SMAP Weather focused applications
18 July 2017, Monterey, CA

ECMWF L-band activities over land

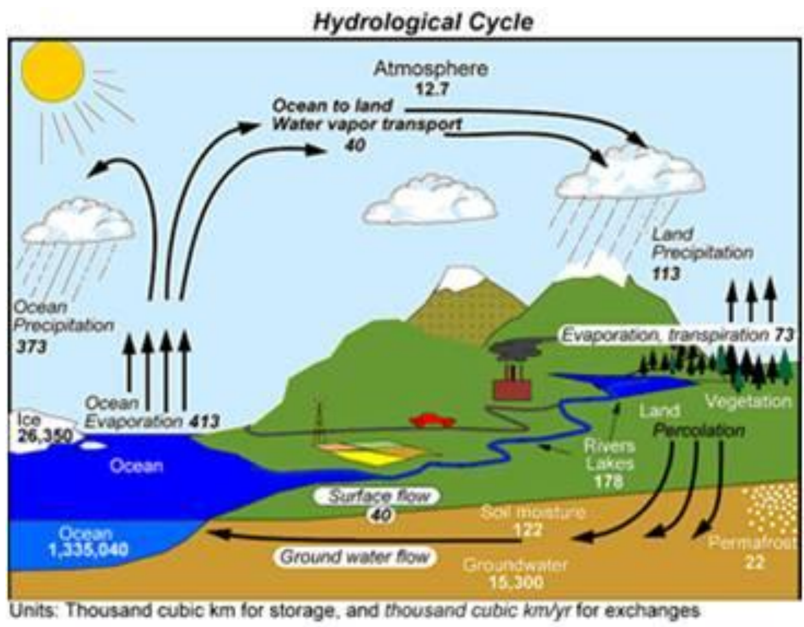
P. de Rosnay, J. Muñoz Sabater, N. Rodríguez-Fernández,
C. Albergel, L. Isaksen, G. Balsamo and S. English,

Introduction: Land Surface for Numerical Weather Prediction (NWP)

Land surfaces:

- Boundary conditions at the lowest level of the atmosphere
- Component of the Earth System, controls the continental hydrological cycle, interaction with the atmosphere on various time and spatial scales
- Crucial for near surface weather conditions,

whose high quality forecast is a key objective in NWP



Trenberth et al. (2007)

→ Use of observations for land surface in NWP systems for monitoring, initialization, and validation

Relevance of L-band observations for soil moisture in NWP systems

ECMWF Soil Data Assimilation

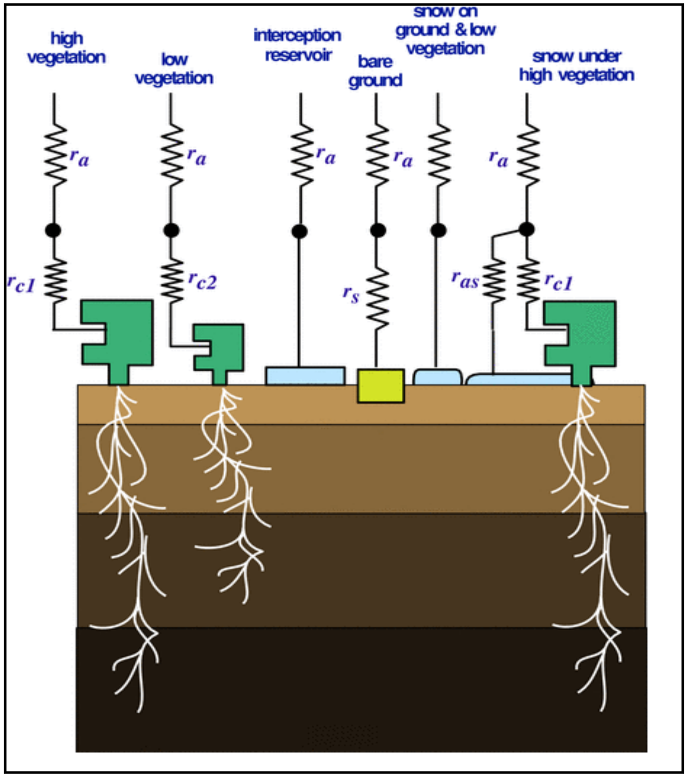
Assimilation of L-band T_B over continental surfaces & investigate the meteorological impact of SMOS data assimilation

Simplified Extended Kalman Filter:
(de Rosnay et al QJRMS 2013)

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

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

$\boldsymbol{x}_b$: background state vector,
$\boldsymbol{y}$: observation vector
$\mathcal{H}$: non linear observation operator
K : Kalman gain matrix: $\mathbf{K} = [\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}]^{-1}\mathbf{H}^T\mathbf{R}^{-1}$



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

Observations:

- Screen Level Variables (**SLV**): T^{2m}, RH^{2m}
- Remote sensing data:
  - **ASCAT** soil water index (METOP-A, METOP-B),
  - **SMOS** L-band Brightness temperatures

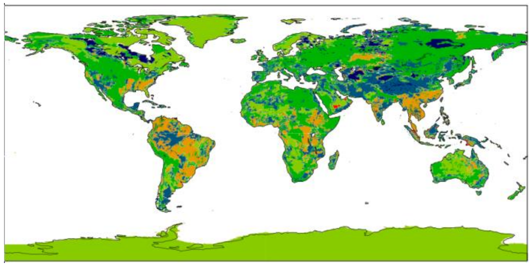
L-band DA: background and observation errors

System configuration

- Objective: find the best combination of observation and background error for L-band DA

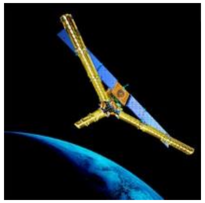
Munoz-Sabater et al. ECMWF ESA report 2016, also in rev 2017

Water holding capacity = *f*(soil texture)



Obs error: SLV and ASCAT: $\sigma(T_{2M})$= 1 K; $\sigma(RH_{2M})$= 4%; $\sigma(SM_{ASCAT})$= 0.05 m^3m^{-3}

	Config.1	Config.2	Config.3
layer-1: 7 cm	ε = 20% WHC [0.03-0.08] m^3m^{-3}	ε = 10% WHC [0.015-0.04] m^3m^{-3}	ε = 10% WHC [0.015-0.04] m^3m^{-3}
layer-2: 21 cm	ε = 10% WHC [0.015-0.04] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}
layer-3: 72 cm	ε = 5% WHC [0.008-0.02] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}	ε = 5% WHC [0.008-0.02] m^3m^{-3}



SMOS Obs error:

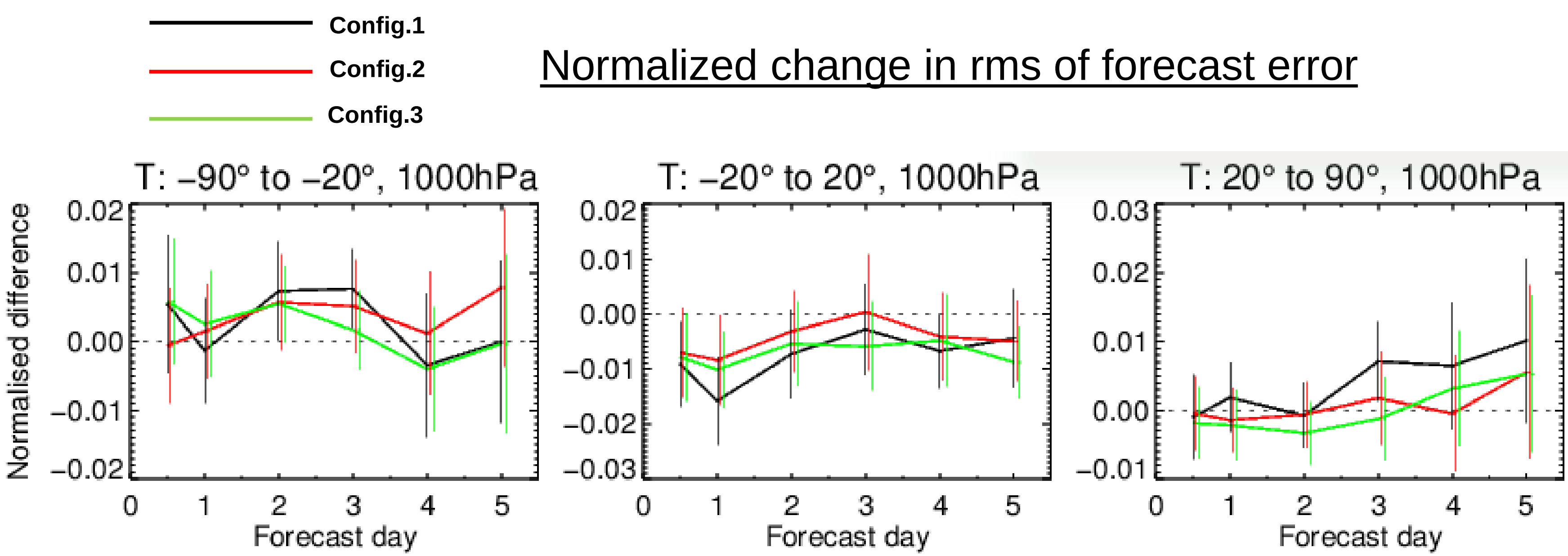
Config.1	Config.2	Config.3
$\sigma(T_B)$= 6 + rad_acc (~ 8.5 to 10 K)	$\sigma(T_B)$= 6 + rad_acc (~ 8.5-10 K)	$\sigma(T_B)$= 6 + 3xrad_acc (~13.5 to 18] K

L-band DA: background and observation errors

System configuration

- DA Experiments period: 15 Sept- 31 Oct 2012
- Reduced atmospheric observing system
- CTRL (SLV) plus 3 tested configurations to define best combination of error specification
- Config. 1 and 2 have negative impact in SH and NH; Config 3 retained

Normalized change in rms of forecast error



SH- extratropics *Tropics* *NH- extratropics*

L-band assimilation in ECMWF IFS

Experimental setup

- System configuration: obs and background error of config 3
- DA experiments period: MJJAS 2012 and MJJAS 2013
- Resolution: T511 (closest to SMOS resolution)
- Experiments:
  - Open Loop: full IFS but no soil analysis
  - SLV (T2m and RH2m)
  - ASCAT only
  - SMOS only
  - ASCAT+SMOS
  - SLV+ASCAT+SMOS

Set of data assimilation experiments using different configuration of the soil moisture observing system

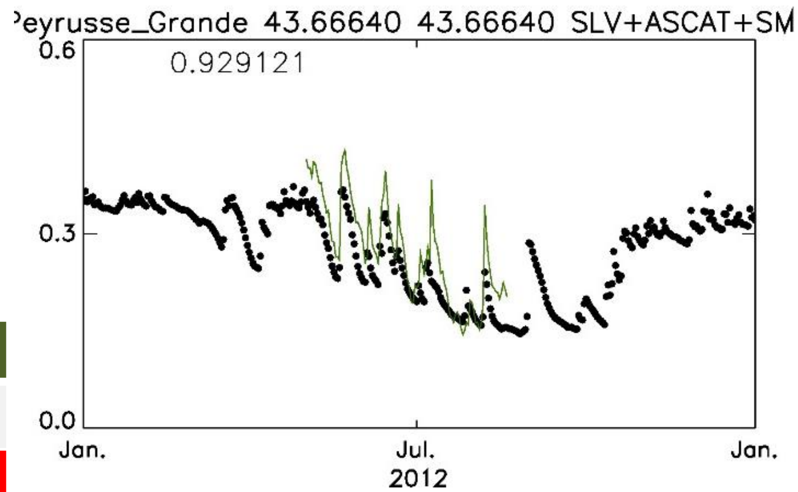
- Evaluation:
  - Soil Moisture from independent in situ (USCRN, SCAN, SMOSMANIA)
  - SYNOP T2m, RH2m
  - NWP evaluation scores against own analysis

L-band assimilation in ECMWF IFS

Soil Moisture evaluation

USCRN	N	RMSD	corr	An_corr	ubRMSD
OL	86	0.129	0.69	0.573	0.051
SLV	86	0.132	0.62	0.523	0.055
ASCAT	86	0.128	0.69	0.568	0.050
SMOS	86	0.124	0.70	0.581	0.051
ASCAT+ SMOS	86	0.125	0.69	0.570	0.051

SMOSMANIA	N	RMSD	corr	An_corr	ubRMSD
OL	10	0.071	0.794	0.664	0.048
SLV	10	0.071	0.737	0.639	0.049
ASCAT	10	0.073	0.800	0.671	0.048
SMOS	10	0.070	0.802	0.670	0.047
ASCAT+ SMOS	10	0.071	0.800	0.670	0.048



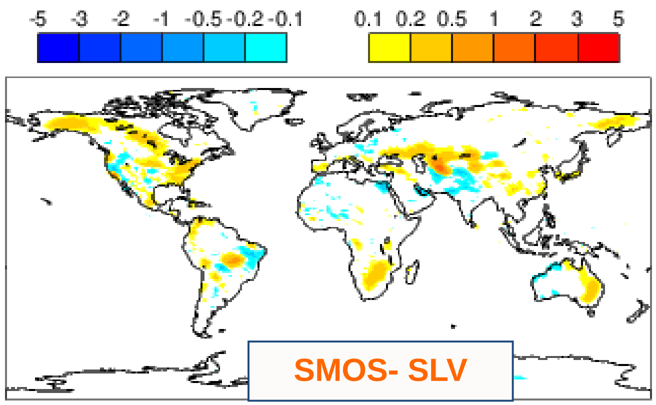
SMOS TB assimilation slightly (but not significantly) improve soil moisture

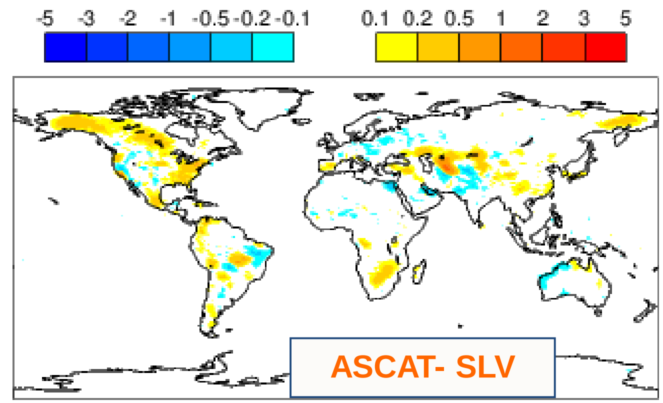
L-band assimilation in ECMWF IFS

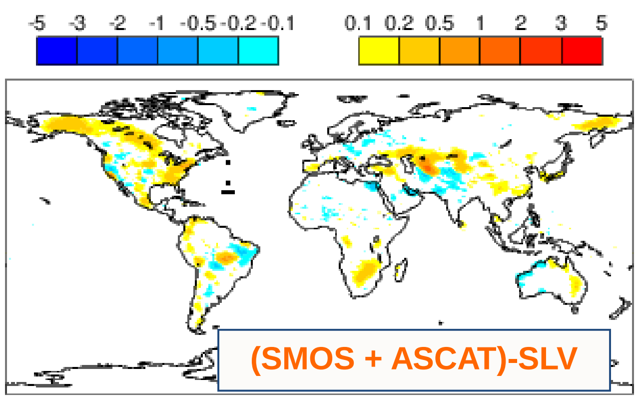
T2m 24h forecasts evaluation for MJJAS 2013

(Total of 306 10-day forecasts initialised at 00&12 UTC)

$\Delta_{error}T^{2m}$ Impact: Normalized change in rms of forecast error for T2m







- **Blue → mean abs error reduced**
- **Red → mean abs error increased**

Assimilation of only SMOS or ASCAT, or both degrade compared to SLV DA
→ We need SLV assimilation!

