Towards an optimised use of SMOS data in the ECMWF Land Data Assimilation System

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Objectives at ECMWF (I): Monitoring

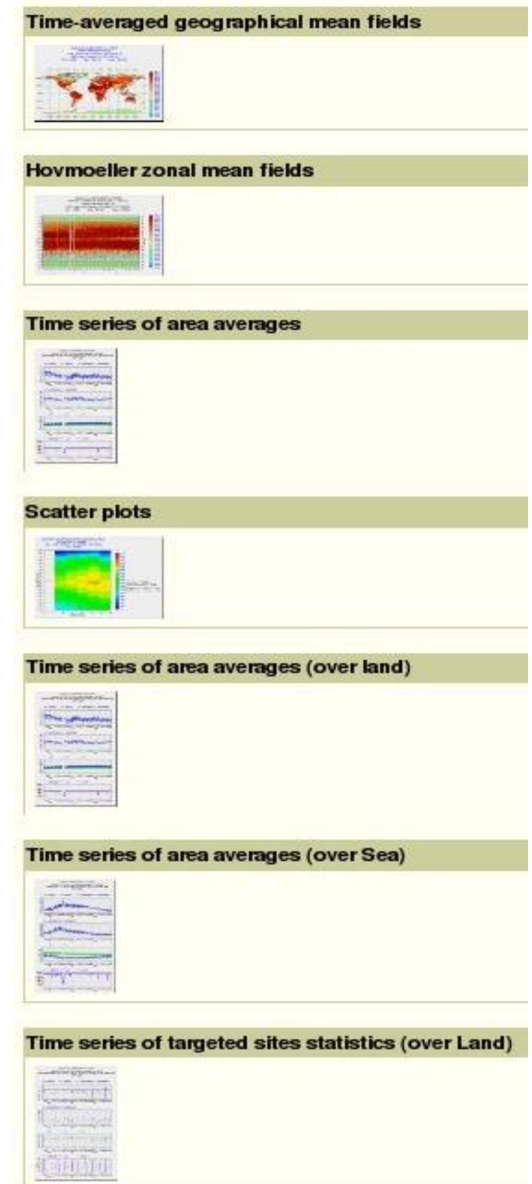
➢ **Routinely production of statistics with SMOS T_B, model equivalents and background departures, <u>in NRT</u>**

- Global scale
- Land and oceans separately,
- Several incidence angles [**10, 20, 30, 40, 50, 60**],
- Two polarisations states [**XX, YY**],
- Independently per continents and hemispheres,

➢ **Statistical products,**

- Time-averaged geographical mean-fields (last 6 weeks of data),
- Hovmöller zonal mean fields (last 3 months),
- Time series of area averages (last 3 months),
- Angular distribution of bias: background departures as function of incidence angle (last 5 weeks).

➢ **Support to CAL/VAL sites →** time series produced for 17 sites

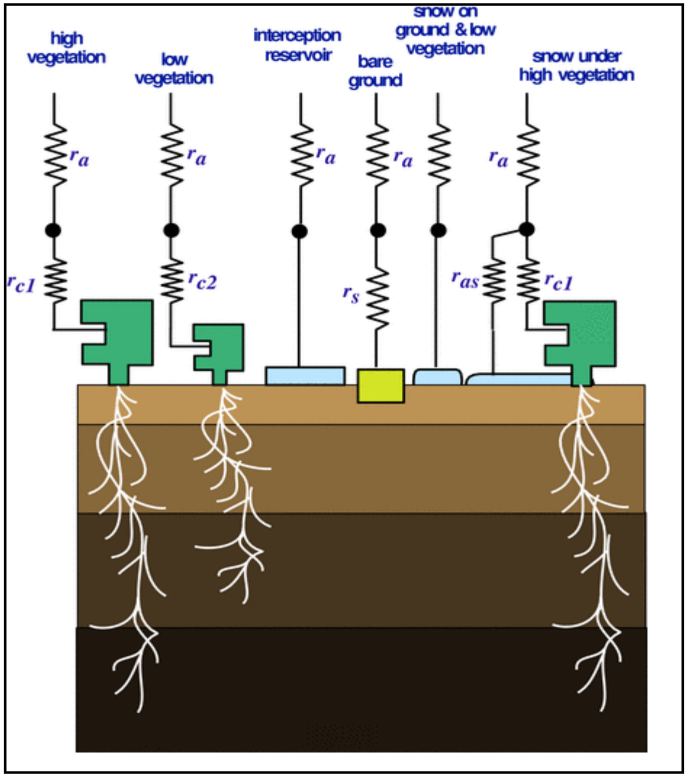


564 images are produced and updated daily → important contribution to the SMOS quality control

