Validations and Applications of Global WindSat Soil Moisture and Vegetation Data

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Existing and Future Microwave Surface Sensors

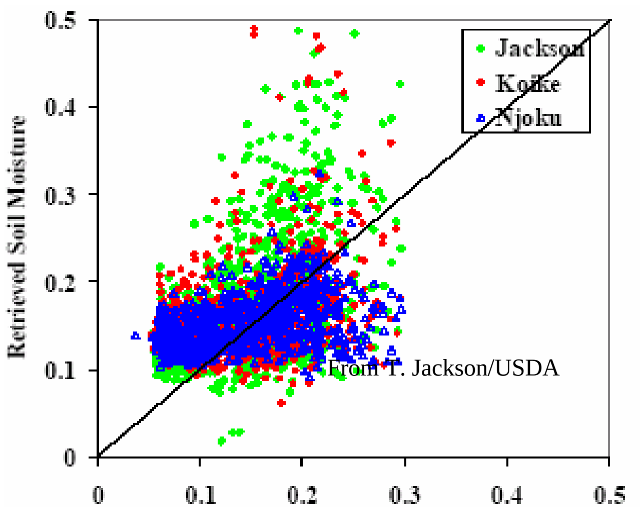
Sensor	Lowest Freq. (GHZ)	Year of Launch
SMMR	6.6	1978
SSM/I	19.3	1987
TMI	10.7	1997
AMSR-E	6.9	2002
WindSat	6.8	2003
SMOS	1.4	2009
PMM	10.7	2013
SMAP	1.4	2015
MIS	6.8	2016

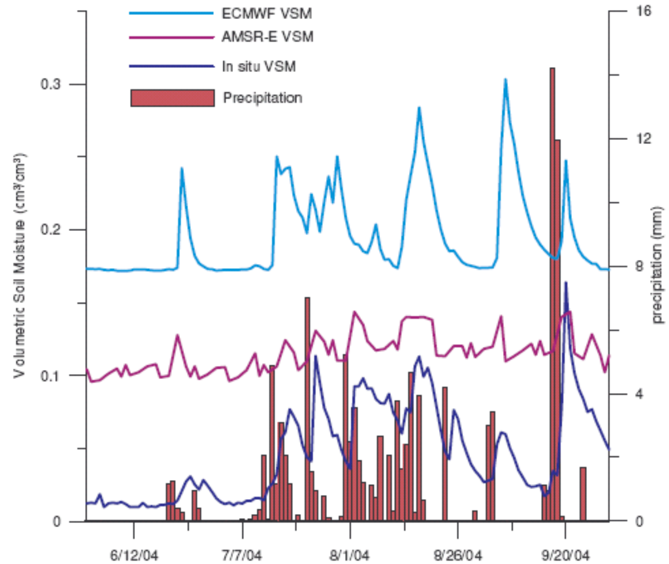
- Since 1978, soil moisture measurement has been attempted for several passive microwave missions using multi-frequency Window channel radiometers (6 – 18 GHz frequencies).
- Dedicated L-band microwave radiometers missions are under development by ESA and NASA specifically for soil moisture sensing (SMOS, SMAP).
- Window channel radiometers can be used to build decadal time series for soil moisture.

Early Results: Issues of Performance

But Much Progress Has been Made Recently

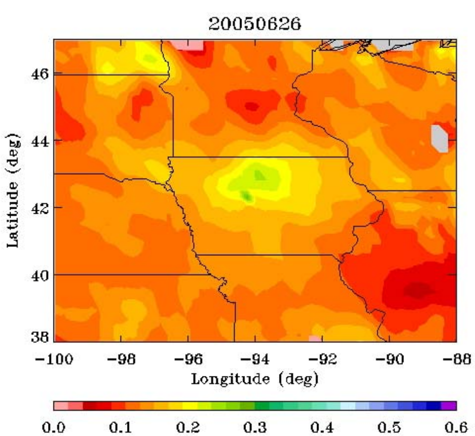
Results from three AMSR-E algorithms

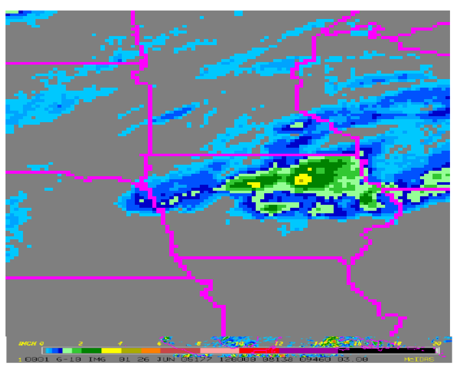




By J. Bolton
USDA

Spatial patterns are inconsistent

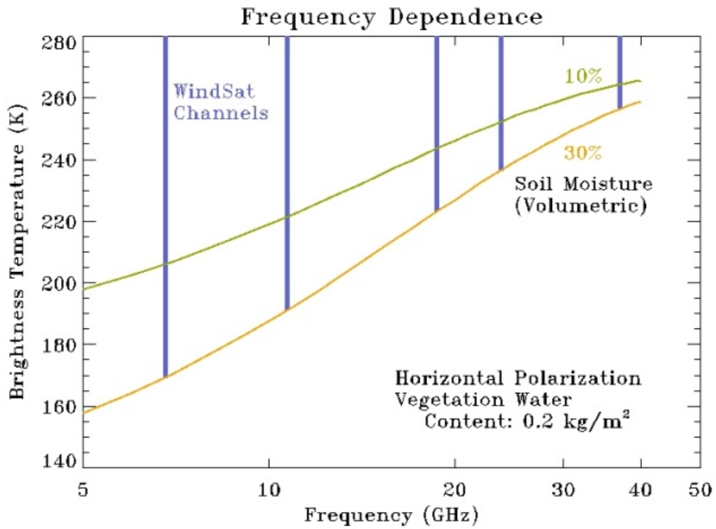


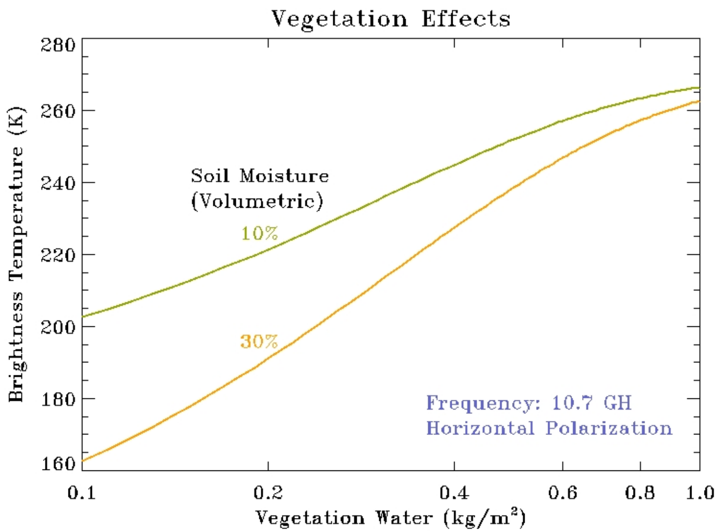


- AMSR-E has been providing the first operational soil moisture data product since 2003.
- However, no current soil moisture data product meets operational or science requirements

There are more than seven SM algorithms; they are best known for their disagreements

Algorithm Overview





Physically Based Six-Channel Algorithm

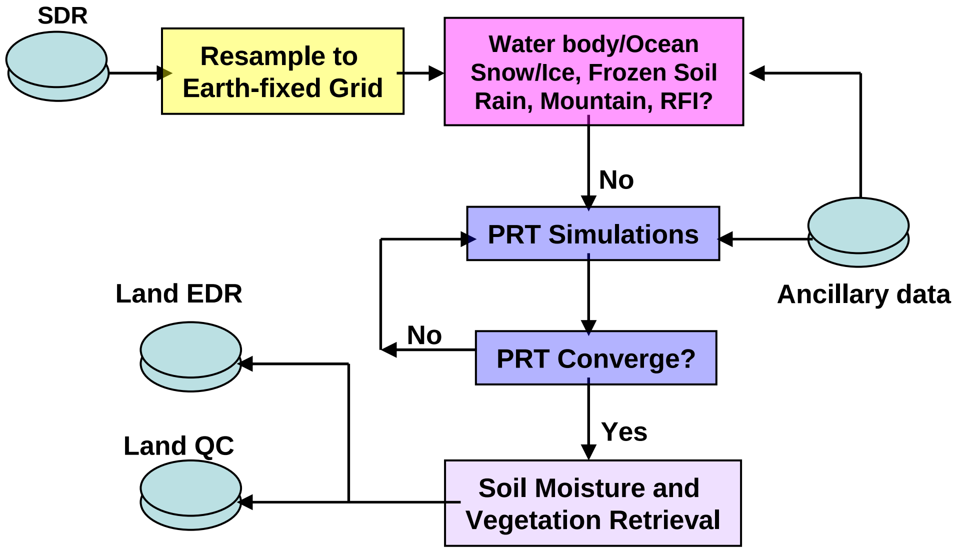
10 to 37 GHz V- & H-Pol channels

Simultaneous retrieval of:

- » **soil moisture**
- » **vegetation water content**
- » **land surface temperature**

Based on maximum-likelihood estimation

$$LH(x) = -\tfrac{1}{2}\sum_j \log(2\pi\sigma_j^2) - \sum_j \frac{\{y_{mj} - y_{sj}(x)\}^2}{2\sigma_j^2}$$

