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Assimilation of ASCAT soil wetness

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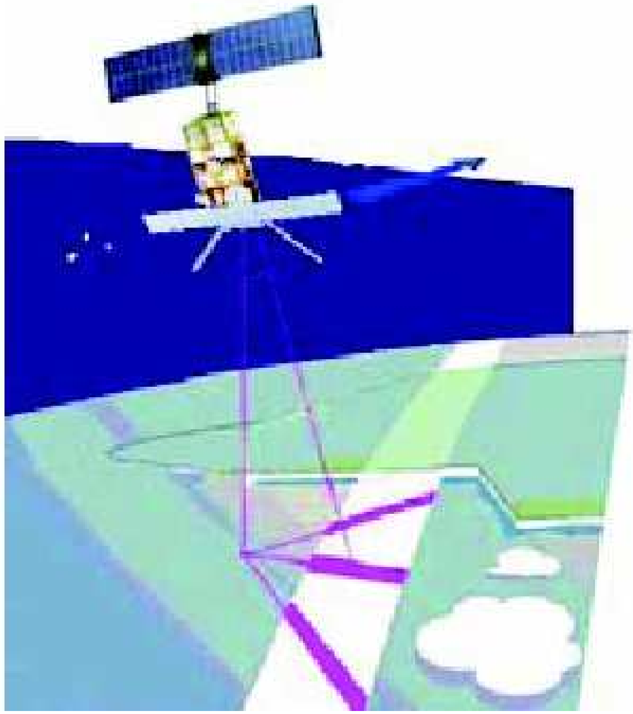
Contents

This presentation covers the following areas

- ASCAT soil wetness pre-processing and QC
- Assimilation
- Trial results
- Comparison with in situ data
- Conclusions

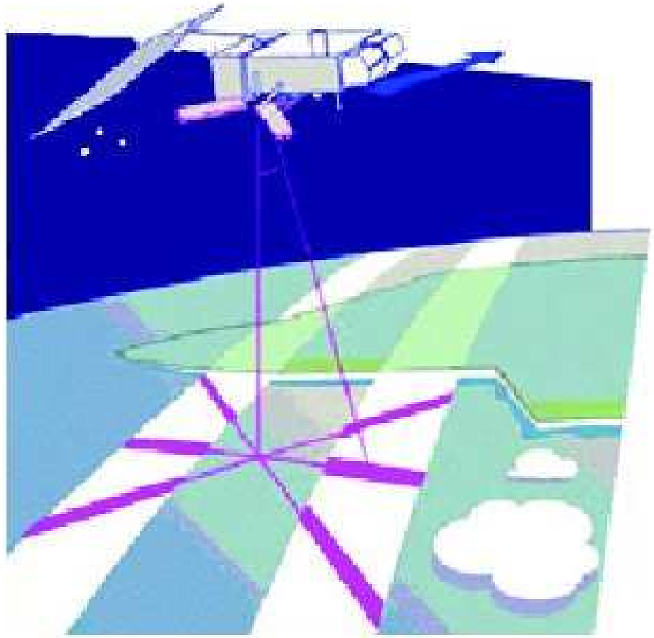
Operational European C-Band Scatterometers

- 2 ERS scatterometers
  (1991 to 2008)
  - 5.3 GHz
  - 3 Antennas
  - Swath width: 500 km
  - Resolution: 50 / (25) km
  - Daily coverage ~ 40%



- 3 METOP scatterometers (ASCAT)
  (launched October 2006, > 14 years)
  - 5.3 GHz
  - Two pairs of 3 Antennas
  - Swath width: 2 x 550 km
  - Resolution: 50 / 25 km
  - Daily coverage ~ 80%

Overpasses at about 9:30 and 21:30 LST



Conversion of ASCAT backscatter measurements to Soil Moisture

- 2 Stage Process:

  1) University of Vienna/EUMETSAT convert ASCAT backscatter measurements to Soil Wetness by a Change Detection Algorithm.

     - Soil Wetness is really a normalised backscatter. (Values range from 0 to 1).

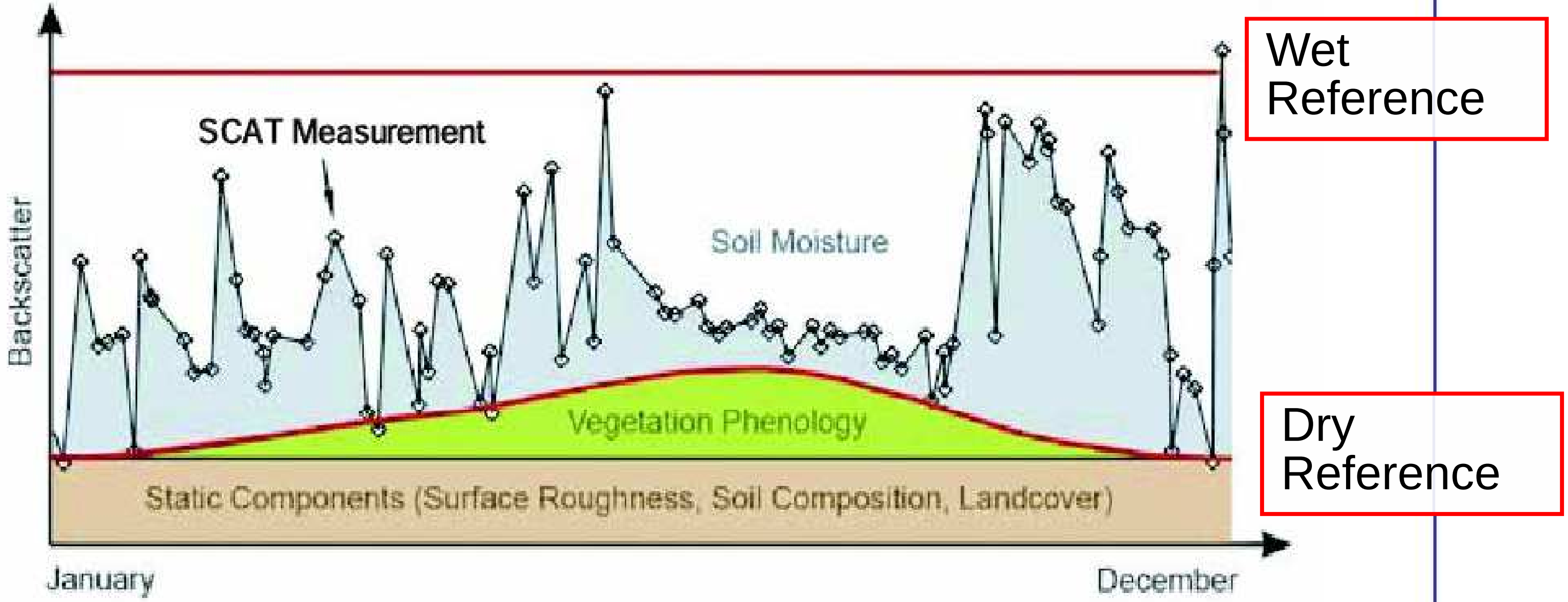
  2) We convert the Soil Wetness to Soil Moisture.

     - This is a non-trivial task!

TU Wien Retrieval Approach

- **Change detection**
  - Accounts indirectly for surface roughness and land cover

$$m_s(t) = \frac{\sigma^0(t) - \sigma^0_{dry}(t)}{\sigma^0_{wet} - \sigma^0_{dry}(t)}$$



Conversion of ASCAT Soil Wetness to Soil Moisture

- We assume a Linear Transformation of the Soil Wetness:

$$\theta_{ASCAT}(t) = a + b \times m_s(t)$$

- OR a Linear Transformation of the Soil Wetness Anomaly

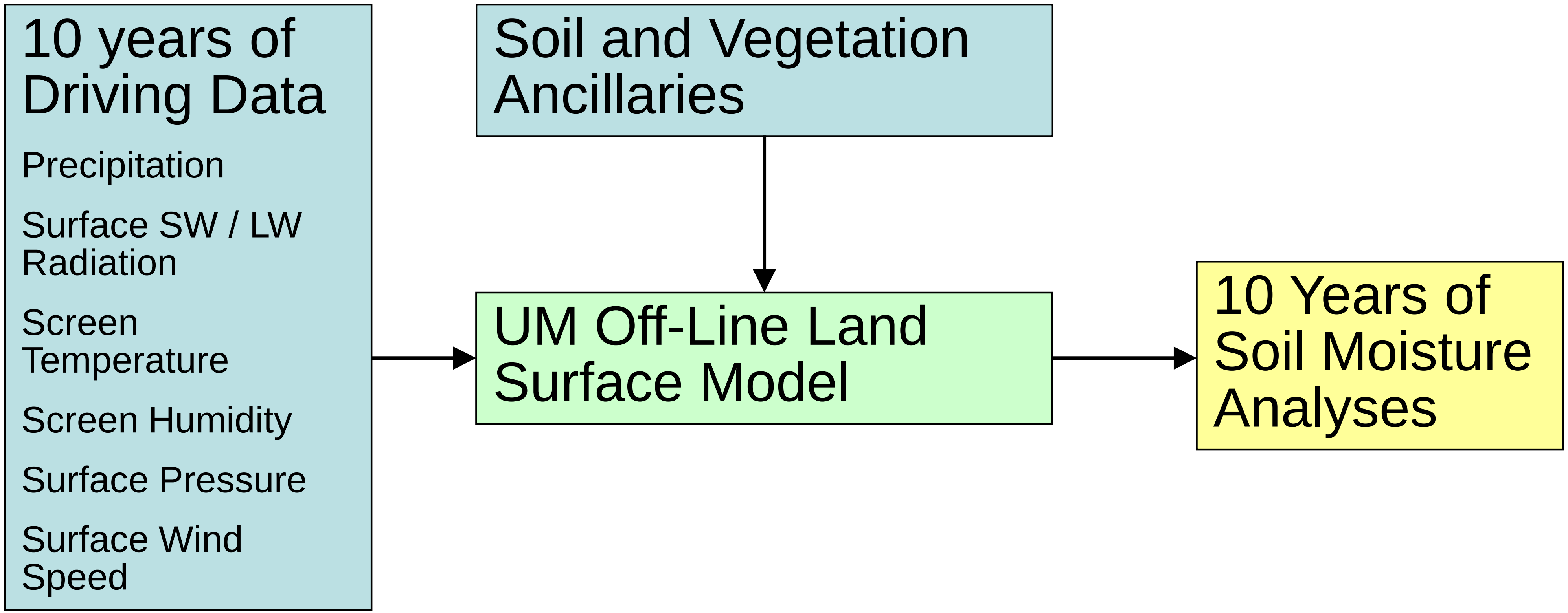
$$\theta_{ASCAT}(t) = \overline{\theta_{UM}(t)} + b \times \{m_s(t) - \overline{m_s(t)}\}$$

  - parameters *a* and *b* vary spatially but not in time. They depend on the properties of the soil and vegetation.
    - *a* is the minimum value of soil moisture
    - *b* is the (maximum minus minimum) value of soil moisture

- We have implemented 5 different methods to determine the *a* and *b* parameters. One used operationally is
  - $b = \theta_s - v\theta_w$, where v is vegetation fraction

UM soil moisture climatology $\overline{\theta_{UM}(t)}$

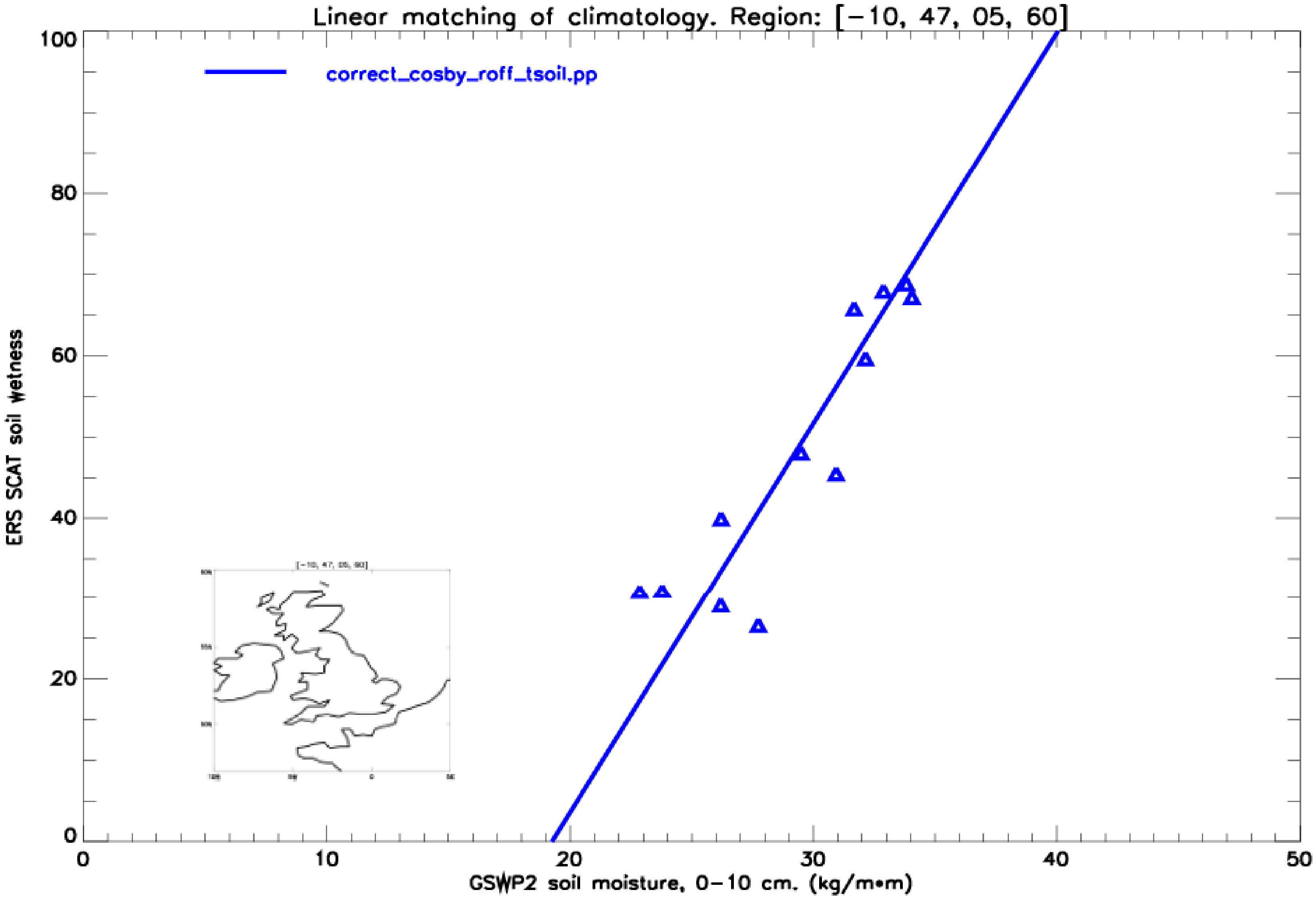
- Drive the UM land surface model (JULES) with 10 years of observation based data from the Global Soil Wetness Project 2 (GSWP2)