[http://old.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/smos/]

Objectives at ECMWF (II): Assimilation

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



LSM : HTESSEL
0-7cm, 7-28cm, 28-100cm, 100-289cm

Simplified Extended Kalman Filter:

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

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

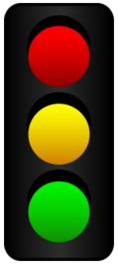
$\boldsymbol{x}_b$: background state vector,
$\boldsymbol{y}$: observation vector
$\mathcal{H}$: non linear observation operator
K : Kalman gain matrix: $\mathbf{K} = [\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}]^{-1}\mathbf{H}^T\mathbf{R}^{-1}$

Observations:

- Screen level variables: T^{2m}, RH^{2m}
- Remote sensing data:
  - ASCAT soil water index (METOP-A, METOP-B),
  - SMOS Brightness temperatures

Summer validation (JJA) ; top layer (0-7 cm)

- **SLV:** assimilation of T^{2m}, RH^{2m}
- **SMOS:** assimilation of only SMOS T_B CDF corrected
- **SMOS+SLV:** assimilation of T^{2m}, RH^{2m} and SMOS T_B CDF
- Validation undertaken over significant stations (p-value<0.05) in 8 countries



→ The worst among the 3 expt.

→ Neither the best nor the worse

→ The best among the 3 expt.

	SLV			SMOS			SMOS + SLV			
Network	Bias	RMSD	R	Bias	RMSD	R	Bias	RMSD	R	N
SMOSMANIA	-0.017	0.067	0.77	-0.043	0.085	0.71	-0.015	0.064	0.78	9
TWENTE	0.024	0.097	0.77	-0.013	0.099	0.71	0.005	0.095	0.76	18
SCAN	-0.088	0.137	0.55	-0.076	0.132	0.55	-0.082	0.135	0.57	98
USCRN	-0.079	0.115	0.67	-0.072	0.116	0.64	-0.074	0.115	0.69	61
MAQU	0.027	0.067	0.75	0.064	0.089	0.79	0.026	0.067	0.74	16
SWATMEX	-0.080	0.095	0.80	-0.126	0.138	0.74	-0.082	0.098	0.79	8
VAS	-0.082	0.105	0.48	-0.072	0.079	0.53	-0.085	0.099	0.59	1
OZNET	-0.104	0.122	0.69	-0.098	0.118	0.72	-0.104	0.122	0.71	30
REMEDHUS	-0.065	0.093	0.57	-0.058	0.080	0.73	-0.068	0.092	0.61	17
UMBRIA	-0.153	0.159	0.65	-0.207	0.210	0.47	-0.153	0.159	0.67	2
HOBE	-0.052	0.076	0.70	-0.031	0.066	0.57	-0.033	0.067	0.69	30

Bias (m^3m^{-3}); RMSD (m^3m^{-3})

Summer validation (JJA) ; root-zone (0-100 cm)

- **SLV:** assimilation of T^{2m}, RH^{2m}
- **SMOS**: assimilation of only SMOS T_B CDF corrected
- **SMOS+SLV**: assimilation of T^{2m}, RH^{2m} and SMOS T_B CDF corrected

- ➢ Validation undertaken over 77 (SCAN) and 50 (USCRN) stations (p-value<0.05)
- ➢ Observations are averaged over 5, 10, 20, 50 cm (and 100 cm also for USCRN)
- ➢ Model SM is averaged over the three layers (7, 28, 100 cm)

