# Assimilation of L-band passive microwave brightness temperatures in the ECMWF land data assimilation system

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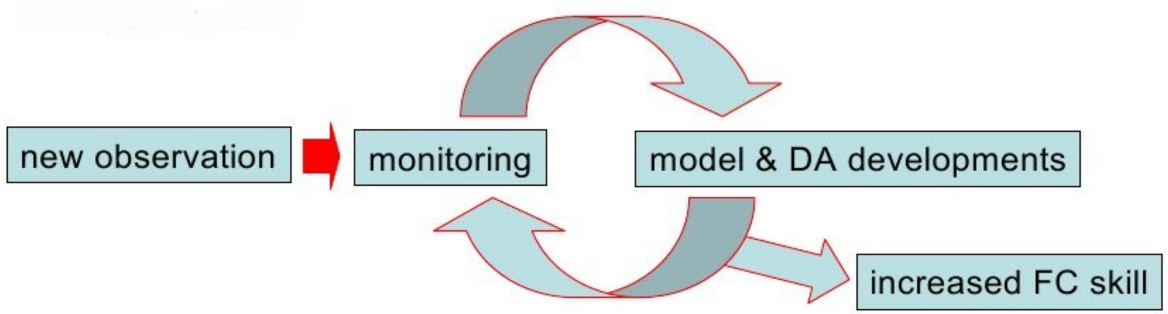
# SMOS & ECMWF

- **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**



# Soil moisture analysis at ECMWF

**Simplified Extended Kalman Filter:**

For each grid point, analysed state vector $\boldsymbol{x}_a$:

$$\boldsymbol{x}_a = \boldsymbol{x}_b + \boldsymbol{K}\,(\boldsymbol{y} - \mathrm{H}\,[\boldsymbol{x}_b])$$

$\boldsymbol{x}_b$ : background state vector,

$\boldsymbol{y}$ : observation vector

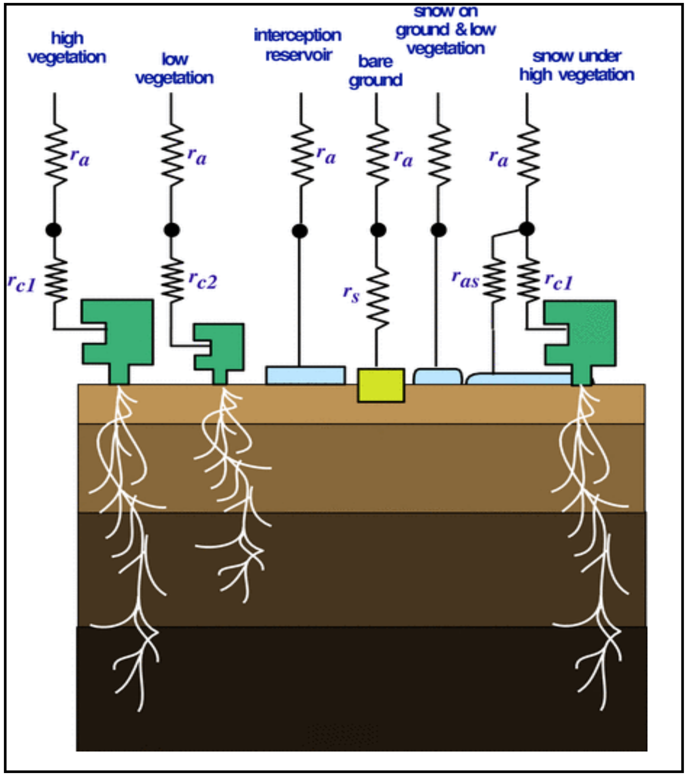
H : non linear observation operator

$\boldsymbol{K}$ : Kalman gain matrix

$$\boldsymbol{K} = [\mathbf{B}^{-1} + \mathbf{H}^{T}\mathbf{R}^{-1}\mathbf{H}]^{-1}\mathbf{H}^{T}\mathbf{R}^{-1}$$