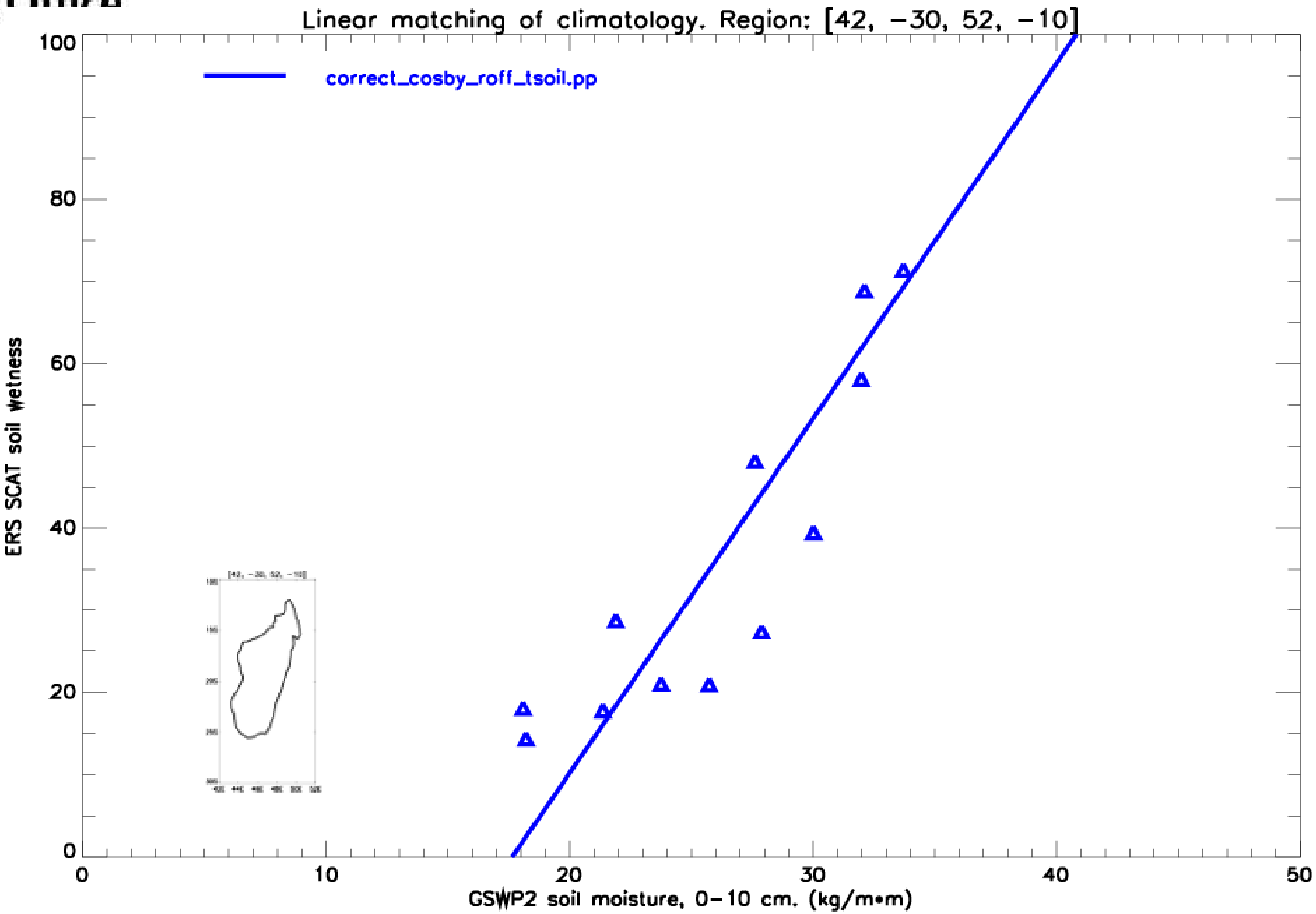
ERS SCAT Soil Wetness Climatology $\overline{m_s(t)}$

- Use ERS1/2 SCAT Soil Wetness data (1991-2000) to construct a Soil Wetness climatology

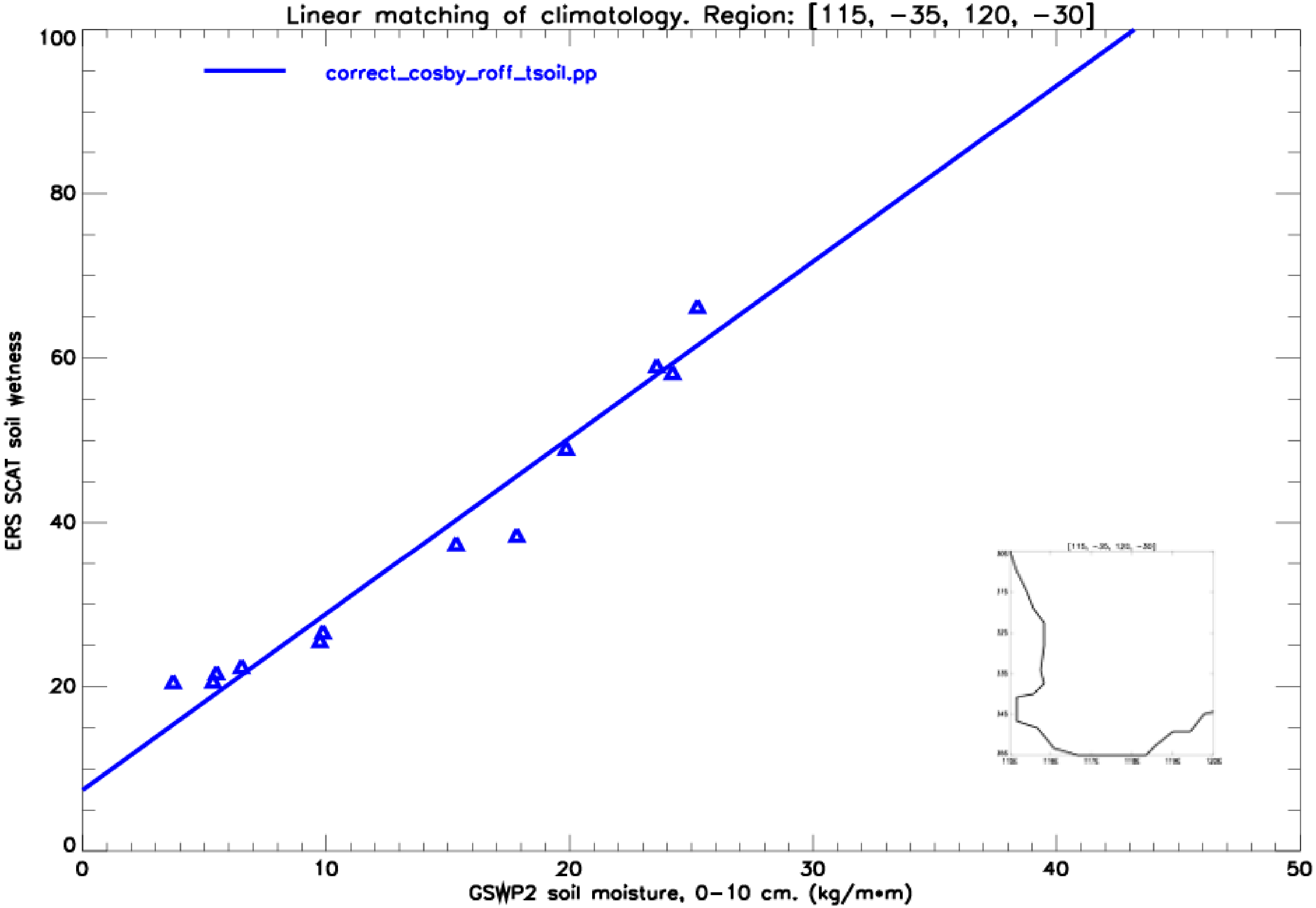
ERS SCAT Soil Wetness vs UM/GSWP2 Soil Moisture monthly means for the UK



Comparison for Madagascar



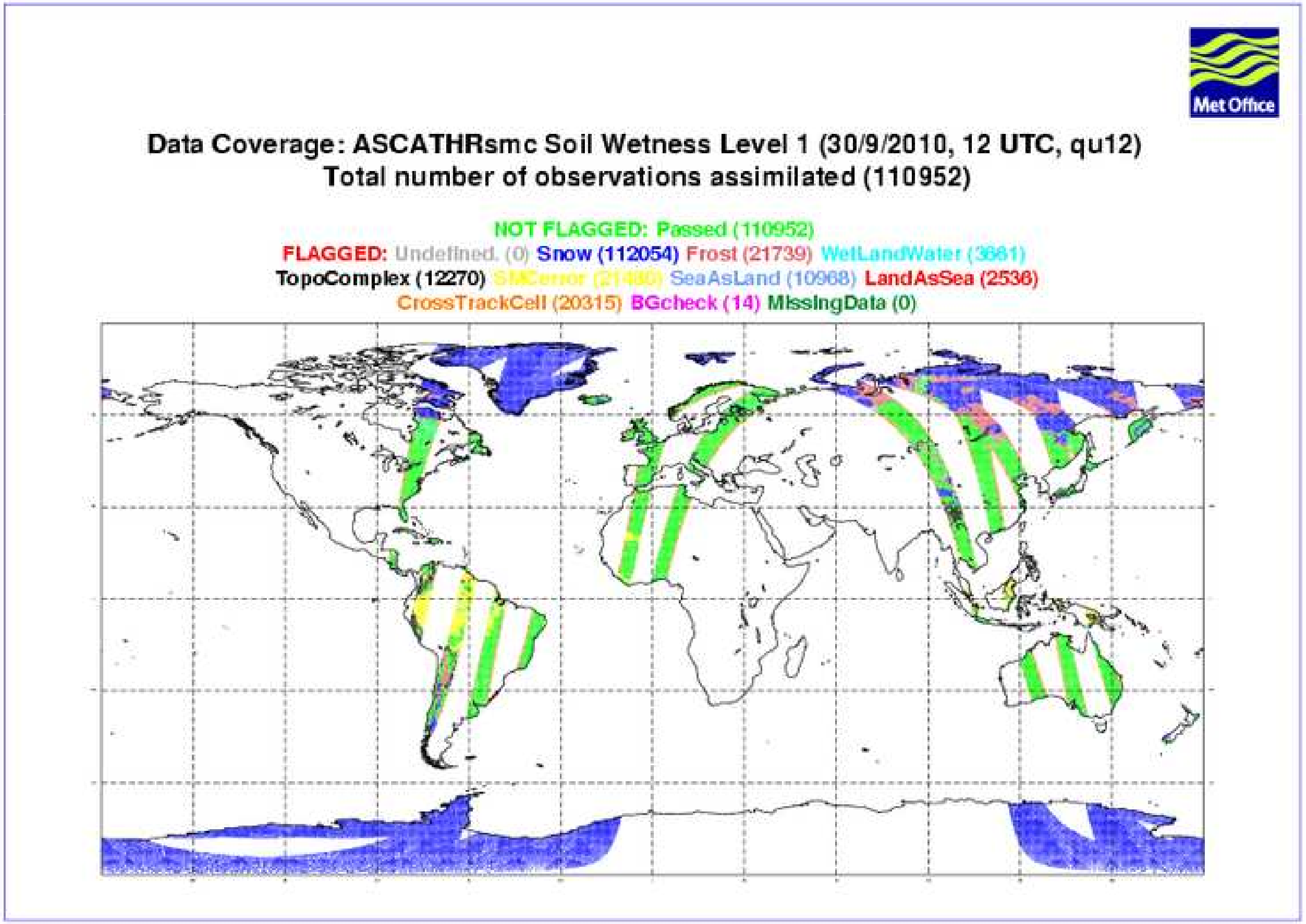
Comparison for S.W. Australia



Quality Control

- ASCAT data is rejected from regions with:
  - Snow
  - Frost
  - Wetlands
  - Mountains
  - Dense Vegetation (e.g. Amazon)
  - Sand Dunes
- ASCAT data is rejected from the edges of the swaths. Cross-track cells: 1-4, 40-43, 77-82.
- A background check is also applied (Lorenc and Hammon,1988).
  - Rejects observations with large o-b

Quality Control

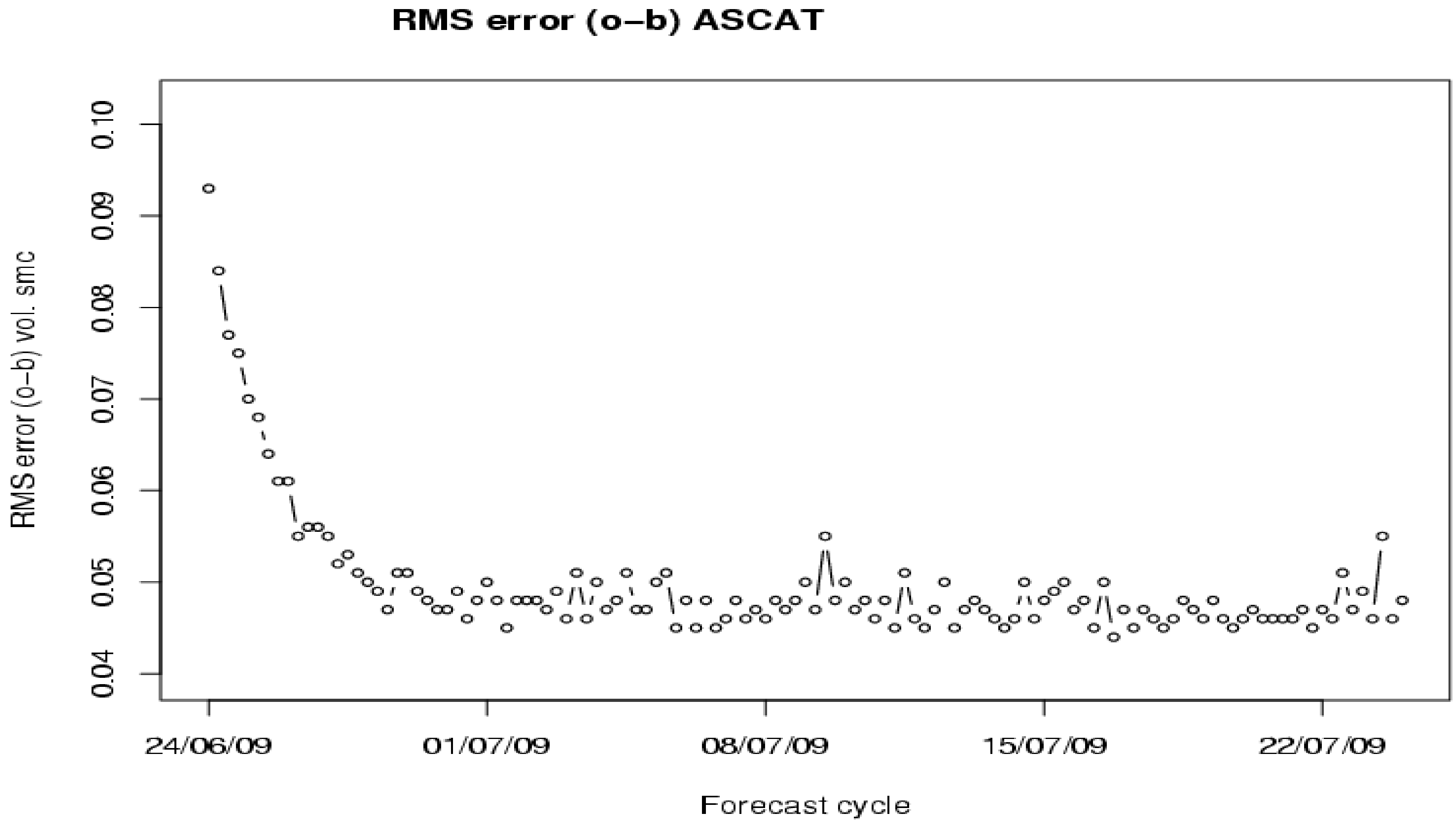


Assimilation

- A simple nudging scheme is used to assimilate the ASCAT derived soil moisture.
  - Only the UM soil level 1 is nudged
- Observations of Screen Temperature and Humidity are also used to nudge the UM soil moisture in all UM soil levels.
  - The ASCAT nudging is applied second.

