Improving Satellite Soil Moisture Data Products for Assimilation in Global Forecast System of NCEP

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Outline:

- *Objectives*
- *Satellite Soil Moisture Sensors and Data Products*
- *Assimilation in Global Forecast System of NCEP*
- *Conclusions and Next Step*

Objectives:

- *What global soil moisture data products do we have from satellite observations?*
- *What's the status of soil moisture data assimilation for operational numerical weather predictions?*

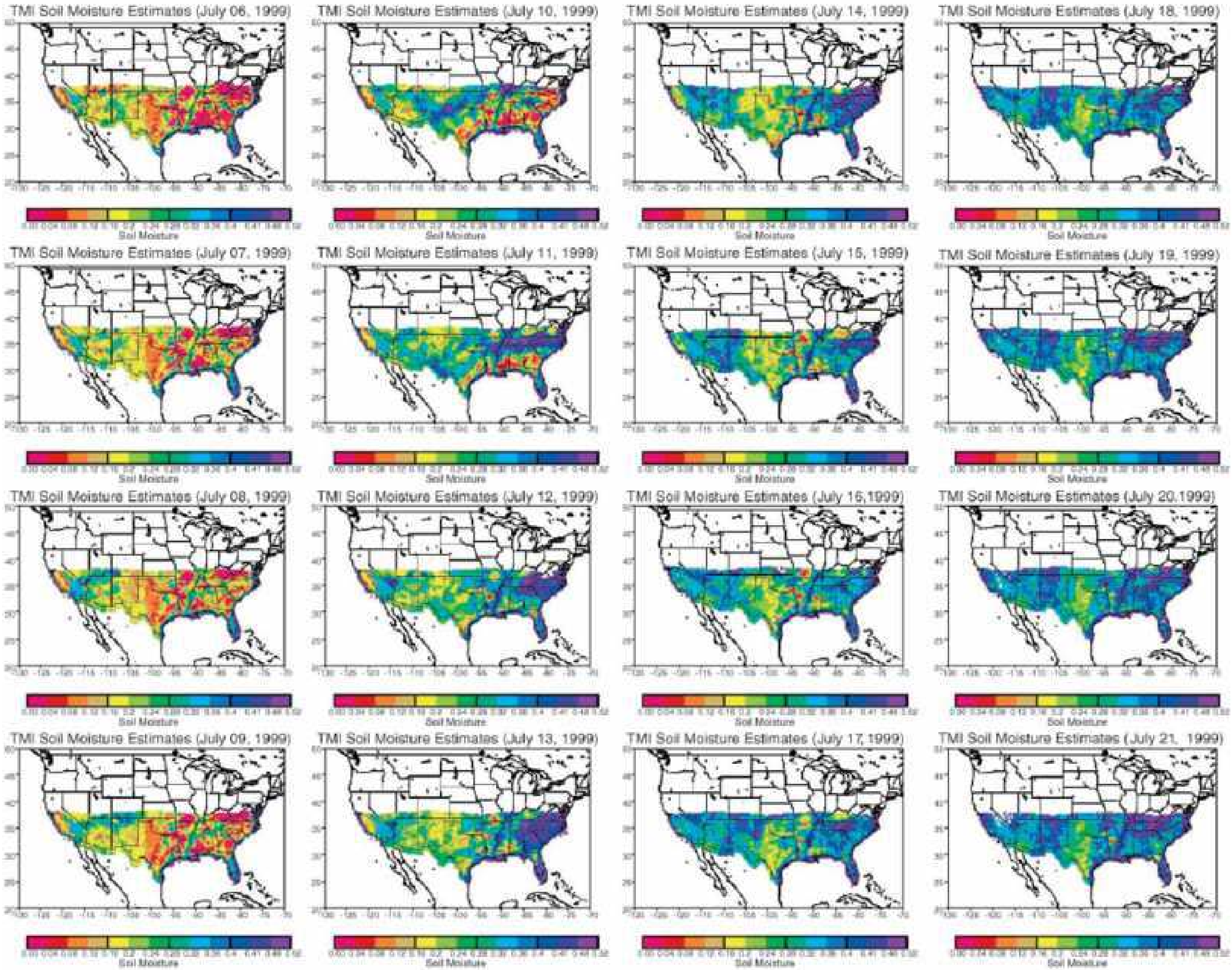
Current Satellite Soil Moisture Sensors:

Parameter	TMI	AMSR-E	Windsat	E/ASCAT
Freq. (GHz)	10.7, 37	6.9, 10.7, 36.5	6.8, 10.7, 37	5.255
Polarization	H, V	H, V	H, V, ±45	VV
Swath (km)	759	1445	1025	2x550
Incid Angle	53	55	53.5/49.9/53	for/nadir/aft
Eq X time	*variable*	1330/0130	1800/0600	various
Footprint (km)	63/39	74/43	38/25	50/25
Data Period	11/97 -	06/02 -	02/03 -	11/06 -

Current Satellite Soil Moisture Data Products:

- ✓ VUT ESCAT (Wagner et al, 1999)
- ✓ GSFC SMMR (Owe et al, 2001)
- ✓ USDA TMI (Bindlish et al, 2003)
- ✓ Princeton TMI (Gao et al, 2006)
- ✓ NASA AMSR-E (Njoku et al, 2003)
- ✓ USDA AMSR-E (Jackson et al, 2007)
- ✓ VUA AMSR-E (Owe et al, 2008)
- ✓ USDA WindSat (Jackson et al, 2008)
- ✓ NRL WindSat (Li et al, 2008)

USDA TMI (Bindlish et al, 2003) :

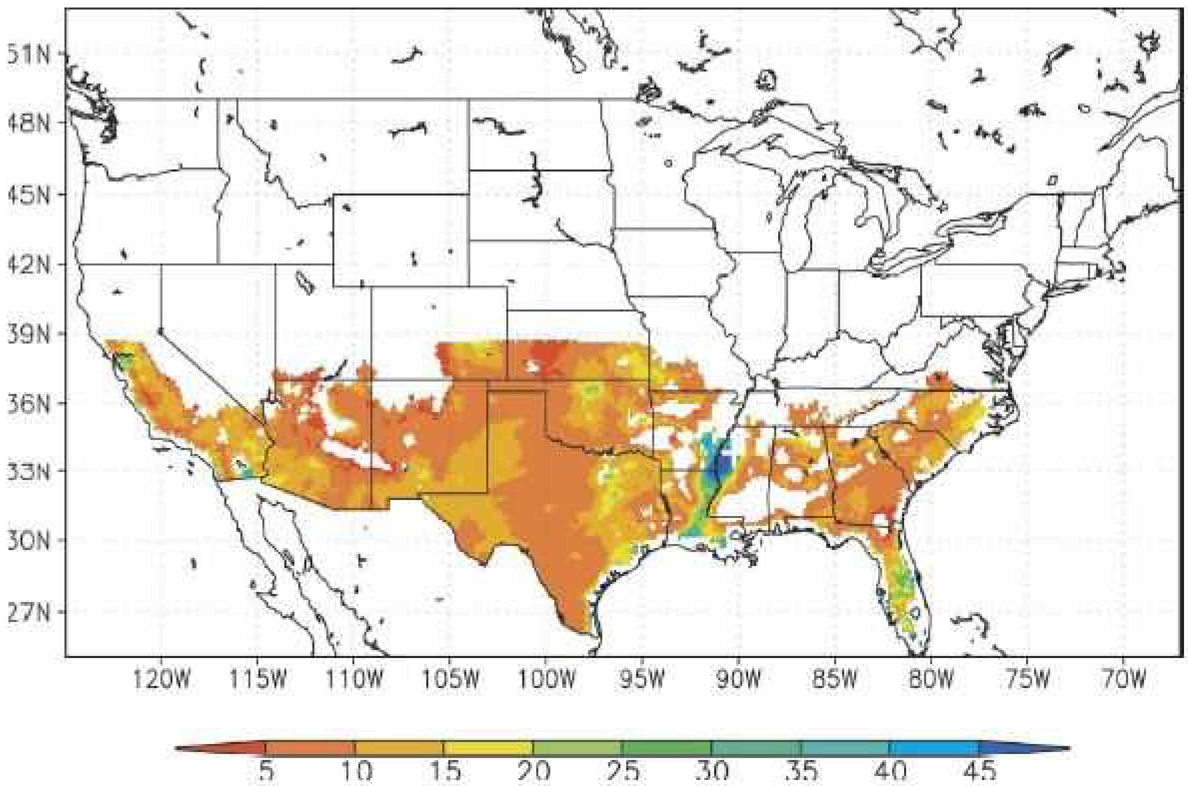


Daily estimates, from July 06 to July 21, 1999

0.0 – 0.52%v/v

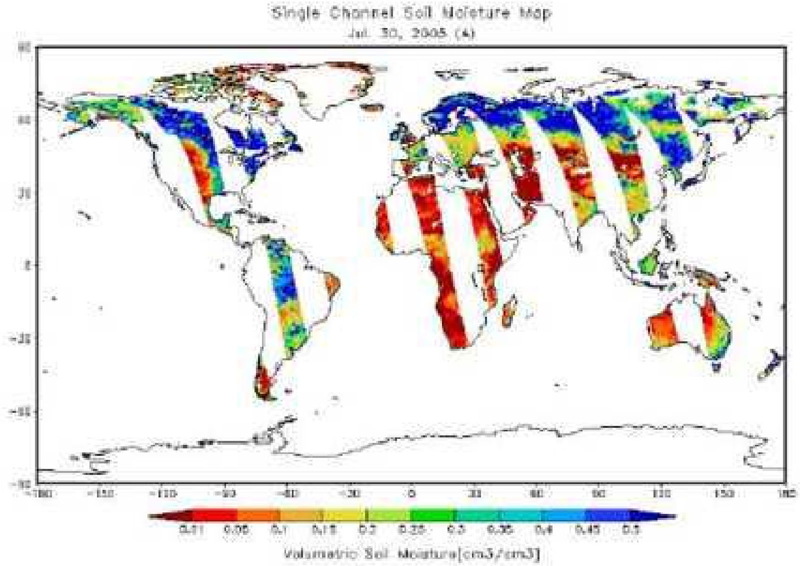
Not consistently available

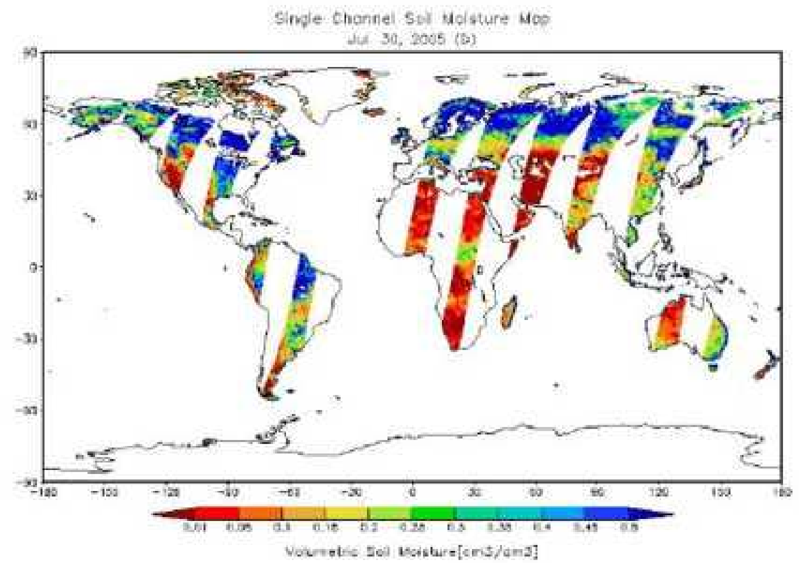
Princeton University TMI (Gao et al, 2006) :



Jan. 1, 1999 with quality masks applied, Not consistently available

USDA WindSat (Jackson et al, 2008) :