SLV

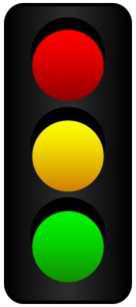
Network	Bias (m^3m^{-3})	RMSD (m^3m^{-3})	R	N
SCAN	-0.041	0.113	0.72	77
USCRN	-0.072	0.111	0.66	50

SMOS

Network	Bias (m^3m^{-3})	RMSD (m^3m^{-3})	R	N
SCAN	-0.027	0.119	0.72	77
USCRN	-0.064	0.106	0.70	50

SMOS + SLV

Network	Bias (m^3m^{-3})	RMSD (m^3m^{-3})	R	N
SCAN	-0.040	0.115	0.73	77
USCRN	-0.066	0.109	0.69	50



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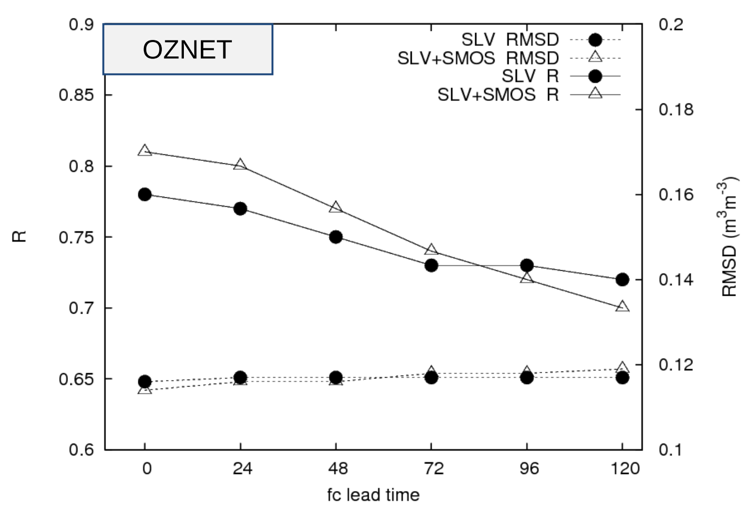
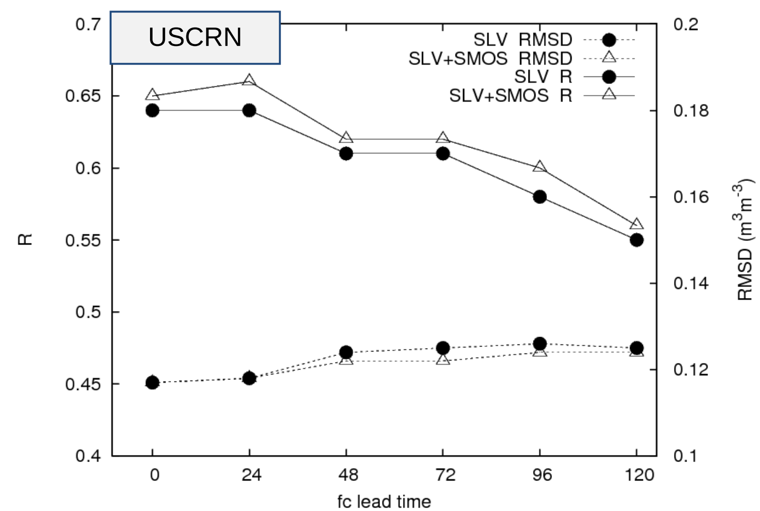
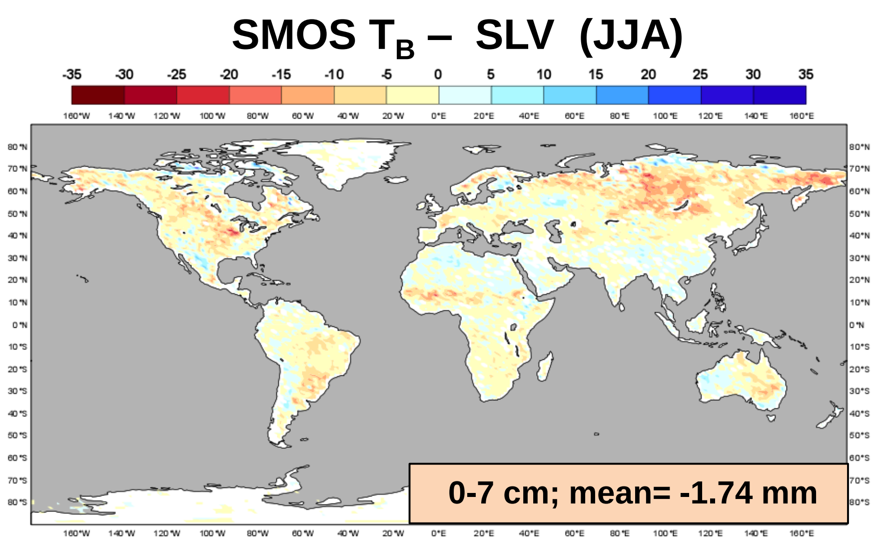
FORECASTS