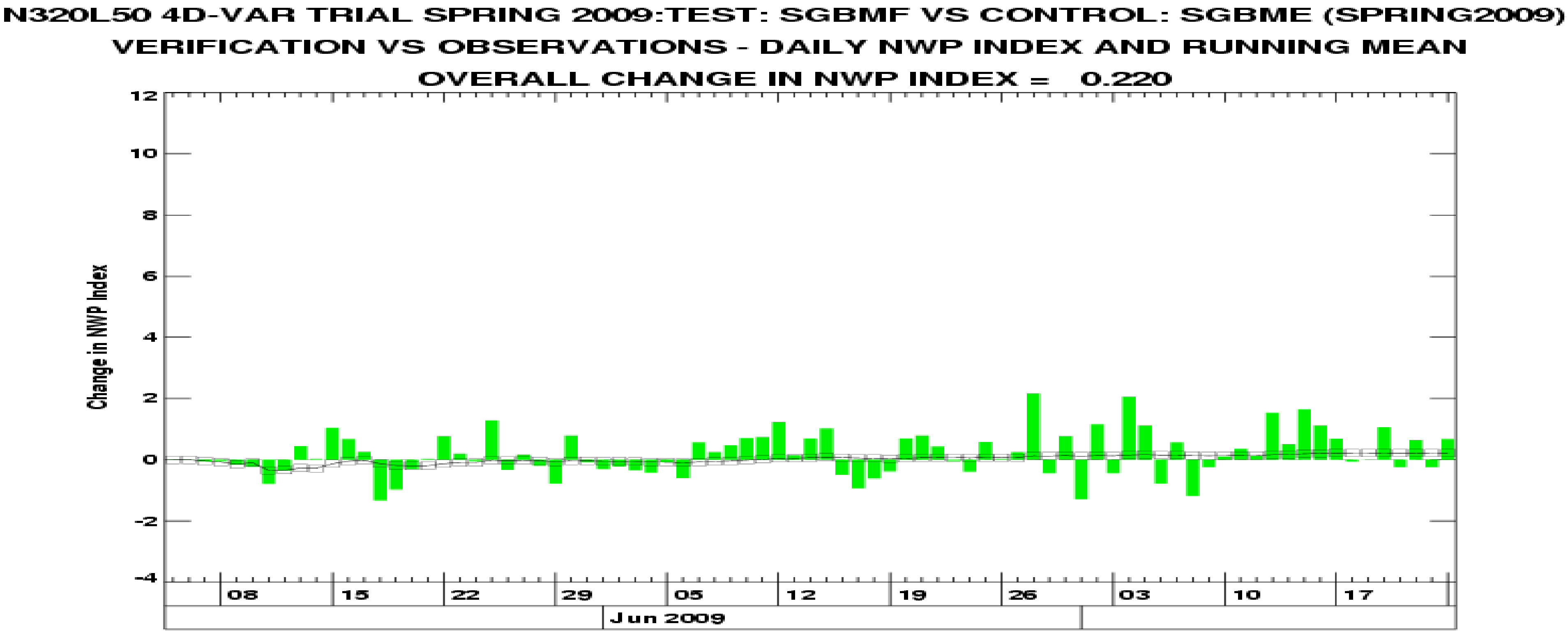
RMS (o-b) stats

- The UM is able to retain the information from the data assimilation and the UM soil moisture converges towards the values derived from ASCAT.



Impact on the Global NWP Index

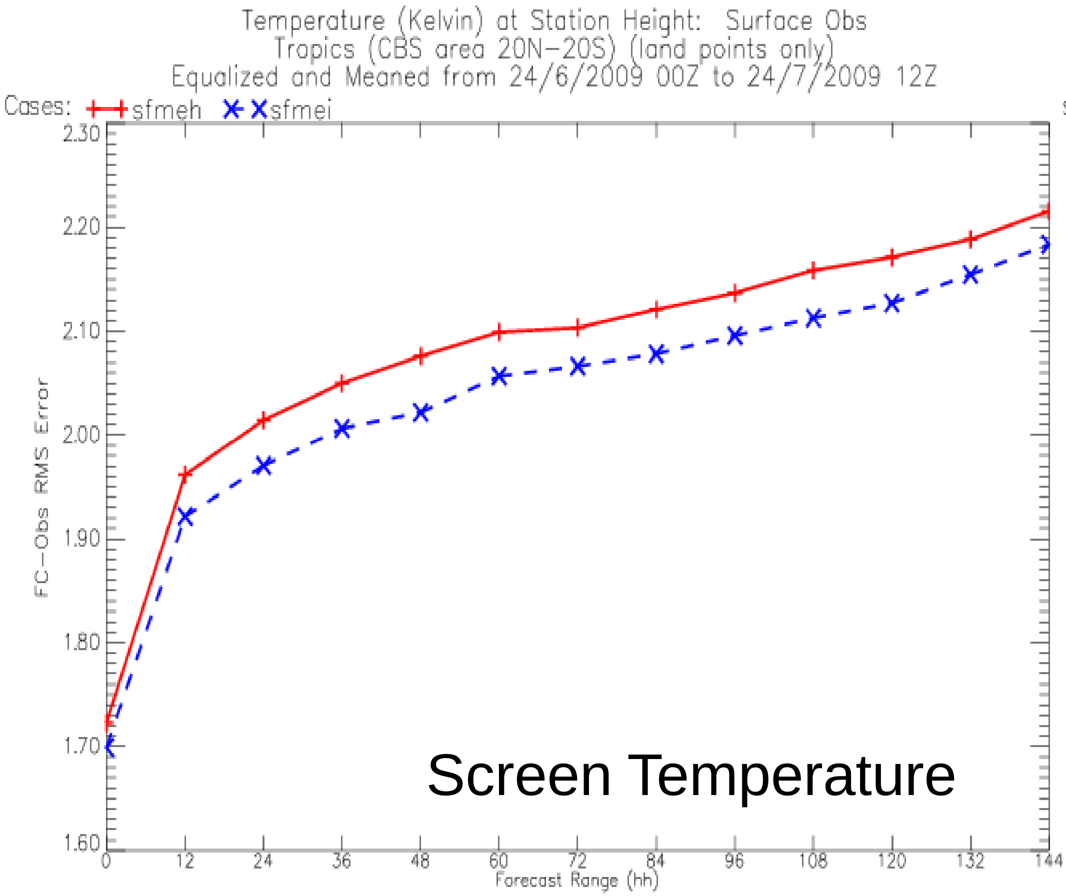
- Trial from May-July 2009
  - vs obs +0.22 vs anal +0.06
  - RMS errors in NH PMSL are reduced, at T+120 by 0.8%.

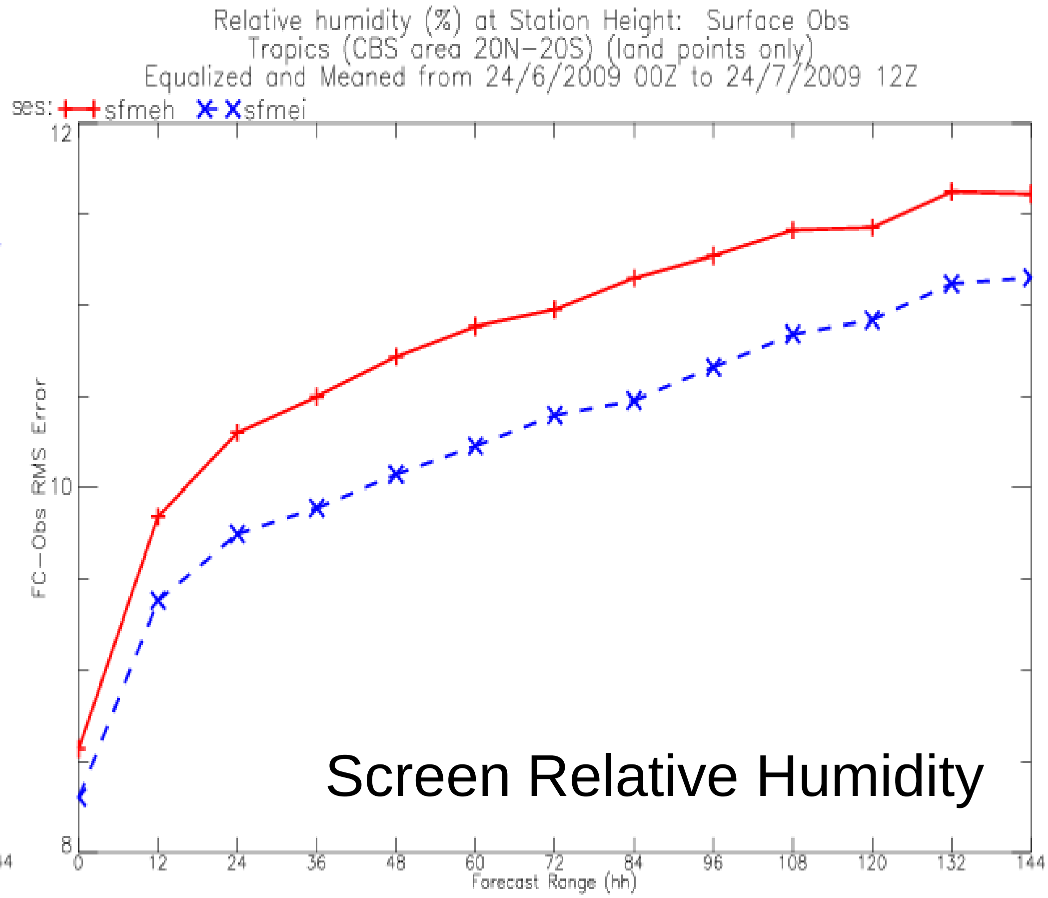


Tropics: RMS errors in screen T and RH (1 month)

Control

Test with ASCAT soil wetness assimilation

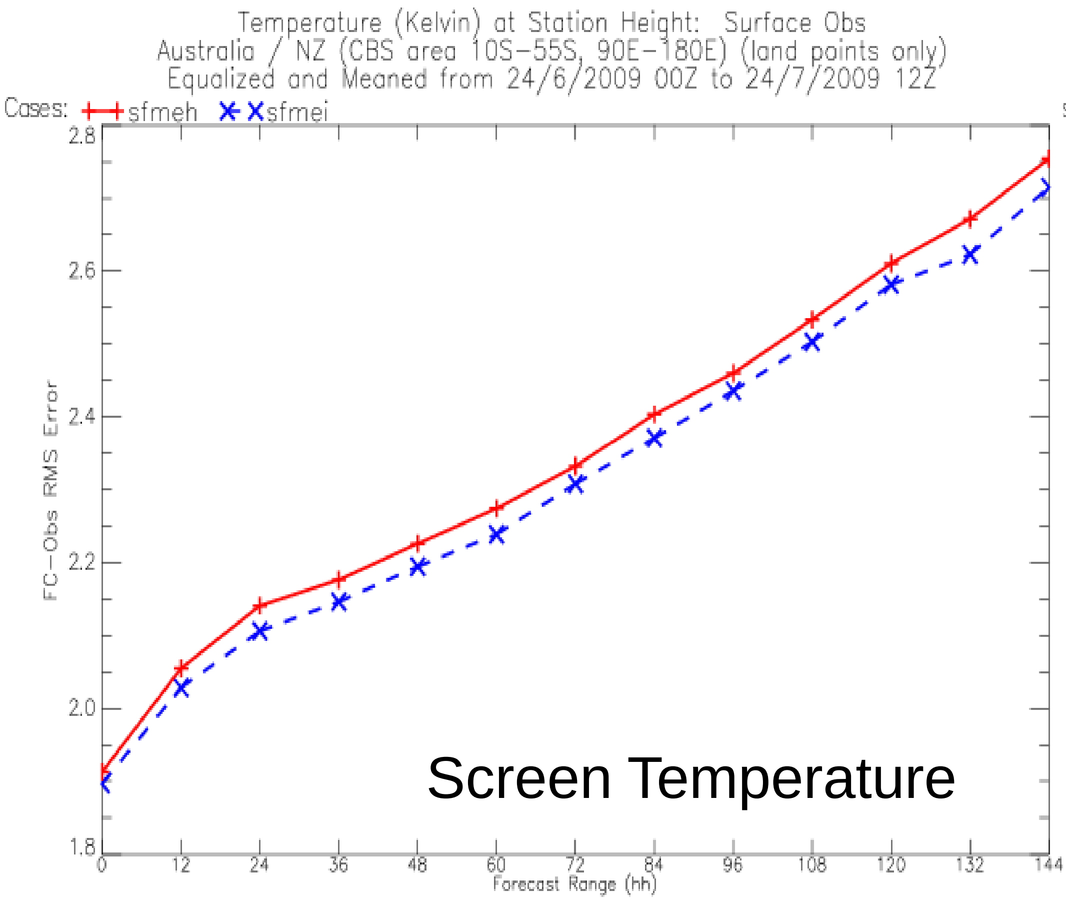


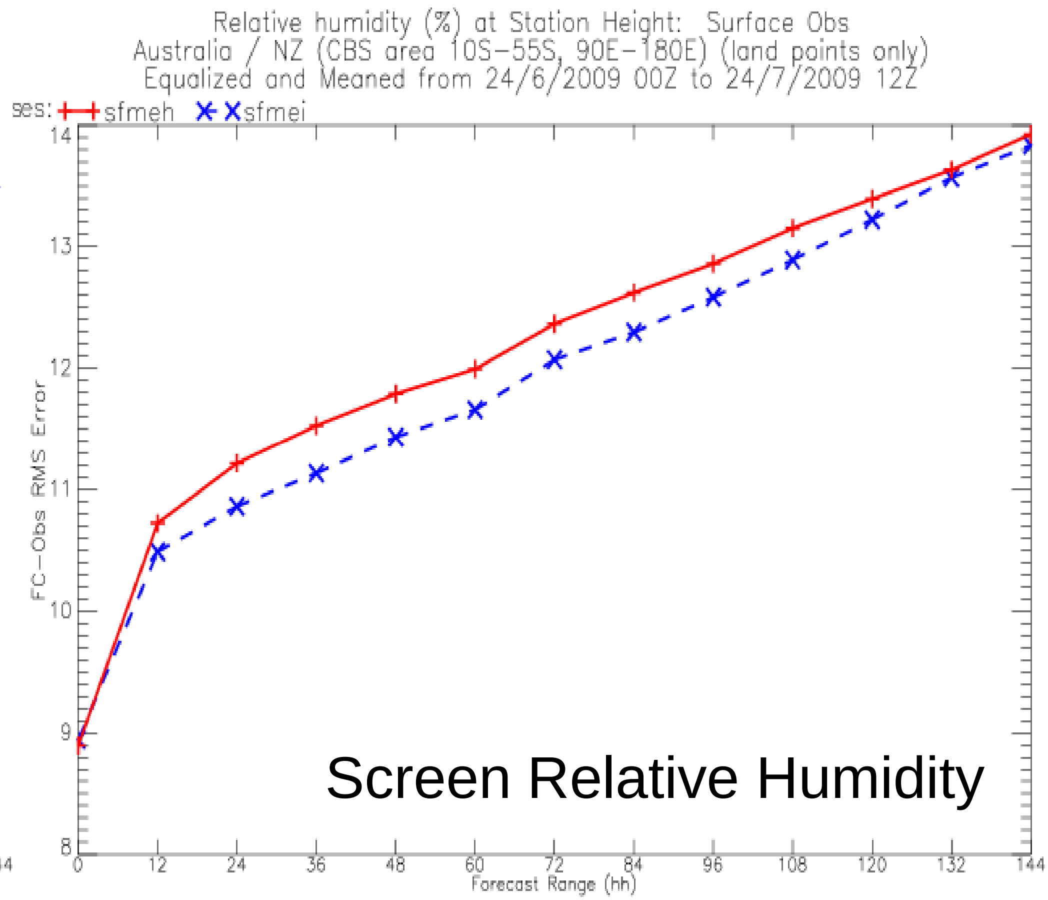


Australia: RMS errors in screen T and RH (1 month)

