Soil Moisture Remote Sensing Science and Applications

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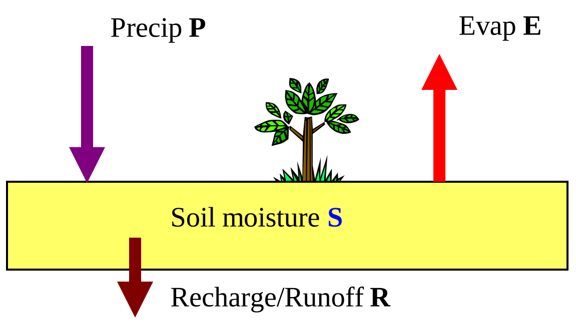
Outline

- **Why Soil Moisture**
- **Soil Moisture Remote Sensing Science**
  MW, TIR
- **Satellite soil moisture product systems**
  SMOPS, GET-D
- **Soil Moisture Data Applications**
  NWP, Drought, Flood, Crop, etc.

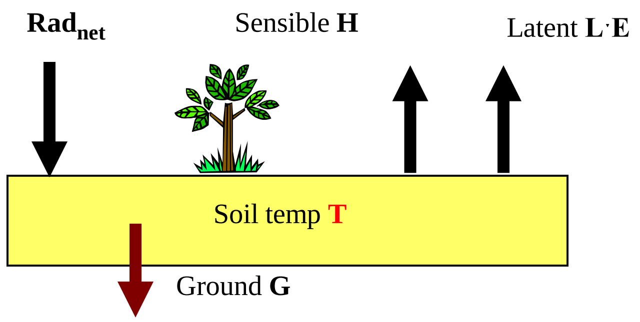
Why Soil Moisture for NOAA

<u>Soil moisture</u> controls land surface **mass** and **energy** partitioning through impacting **<u>evapotranspiration</u>**

Mass balance



Energy balance



$$V\frac{dS}{dt} = P - E(T, S) - R(S)$$

$$\longleftrightarrow$$

$$c\frac{dT}{dt} = Rad_{net}(T) - H(T) - L \cdot E(T, S)$$

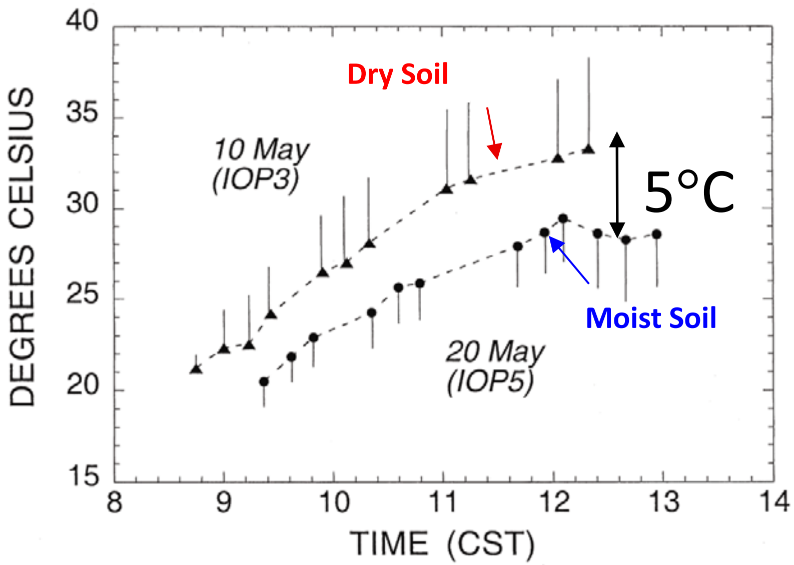
Evaporation & soil moisture **couple mass & energy balances** at land surface

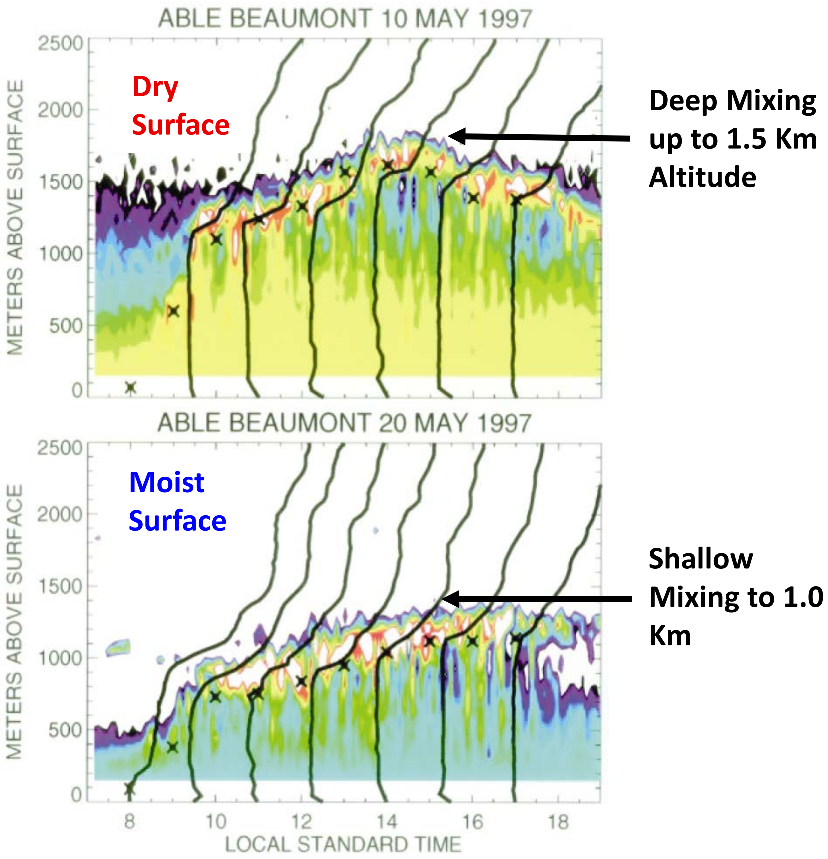
L is the latent heat of vaporization: $2.5\text{x}10^6$ [J/kg]

Why Soil Moisture for NOAA

Over land actual evapotranspiration depends on both **incident energy** and **soil moisture**.

May 10	Dry soil, clear, mild winds. (**LE≈H**)
May 18	90 mm Rain
May 20	Moist soil, clear, mild winds. (**LE>H**)

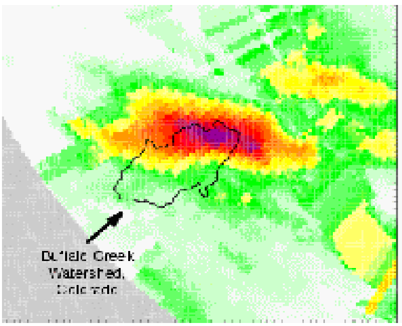




CASES’97 Field Experiment, *BAMS*, 81(4), 2000.

Soil Moisture Impact on Weather Forecasting

Observed Rainfall from intense storm in Colorado:

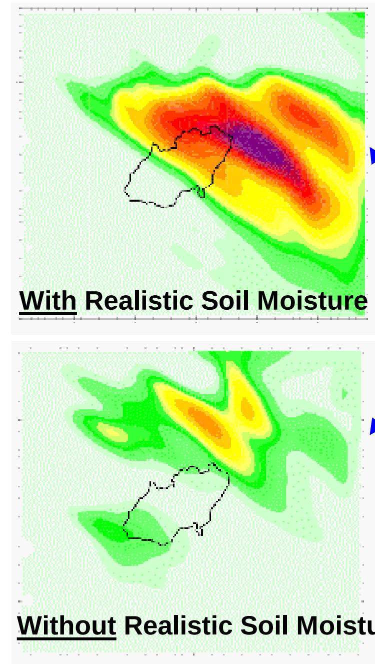


Buffalo Creek Basin

Observed Rainfall
0000Z to 0400Z 13/7/96
(Chen et al., NCAR)

24-Hours Ahead Atmospheric Model Forecasts

Model forecasts with and w/o soil moisture:



Actual storm event is forecasted accurately only if soil moisture information is available.

Soil Moisture Data Will Improve Numerical Weather Prediction (NWP) Over the Continents by Accurately Initializing Land Surface States

“The experience of the last ten years at ECMWF has shown the importance of soil moisture...Soil moisture is a major player on the quality of weather parameters such as precipitation, screen-level temperature and humidity and low-level clouds."

Anthony Hollingworth, ECMWF

"The strong motivation for this land data assimilation and land-monitoring space missions such as Hydros is that the land states of soil moisture, soil ice, snowpack, and vegetation exert a strong control on ...the heating and moistening of the lower atmosphere…forecast of tomorrow's heat index, precipitation, and severe thunderstorm likelihood."

Louis Uccellini, NCEP

Soil Moisture Impacts on Others

Drought & Ag Production

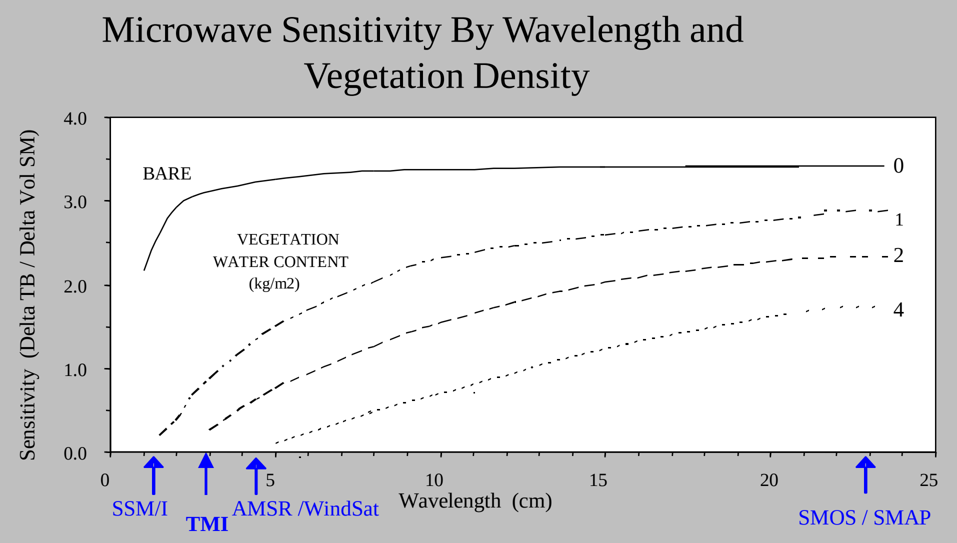
Military Mobility

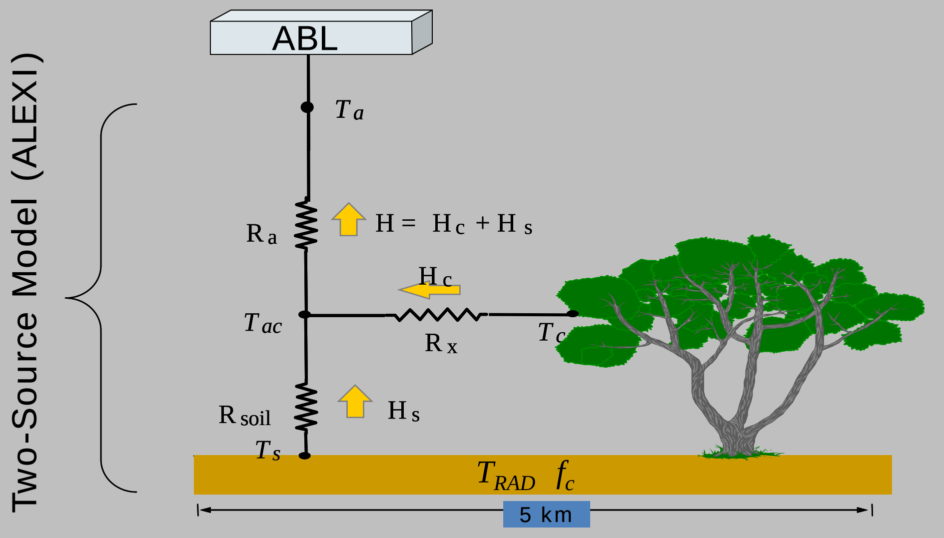
Soil Moisture Remote Sensing Science

Two ways to retrieve soil moisture from satellites:

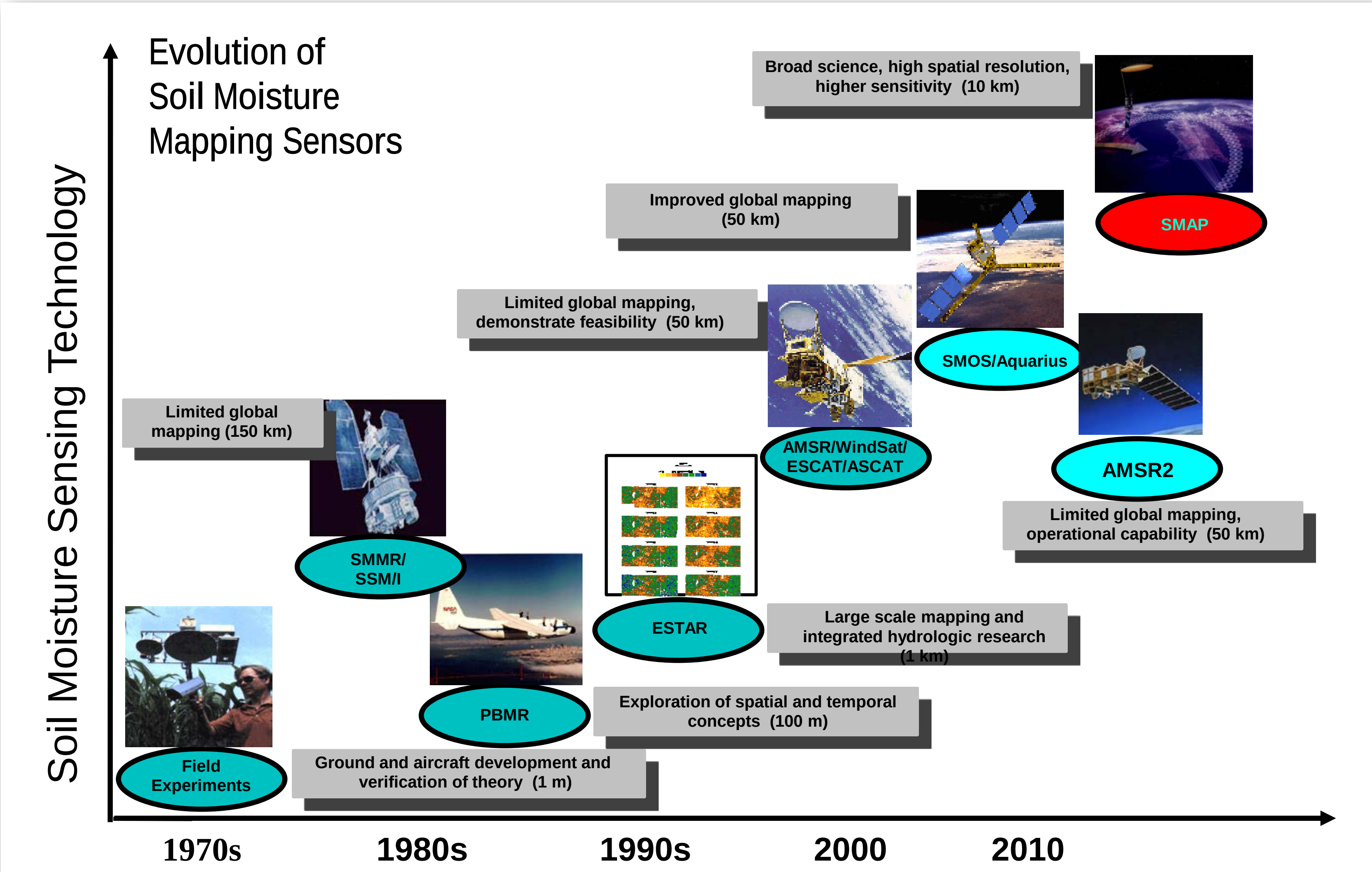
- **Microwave (MW):** Observed MW brightness temperature depends on soil dielectric constant that is related to soil moisture:
  - **Strength:** higher reliability based on direct physical relationships
  - **Weakness:** antenna technology limits spatial resolution

- **Thermal Infrared (TIR):** Observed surface temperature changes result from surface energy balance that is dependent on soil moisture:
  - **Strength:** TIR sensor could have higher spatial resolution
  - **Weakness:** relies on land surface energy balance model that is prone to input data errors.