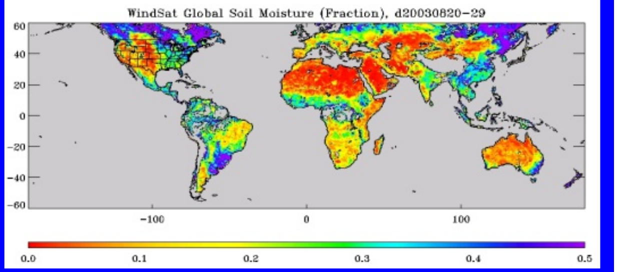


WindSat Validation Methodology

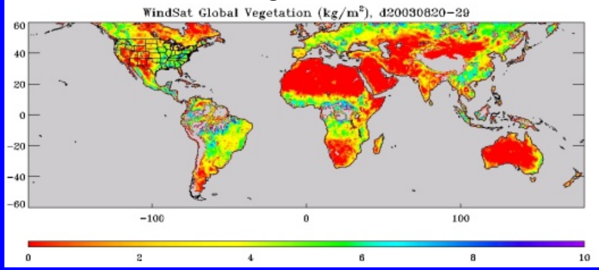
Validation Strategy:
Comparisons of multi-scale data sources

- **Global Ground In-Situ**
  - SMEX/USDA Micronet
  - SMOSREX, NAFE
  - JAXA Mongolia ASSH
- **Precipitation Patterns**
  - AVHRR
  - NEXRAD
- **Vegetation Dynamics/Validation**
  - NDVI/GVF dynamics
  - SMEX05 field validation
- **Soil Moisture Climatology**
  - Climate Regime
  - Global precipitation/Monsoon

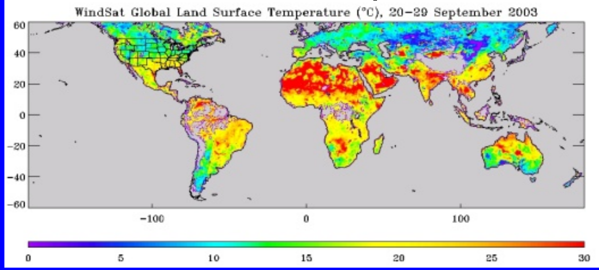
Soil Moisture



Vegetation

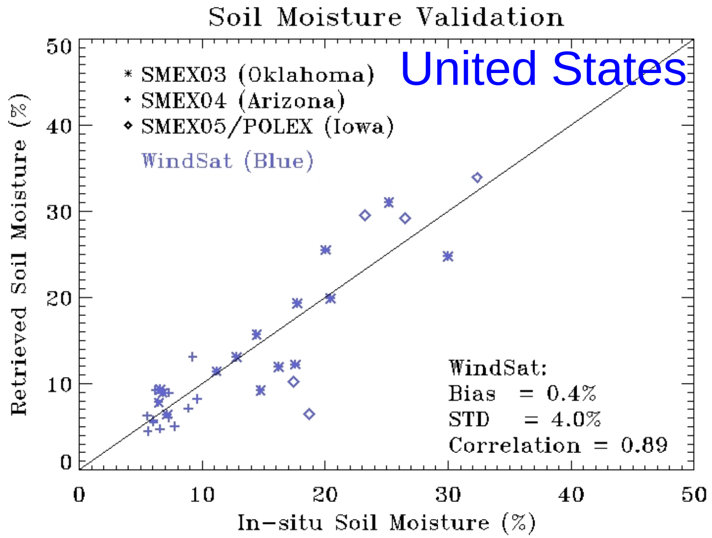


Land Surface Temperature



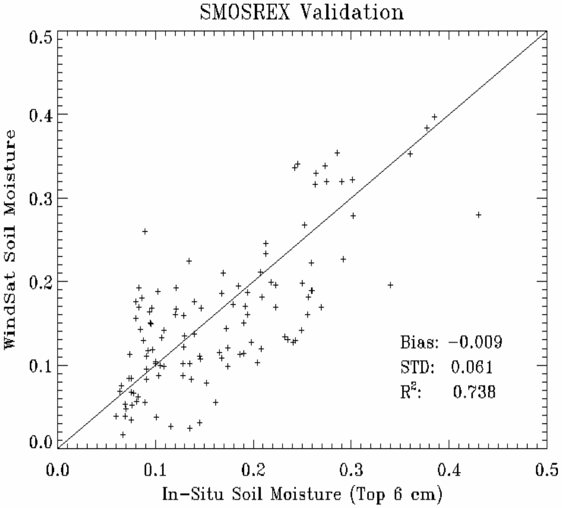
SMEX 2003 – 2005 Validation

USDA Validation Sites:
SMEX03: rangeland and winter wheat
SMEX04: sparse shrubland, mountains
SMEX05: agricultural – corn, soybean

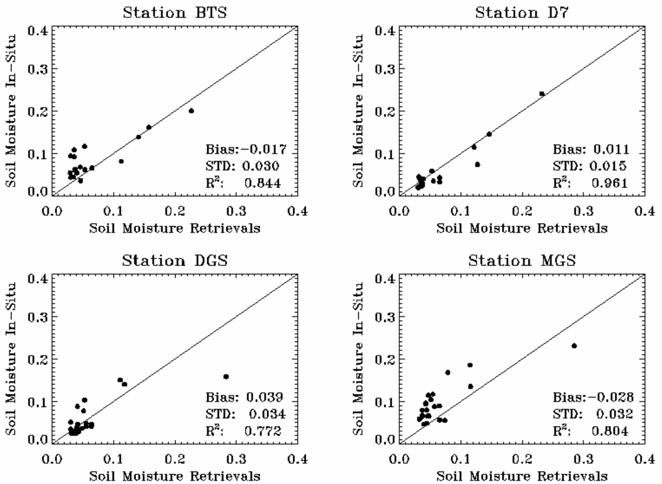


Other Validation Sites:
SMOSREX, France:
» Grassland, wheat, corn
CEOP, Mongolia:
» Arid rangeland

France



Mongolia



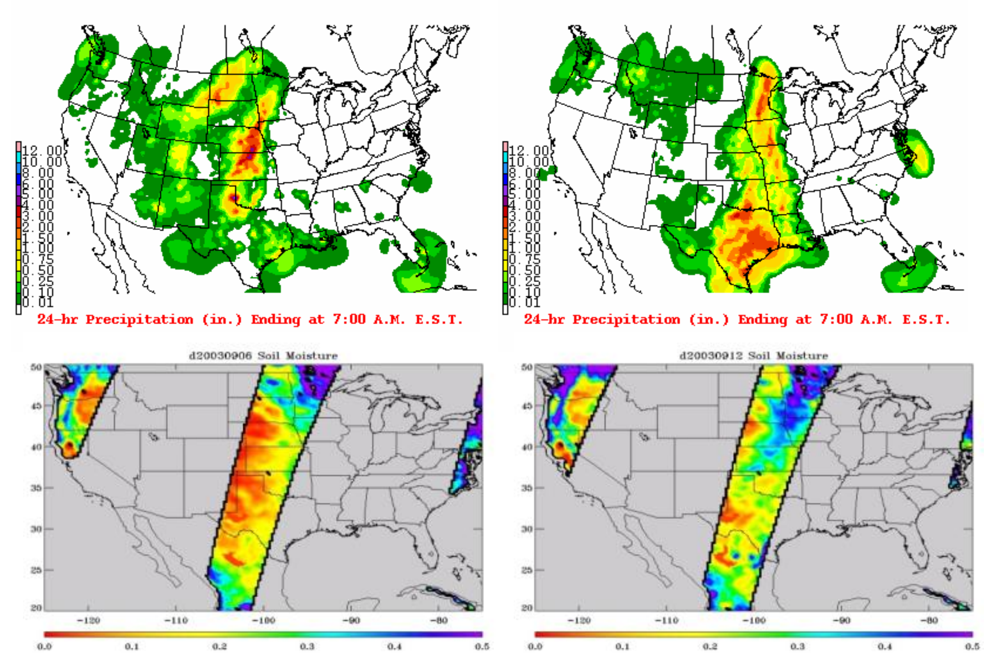
Soil Moisture Pattern Validations

The consistency with precipitation pattern is essential for the soil moisture to be assimilated by the NWP

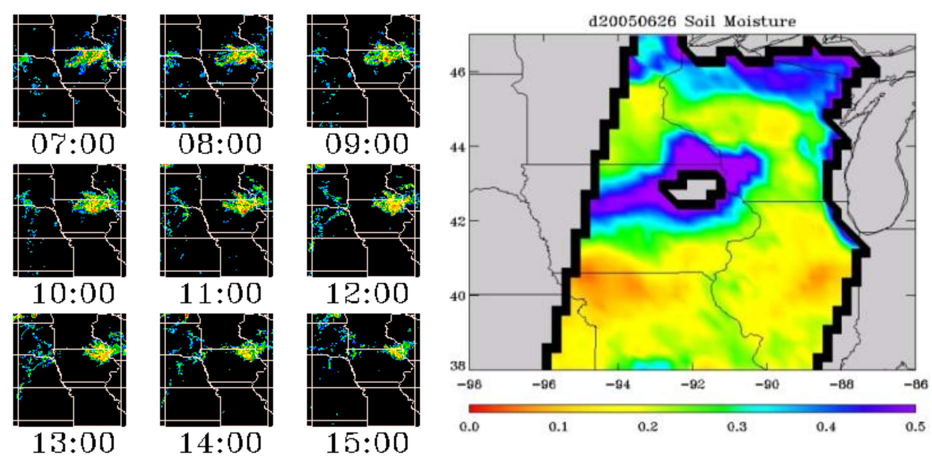
A major rain event following an extreme drought was observed by both AVHRR total precipitation and WindSat soil moisture

NEXRAD and WindSat data show consistent features of a localized T-storm during SMEX05