Control

Test with ASCAT soil wetness assimilation

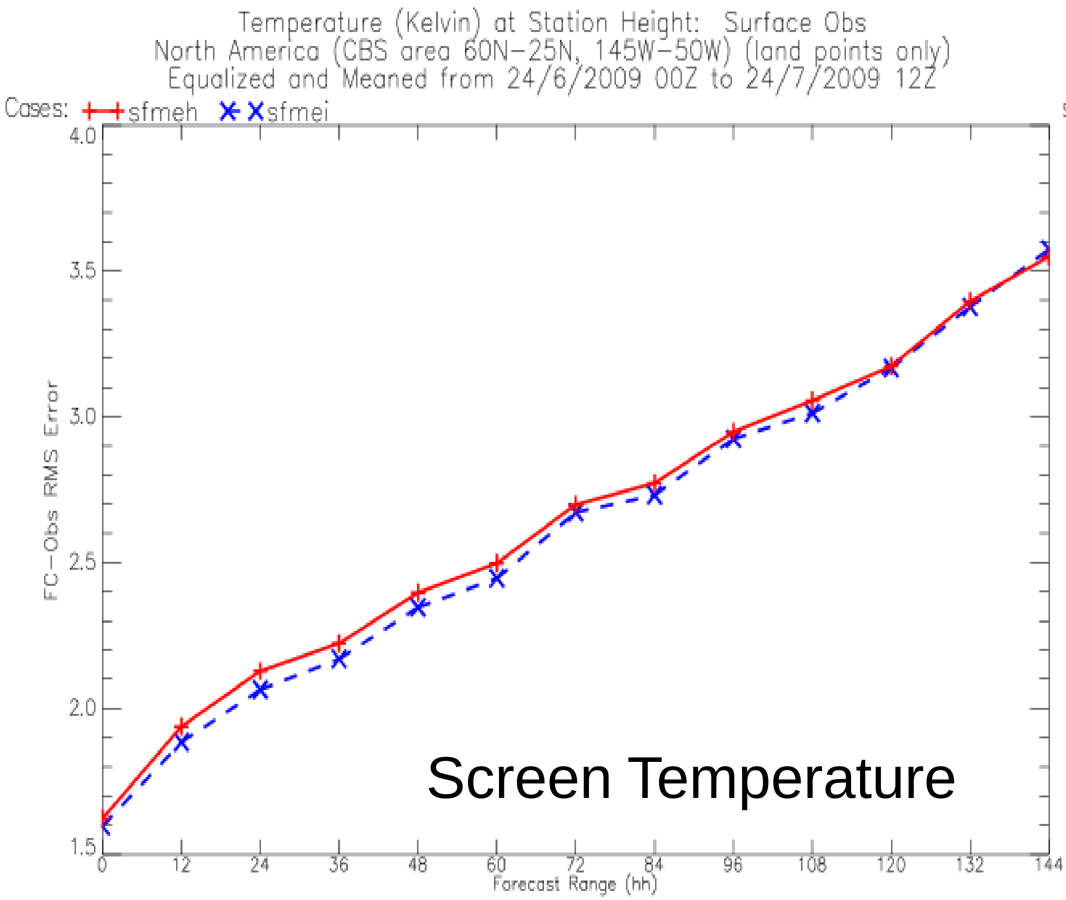


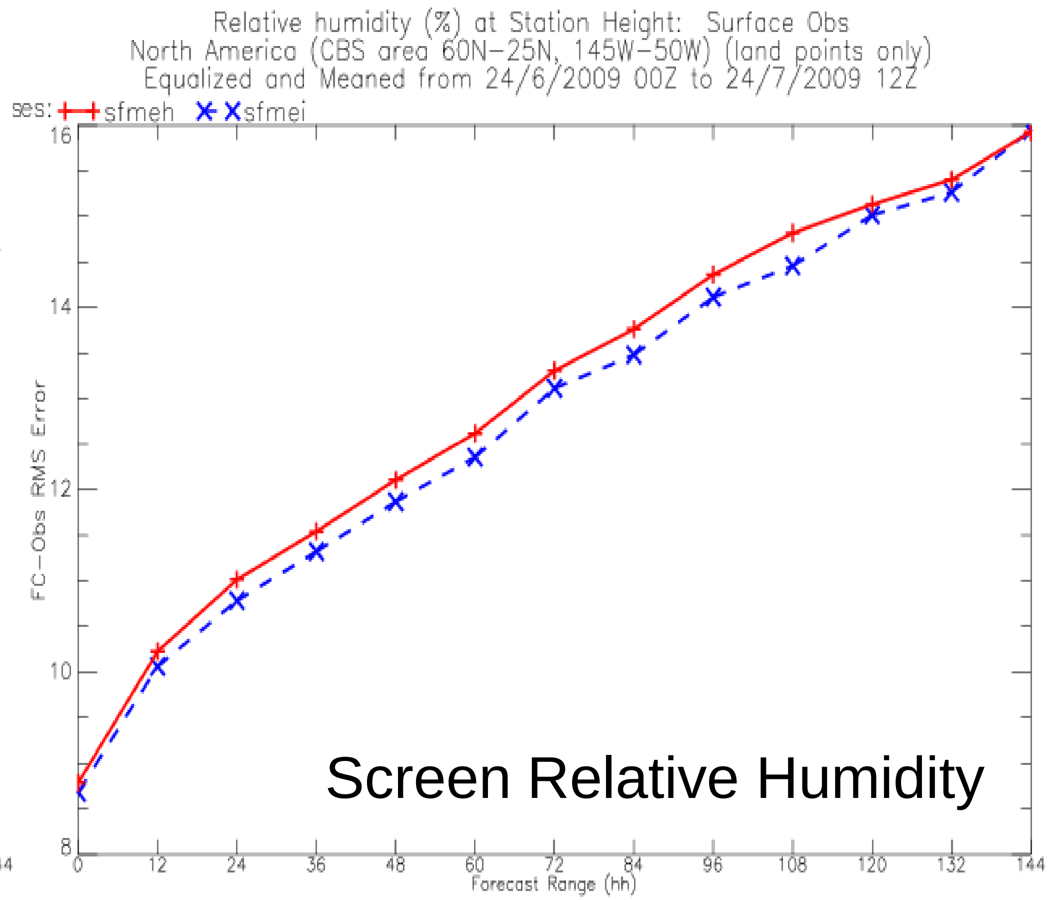


North America: RMS errors in screen T and RH (1 month)

Control

Test with ASCAT soil wetness assimilation

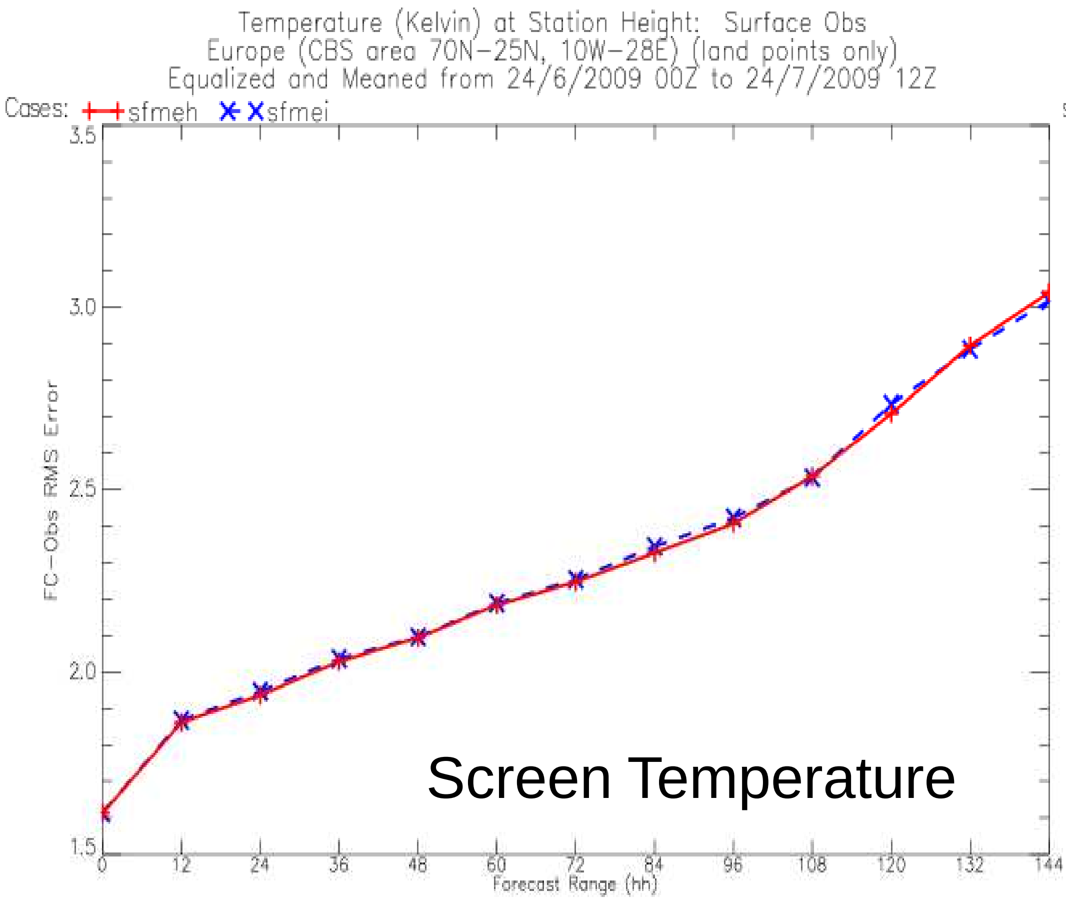


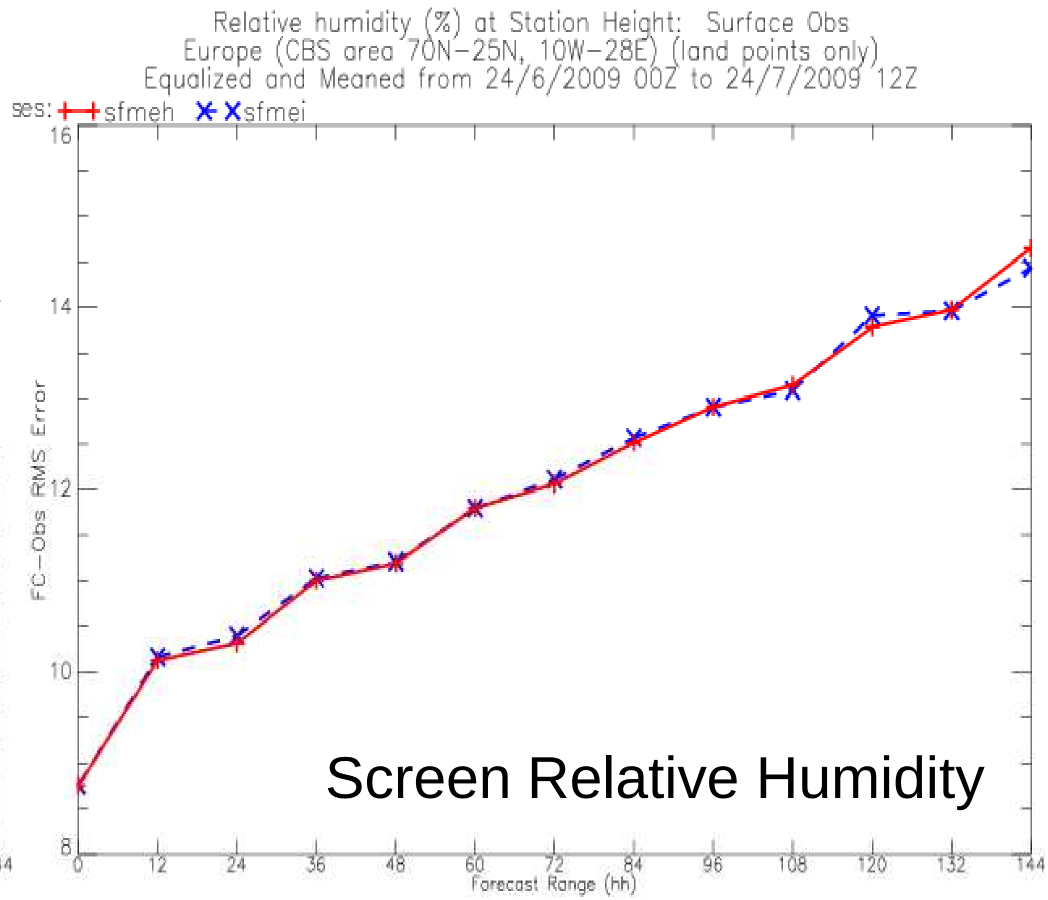


Europe: RMS errors in screen T and RH (1 month)