SMOS DA impact experiments



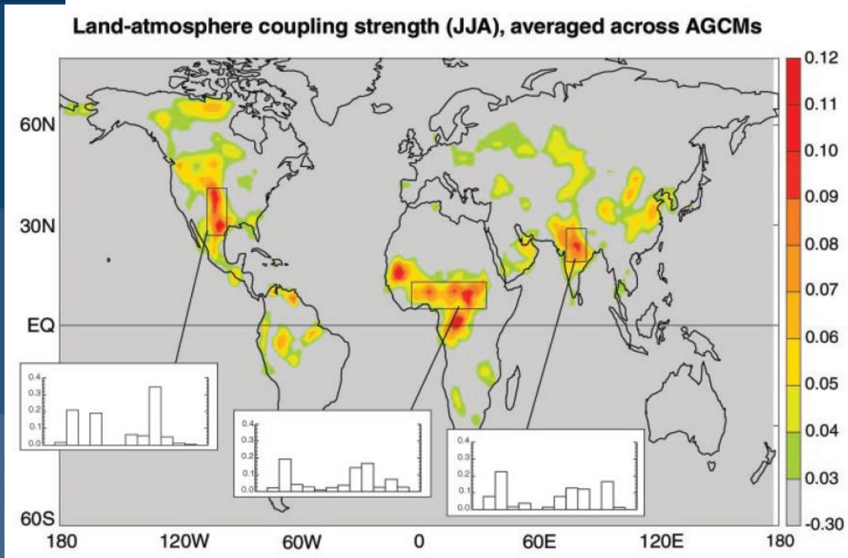




SM analyses were validated against more than 600 in-situ stations in 10 different countries:

- Impact on soil moisture is high!,
- Trend to dry the soil
- SM dynamic is improved and bias reduced,
- Root-zone is better characterised,

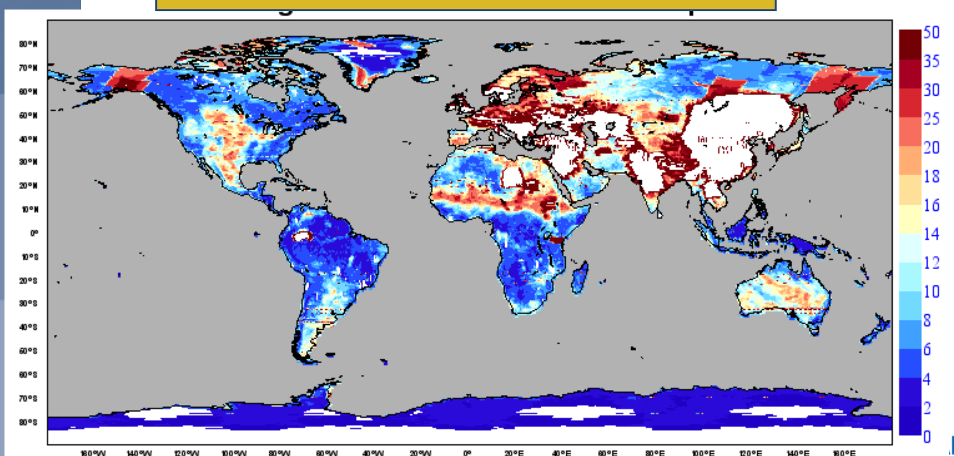
Potential atmospheric impact?



