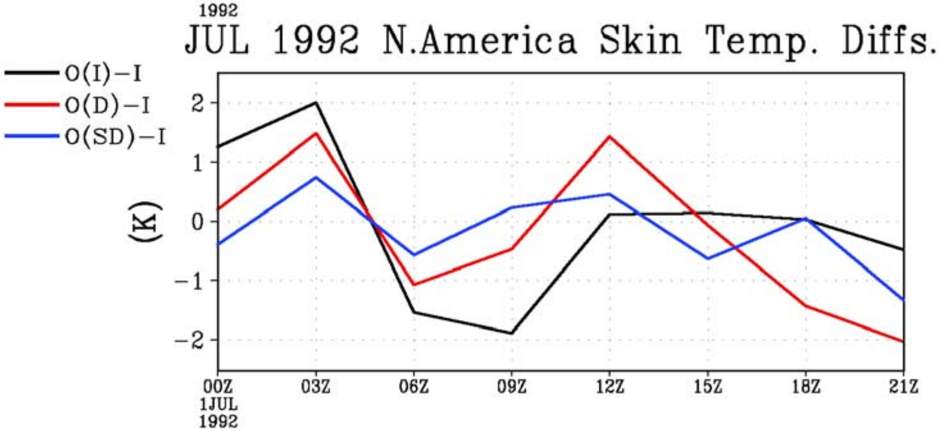
Data Assimilation: T_s Assimilation Results

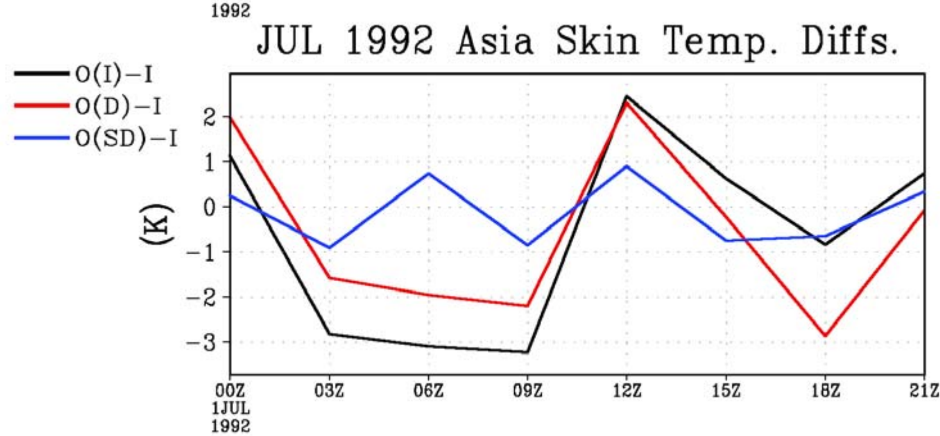










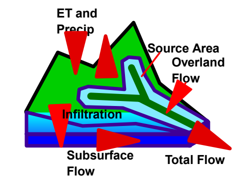


North American LDAS: Specifics 1

Goal: provide accurate, near-real-time and retrospective land surface states over North America

Resolution: 1/8 degree; continental U.S; <1 hour time step; near *real time* & *retrospective*.

Models: ***Mosaic***, ***VIC***, ***NOAH***, Sacramento, CLM, Catchment, TOPLATS, Bucket.



Assimilation: Surface temperature, snow, soil moisture.

Forcing: Eta model and observed Stage-4/gage precipitation, GOES insolation **(NCEP)**.

Timing: real-time, short-term retrospective, long-term retrospective.

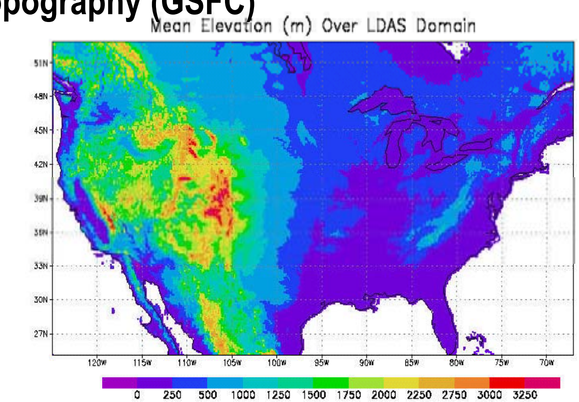
- Real-Time **(NCEP)**: LDAS results and forecasts available within 24 hours of real-time
- Short-Term Retrospective **(GSFC)**: Identical to real-time for modern forcing (1996-present)
- Long-Term Retrospective **(UW-P)**: 50+ years using reduced resolution and best available forcing.

Parameters:

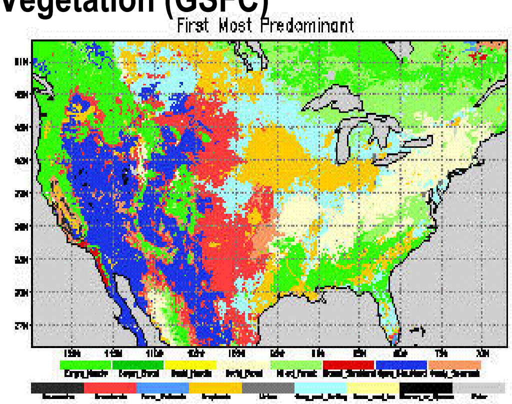
- Vegetation: UMD classification, parameter mapping **(GSFC)**.
- Soil: Soil Maps and Parameters **(OH)**.
- Topography: Digital Elevation Models **(GSFC)**.

Position	Column	Row	Longitude	Latitude
Lower Left	1	1	-124.9375	25.0625
Lower Right	464	1	-67.0625	25.0625
Upper Right	464	224	-67.0625	52.9375
Upper Left	1	224	-124.9375	52.9375

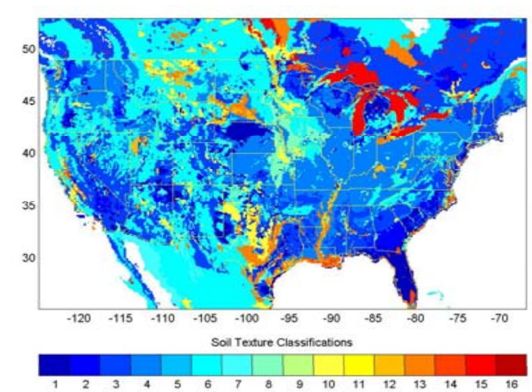
Topography (GSFC)



Vegetation (GSFC)



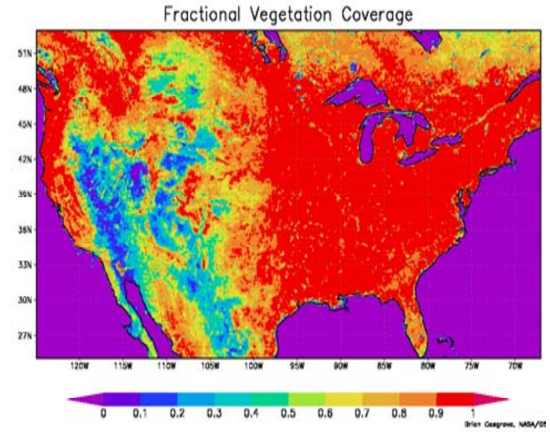
Soils (NWS-OH)



North American LDAS: Specifics 2

Vegetation: DeFries et al., University of Maryland

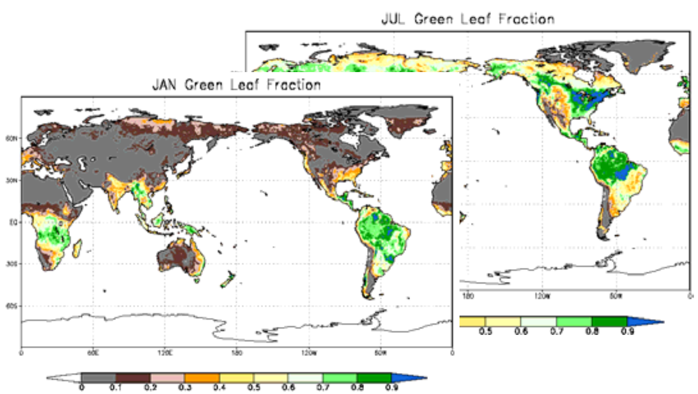
- Can be modified by 1km Max Fractional Vegetation, Zeng & Dickinson
- Seasonal cycle specified by NESDIS green vegetation product



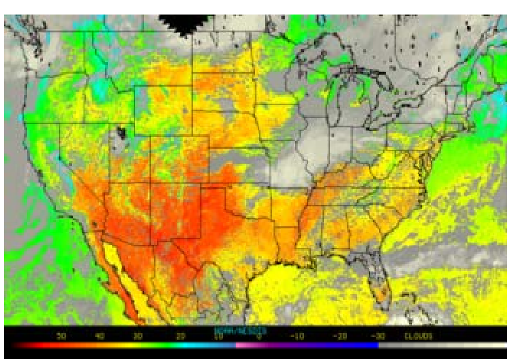
Data Availability: Real-time and short-term retrospective

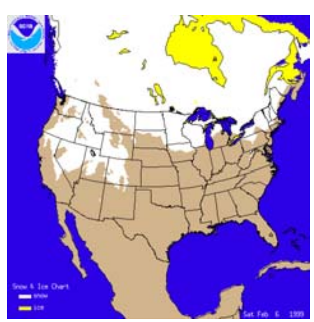
- "Modern" forcing available from 1996 - uses the same modern forcing and resolution as is used in the real-time LDAS

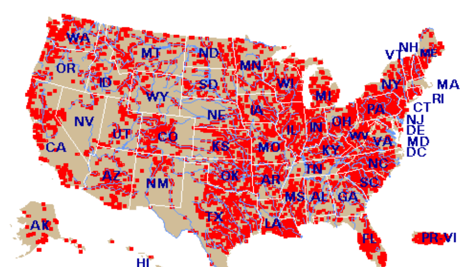
LDAS Forcing Product	Time Res.	Space Res.	Archive	Real-Time
Eta EDAS Analysis	3hr	40km	June 1996	5hr
Eta 3hr Forecast	3hr	40km	June 1999	5hr
Eta 6hr Forecast	6hr	40km	June 1996	5hr
NESDIS GOES SW dwn	1hr	1/2 degree	June 1999	2hr
Pinker GOES SW dwn	1hr	1/2 degree	Jan 1996	2hr
Stage-4 Gage-Radar Ppt	1hr	4, 15km	May 1996	10hr
RFC Gage-Only Precip	24hr	4km	Jan 1998	18hr
CPC Gage Only Precip	24hr	1/4 degree	July 1997	12,24hr

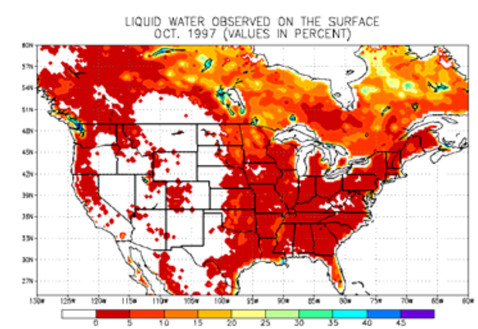


Other Data: GOES-Temps, Snow, Streamflow, SSMI Products


Skin temperature derived from NOAA/NESDIS GOES.