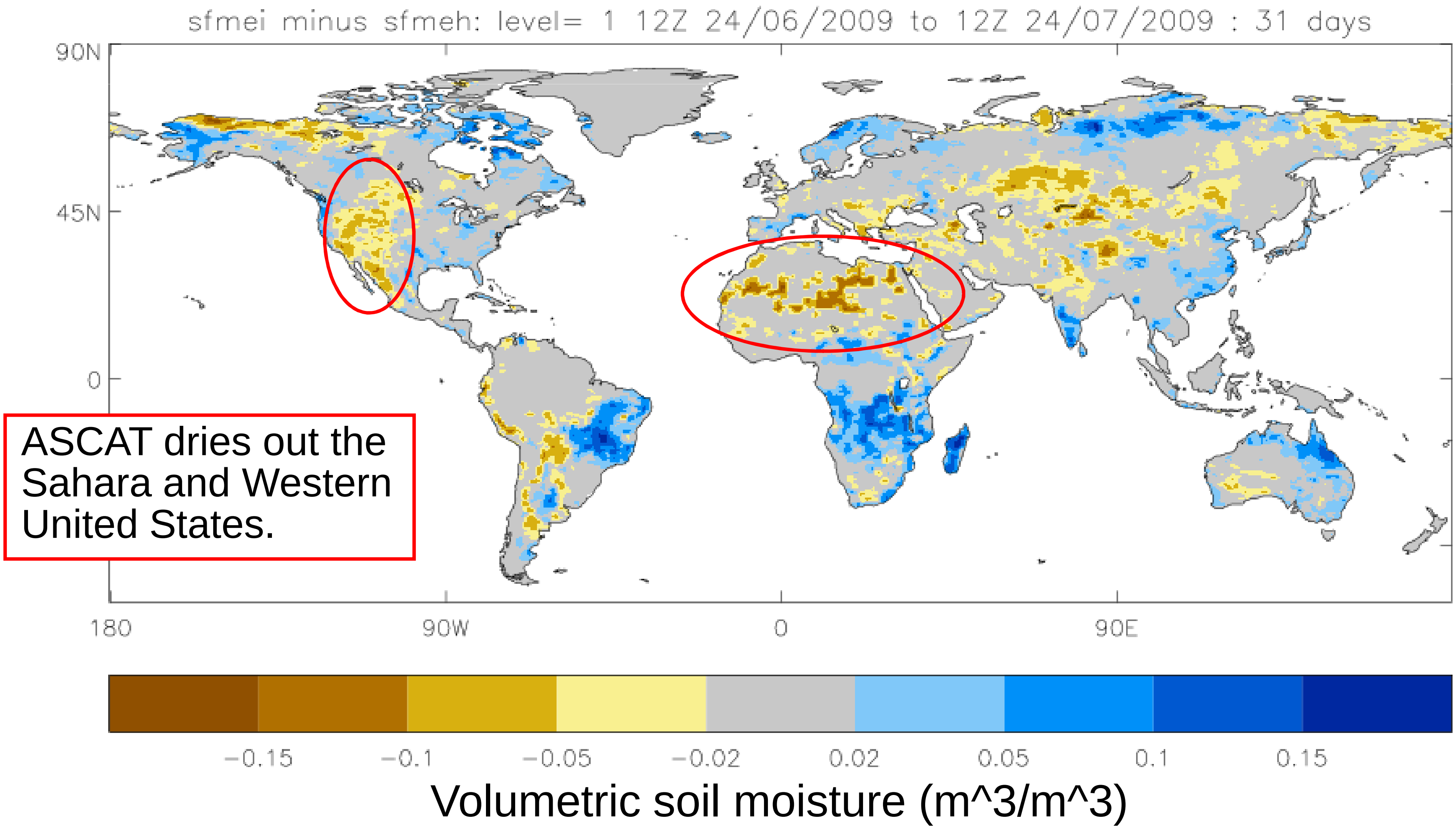
Control

Test with ASCAT soil wetness assimilation



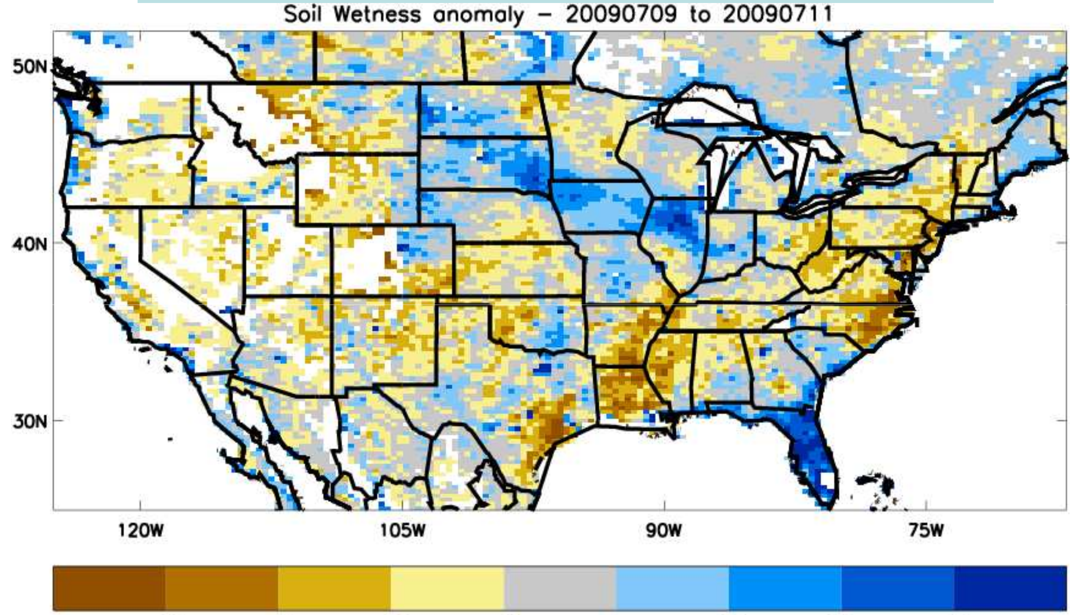


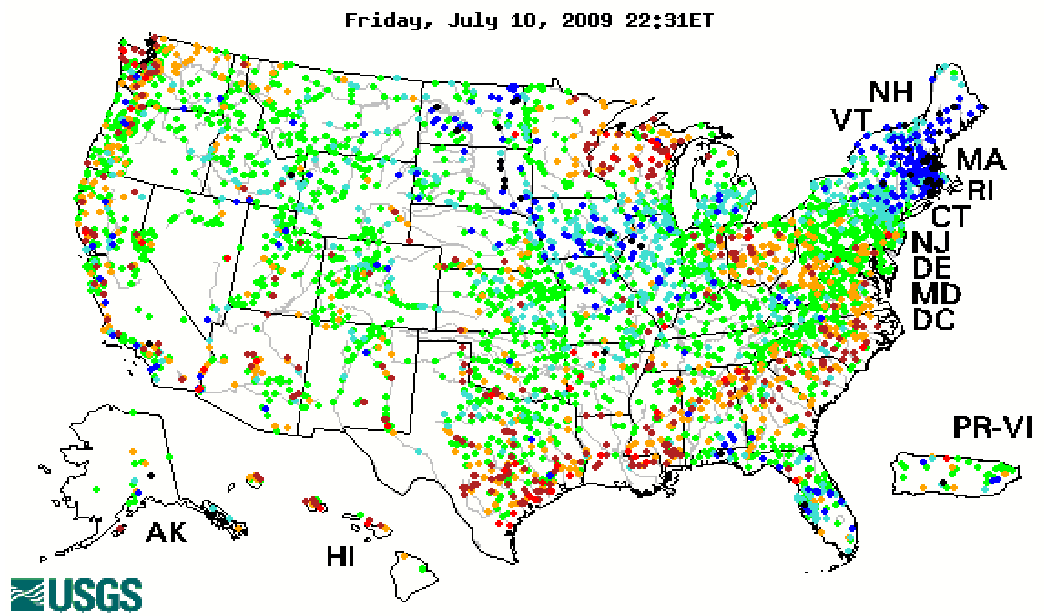
Difference in time mean Unified Model top level volumetric soil moisture (test – control)