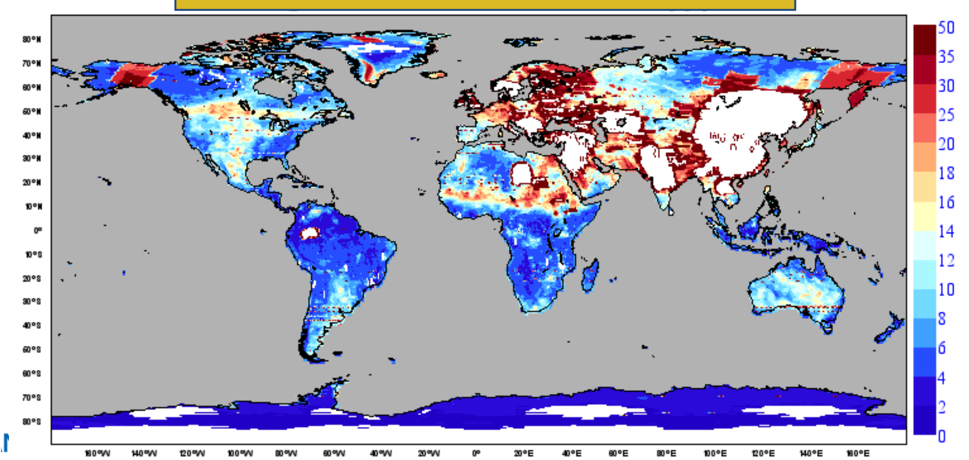
Koster et al., 2004 (*Science*); Are there locations for which soil moisture anomalies have an impact on precipitation?

- **Mostly in transition zones, where enough evaporation to trigger convection and evaporation sensitive to soil moisture, we may expect soil moisture to influence precipitation (under hypothesis of being a local effect).**
- **This picture is for boreal summer, because in summer evaporation rates are higher and because most of land masses are in NH.**

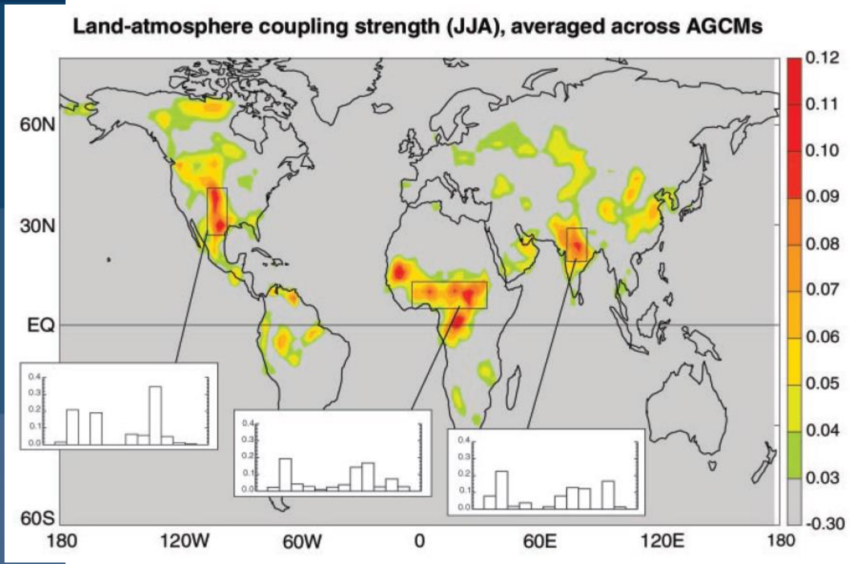
June, July, August → 40XX pol; Average STD TB



June, July, August → 40YY pol; Averaged STD TB



Potential atmospheric impact?