Major Rain Event Observed by AVHRR and WindSat at <u>Synoptic scale</u>

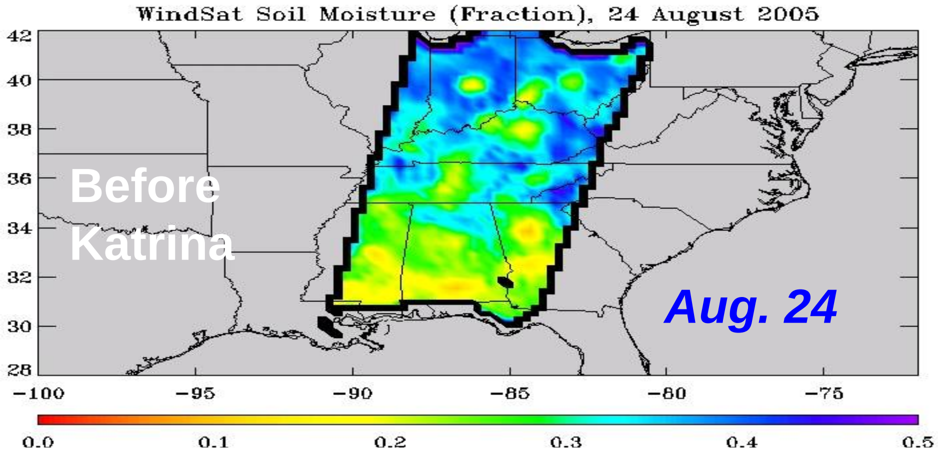


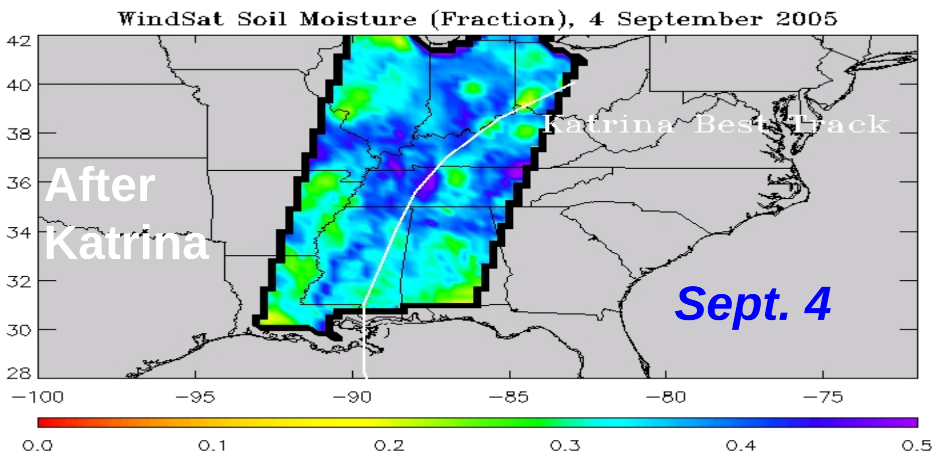
<u>Mesoscale</u> T-Storm Observed by NEXRAD and WindSat during SMEX05



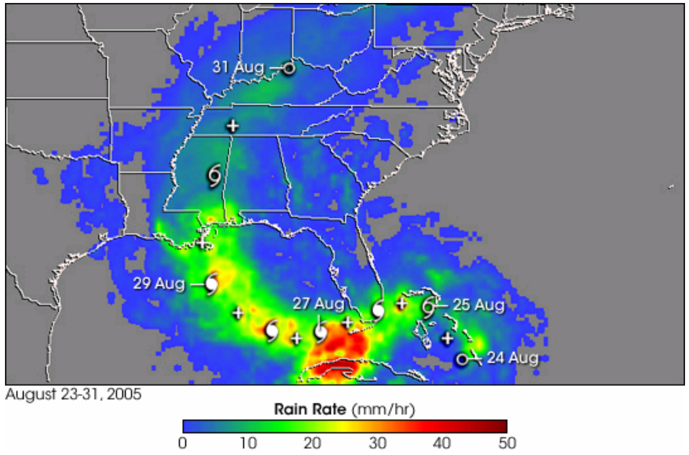
Hurricane Katrina

***The WindSat soil moisture data capture the dramatic wetting-up event along the best track of hurricane Katrina*.**



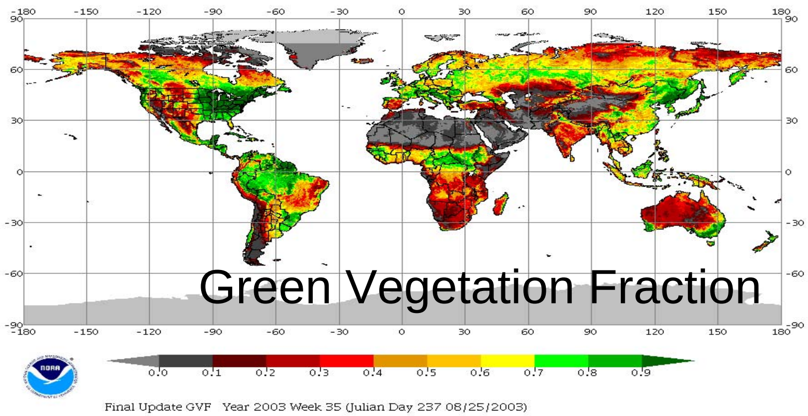


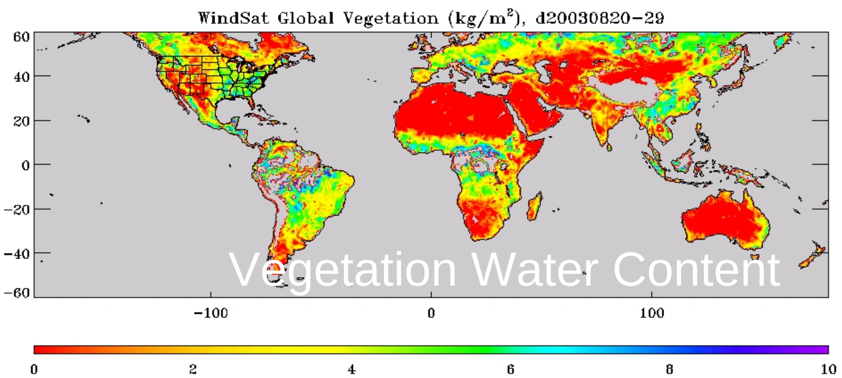
The top left panel shows soil moisture retrievals four days before Katrina made landfall on 29 August, and bottom left panel shows soil moisture retrievals four days after the end of Katrina on 4 September.



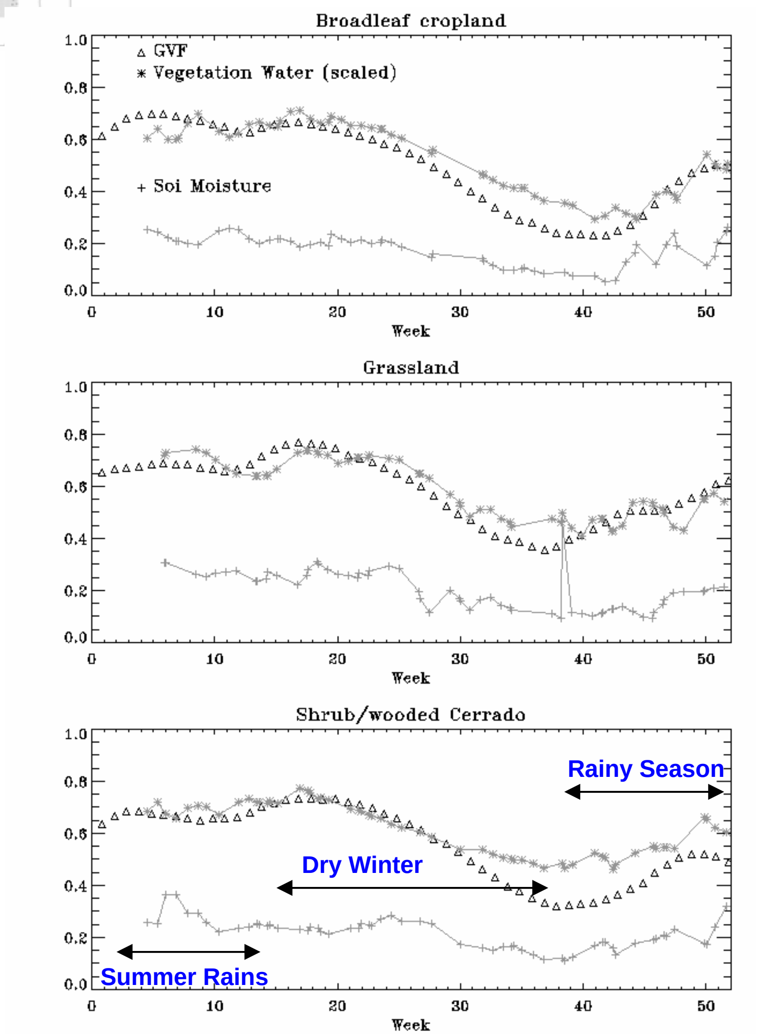
WindSat Vegetation Data Validation

The WindSat vegetation water content is consistent with the Green Vegetation Fraction derived from AVHRR data.