Water anomalies: 9 to 11 July 2009

ASCAT surface soil wetness anomaly

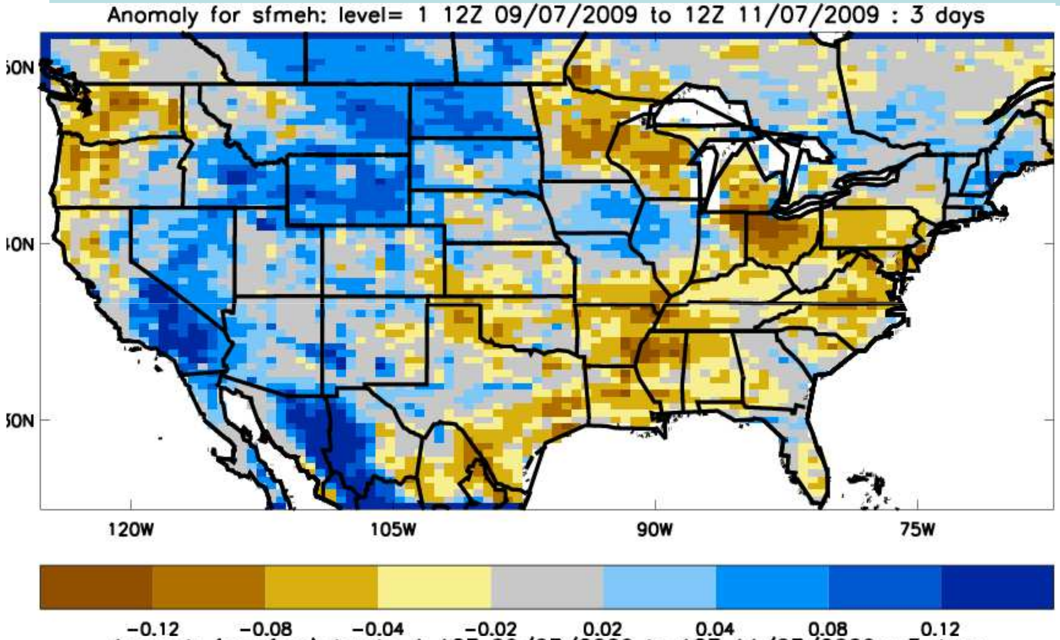




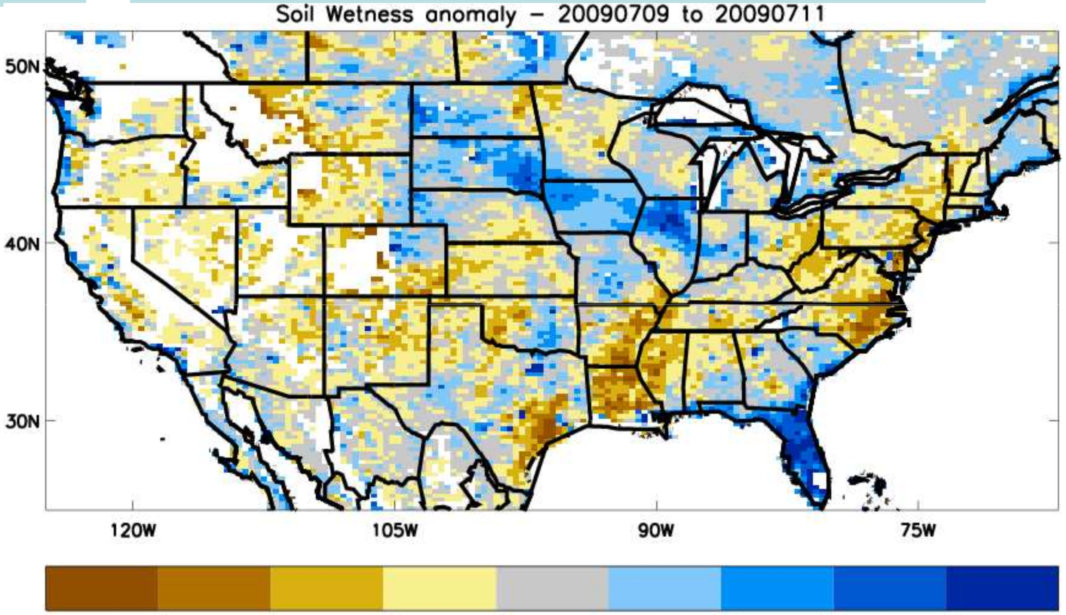
River Flow anomaly

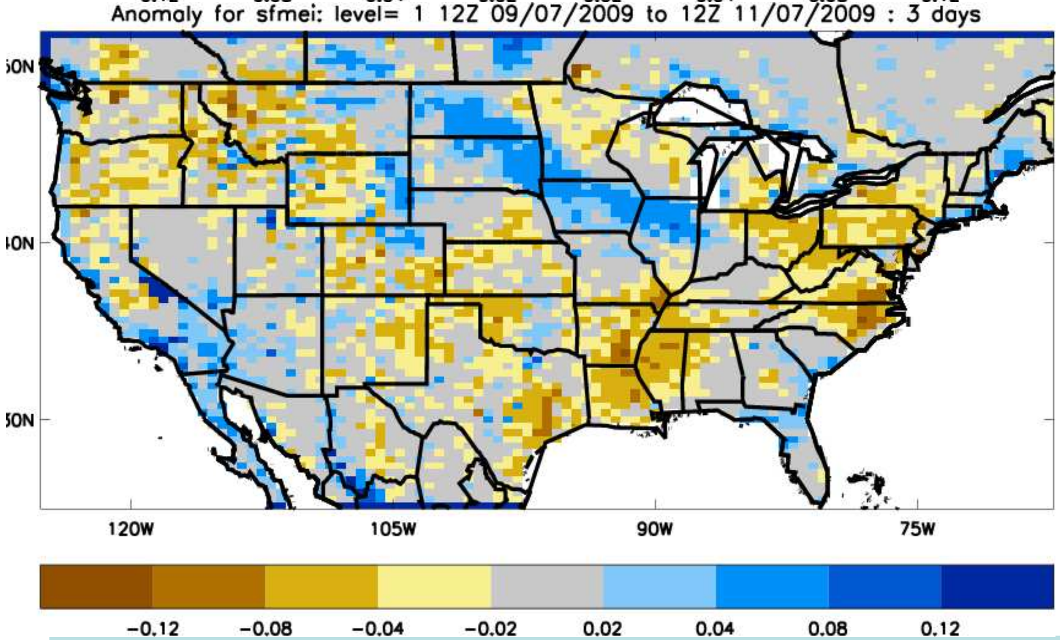
Water anomalies: 9 to 11 July 2009

Control run: top 10cm UM soil moisture anomaly

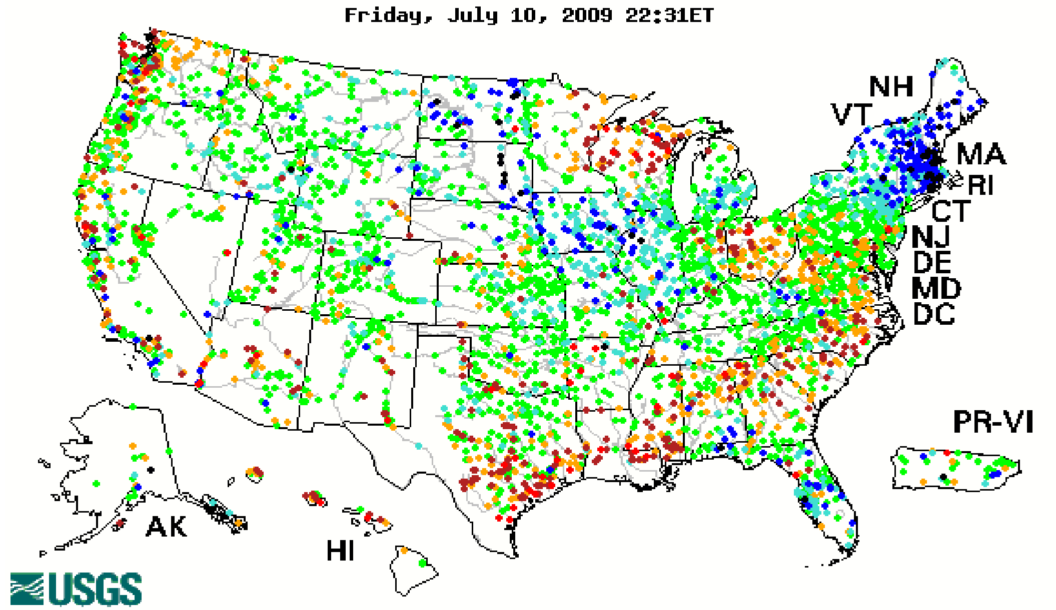


ASCAT surface soil wetness anomaly



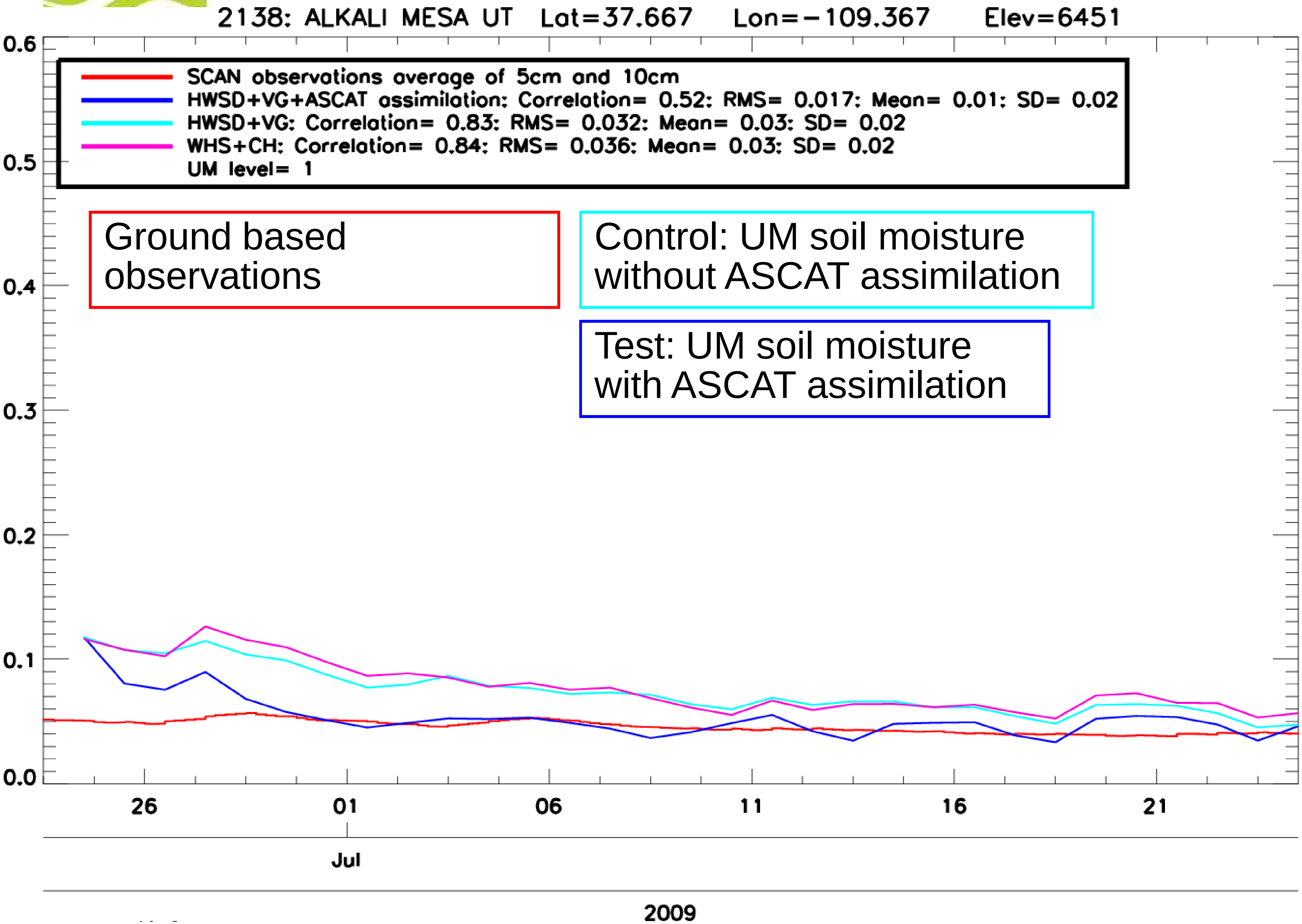


Test run: top 10cm UM soil moisture anomaly

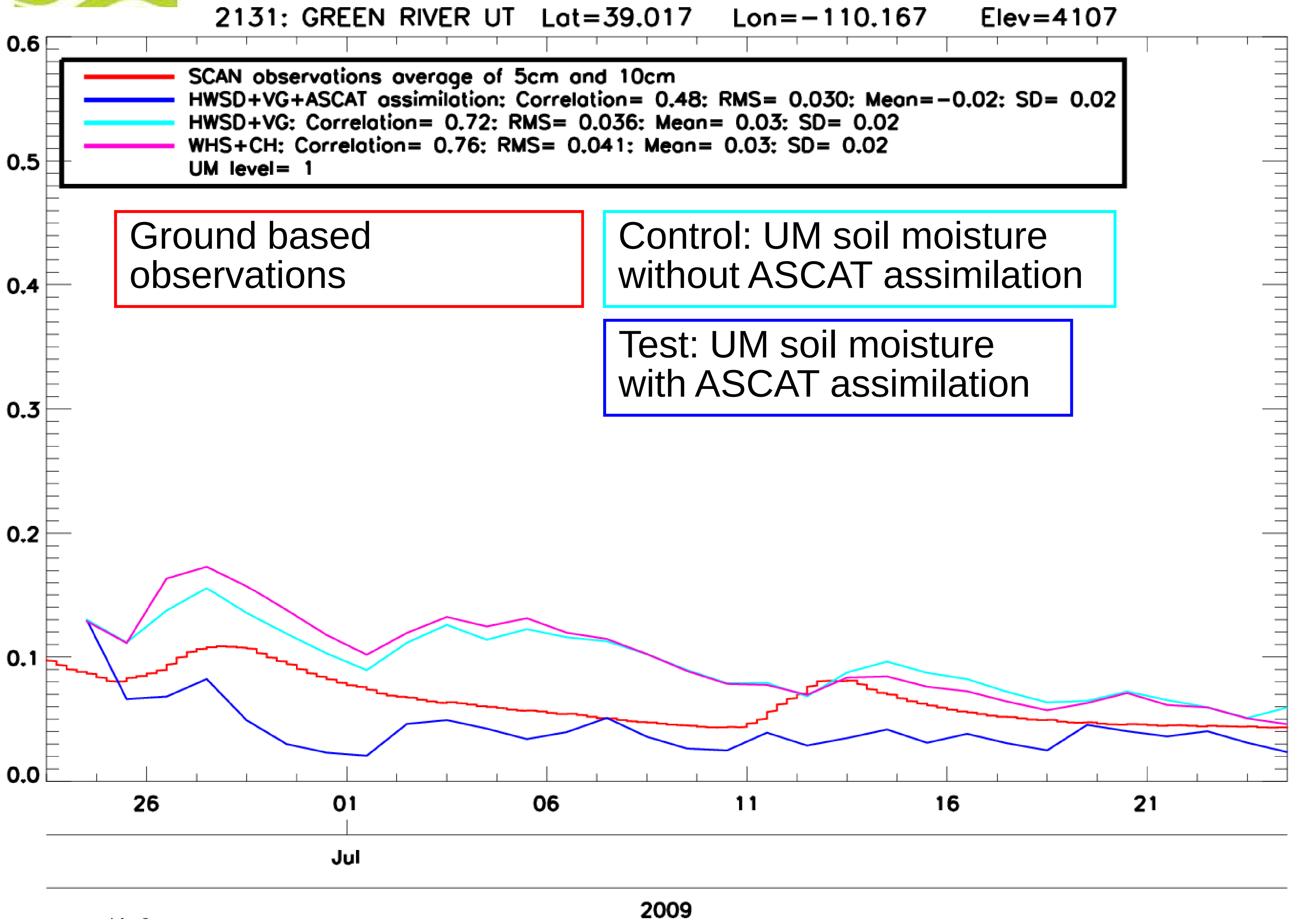


River Flow anomaly

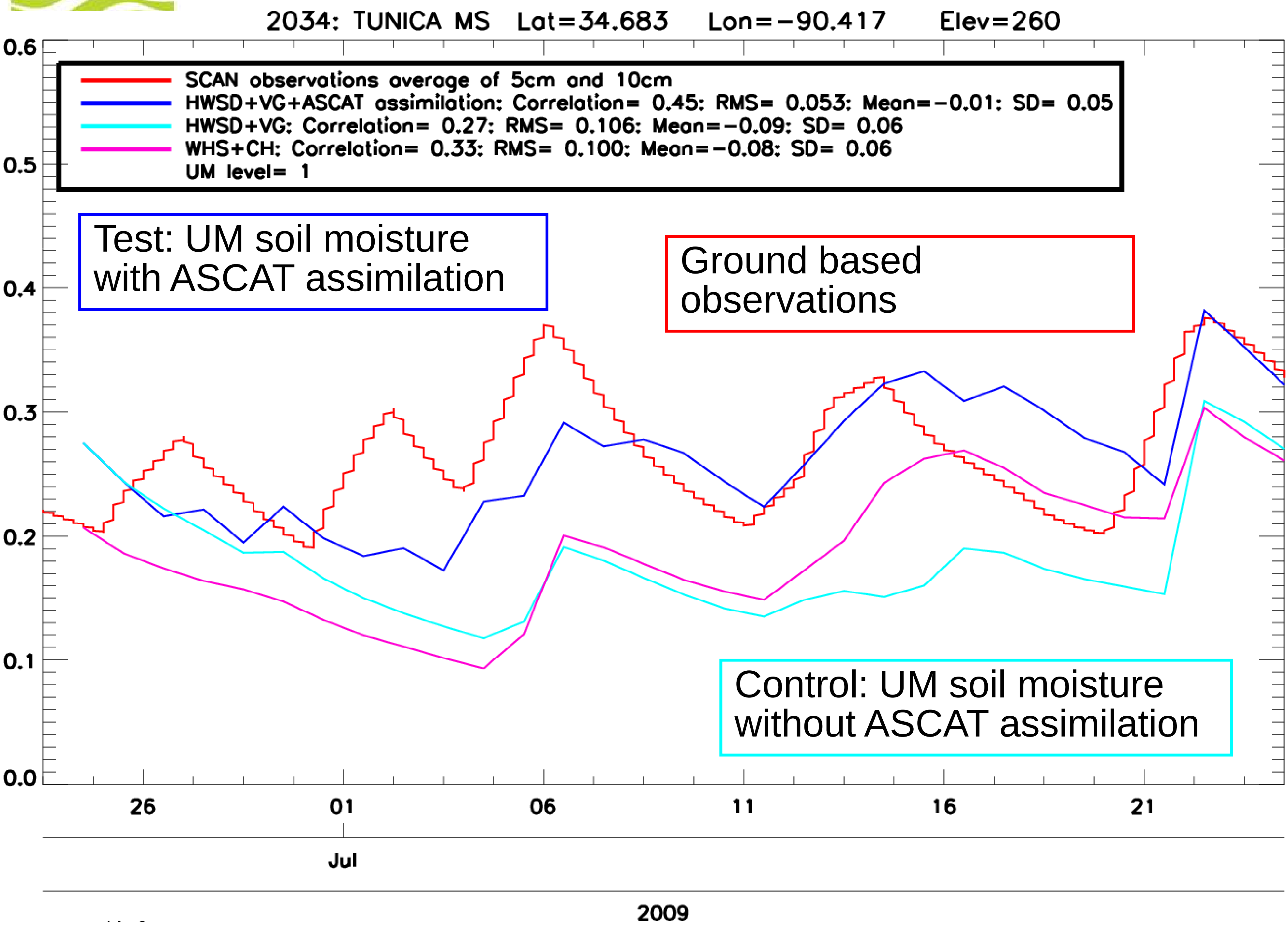
Western US: Utah



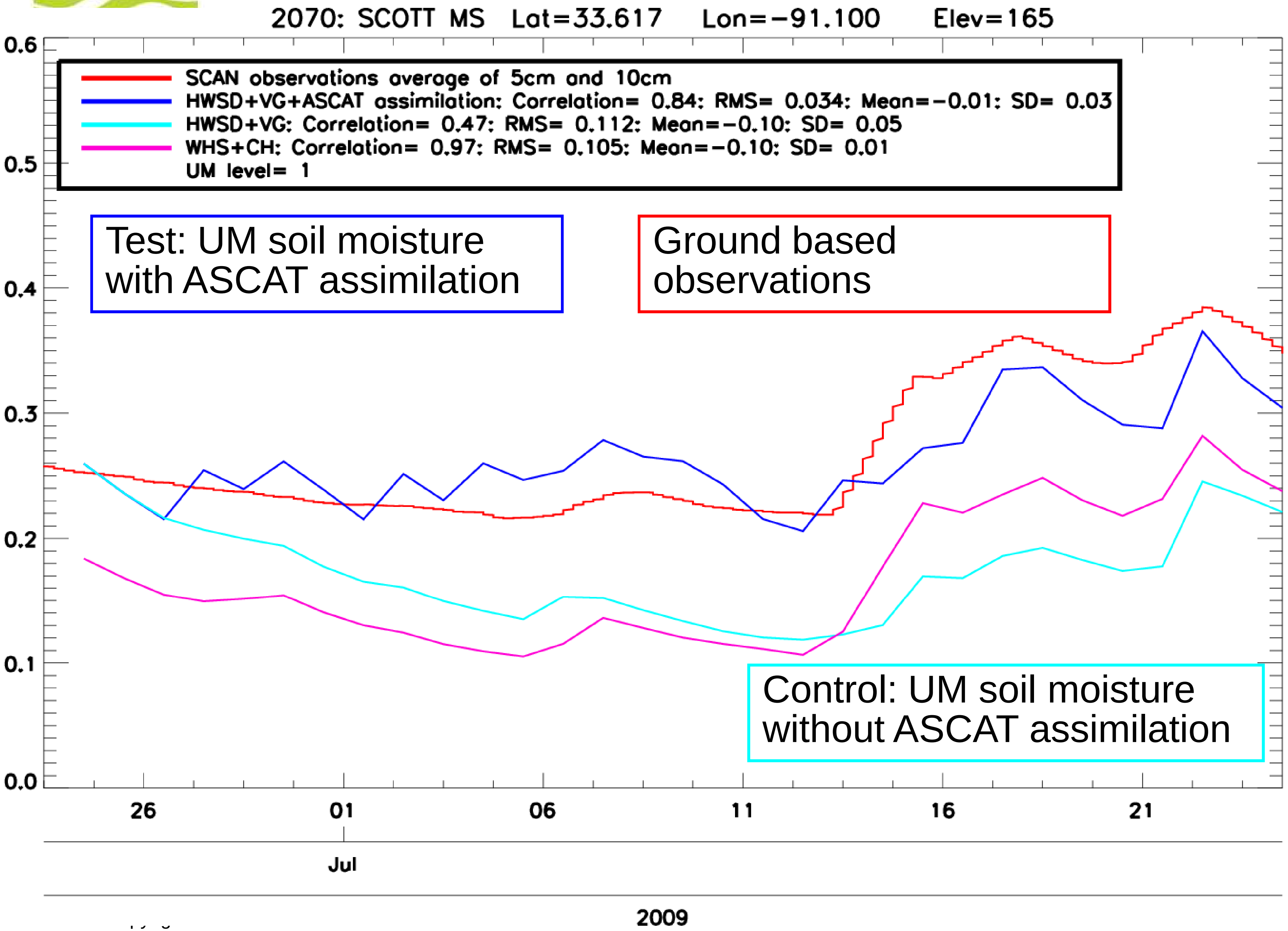
Western US: Utah



Eastern US: Mississippi



Eastern US: Mississippi



Conclusions

- We have implemented a simple and cheap method to assimilate measurements of ASCAT soil wetness (operational since 14th July 2010).

- Our pre-operational trials indicates that ASCAT soil wetness assimilation improves forecasts of screen temperature and humidity for the tropics. Impact in other regions is slightly positive or neutral.

- Comparison against ground based soil moisture observations also indicates an improvement in model soil moisture.

- We are planning the development of a Kalman Filter based land DA scheme that can propagate surface information into the deeper soil levels.

Conclusions (2)

- Technical Report available (Dharssi et al., 2010)
- Tests of new EUMETSAT ASCAT pre-processing in progress

Questions?

Summary

- ASCAT soil wetness assimilation implemented operationally on 14th July 2010.
- Assimilation method is simple and cheap.
  - Only the level 1 soil moisture is nudged.
  - Other Met Centres are developing Kalman Filters that can propagate surface information into the deeper soil levels.
    - Kalman Filters are computationally expensive and so far only show a neutral impact for NWP.
- Our pre-operational trials indicate that ASCAT soil wetness assimilation improves forecasts of screen temperature and humidity for the tropics. Impact in other regions is slightly positive or neutral.
- Impact on the global NWP Index is neutral/slightly positive.