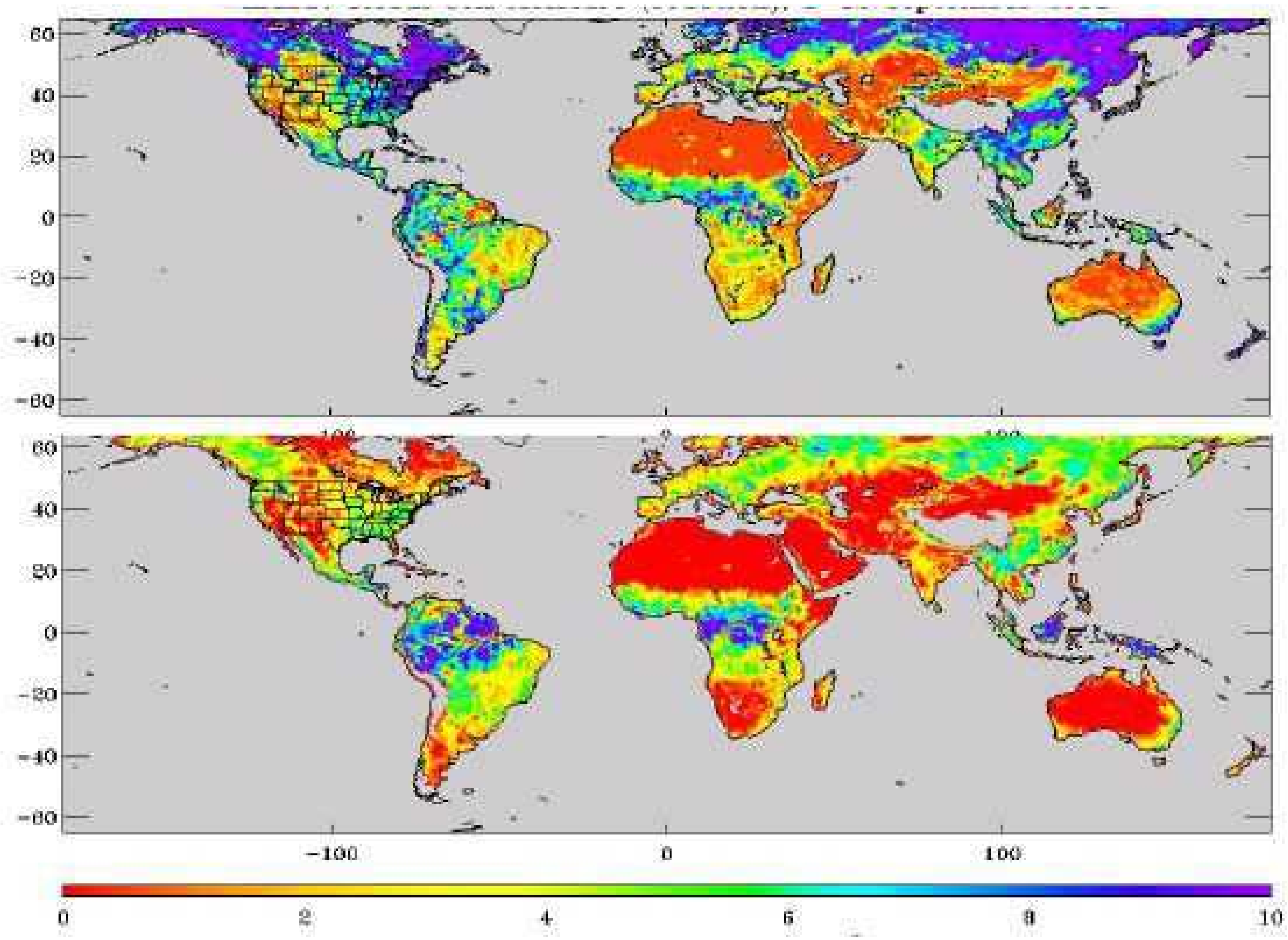


WindSat global volumetric soil moisture (%) for July 30, 2005.

0.0 – 0.5 v/v

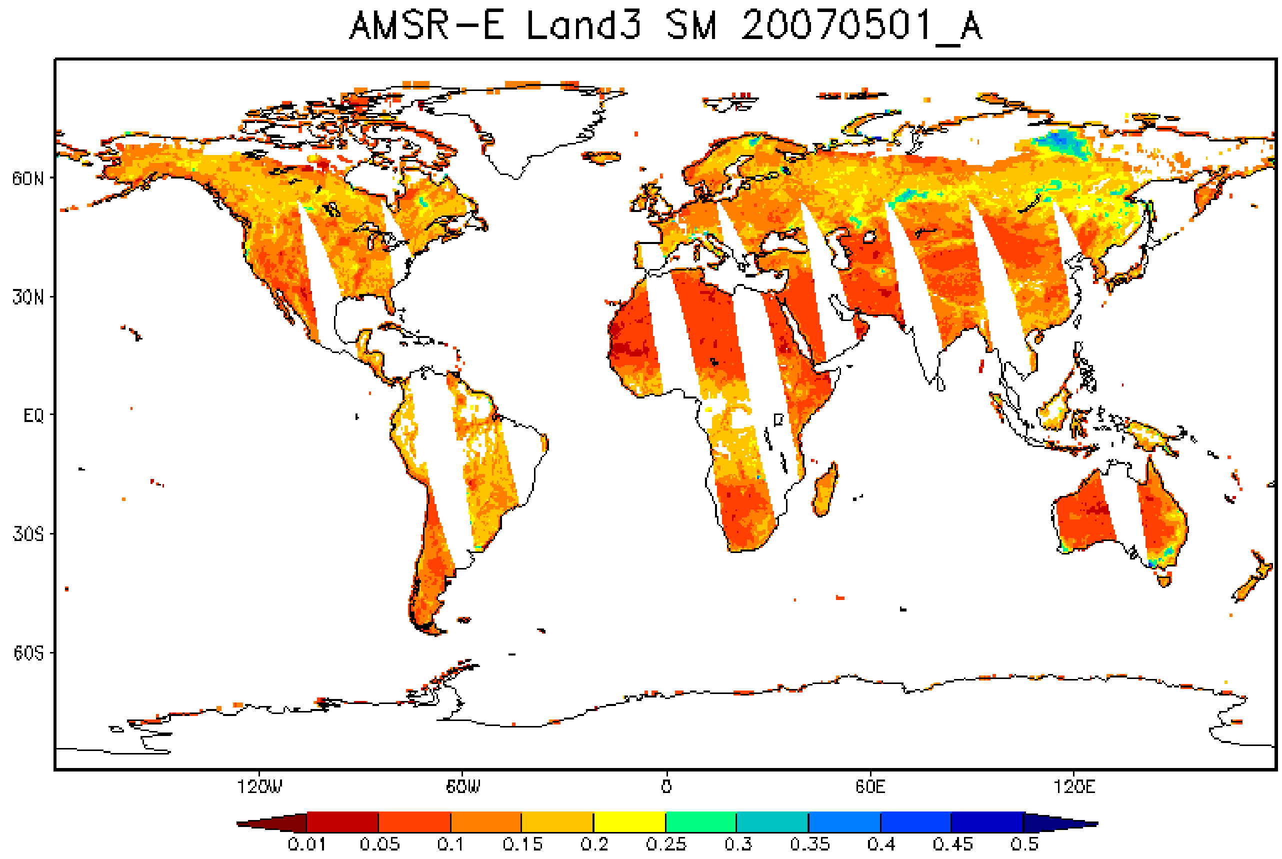
Not consistently available

NRL WindSat (Li et al, 2008) :



WindSat global volumetric soil moisture (%) and vegetation water content (kg/m2) retrievals for 1 – 12 September 2003.

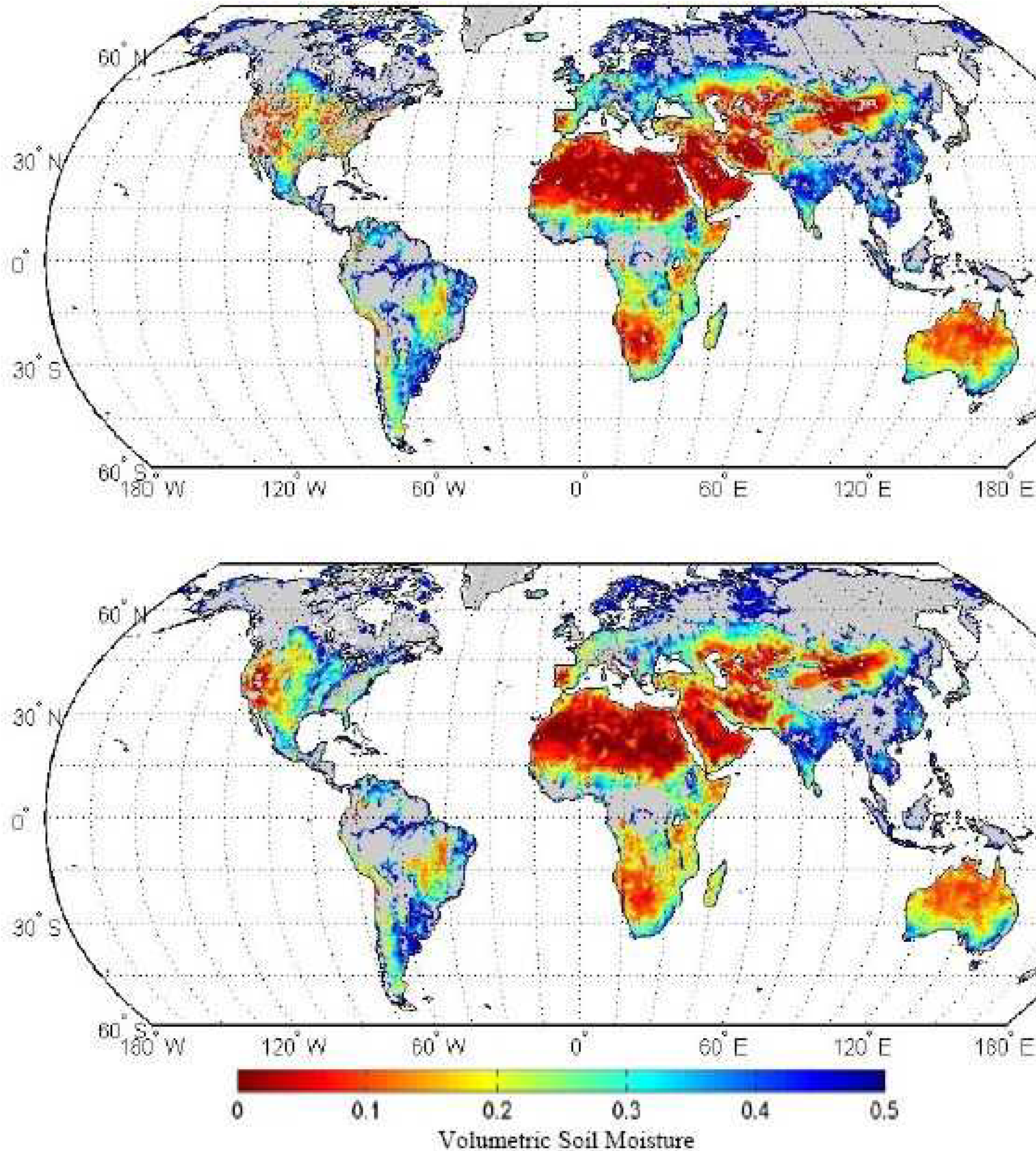
NASA AMSR-E (Njoku et al, 2003) :



Within US:
0.1 – 0.2 v/v

Spatial and temporal variations too small

VUA-GSFC AMSR-E (Owe et al, 2008) :



Monthly for July 2003:

Top: 6.9GHz Bottom: 10.7 GHz

Not currently available

Current Satellite Soil Moisture Data Products:

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- ✓ USDA WindSat (Jackson et al, 2008)
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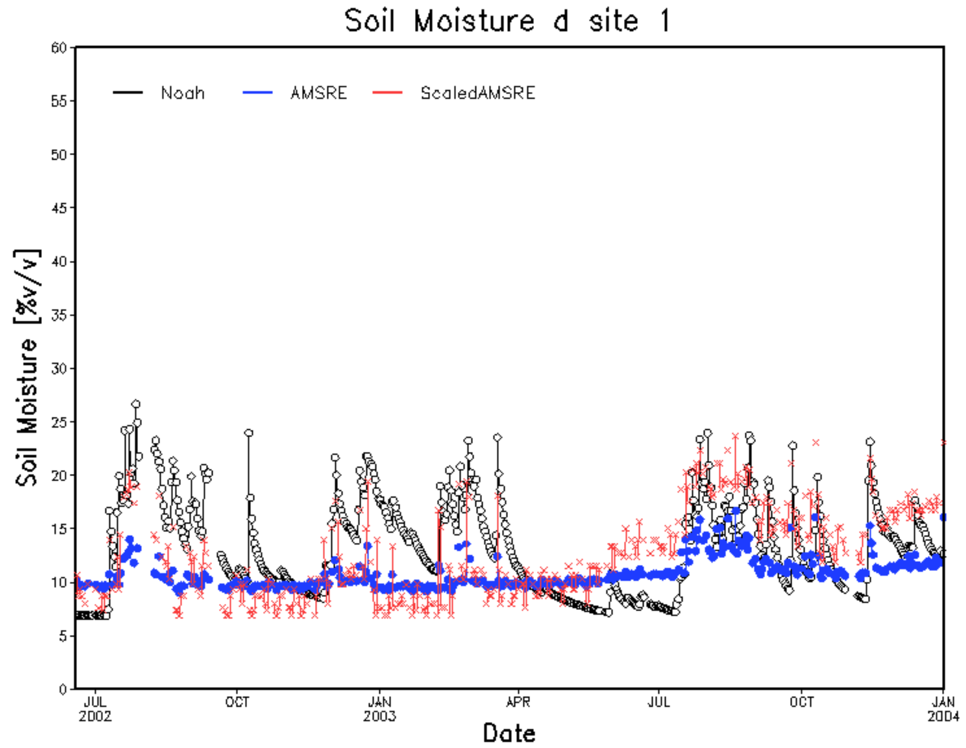
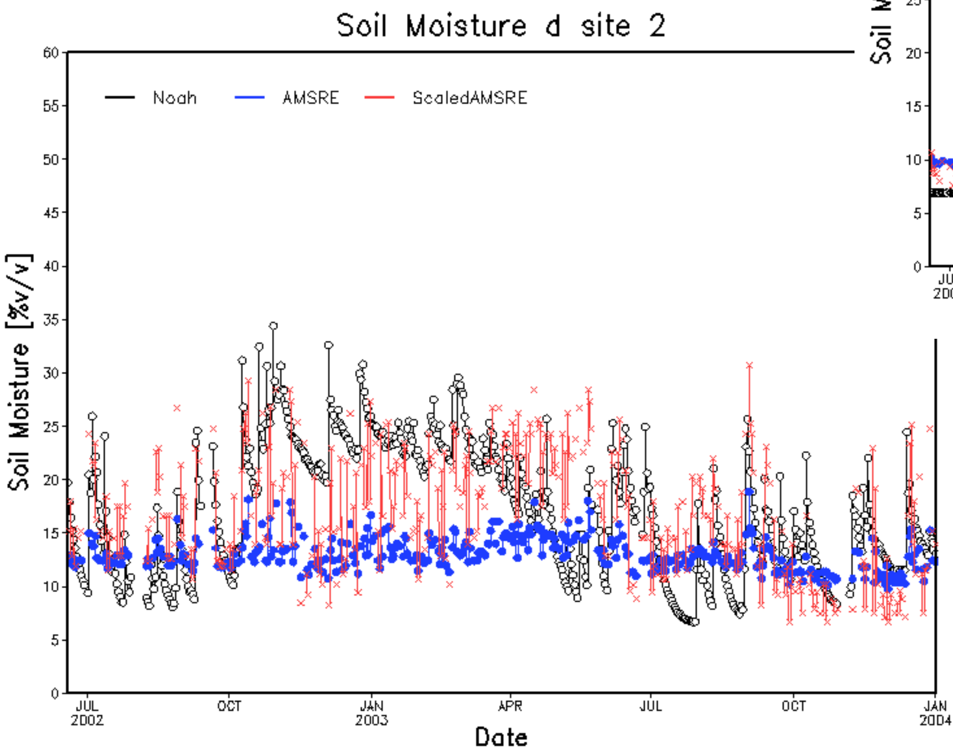
Current Satellite Soil Moisture Products:

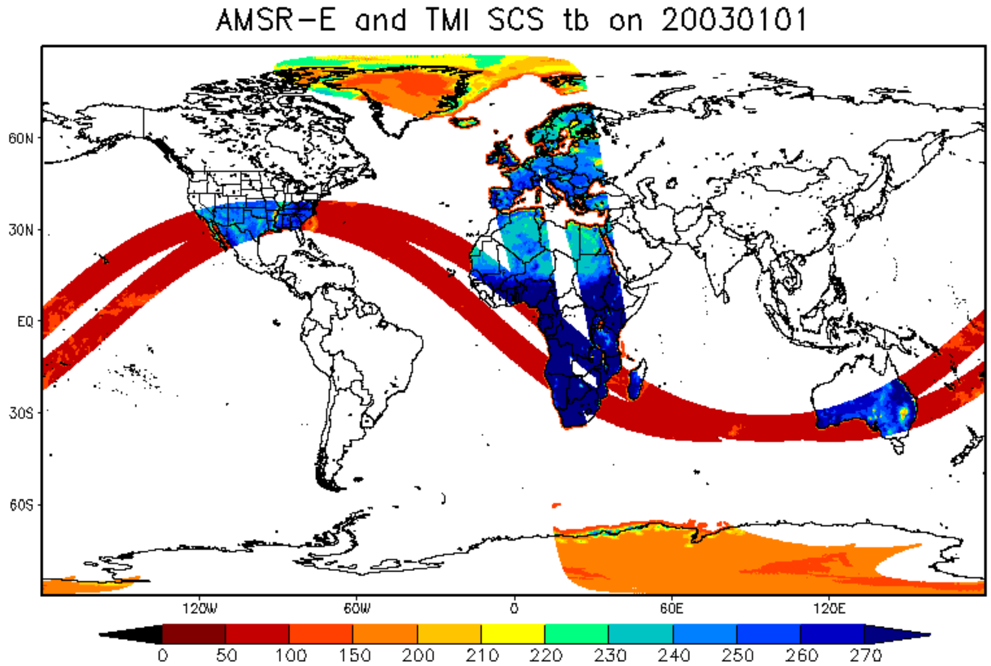
NASA AMSR-E Compared with Noah Simulations



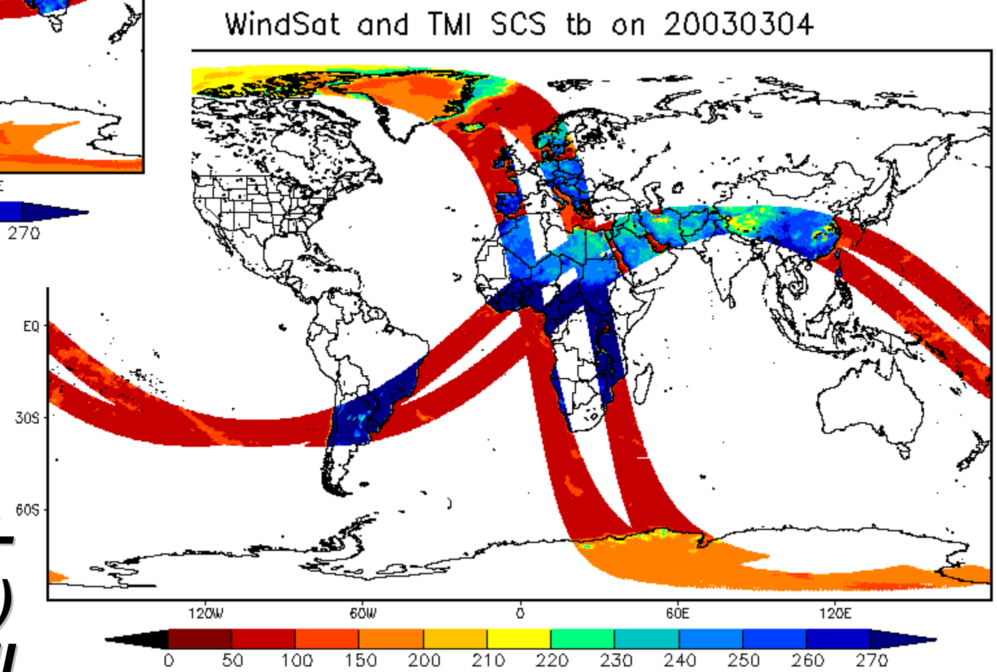


Site 1: WG, AZ
Site 2: LW, OK

Soil Moisture Sensor Comparison/Calibration:

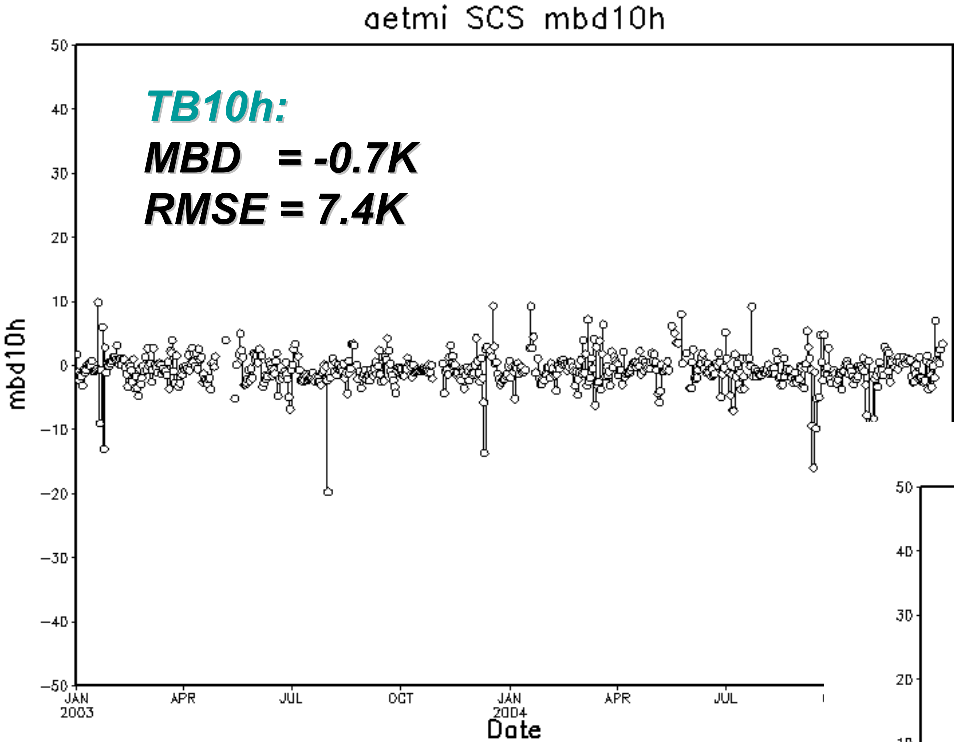


Simultaneous Conical-scanning Overpass (SCO) between AMSR-E and TMI

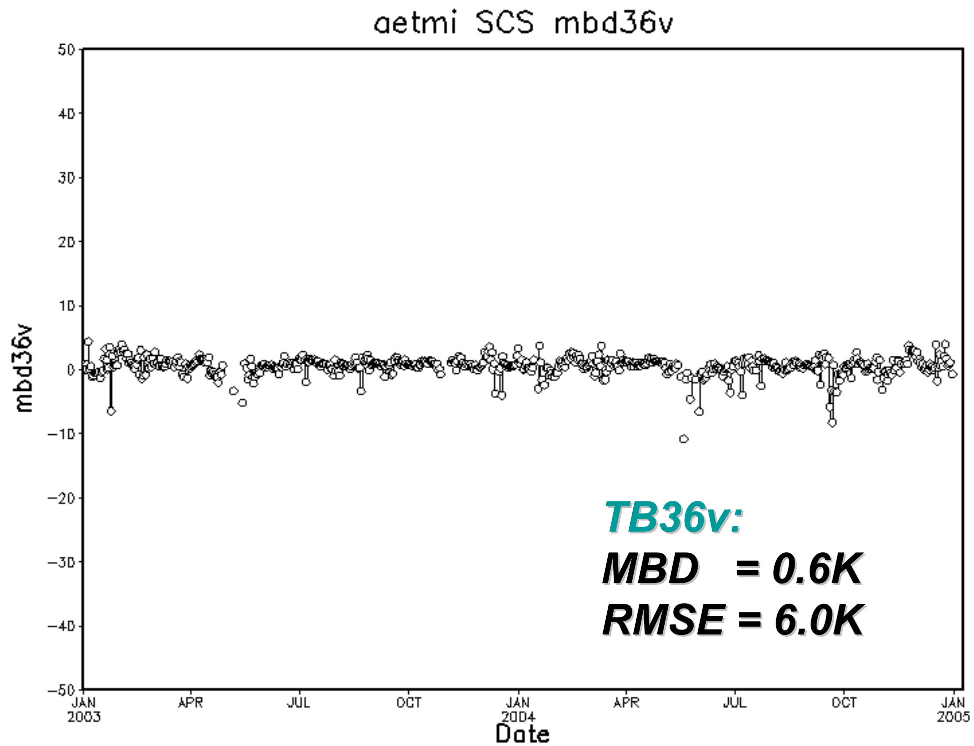


Simultaneous Conical-scanning Overpass (SCO) between WindSat and TMI

Soil Moisture Sensor Comparison/Calibration:

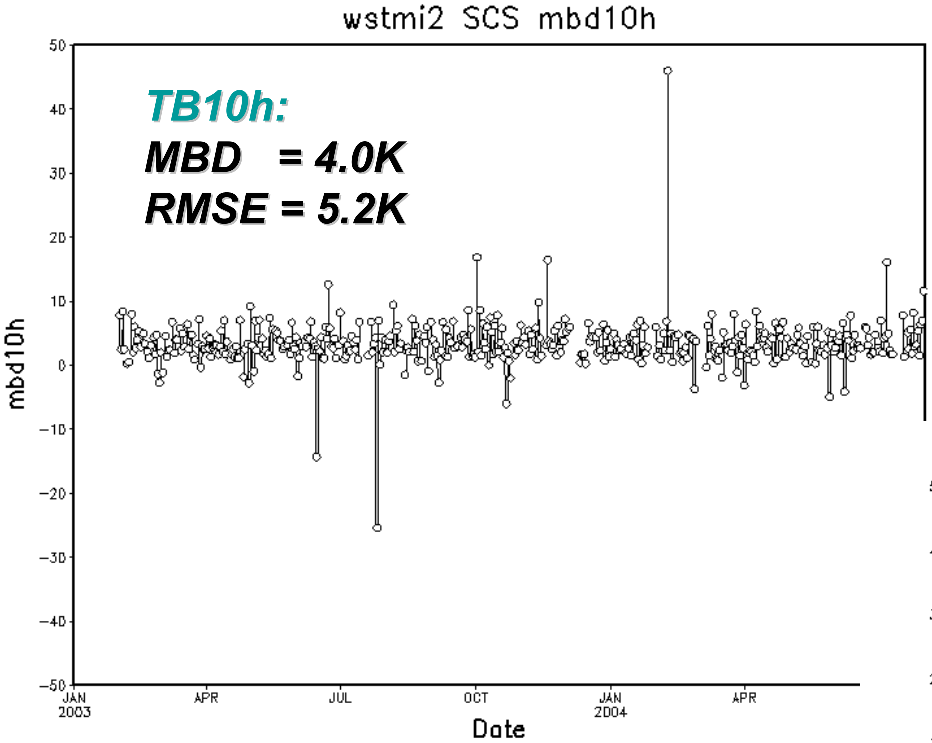


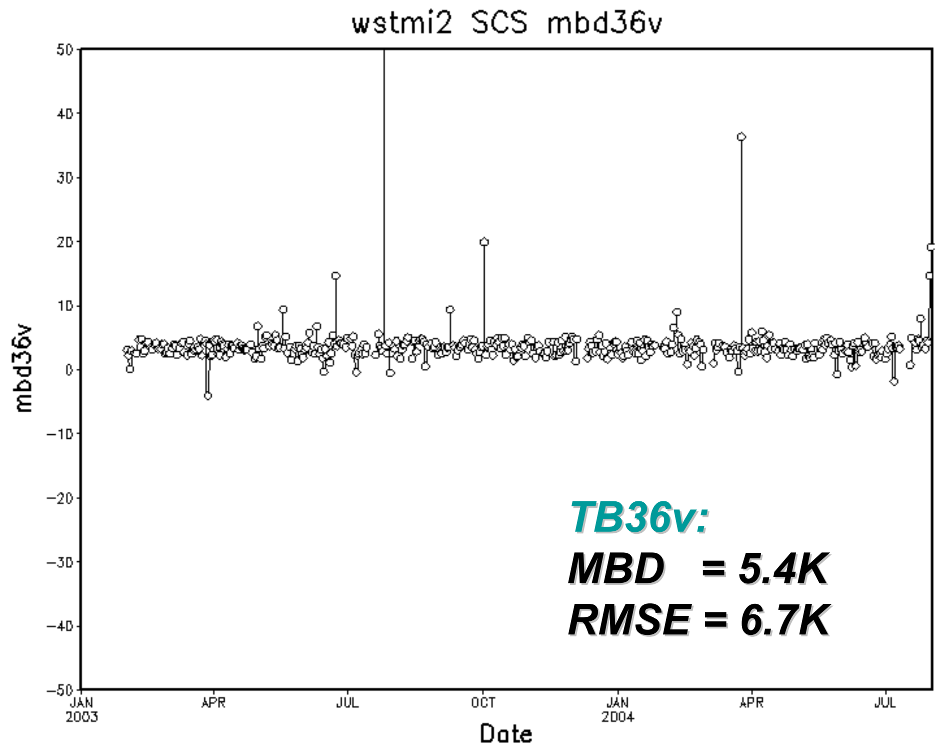
AMSR-E vs TMI



Soil Moisture Sensor Comparison/Calibration:

WindSat vs TMI





Soil Moisture Retrievals:

Multi-channel Inversion Algorithm (MCI):

$$\min\{ \quad \chi^2 = \sum_{i=1}^{6} \left(\frac{T_{B,i}^{obs} - T_{B,i}^{cmp}}{\sigma_i} \right)^2 \}$$

$$T_{B,i}^{cmp} = T_{skin} \{e_{r,p} \exp(-\tau_i/\cos\theta) + (1-\omega)[1-\exp(-\tau_i/\cos\theta)][1+R_{r,i}\exp(-\tau_i/\cos\theta)]\}$$

$$\tau_i = b * VWC$$

$$R_{r,i} = R_s \exp(h \cos^2\theta)$$

$R_s = f(\varepsilon)$ -- Fresnel Equation

$\varepsilon = g(SM)$ -- Mixing model

$$T_{B,i}^{obs} = T_{B06h}, T_{B06v}, T_{B10h}, T_{B10v}, T_{B18h}, T_{B18v}$$

Soil Moisture Retrievals:

Single Channel Retrieval (SCR) Algorithm:

$$T_{B10h} = T_s\,[1 - R_r \exp(-2\tau/\cos\theta)]$$

$$R_r = R_s \exp(h \cos^2\theta)$$

$$R_s = f(\varepsilon)$$ -- Fresnel Equation

$$\varepsilon = g(SM)$$ -- Mixing model

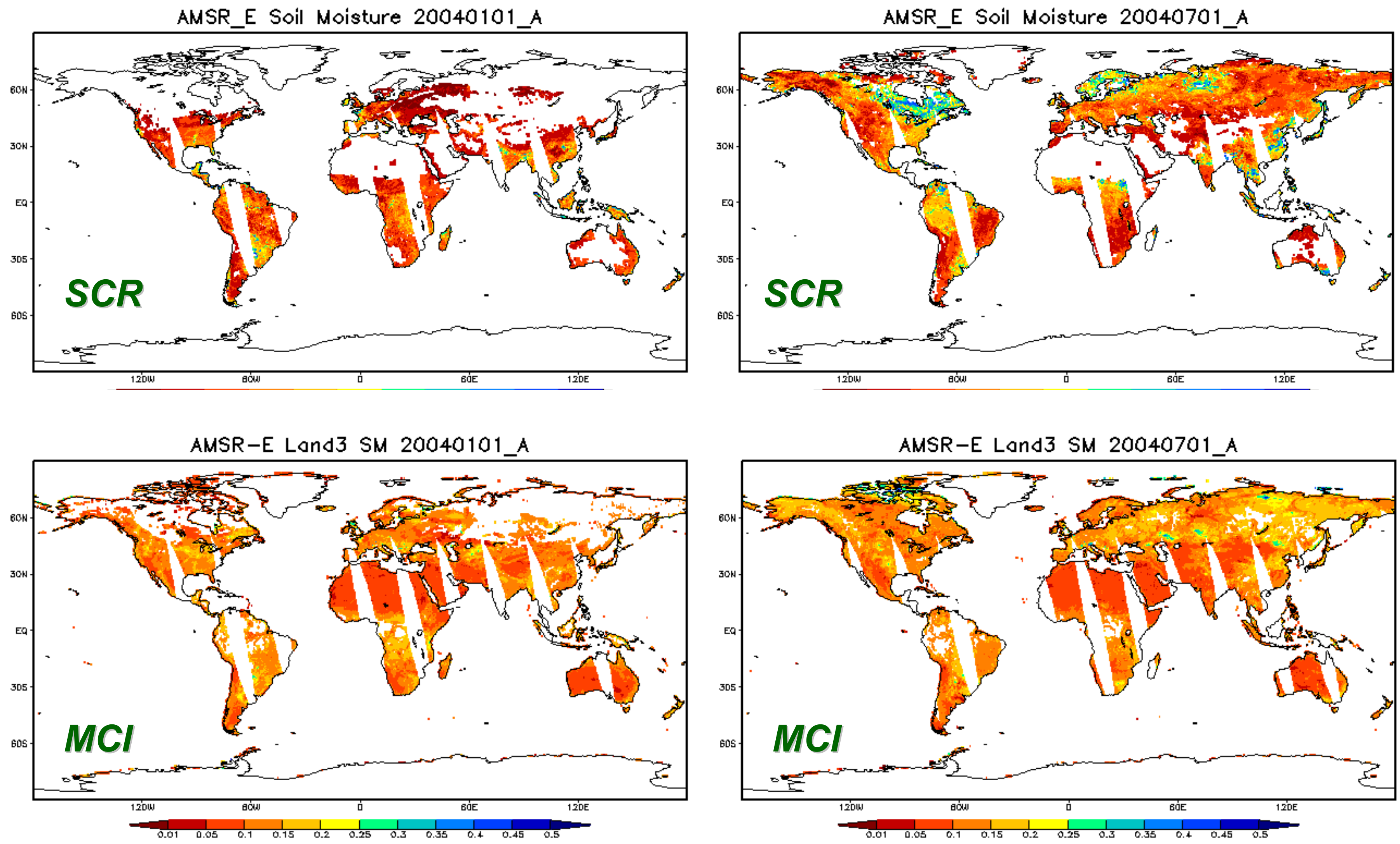
$$T_s = reg_1(T_{B37v}) \text{ or } T_s^{LSM}$$

$$\tau = b * VWC$$

$$VWC = reg_2(NDVI)$$

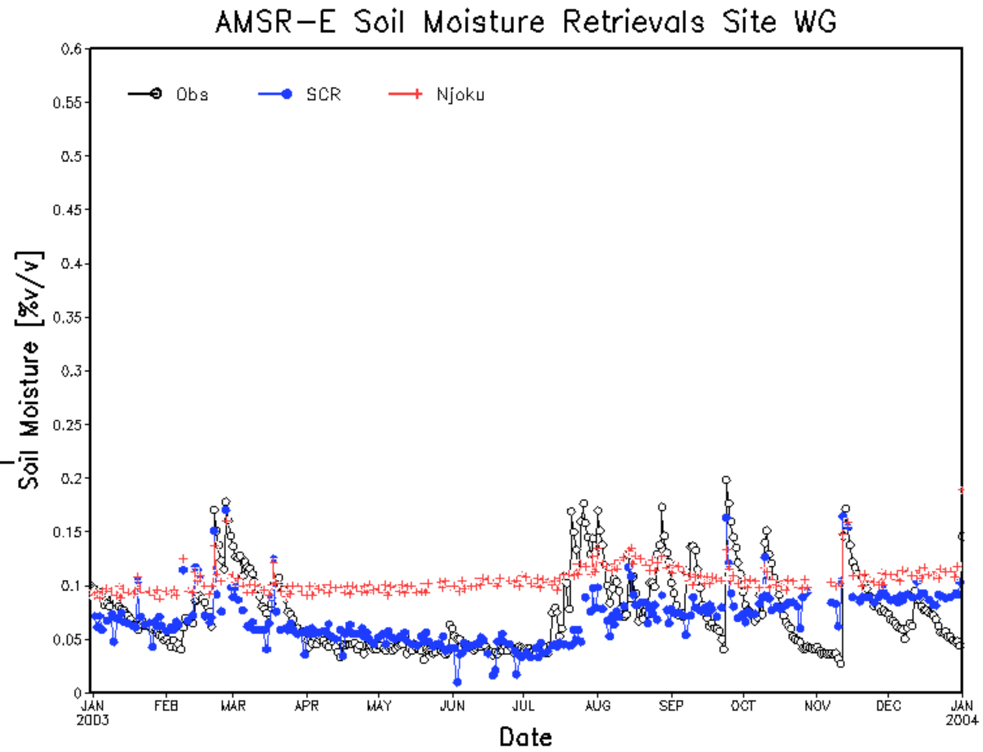
SCR can be applied to different sensors for a consistent satellite soil moisture data product.