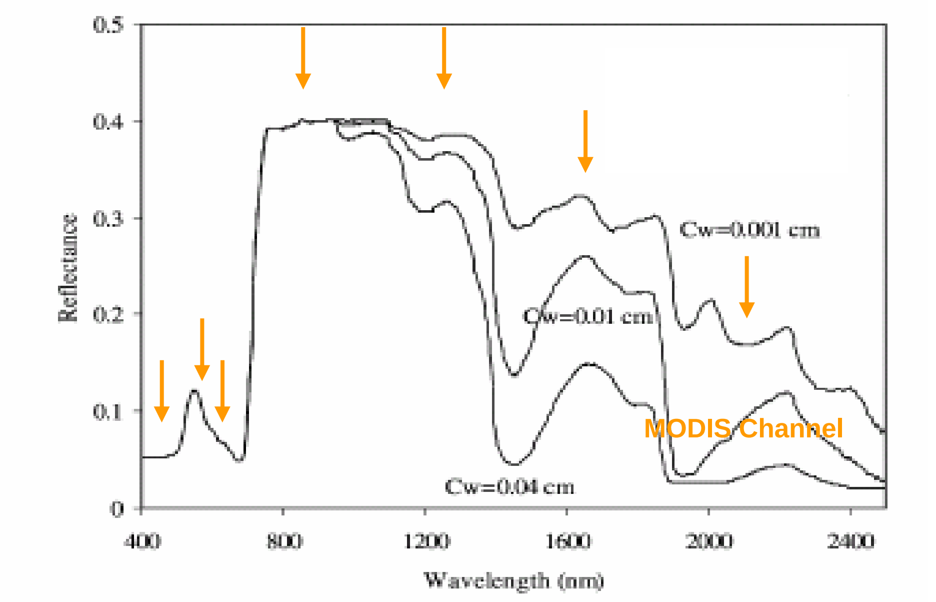


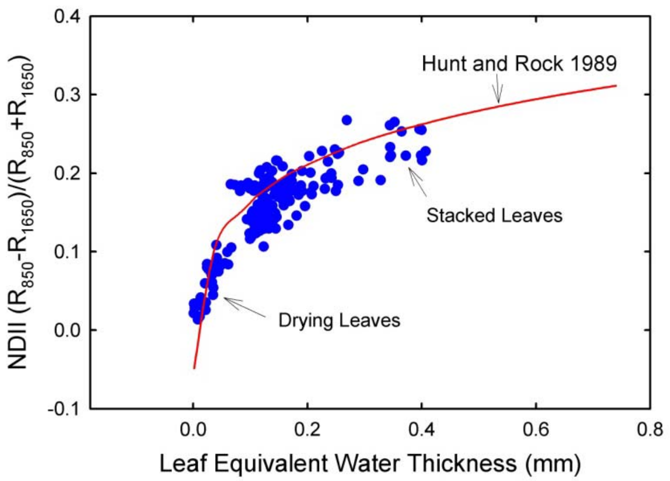
Brazil Cerrado



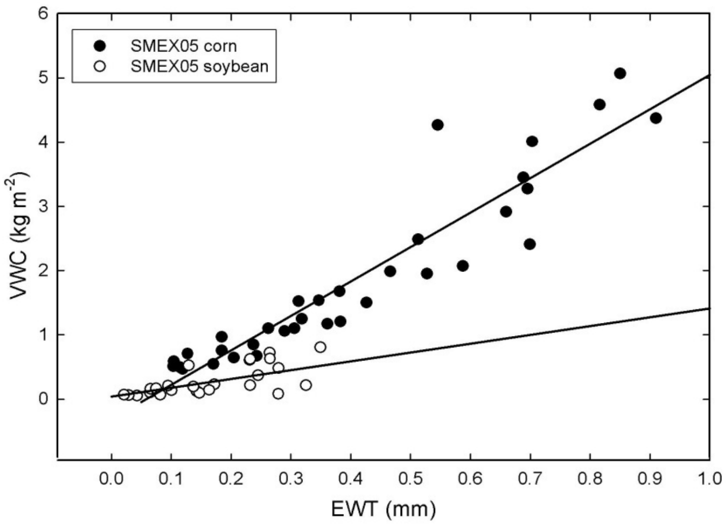
Optical VWC Data -- By R. Hunt, T. Yilmaz, and T. Jackson

Reflectance is a function of the canopy water in the leaves





SMEX05

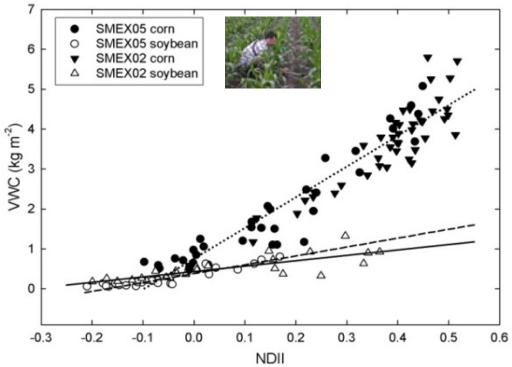


The Normalized Difference Infrared Index (NDII) is linearly related to canopy water (EWT):

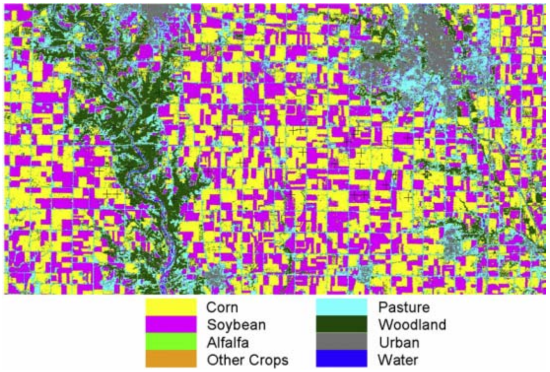
$NDII = (R_{0.85}-R_{1.65})/(R_{0.85}+R_{1.65})$

allometric relationship exists between VWC and EWT, considering leaves must be supported by stems and stems supply water required for transpiration to the leaves.

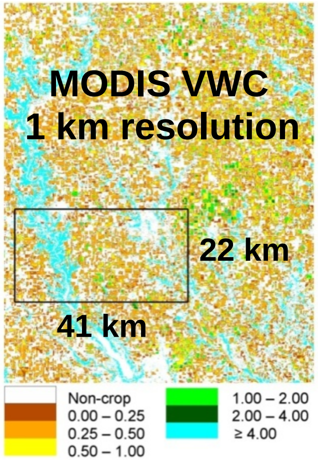
WindSat Vegetation Data Validation



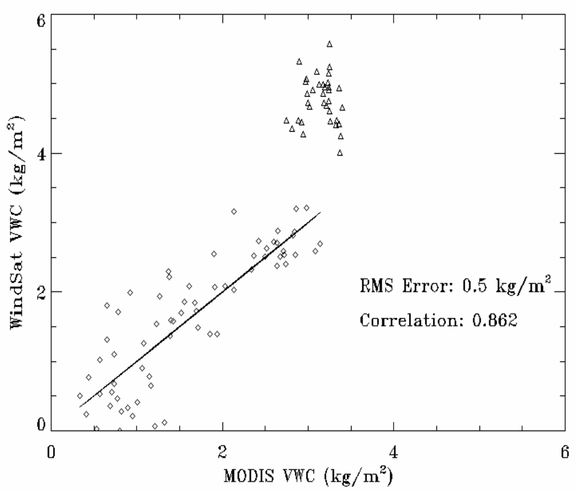
Field Experiment Optical Vegetation Algorithm



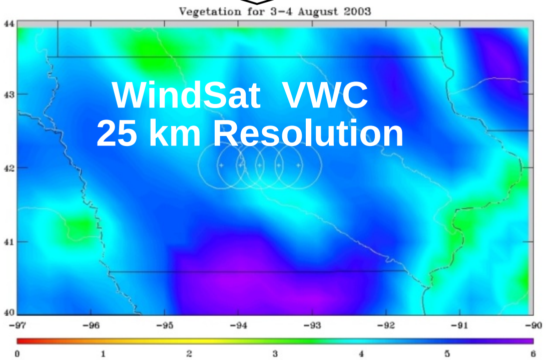
Land Surface Type (15 m cell size)



- » Optical Vegetation Water Content (VWC) algorithms were built for every vegetation type using field experiment data
- » Combined with land surface type data, the algorithms generated MODIS VWC, which were aggregated to WindSat resolution.
- » Optical and microwave VWC data show good agreements
- » MODIS VWC saturate at ~3.5 kg/m^3



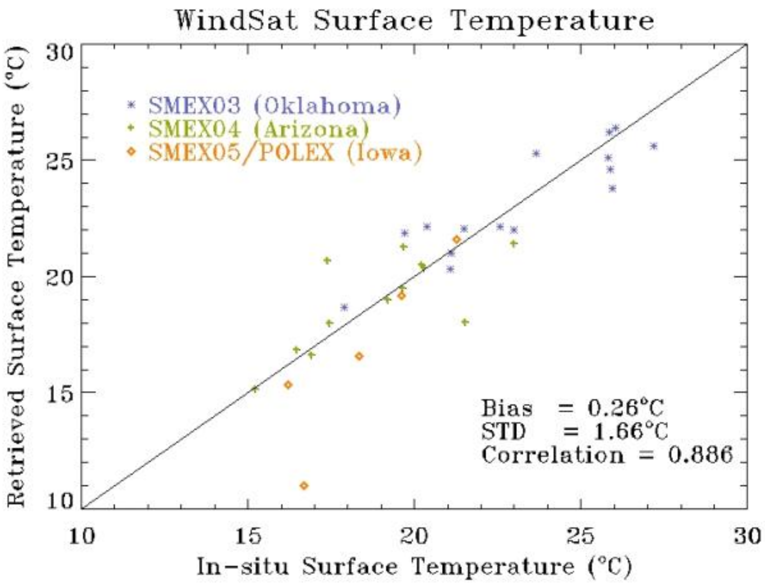
The first comparison of Optical and MW VWC data

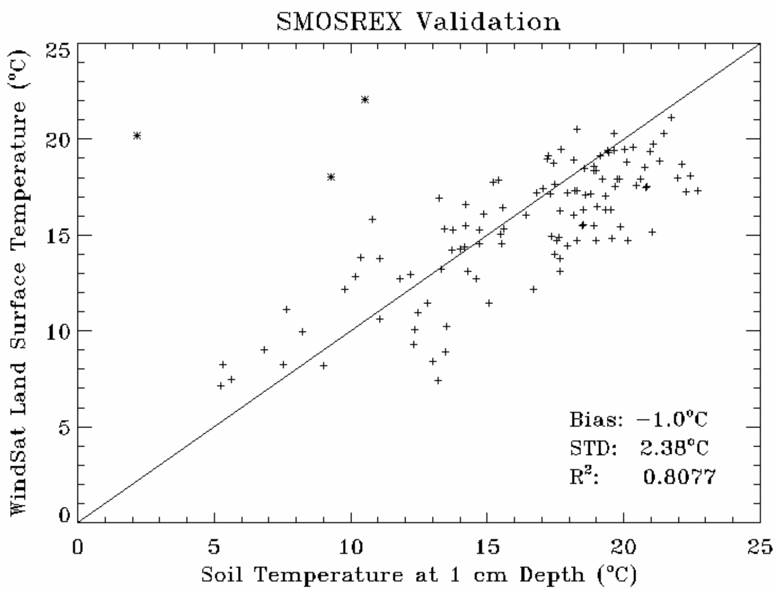


WindSat Vegetation Data Has Been Released

WindSat Land Surface Temperature Data Validations

- SMEX LST validation is based on skin temperature measured by networks of IR sensors
- SMOSREX LST validation is based on point measurements of soil temperature at 1 cm depth
- Further validation will be based on model assimilation of MODIS and AIRS data