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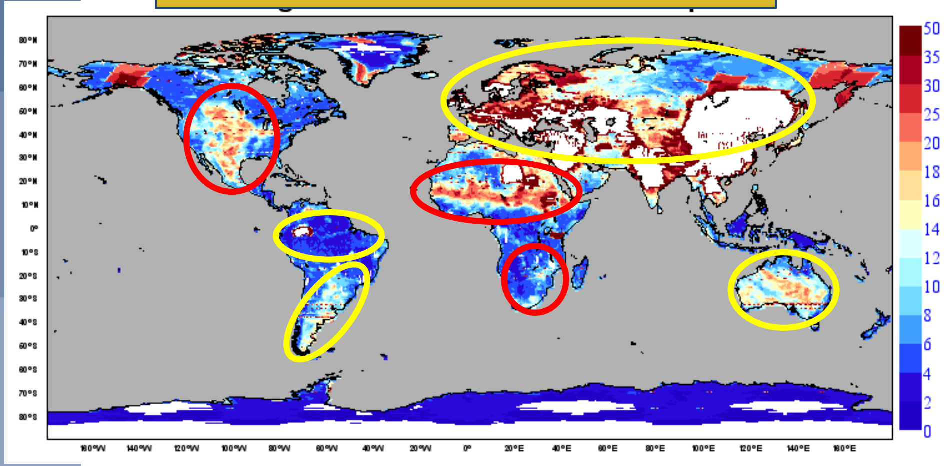

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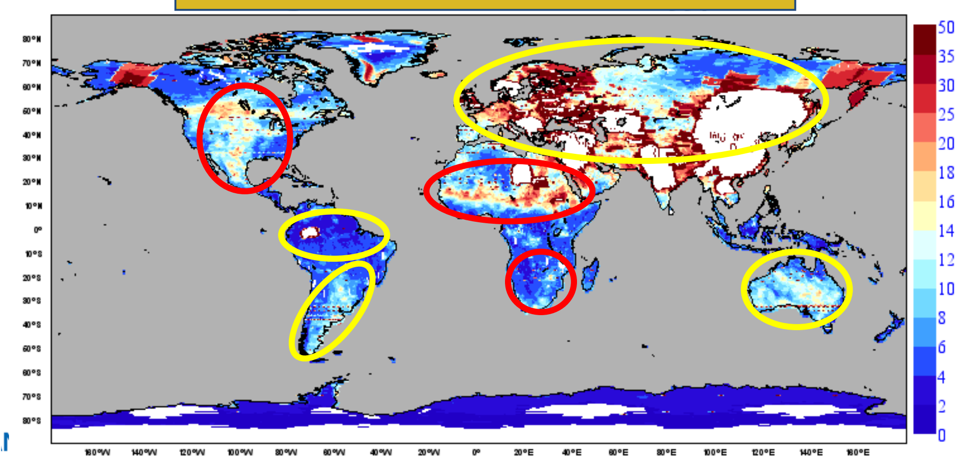
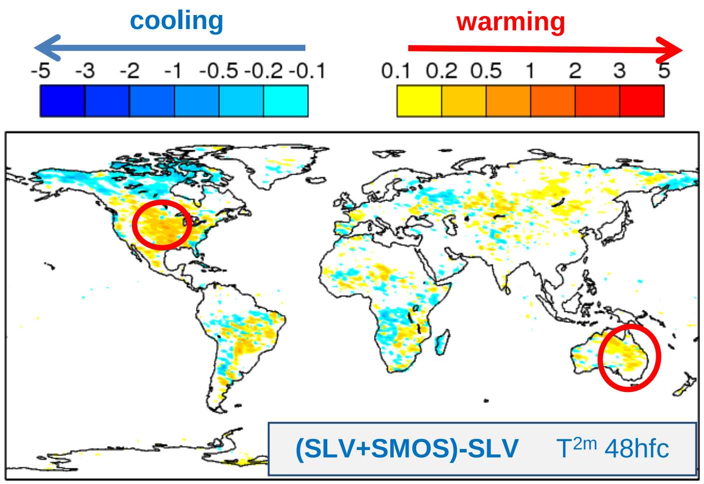
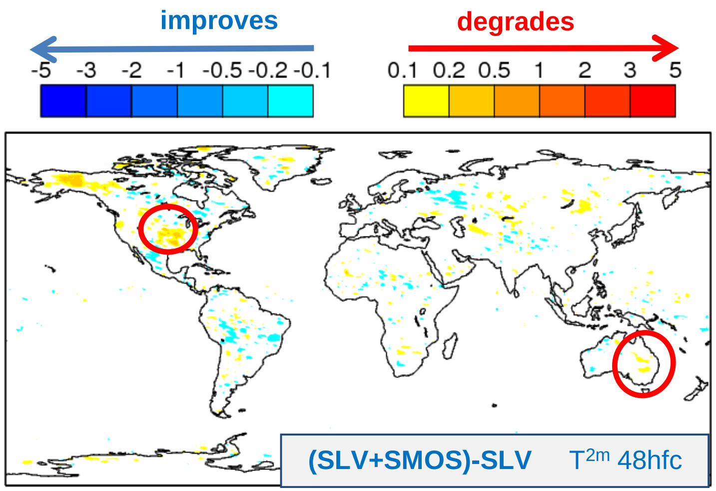