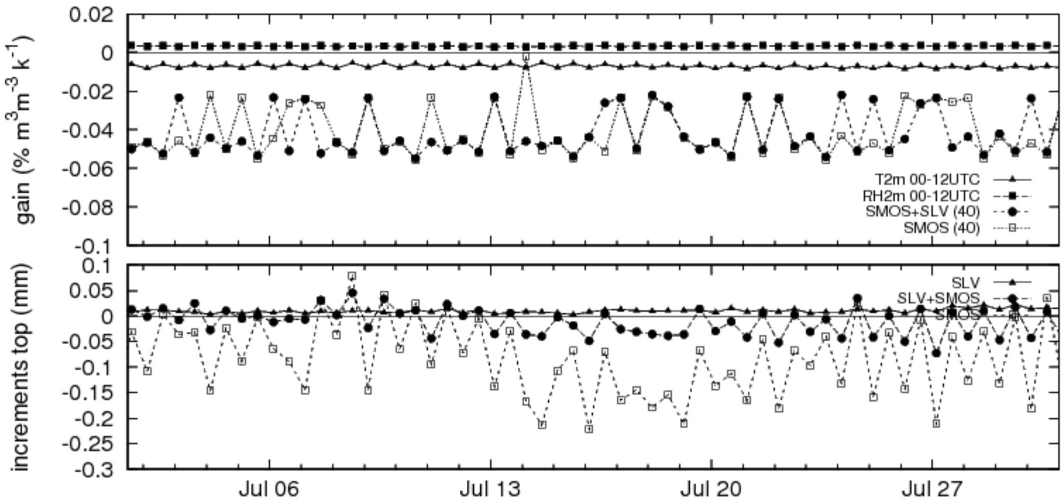
**Used observations:**

- Operations: screen level variables (SLV): $T^{2m}$, $RH^{2m}$
- Research:
  - ASCAT soil water index (METOP-A, METOP-B),
  - SMOS Brightness temperatures



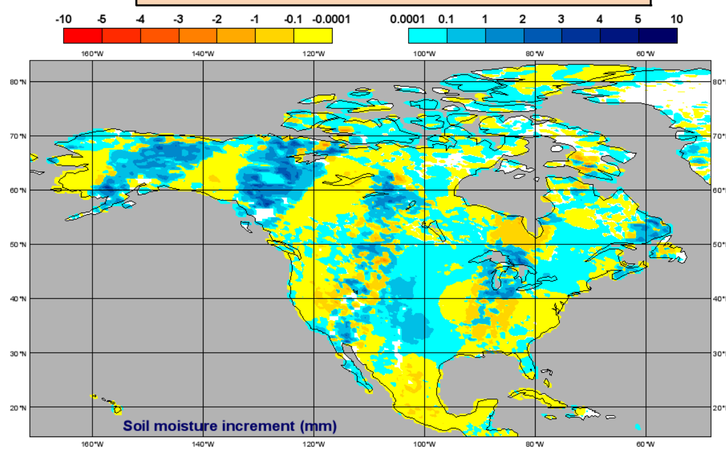

**LSM : HTESSEL**
0-7cm, 7-28cm, 28-100cm, 100-289cm
(*Balsamo et al., JHM, 2009*)

# SMOS DA impact experiments

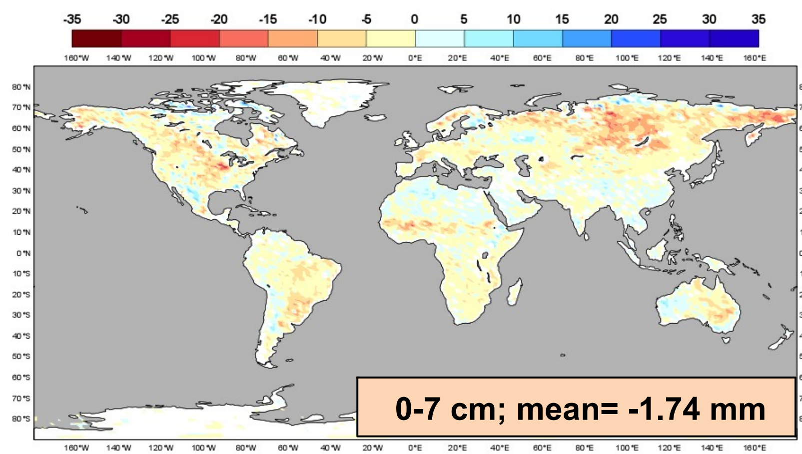



- Large increments for the top layer when assimilating SMOS TB only,
- Generally, SMOS tends to dry the model SM, whereas screen variables tend to add some water. Precipitation is also modified!
- Do we want lower gain for SMOS?

