Can SMOS improve the weather forecast?

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[4] CESBIO, Toulouse, France

Outline

- Background & context,
- ECMWF soil moisture analysis,
- New soil moisture product based on the assimilation of screen level variables and SMOS T_B → SMOS-DA-v1.0,
- Validation, Impact on the forecast skill and diagnostics,
- Conclusions

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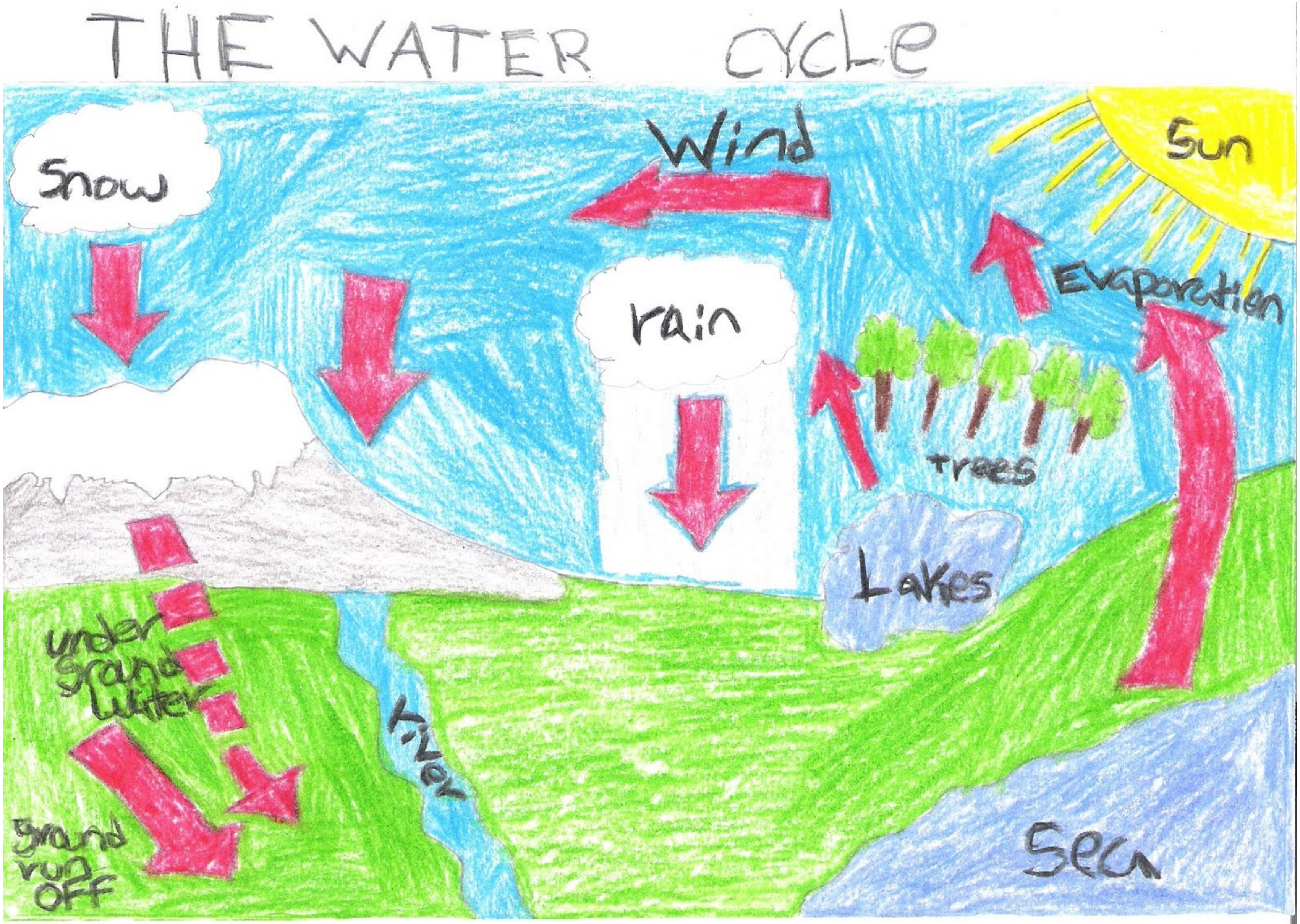

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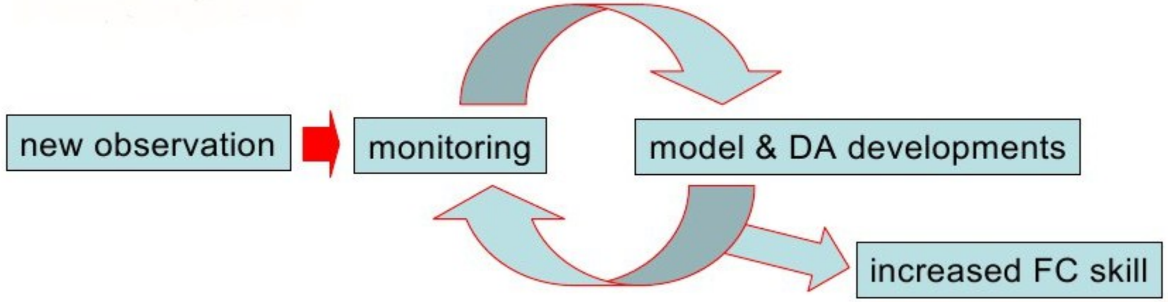
SMOS

- **Mission objective** provide global measurements of two key variables in the water cycle: soil moisture and ocean salinity.

- **L-band mission (**2D interferometric radiometer**);** transparent to clouds, large penetration depth, less sensitive to vegetation canopy and soil roughness,.

- **Objectives at ECMWF**:
  - ➢ Global **monitoring** of T_B at the satellite antenna reference frame, in NRT
  - ➢ **Assimilation** of SMOS T_B over continental surfaces & investigate the meteorological impact of SMOS data assimilation

Introducing new observations is an efficient way to improve the forecast/analysis



Defining “weather forecast improvement”

- How do we measure an improvement (or degradation) of the weather forecast?

vs.

?

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Defining "weather forecast improvement"

- How do we measure an improvement (or degradation) of the weather forecast?

vs.

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- Necessity of defining:
  - **<u>"Target"</u>** variable
    - atmospheric variables (pressure, temperature, wind speed, etc.)
    - land-variables (soil moisture, soil temperature, snow, etc.)
    - ocean variables (SST, ocean salinity, etc.)
  - Validation **<u>metrics</u>**; R, RMSD, STD, persistence, etc.
  - Independent data used as "true" or **<u>reference;</u>**
    - in-situ observations, remote sensed data, climatology, reanalysis

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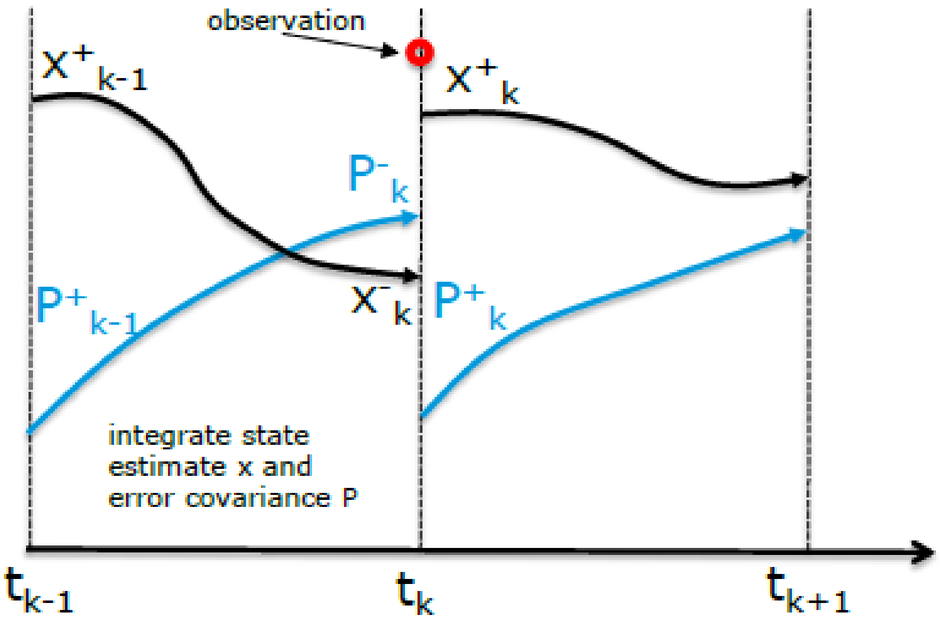
ECMWF soil moisture analysis: *The SEKF*

Simplified Extended Kalman Filter



1. Initial state estimate at k=0:

Mean state $\mathbf{x}^-_0$

Covariance $\mathbf{P}^-_0$

2. Calculate Kalman gain:

$$K_k = P^-_k H^T_K [H_k P^-_K H^T_K + R_K]^{-1}$$

3. Update the state estimate:

$$x^+_k = x^-_k + K_k [y_k - H_k x^-_k]$$

$$P^+_k = P^-_k - K_k H_k P^-_k$$

4. Propagate state estimate in time:

$$x^-_{k+1} = f_k(x^+_k)$$

$$P^-_{k+1} = M_k P^+_k M^T_k + Q_k$$

ECMWF implementation (Drusch et al. 2009, de Rosnay et al. 2012):

- **P** and **R** diagonal and static (σ_{sm} = 0.01 m^3m^{-3} ; σ_T = 2 K ; σ_{rH} = 10%),
- **H** = [H($\mathbf{x}^n$ + $\delta\mathbf{x}^n$) – H($\mathbf{x}^n$)] / $\delta\mathbf{x}^n$ with $\delta\mathbf{x}^n$ = 0.01 m^3m^{-3} and n=3;

Introduction of SMOS data in the soil moisture analysis (Muñoz-Sabater et al., 2012)

- SMOS T_B introduced in **R** (σ_{TBj} == rad_acc (TB $_j$))
- **H** calibrated for SMOS ($\delta\mathbf{x}^n$ [0.005, 0.01] m^3m^{-3} , H^-_{max} = H^-_{max} =250 K/m^3m^{-3})
- Point wise CDF matching as bias correction prior to assimilation.