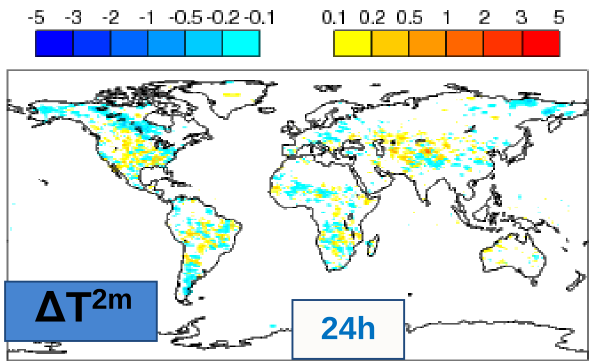
L-band assimilation in ECMWF IFS

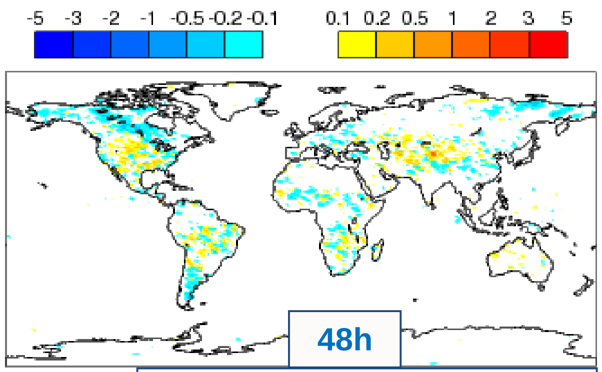
T2m forecasts evaluation for MJJAS 2013

(Total of 306 10-day forecasts initialised at 00&12 UTC)

T2m: ALL [SLV+ASCAT+SMOS] – SLV

Sensitivity:
Difference in T2m forecast

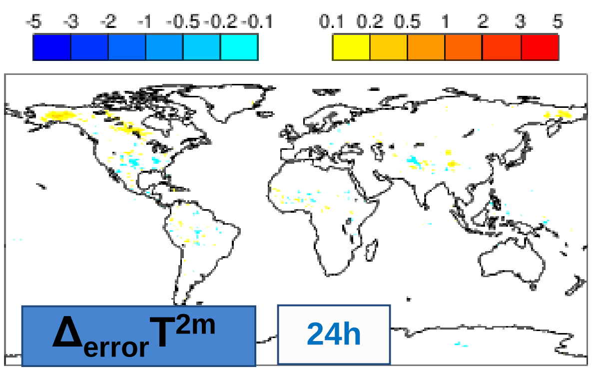


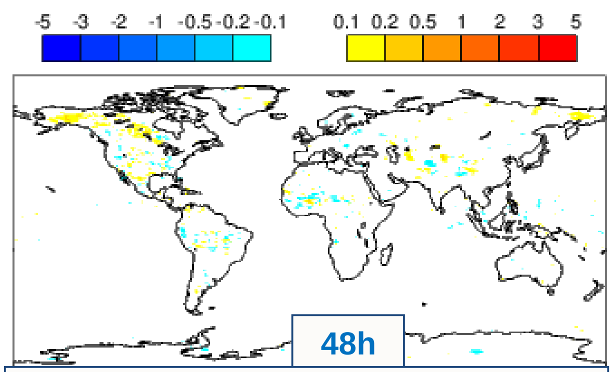


- Blue → air temp is colder
- Red → air temp is warmer

Neutral to slightly positive impact of adding SMOS and ASCAT on the top of SLV

Impact:
Normalized change in rms of forecast error for T2m



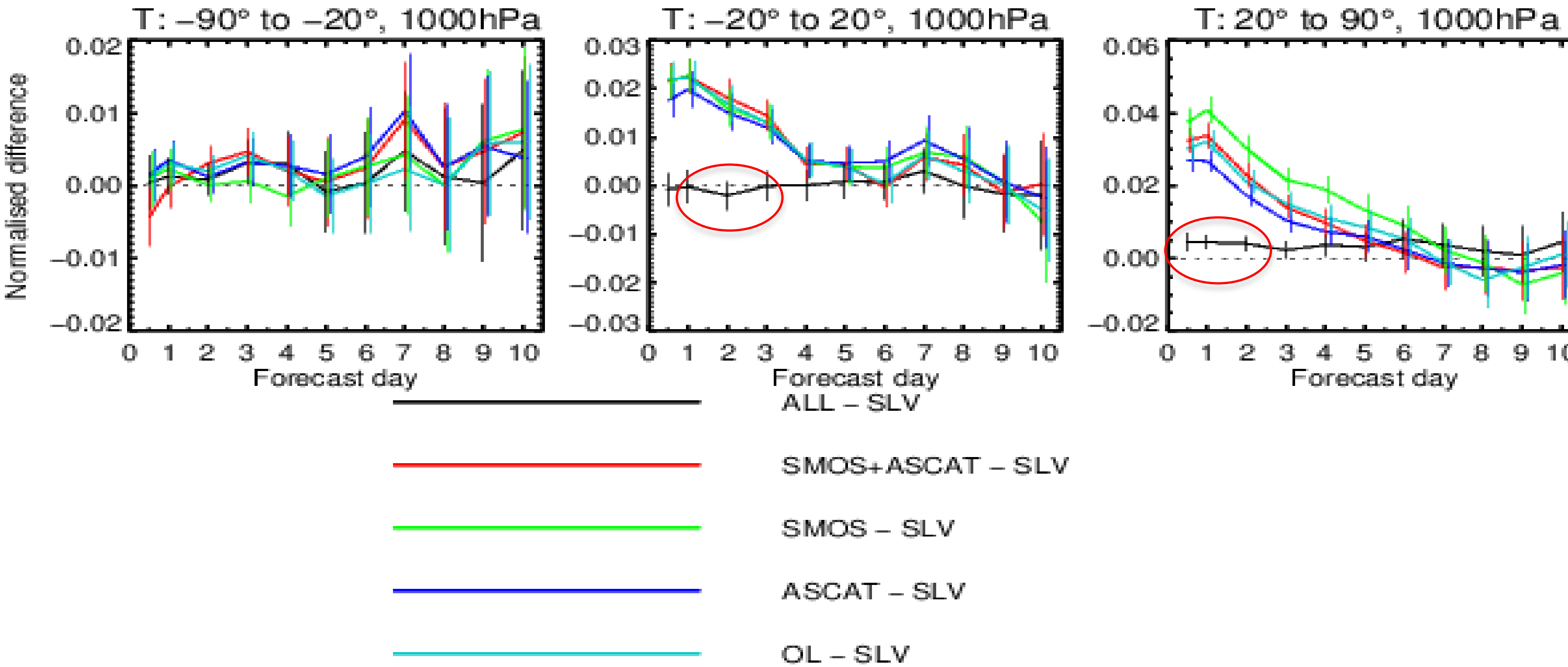


- Blue → mean abs error reduced
- Red → mean abs error increased

L-band assimilation in ECMWF IFS

Atmospheric forecasts evaluation for MJJAS 2013

Normalised difference in temperature RMSE



- Experiments not using SLV show degraded temperature forecasts
- Neutral - impact of SMOS and ASCAT

→ further model improvement required? (soil moisture/ evapotranspiration)

L-band forward modelling and bias correction

For assimilation and monitoring

- CMEM (Community Microwave Emission Modelling Platform) developed and maintained by ECMWF **(de Rosnay et al., JGR 2009)**
- Implemented in the IFS and used for L-band forward simulation in operations (**Munoz Sabater et al., ECMWF ESA reports 2009,2010,2016**)
- CDF-matching bias correction at monthly scale **(de Rosnay et al, SMOS conf 2015)**

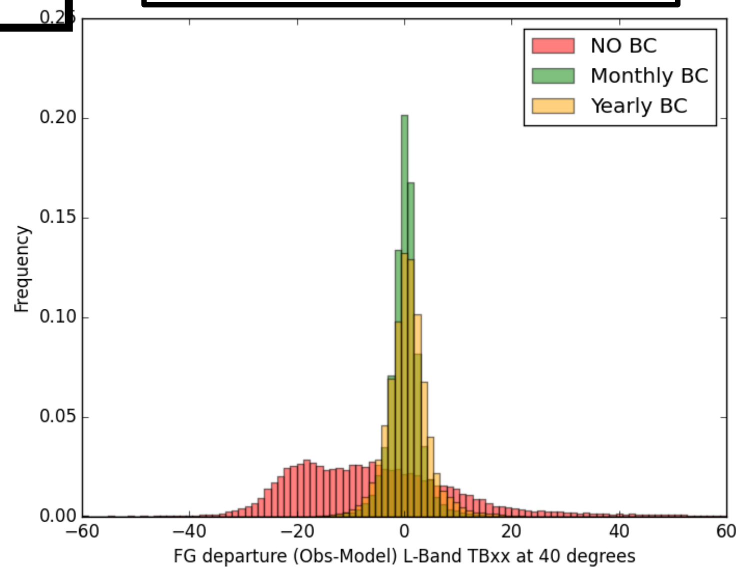
$$TB^*_{SMOS} = a + b\,TB_{SMOS}$$

with $a = \overline{TB}_{ECMWF} - \overline{TB}_{SMOS}\,(\sigma_{ECMWF}/\sigma_{SMOS})$

$b = \sigma_{ECMWF} / \sigma_{SMOS}$

Monthly CDF-matching based on multi year SMOS data
→ mean and variance are matched

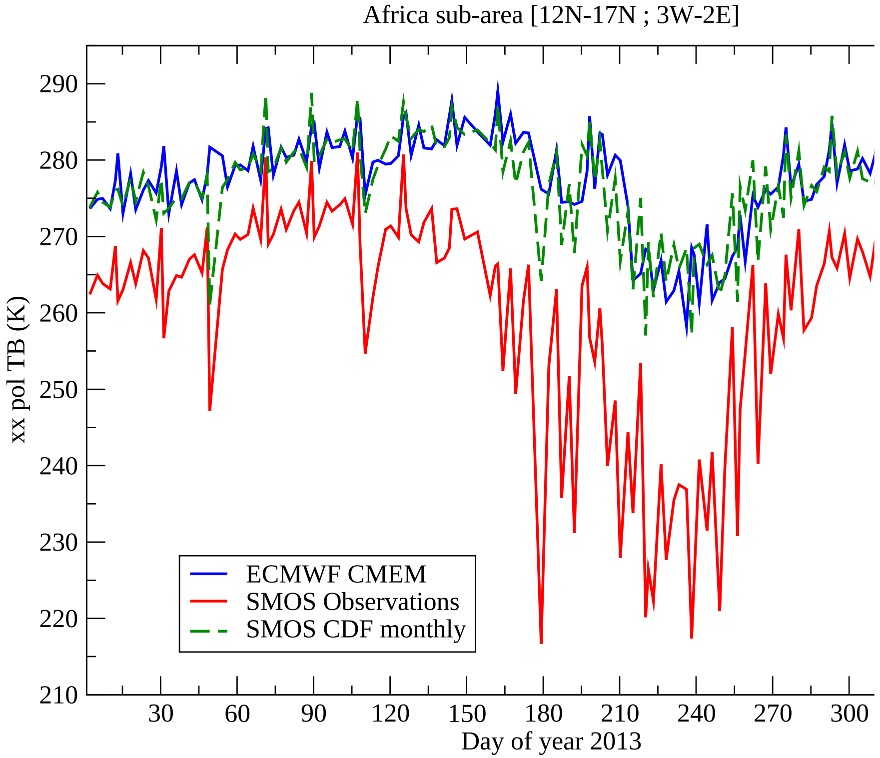
SMOS FG departure (O-F)
Jan 2013, XX pol 40 degrees