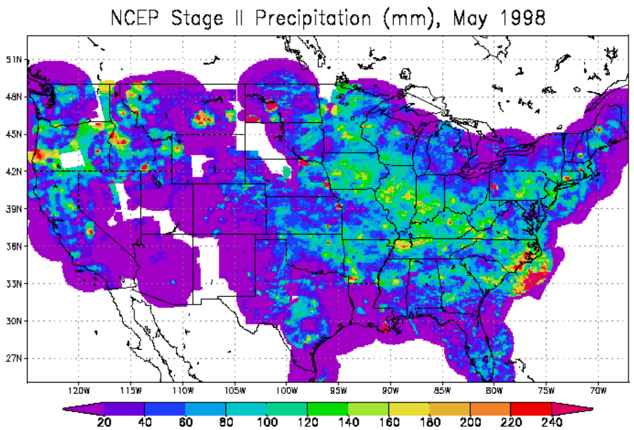




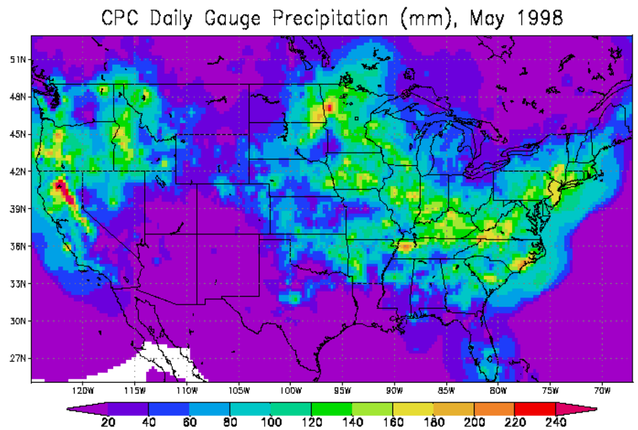
North American LDAS: Precipitation

Data	Advantages	Disadvantages
NCEP Stage II Doppler radar / RFC gauge	Hourly, 4km	Errors in radar magnitude Holes in coverage
CPC daily rain gauge data	Accurate	Coarse temporal resolution Sparse coverage over Canada, Mexico 0.25 Degree Resolution
CPC Reprocessed daily rain gauge data	Most accurate (additional stations and qc checks)	Coarse temporal resolution Light coverage over Canada, Mexico 0.25 Degree Resolution Only through 1998

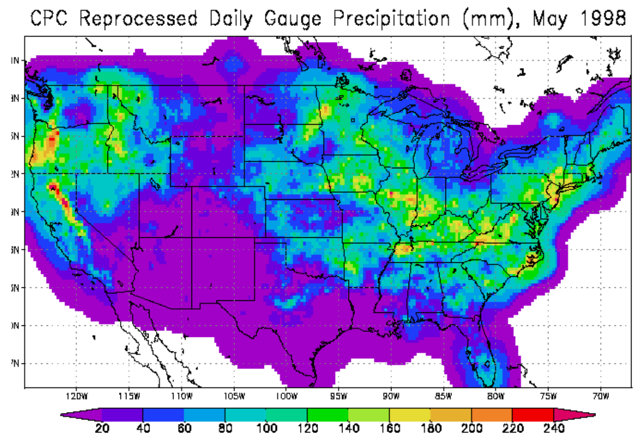
Doppler Radar Precipitation



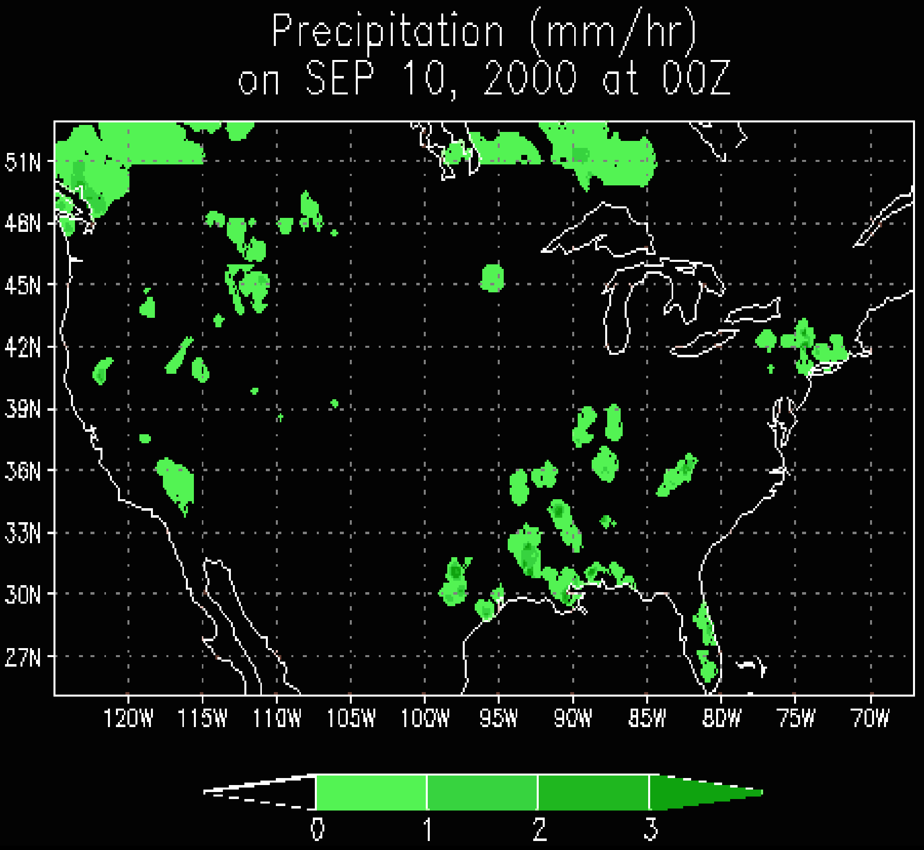
Interpolated Gage Precipitation

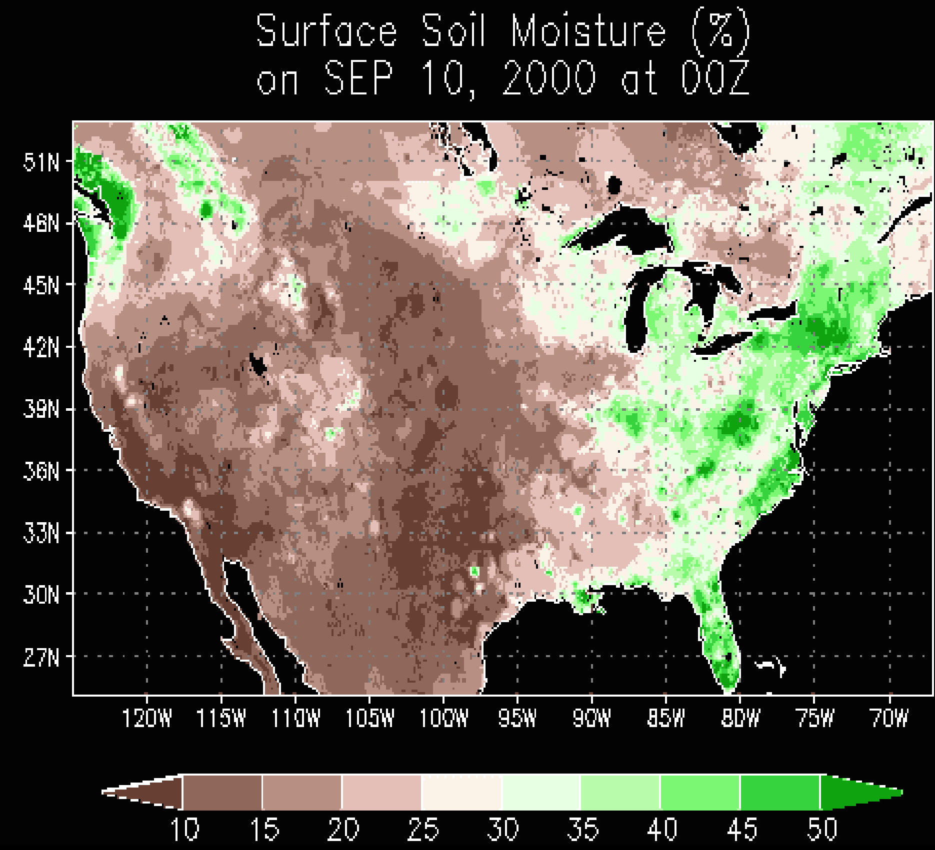


Merged LDAS Precipitation



- Use ETA model, Stage II and CPC data to form best available product—a temporally disaggregated hourly CPC gage value





LDAS Predictions: Hourly Sept. 2000 Precipitation and Soil Moisture

European Land Data Assimilation System (ELDAS)

Development of a European Land Data Assimilation System to predict floods and droughts

B.J.J.M. van den Hurk, A.J. Feijt, Han The

Develop and test a system to generate high quality regional scale soil moisture, and assess the improvements it can cause in predicting drought or flood events in coupled model predictions.

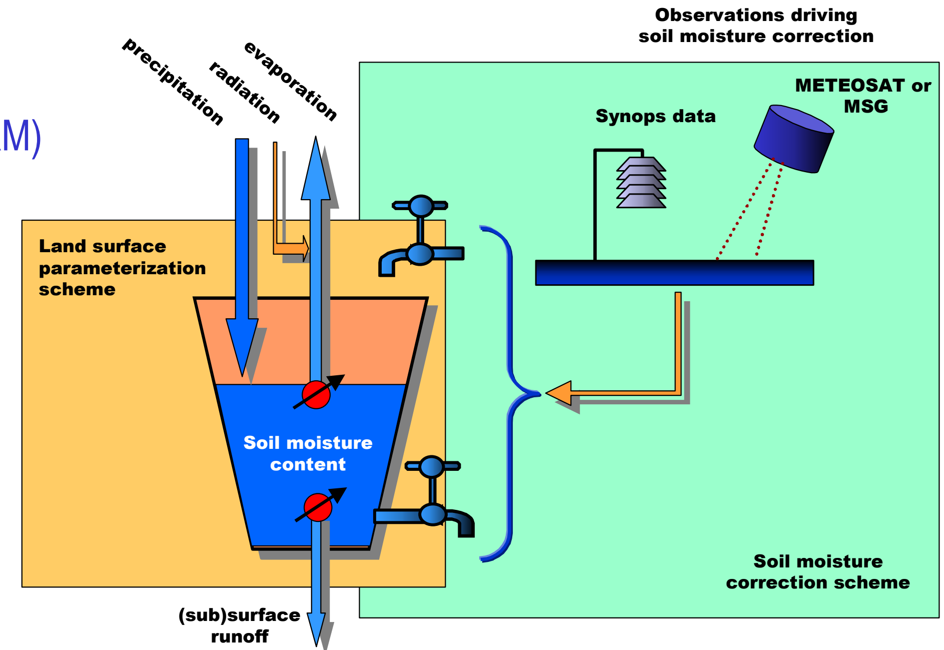
- The design of a flexible soil moisture estimation system and the production of soil moisture fields
- The evaluation of the impact of using these soil moisture fields in Numerical Weather Prediction (NWP), in flood- and drought predictions, and climate applications.