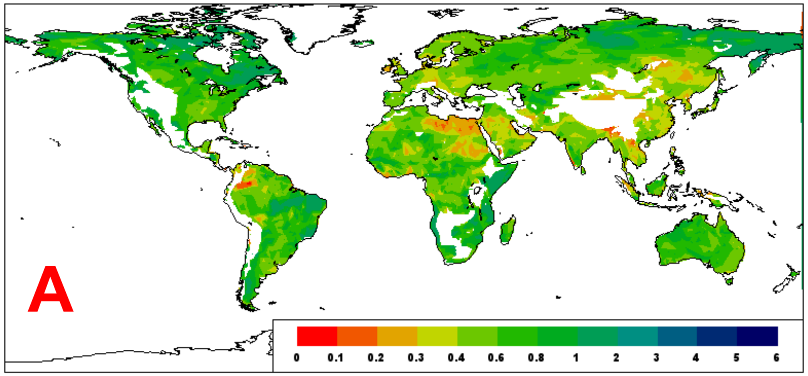
Bias correction

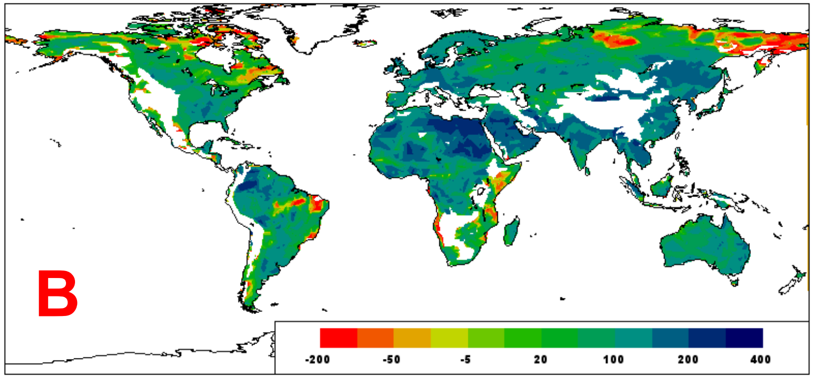
CDF-matching → matches mean and variance of two distributions

$$T_B(BC) = \mathbf{A} * T_B^{SMOS} + \mathbf{B}$$

$A = \sigma_{CMEM} / \sigma_{SMOS}$

$B = T_B^{CMEM} - T_B^{SMOS} * (\sigma_{CMEM} / \sigma_{SMOS})$





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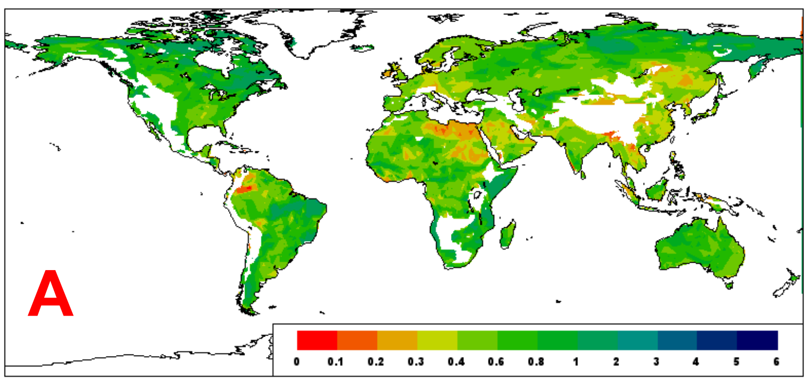
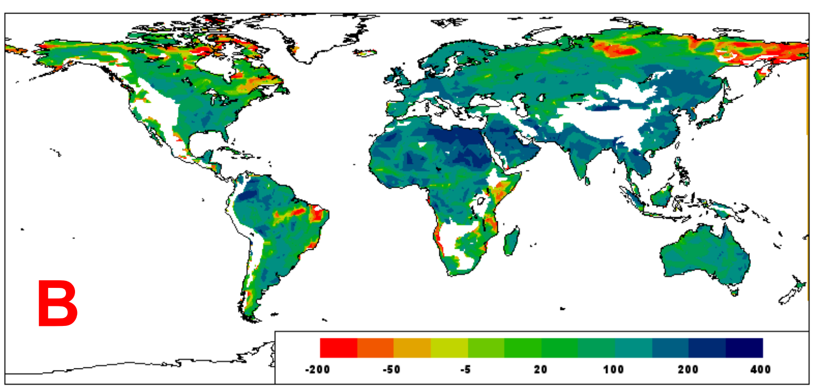
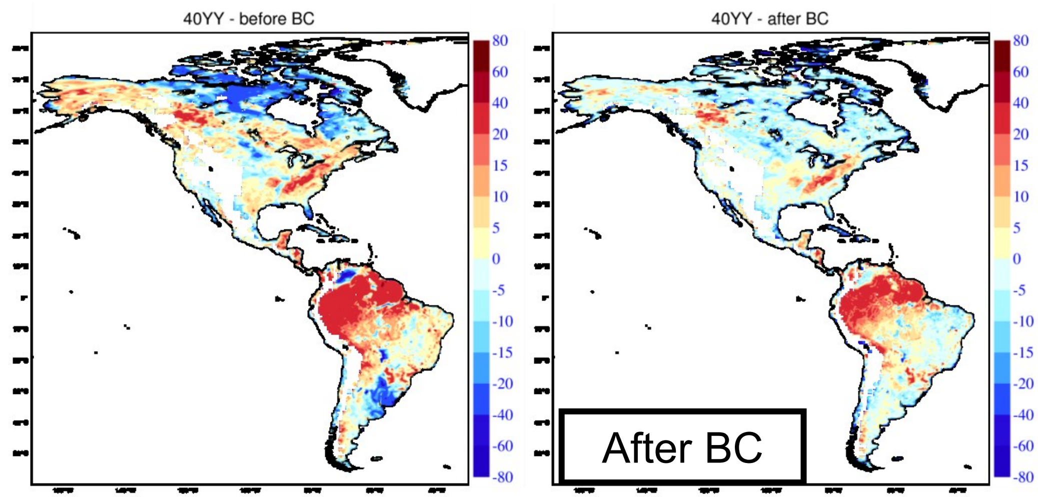
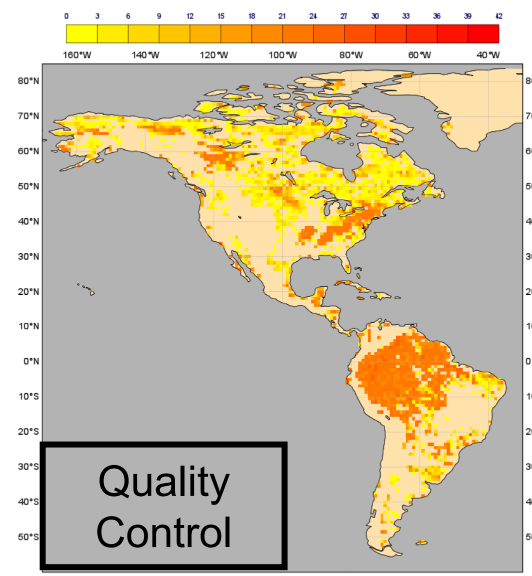








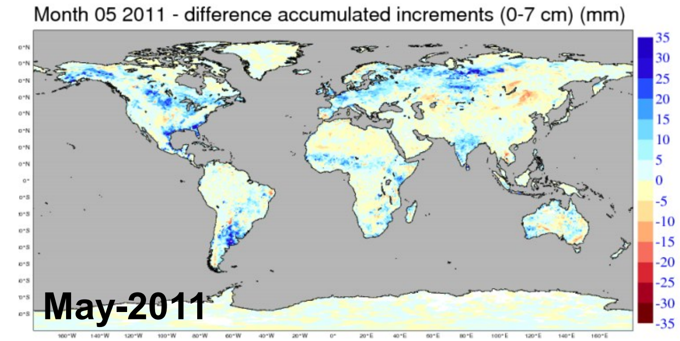
Percentage of rejected observations (%)