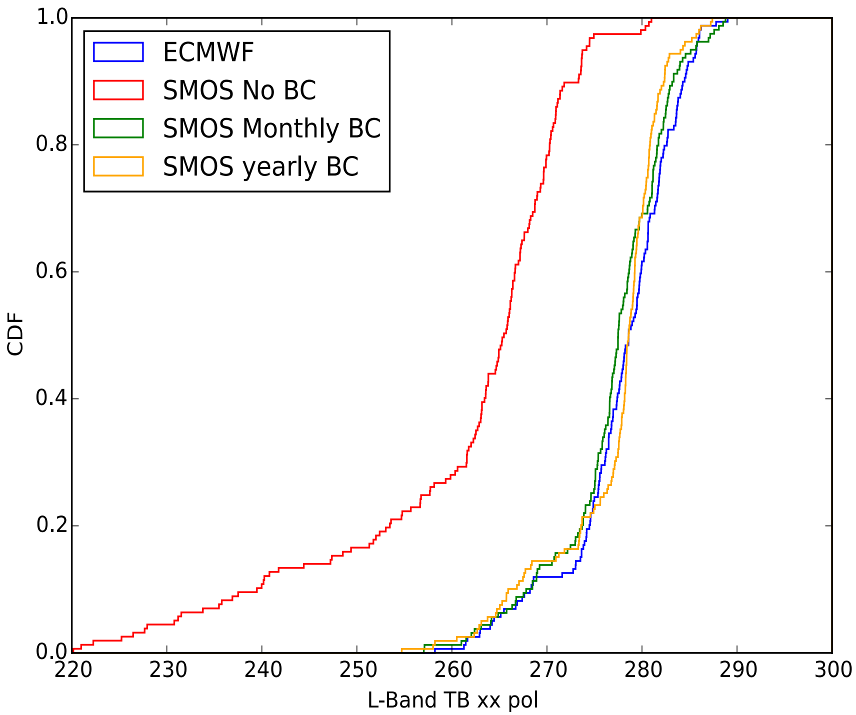


L-band forward modelling and bias correction

For assimilation and monitoring

SMOS and ECMWF TB (K) in West Africa (12N-17N ; 3W-2E)

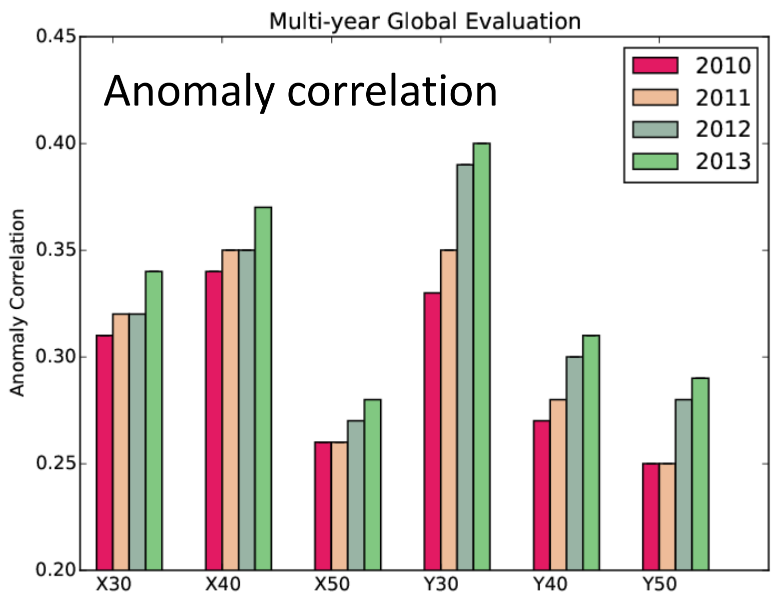




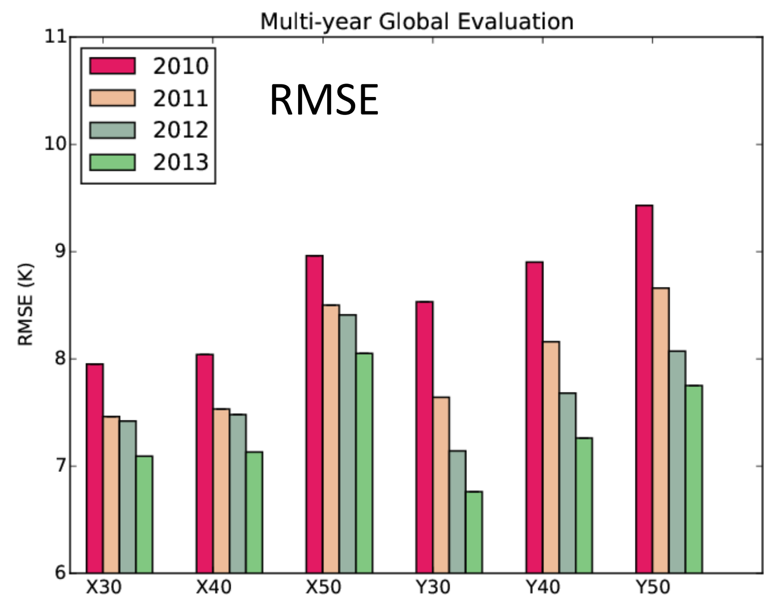
Monthly CDF-matching → mean and variance are matched
Event scale temporal dynamics of the observations remains

SMOS Forward modelling

- CMEM+ERA-Interim-Land → ECMWF SMOS TB for 2010-2013
- Comparison between ECMWF TB and SMOS NRT TB (both reprocessed)
- **Consistent improvement of SMOS data at Pol xx and yy, for incidence angles 30, 40, 50 degrees**



Polarisation (xx or yy) and incidence angle (30, 40, 50)



Polarisation (xx or yy) and incidence angle (30, 40, 50)

Satellite data monitoring for NWP

Active microwave data:
ASCAT MetOP-A (2006-), MetOP-B (2012-)
C-band (5.6GHz)
NRT Surface soil moisture

Operational product
→ operational continuity

Passive microwave data:
SMOS L-band (1.4 GHz)
NRT Brightness Temperature

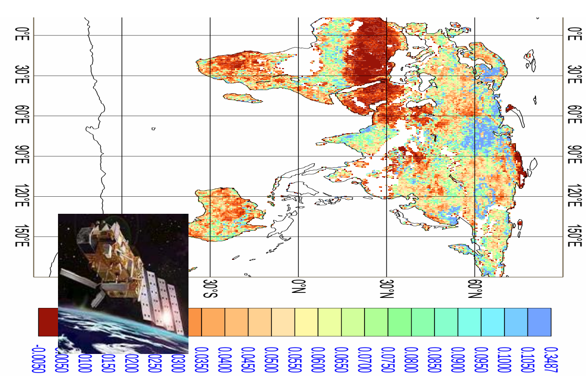
Dedicated soil moisture mission
Best sensitivity to soil moisture

Active and Passive:
SMAP

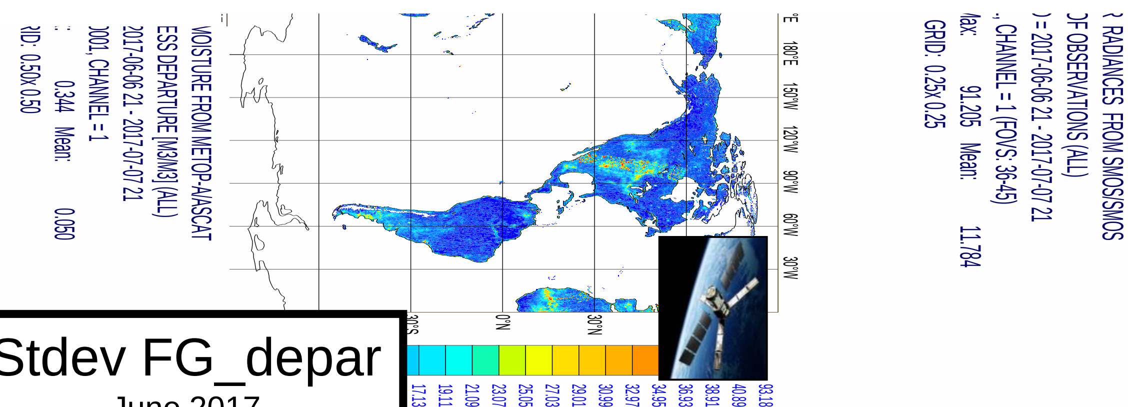
L-band TB, 2015
Dedicated
soil moisture
mission

Operational Monitoring of surface soil moisture satellite obs:

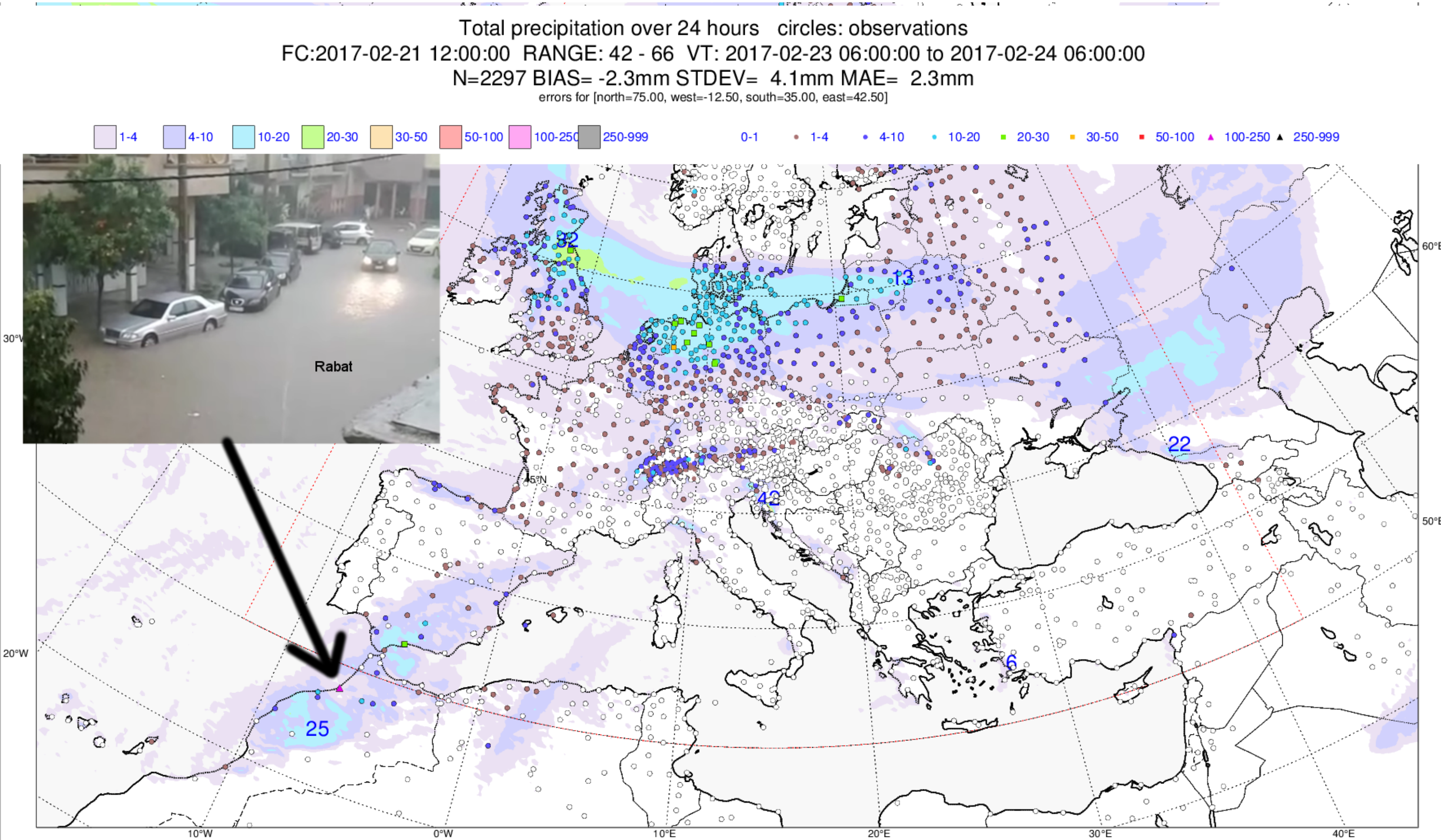
ASCAT/A soil moisture (m^3m^{-3}) 40º SMOS TB (K)



Stdev FG_depar
June 2017

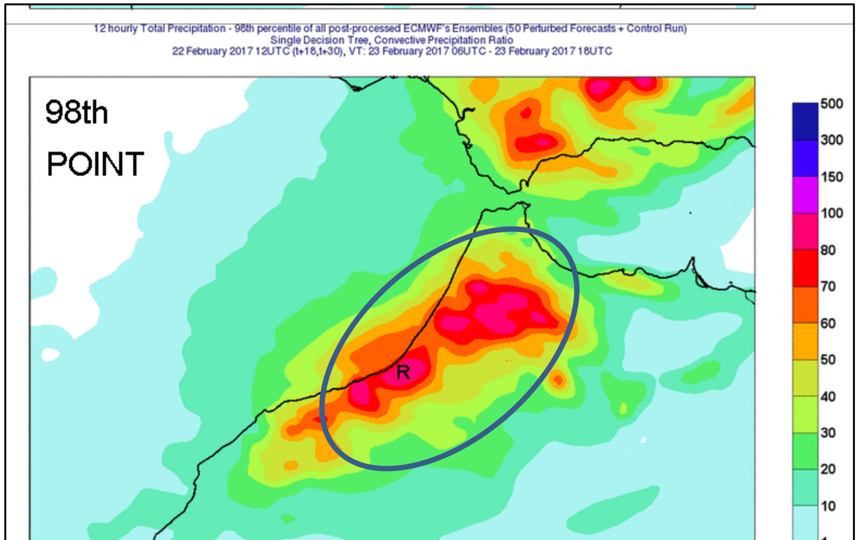


Flask flood in Morocco on 23 February 2017



Flask flood in Morocco on 23 February 2017

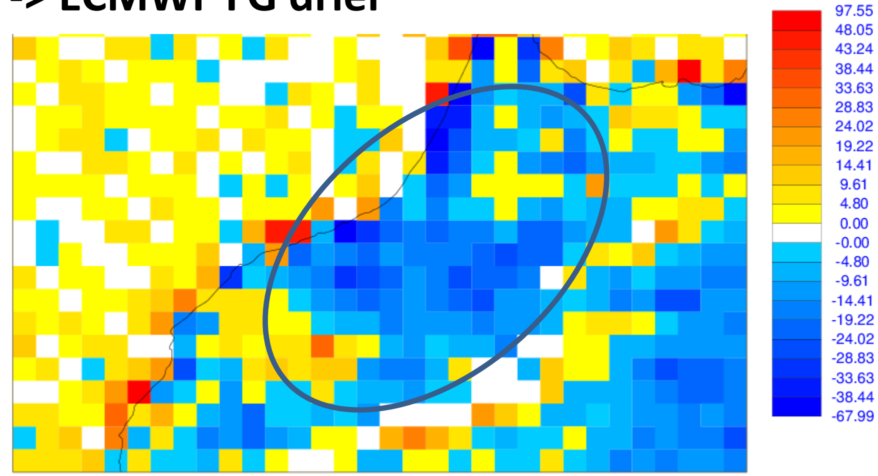
SMOS TBh (30degrees)
First Guess departure: Obs-Model (K)
23-28 Feb