**Assimil $T^{2m}$, $RH^{2m}$ & SMOS $T_B$**



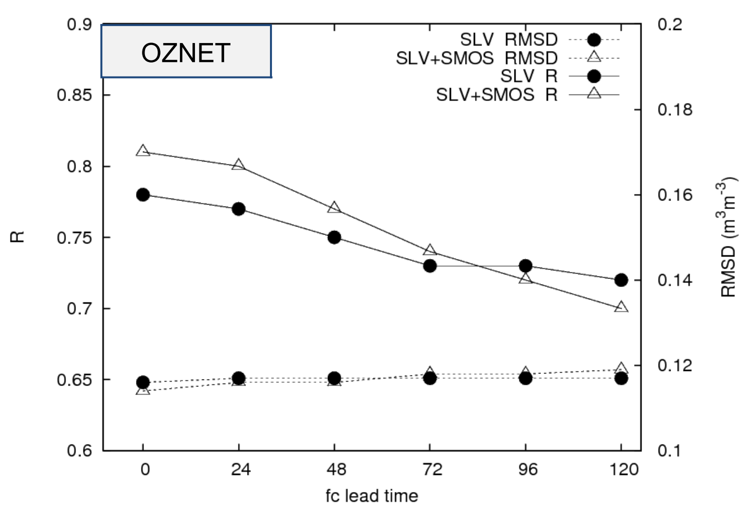

**SMOS $T_B$ – SLV (JJA)**

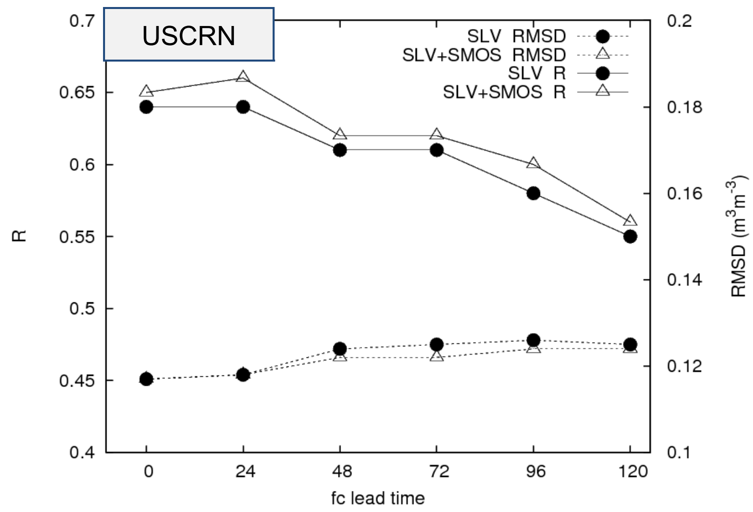


# Validation on soil moisture

**SM analyses were validated against more than 600 in-situ stations in 10 different countries:**

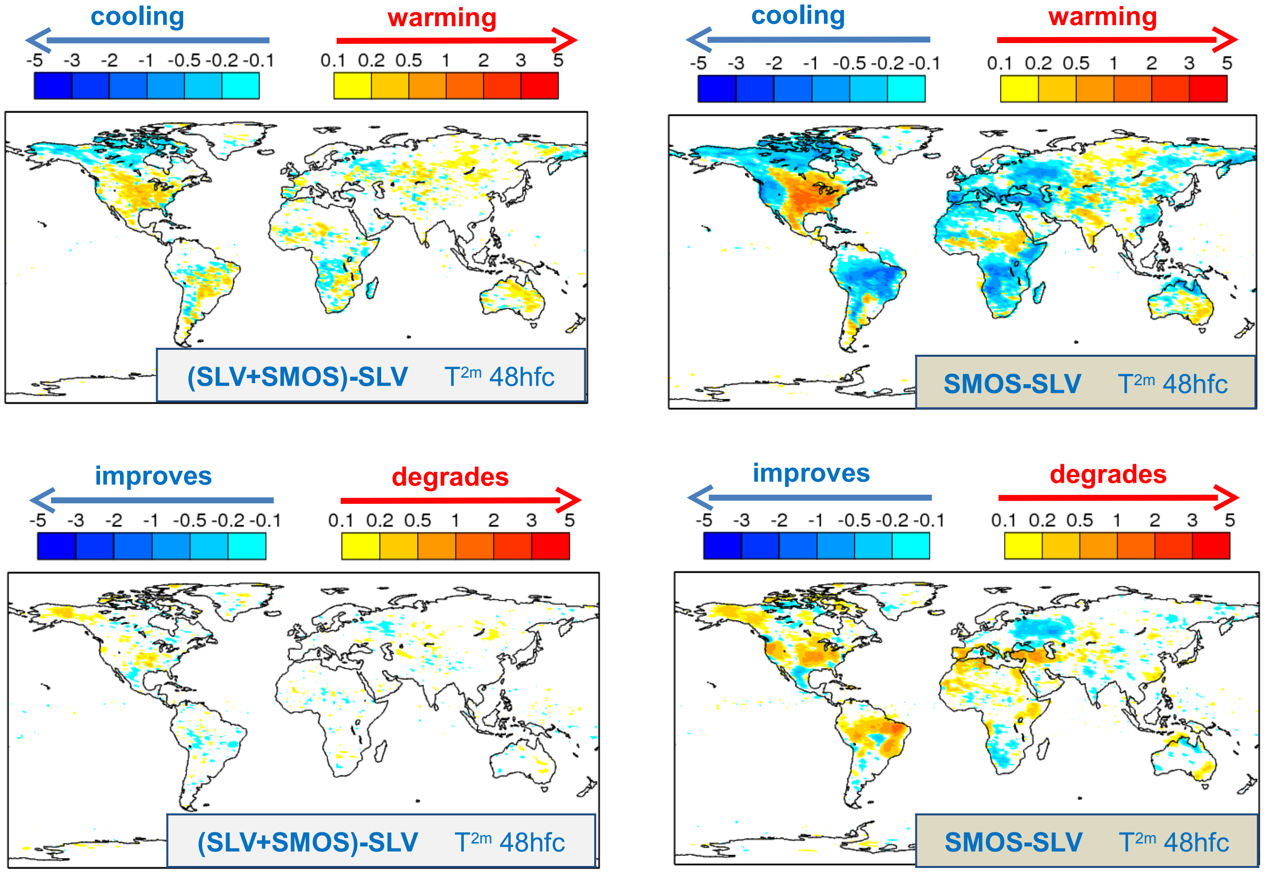
- Impact on soil moisture is high!,
- Either assimilating SMOS data alone or in combination with SLV is beneficial for soil moisture,
- However, SLV+SMOS obtains the better results averaged over all the networks,
- But, assimilating SMOS only is the best in semi-arid climates with strong seasonal cycle,
- For the root-zone, validation against US networks show benefits assimilating SMOS data,