Participants

- 6 met centres (KNMI,ECMWF,DWD,INM,SMHI,CNRM)
- 2 hydro institutes (SMHI,CEH)
- 3 university research groups (Alterra,MIUB,VUW)

External Advisory Board

Paul Houser, Jan Polcher, Joost Nieveen,
Michael Berger, Carlos Da Camara,
Sten Bergström, Jim Haywood

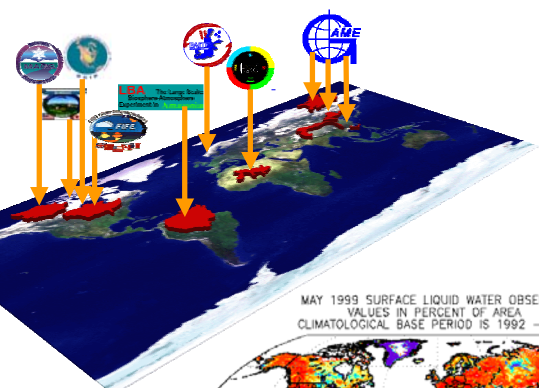


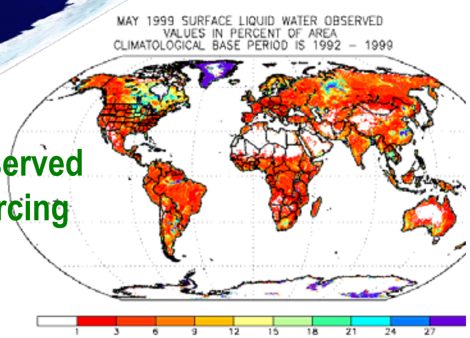
Paul R. Houser, NASA/GSFC Hydrological Sciences
Paul.Houser@gsfc.nasa.gov

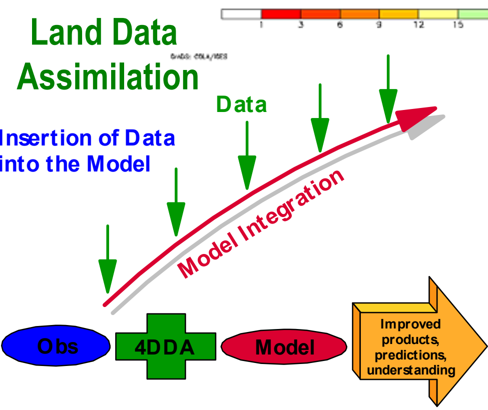
Global Land Data Assimilation System

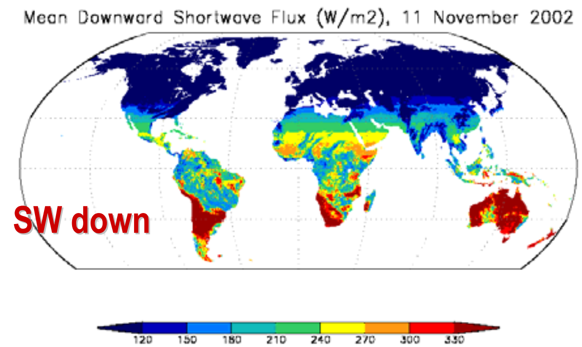
Objective: A 1/4 degree (and other) global land modeling and assimilation system that uses all relevant observed forcing, storages, and validation. Expand the current N. American LDAS to the globe. 1km global resolution goal

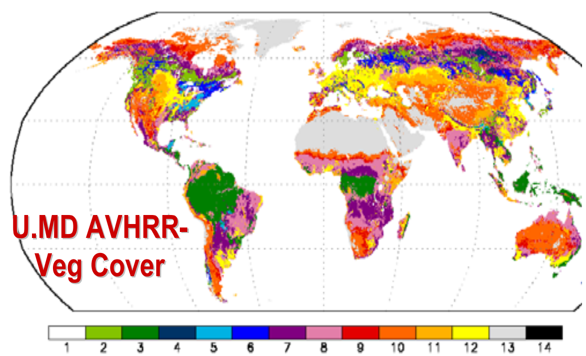
Consistent Global Intercomparison

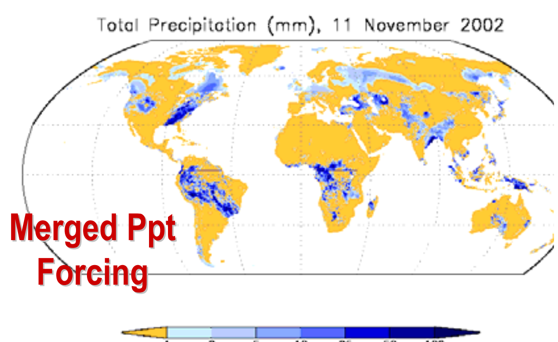


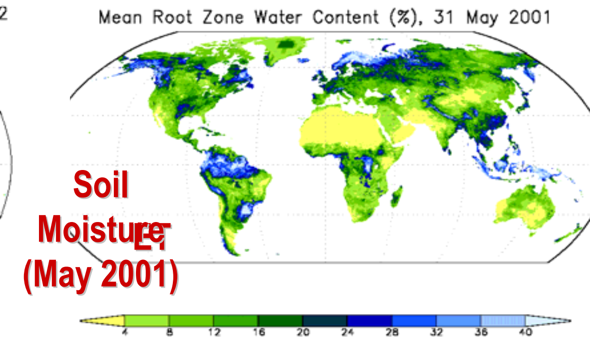


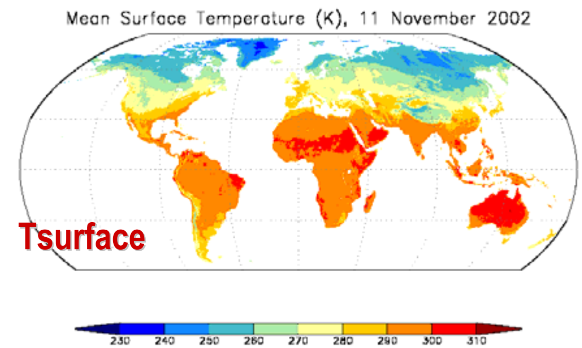


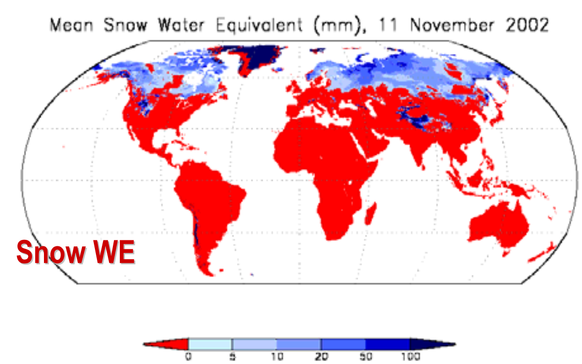










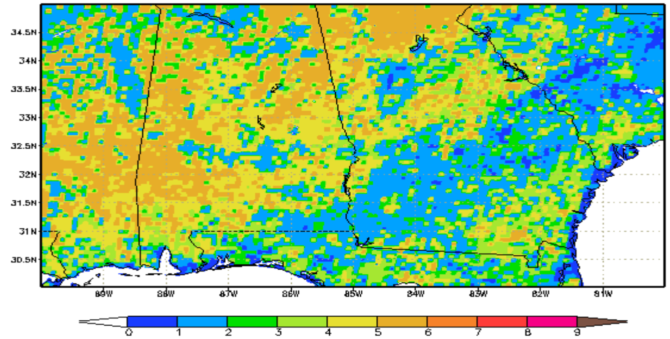


Summary of Data Sources for GLDAS

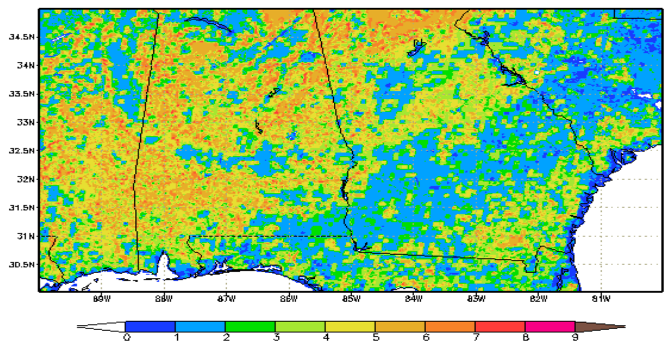
Type of Data	Source	Original Spatial Resolution	Time Period
Modeled Forcing	NASA Goddard Earth Observing System (GEOS)	1.0°	12/2000 – present
	NOAA Global Data Assimilation System (GDAS)	~ 0.7°	1/1999 – present
	ECMWF forecasts and analyses	~ 39 km	10/2001 – present
	Berg et al. (2002) bias corrected ECMWF reanalysis	0.5°	1/1979 – 12/1993
	Berg et al. (2002) bias corrected NCEP/NCAR reanalysis	0.5°	1/1985 – 12/1993
Observation-Based SW and LW Radiation Forcing	Derived at NASA/GSFC using U.S. Air Force Weather Agency cloud and snow analyses	0.25°	3/2001 – present
Observation-Based Precipitation Forcing	U.S. Naval Research Laboratory	0.25°	4/2001 – present
	NASA/GSFC Mesoscale Atmospheric Processes Branch	0.25°	3/2002 – present
	NOAA Climate Prediction Center	2.5°	1/1979 - present
Observation-Based Snow Cover	Derived at NASA/GSFC using Terra-MODIS satellite observations	0.125°	11/2000 - present
Observation-Based Leaf Area Index	Boston University Department of Geography	16 km	7/1982 – 5/2001
Observation-Based Surface Temperature	Television Infrared Observation Satellites (TIROS) Operational Vertical Sounder (TOVS)	~ 15 km	1/1998 – 12/1998
Vegetation Class	University of Maryland, AVHRR-derived	1 km	static
	Boston University, MODIS-derived	1 km	static
Soils	USDA Agricultural Research Service	5'	static
Elevation	GTOPO30 digital elevation model	30"	static