MW Soil Moisture Remote Sensing Technology



MW Soil Moisture Remote Sensing: Retrieval Algorithm Science

Soil Moisture Retrieval Algorithms

Multi-channel Inversion Algorithm (MCI):

(Njoku & Li, 1999)

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

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

$$\tau_i = b * VWC$$

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

$R_s = f(\varepsilon)$ -- *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 Retrieval Algorithms

Land Parameter Retrieval Model (LPRM):

(Owe, de Jeu & Holmes, 2008)

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

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

$\tau = f(MPDI)$, $MPDI = (T_{Bv}-T_{Bh})/(T_{Bv}+T_{Bh})$

$e_h = f(e_s, h, Q)$

$e_s = f(\varepsilon)$ -- Fresnel equation

$\varepsilon = f(SM)$ -- Mixing model (Dobson'85, others)

$T_s = f(T_{B37v})$ or T_s^{LSM}

$T_{Bh}^{obs} = T_{B06h}$, T_{B10h} or T_{B18h}

Soil Moisture Retrieval Algorithms

Single Channel Retrieval (SCR) Algorithm:

(Jackson, 1993)

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

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

$$R_s = f(\varepsilon) \quad \text{-- Fresnel Equation}$$

$$\varepsilon = g(SM) \quad \text{-- Mixing model}$$

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

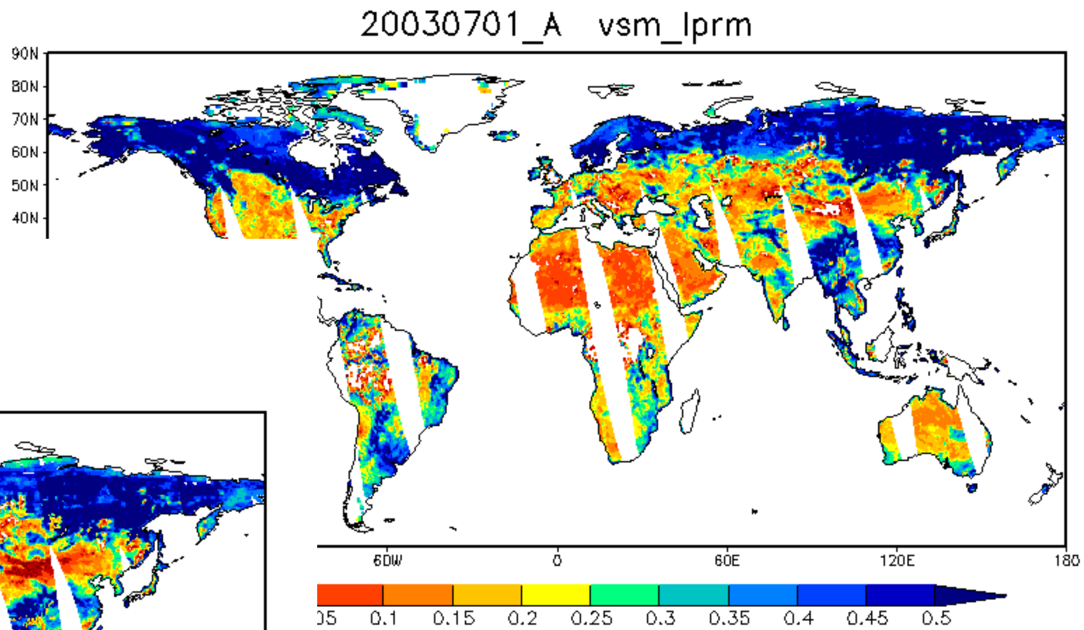
$$\tau = b * VWC$$

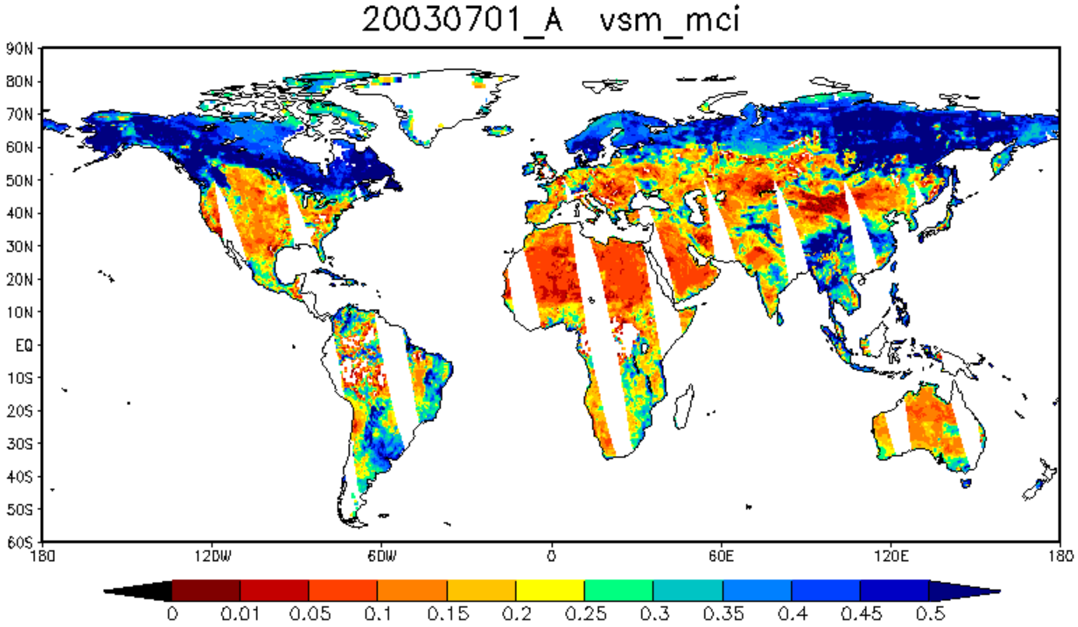
$$VWC = reg_2(NDVI)$$

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

Impact of Tau = f(MPDI) on SM Retrievals:

LPRM with τ = f(MPDI)

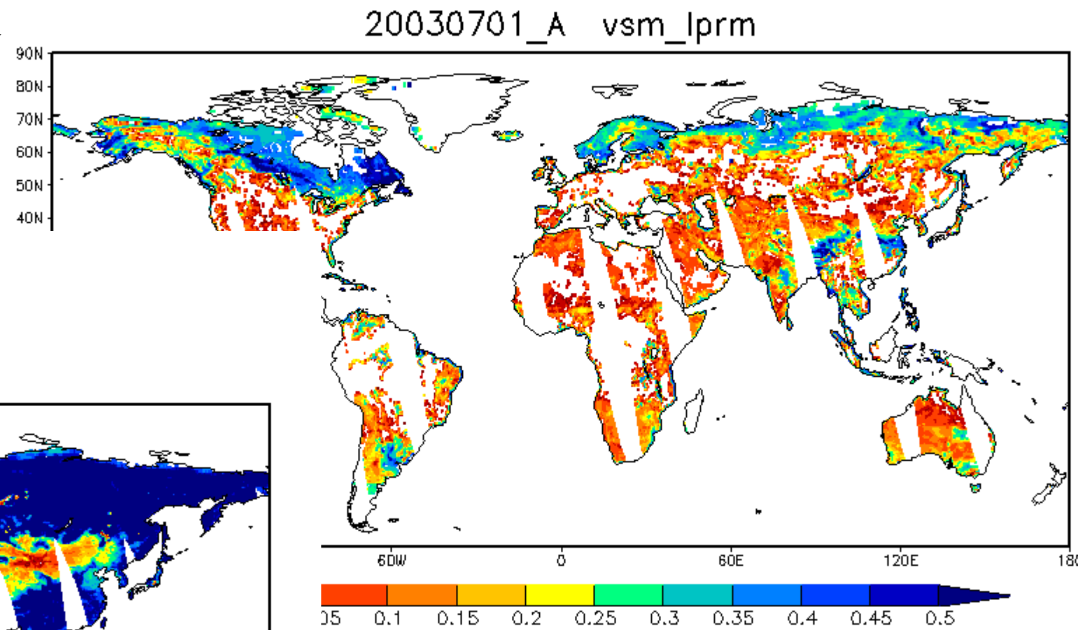


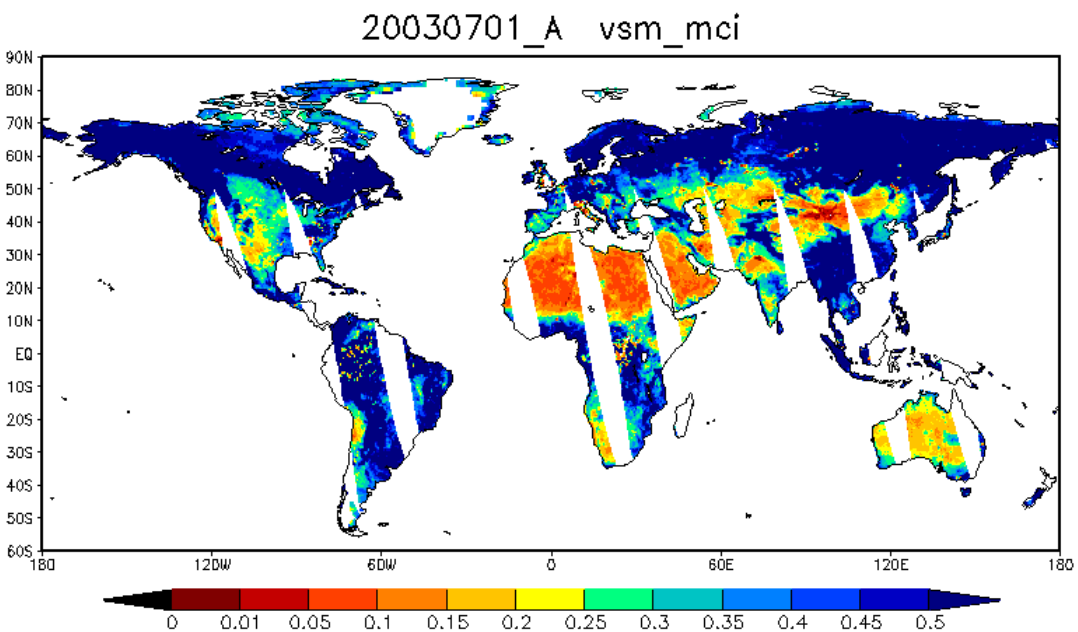


MCI with T_s= f(T_{B37v})

Impact of Ts error on LPRM/MCI Retrievals:

T_s + 2K

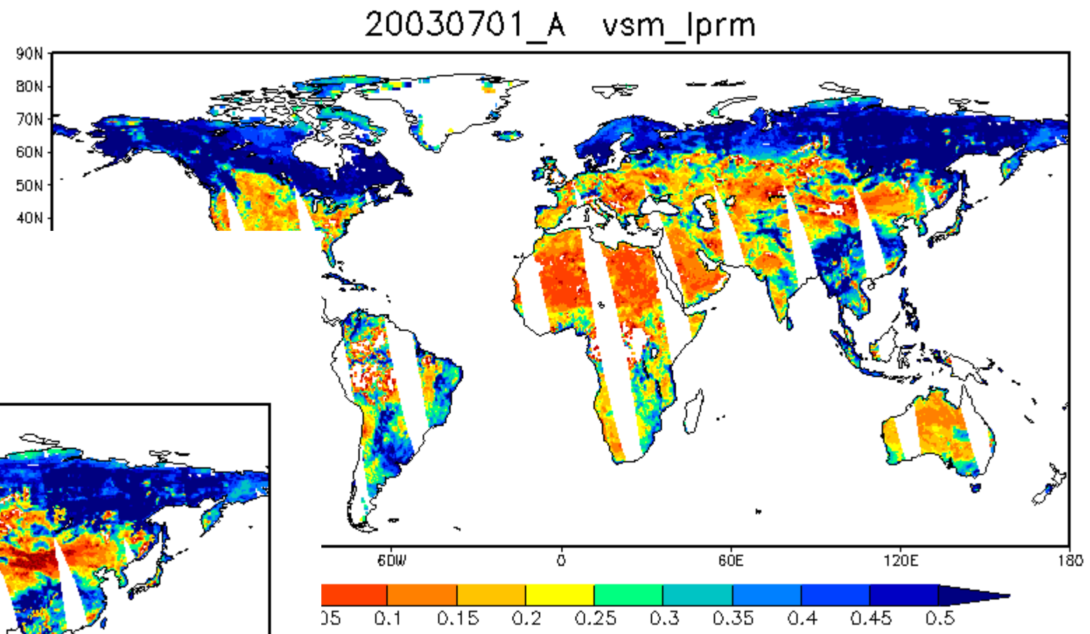


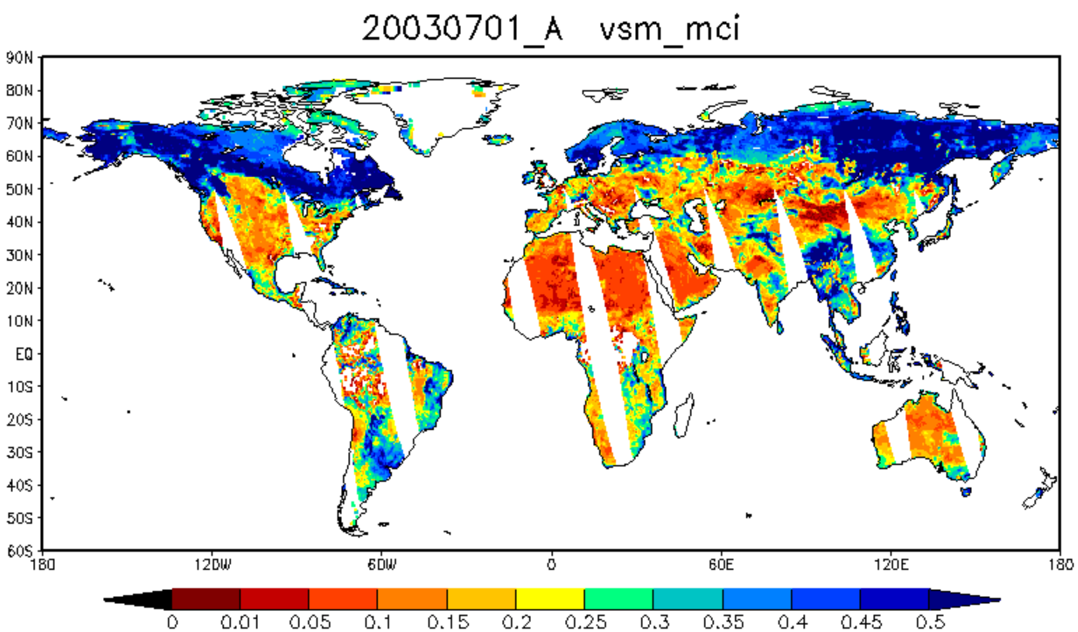


T_s – 2K

Impact of Ts error on LPRM/MCI Retrievals:

No T_s errors

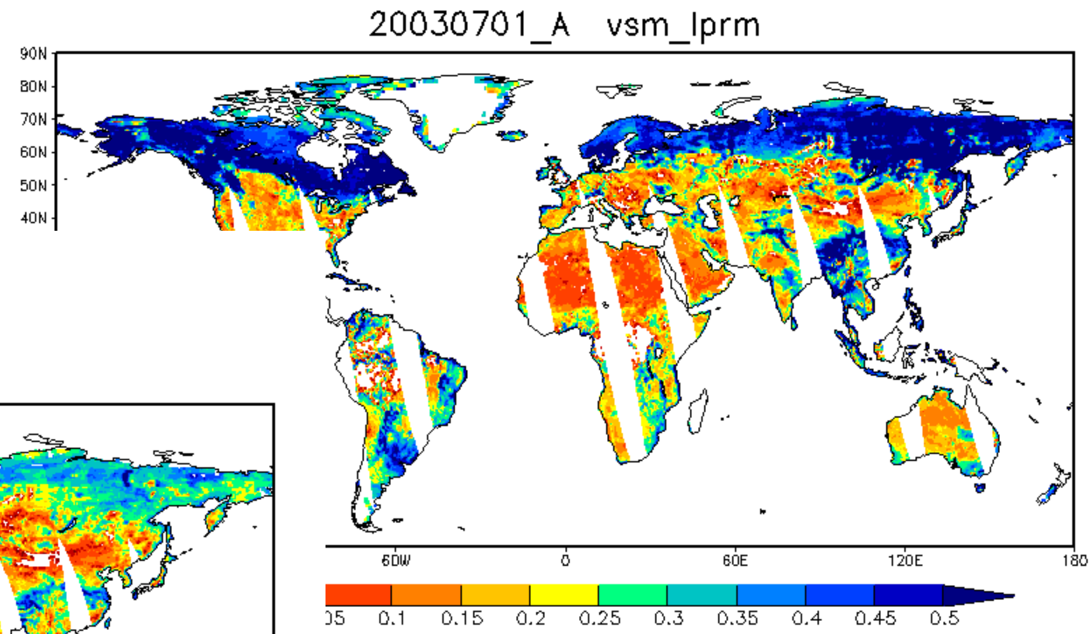


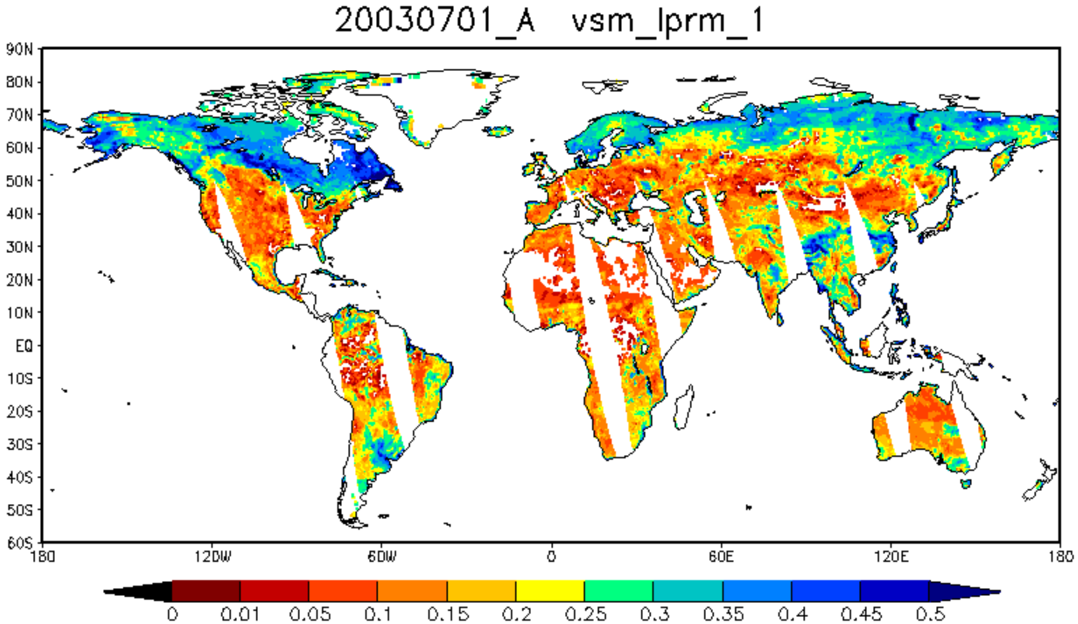


No T_s errors

Impact of Tb error on LPRM/MCI Retrievals:

T_{bh} + 2K
T_{bv} - 2K

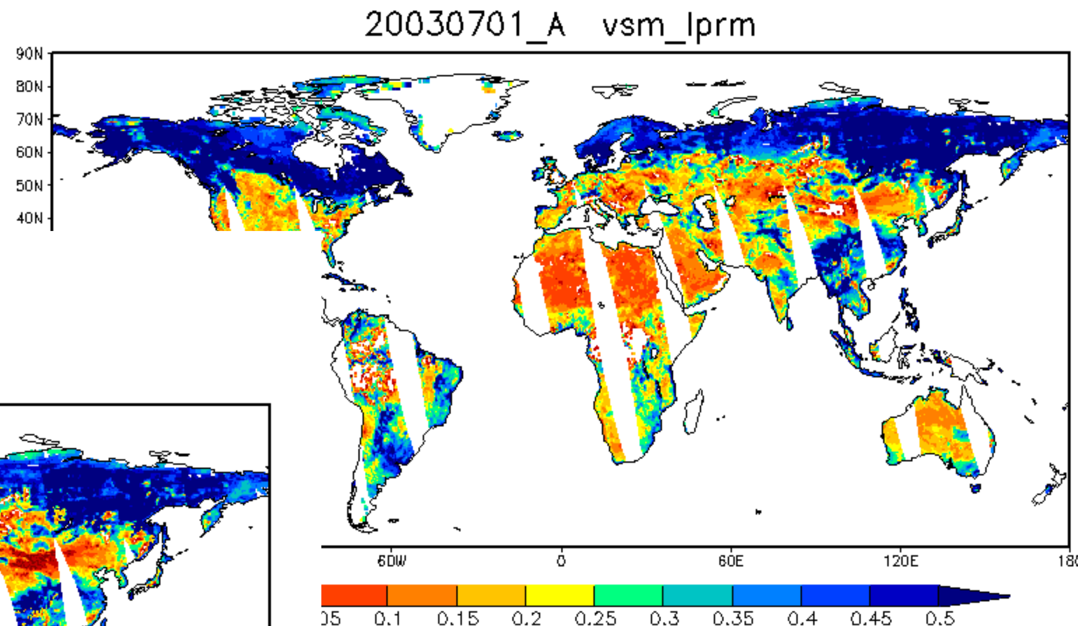


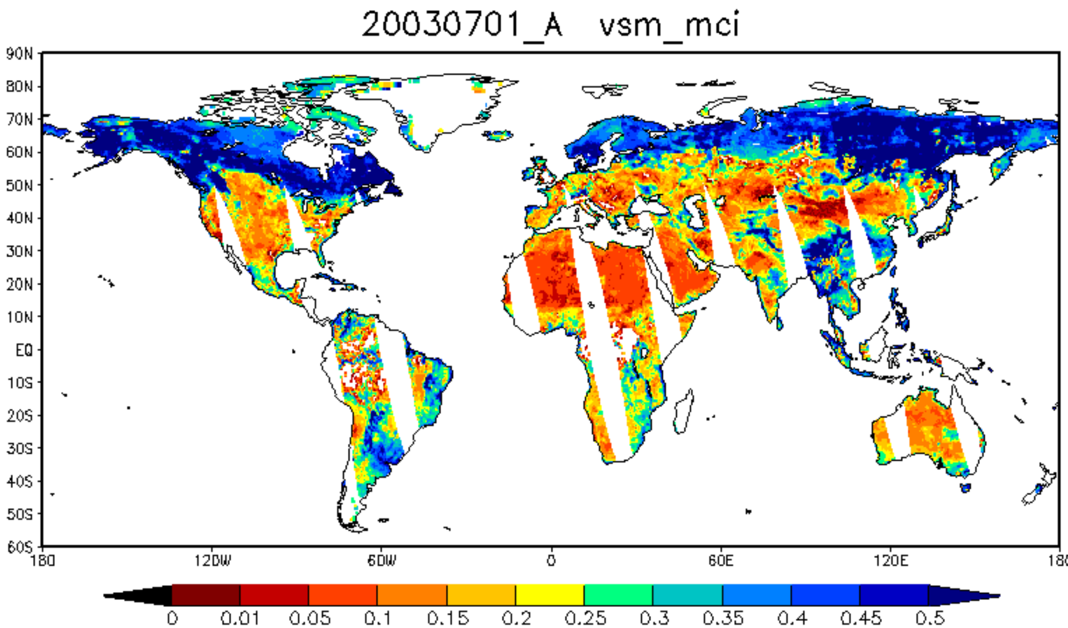


T_{bh} - 2K
T_{bv} + 2K

Impact of Tb error on LPRM/MCI Retrievals:

No T_b errors

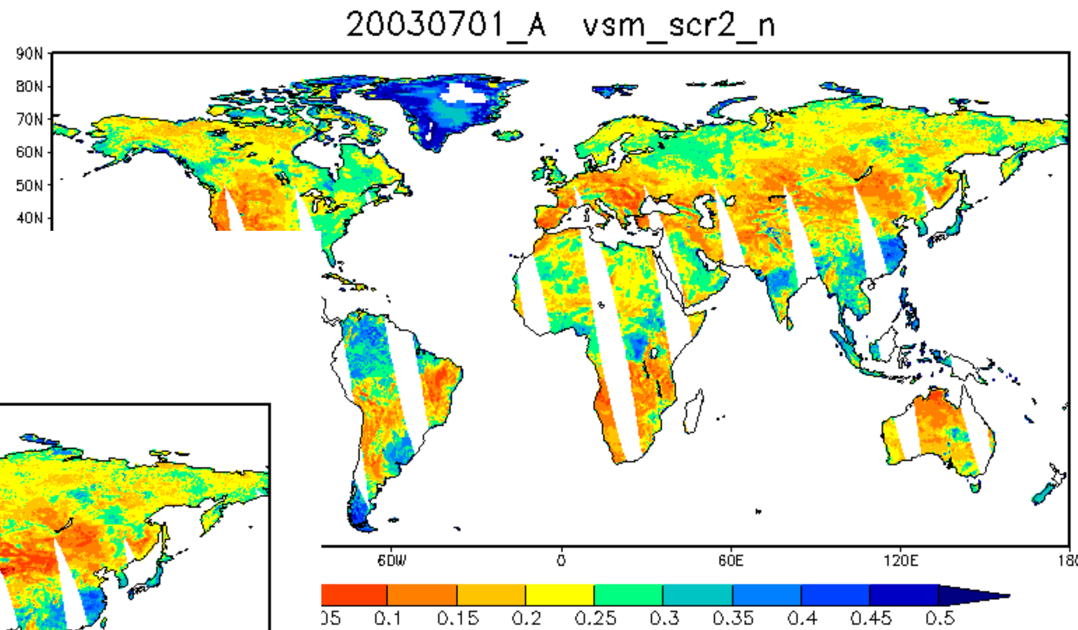


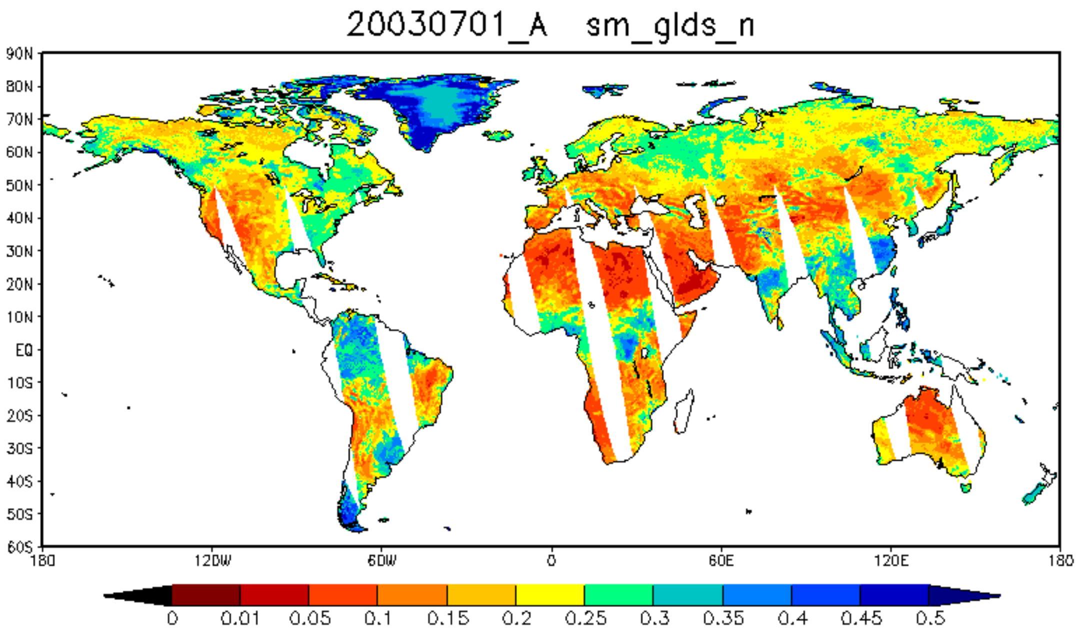


No T_b errors

Impact of Tau error on SCA Retrievals:

τ + 0.01

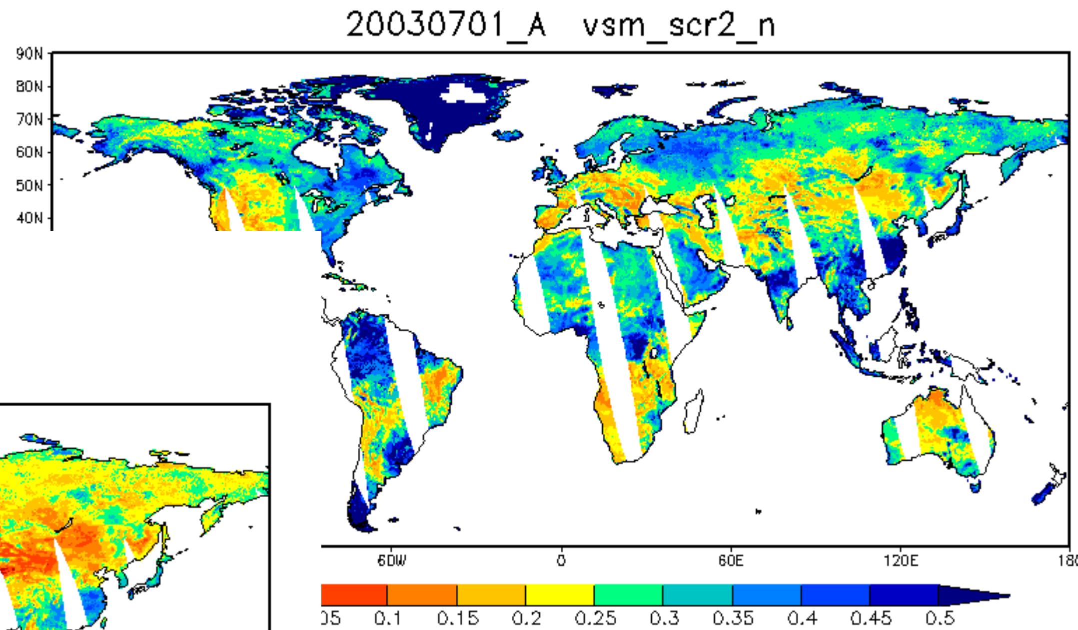


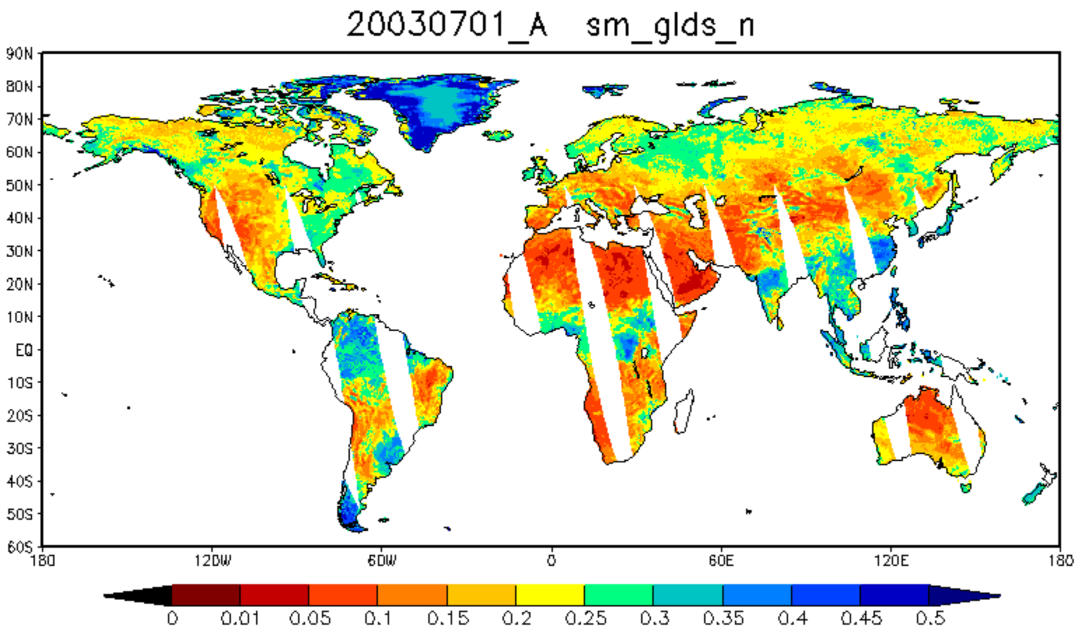


No τ error

Impact of Tau error on SCA Retrievals:

τ + 0.05

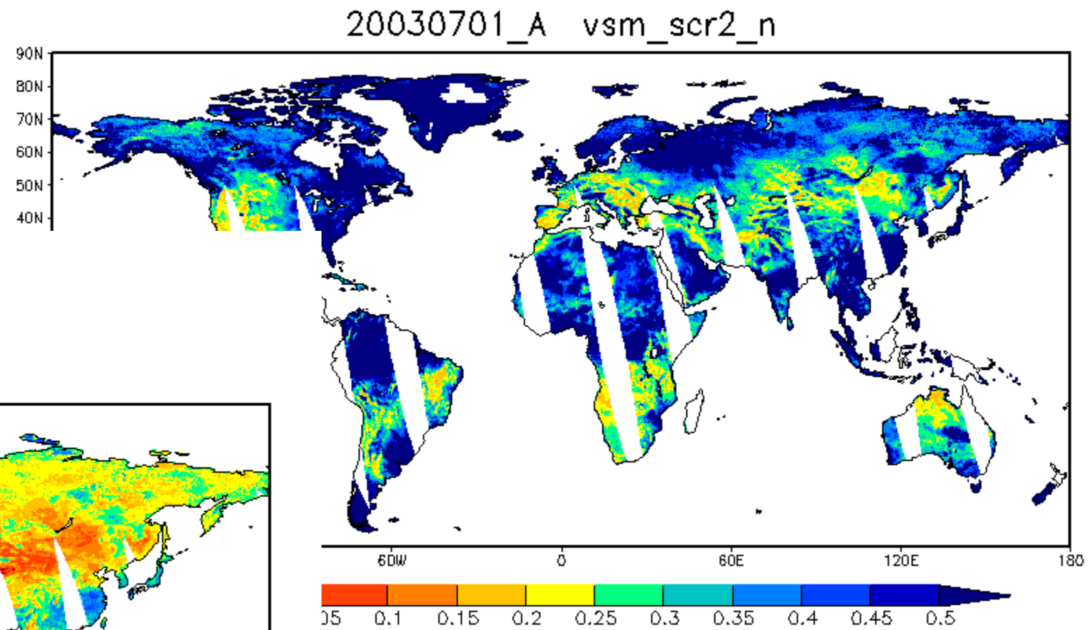


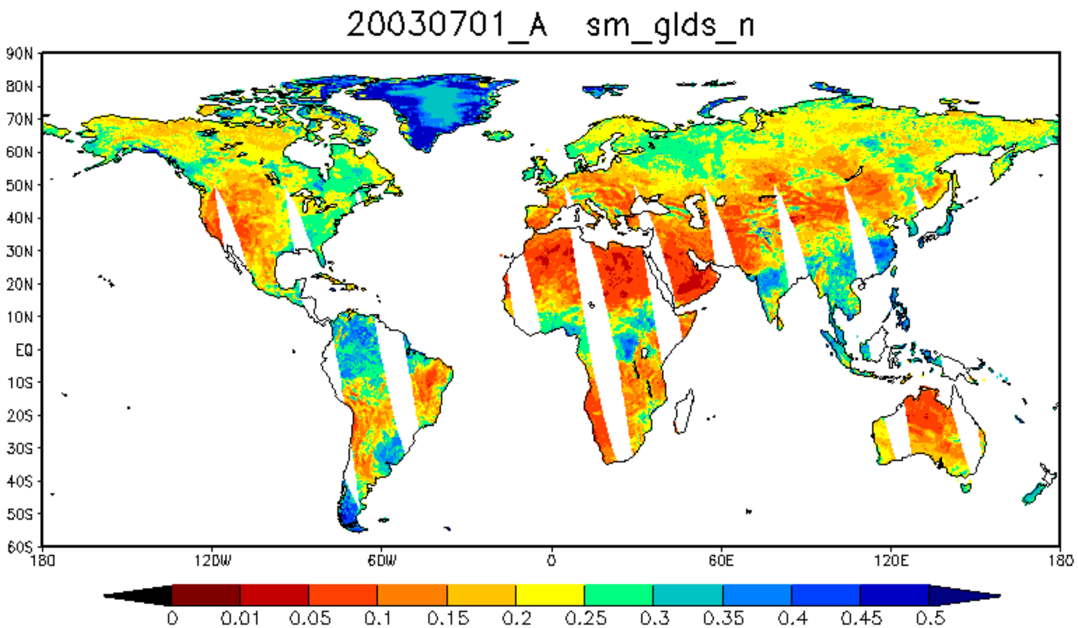


No τ error

Impact of Tau error on SCA Retrievals:

τ + 0.1

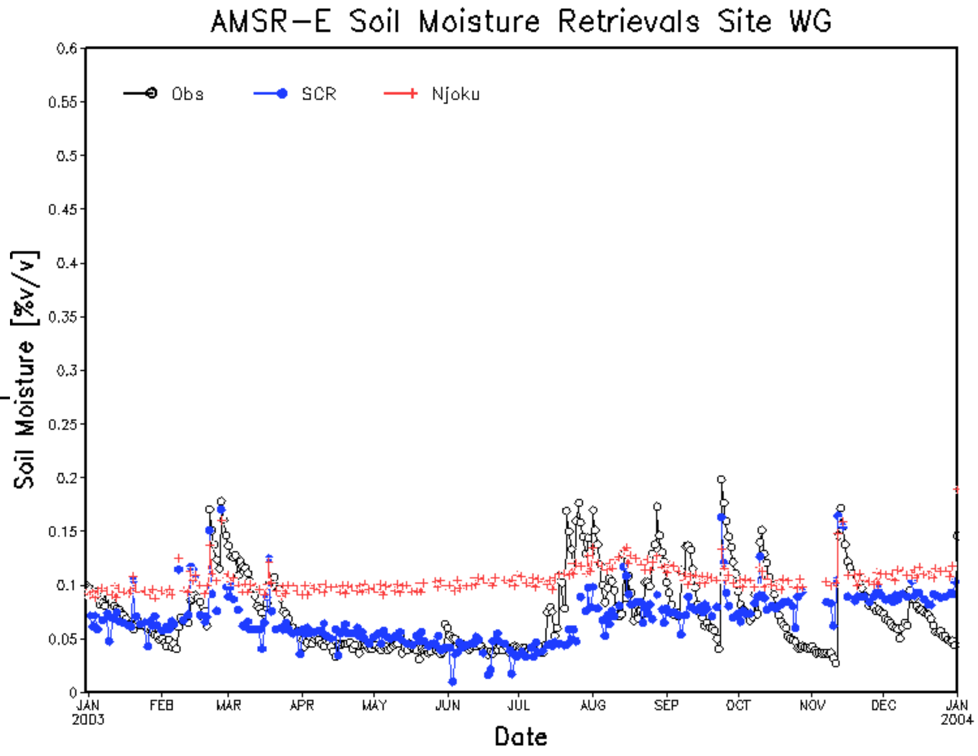


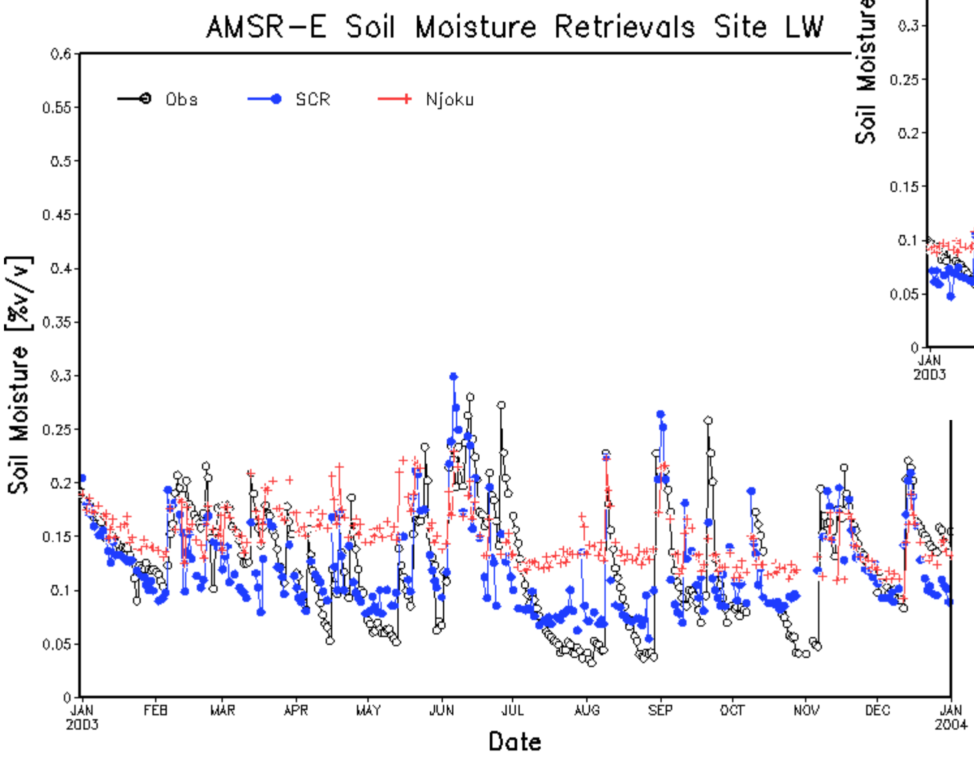


No τ error

Soil Moisture Retrieval Validation

SCR and MCI Compared with In Situ Measurements





Soil Moisture Operational Product System (SMOPS)

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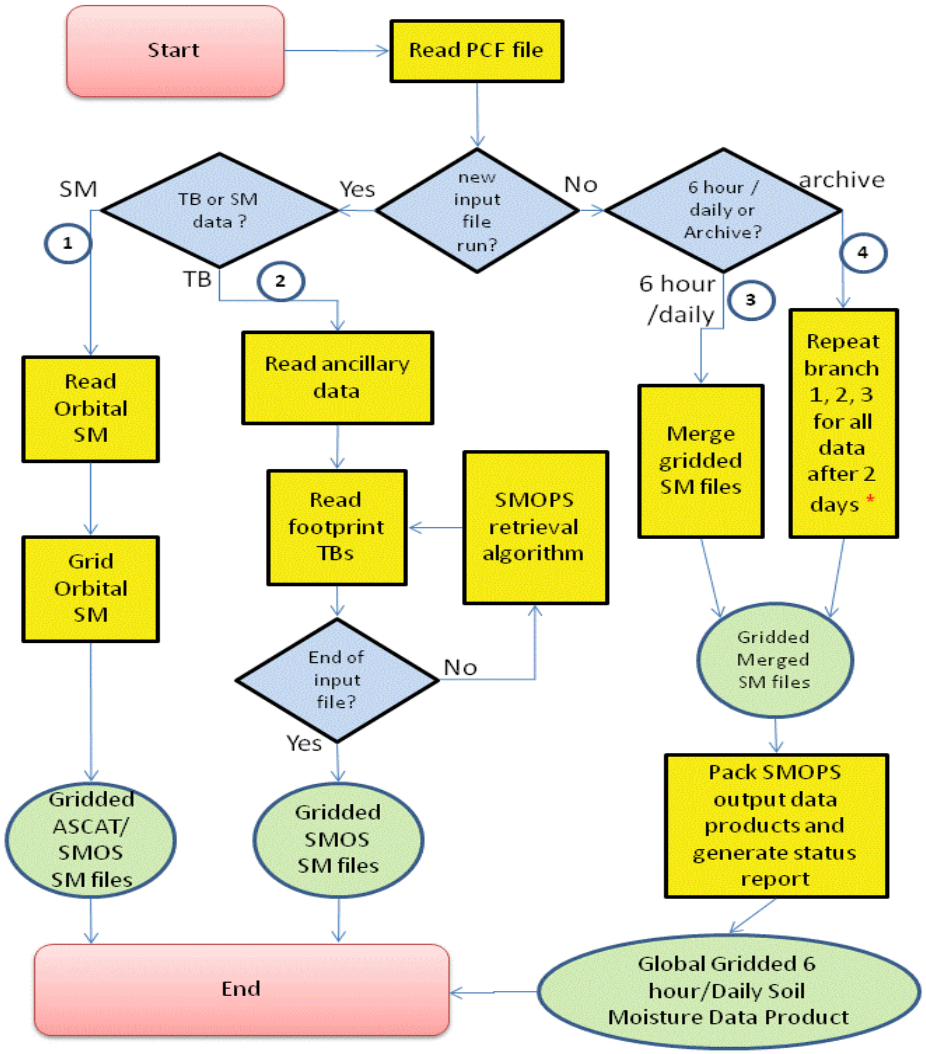
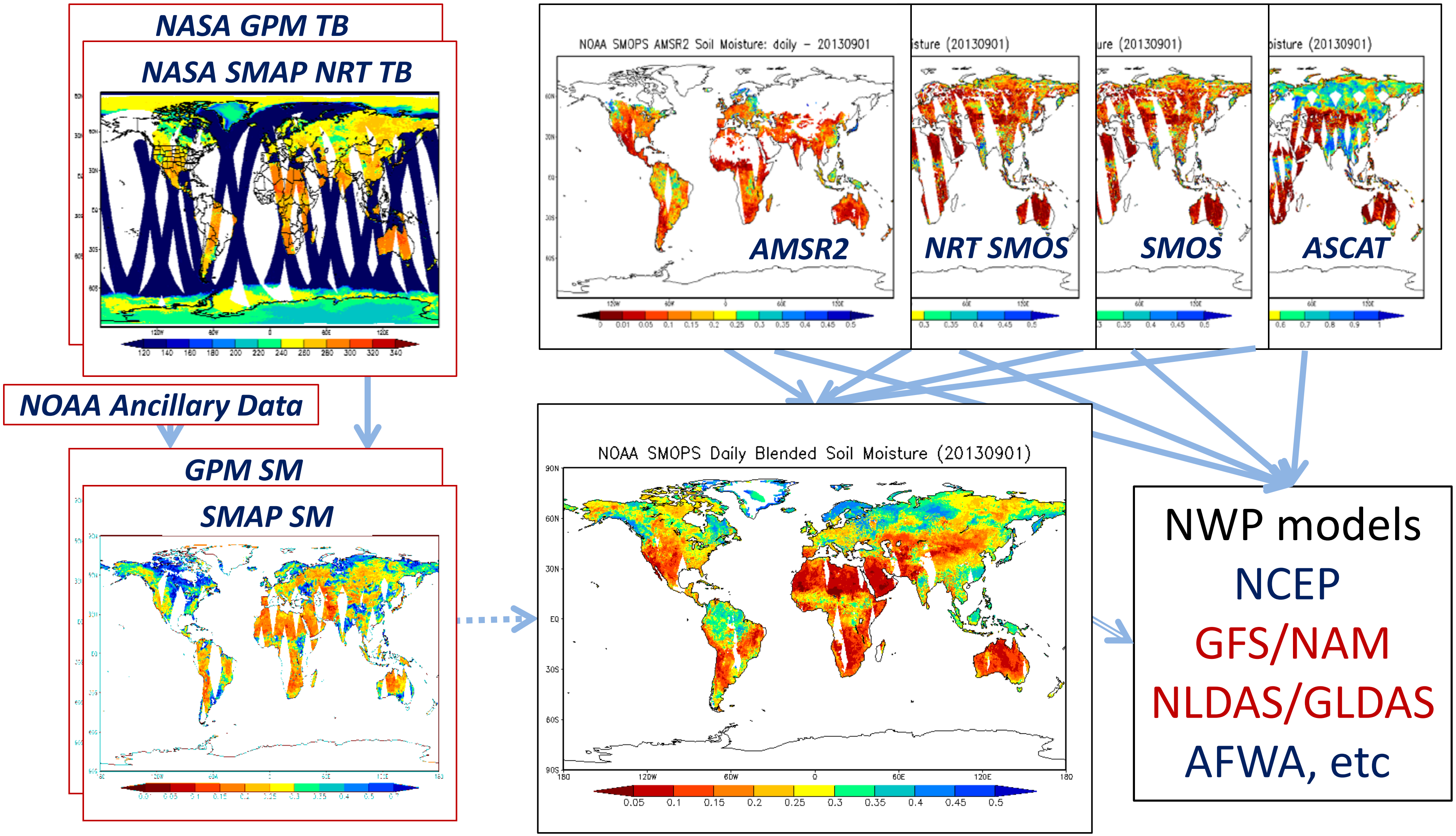


* *All data acquired within the 6 hour or whole day time period arrived in the past 48 hours*

1. **SM ingesting**
2. **SM retrieving**
3. **SM merging**
4. **Reprocessing for the archive product**

Soil Moisture Operational Product System

SMOPS 2.0/3.0



NESDIS SMOPS 3.0 upgraded over the current SMOPS 2.0 will Ingest NASA SMAP NRT and GPM TB data to retrieve global soil moisture with NOAA ancillary Data