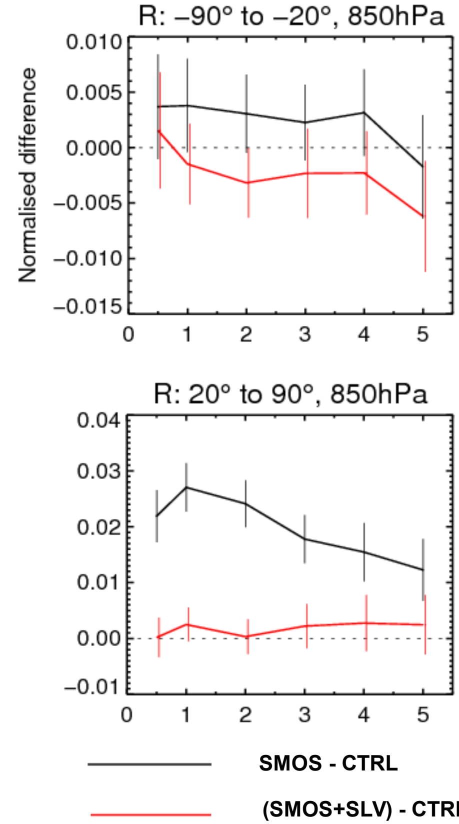



- The correlation coefficient (R) decreases with fc lead time, and RMSD increases slightly,
- The skill in the fc of soil moisture with SLV+SMOS is superior to SLV at least up to 72h (5 days for USCRN),
- Primary objective is achieved!