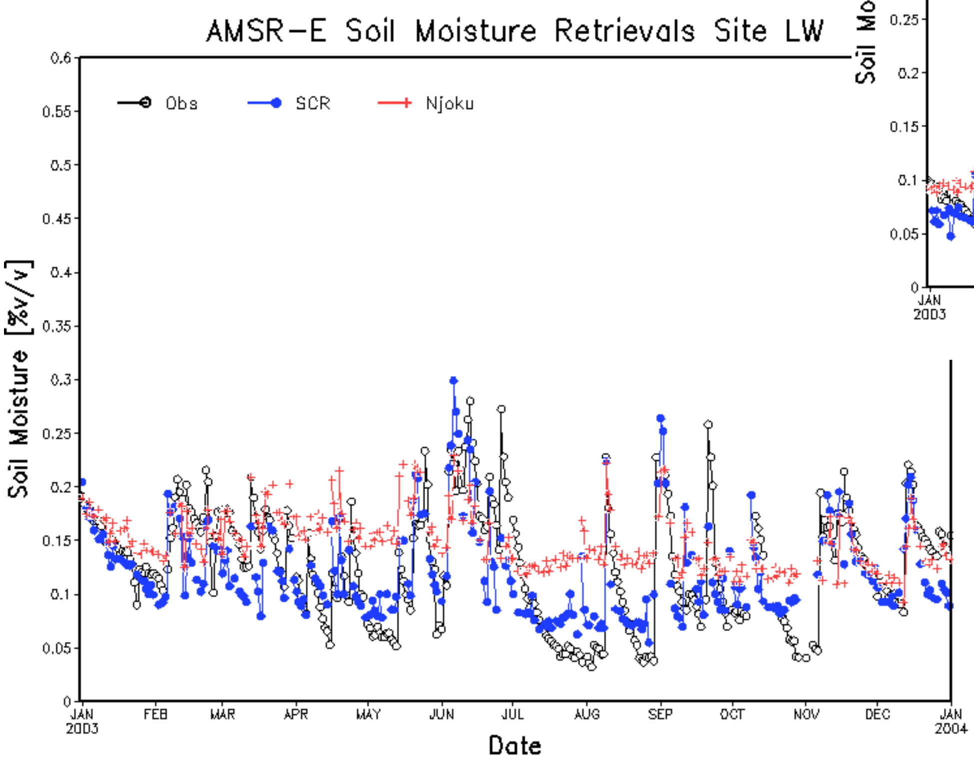
Comparison of Soil Moisture Retrievals:



Current Satellite Soil Moisture Products:

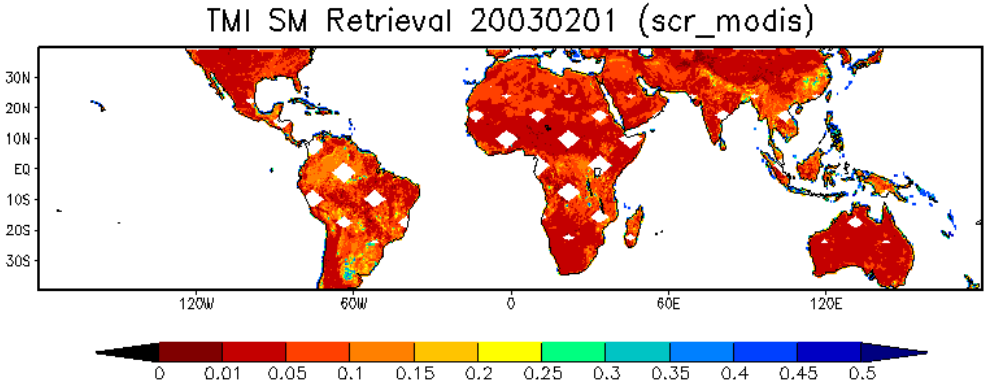
NASA and USDA AMSR-E Compared with In Situ Measurements

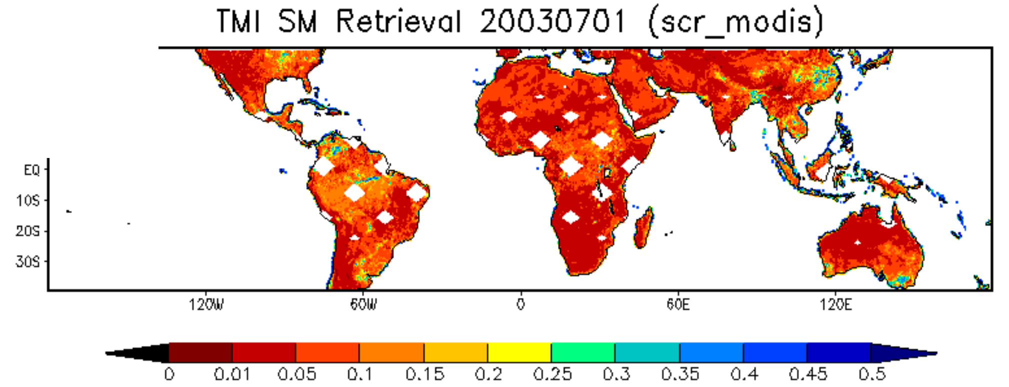




Single Channel Retrieval Results:

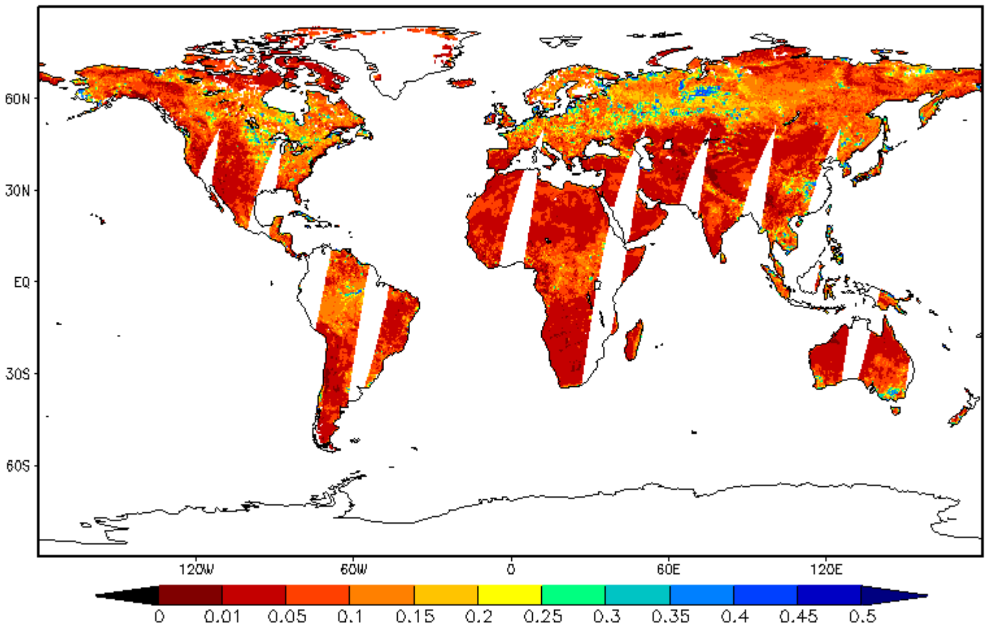
from TMI





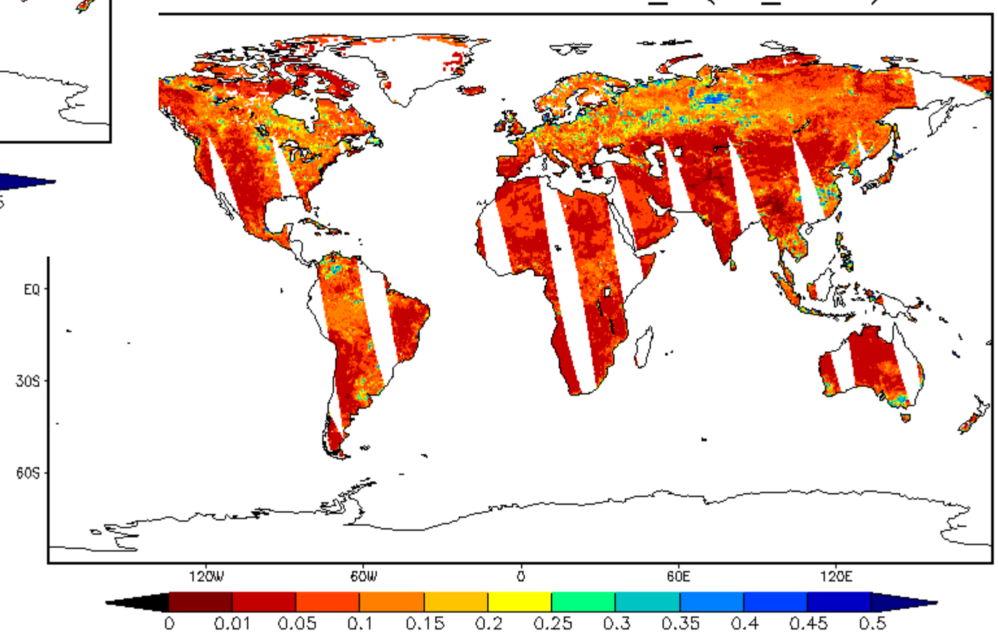
Single Channel Retrieval Results:

AMSR-E SM Retrieval 20030701_d (scr_modis)

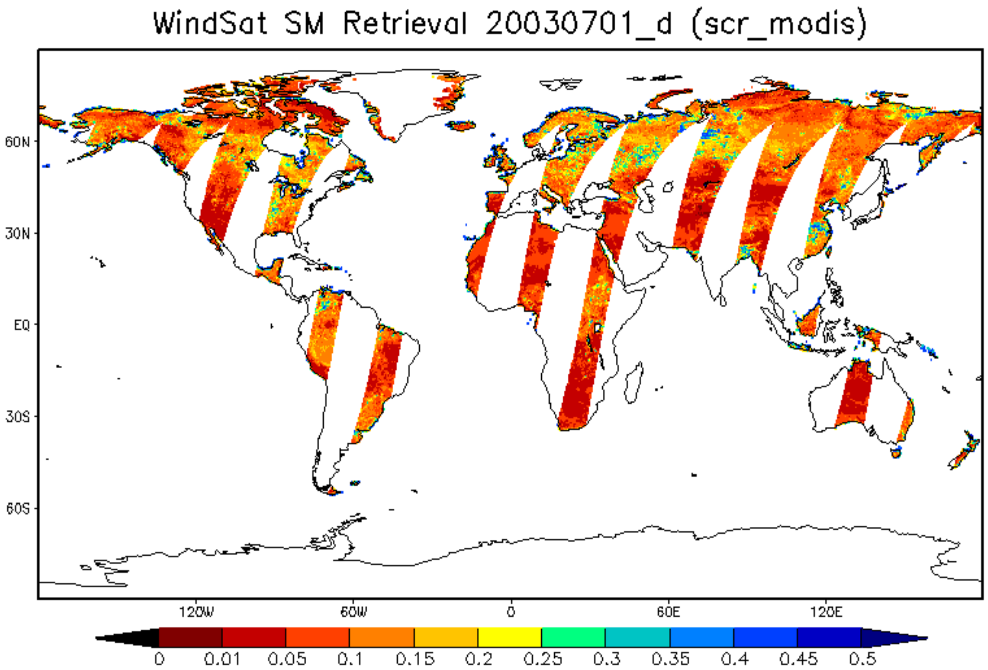


from AMSR-E

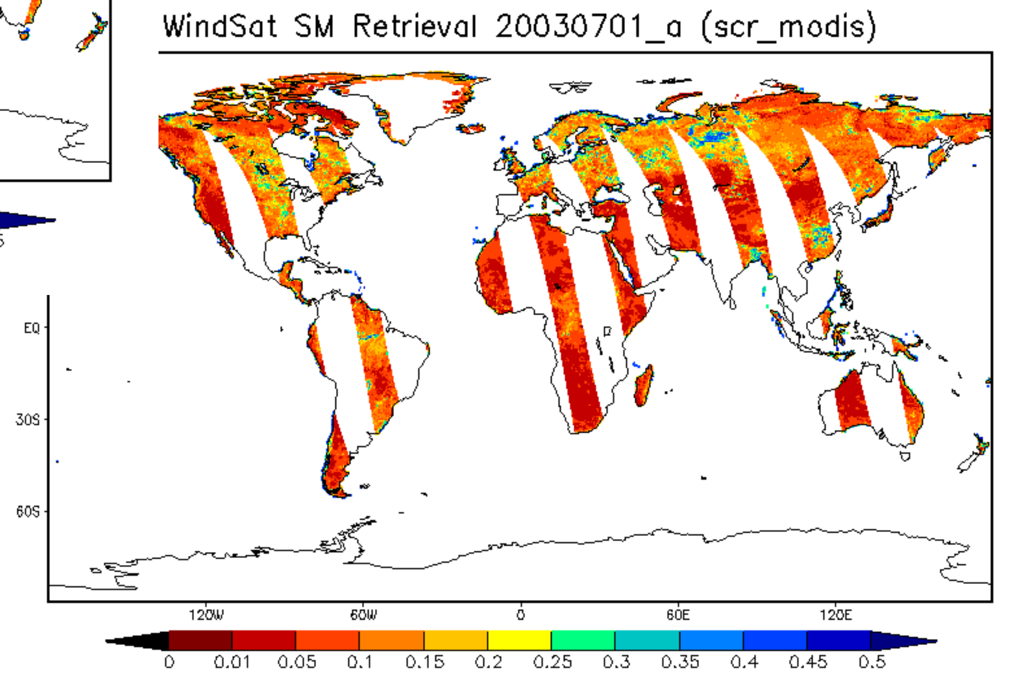
AMSR-E SM Retrieval 20030701_a (scr_modis)