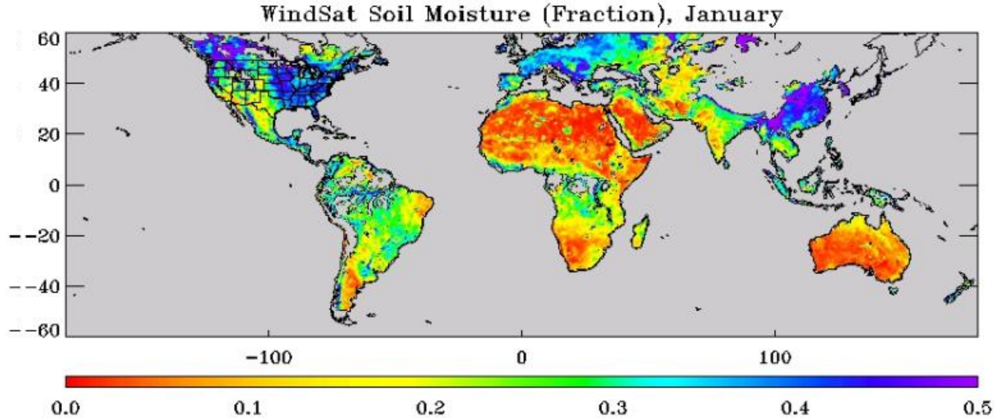




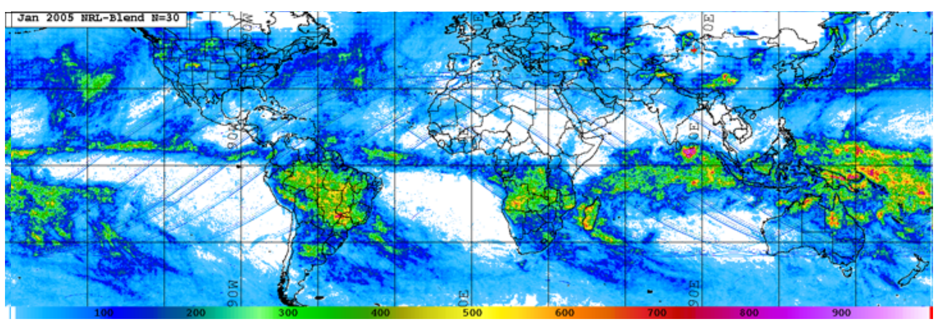
Soil Moisture and Precipitation Monthly Climatology (2003-2007)

The spatial and temporal variations is highly correlated with global monsoon systems

2003-2007



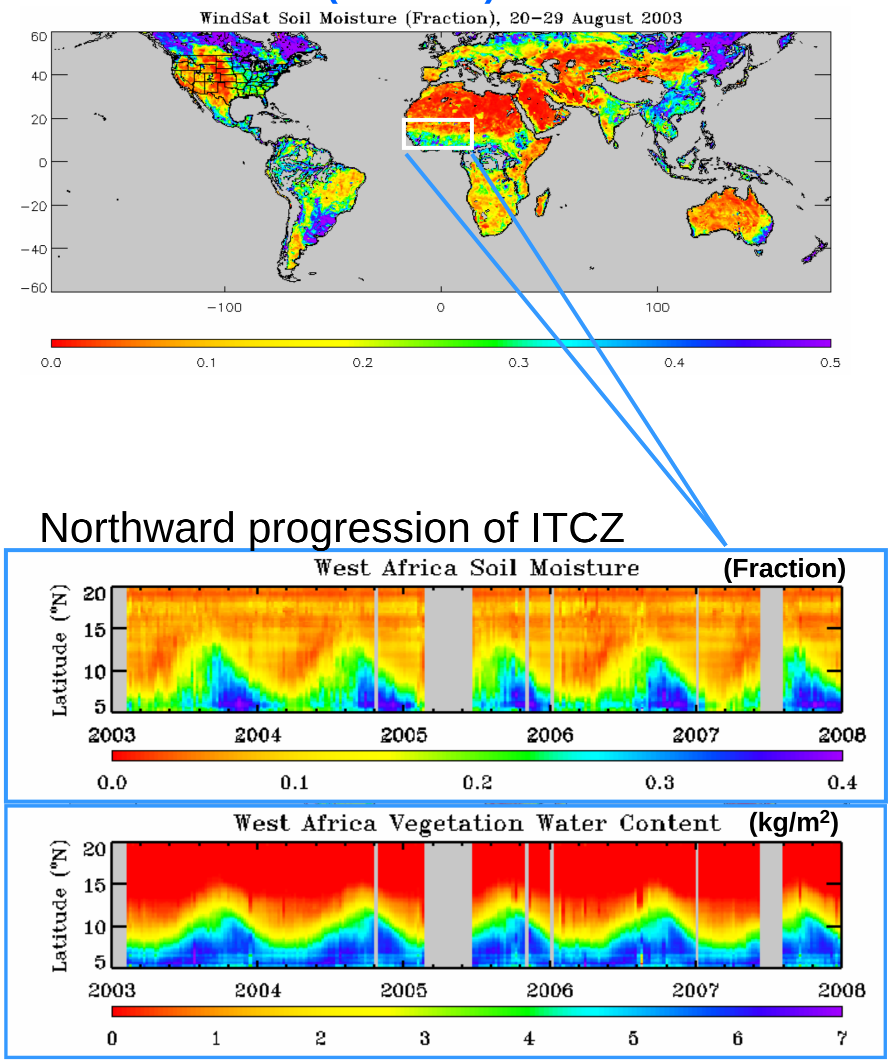
2005



Soil Moisture and Vegetation Climatology

1 – 12 Sep. 2003

Soil Moisture (Fraction)

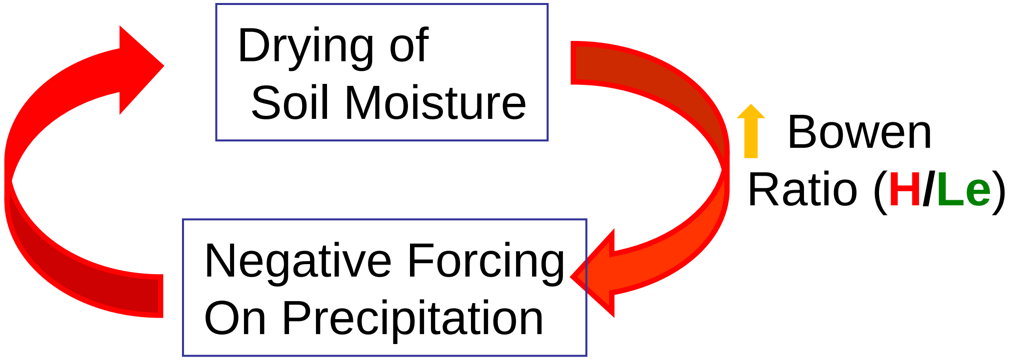


- ***Soil moisture and vegetation water content data are binned in latitude and time over West Africa***
- ***The binned West Africa data show wave structures that are consistent with progression of ITCZ***
  - *From June to September, the northward progression of soil moisture is consistent with northward monsoon movement during rainy season*
  - *From November to January, soil moisture recede to the south to start another cycle*
  - *The wave propagation of vegetation water content is similar to soil moisture wave with a phase delay of about 1 to 2 weeks, reflecting a slower response of vegetation to rainfall than soil moisture*
  - *The soil and vegetation conditions are wetter from the November to January period than the June to September period, demonstrating their memory effects*

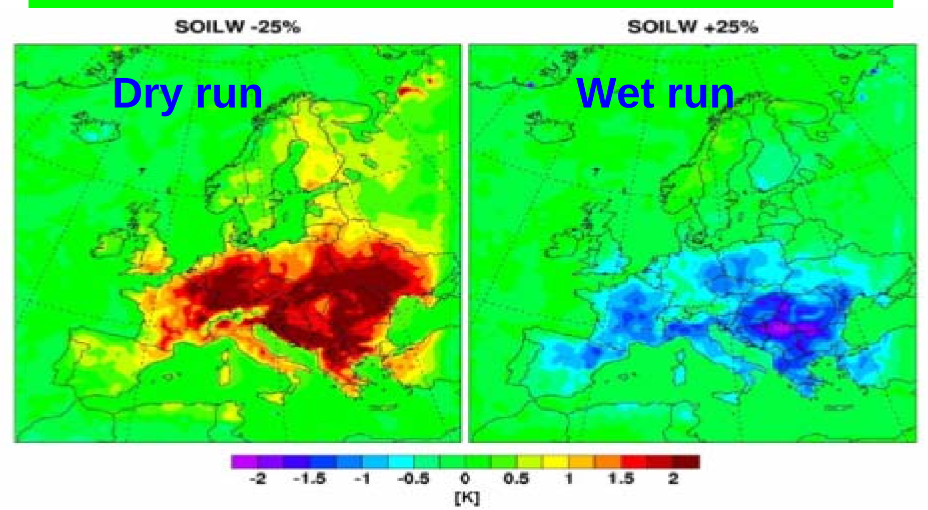
Extreme Heat Wave Mechanisms
Roles of Soil Moisture, Vegetation, and LST

Soil Moisture – Precipitation Feedback

(*Zaithik et al., Int. J. Climatol. 26: 743–769, 2006*)