# Impact in the forecast skill

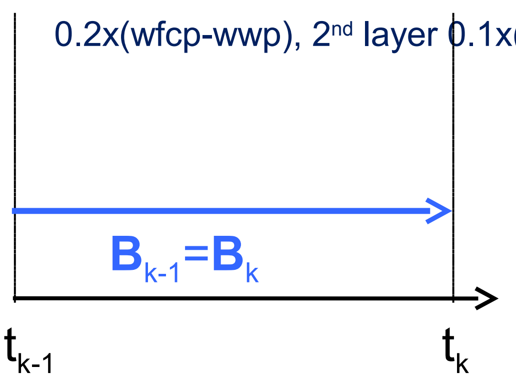


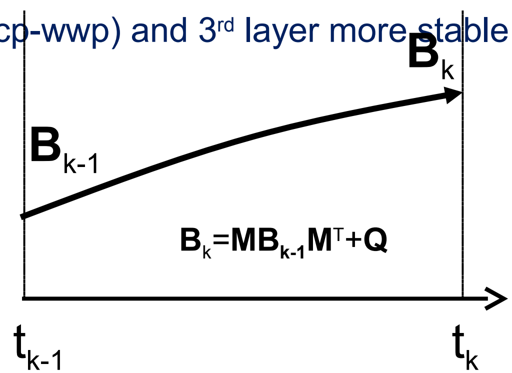



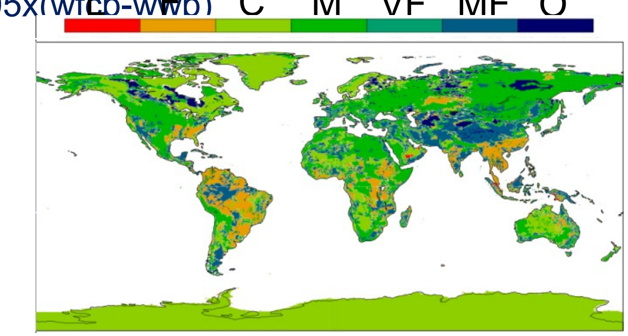

- Larger impact by assimilating only SMOS $T_B$, as SM increments are stronger,
- Influence is primarily close to the surface, whereas is very weak in the upper troposphere,
- SMOS increments produce warmer and drier atmosphere in center US, Sahel, South of Africa and Australia → hot-spots for NWP impact,
- Small impact in the skill of the forecast by assimilating SLV+SMOS, whereas SMOS only has a larger impact but with mixed signs.

# Experiment types

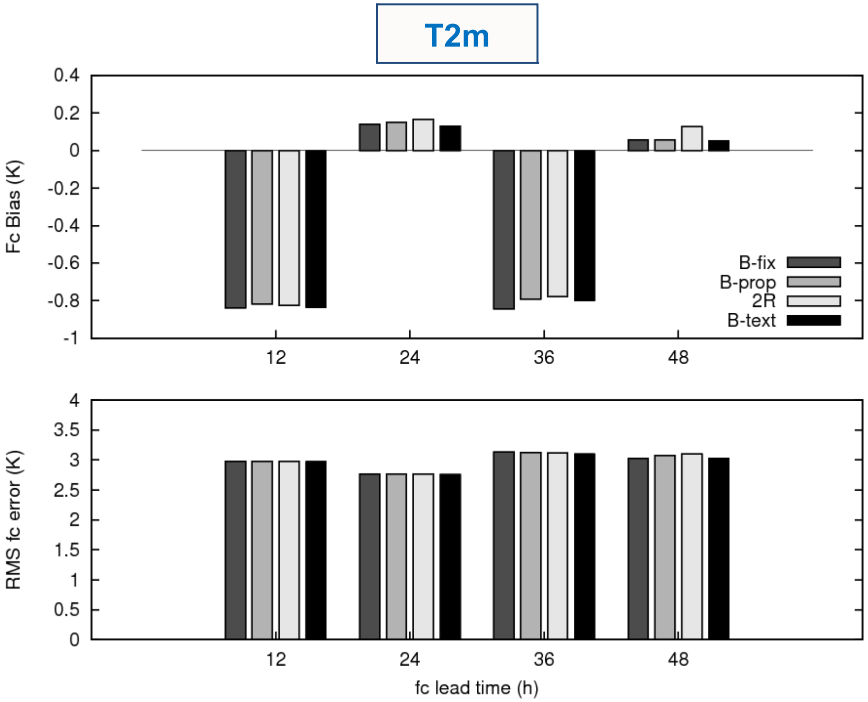
- **OL →** free soil moisture run (SLV and all the other surface variables are still analysed)
- **SLV →** assimilation of only $T^{2m}$, $RH^{2m}$ (simulate surface operational conditions)
- **SLV+SMOS →** assimilation of $T^{2m}$, $RH^{2m}$ and SMOS $T_B$ with **B** static
- **SMOS B-fix →** assimilation of only SMOS $T_B$ with **B** static
- **SMOS PDI →** pseudo direct-insertion of SMOS $T_B$ . SEKF filters still apply to increments and departures
- **SMOS 2R →** assimilation of only SMOS $T_B$, doubling the observation error (2**R**),
- **SMOS B-prop →** assimilation of only SMOS $T_B$ with **B** propagated between two cycles. Background error grows along the assimilation window. Model error was set to 0.01 $m^3m^{-3}$,
- **SMOS B-text →** assimilation of only SMOS $T_B$; background error is defined as a proportion of the water holding capacity (WHC). For a medium texture soil, 10% of WHC is equivalent to doubling background error (0.02 $m^3m^{-3}$), or 20 mm for the 1st meter of soil.
- **SMOS 3DB →** an 3D structure background model error is assumed. The model top layer is affected by short-scale variability and more sensitive to precipitation errors → larger error: 0.04 $m^3m^{-3}$, approximately equal to 0.2x(wfcp-wwp), 2nd layer 0.1x(wfcp-wwp) and 3rd layer more stable 0.05x(wfcp-wwp)