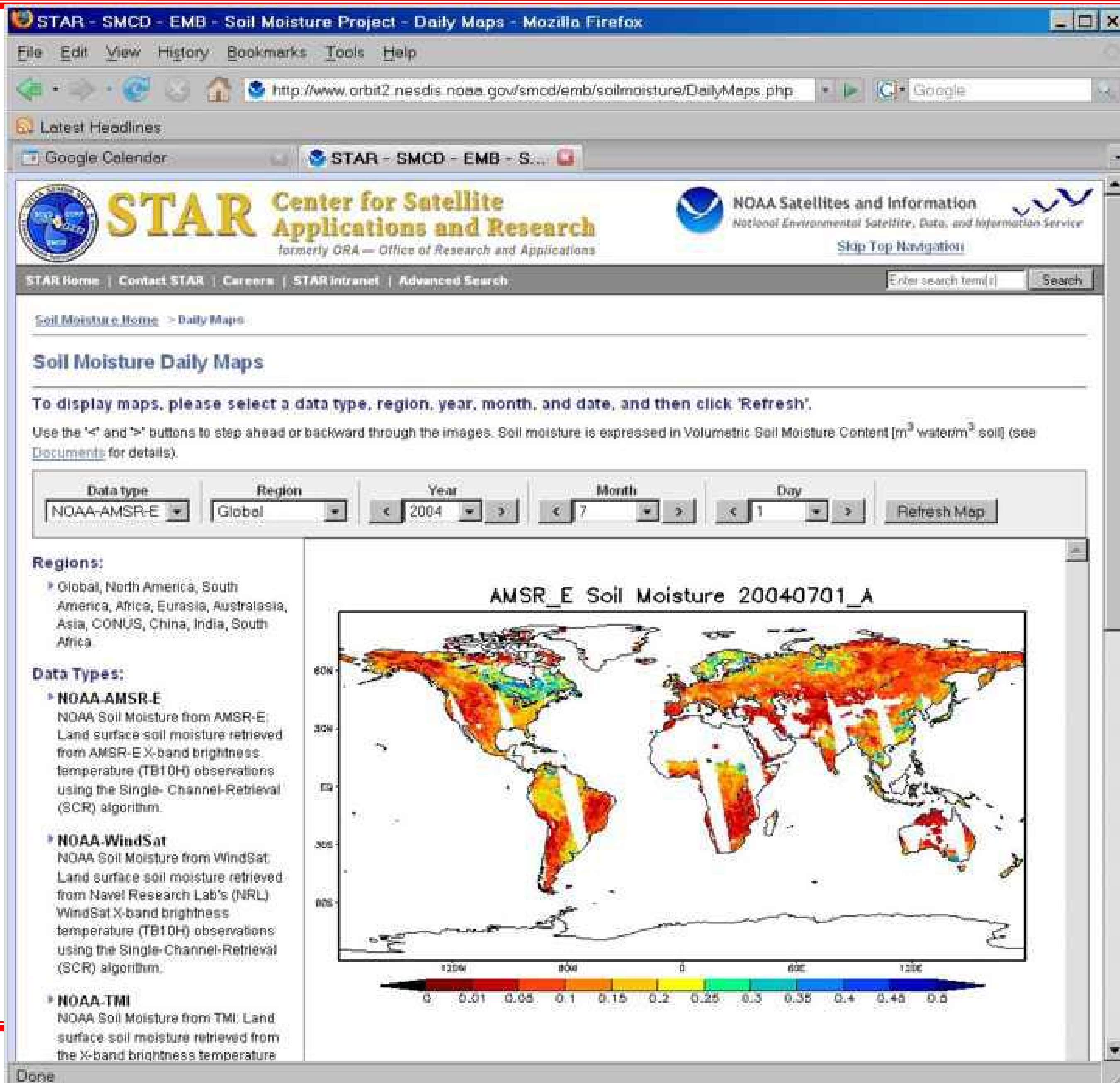
Single Channel Retrieval Results:



from WindSat



NOAA Global Soil Moisture Data Portal:



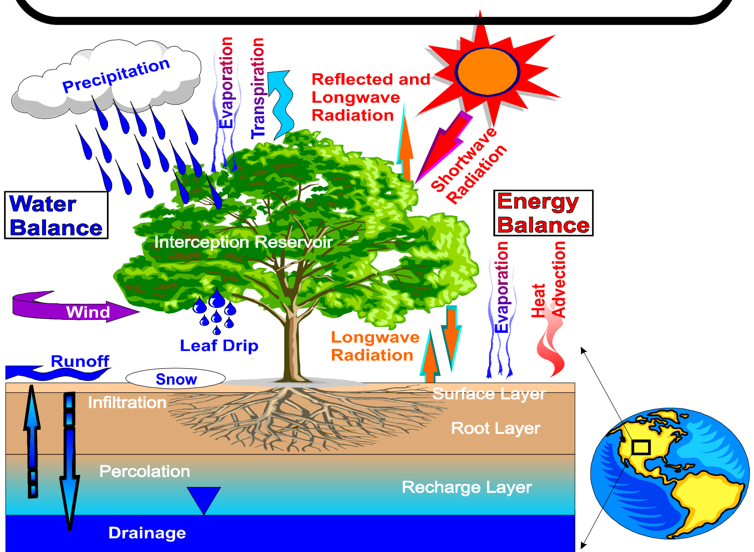
Data Assimilation in Land Information System (LIS):

Inputs

- Topography, Soils
- Land Cover, Vegetation Properties
- Meteorology
- Snow Soil Moisture Temperature

Physics

- Land Surface Models



- Data Assimilation Modules

Outputs

- Soil Moisture & Temperature
- Evaporation
- Runoff
- Snowpack Properties

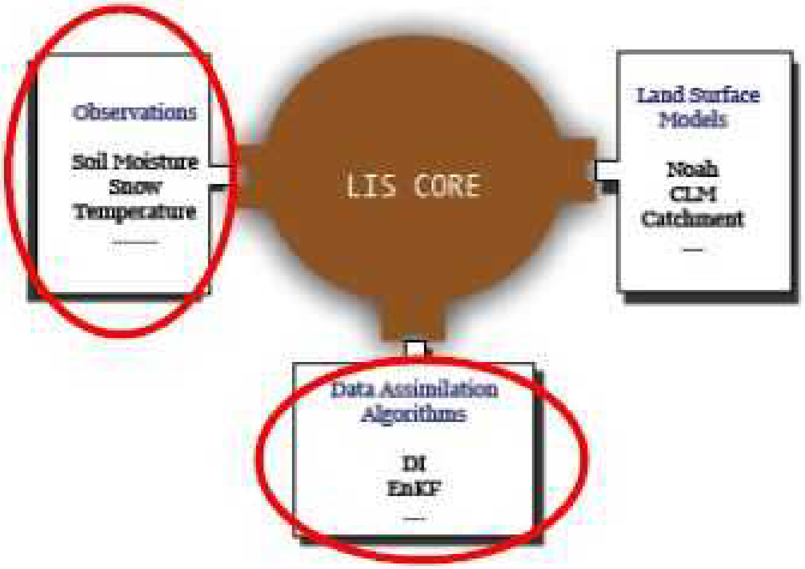
Applications

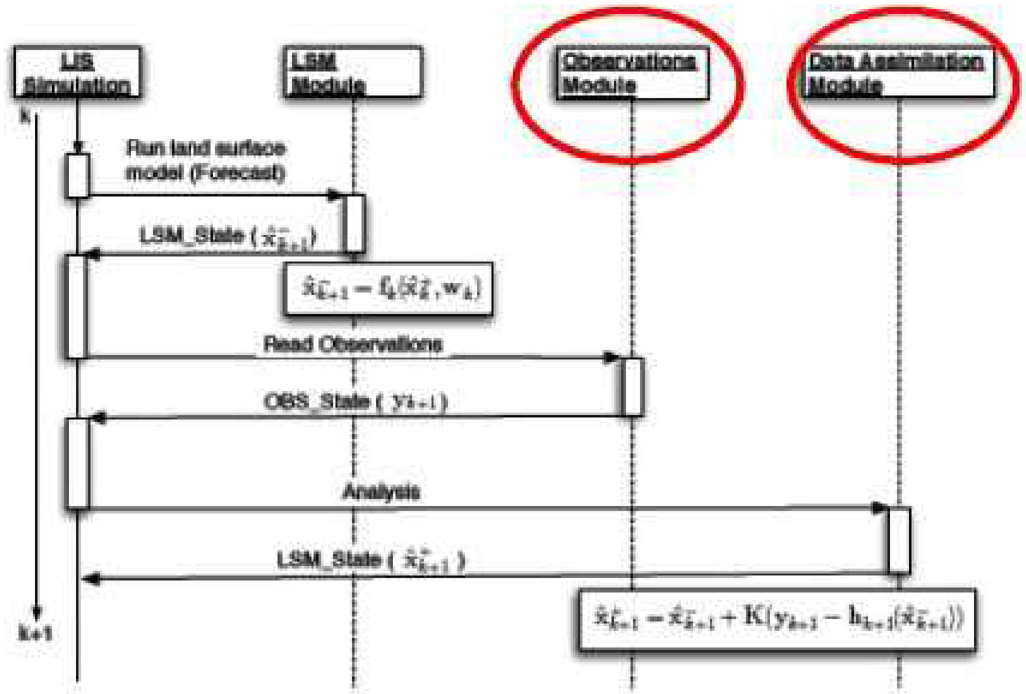
- Weather/ Climate
- Water Resources
- Homeland Security
- Military Ops
- Natural Hazards

(Courtesy of Houser & Peters-Lidard, 2006)

Data Assimilation in Land Information System (LIS):

Generic LIS-DA framework already in place, including the NASA/GMAO EnKF module, and has been demonstrated for soil moisture and snow examples (Kumar et al., AWR 2008, in press):



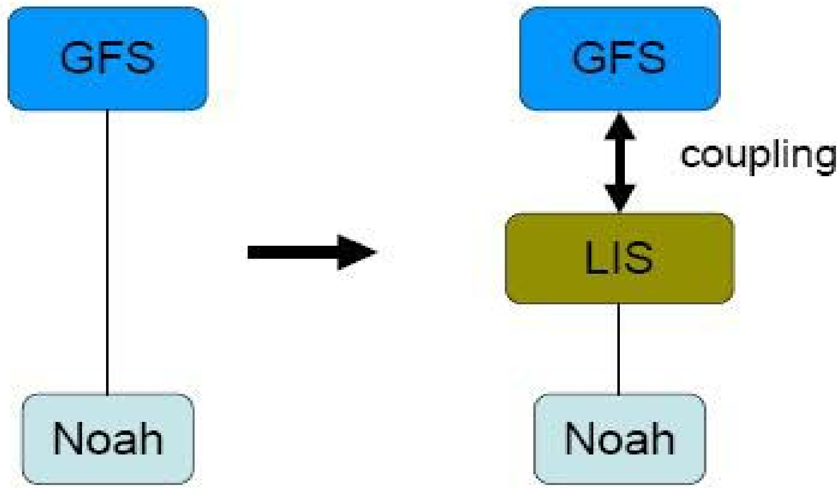


(Courtesy of Kumar, 2008)