Seasonal Observed Vegetation; July

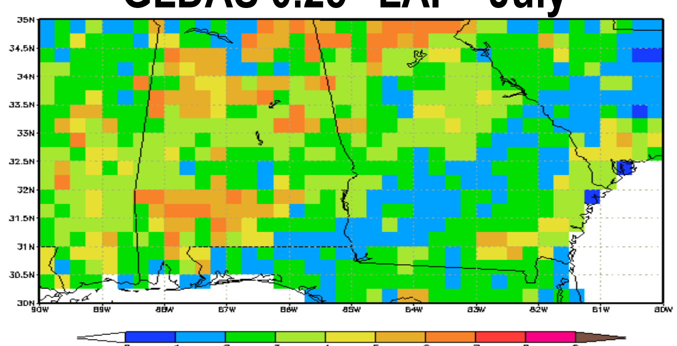
AVHRR 8 km LAI -- July



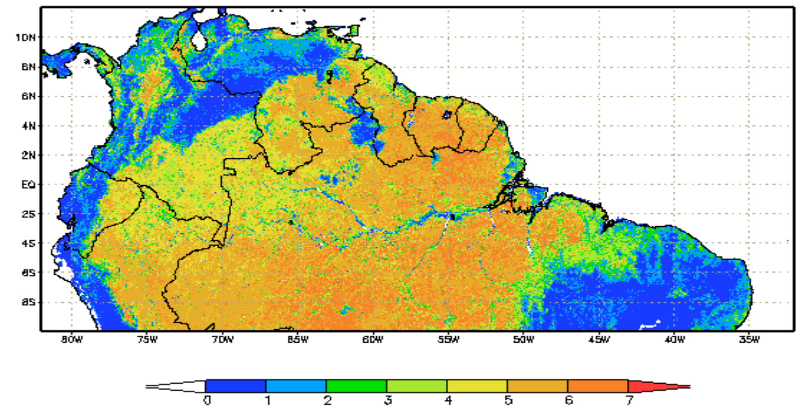
AVHRR Reconstructed 1 km LAI -- July



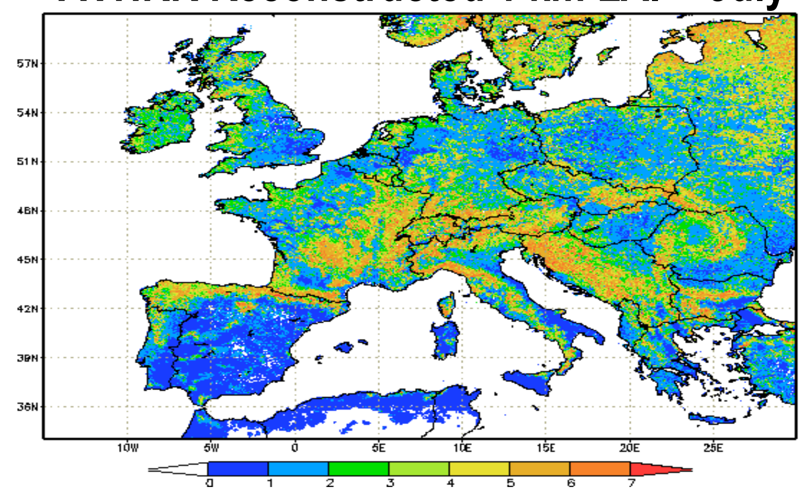
GLDAS 0.25° LAI -- July



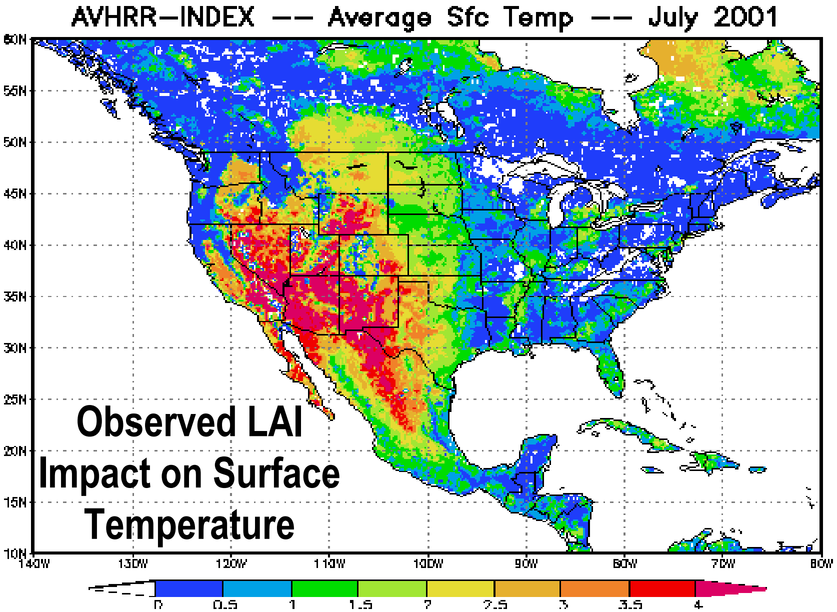
AVHRR Reconstructed 1 km LAI -- July

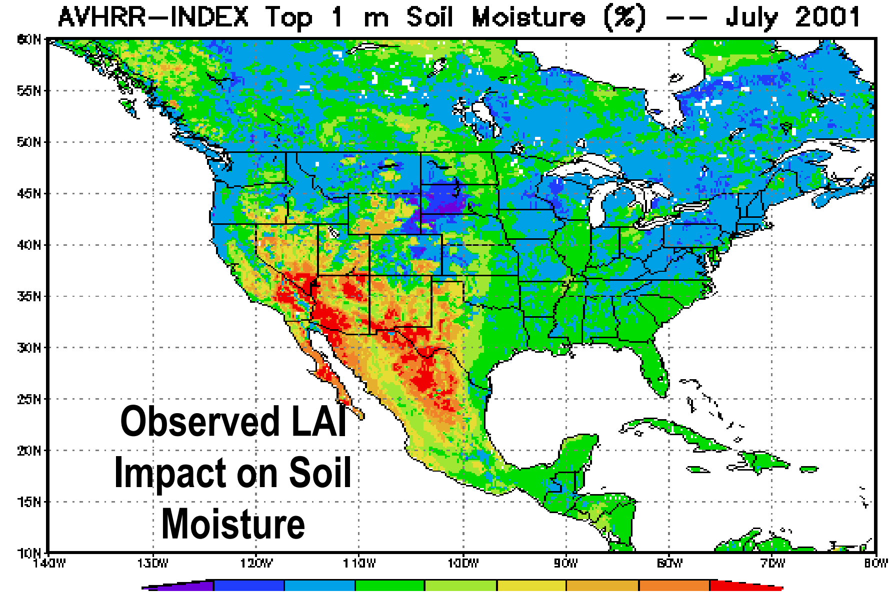


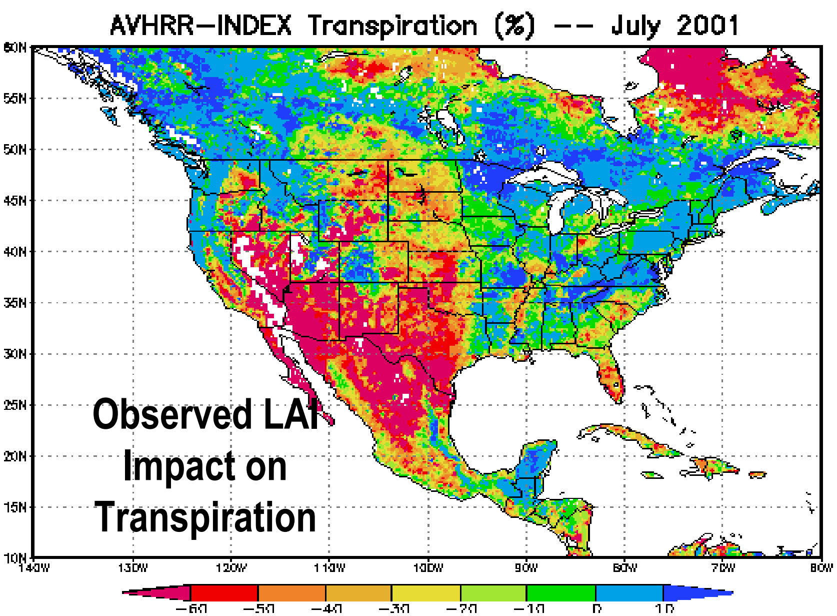