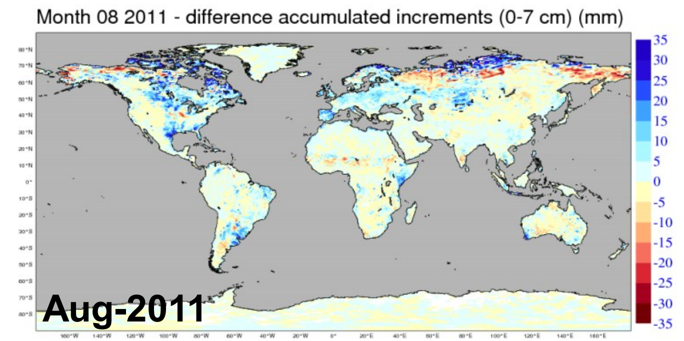
SMOS-DA-v1.0 – *Configuration setup*

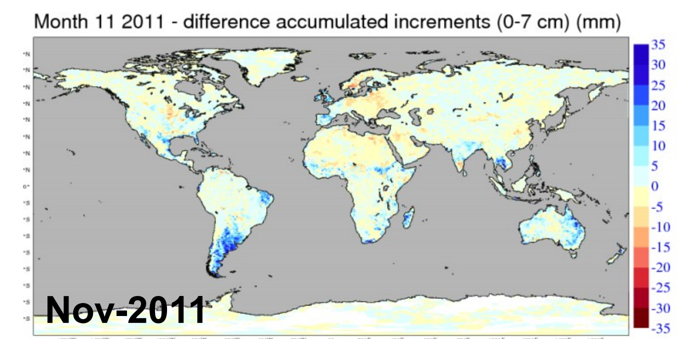
Assimilation of SMOS T_B in the antenna reference frame at **global** scale (SEKF)

- Period: **1 May 2010** 00UTC – **31 October 2012** 12UTC analysis
- Resolution: **T511** (~40 km)
- Observations:
  - NRT brightness temperatures (**Reprocessed dataset 2010-2011**),
  - **30, 40, 50** degrees ± ΔT_B=0.5 K
  - **XX & YY** polarisations
  - Only AF-FOV
  - RFI flag used (BUFR info flag, bit-1)
  - Bias corrected using a point-wise CDF matching
- CMEM configuration; best for R (Wang(DIEL), Wsimple(RGH), Wigneron(VEG))
- **Jacobians calibrated** ($\Delta\theta j = 0.01 m^3m^{-3}$, $H^-_{max} = H^-_{max} = 250 K/m^3m^{-3}$)
- **STD of observations error** → radiometric accuracy
- Full observational system used for the atmosphere,

- **CTRL:** assimilation of T^{2m}, RH^{2m}
- **SMOS-DA-v1.0**: assimilation of T^{2m}, RH^{2m} + SMOS T_B CDF







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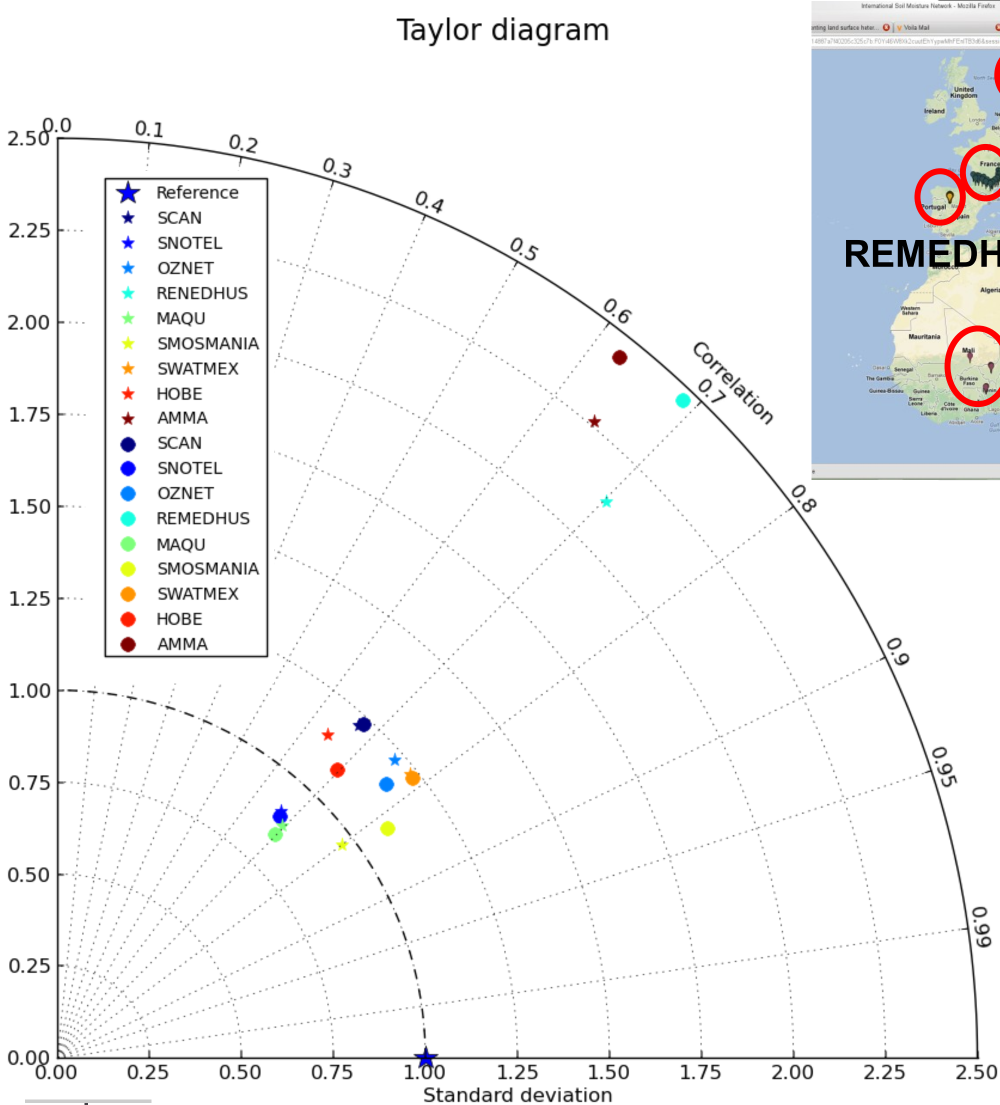
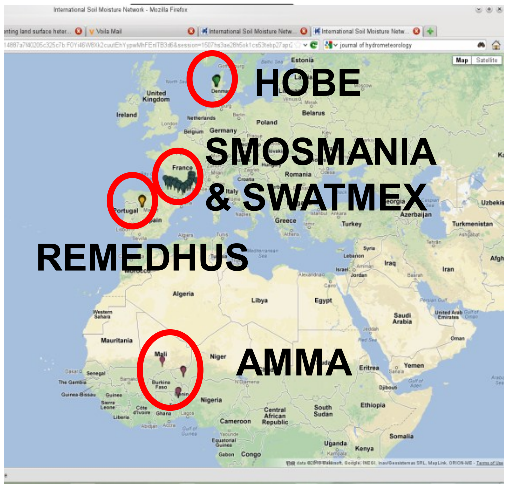
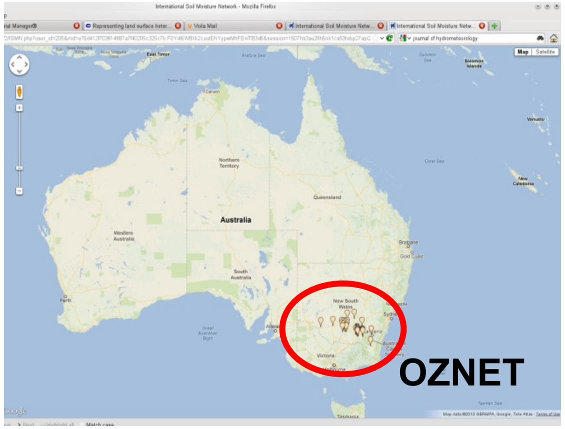
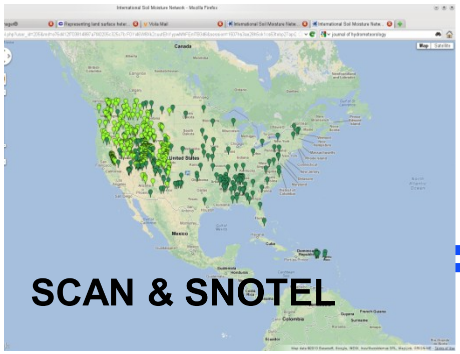
Validation against ISMN - *2010*