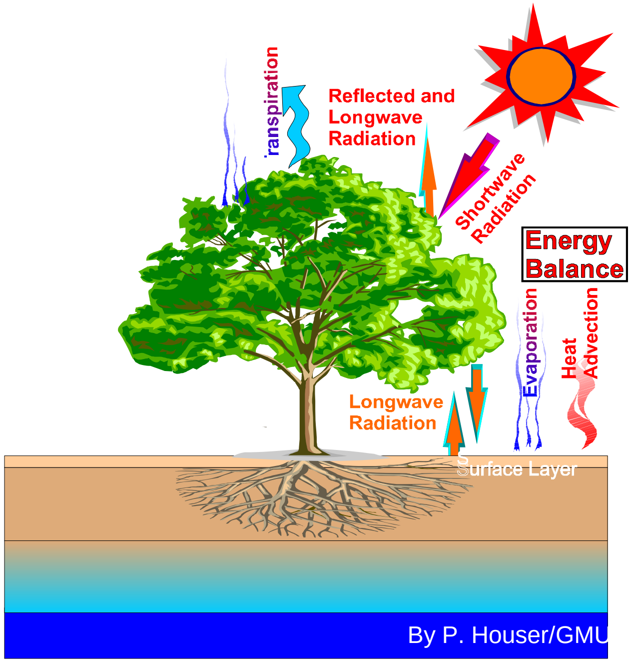


LST anomaly due to soil water perturbation



Climate High-Resolution Model (CHRM) Simulations

Drs. E. Fischer and S. Seneviratne/ETH, Zurich, Switzerland



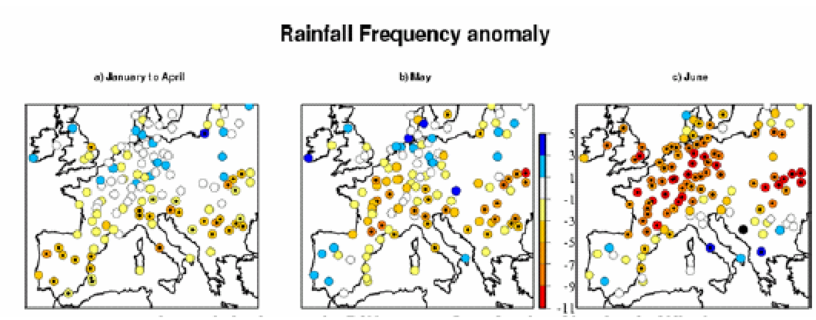
***Energy Balance*.**

$$R_n - G = Le + H = Q_t$$

- R_n : net radiation available at surface
- G : heat flux into the soil
- Le : latent heat flux
- H : sensible heat flux
- Q_t : total turbulent energy flux into the PBL

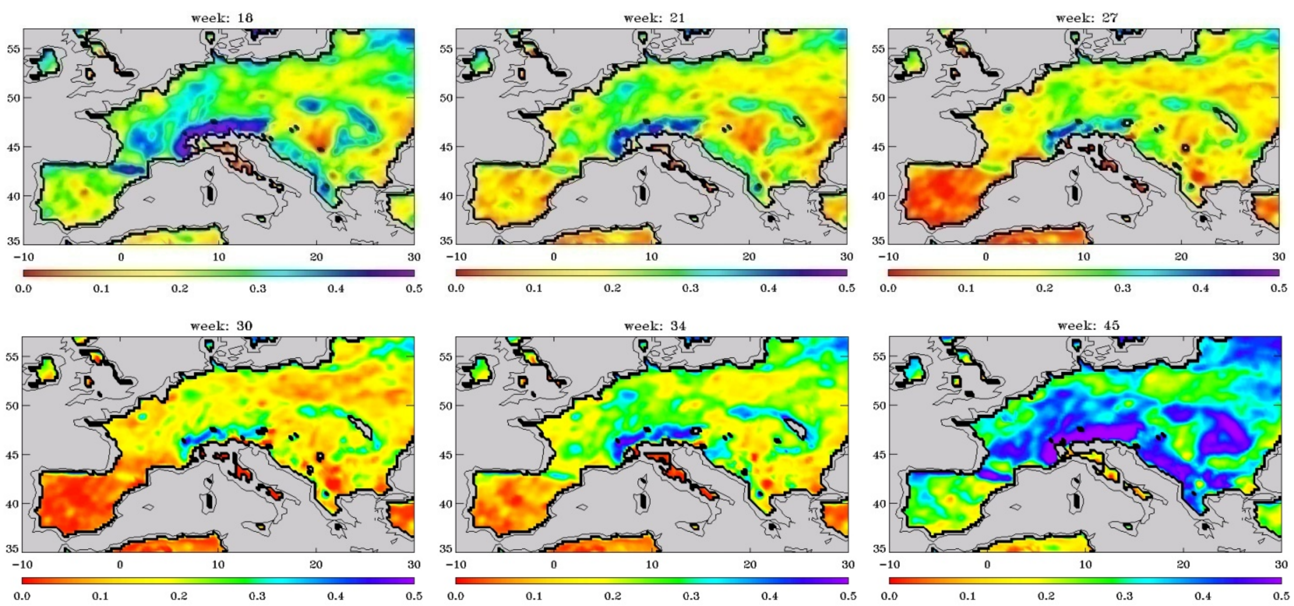
European Summer Climate

- **Potentially influenced by SST and SM, when the large-scale westerly flow weakens in the summer**
- **Drought propagation play an important role in maintaining the hot summer**
- **Using precipitation data as proxy; no direct SM evidence published**



By Vautard et al, 2007

Soil Moisture



The 2003 European Heat Wave

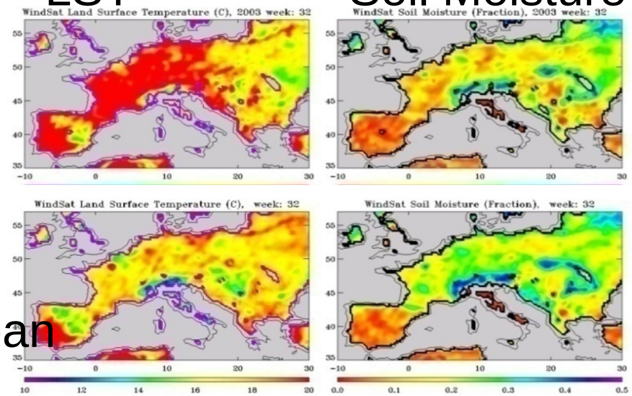
WindSat Data Captured three reported LST anomalies, and revealed their differences in surface conditions

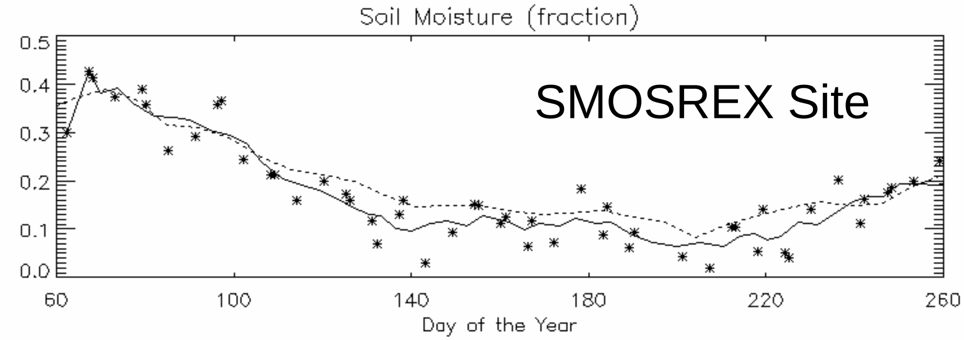
WindSat land surface retrievals corroborate well with the climate simulations. The land-atmosphere coupling played an important role for the evolution of heat waves. Early green-up and positive vegetation anomaly resulted in rapid loss of soil moisture in spring and extreme drought and vegetation stress in the summer, which triggered a positive feedback between soil moisture and temperature. When combined with an anti-cyclonic atmospheric circulation, a strong positive feedback amplified the temperature extreme, resulting in a record-breaking heat wave.