LIS and Global Forecast System (GFS) of NCEP:

Initial Coupling Design of GFS-LIS

Replicate the benchmarks



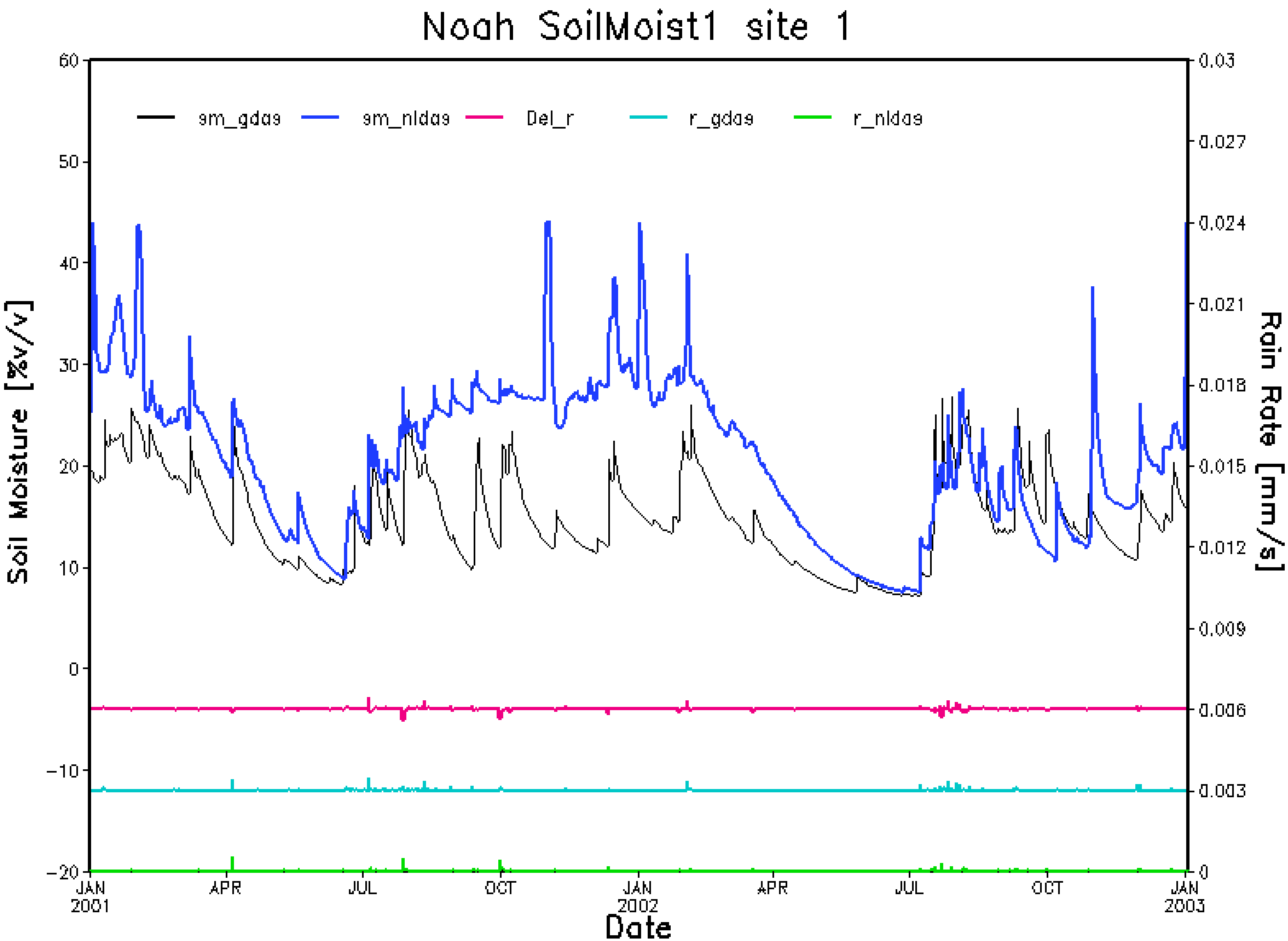
GFS calls Noah through LIS with the same GFS's initialization and the same version of Noah

(Courtesy of Peters-Lidard, 2007)

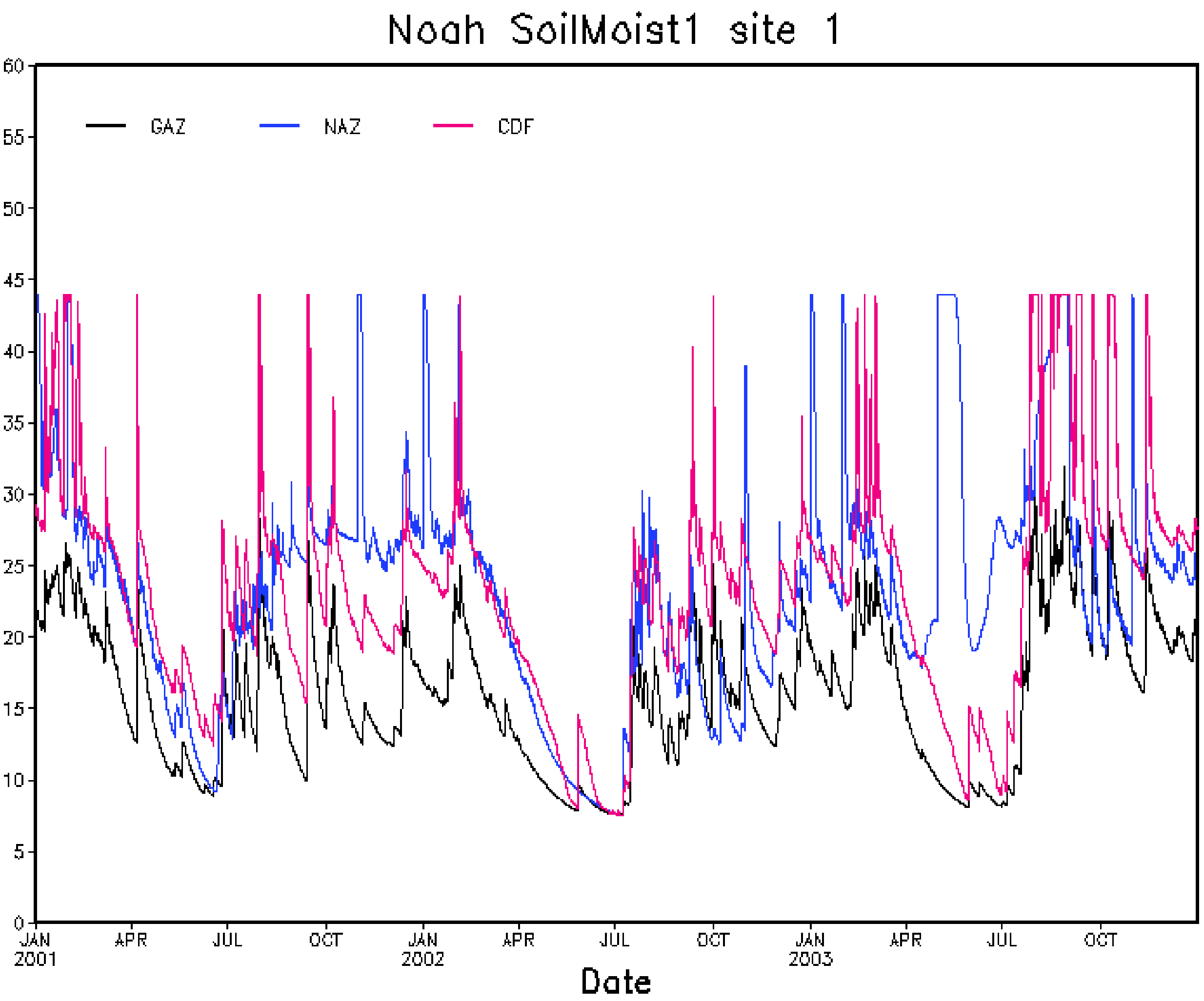
LIS-GFS Soil Moisture Data Assimilation Issues:

1. ***Climatology difference between satellite data products and Noah LSM simulations;***
2. ***Optimal EnKF data assimilation requires correct model and observation error variances parameters;***
3. ***Satellite sensing depth does not match with Noah LSM top soil layer depth.***

Issue 1: Climatology difference



Solutions for Issue 1: CDF Matching



- Data assimilation purpose is to correct model simulations with observations, but CDF matching seems to use model simulations to change observations.
- CDF matching may cause some artifacts to observations.

Solutions for Issue 1: Dee method

$$\mathbf{x}^a = (\mathbf{x}^f - \mathbf{b}^a) + \mathbf{K}\ [\mathbf{y}^o - \mathrm{H}(\mathbf{x}^f - \mathbf{b}^a)]$$

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

$$\mathbf{b}^a = \mathbf{b}^f - \mathrm{L}[\mathbf{y}^o - \mathrm{H}(\mathbf{x}^f - \mathbf{b}^f)]$$

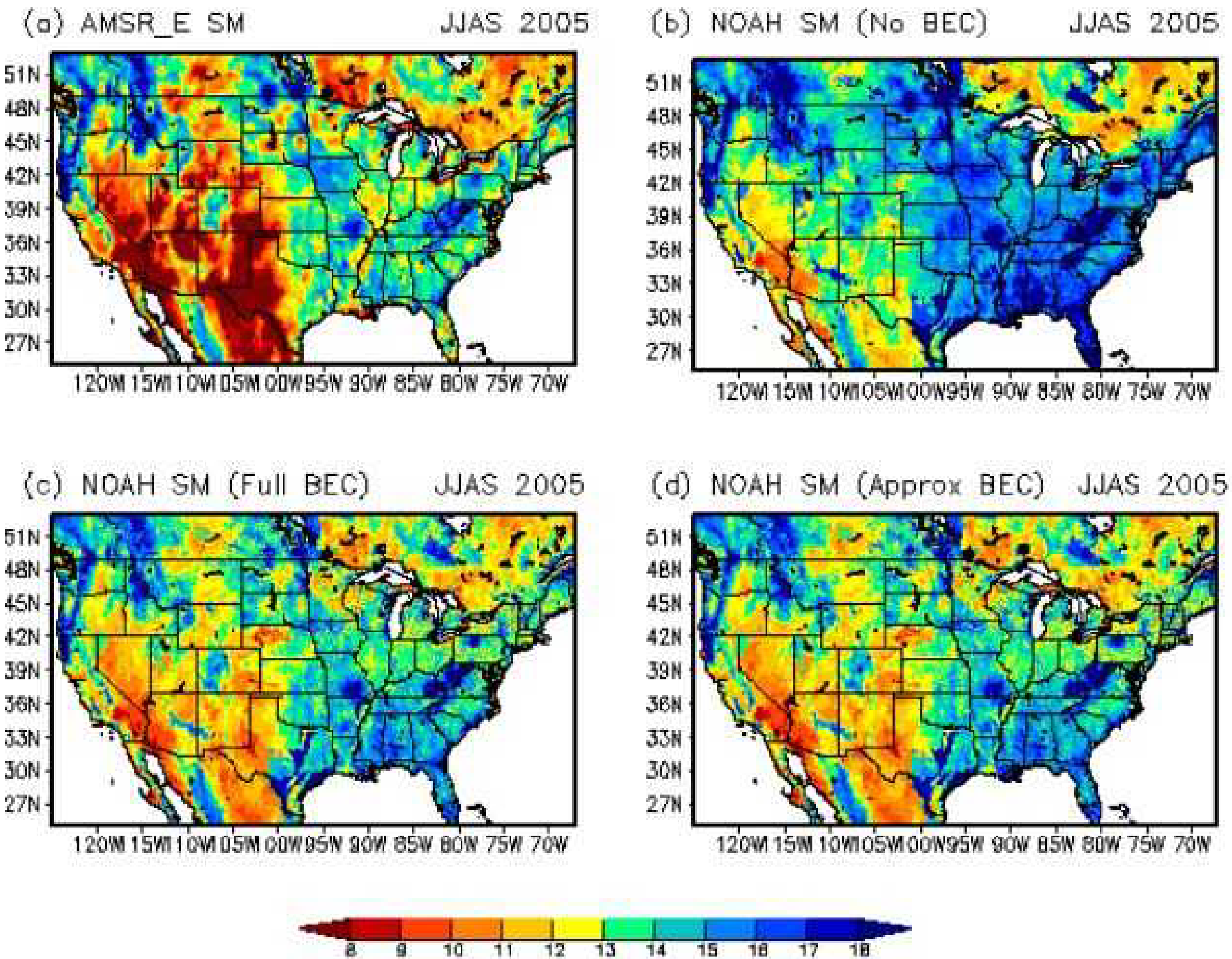
Full Scheme:

$$\mathrm{L} = \mathbf{P}_b^f \mathbf{H}^T (\mathbf{H}\mathbf{P}_b^f \mathbf{H}^T + \mathbf{H}\mathbf{P}_x^f \mathbf{H}^T + \mathbf{R})^{-1}$$