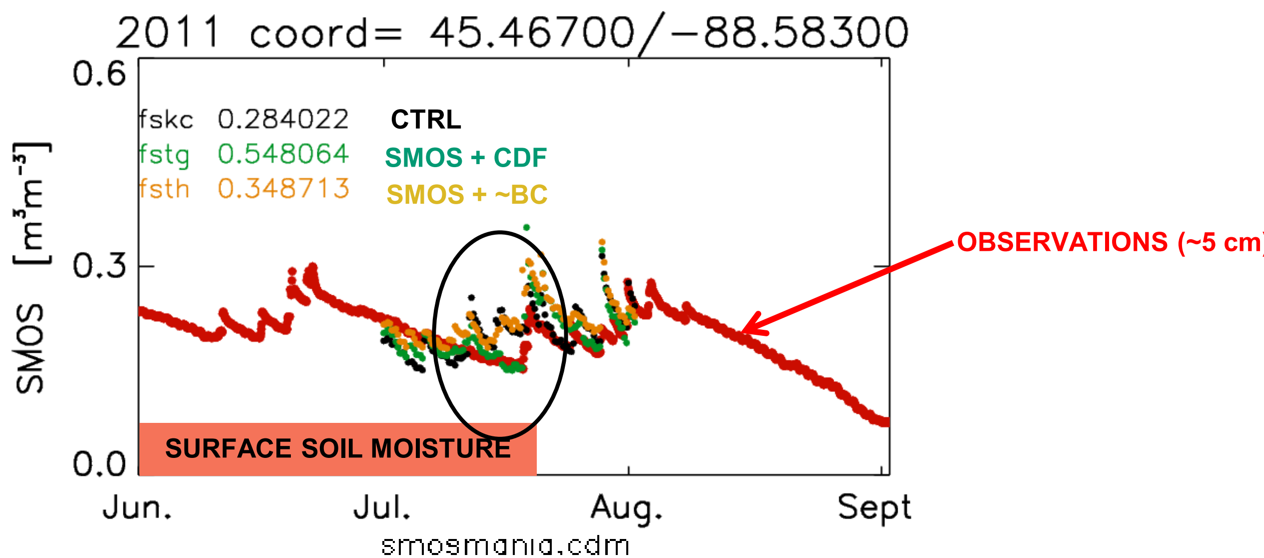
SMOS exp analysis against observations

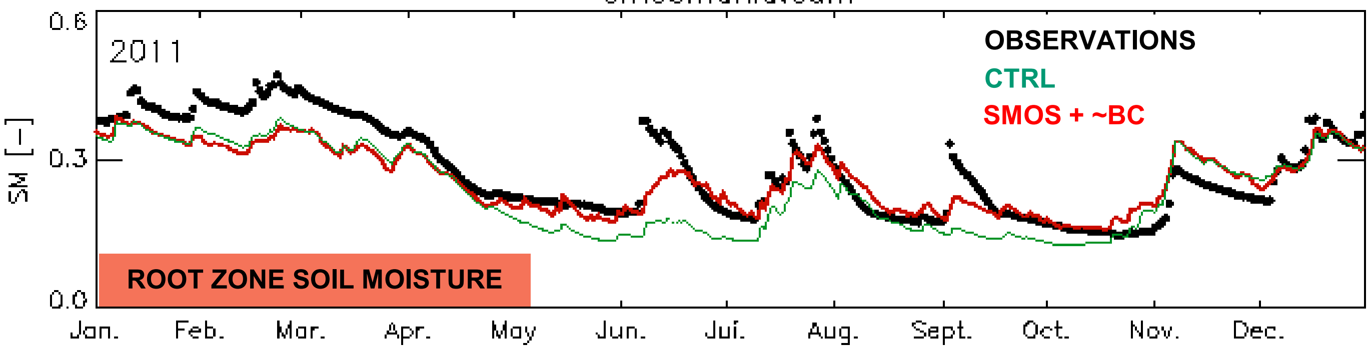
Control analysis against observations

Validation 2011

REMEDHUS	CTRL	SMOS + CDF
R	0.74	0.81
RMSD	0.11	0.11
Bias	-0.07	-0.06

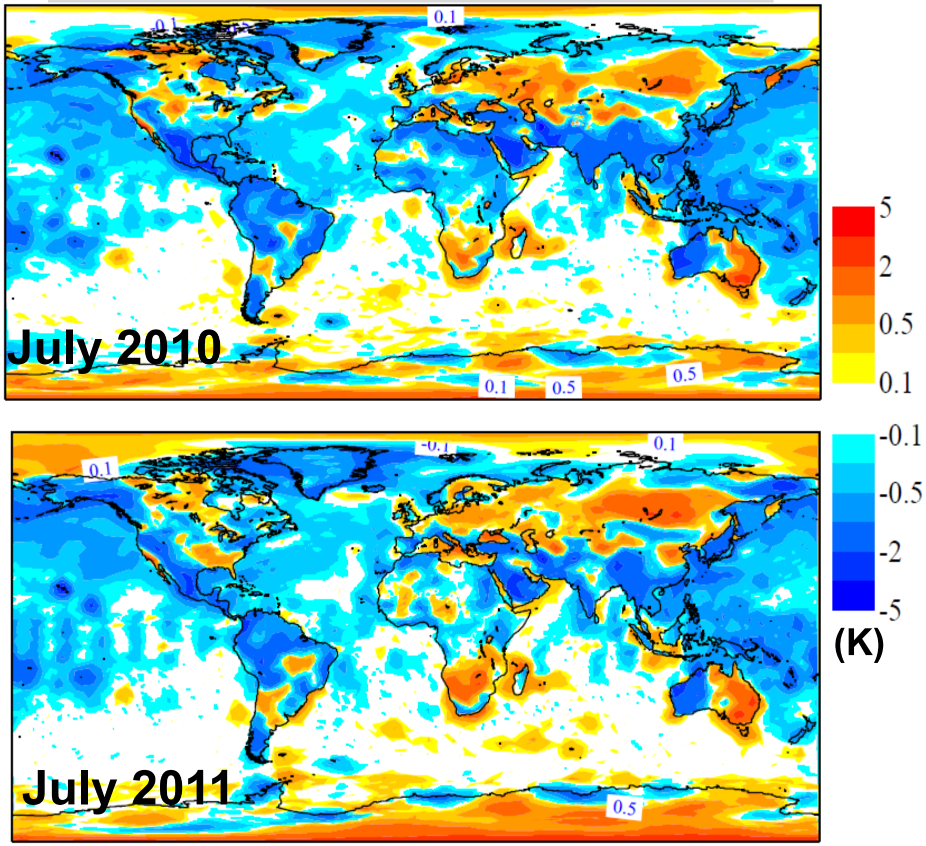
AMMA	CTRL	SMOS + CDF
R	0.56	0.70
RMSD	0.049	0.047
Bias	-0.038	-0.029



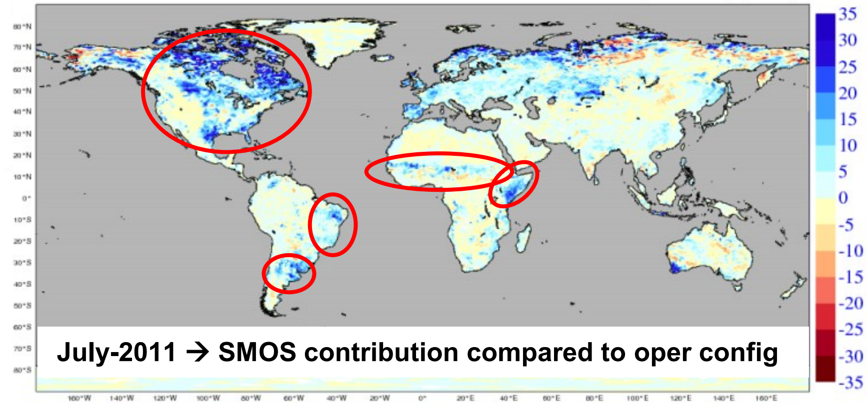


2m Temperature sensitivity and bias

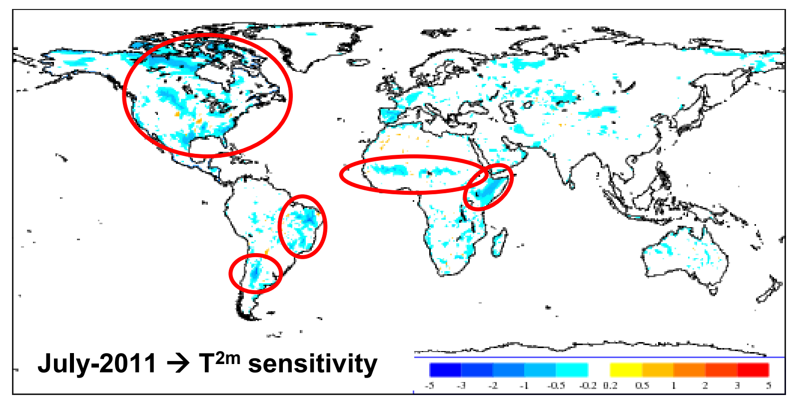
24h forecast T^{2m} bias , 00UTC



Month 07 2011 - difference accumulated increments (0-7 cm) (mm)