AVHRR Reconstructed 1 km LAI -- July

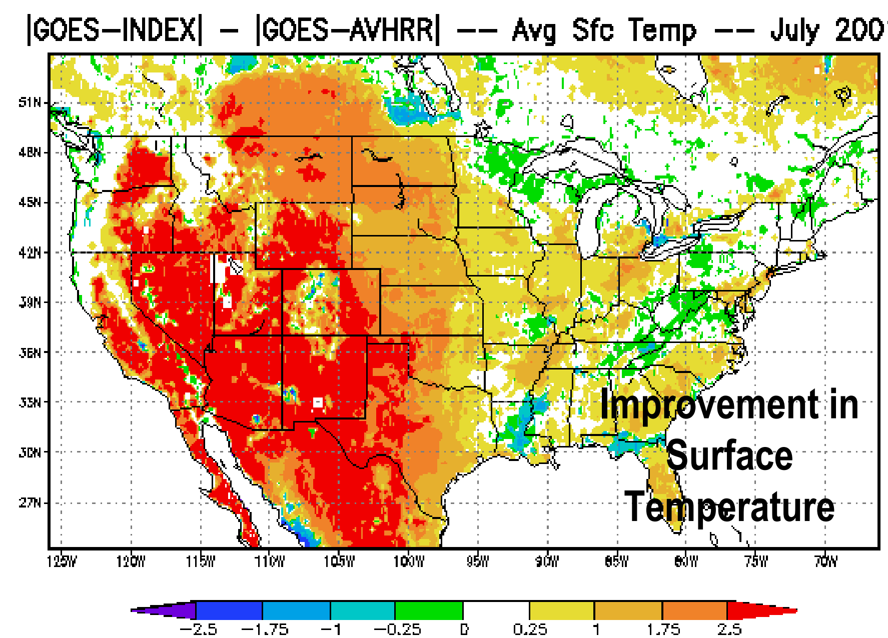


Impact of observed LAI on Predictions

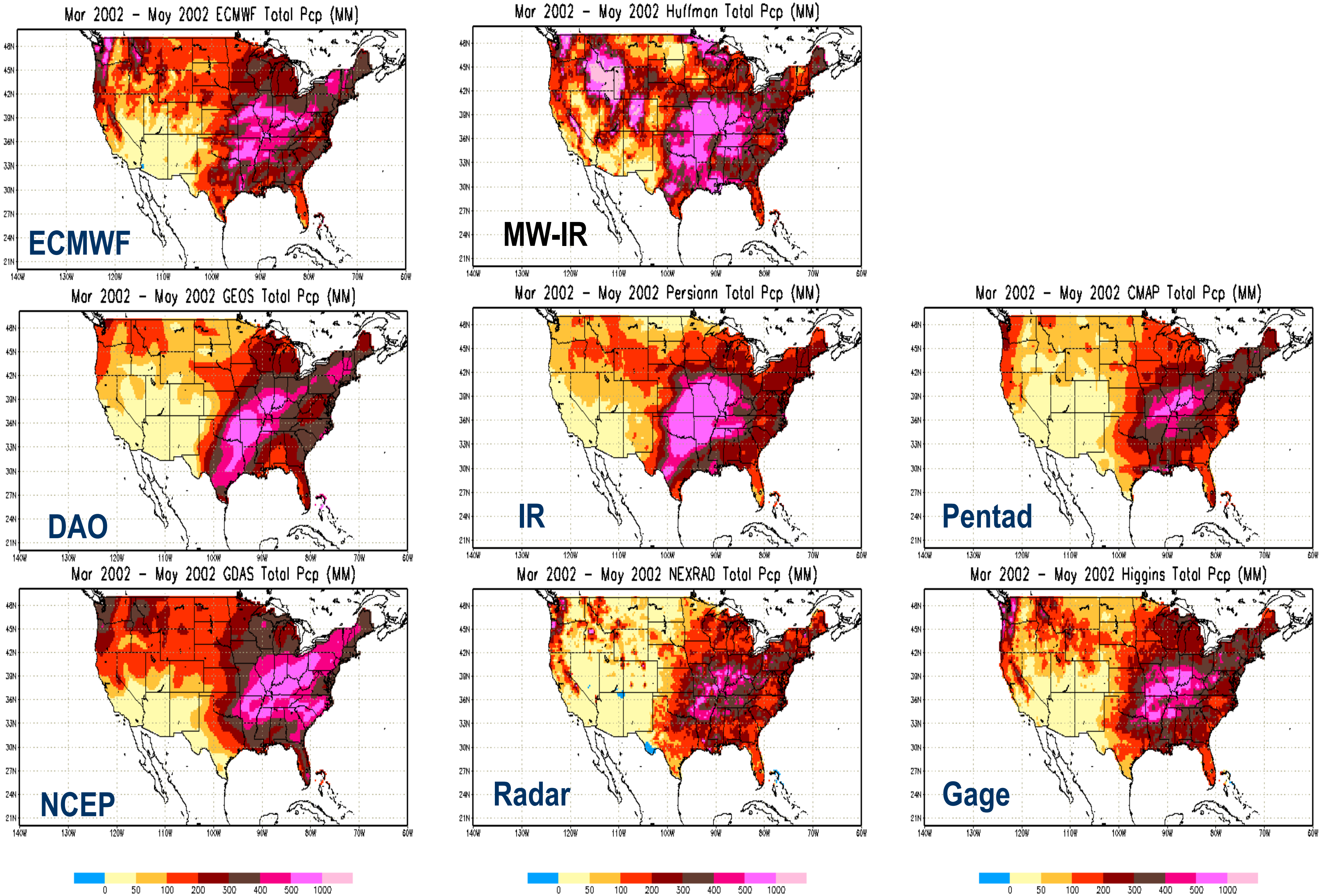




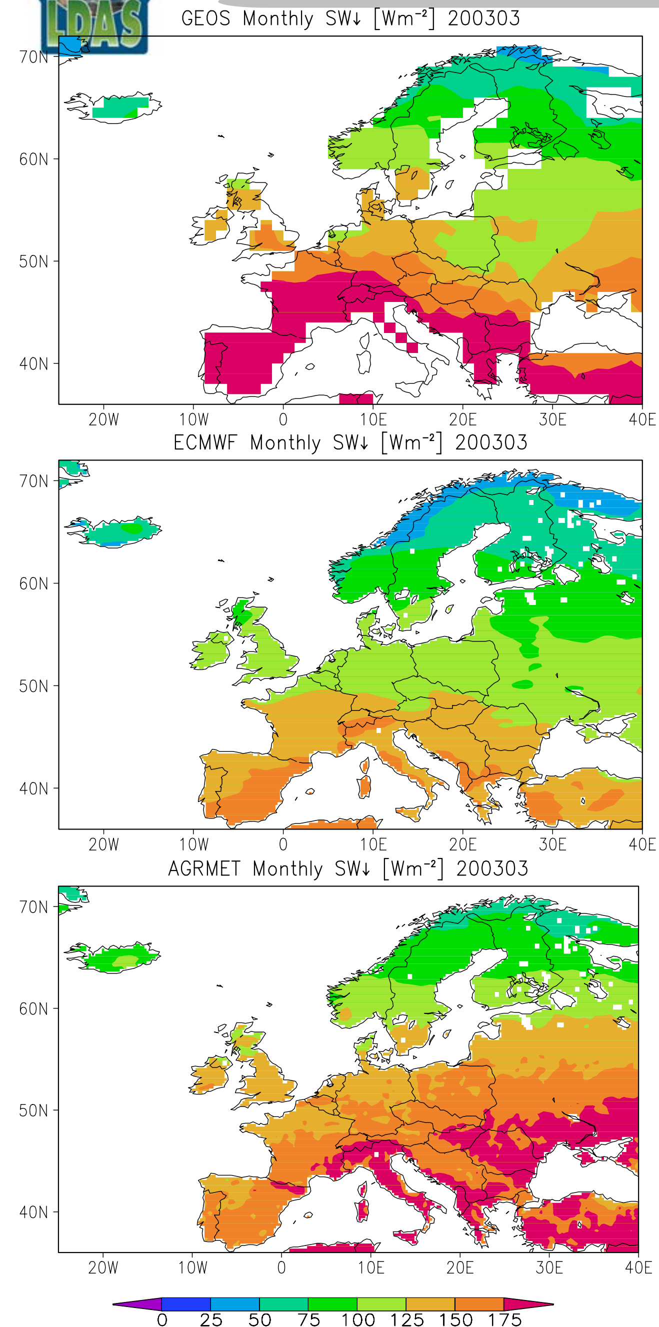




Total MAM Precipitation (mm) Evaluation



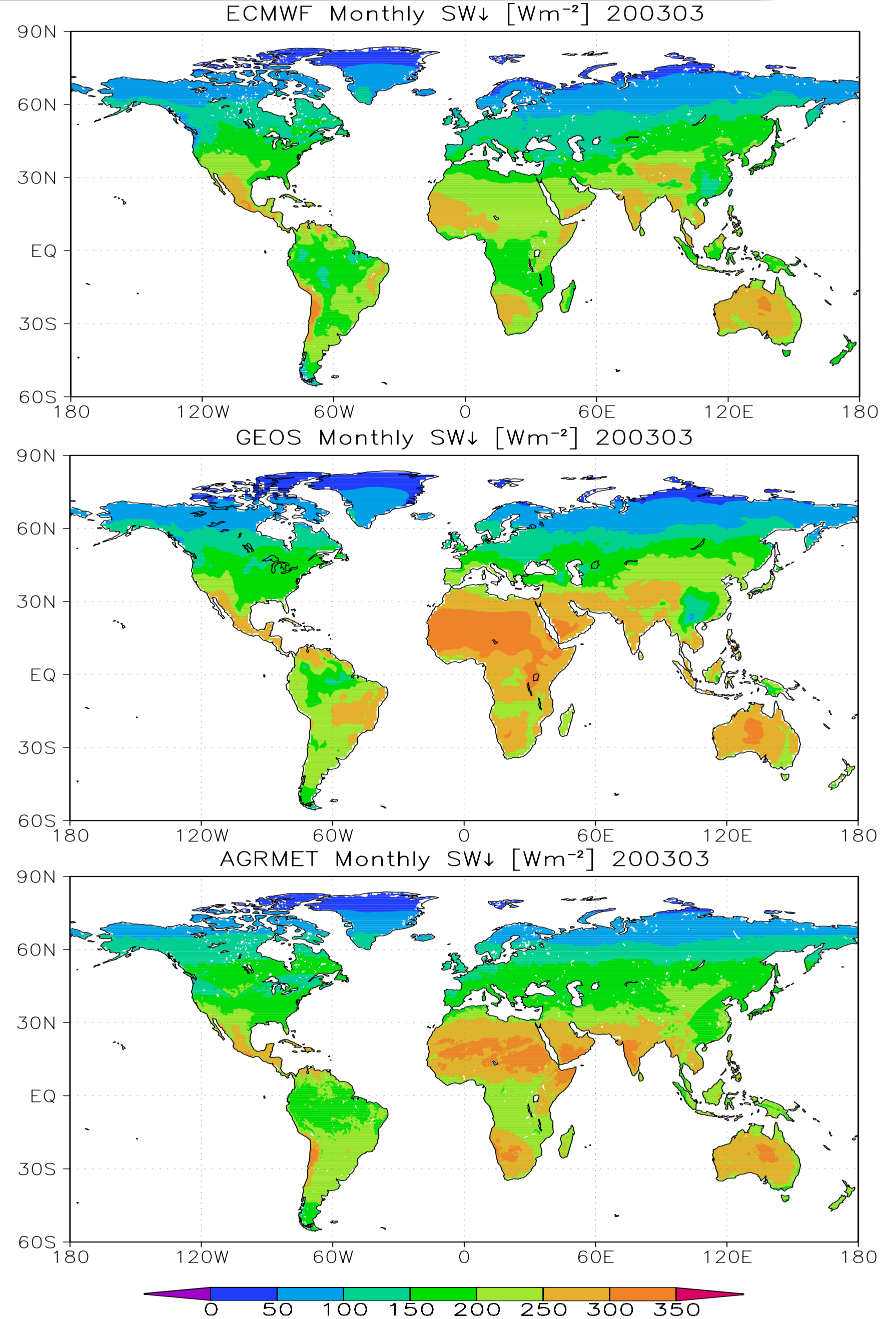
Monthly Mean Surface SW↓ March 2003



DAO

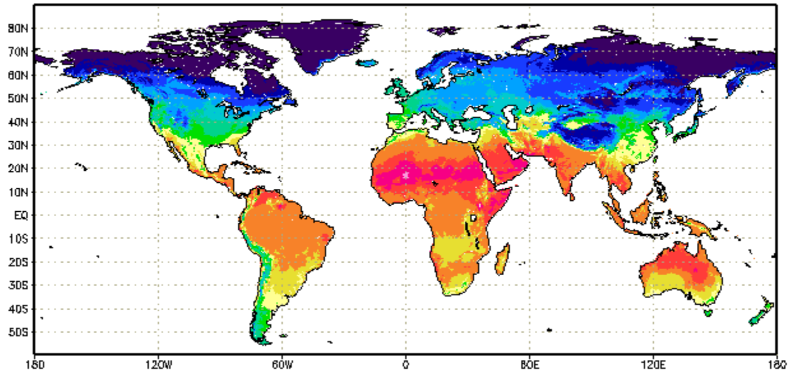
ECMWF

AGRMET (GEO Obs)