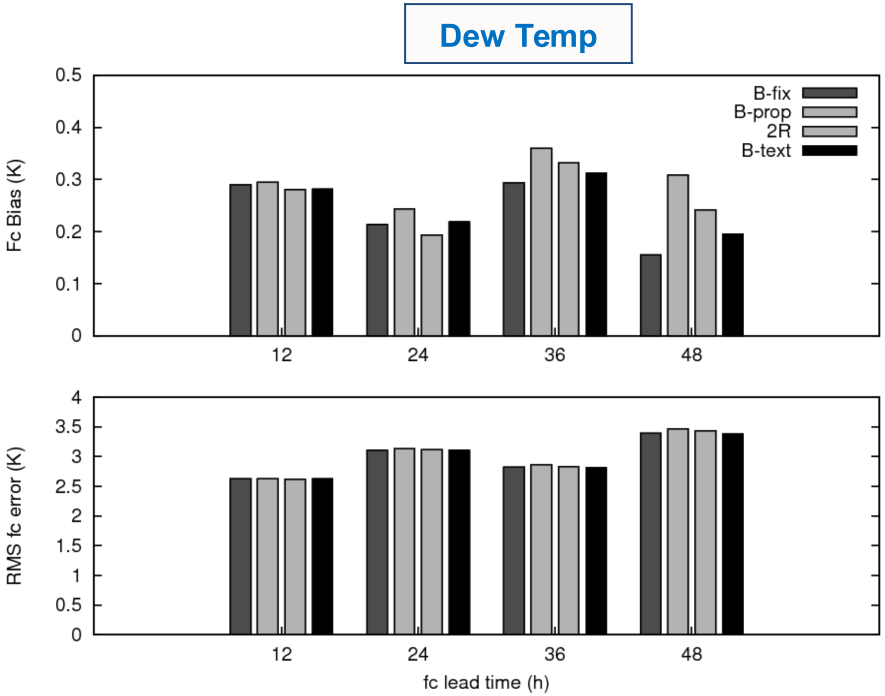


# T2m and Dp Temperature forecast impact

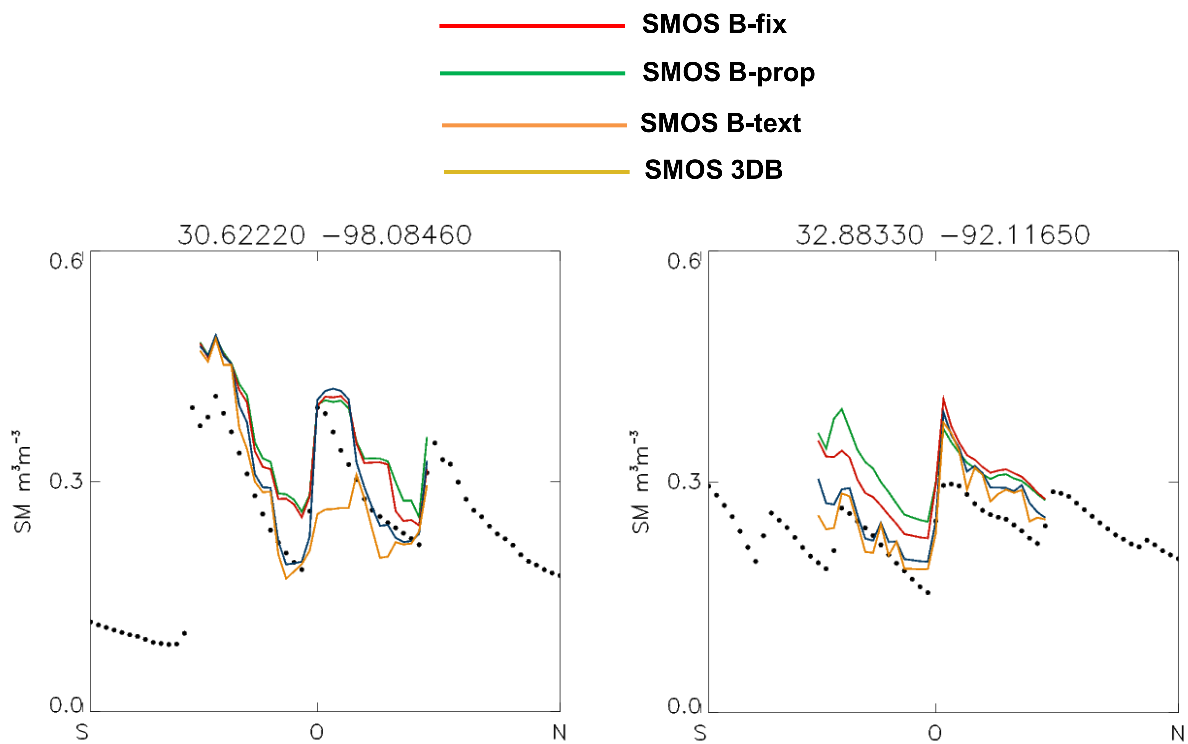


# Validation against in-situ data (top layer)

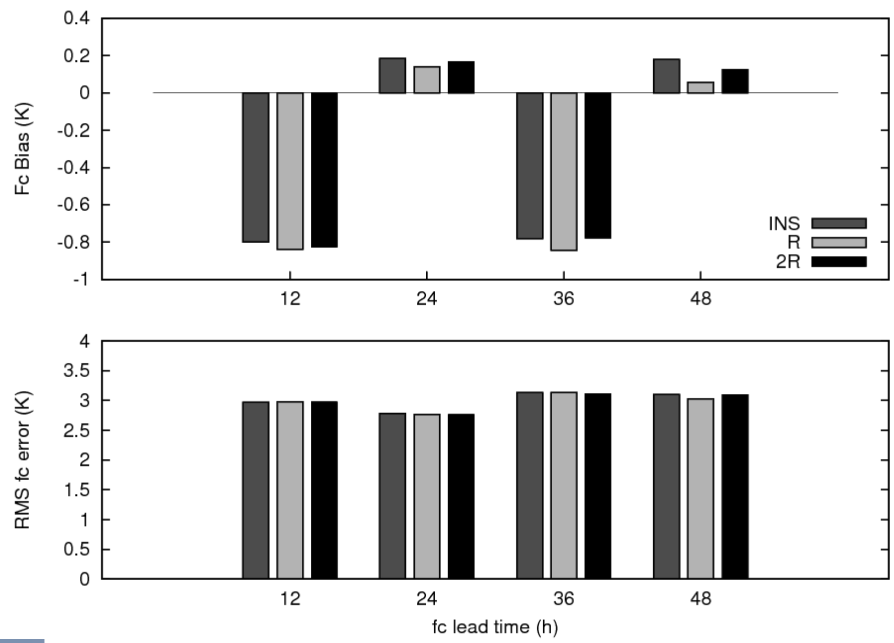
| USCRN | Bias ($m^3m^{-3}$) | RMSD ($m^3m^{-3}$) | R | N |
|---|---|---|---|---|
| SMOS B-fix | -0.085 | 0.109 | 0.70 | 64 |
| SMOS B-prop | -0.088 | 0.111 | 0.69 | 64 |
| SMOS Btext | -0.074 | 0.104 | 0.67 | 64 |
| SMOS + 3DB | -0.071 | 0.102 | 0.65 | 64 |

| SCAN | Bias ($m^3m^{-3}$) | RMSD ($m^3m^{-3}$) | R | N |
|---|---|---|---|---|
| SMOS B-fix | -0.022 | 0.095 | 0.70 | 77 |
| SMOS B-prop | -0.025 | 0.095 | 0.70 | 77 |
| SMOS Btext | -0.015 | 0.094 | 0.66 | 77 |
| SMOS + 3DB | -0.016 | 0.094 | 0.64 | 77 |