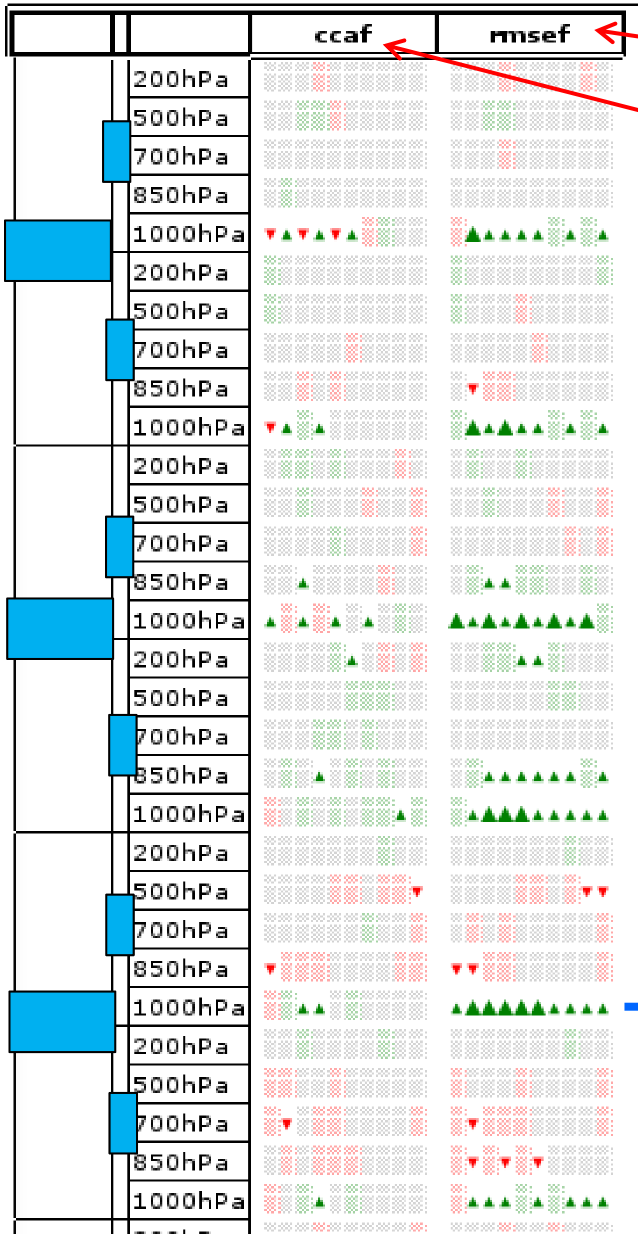
2T mean[SLV+SMOS(fsx2)+24-AN(0001)]-mean[SLV(ftec)+24-AN(0001)]



Robust, location and time dependent T^{2m} bias (verification against own analysis)

SM increments due to assimilation of SMOS data have an impact on T^{2m} and partly explain the systematic bias.

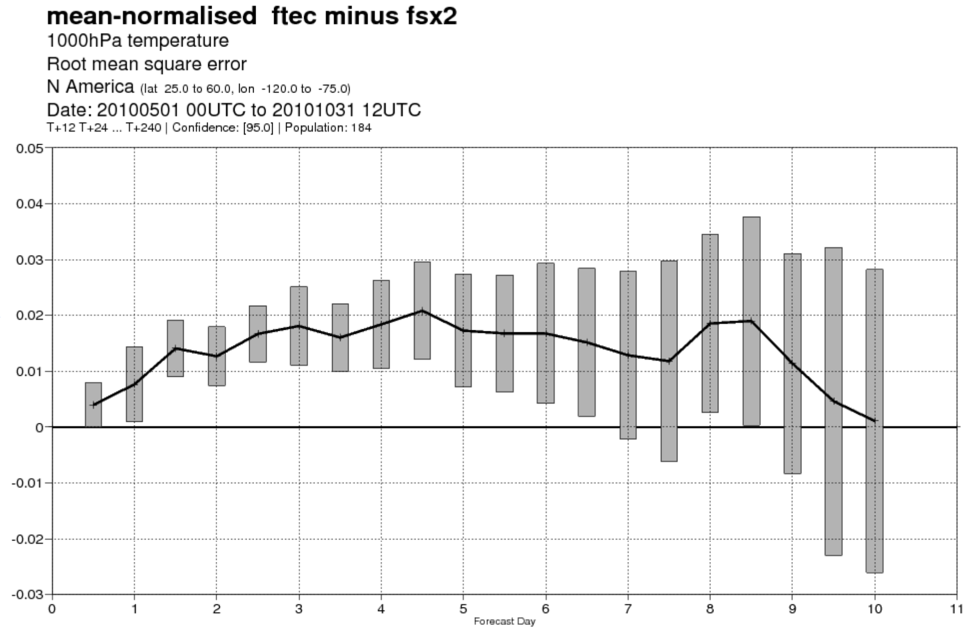
Verification on air temperature and humidity



Root-mean square forecast error

Anomaly correlation forecast

Summer-2010
(Jun, Jul, Aug)



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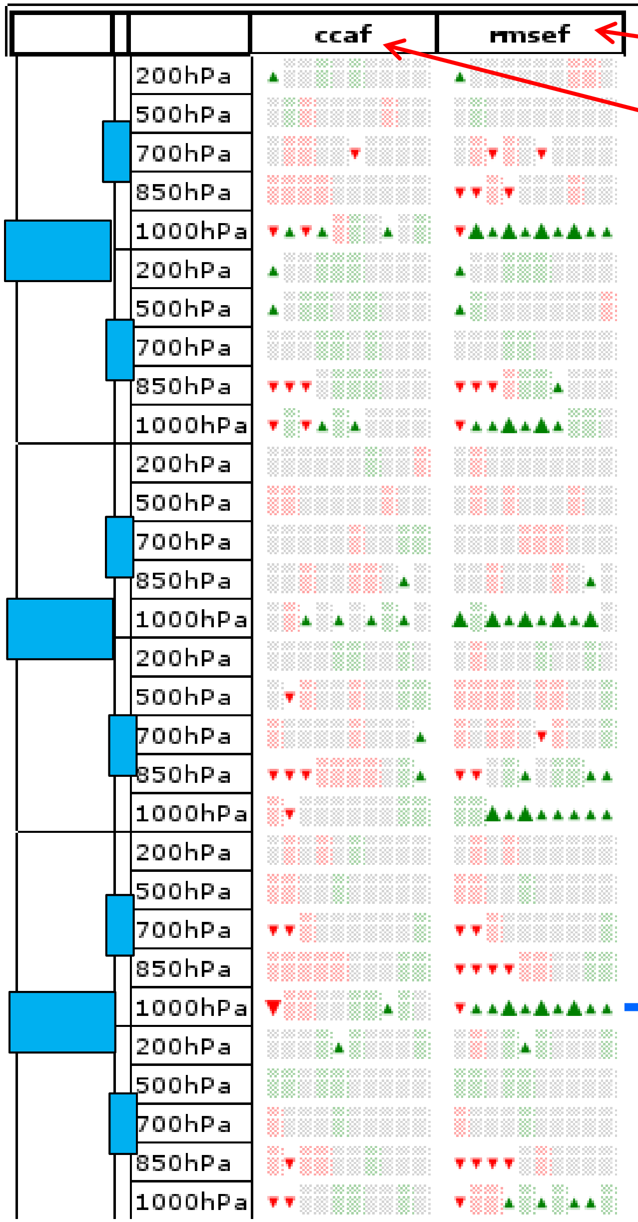
Verification on air temperature and humidity



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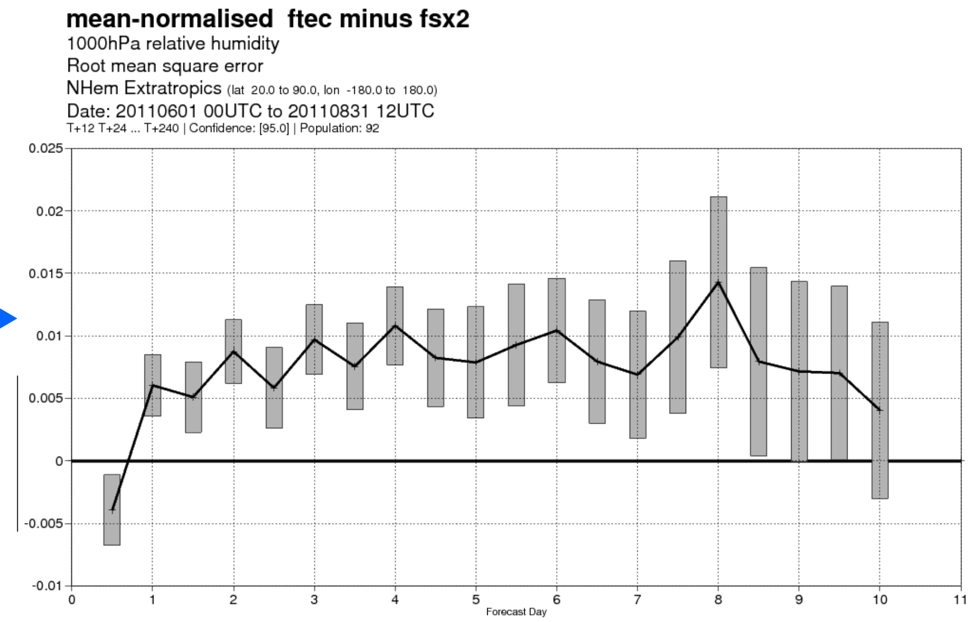