Technical Report

- http://www-nwp/~frid/ascat_trials/trials.pdf

Why do we care about soil moisture?

- Soil moisture, together with other land properties, has a **significant impact on forecasts of screen temperature and humidity**. Affects the global NWP Index through it's impact on forecasts of mean sea level pressure.

- Influences the exchange of heat and moisture between the atmosphere and land surface.

  - Soil moisture affects evaporation from plants and bare soil.

  - Soil moisture affects the soil heat capacity and soil thermal conductivity and thus the ground heat flux.

- Potentially also important for forecasts of clouds and precipitation.

Why don’t we use ground based measurements of soil moisture?

- Currently, a global ground based soil moisture observation network does not exist.
  - One reason is that soil moisture can vary significantly over short distances and so measurements made at one location are not so informative about conditions at nearby locations.
- Some regional networks do exist but getting near real-time data is difficult and unreliable.
  - Regional Soil Moisture observing networks are very useful for verification.

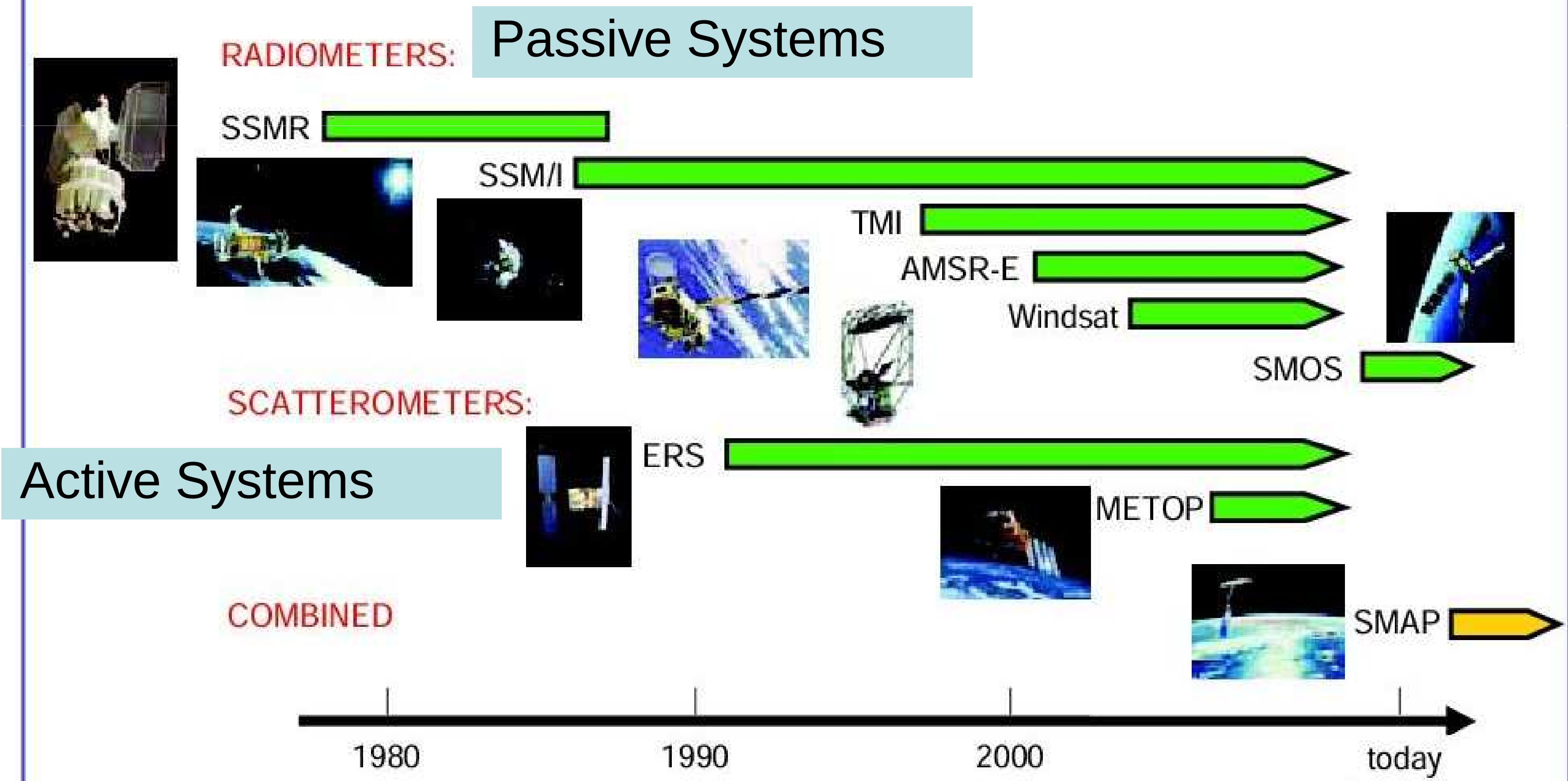
Current Soil Moisture Analysis Scheme

- At present we use observations of screen temperature and humidity to analyse soil moisture
  - A nudging scheme
- ECMWF, Meteo-France and other Met Centres also use observations of screen temperature and humidity for their soil moisture analysis

Satellite based measurements of soil moisture (1)

- Remote sensing by satellites is attractive since satellites offer global data coverage.
- Horizontal resolution is similar to that of global NWP models ~ 25 km.
- At microwave frequencies the dielectric constant of liquid water (~80) is much higher than that of the soil mineral particles (< 5) or ice. An increase in soil moisture leads to an increase in the dielectric constant of the soil.
    - Active system: The soil dielectric constant affects the backscatter from the soil.
    - Passive system: The soil dielectric constant affects the soil emissivity and consequently the brightness temperature.

Microwave Sensors



Vienna University of Technology
Institute of Photogrammetry and Remote Sensing

Comparison of Satellites

AMSRE Advanced Microwave Scanning Radiometer – EOS	ASCAT Advanced SCATterometer	SMOS Soil Moisture Ocean Salinity
Passive	Active	Passive
6.9 GHz (C band) 10.7 GHz (X band)	5.3 GHz (C band)	**1.4 GHz (L band)**
Radio Frequency Interference (RFI) in the C band	**No known RFI problems**	**RFI problems detected**
~ 60 km (C) ~ 40 km (X)	25 and 50 km	~ 40 km
Global coverage < 2 days	Daily coverage 82%	Repeat cycle < 3 days
2002 to 2014 (?)	**2006 to 2020 (at least)**	**2009 to 2012/14**

Satellite based measurements of soil moisture (2)

- Satellites microwave sensors only sense a thin top layer of soil
  - a few cm for L band
  - ~1cm for C band
  - a few mm for X band
- Microwave backscatter/brightness temperature is affected by many factors, including:
  - Vegetation water content
  - Soil roughness
  - Lower frequencies are less affected so SMOS should be more accurate than ASCAT and AMSR-E.

Challenges to using Satellite derived soil moisture for NWP

1. Satellites only sense a thin top layer of soil; ~1cm.

2. Satellites don’t measure soil moisture! Accurate retrieval algorithms are needed to convert satellite measurements of backscatter/brightness temperature into soil moisture.

3. Land surface models contain biases and approximations so assimilating more accurate soil moisture may make the NWP model’s surface fluxes of heat and moisture worse and therefore make forecasts worse.

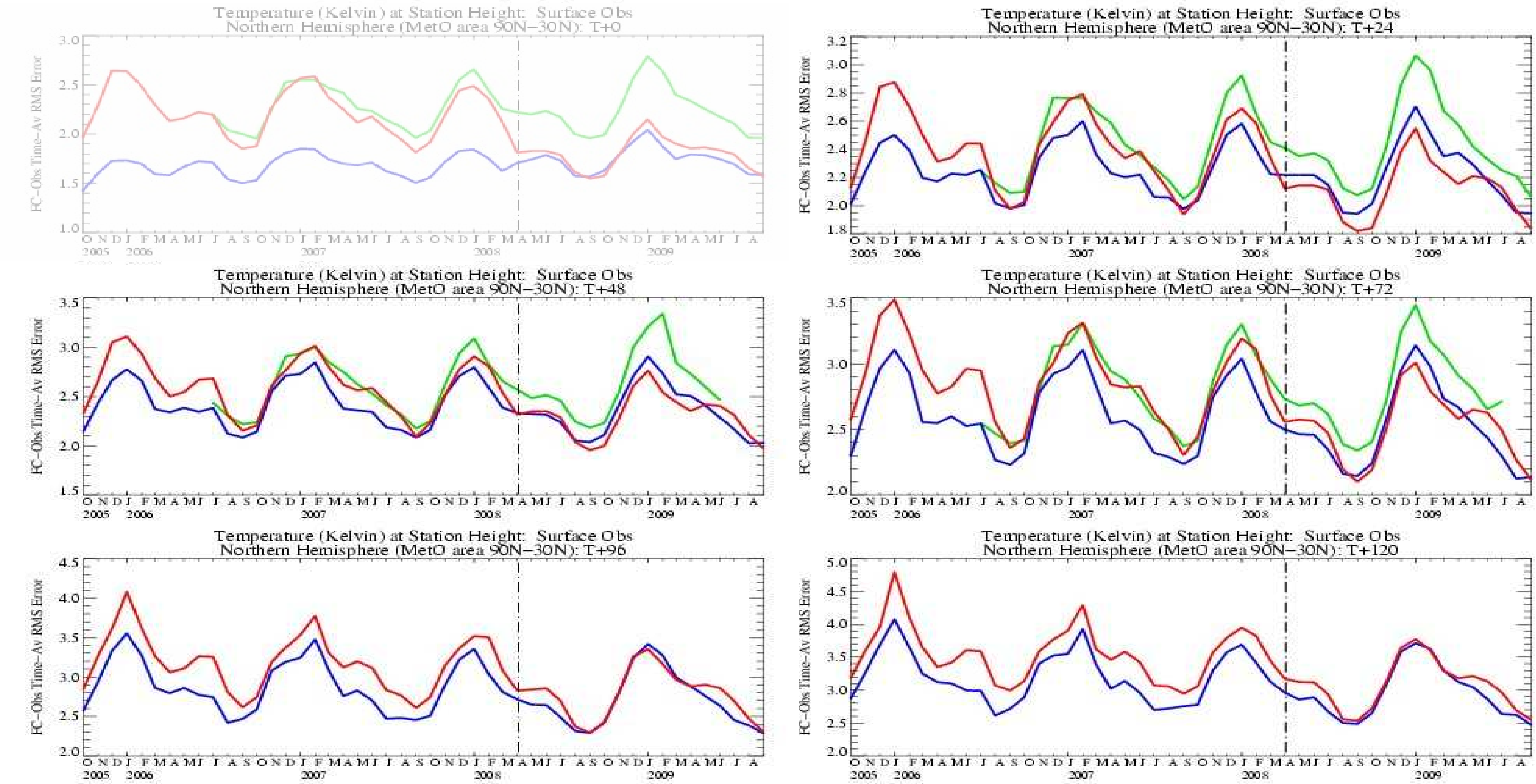
    i. Improving the land surface model and parameters is as important as improving the land data assimilation.

    ii. For example, introduction of Soil Moisture Nudging highlighted several deficiencies with the land surface model that were resolved at PS18.

Improvement in forecasts of Screen Temperature from PS18 (Apr 2008)

Met Office

Cases: UKMO NWP Centre 1 NWP Centre 2



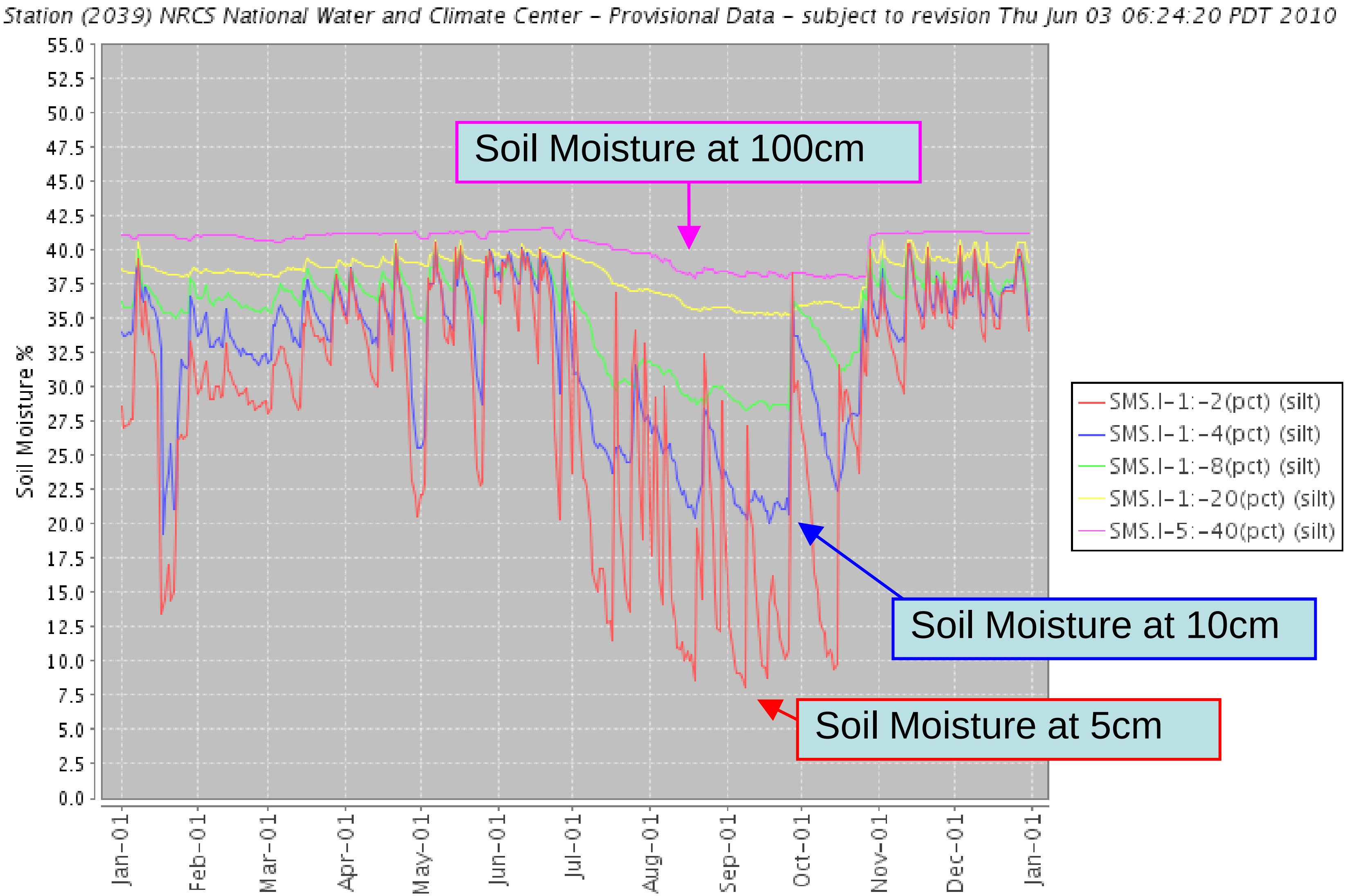
Satellites only sense a thin top layer of soil; ~1cm.

- For NWP we require knowledge of soil moisture in the plant root-zone (~ top 1m of soil) since plants extract soil water through the roots which then evaporates from their leaves.