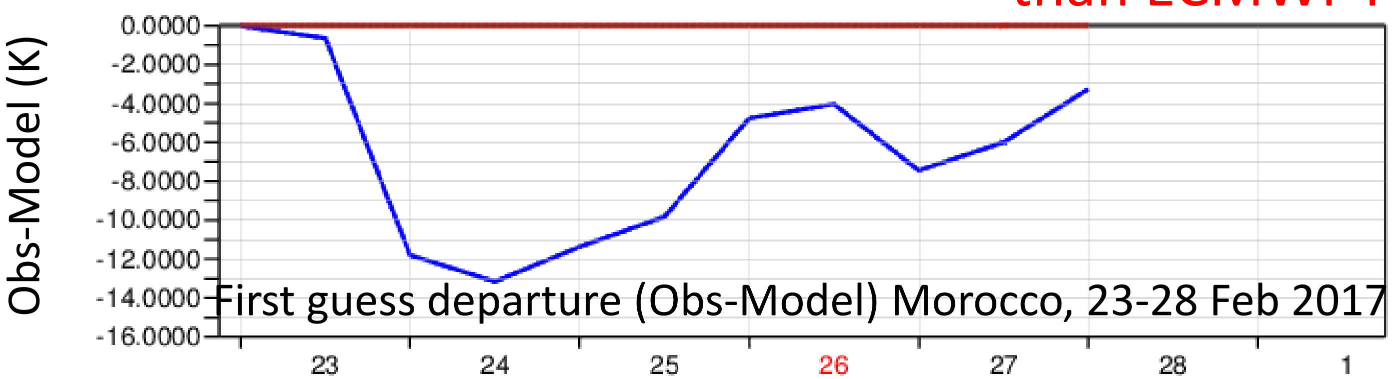
Precipitation on 23 February

SMOS colder/wetter than FG

-> ECMWF FG drier



→ Flood better captured by SMOS than ECMWF First guess



SMOS Neural Network Soil Moisture

Two (distinct) L-band NN activities conducted at ECMWF

1) NRT ESA SMOS Neural Network soil moisture
   NN trained on ESA's SMOS operational soil moisture
   (Rodriguez-Fernandez et al, HESS 2017)

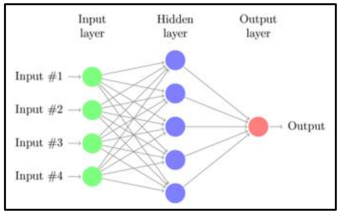
2) Data Assimilation experiments to use NN soil moisture
   Following idea of Aires et al 2005
   NN SM data set trainined on ECMWF soil moisture
   → No need for forward model, no bias correction
   (Rodriguez-Fernandez et al, ECMWF ESA Report, 2017)

Collaboration ECMWF, ESA, CESBIO, Observatoire de Paris

Data Assimilation of SMOS Neural Nework SM

- **SMOS Tbs, polarization H &V , angles 30º-45º**
- **Normalization with local extreme SM**

Best input data



Fixed NN weights

NN soil moisture
Trained on ECMWF SM
→ ready for DA

- **Off-line DA experiment with a priori processed SMOS NN SM**
- **For research purpose (training procedure not compatible with operational NWP)**

(Rodriguez-Fernandez et al, ECMWF ESA Report, 2017)

Data Assimilation of SMOS Neural Newtork SM

Experimental setup

(Rodriguez-Fernandez et al, ECMWF ESA Report, 2017)

- One year assimilation experiments in offline LDAS (forced by ERA-Interim)
- Sensitivity to observation errors → 13 experiments
  - Open Loop } **OL**
  - SMOS NN SM σ x1
  - SMOS NN SM σ x3
  - SMOS NN SM σ x9 } **SMOS**
  - SMOS NN SM σ x1 + T2m + RH2m
  - SMOS NN SM σ x3 + T2m + RH2m
  - SMOS NN SM σ x9 + T2m + RH2m } **SMOS + SLV**
  - ASCAT SM σ x1
  - ASCAT SM σ x2
  - ASCAT SM σ x4 } **ASCAT**
  - ASCAT SM σ x1 + T2m + RH2m
  - ASCAT SM σ x2 + T2m + RH2m
  - ASCAT SM σ x4 + T2m + RH2m } **ASCAT+ SLV**

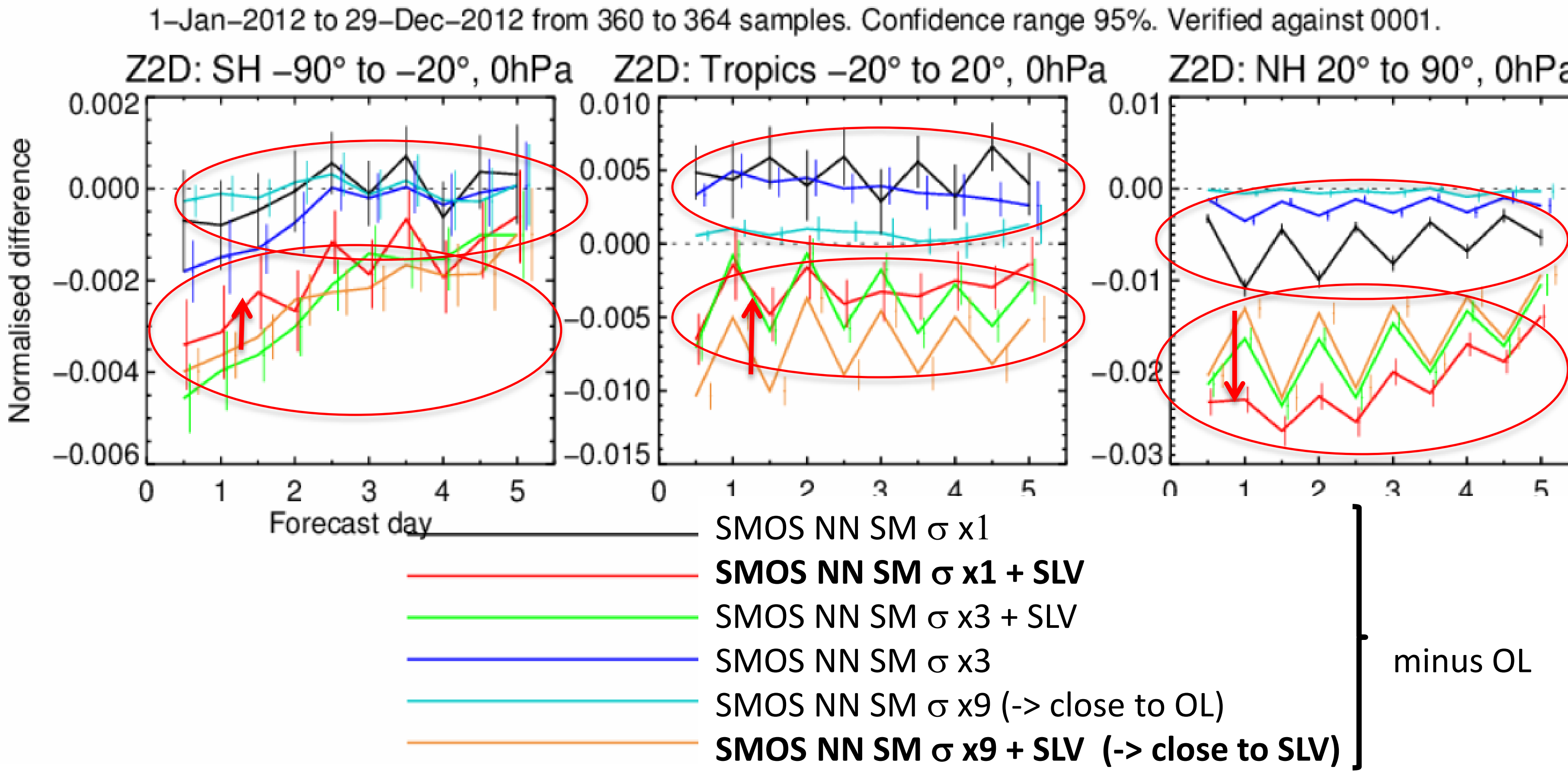
→ Different relative weights of observations with respect to the model were tested

- Set of atmospheric Forecasts for each analysis experiment

Data Assimilation of SMOS Neural Newtork SM

Forecasts verification 2012

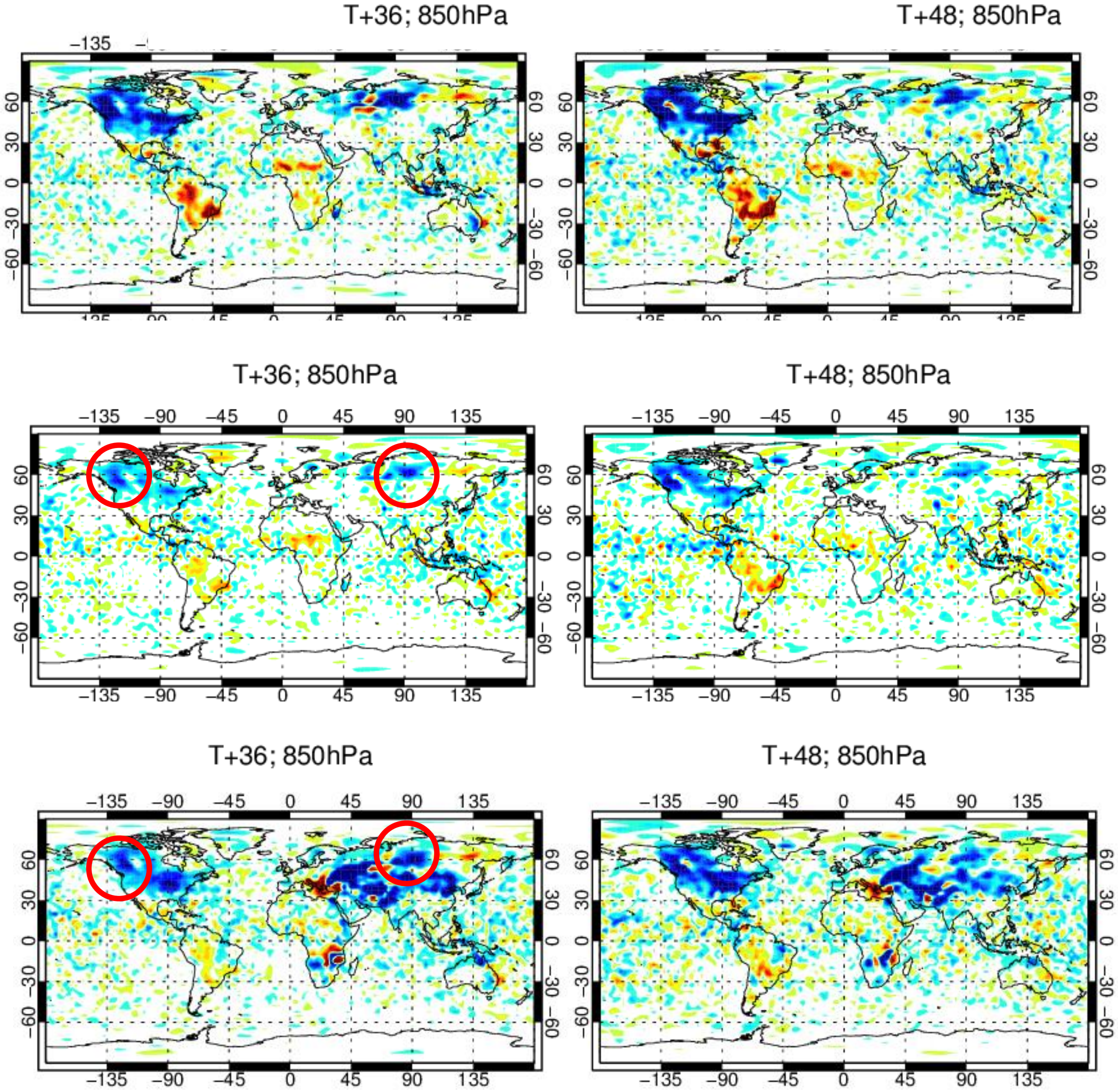
Dew point temperature
RMSE normalized difference with OL



- Consistent with previous coupled IFS results: we need SLV observations
- Positive impact of SMOS in NH, Negative/neutral in TR/SH

Data Assimilation of SMOS Neural Newtork SM

Forecasts verification 2012



<u>Impact:</u>
Normalized change in rms of forecast error for T2m

SMOS NN SM σ x1 vs OL

SMOS NN SM σ x3 vs OL

SMOS NN SM σ x3 +SLV vs OL

Summary

- L-band used for a large range of activities at ECMWF
- SMOS is implemented in the operational IFS and used for monitoring
- L-band at ECMWF:

- Forward modeling (CMEM)
- Bias correction (seasonal CDF matching)
- Operational NRT SMOS monitoring, value of L-band TB for extreme events
- SMOS TB assimilation
- SMOS NRT SM production for ESA
- SMOS ECMWF NN SM product assimilation (research)

- Both TB DA and SM NN DA lead to an overall neutral NWP impact.