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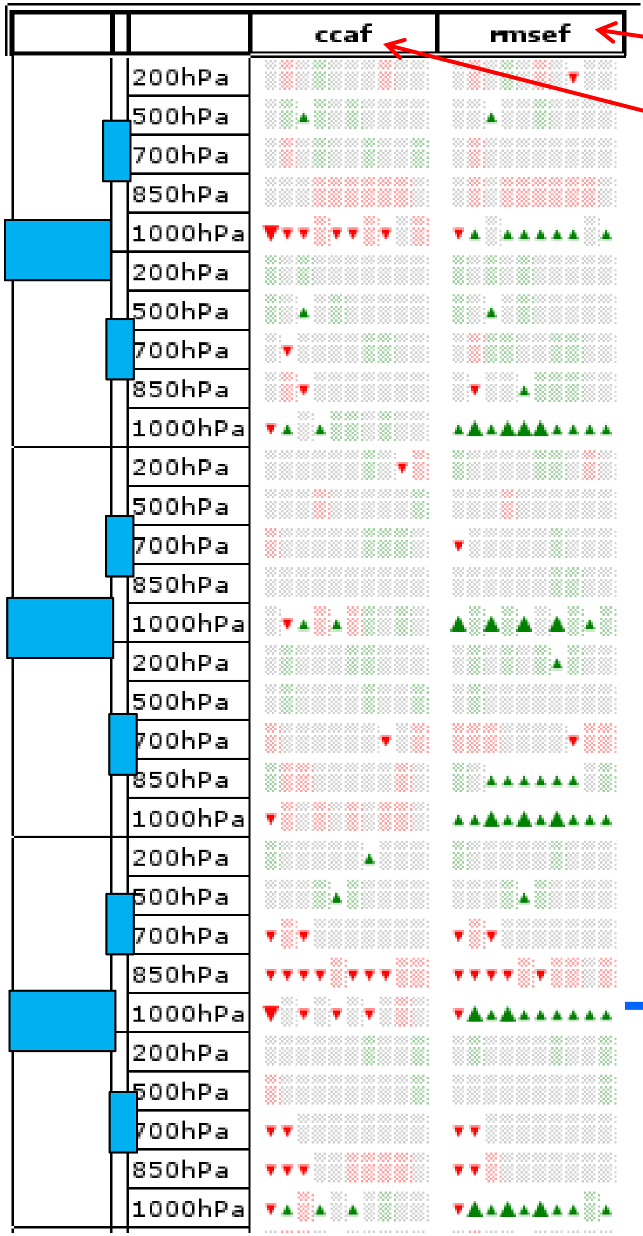
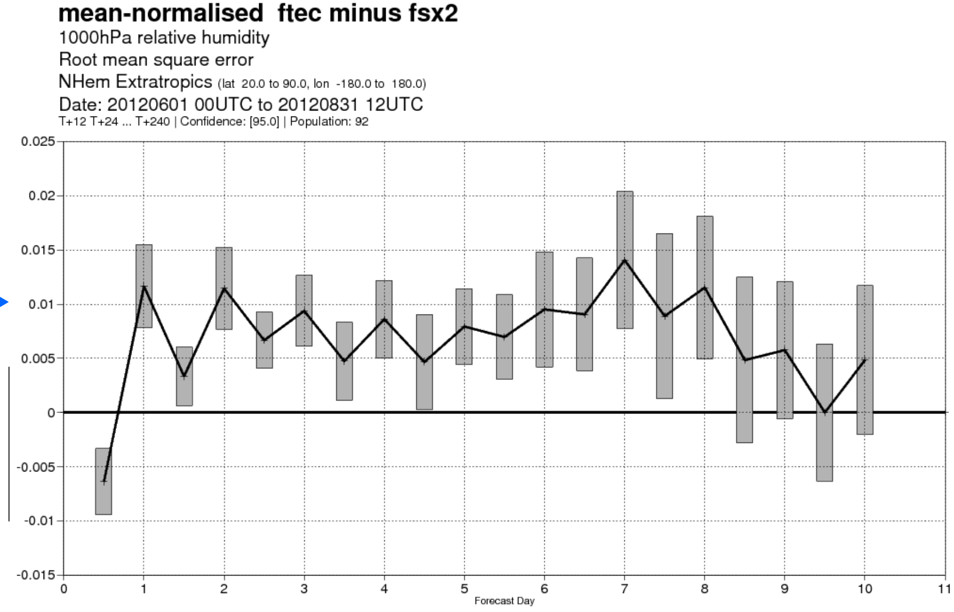


Root-mean square error forecast

Anomaly correlation forecast

Summer-2012
(Jun, Jul, Aug)



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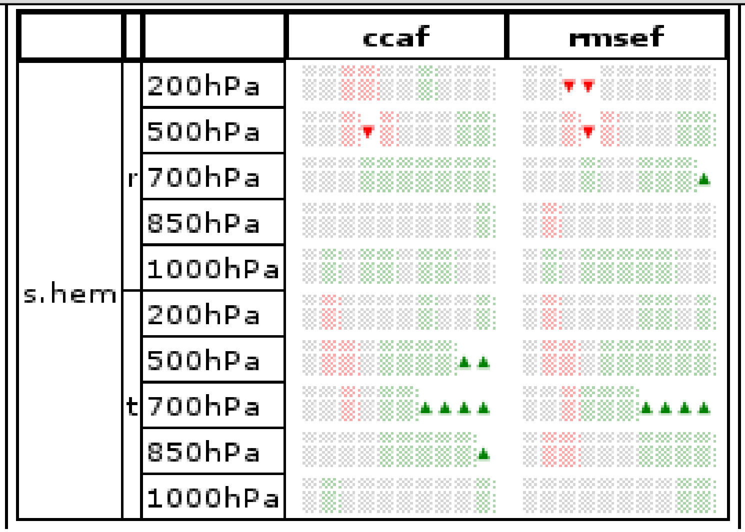
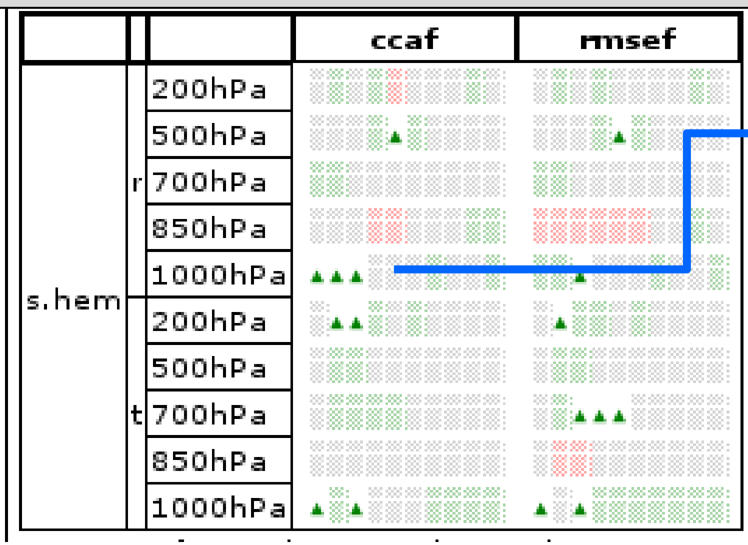
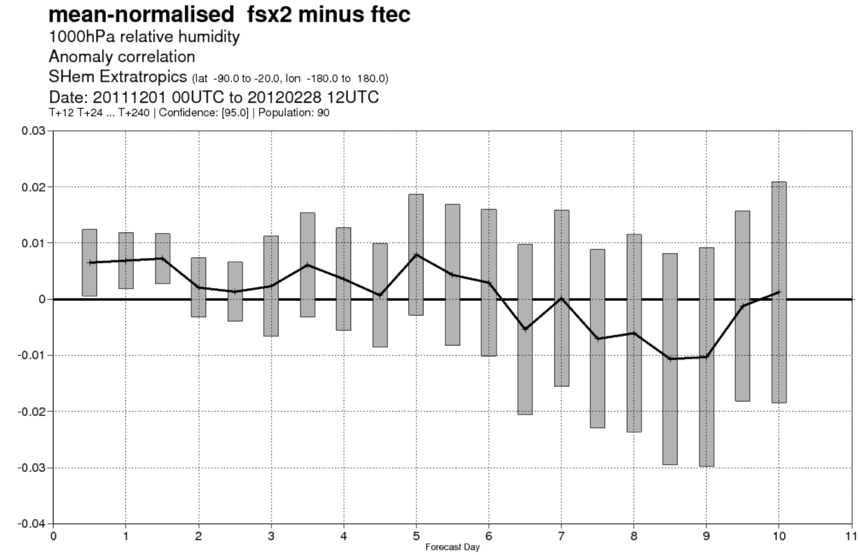
Verification on air temperature and humidity

Winter 2010-11 (Dec, Jan, Feb)



Winter 2011-12 (Dec, Jan, Feb)