SMOPS Product Suite

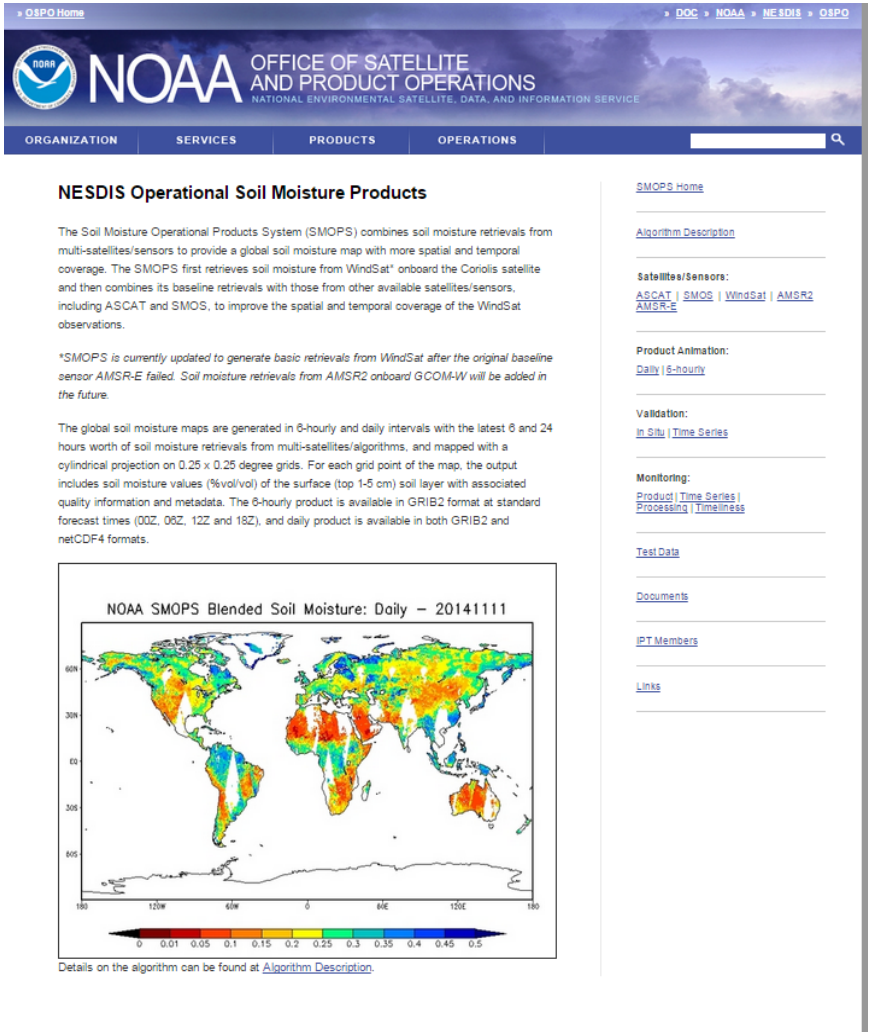
Products	Description	Format	Projection	Spatial Coverage	Spatial Resolution	Main Purpose
SMOPS 6-Hour Product	SMOPS 6-hour Gridded Soil Moisture	GRIB2	Lat/Long	Global	0.25 degree (720x1440)	For operational use
SMOPS Daily Product	SMOPS Daily Gridded Soil Moisture	GRIB2	Lat/Long	Global	0.25 degree (720x1440)	For operational/research use
SMOPS Archive Product	SMOPS Daily Gridded Soil Moisture	netCDF4	Lat/Long	Global	0.25 degree (720x1440)	For research use

SMOPS Product Data Layers

Soil Moisture Product	SMOPS Version 1.3	SMOPS Version 2.0	SMOPS Version 3.0
SMOPS Blended	√ (1)	√ (1)	√ (1)
NOAA AMSR-E	√ (2)	×	×
NOAA NRT SMOS	×	√ (2)	√ (2)
ESA SMOS	√ (3)	√ (3)	√ (3)
EUMETSAT ASCAT-A	√ (4)	√ (4)	√ (4)
EUMETSAT ASCAT-B	√ (5)	√ (5)	√ (5)
NOAA WindSat	√ (6)	×	×
NOAA AMSR2	×	√ (6)	√ (6)
NOAA GMI	×	×	√ (7)
NOAA NRT SMAP	×	×	√ (8)
NASA SMAP	×	×	√ (9)

NOAA Soil Moisture Operational Product System (SMOPS)

http://www.ospo.noaa.gov/Products/land/smops/index.html



- **Developed by NOAA/NESDIS/STAR**
- **Operationally running at NOAA/NESDIS/OSPO**

Operational data access contact:
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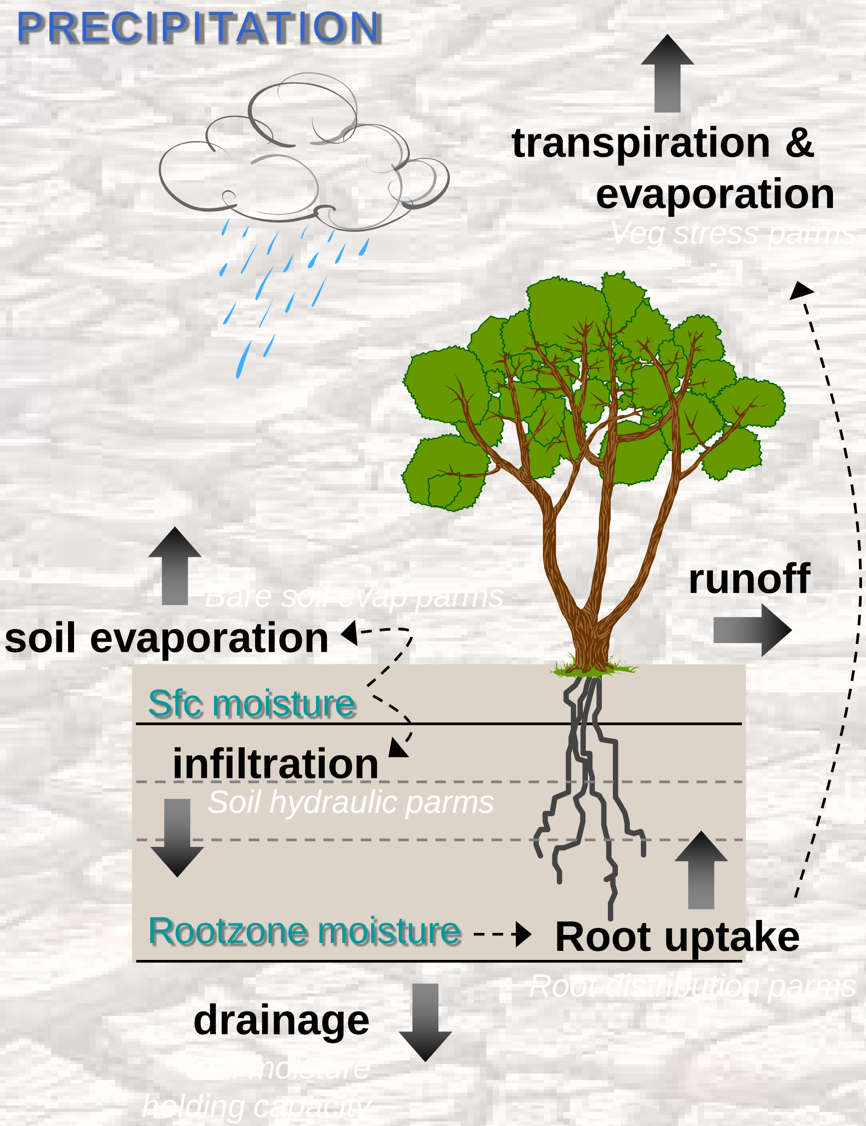
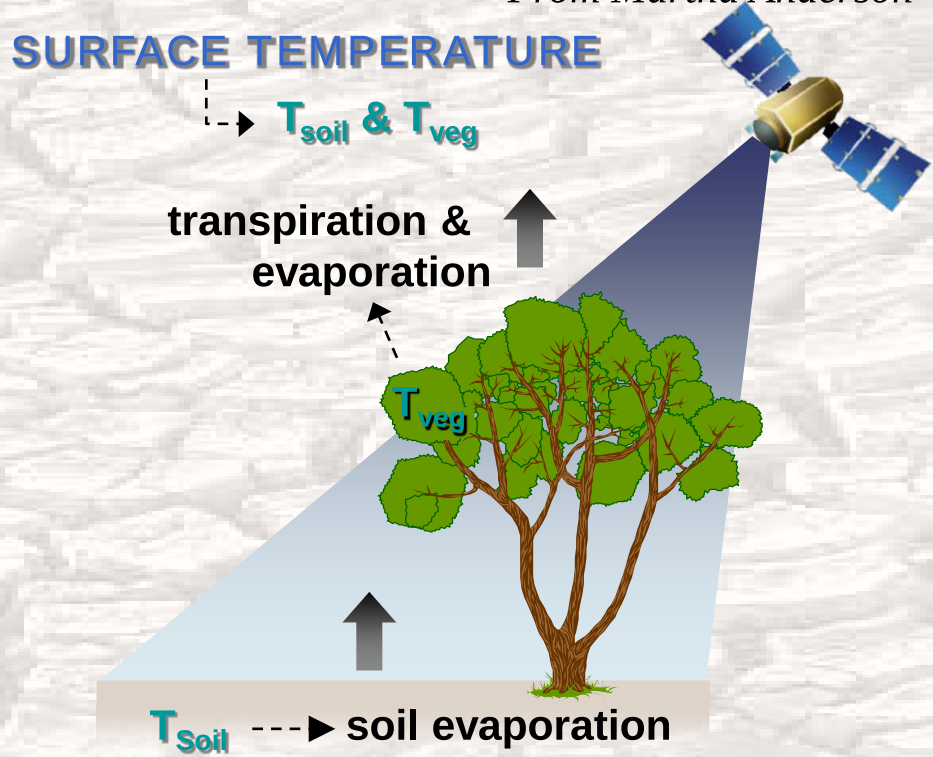
Science and historical data contact:
Xiwu.Zhan@noaa.gov,
Jicheng.Liu@noaa.gov,

TIR Soil Moisture Remote Sensing: Retrieval Algorithm Science

From Martha Anderson





Given known radiative energy inputs, how much water loss is required to keep the soil and vegetation at the observed temperatures?

WATER BALANCE APPROACH

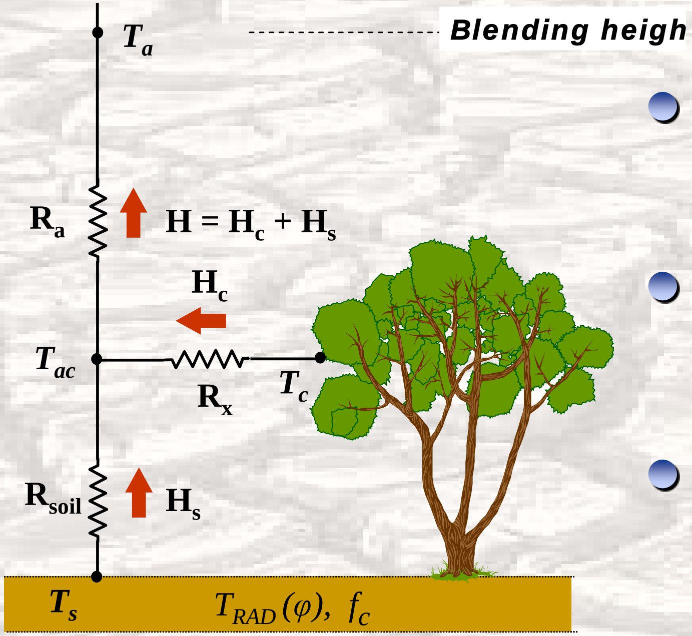
("forward modeling")

REMOTE SENSING APPROACH

("inverse modeling")

From Martha Anderson

Two-Source Energy Balance (TSEB)



- $T_{RAD}(\theta) \sim f_c(\theta)T_c + [1\text{-}f_c(\theta)]T_S$
- Canopy and soil H from T network
- Canopy transpiration (LE_C) from PT or LUE scheme
- Soil evaporation as residual: $LE_S = RN - H - G - LE_C$

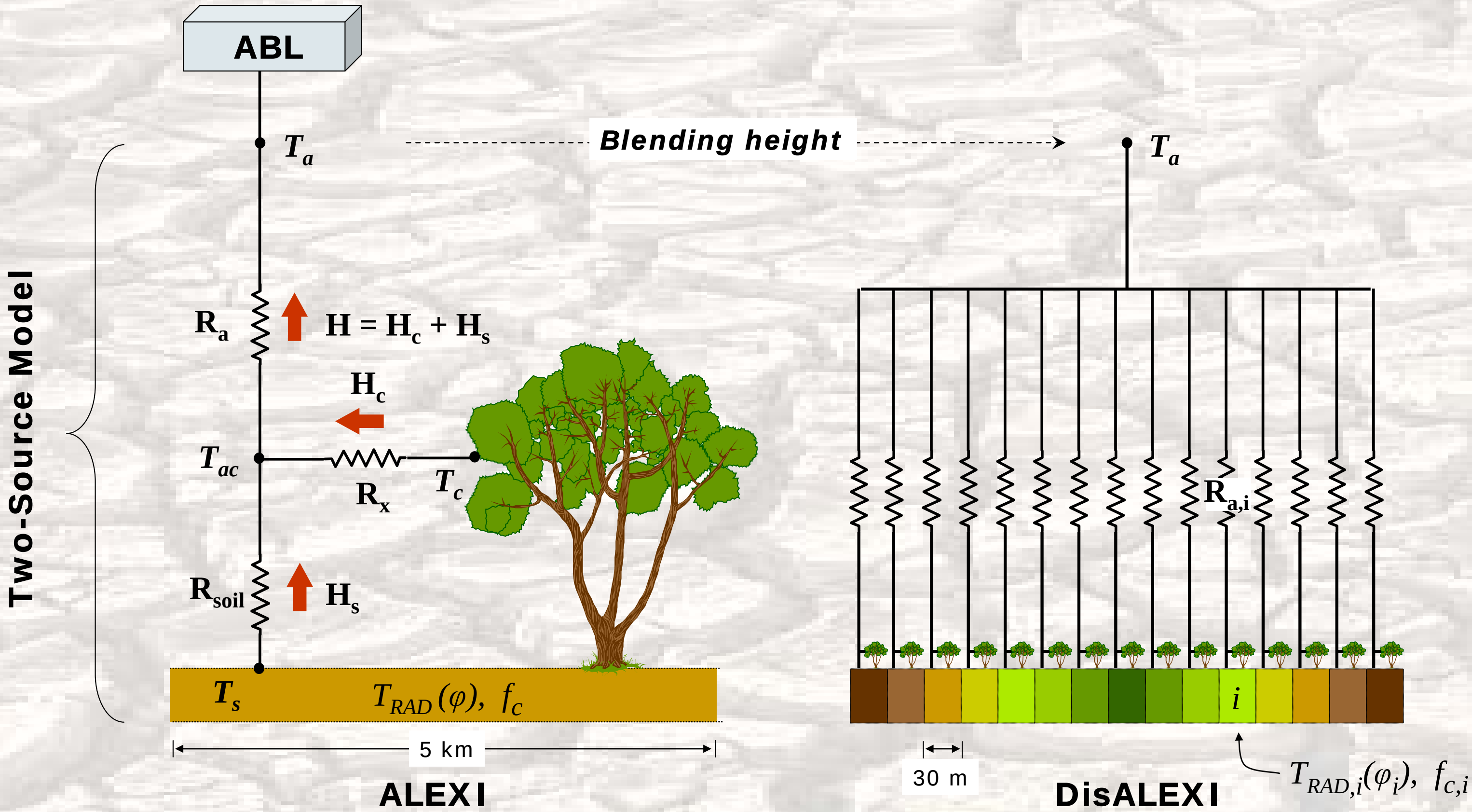
Norman, J. M., W. P. Kustas, and K. S. Humes (1995) *Agric. For. Meteorol.*, 77, 263-293.