- Monitoring emphasizes potential of L-band data in extreme conditions.

ECMWF

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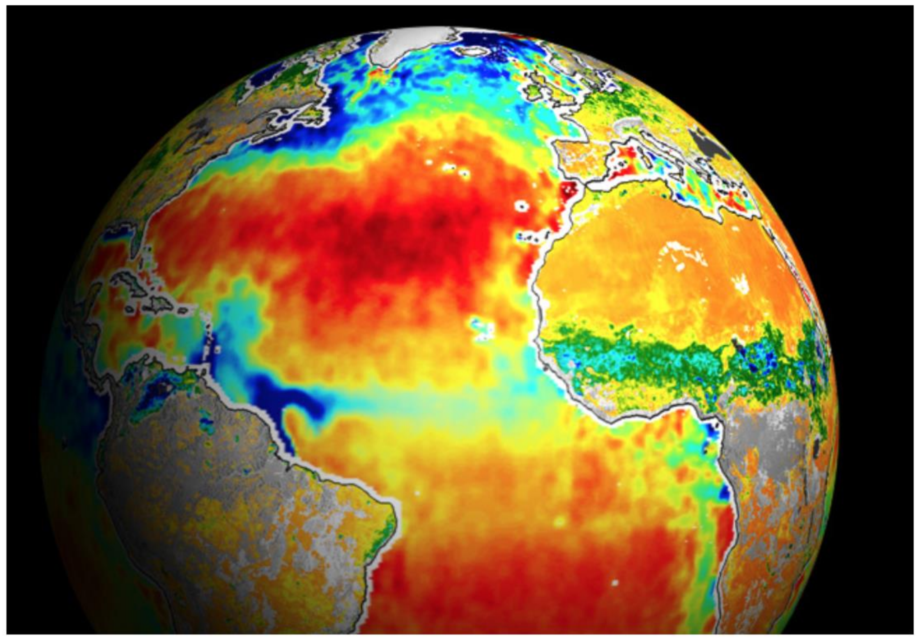
ECMWF | Reading | 4-6 December 2017



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Programme (to follow)

Local information

esa

https://www.ecmwf.int/en/learning/workshops/workshop-using-low-frequency-passive-microwave-measurements-research-and-operational-applications

More slides

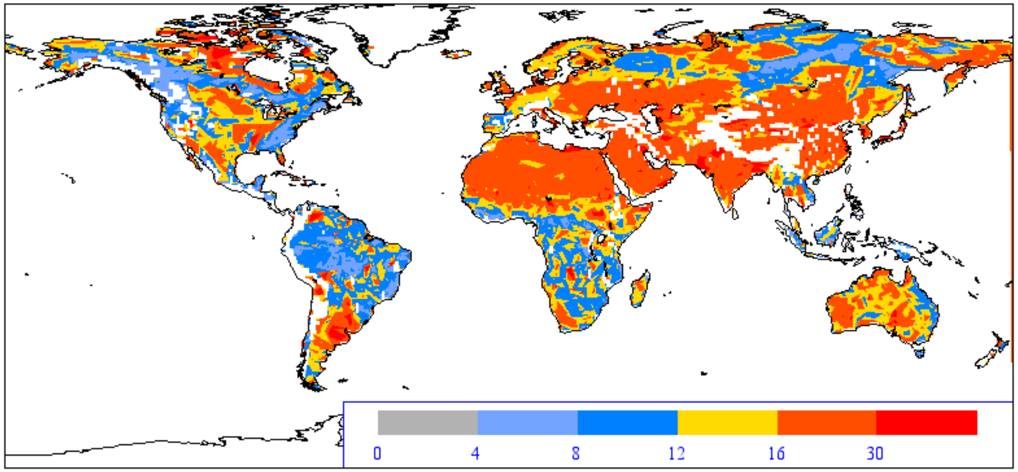
ECMWF L-band TB Bias correction

2012

Comparison between SMOS Obs and ECMWF Model

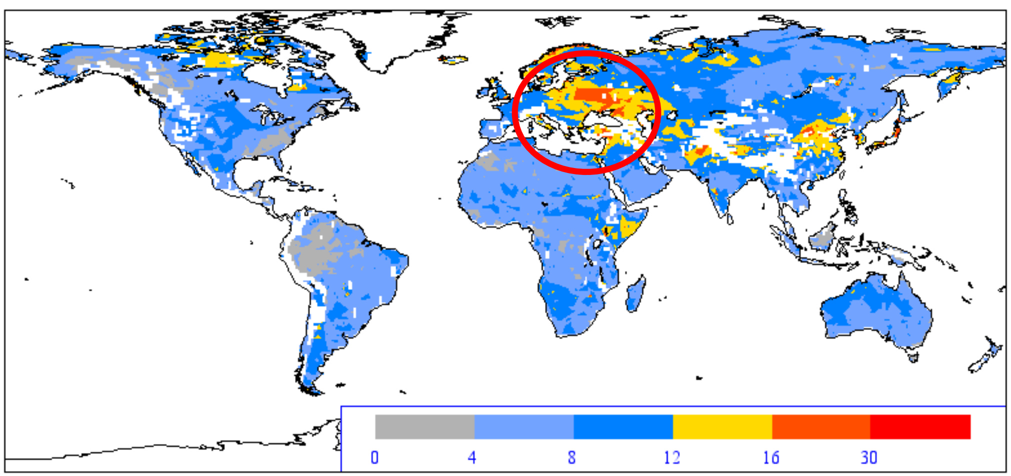
RMSD (K)

TBxx, 40 degrees



Before bias correction (17.7K)

e 40



After bias correction (7.5K)

Low residual RMSD, except in RFI affected areas
More info: CESBIO SMOS blog
http://www.cesbio.ups-tlse.fr/SMOS_blog/

Increments: ASCAT

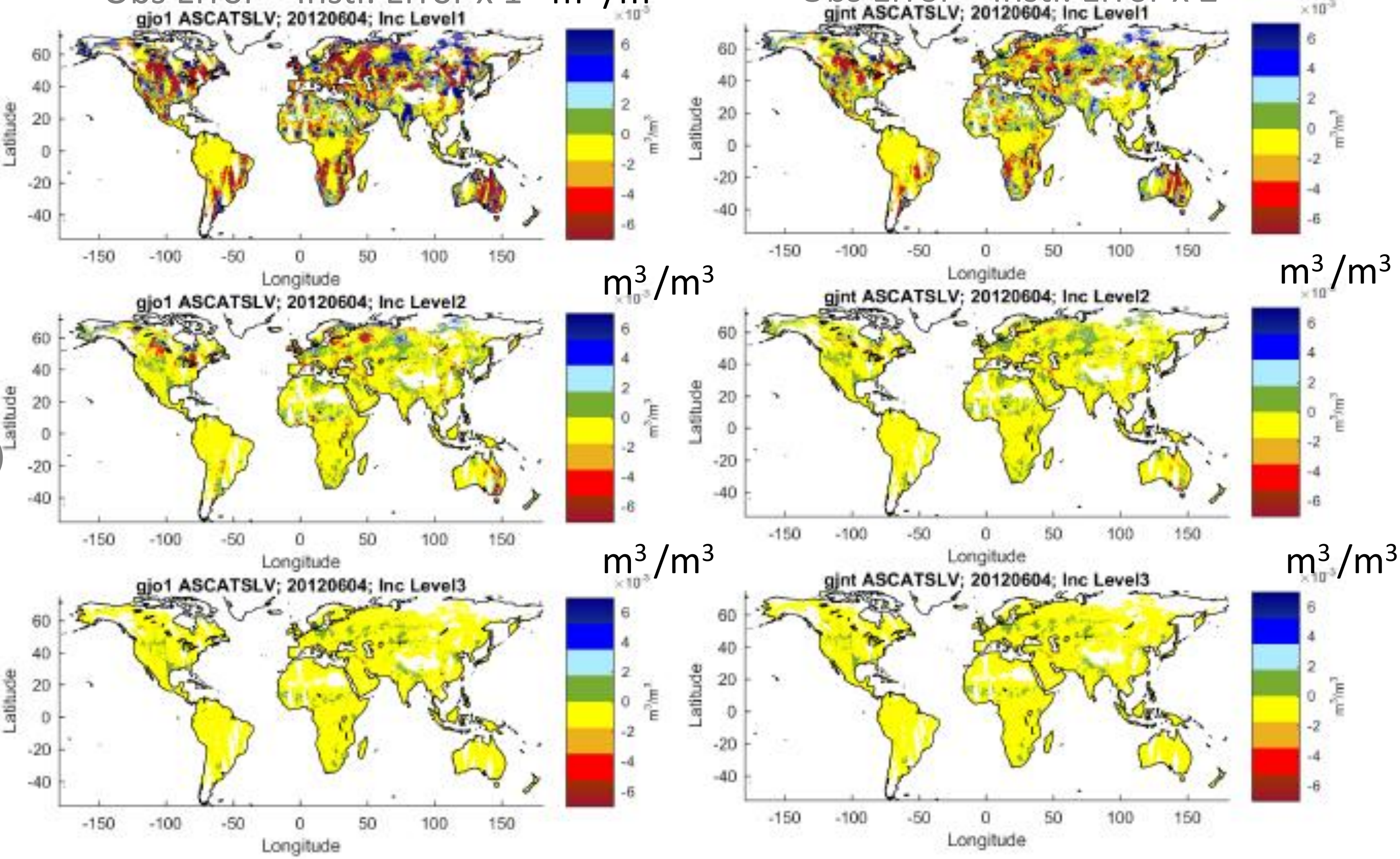
$$x_a - x_b = K\,(y_0 - \mathcal{H}[x_b])$$

Obs Error = Instr. Error x 1 | Obs Error = Instr. Error x 2

Layer 1 (0-7cm)

Layer 2 (7-28cm)

Layer 3 28-100cm



Increments: SMOS NN

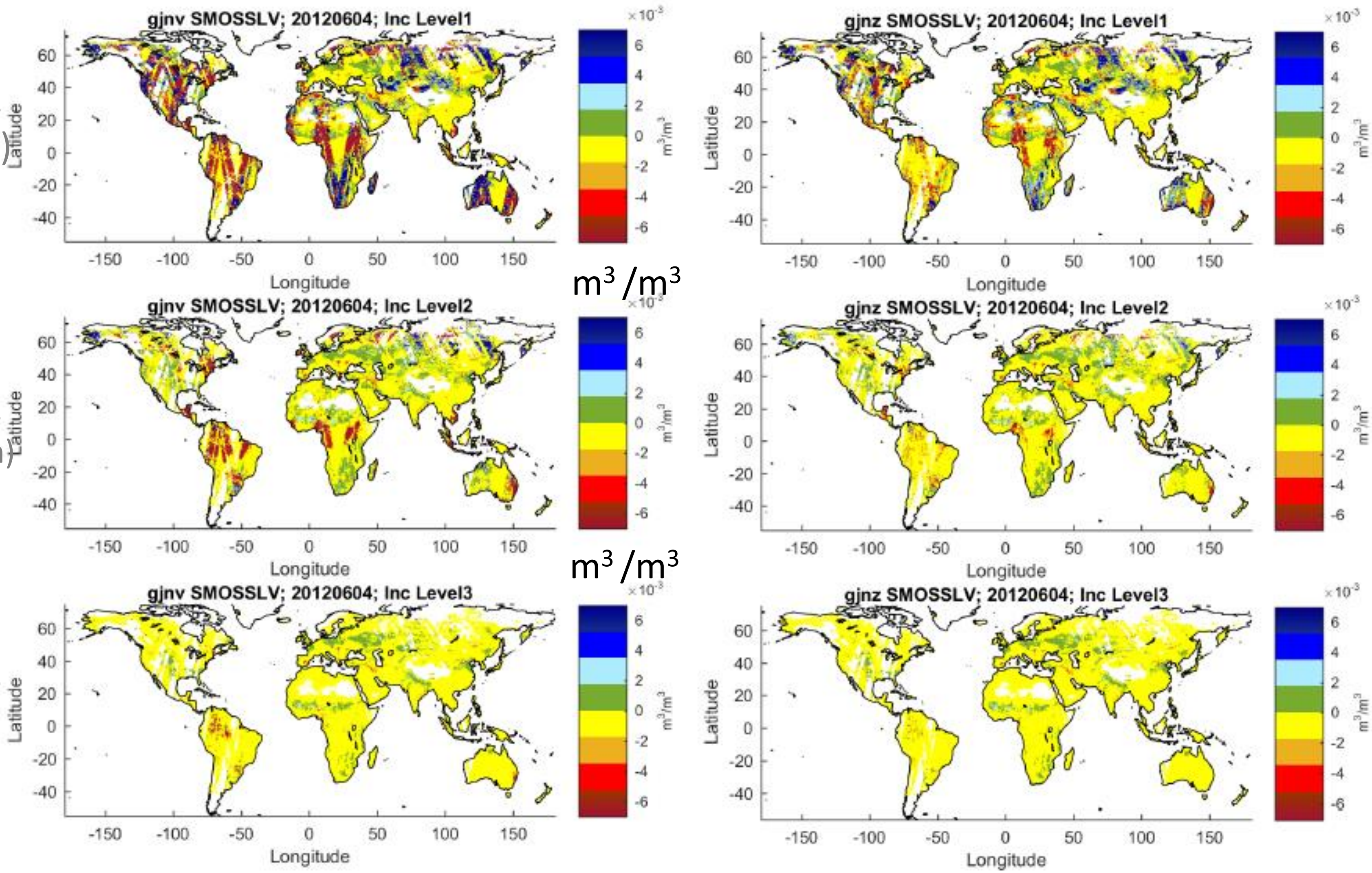
$x_a - x_b = K\,(y_0 - \mathcal{H}[x_b])$