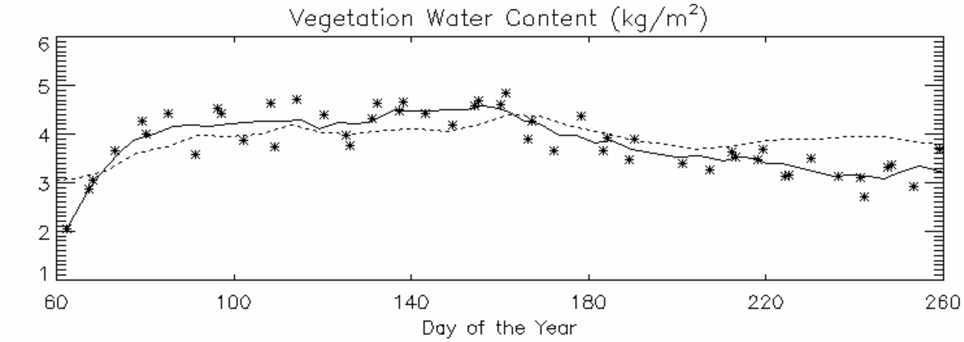
LST | Soil Moisture

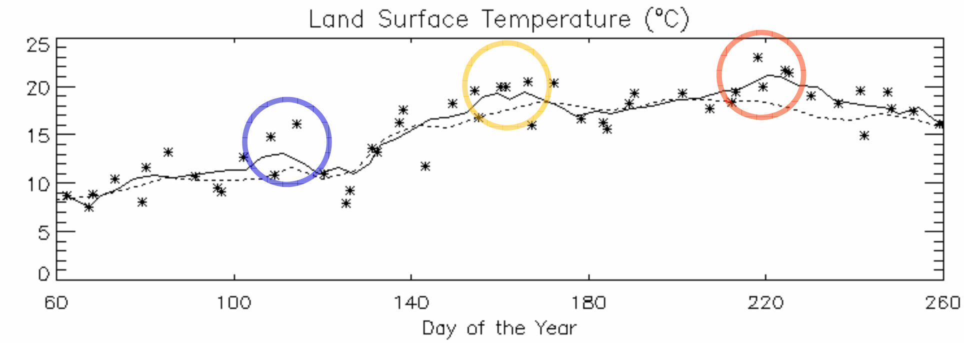
Week 23 2003

Week 23 5 year mean

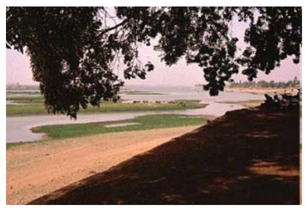


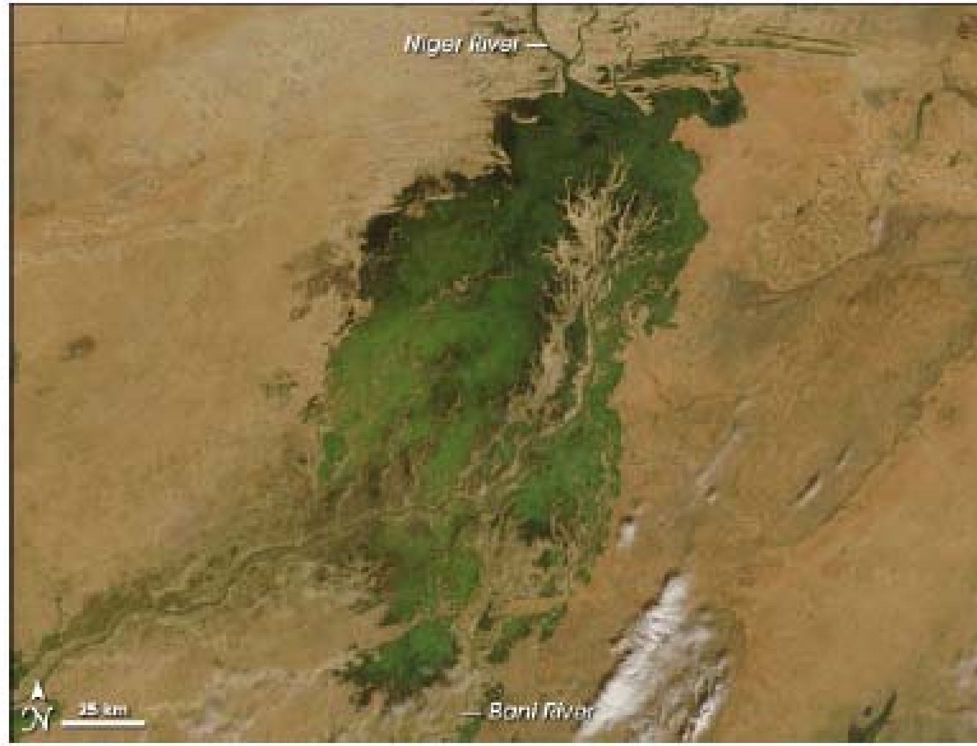






Inland Niger Delta, Modis Gallery





Fed by floodwaters from the Niger River, the Bani River, and a network of smaller streams, the inland Niger delta grows to some 20,000 square kilometers (7,700 square miles) during the four-month rainy season that begins each July. During the dry season, the inland delta can shrink to roughly 3,900 square kilometers (1,500 square miles).

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASAs Terra satellite took this picture of the Inland Niger Delta on November 11, 2007 shortly after the end of the rainy season when the landscape remained lush and green. This inland delta is a complex combination of river channels, lakes, swamps, and occasional areas of higher elevation. One such area of higher elevation is obvious in this image, and it forms a branching shape, like a tan tree pushing up toward the north.

This wet oasis in the African Sahel provides habitat both for migrating birds and West African manatees. The fertile floodplains also provide much needed resources for the local people, who use the area for fishing, grazing livestock, and cultivating rice.

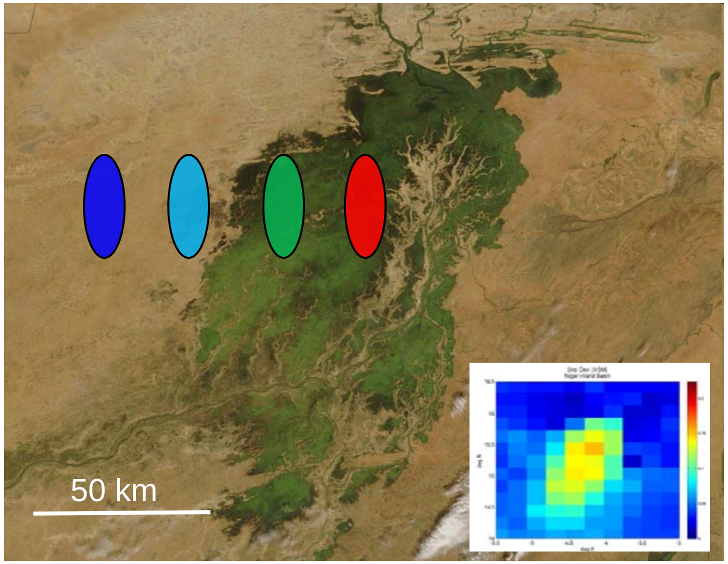
* References Metropolitan Museum of Art. Inland Niger Delta. Accessed November 16, 2007.
* World Wildlife Fund. Inner Niger Delta Flooded Savanna. Accessed November 16, 2007.
* Lange K.E. (2001, June) Djénné: West Africas Eternal City. National Geographic. Accessed November 16, 2007.

NASA image courtesy the MODIS Rapid Response Team at NASA GSFC. The Rapid Response Team provides daily images of this region.

Flood in Inland Niger Delta (Mali)

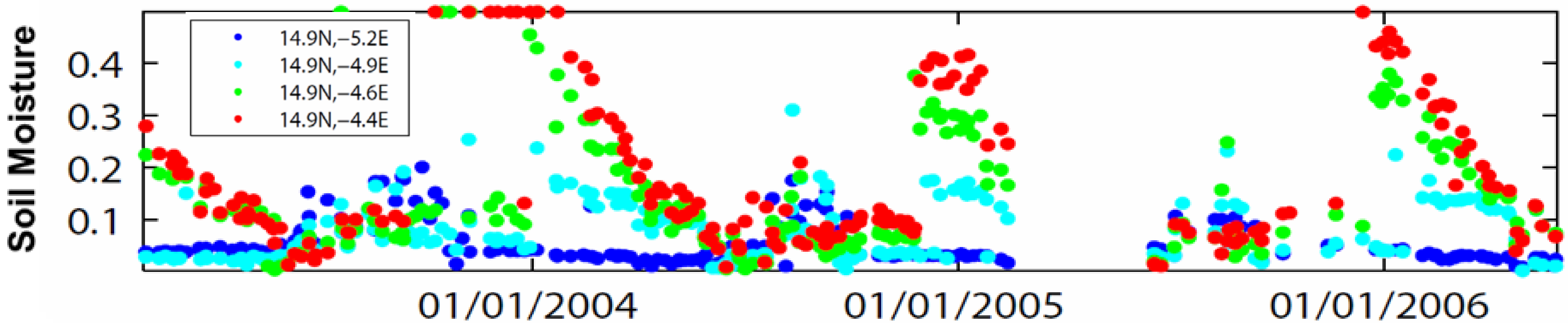
By Dr. S. Steele-Dunne, TU Delft, The Netherlands

- Located in the semi-arid Sahel area, and fed by floodwaters from Niger and Bani rivers, inland Niger delta grows to 20,000 km^2 in the rainy season and shrink to 3,900 km^2 in the dry season
- MODIS and WindSat images (to the right) show the contrast between the semi-arid background and the wet delta
- Four WindSat observation points are selected:
  - Two points outside the delta respond to rainy season (July – September) with peak soil moisture less than 20%, confirm small impacts of rainfall
  - Two points inside the delta respond to the surge of floodwater reaching the delta in October, then dry down slowly from saturation due to infiltration and evaporation



NASA MODIS picture on 11/11/2007

Insert: WindSat soil moisture standard deviation



Revealed the WindSat Potential in Flood Monitoring and Analysis of Stream Flow/River Crossing

Summary

- Validated a six-channel soil moisture algorithm for WindSat
  - » The WindSat land data products were validated globally at multiple scales and against multiple data sources.
- Data analysis revealed its great potential in science and operational applications, particularly climate research.
- It’s now meaningful to build decadal soil moisture observations using current and planned window-channel radiometers (GPM/TMI/GMI, AMSR-E/AMSR-2, WindSat, and MIS).