Local scale

Surface temp:	T_{RAD}	- Infrared thermometer
Air temp:	T_a	- Micromet tower

From Martha Anderson

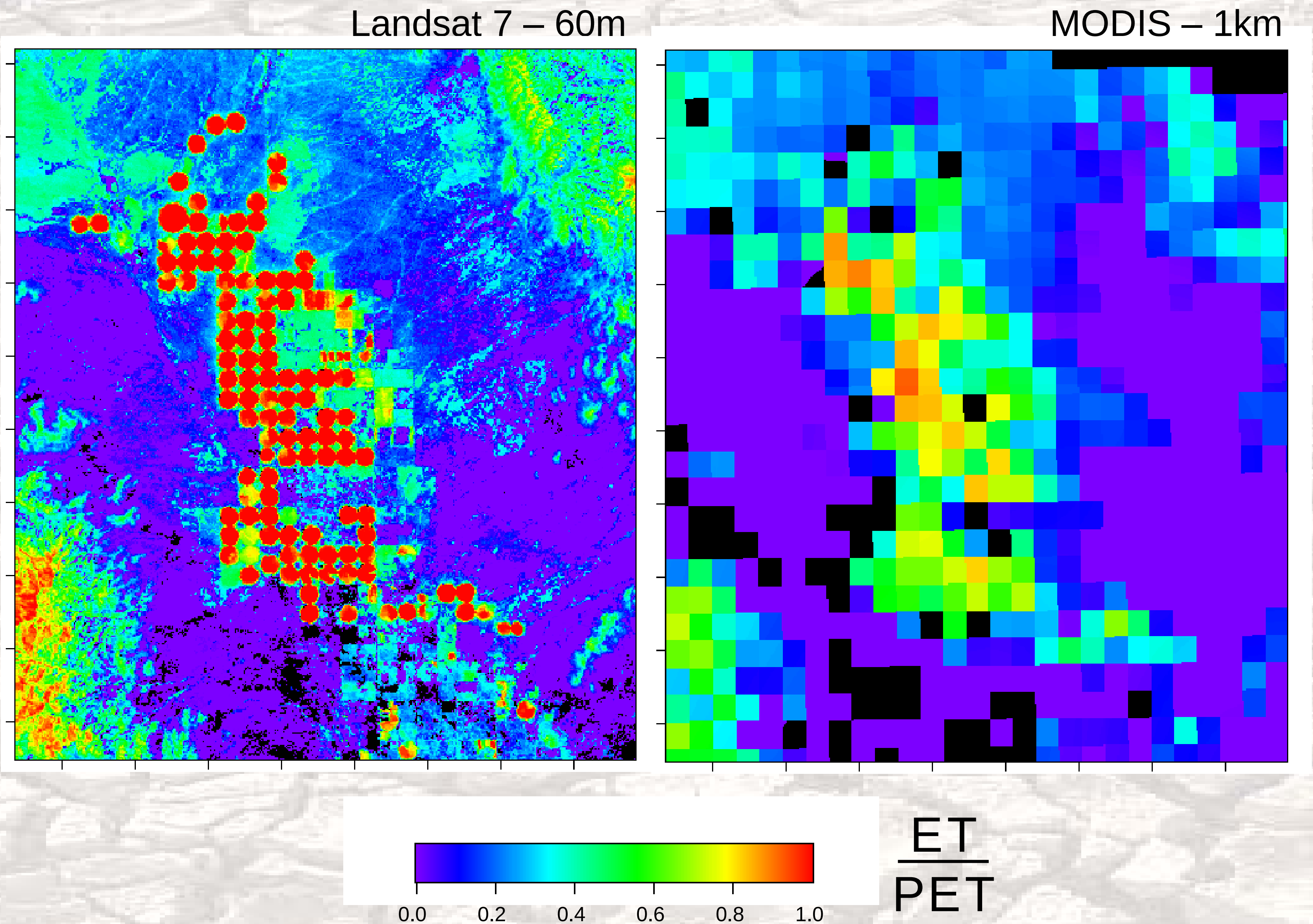
Atmosphere-Land Exchange Inverse (ALEXI)



	Regional scale	Landscape scale
Surface temp:	**ΔT_{RAD} - GOES**	**T_{RAD} - TM, ASTER, MODIS**
Air temp:	**T_a - MODIS**	**T_a - ALEXI**

From Martha Anderson

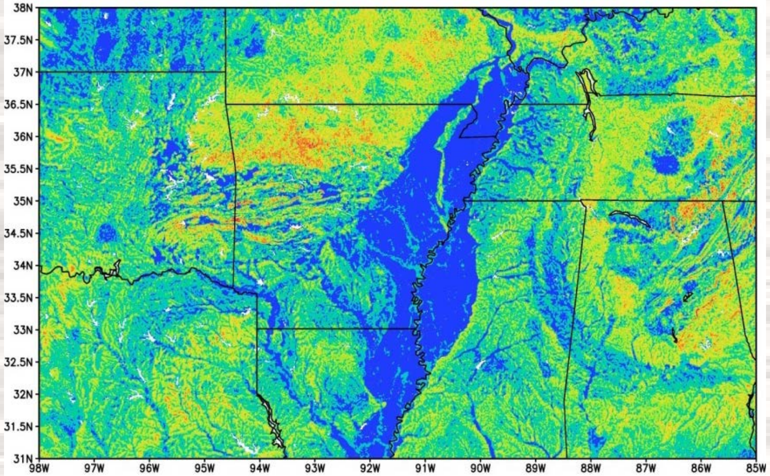
Sensitivity to irrigation

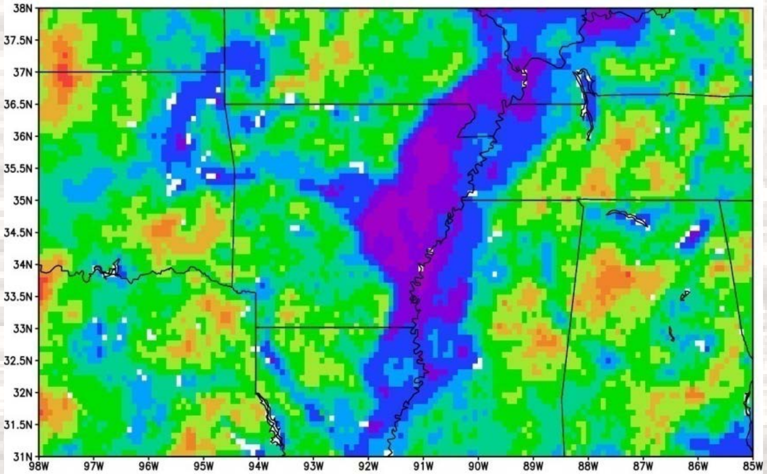


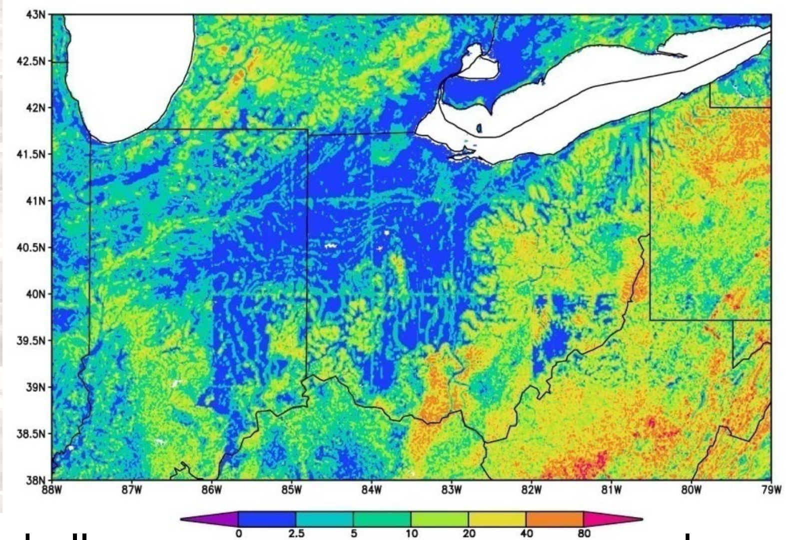
From Martha Anderson

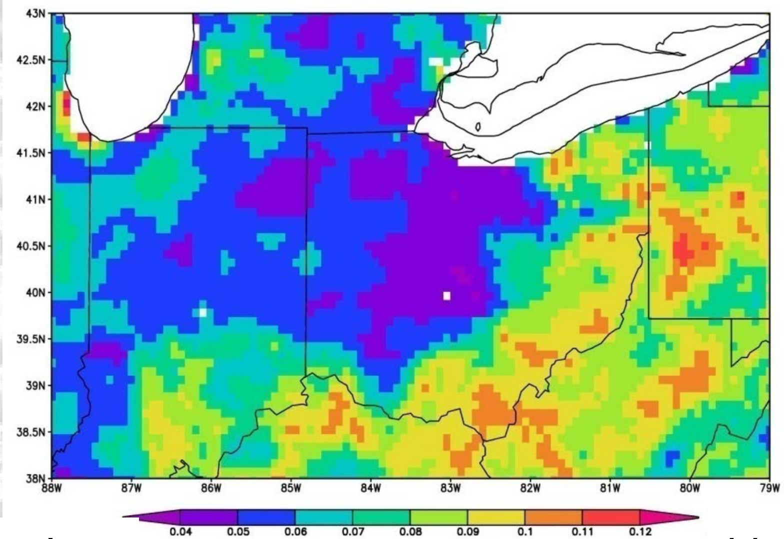
Sensitivity to shallow water tables

Simulated climatological water table* | Temporal variability in ET/PET







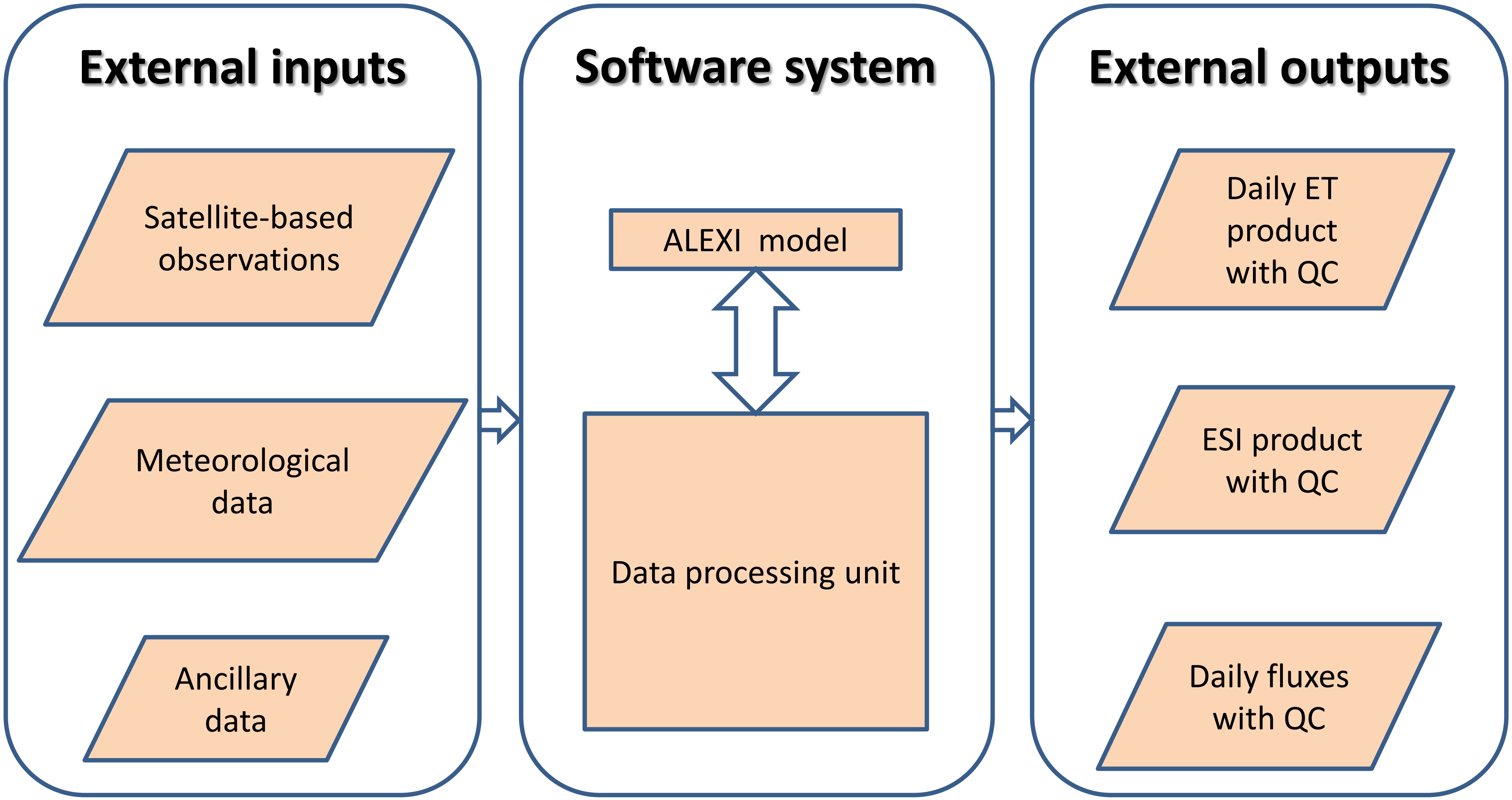


shallow — deep | low — high

* Miquez-Macho et al, BAMS, 90, 663-672

GOES ET and Drought Product System
(GET-D)

GET-D General Architecture



GET-D Input Data

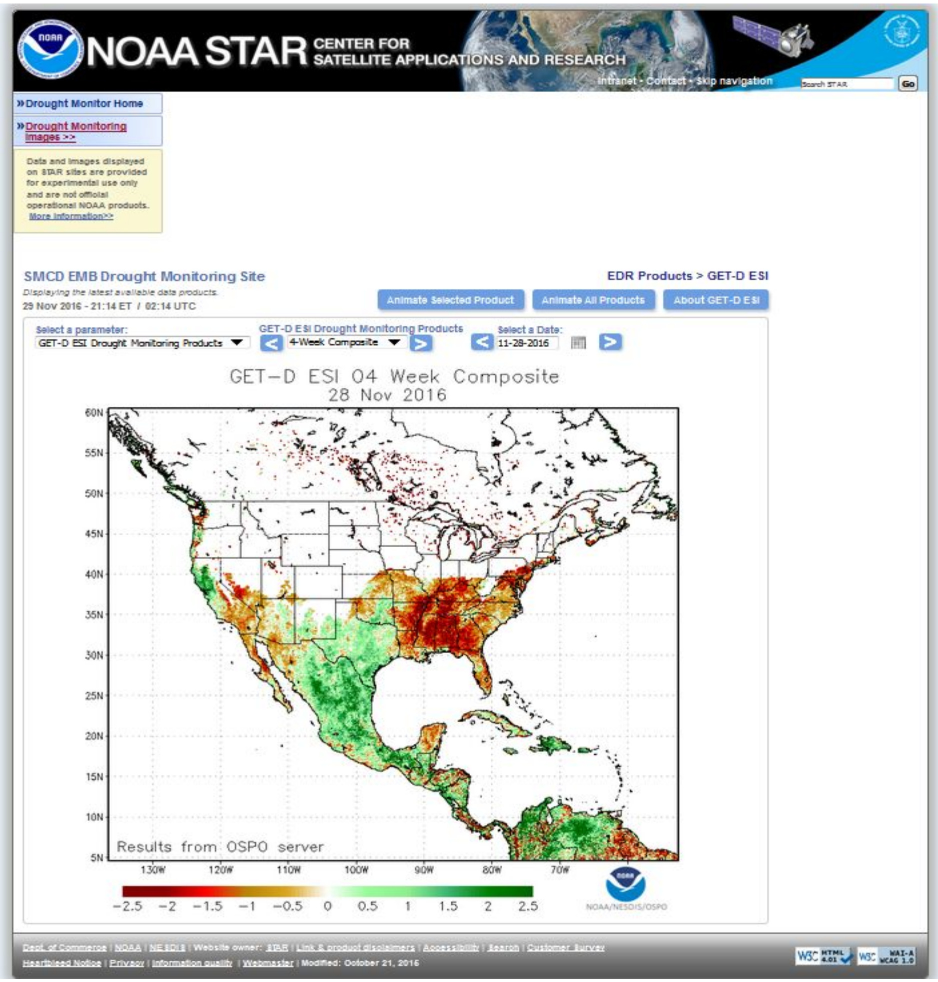
Name	Category	Source	Description
Brightness temperature	Satellite observation	GOES	GOES East/West Imagery; 11micron/3.9 micron brightness temperature
Insolation	Satellite observation	GSIP	GSIP real time insolation
Vegetation Index	Satellite observation	VIIRS	VIIRS EVI
Snow mask	Satellite observation	NOAA IMS	IMS Daily Northern Hemisphere Snow and Ice Analysis
Air temperature	Meteorological data	CFS	Surface and pressure level profiles
Specific humidity	Meteorological data	CFS	Surface and pressure level profiles
Geopotential height	Meteorological data	CFS	Surface and pressure level profiles
Wind speed	Meteorological data	CFS	Surface
Downwelling longwave radiation	Meteorological data	CFS	Surface
Land Cover	Ancillary data	University of Maryland	Land cover classes in 1km resolution (static)
Albedo	Ancillary data	MODIS	Surface Albedo from MODIS (static)
Clear day insolation	Ancillary data	GSIP	Clear day insolation (static)