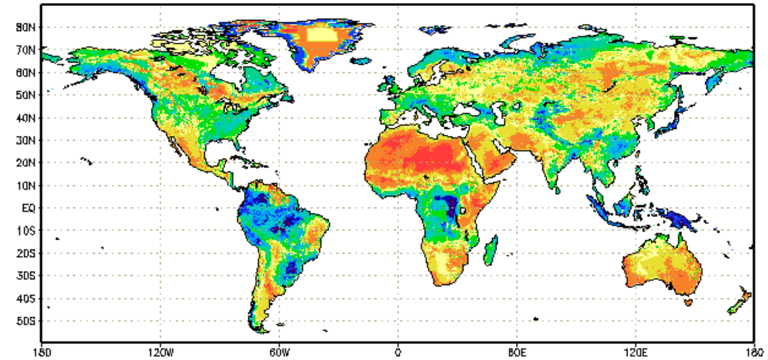
DAO vs ECMWF GLDAS Results

Mean Daily Sfc Temperature -- GEOS -- 9 April 2003

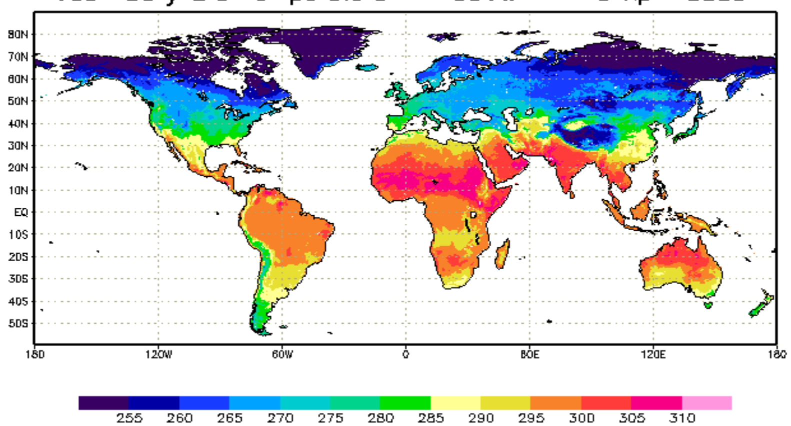


DAO

Mean Daily Top 1 m SWC (kg/m2) -- GEOS -- 9 April 2003

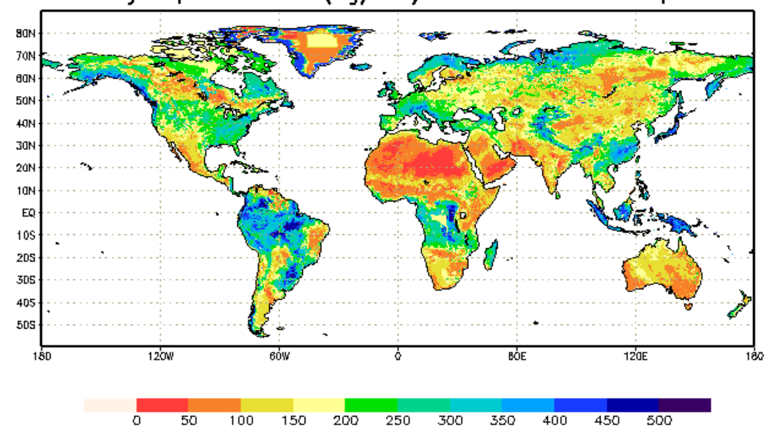


Mean Daily Sfc Temperature -- ECMWF -- 9 April 2003

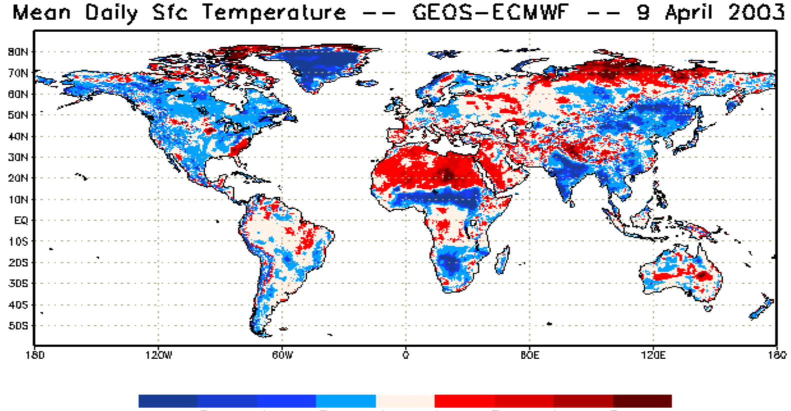


ECMWF

Mean Daily Top 1 m SWC (kg/m2) -- ECMWF -- 9 April 2003

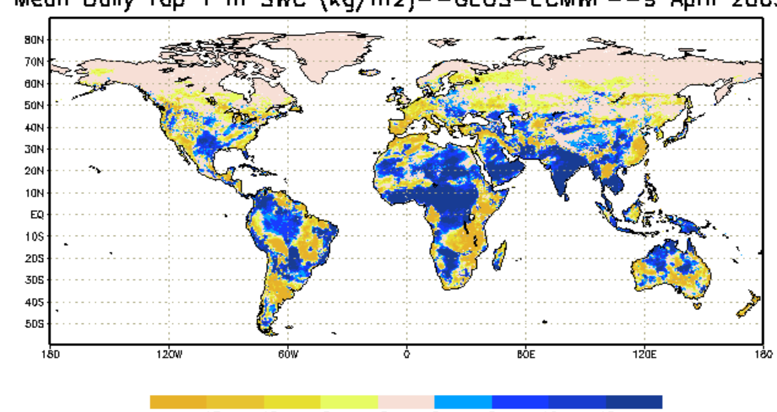


Mean Daily Sfc Temperature -- GEOS-ECMWF -- 9 April 2003



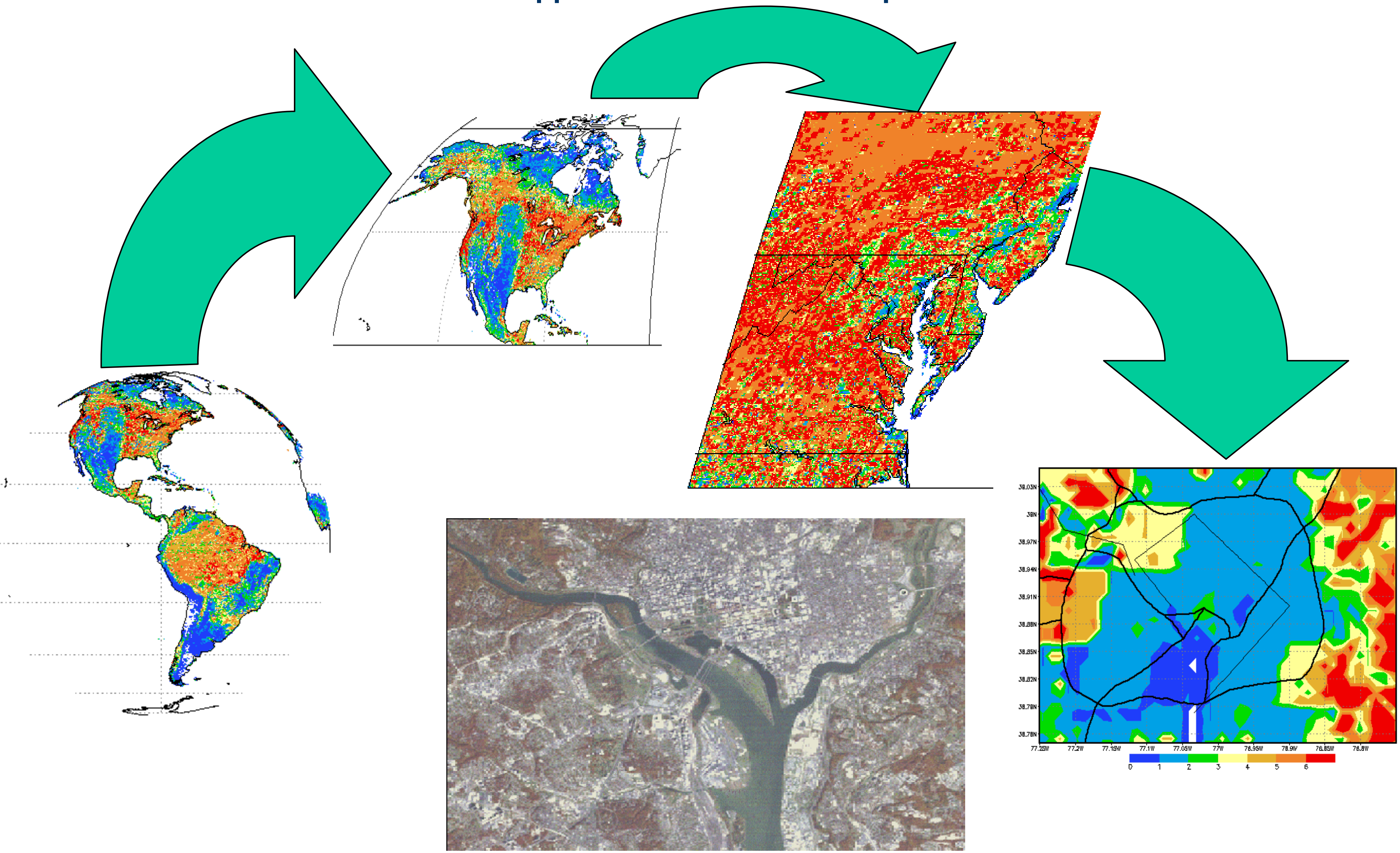
DAO-ECMWF

Mean Daily Top 1 m SWC (kg/m2)--GEOS-ECMWF--9 April 2003

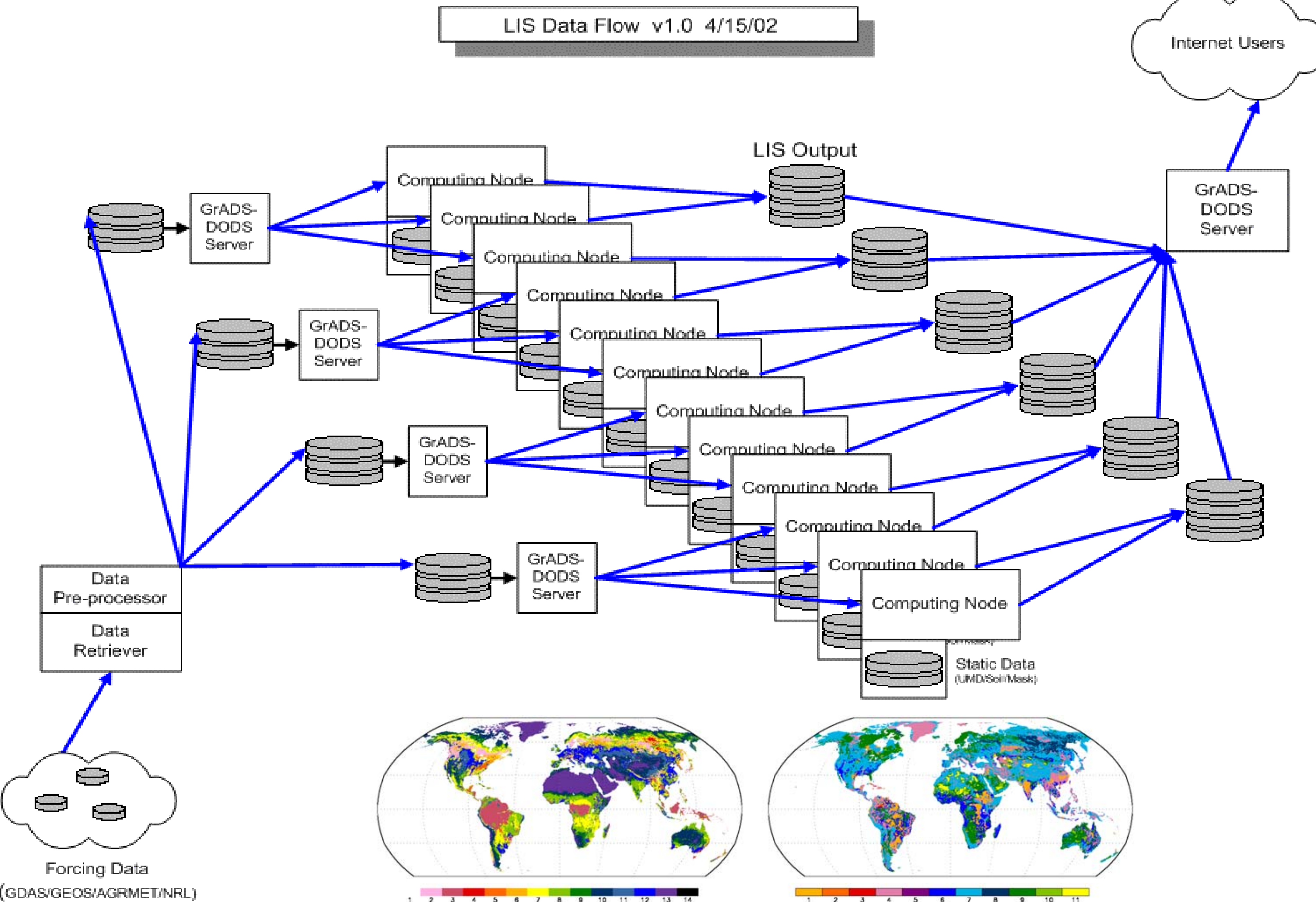


Land Information System: *A high-performance extension of GLDAS*

The 1-km resolution land surface data assimilation possible with LIS will approach that of an aerial photo.

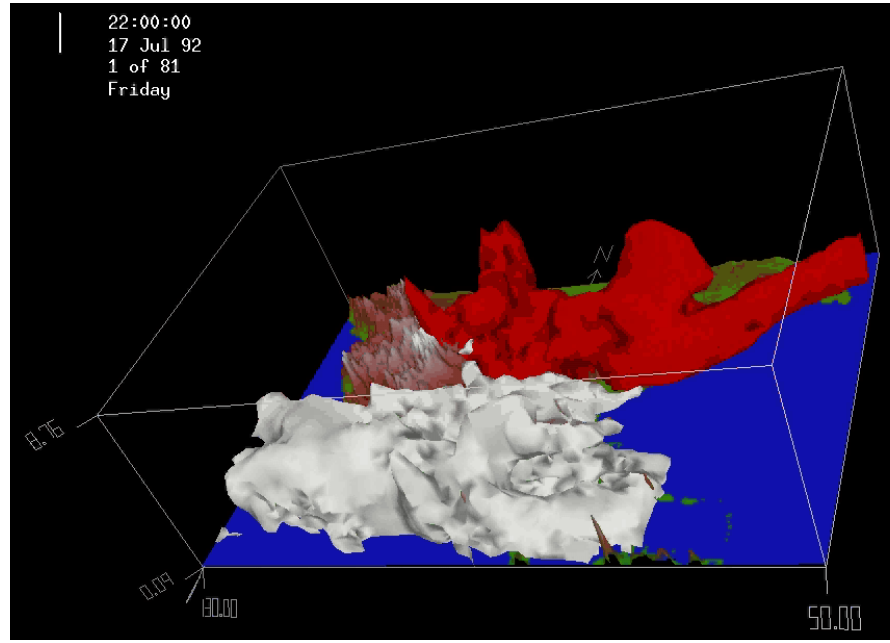


Land Information System: *A high-performance extension of GLDAS*



Water Cycling Research: coupling LDAS results

- Objective: To better understand the water cycle by quantifying geographic sources (local and remote) of precipitating waterSoil water anomalies likely affect the local continental source of water for precipitation in the monsoon (e.g. Atlas et al. 1993)