The 2003 European Heat Wave

WindSat Data Captured three reported LST anomalies, and revealed their differences in surface conditions

Day 60 – 110
- Warmer spring temperature
- Normal soil moisture level
- Rapid vegetation green-up

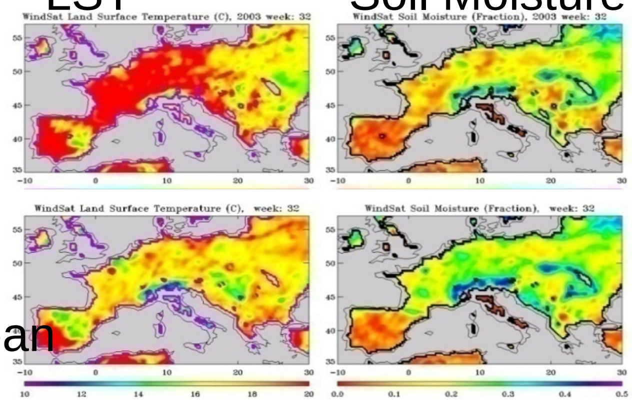
Day 110 - 160
- Soil moisture was below average
- VWC was above the average until day 150-160, depleting soil moisture

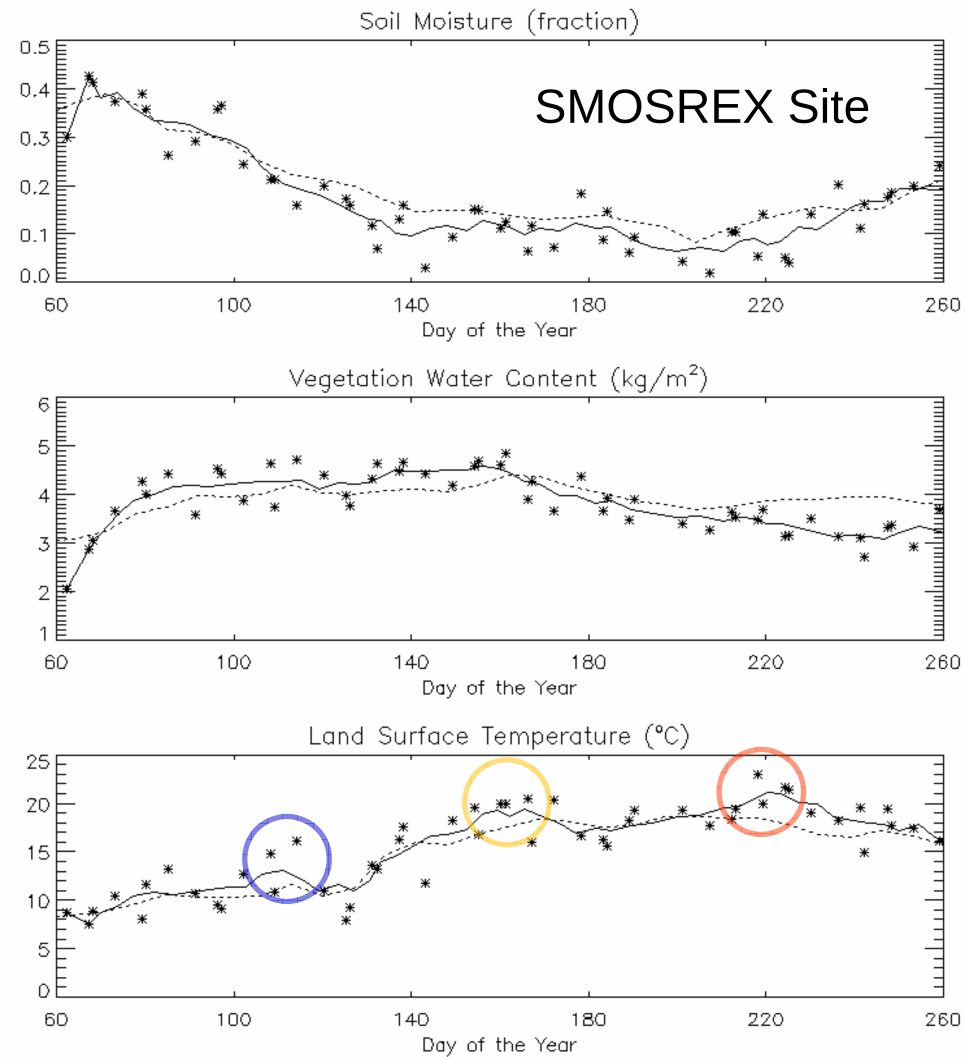
Late Summer
- When the heat wave hits near day 220, both soil moisture and VWC were low.

LST | Soil Moisture

Week 23 2003

Week 23 5 year mean





Soil Moisture Climatology

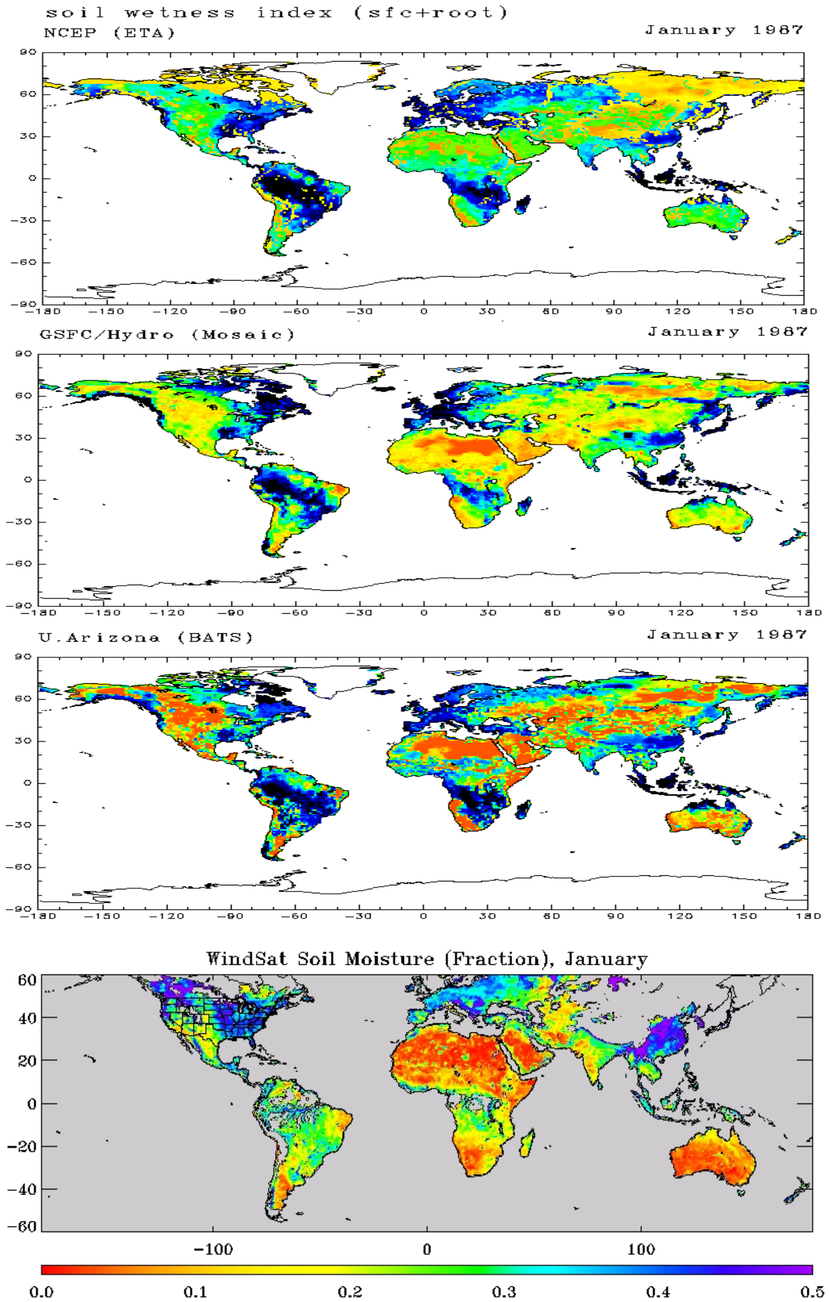
Land Surface Model (LSM) determines soil moisture using precipitation and vegetation data. There is no direct soil moisture measurements

LSMs differ in their parameterization, resulting in different soil moisture from the same inputs

LSMs disagree with each other on soil moisture climatology

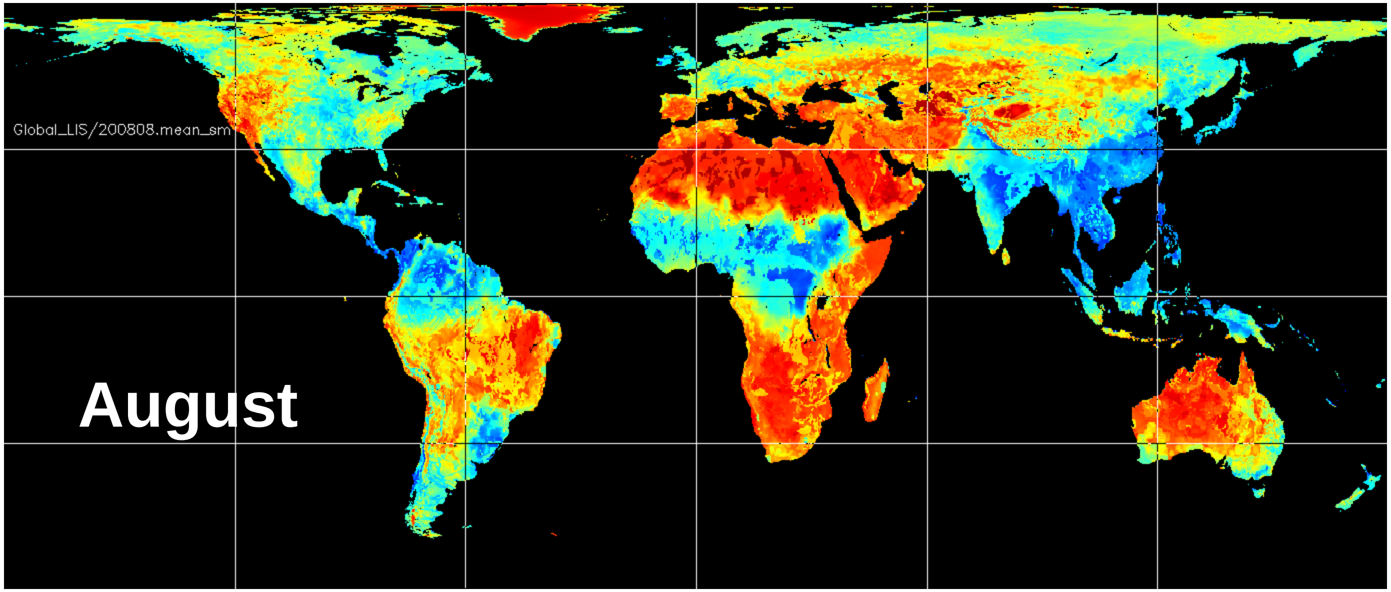
WindSat and LSM soil moisture maps have similar global features

WindSat soil moisture climatology can provide a platform for model comparisons in terms of LSM parameterization.



WindSat and LIS data Comparison

LIS



WindSat