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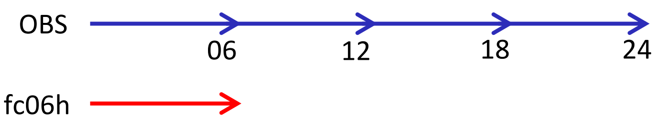
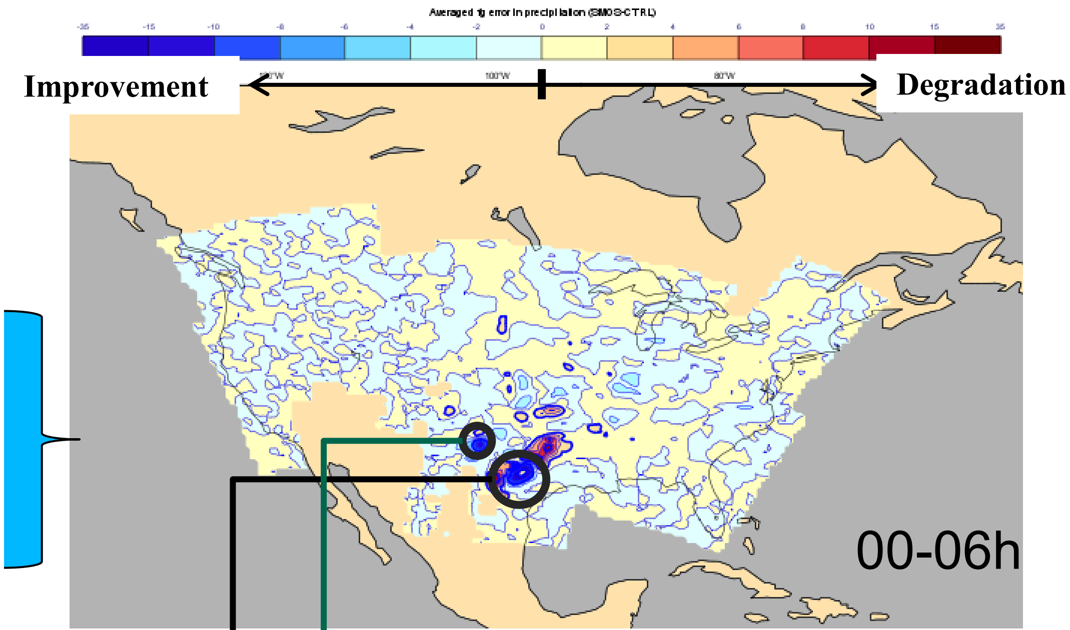
Impact on forecasted precipitation

- **"Truth"**: 6h accumulated precipitation from radar observations of the **NEXRAD** network,

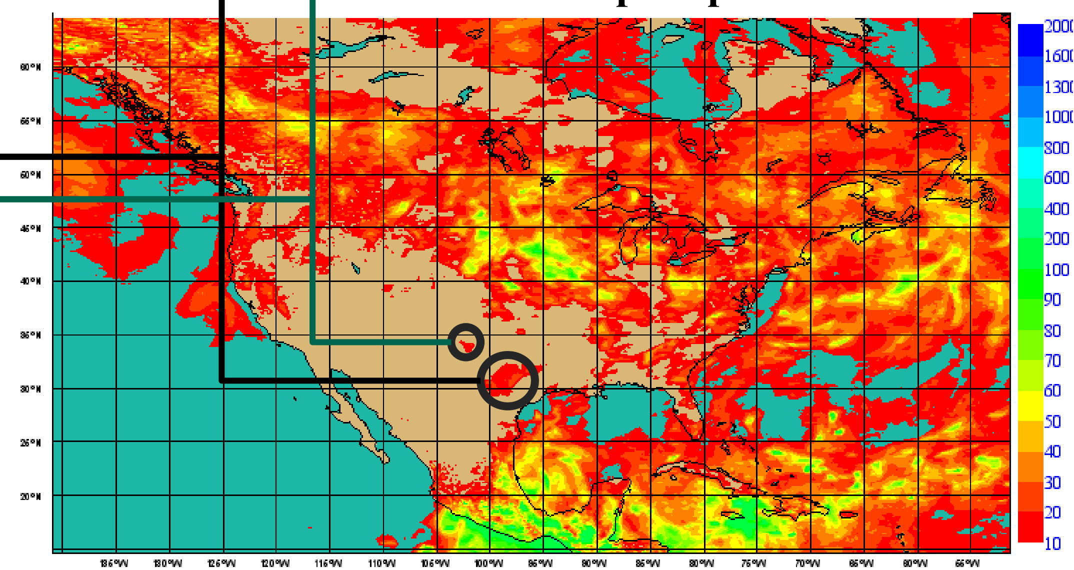
- Target variable: **fg-departure fc error**;

Impact 6h fc= $(OBS_{00\text{-}06}\text{-}fc_{06})_{EXPT} - (OBS_{00\text{-}06}\text{-}fc_{06})_{CTRL}$





June 2011 – accumulated precipitation 00-06UTC



June 2011 → The two areas with the largest improvements in forecasted precipitation (for the period 00-06h), coincide with two isolated convective cumulus of precipitation.

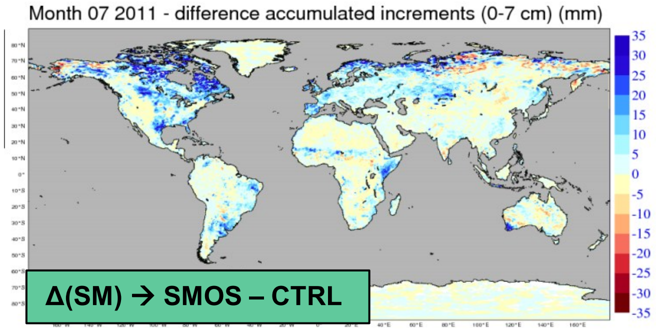
Impact of the fc precipitation limited to the first 12h fc.

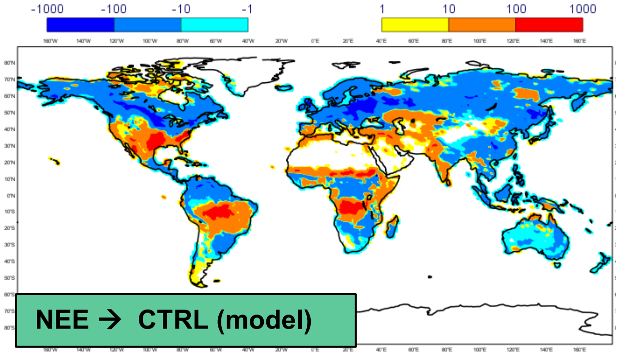
Impact in the carbon cycle – *July 2011*

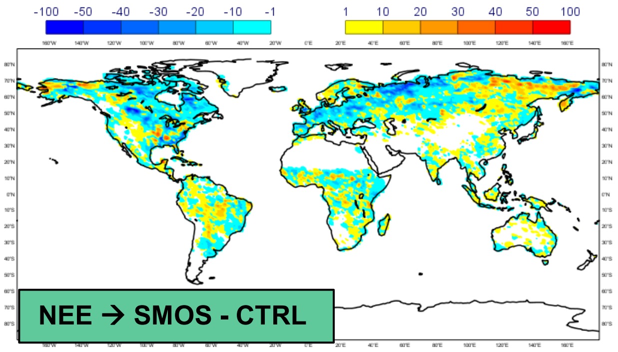
- New **CTESSEL** provides a vegetation-interactive formulation → coupling water-carbon cycles

NEE = R_{eco} – GPP
- <0 ; CO_2 uptake
- >0 ; CO_2 emission

- Climate forcings:
  - R_{eco} → f(SM, T)
  - GPP → f(SM, T, Rad)







- **High sensitivity** to SMOS data assimilation in:
  - Summer of NH → increase of GPP at higher ratio than R_{eco} (NEE becoming more negative) → **Positive impact** because CTESSEL underestimates CO_2 sink in summer of NH,
  - Sahel → Increase of soil moisture leads to increase in GPP during West African Monsoon,
  - Rio de La Plata, Horn of Africa
- Other complex feedback, via Temperature and cloud/radiation, can interfere with soil moisture impact,
- Further evaluation with CO_2 observations required to confirm the positive impact in the carbon fluxes estimation

Conclusions (I)

- SMOS has shown very good sensitivity to sm variations → clear potential for NWP,
- ECMWF has successfully incorporated SMOS data in the IFS (monitoring & assimilation),
- ECMWF soil moisture analysis based on an EKF; ready to assimilate SMOS data,
- Production of a new SM product based on the assimilation of T^{2m}, RH^{2m} and SMOS T_B,

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- Production of a new SM product based on the assimilation of T^{2m}, RH^{2m} and SMOS T_B,
- Evidence of positive impact of SMOS in:
    - Air temperature and humidity at 1000 and 850 hPa,
    - Up to 7-8 days,
    - In Europe, North America and NH, in summer of NH (J,J,A),
    - In South Hemisphere in summer of SH (D,J,F),
    - Low impact was found in spring and autumn → lower increments
- The data assimilation system needs to be tuned:
    - Over East of Asia (RFI quality control),
    - South Hemisphere (lower impact compared to NH),
    - Australia (less amount of data and lower soil moisture levels in general),
    - Tropics (special regions and still high bias remaining)
- Impact on the precipitation forecast at short term and in the carbon cycle.