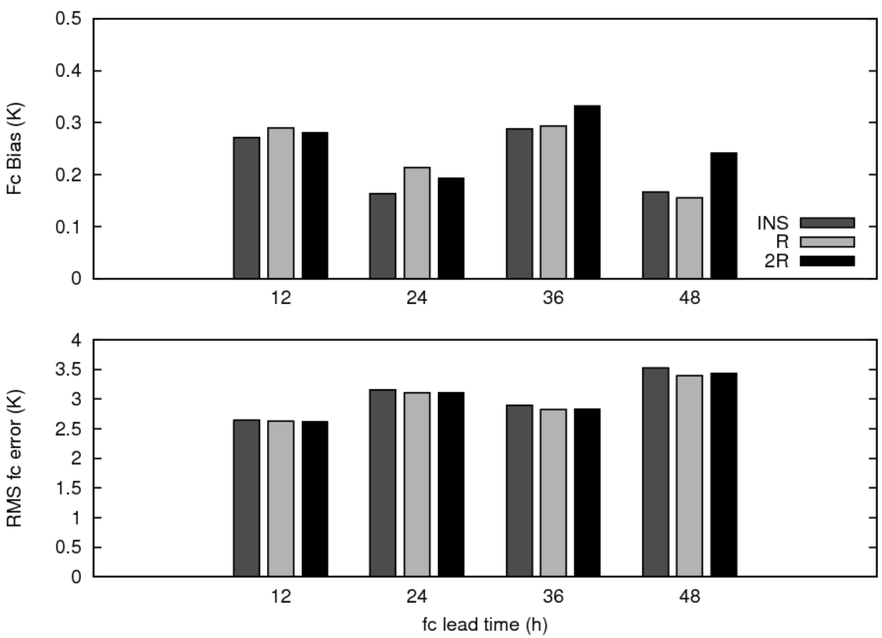


# T2m and dew point temperature forecast impact

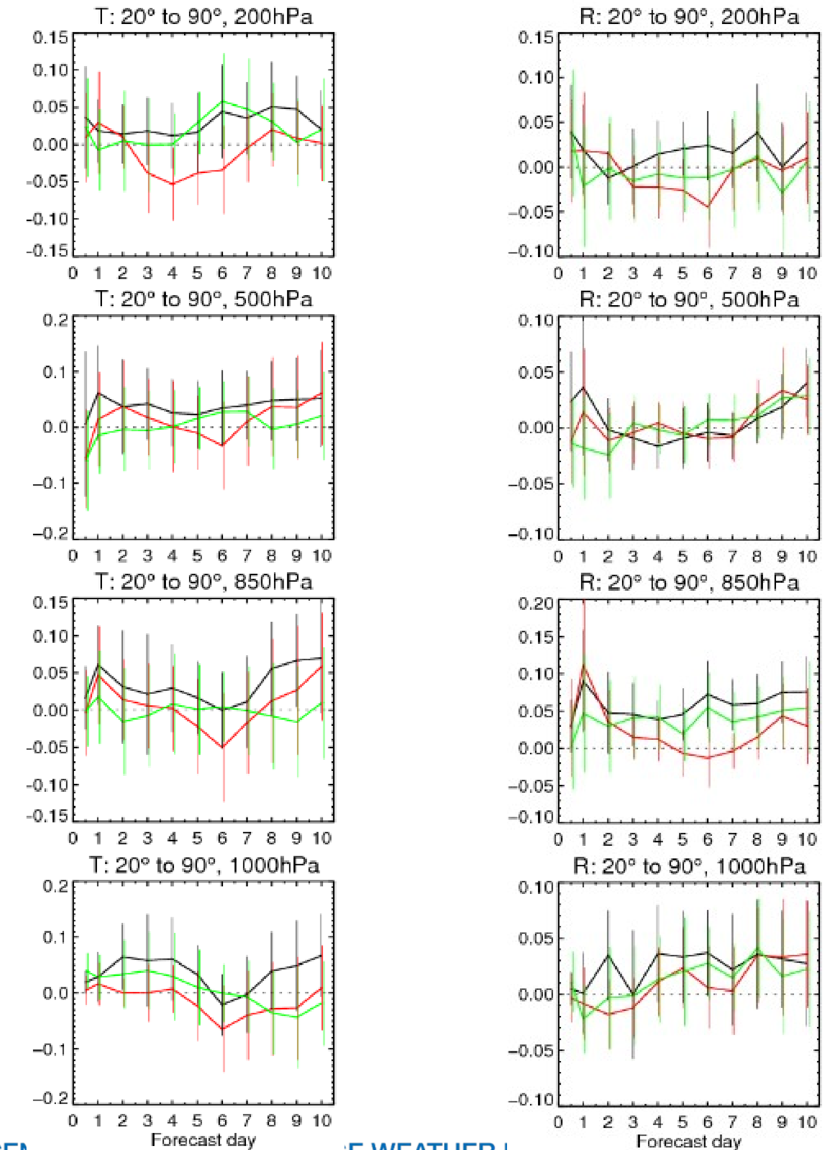
T2m




Dew Temp



# Air temperature and humidity verification




SMOS 2R - Bfix

SMOS Bprop - Bfix

SMOS Btext - Bfix

# Conclusions

- A series of several 1-month experiments have been run to study:

    a) The effect of different type of observations in the soil moisture analyses,
    b) The effect of different configurations of the B-matrix,
    c) The effect of different weights given to SMOS observations in the SEKF,

a) Compared to a free run, assimilating screen-level variables is neutral for soil moisture analysis. However, it benefits the forecast of air temperature and humidity, up to 10%.
In contrast, the assimilation of SMOS observations reduces bias and RMSD against in-situ data, for both, top layer and root-zone. The correlation coefficient is penalized for the larger variability introduced by the increments and for just one month. The atmospheric impact is still positive compared to the free run, but not as much as for SLV assimilation.

b) Redefining the B-matrix as a function of the soil texture (B-text or 3D-B experiments) obtains the best results in terms of Bias and RMSD against in-situ data for the top layer. However, the variability of the increments can affect the correlation over short time scales. Among these experiments, the atmospheric impact was found to be neutral.

c) The current weight given to SMOS observations obtain closest analysis to in-situ data. However, doubling the SMOS observation error will reduce the variability of the increments (lower gain) and that improves the correlation against in-situ.