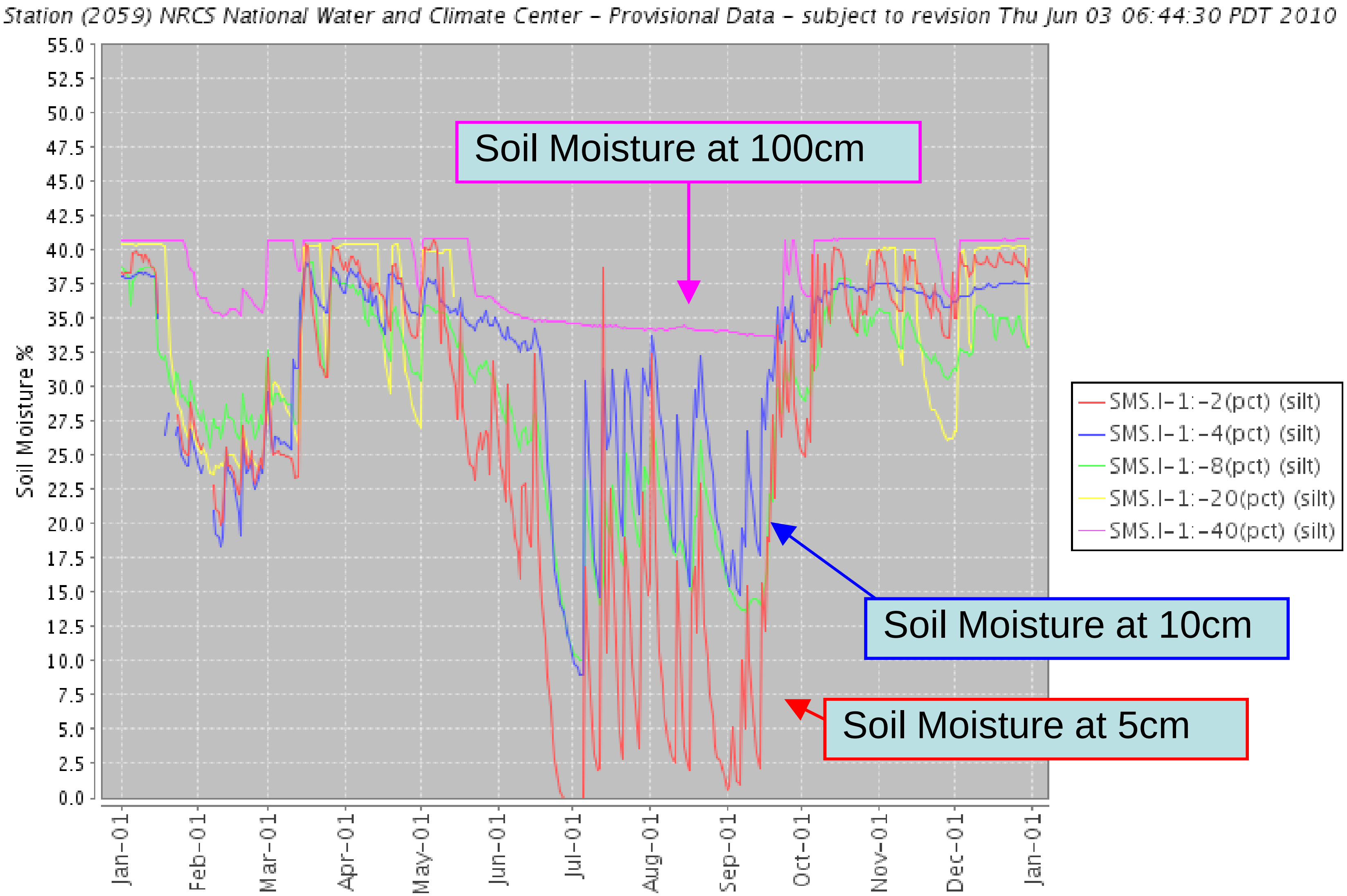
- There are often significant vertical gradients in the soil moisture.

  - In the summer the surface soil can become very dry while the deep soil layers are close to saturation.

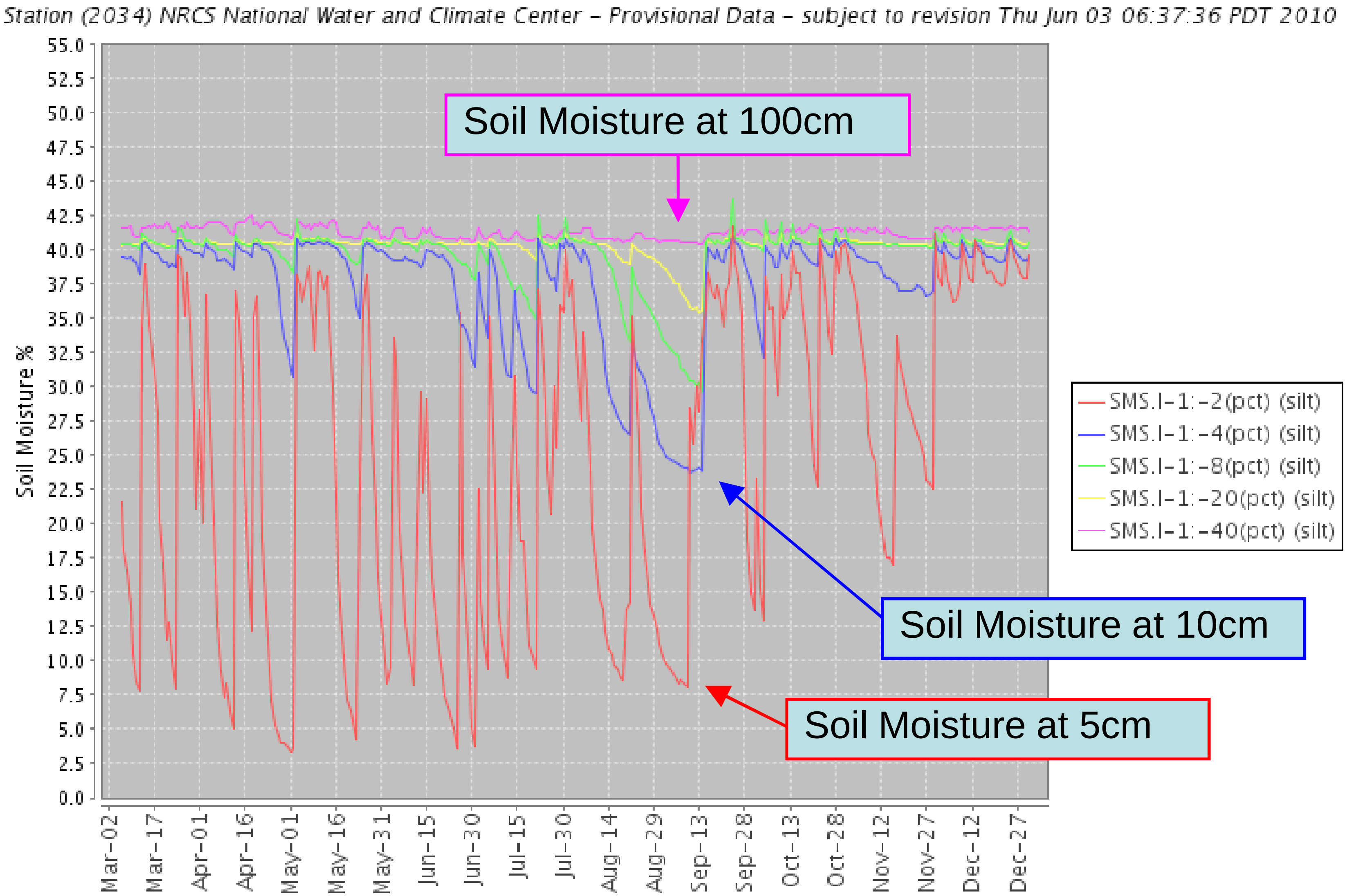
Variation of soil moisture with depth: measurements from in-situ sensors at a station in Virginia state, US.



Variation of soil moisture with depth: measurements from in-situ sensors at a station in Alabama state, US.



Variation of soil moisture with depth: measurements from in-situ sensors at a station in Mississippi state, US.



Soil moisture retrieval algorithms

- Experience with AMSR-E shows that most soil moisture retrieval algorithms give poor results.
  - The daily AMSR-E soil moisture product provided by the National Snow and Ice Data Centre (NSIDC) has a very low correlation with ground based measurements.
  - The AMSR-E soil moisture product provided by the University of Amsterdam (VUA) has a high correlation with ground based measurements. This product seems to be released with a six-month delay.

Comparison of AMSR-E Retrieval Algorithms (X-band)

Stats for retrieved soil moisture vs ground based soil moisture observations.

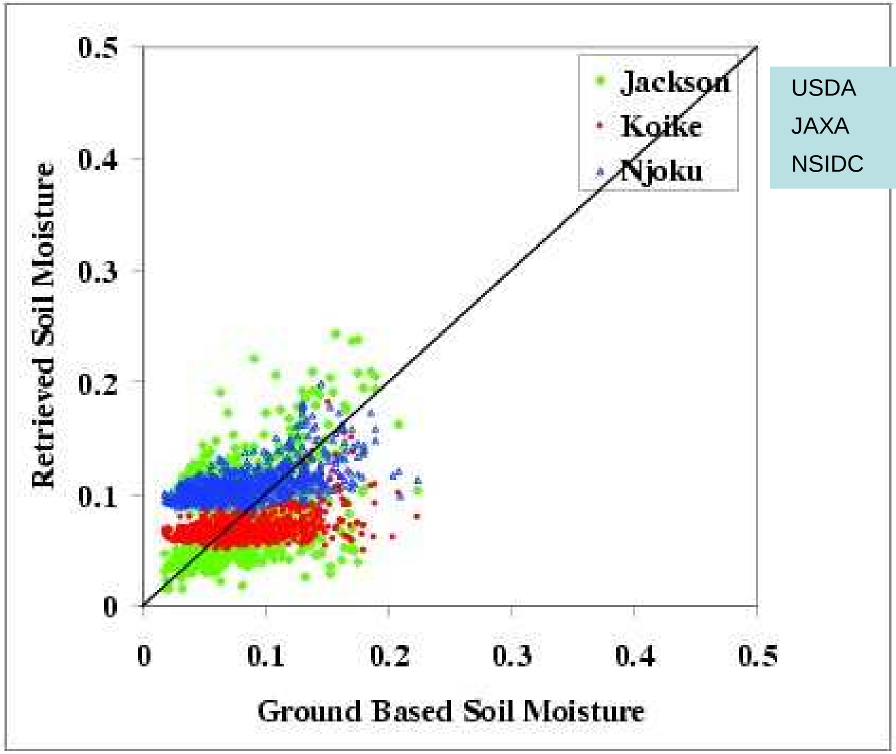
Adelong, Australia (2006). Courtesy of Clara Draper.				
	NSIDC-NASA Njoku et al (2003)	VUA-NASA Owe et al (2001)	JAXA Koike et al (2004)	USDA Jackson et al (1993)
Correlation	**0.15**	**0.80**	0.43	0.16
RMS (m^3/m^3)	**0.045**	**0.022**	0.038	0.045

SMOSREX, France (2003-2005). Rudiger et al (2009)				
	NSIDC-NASA Njoku et al (2003)	VUA-NASA Owe et al (2001)	JAXA Koike et al (2004)	USDA Jackson et al (1993)
Correlation	**0.11**	**0.78**	N/A	N/A
RMS (normalised soil moisture)	**0.36**	**0.19**	N/A	N/A

from Jackson et al (2006)

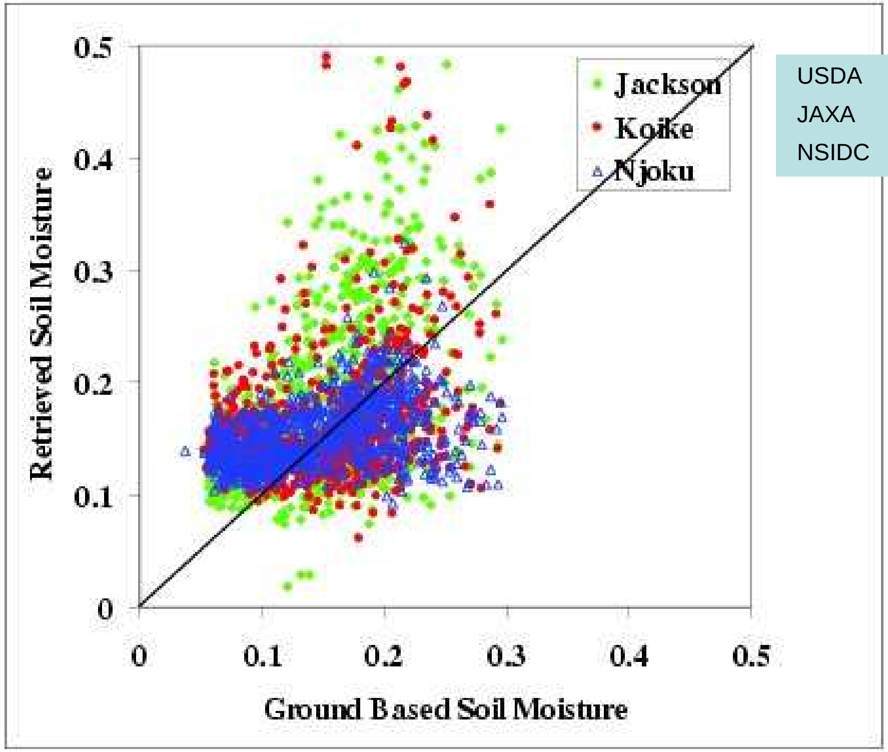
AMSR-E Soil Moisture Algorithm Validation Exercise Using Data from Walnut Gulch, AZ (WG) and Little Washita, OK (LW) June 18, 2002-Dec. 31, 2005

WG Arizona



USDA
JAXA
NSIDC

LW Oklahoma



USDA
JAXA
NSIDC

How Does the UM use soil moisture?

- Evaporation from plants

$$E = \rho \frac{\Delta q}{R_a + R_{s,veg}}$$

$$R_{s,veg} = \frac{R_s^{\min}}{\beta_{veg}}$$

E	Evaporation
ρ	Density of Air
Δq	Difference in Specific Humidity between the surface and model level 1
R_a	Aerodynamic Resistance between the surface and model level 1

Bulk Stomatal Resistance

$$R_{s,veg} = \frac{R_s^{\min}}{\beta_{veg}}$$

Calculated by a photosynthesis model and depends on vegetation type, temperature, humidity and incident solar radiation.

The soil moisture availability depends on soil moisture, plant root fraction and soil texture.

Soil texture is primarily determined by the size distribution of the soil particles.

Soil Moisture Availability

$$\beta_{veg} = \sum_{k=1}^{4} f_k \beta_{veg,k} \qquad \sum_{k=1}^{4} f_k = 1$$

$$\beta_{veg,k} = \begin{cases} 0 & \theta_k < \theta_w \\ \dfrac{\theta_k - \theta_w}{\theta_c - \theta_w} & \theta_w < \theta_k < \theta_c \\ 1 & \theta_k > \theta_c \end{cases}$$

θ_k Soil Moisture in soil level k

θ_w Wilting Point

θ_c Critical Point

Wilting and Critical Points

- The wilting point and critical point are as important as the soil moisture in controlling evaporation from plants.
- The wilting point and critical point are determined by the soil texture. Therefore, soil texture is as important as soil moisture.
- Therefore, to improve the model soil moisture we also have to improve the model soil texture and soil hydraulic parameters (and other land parameters).
  - For example, include the vertical variation of soil texture in the UM.