GET-D Output Products

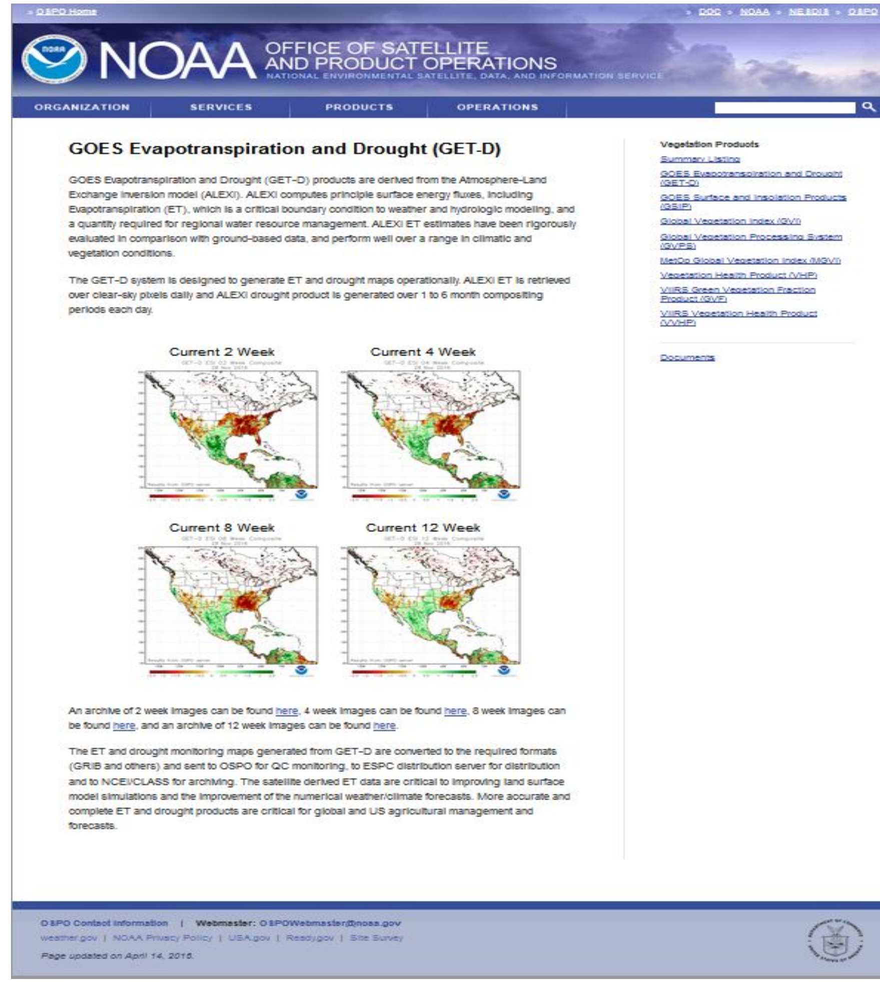
Variables	Description
ET product with QC	Daily ET map
ESI products with QC	2,4,8, 12-week composite drought map
Flux products with QC	Daily sensible heat, soil heat, downward short wave radiation, long wave down/up ward radiation and net radiation
Coverage	North America
Spatial Resolution	8km

GET-D Websites

NESDIS-STAR:
https://www.star.nesdis.noaa.gov/smcd/emb/droughtMon/products_droughtMon.php

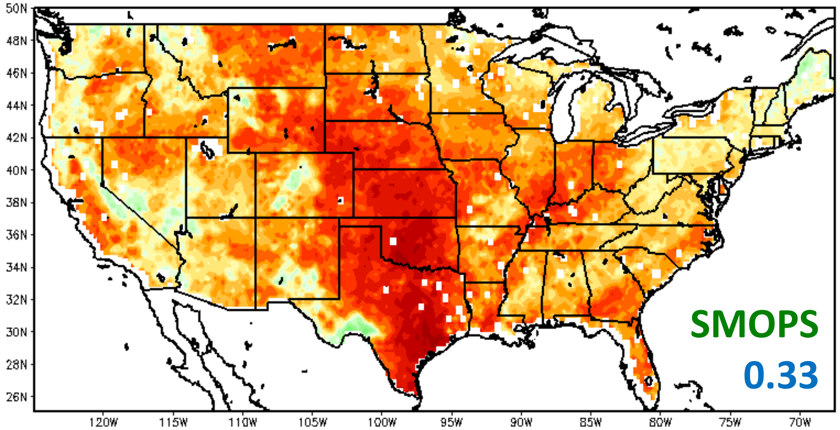


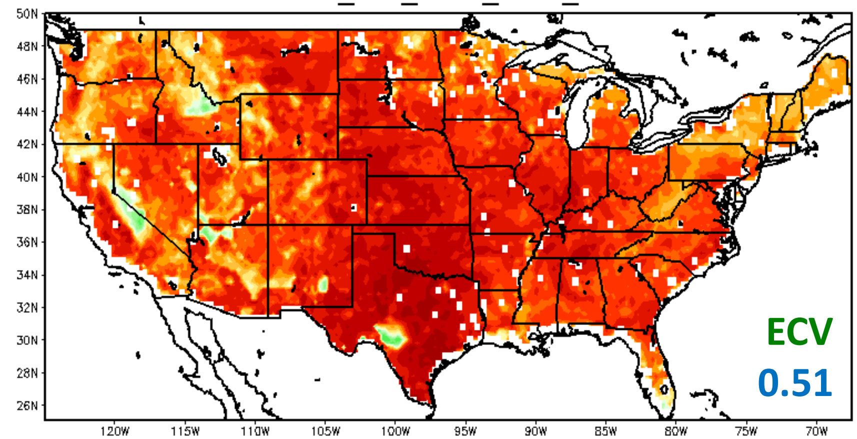
NESDIS-OSPO:
http://www.ospo.noaa.gov/Products/land/getd/

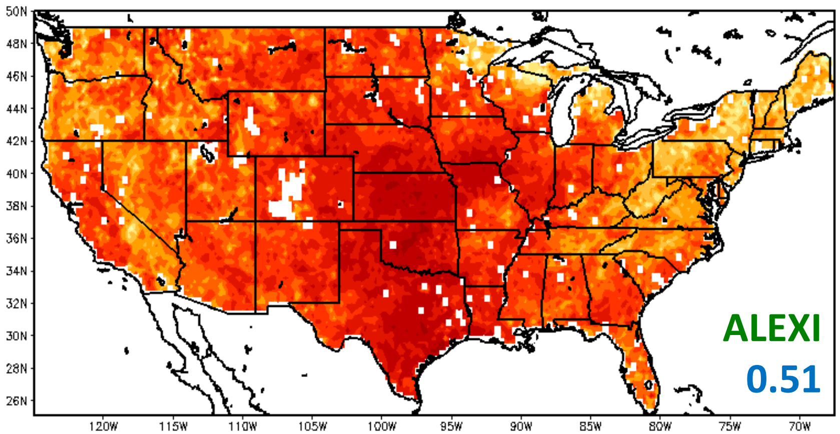


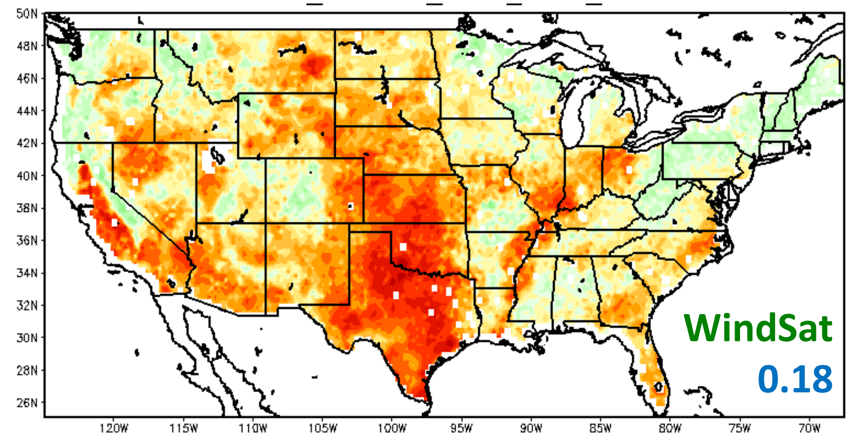
Product Accuracy Validation

Comparison with NLDAS Noah LSM Estimates

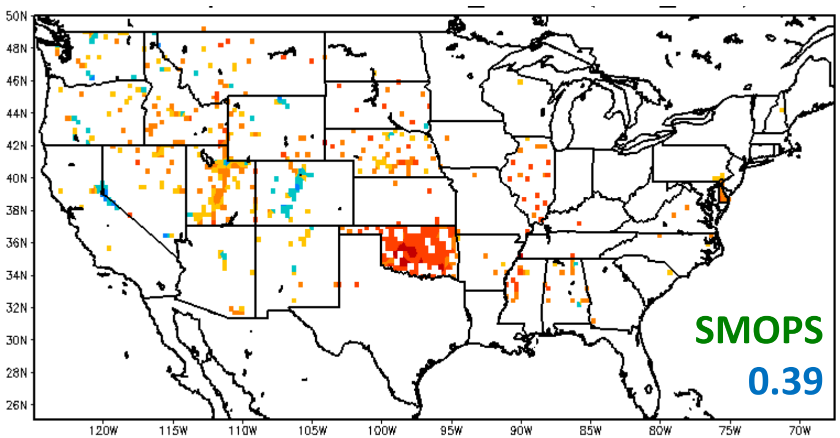


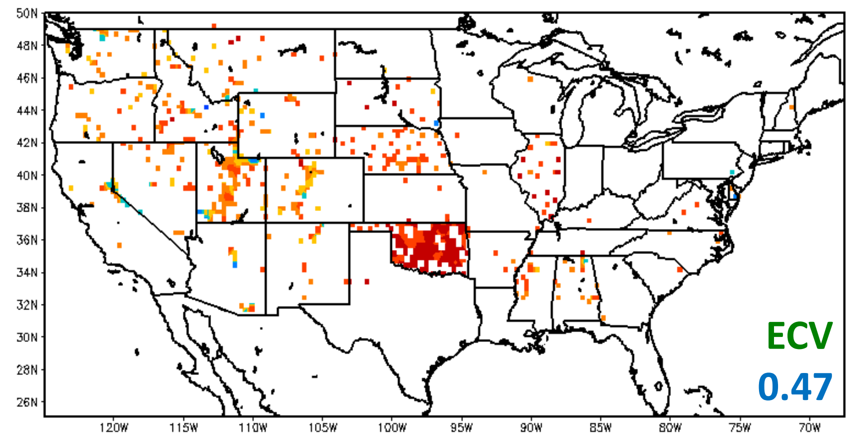


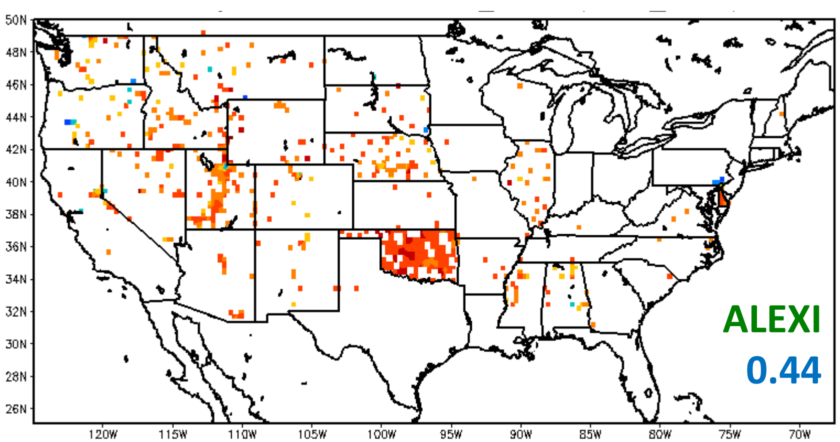


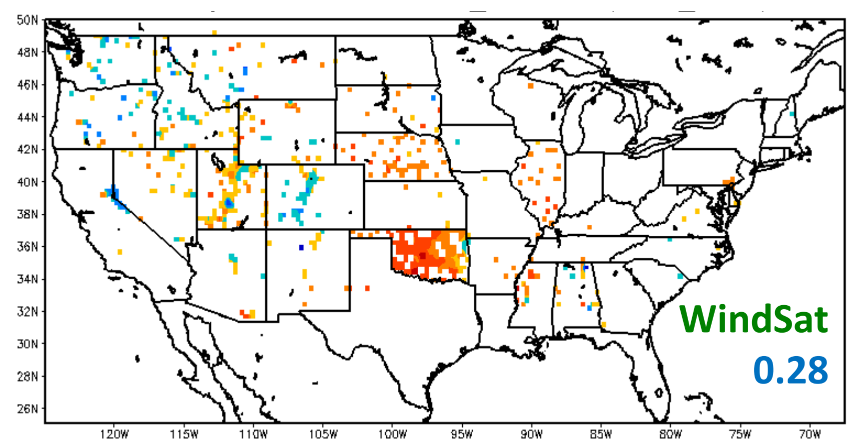


Comparison with *in situ* Measurements







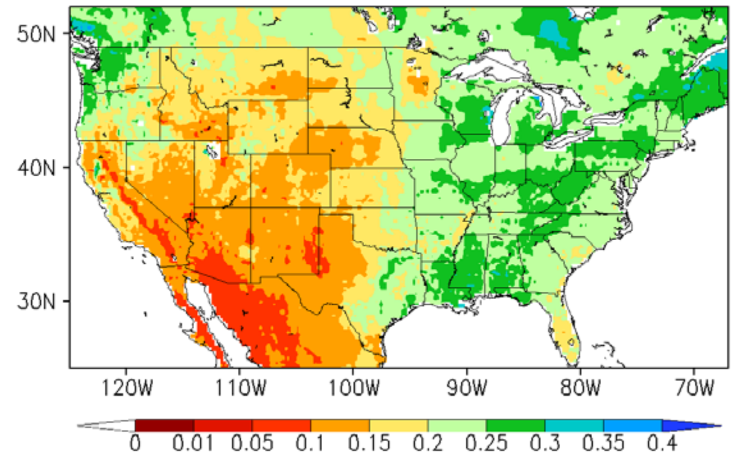


Soil Moisture Product Applications

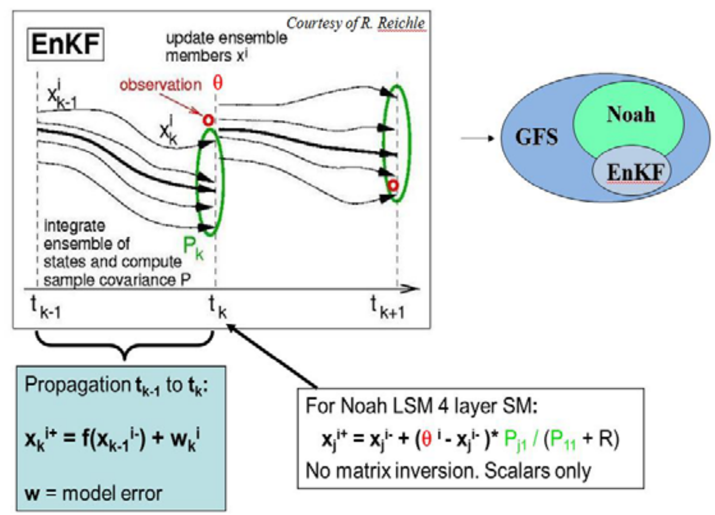
Assimilation of SM in NCEP GFS

- SMOPS combines soil moisture retrievals from multiple satellites sensors to provide a global climatologically consistent soil moisture map with more spatial and temporal coverage.