- Controlled sensitivity experiments can be performed, using GLDAS initial conditions for the FVGCM
- Using realistic perturbations, what is the impact of wet and dry anomalies on the monsoon precipitation, and the relative sources of water



North America: Water evaporates from the Caribbean Sea moving westward (white isosurface) as the circulation changes this water is transported northward into the US. (The red isosurface shows water that has evaporated from the central US)

Bosilovich and Schubert, 2002; Bosilovich 2002

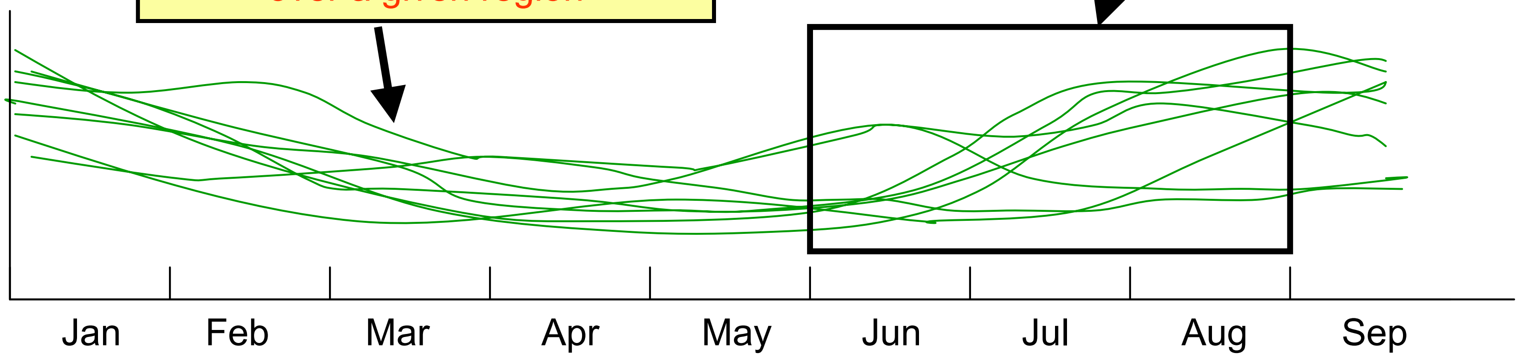
Simulations performed: For each year between 1979 and 1993,

1. AMIP ensemble

9 AGCM simulations, run in parallel with observed SSTs, provide 9 realizations of rainfall over a given region

The 9 JJA rainfall totals are averaged to give a mean rainfall “forecast” in absence of land surface initialization

precipitation over region X

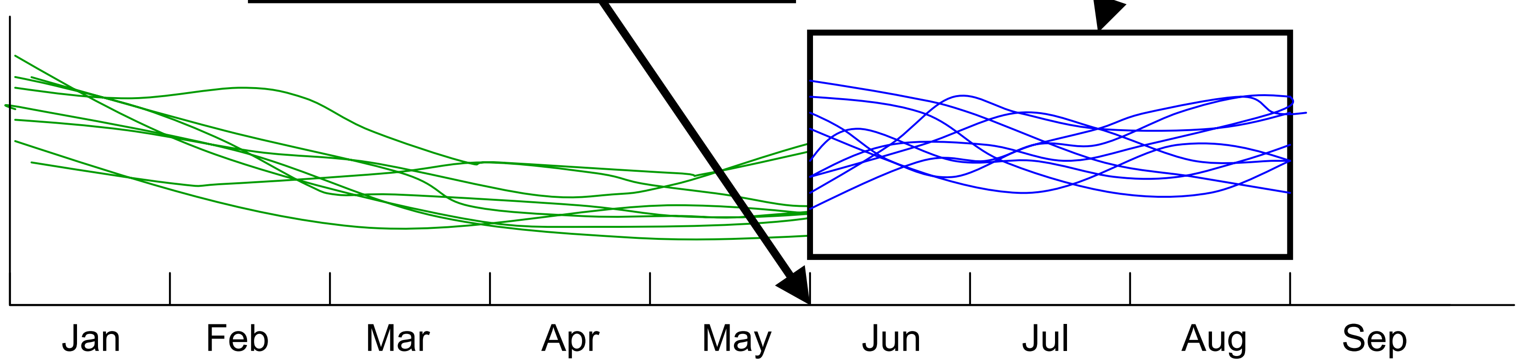


2. LDAS ensemble

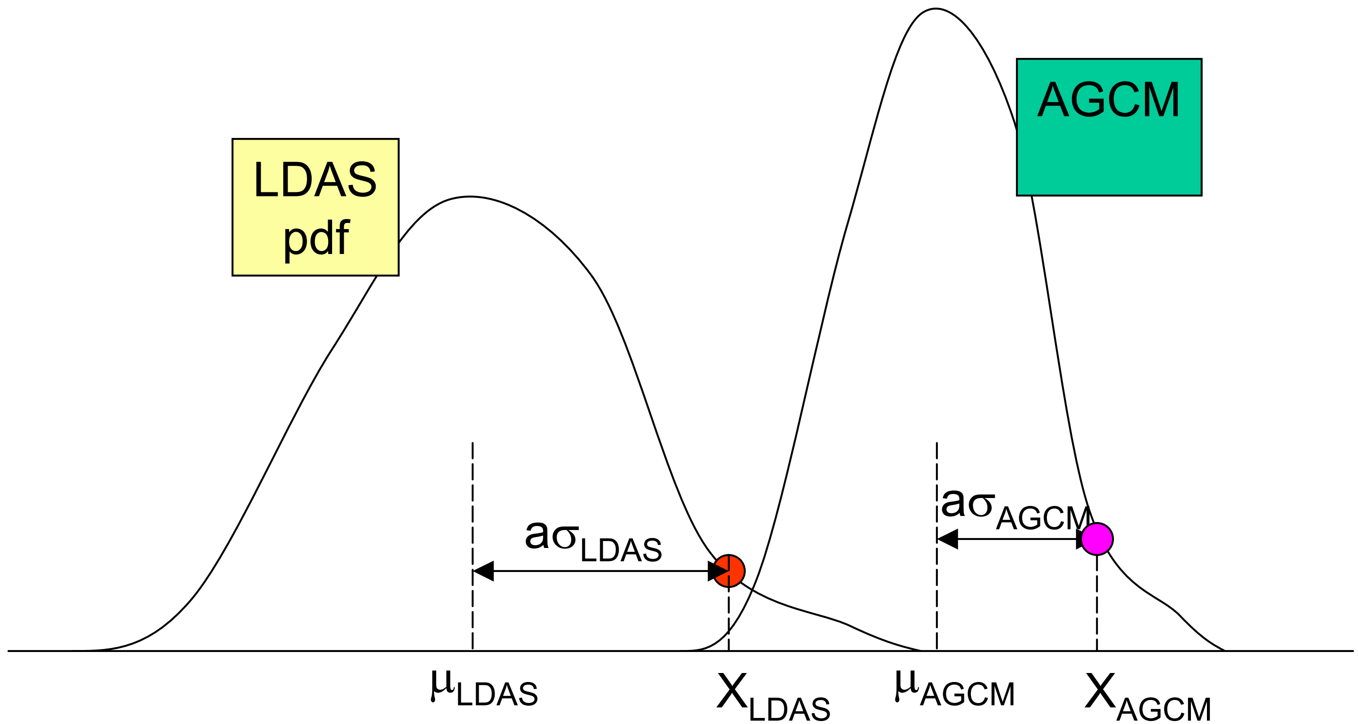
Impose the offline LDAS surface states on June 1