Obs Error = Instr. Error x 1 m^3/m^3 | Obs Error = Instr. Error x 3

Layer 1 (0-7cm)

Layer 2 (7-28cm)

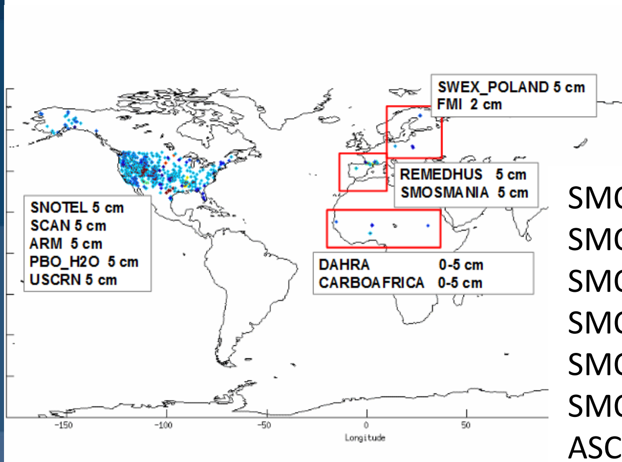
Layer 3 28-100cm



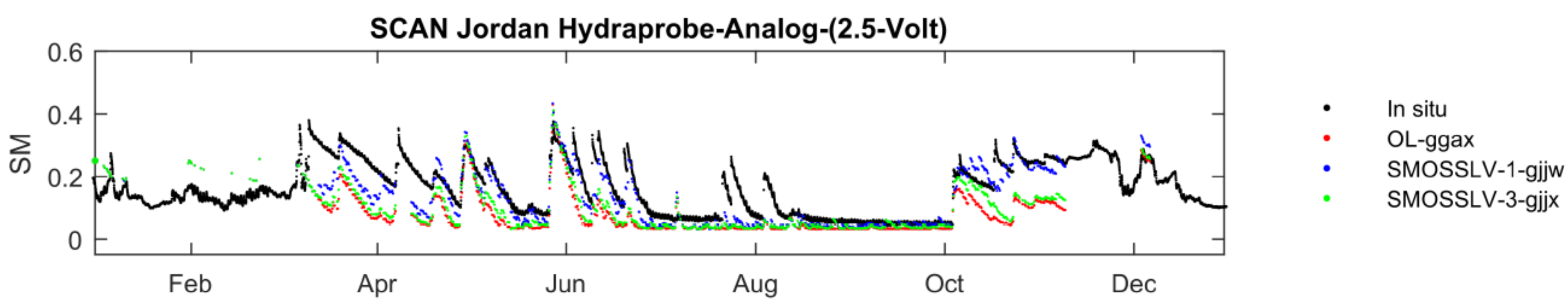
|Inc| < 0.1 m^3/m^3

Data Assimilation of SMOS Neural Newtork SM

Validation soil moisture



SM	Mean STD	Mean R	Mean Bias	Mean STD	Mean R	Mean Bias
	ARM Sensors= 31; Npt= 717			HOBE Sensors= 46; Npt= 687		
SMOS SM σ x1	0.058	0.64	0.040	0.037	0.68	-0.002
SMOS SM σ x3	0.061	0.63	0.034	0.038	0.71	-0.010
SMOS SM σ x9	0.064	0.61	0.030	0.039	0.71	-0.013
SMOS SM σ x1 + SLV	0.058	0.64	0.040	0.037	0.68	-0.002
SMOS SM σ x3 + SLV	0.060	0.63	0.035	0.038	0.71	-0.009
SMOS SM σ x9 + SLV	0.064	0.60	0.031	0.038	0.71	-0.012
ASCAT SM σ x1	0.064	0.63	0.029	0.043	0.67	-0.016
ASCAT SM σ x2	0.063	0.62	0.030	0.040	0.70	-0.015
ASCAT SM σ x4	0.064	0.61	0.029	0.039	0.71	-0.014
ASCAT SM σ x1 + SLV	0.063	0.62	0.031	0.043	0.66	-0.016
ASCAT SM σ x2 + SLV	0.063	0.61	0.031	0.040	0.70	-0.014
ASCAT SM σ x4 + SLV	0.064	0.60	0.031	0.039	0.71	-0.013
Open loop	0.065	0.60	0.029	0.039	0.71	-0.014

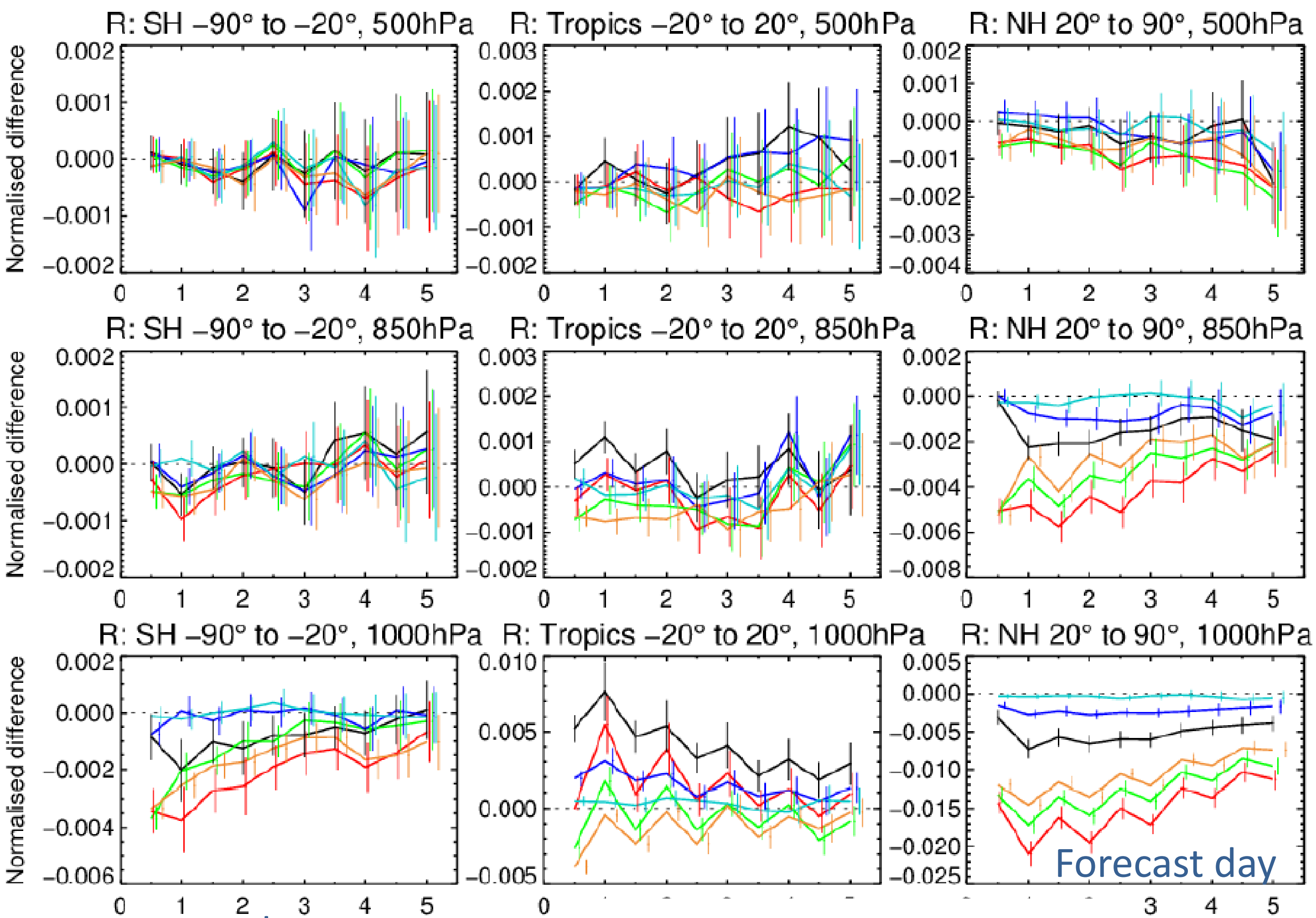


→ **neutral impact of SMOS and ASCAT DA on soil moisture depending on site**

SM	Mean STD	Mean R	Mean Bias	Mean STD	Mean R	Mean Bias	Mean STD	Mean R	Mean Bias
	ARM Sensors= 31; Npt= 717			HOBE Sensors= 46; Npt= 687			SCAN Sensors= 240; Npt= 816		
SMOS NN SM σ x1	0.058	0.64	0.040	0.037	0.68	-0.002	0.054	0.54	0.043
SMOS NN SM σ x3	0.061	0.63	0.034	0.038	0.71	-0.010	0.055	0.55	0.038
SMOS NN SM σ x9	0.064	0.61	0.030	0.039	0.71	-0.013	0.056	0.54	0.036
SMOS NN SM σ x1 + T2m + RH2m	0.058	0.64	0.040	0.037	0.68	-0.002	0.054	0.54	0.043
SMOS NN SM σ x3 + T2m + RH2m	0.060	0.63	0.035	0.038	0.71	-0.009	0.055	0.55	0.038
SMOS NN SM σ x9 + T2m + RH2m	0.064	0.60	0.031	0.038	0.71	-0.012	0.056	0.54	0.036
ASCAT SM σ x1	0.064	0.63	0.029	0.043	0.67	-0.016	0.056	0.54	0.032
ASCAT SM σ x2	0.063	0.62	0.030	0.040	0.70	-0.015	0.055	0.54	0.034
ASCAT SM σ x4	0.064	0.61	0.029	0.039	0.71	-0.014	0.056	0.54	0.035
ASCAT SM σ x1 + T2m + RH2m	0.063	0.62	0.031	0.043	0.66	-0.016	0.056	0.53	0.033
ASCAT SM σ x2 + T2m + RH2m	0.063	0.61	0.031	0.040	0.70	-0.014	0.055	0.54	0.035
ASCAT SM σ x4 + T2m + RH2m	0.064	0.60	0.031	0.039	0.71	-0.013	0.056	0.54	0.035
Open loop	0.065	0.60	0.029	0.039	0.71	-0.014	0.056	0.54	0.035
	CTP-SMTMN Sensors= 33; Npt= 365			HYDROL-NET-PERUGIA Sensors= 2; Npt= 719			SMOSMANIA Sensors= 19; Npt= 1009		
SMOS NN SM σ x1	0.048	0.53	0.114	0.057	0.79	0.078	0.053	0.79	0.066
SMOS NN SM σ x3	0.048	0.53	0.114	0.057	0.79	0.079	0.053	0.80	0.063
SMOS NN SM σ x9	0.048	0.53	0.114	0.057	0.79	0.079	0.054	0.80	0.062
SMOS NN SM σ x1 + T2m + RH2m	0.048	0.53	0.113	0.057	0.79	0.074	0.053	0.79	0.065
SMOS NN SM σ x3 + T2m + RH2m	0.048	0.53	0.113	0.057	0.79	0.075	0.053	0.80	0.062
SMOS NN SM σ x9 + T2m + RH2m	0.048	0.53	0.113	0.057	0.79	0.075	0.053	0.80	0.060
ASCAT SM σ x1	0.047	0.57	0.113	0.056	0.78	0.067	0.054	0.79	0.059
ASCAT SM σ x2	0.048	0.54	0.114	0.057	0.79	0.075	0.053	0.80	0.060
ASCAT SM σ x4	0.048	0.53	0.114	0.057	0.79	0.078	0.054	0.80	0.061
ASCAT SM σ x1 + T2m + RH2m	0.047	0.57	0.113	0.056	0.78	0.064	0.054	0.79	0.059
ASCAT SM σ x2 + T2m + RH2m	0.047	0.55	0.113	0.057	0.79	0.072	0.053	0.80	0.060
ASCAT SM σ x4 + T2m + RH2m	0.048	0.54	0.113	0.057	0.79	0.075	0.053	0.80	0.060
Open loop	0.048	0.53	0.114	0.057	0.79	0.079	0.054	0.80	0.062