- Positive impact has been shown on the model performance, particularly for precipitation forecasts by assimilating SMOPS blended product into GFS using a simplified EnKF

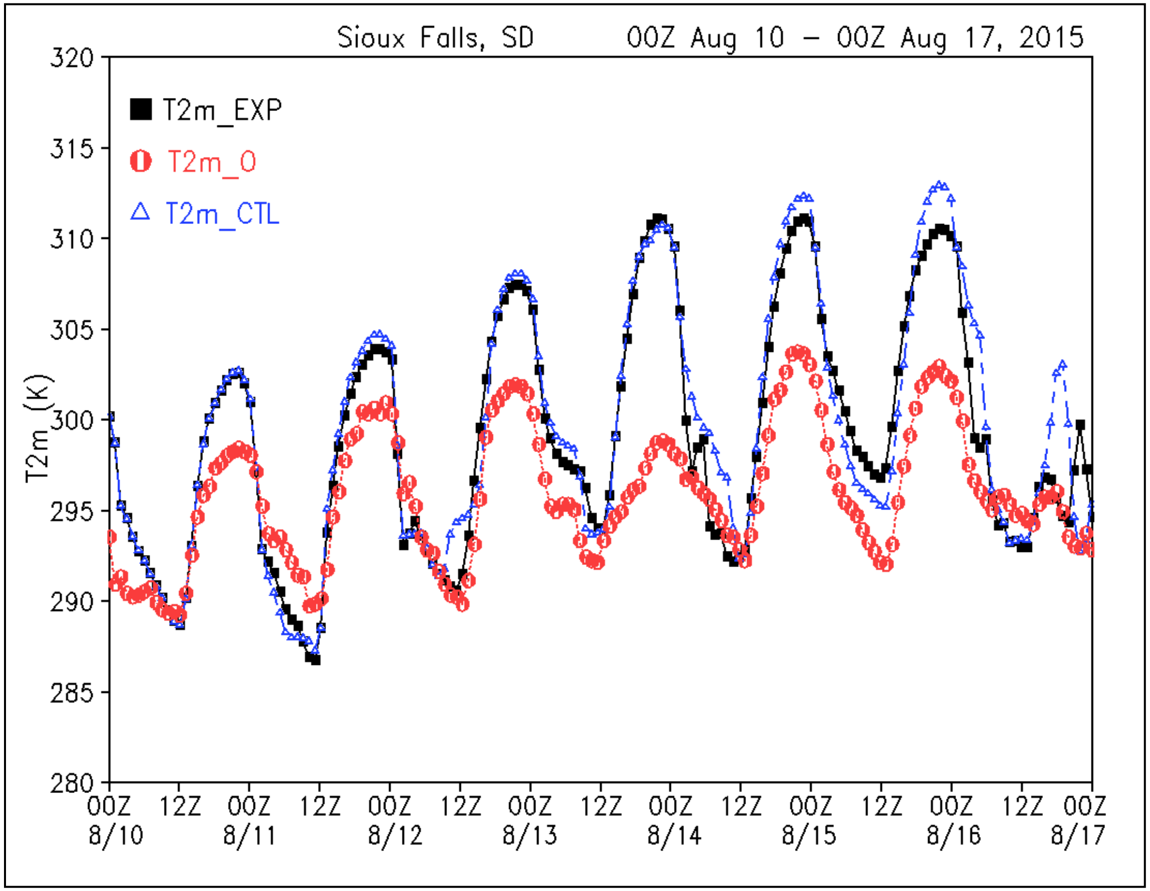


SMOPS blended product over CONUS in Apr 2012



A Simplified EnKF data assimilation utility implemented in NCEP GFS

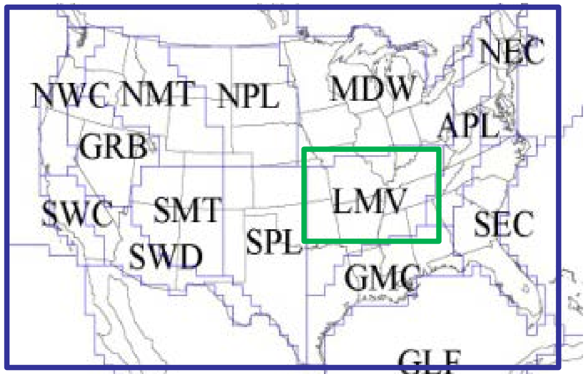
Assimilation of SM in NCEP GFS



Assimilating SMAP SM from 8/1 – 8/10/2015 Reduces the warm biases of NCEP GFS four (4) day forecasts of 2 meter air temperature

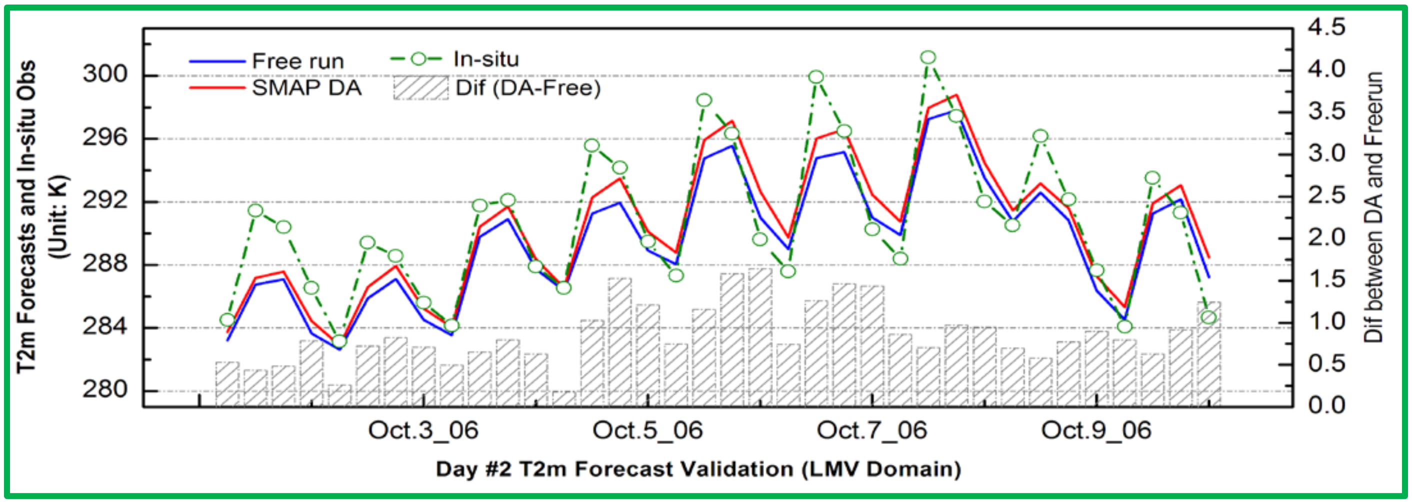
T2m Forecasts compared with In-situ Observations (LMV Domain)

- Average T2m forecasts from WRF Free run and SMAP DA run compared with In-situ measurements
- Validation domains: LMV domain (~200 sites)
- Validation period: Day 2 forecast, Oct. 2nd – Oct. 9th, 2015
- Corrected daytime warm bias



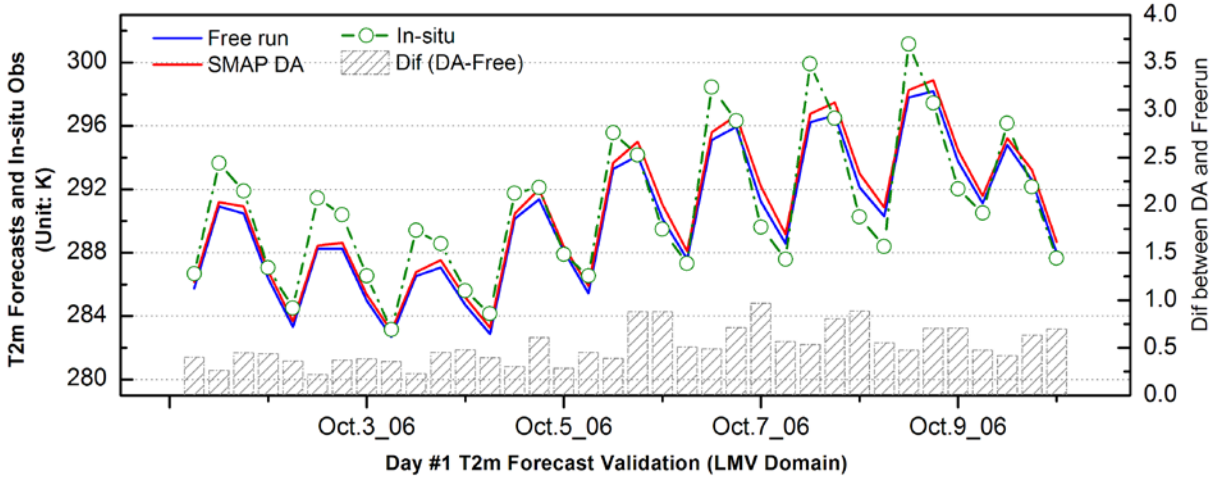
Sub-regions in NCEP WRF-NMM forecast verification system

LMV

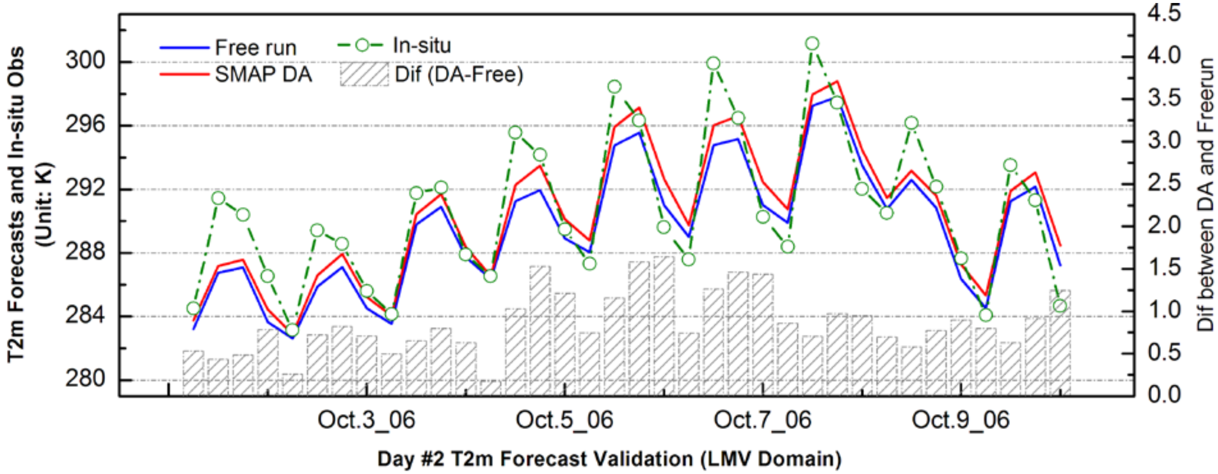


T2m Forecasts compared with In-situ Observations (LMV Domain; 2-Day validation)

Day 1



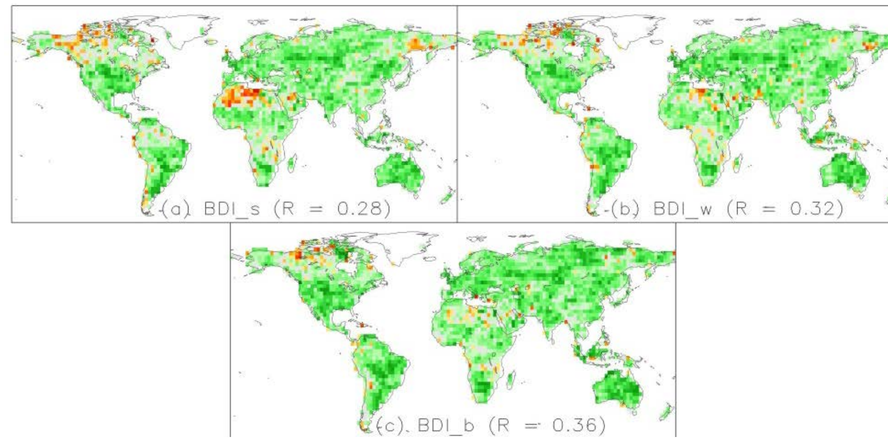
Day 2



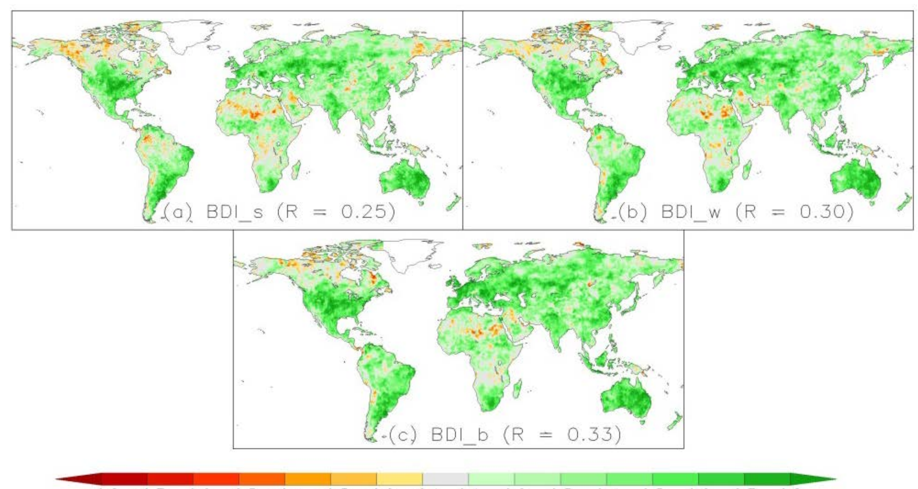
Enhance Agricultural Drought Monitoring Using SNPP/JPSS Land EDRs for NIDIS

Jifu. Yin, X. Zhan, C. Hain, J. Liu, L. Fang, M. Ek, J. Huang, M. Anderson, M. Svoboda

- Objectives
  - Improve current US and global drought monitoring via using near real time SNPP/JPSS land data products
- Primary sensors involved
  - S-NPP/VIIRS
  - GCOM-W1/AMSR2
- Primary ground data
  - Palmer Drought Severity Index (PDSI)
  - Standardized Precip ET Index (SPEI)
  - In situ observations
- Targeted end users
  - NIDIS of USDA, NOAA and USGS
  - NWS-NCEP

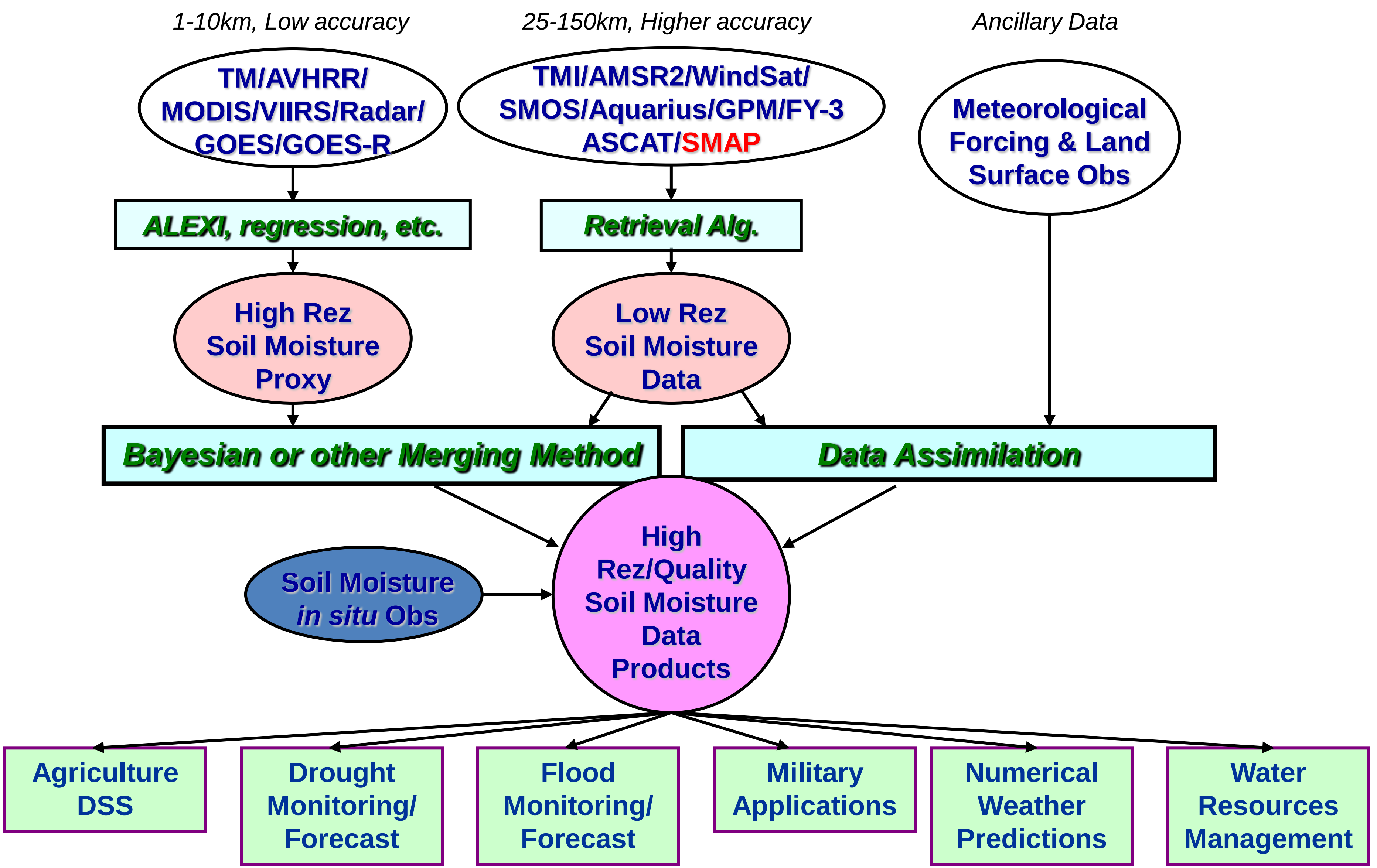


Correlations of BDIs with PDSI



Correlations of BDIs with SPEI

Soil Moisture Science and Applications



Thanks from NESDIS soil moisture gang!