The 9 new JJA rainfall totals are averaged to give a mean rainfall forecast reflecting soil moisture initialization

precipitation over region X



Scaling Approach

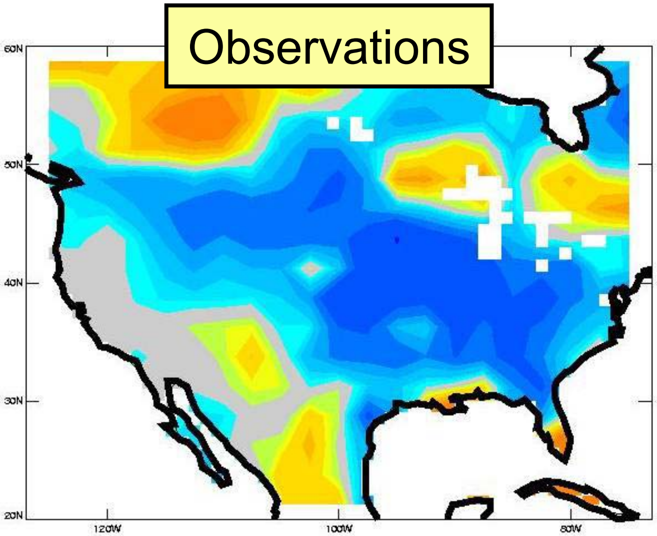


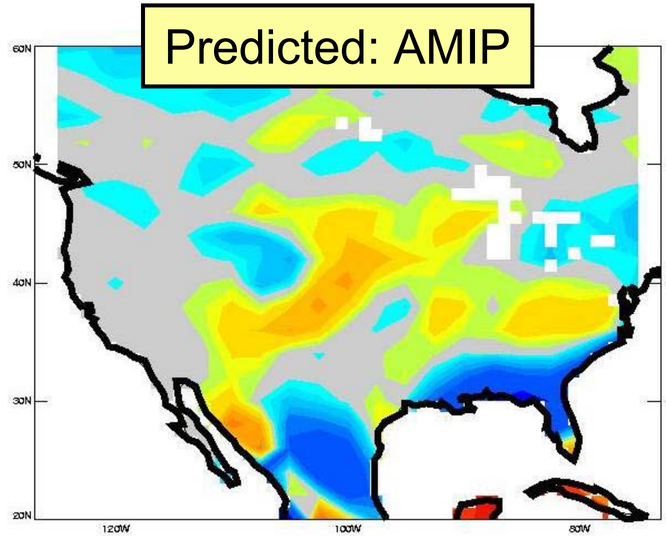
Use standard normal deviates:

$$\frac{X_{AGCM} - \mu_{AGCM}}{\sigma_{AGCM}} = \frac{X_{LDAS} - \mu_{LDAS}}{\sigma_{LDAS}}$$

1988 Midwestern U.S. Drought

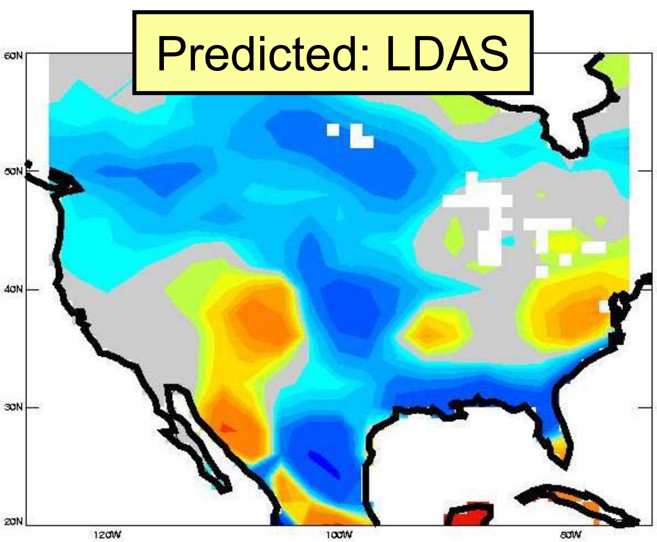
(JJA precipitation anomalies, in mm/day)

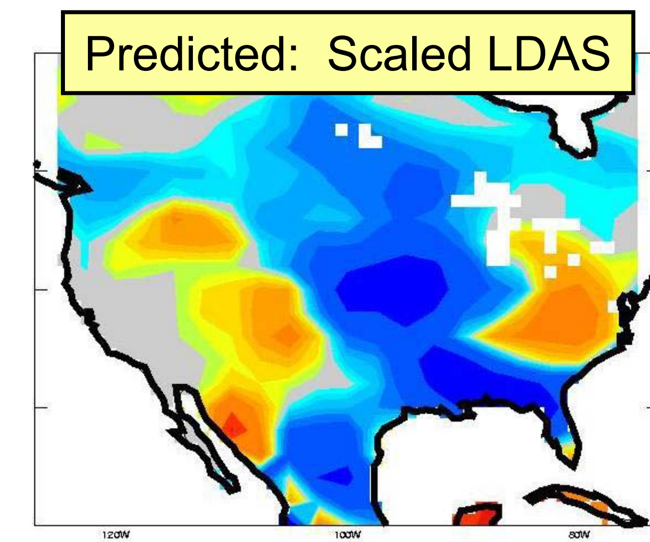


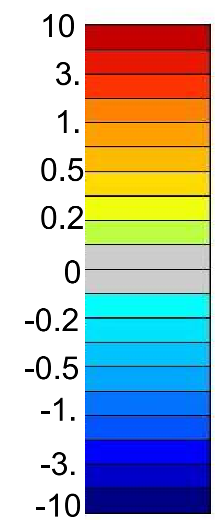


Without soil moisture initialization

With soil moisture initialization

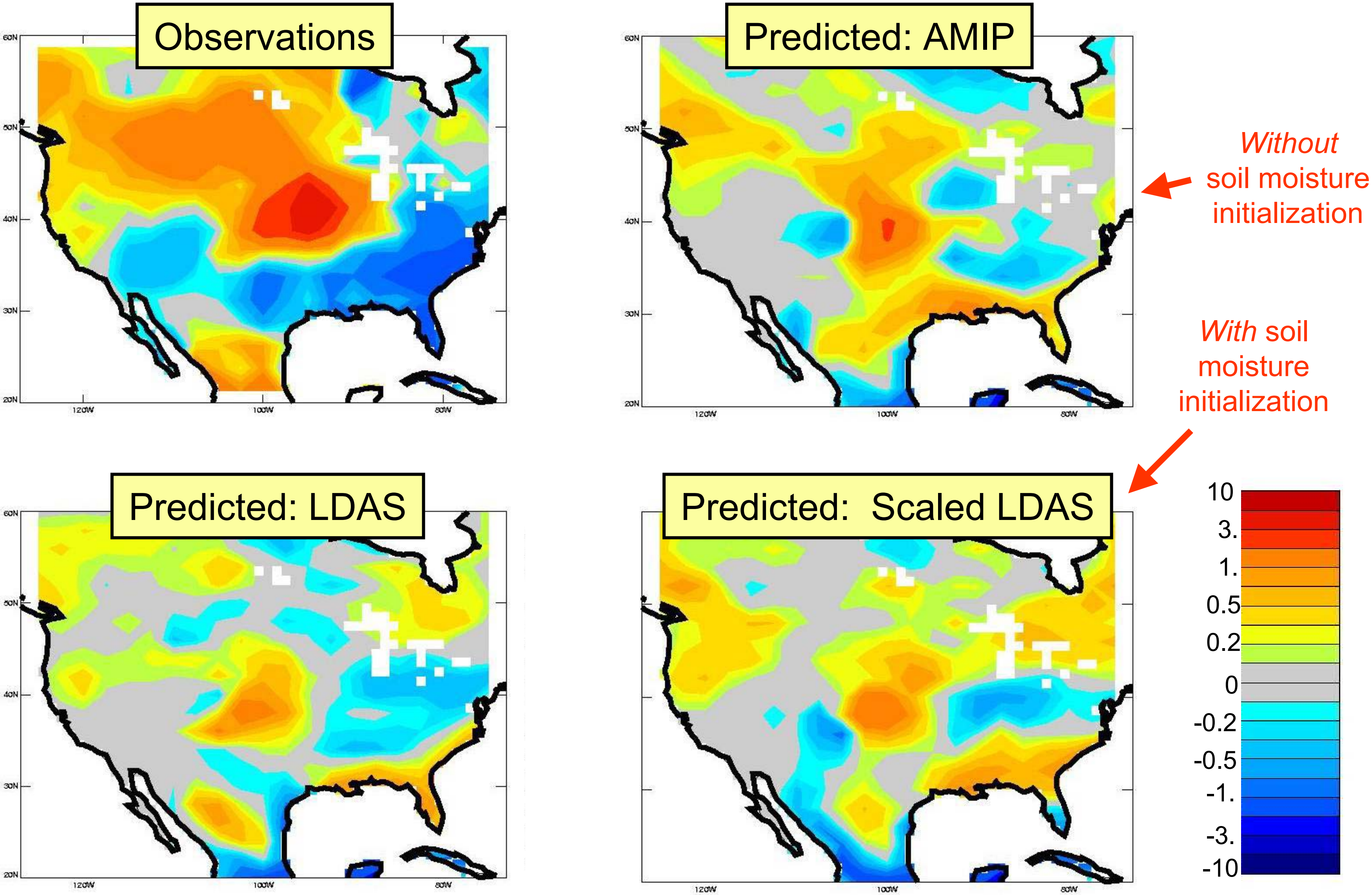






1993 Midwestern U.S. Flood

(JJA precipitation anomalies, in mm/day)



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.