Humidity (whole 2012)

rms



SMOS NN SM σ x1

SMOS NN SM σ x1 + T2m + RH2m

SMOS NN SM σ x3 + T2m + RH2m

SMOS NN SM σ x3

SMOS NN SM σ x9

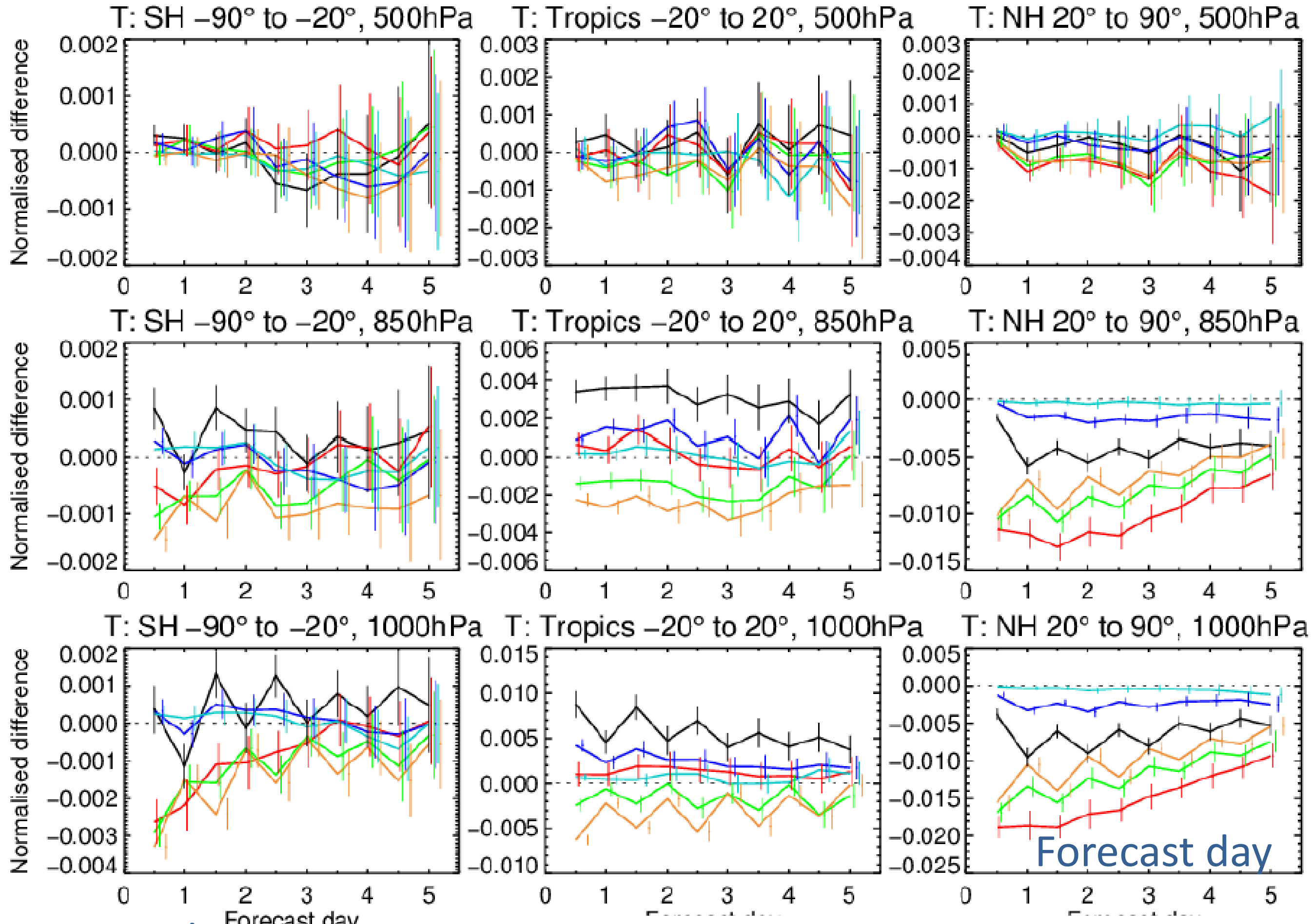
SMOS NN SM σ x9 + T2m + RH2m

Minus Open Loop

ECMWF EUROPE

Temperature (whole 2012)

rms

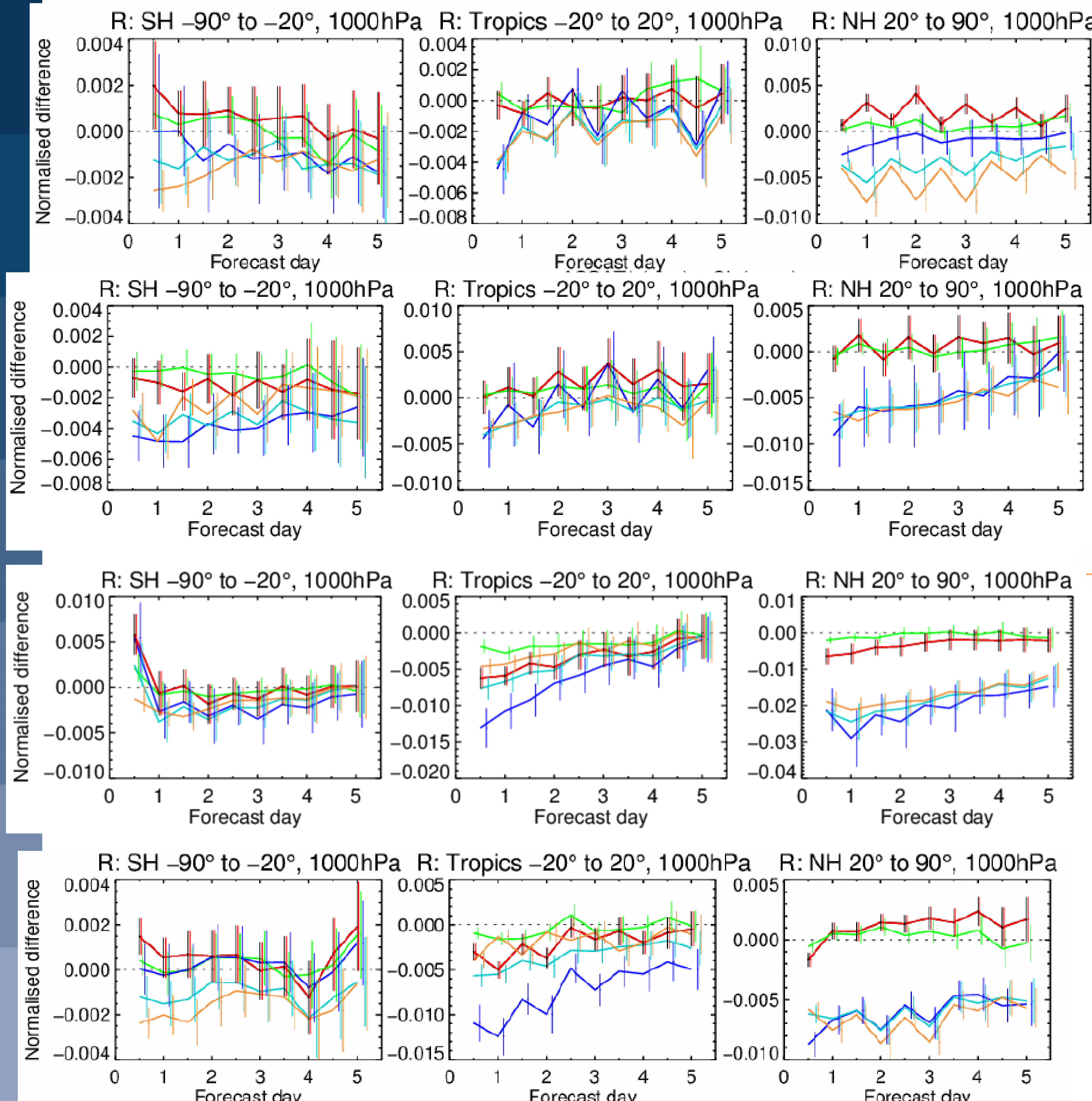


SMOS NN SM σ x1
SMOS NN SM σ x1 + T2m + RH2m
SMOS NN SM σ x3 + T2m + RH2m
SMOS NN SM σ x3
SMOS NN SM σ x9
SMOS NN SM σ x9 + T2m + RH2m

Minus Open Loop

EC

Humidity
(3 months periods)



Jan-- Mars

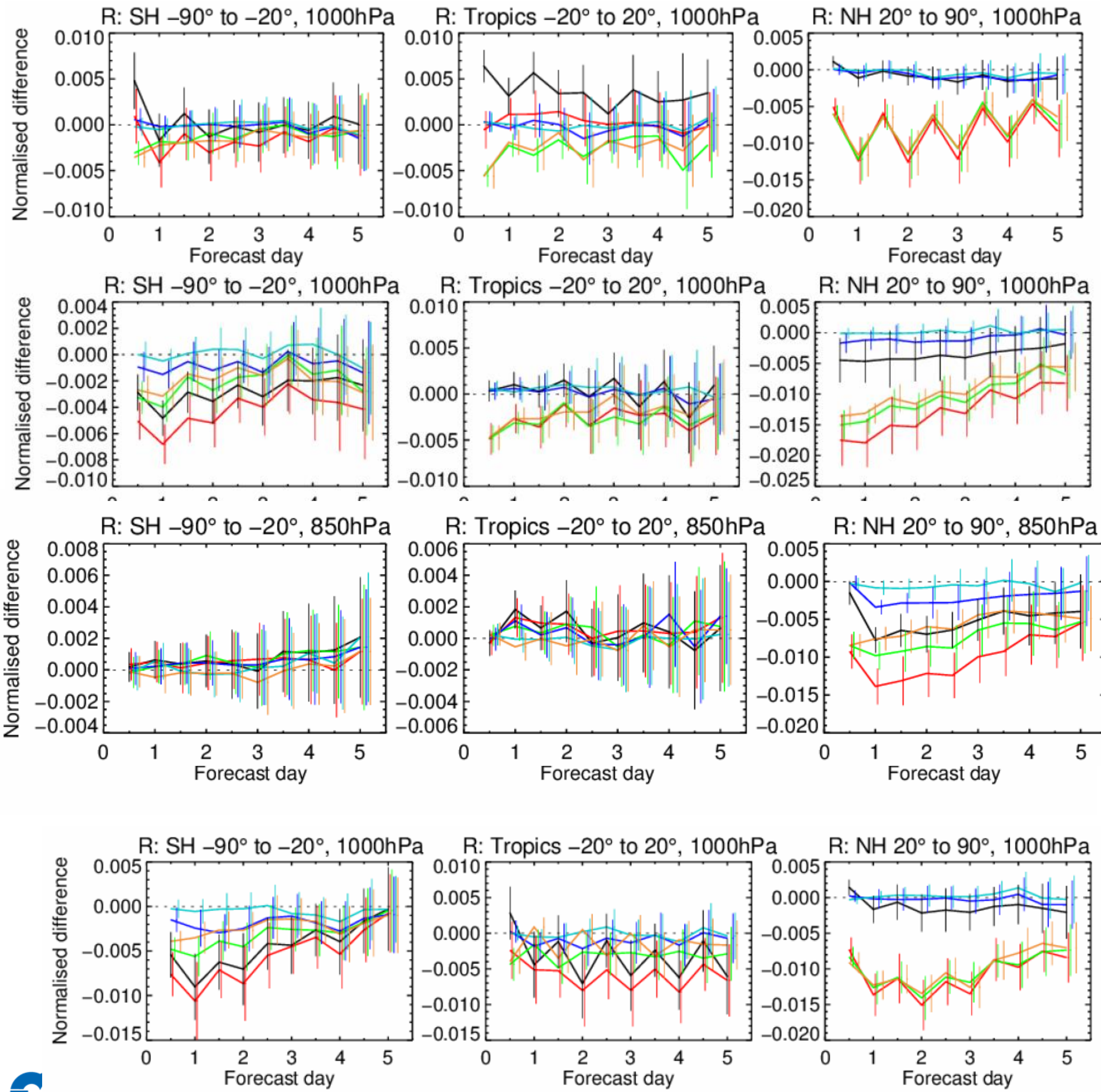
April-June

July-September

October-December

—	ASCAT SM σ x1
—	ASCAT SM σ x2
—	ASCAT SM σ x4
—	ASCAT SM σ x1 + T2m + RH2m
—	ASCAT SM σ x2 + T2m + RH2m
—	ASCAT SM σ x4 + T2m + RH2m

Humidity
(3 months periods)