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Conclusions (II)

- <u>Can SMOS improve the weather forecast?</u>

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Conclusions (II)

- **Can SMOS improve the weather forecast?**
  - There are clear signs of the potential of SMOS to improve the weather forecast, but…
    - Only observations of best quality should be used,
    - Greater chances of success will depend on the good use/tune of the assimilation system

- Further work with the data assimilation system is needed;
  - Quality control of the observations (RFI screening in DA),
  - Jacobians,
  - Model errors treatment

- Improved accuracy of L-band simulations through;
  - Improved model physics,
  - Improved climatic fields,
  - Improved radiative transfer model

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Thanks for your attention !

contact: joaquin.munoz@ecmwf.int

Further information:

SMOS online monitoring in NRT:
http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/smos/

ECMWF SMOS website:
http://www.ecmwf.int/research/ESA_projects/SMOS/index.html

ECMWF CMEM website:
http://www.ecmwf.int/research/data_assimilation/land_surface/cmem/cmem_index.html

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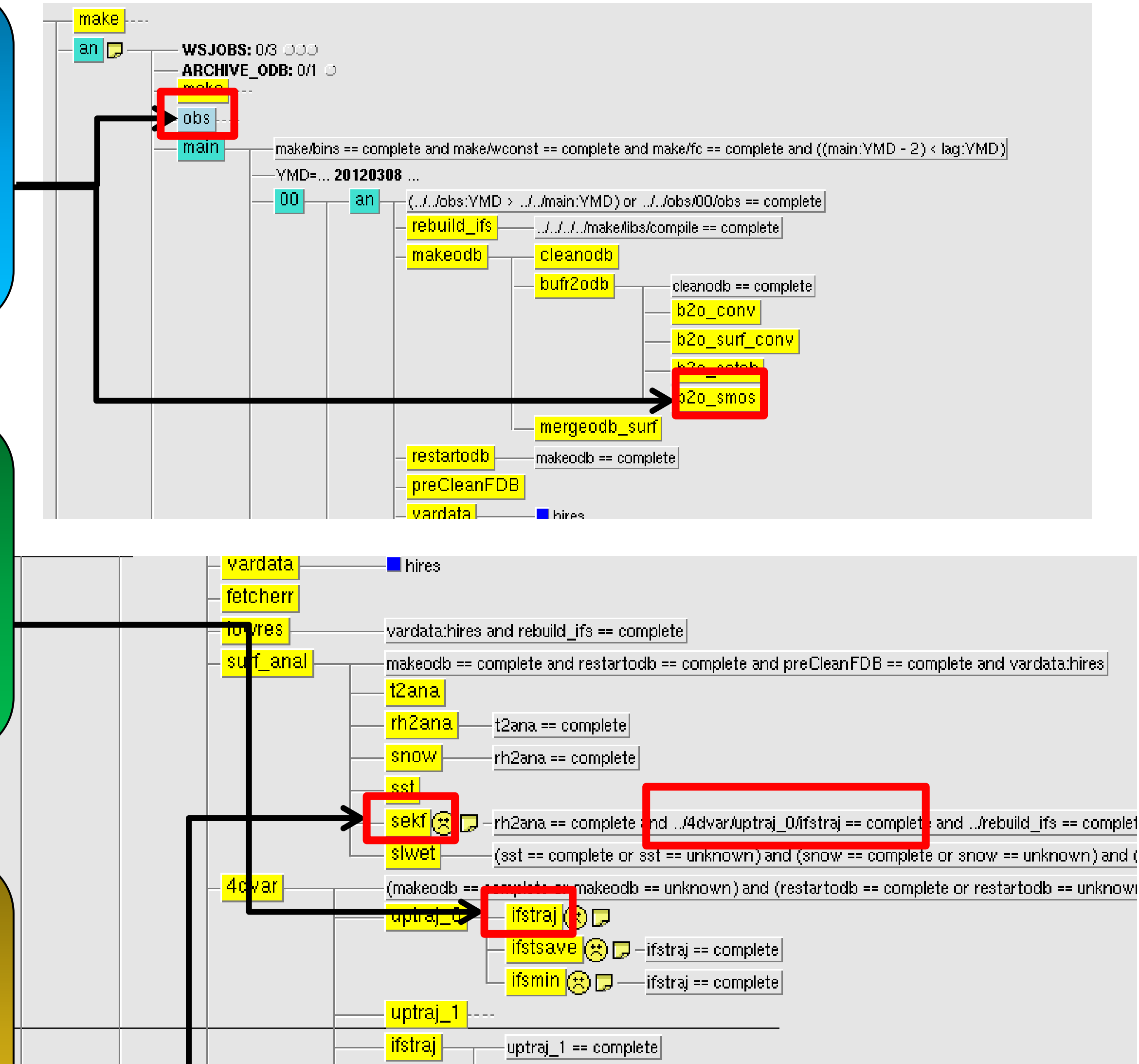
SMOS task scheduling

BUFR & ODB spaces: quality checks, thinning, setup of SMOS monitoring and CMEM configuration, creation of internal database for SMOS, distribution of observations per processor and time slots, merging of remote sensing data in a single database for surface analysis, etc.

4DVAR space: collocation of observations with model grid, screening and flagging of each observation, forward model computation, feedback to ODB database, first-guess departures, monitoring statistics ,etc.

SEKF space: retrieval of observations to assimilate and matching with modelled equivalents for same model time step and location, perturbed runs and storing of perturbed T_B, innovation vector and soil moisture increment computation, etc.



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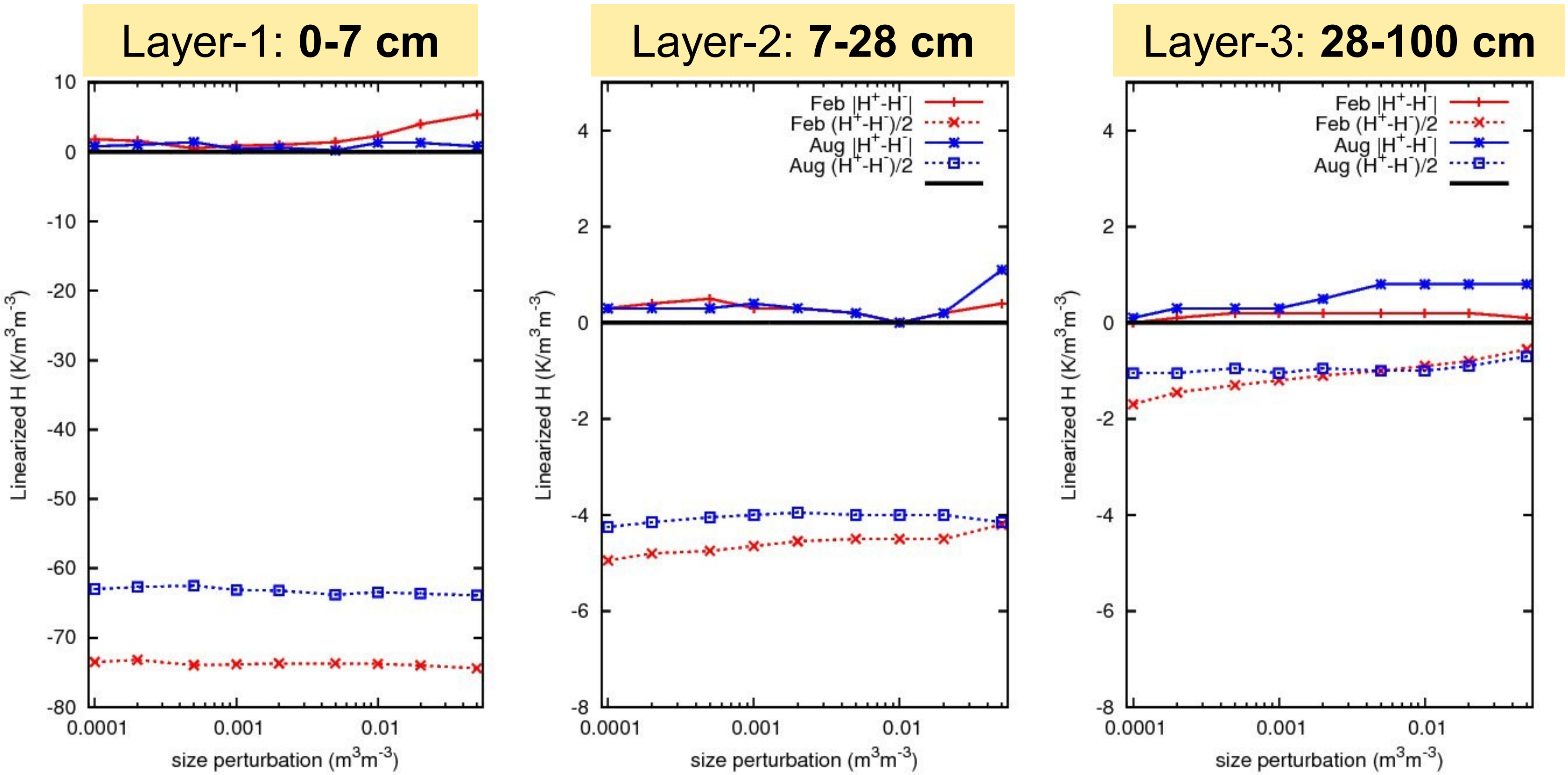
Jacobians calibration $H = \Delta T_B / \Delta \theta$



- **Sensitivity of T_B to soil moisture is negative,**
- **Larger sensitivity for first soil layer → It is expected larger correction of first layer of SM to correct towards SMOS observations.**
- **The optimal perturbation value is between 0.005 m^3m^{-3} and 0.01 m^3m^{-3}. For consistency with T^{2m} and RH^{2m}, 0.01 m^3m^{-3} will be used.**