Simplified Scheme:

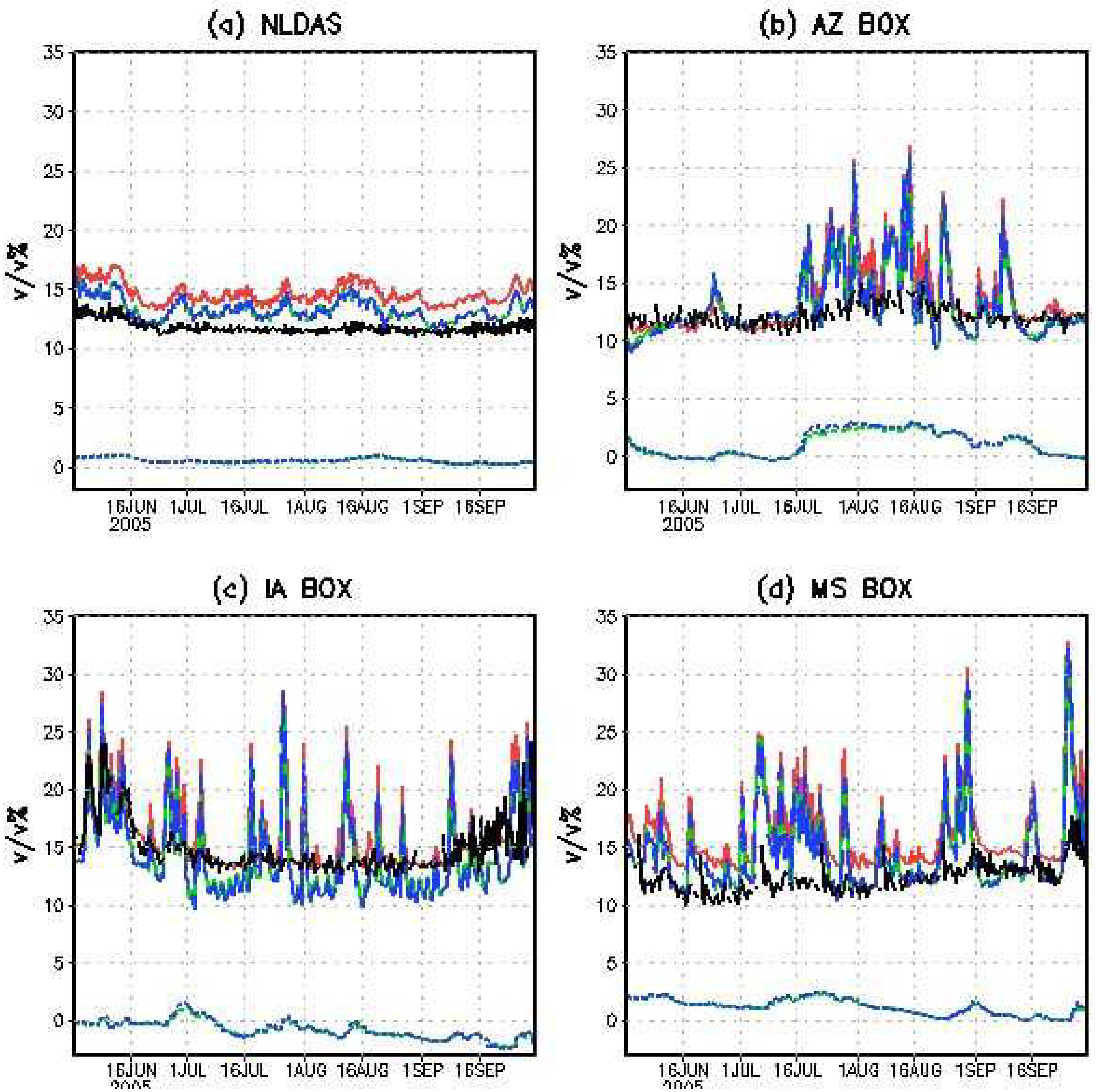
$$\mathrm{L} = \alpha \mathbf{K}$$

Solutions for Issue 1: Dee method



(Courtesy of Luo, Houser & Zhan, 2008)

Solutions for Issue 1: Dee method



(Courtesy of Luo, Houser & Zhan, 2008)

Solution for Issue 2: Adaptive EnKF

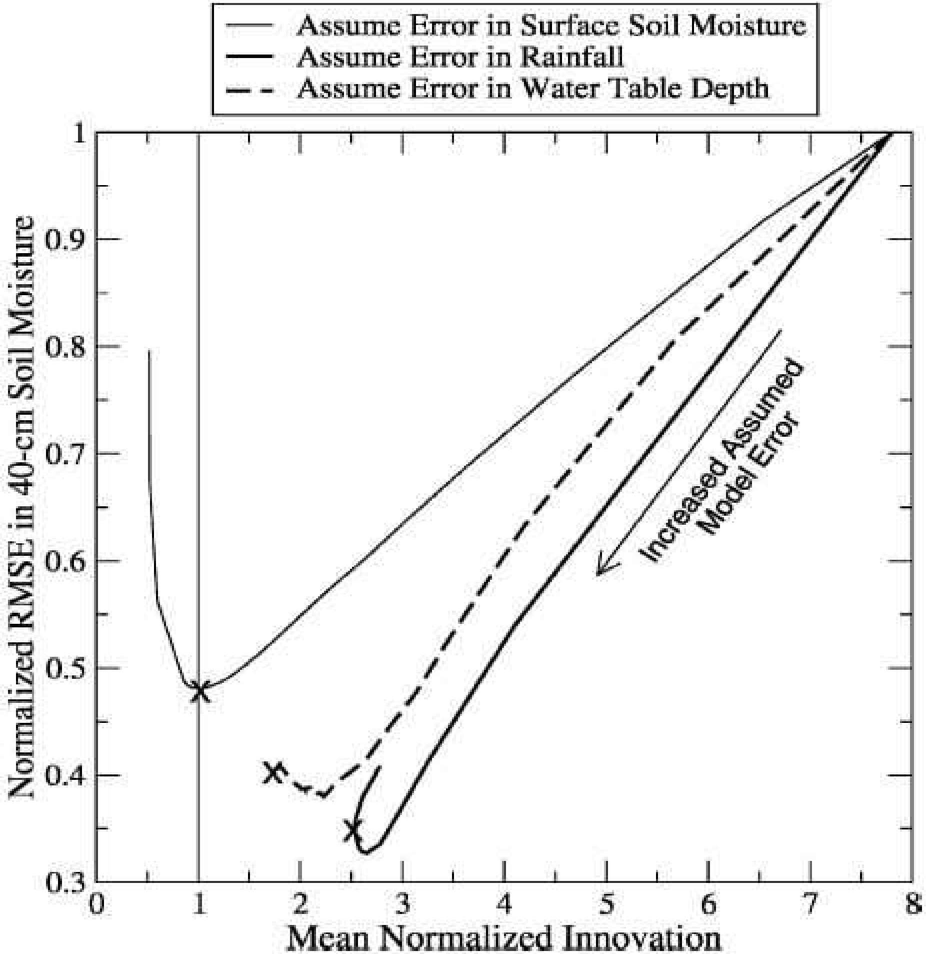
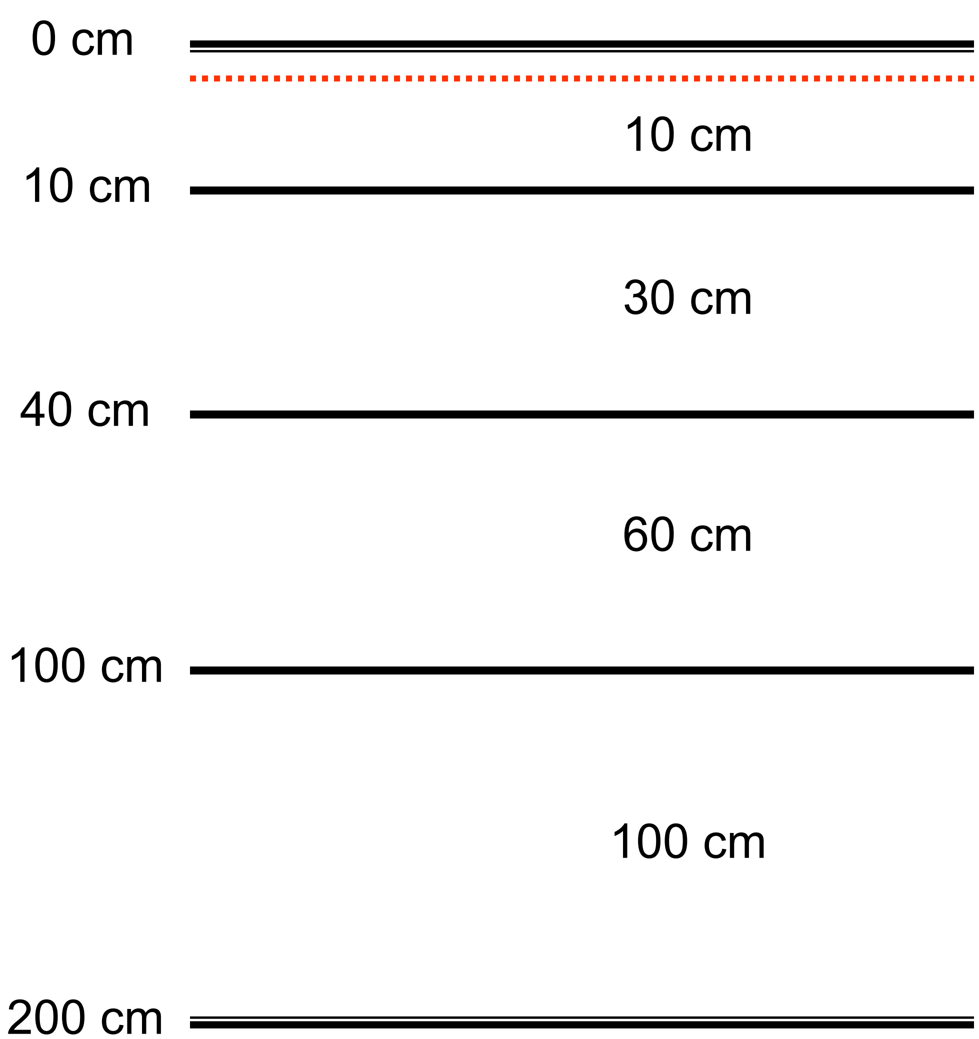


FIG. 7. Relationship between mean normalized innovations ($\overline{\alpha}$) and normalized EnKF-based root-zone soil moisture predictions for the case of actual error is distributed between model surface soil moisture predictions, rainfall forcing, and water table depth predictions, and assumed model error is limited to a single source.

- Crow & van Loon (2006) found that EnKF gives optimal results when the model error variance parameter makes the mean normalized innovation equals 1.
- Rechiele et al (2008) tested that an adaptive EnKF with internal adjustments to model and observation errror variances parameters is achievable.

(Courtesy of Crow & van Loon, 2006)

Solutions for Issue 3: Noah LSM top layer depth



Satellite sensing depth 0.2 – 5cm

- The depth difference may have impact on soil moisture diurnal cycling, drying down period length, and correlation between the top layer and the deeper layers which is the base for using top layer observation to update deep layer simulations.

Conclusions/Future Work:

- ***Current satellite soil moisture retrievals have significant difference across sensors and retrieval algorithms.***
- ***Using Simultaneous Conical-scanning Overpass (SCO) to calibrate brightness temperature observations and the Single Channel Retrieval (SCR) algorithm may provide a more consistent global soil moisture data product.***

- ***Each of these satellite soil moisture data products may have significantly different climatology from the Noah LSM climatology. Bias correction methods need to be further tested and implemented in LIS-GFS.***
- ***The EnKF in LIS-GFS needs to be examined for obtaining optimal soil moisture estimates.***
- ***Noah LSM top layer depth and correlation with deeper layers need to be examined for assimilating shallow observations of satellite sensors.***