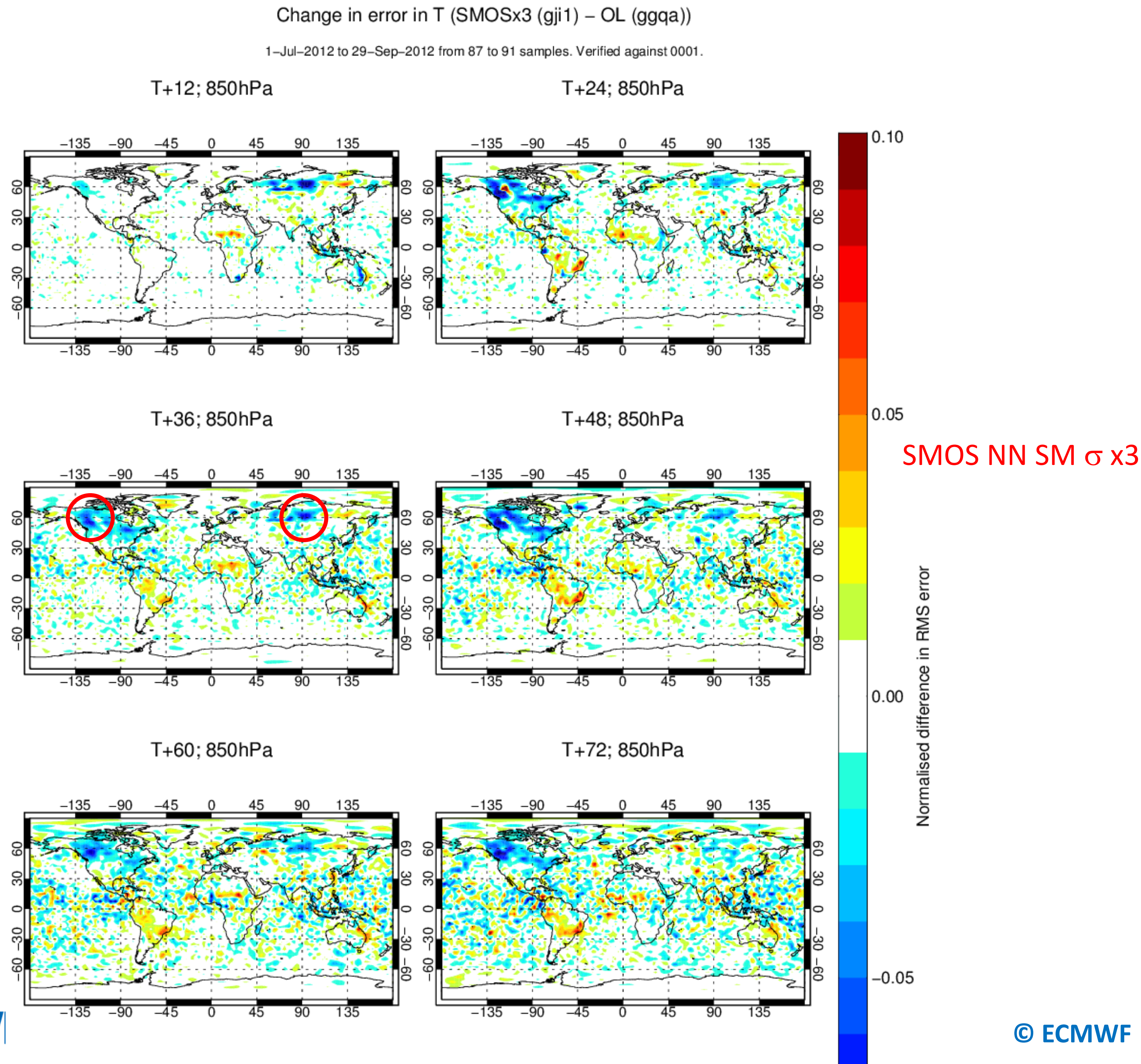


Jan-- Mars

April-June

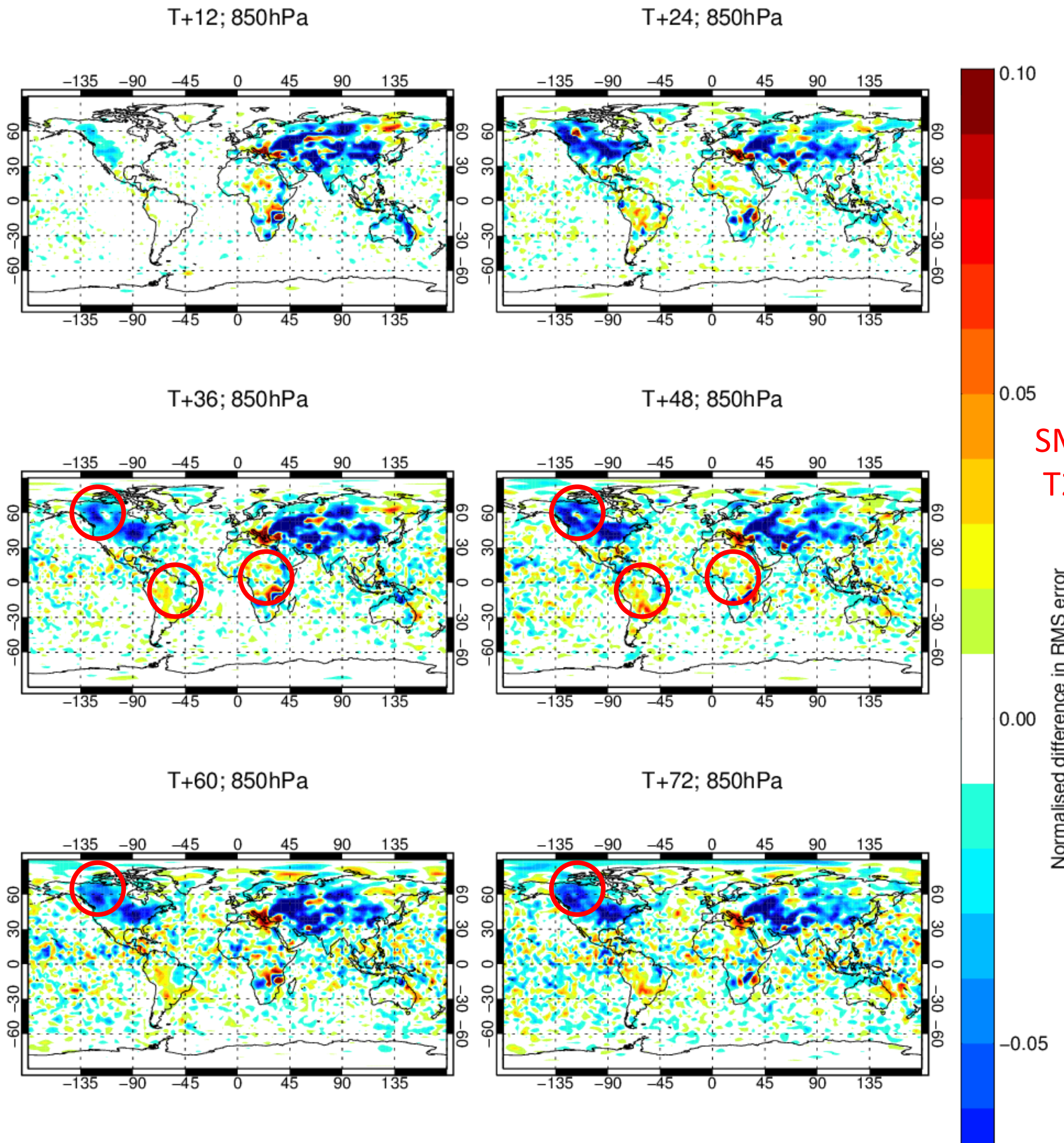
July-September

October-December


Change in error in T (SMOSx3 (gji1) – OL (ggqa))
1–Jul–2012 to 29–Sep–2012 from 87 to 91 samples. Verified against 0001.
T+12; 850hPa
T+24; 850hPa
T+36; 850hPa
T+48; 850hPa
T+60; 850hPa
T+72; 850hPa
0.10
0.05
0.00
–0.05
Normalised difference in RMS error
SMOS NN SM σ x3

Change in error in T (SMOSx3 SLV (gji2) – OL (ggqa))

1–Jul–2012 to 29–Sep–2012 from 87 to 91 samples. Verified against 0001.

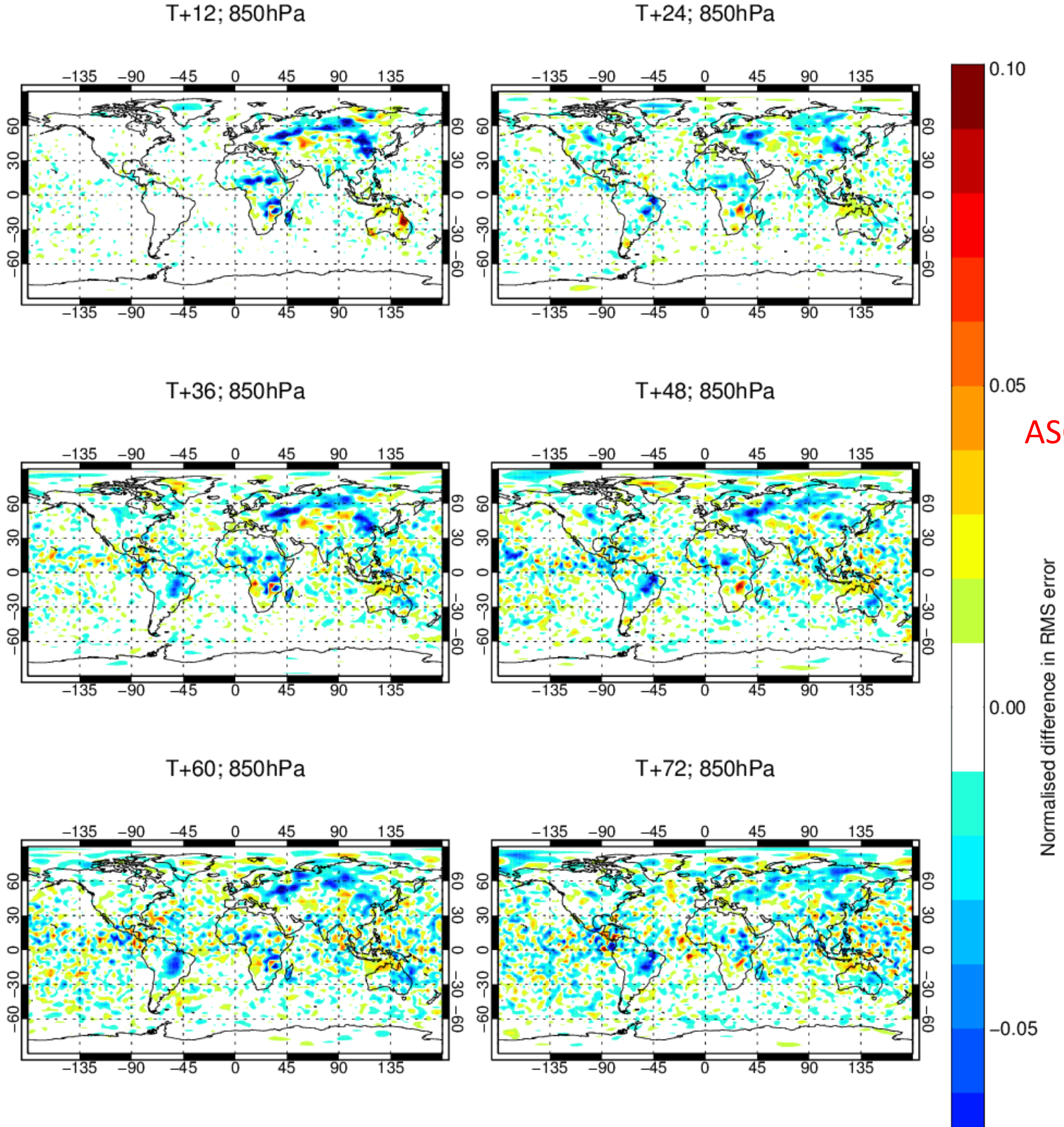


SMOS NN SM σ x3

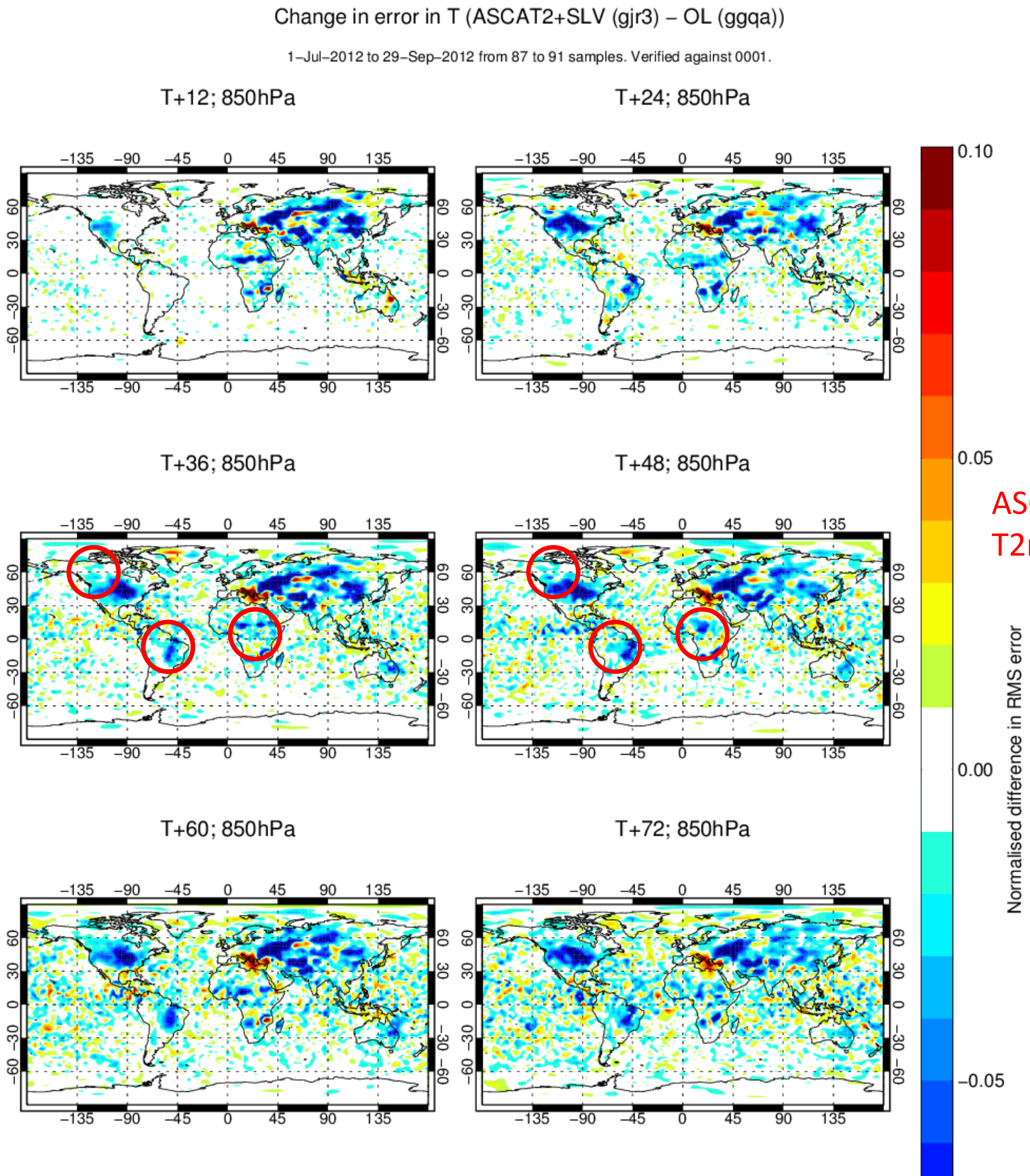
T2m + RH2m

Change in error in T (ASCAT2 (gjqw) – OL (ggqa))

1–Jul–2012 to 29–Sep–2012 from 87 to 91 samples. Verified against 0001.



ASCAT SM σ x2



ASCAT SM σ x2
T2m + RH2m