Impact in the forecast skill

Sensitivity



FC impact

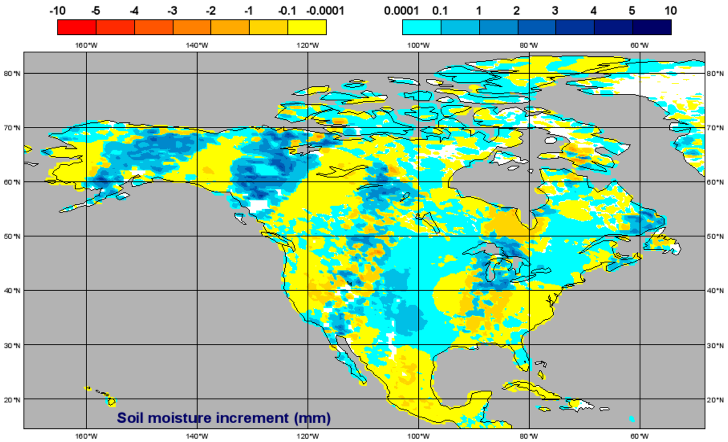


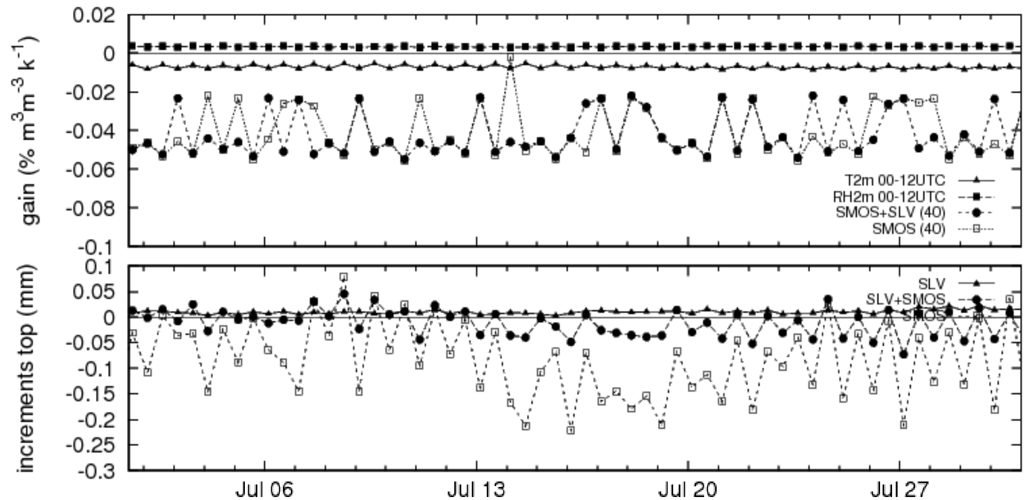
→ SMOS increments produce warmer and drier atmosphere in center US, Sahel, South of Africa and Australia → hot-spots for NWP impact,

→ Small impact in the skill of the forecast by assimilating SLV+SMOS.

SMOS DA impact experiments

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





SMOS DA impact experiments

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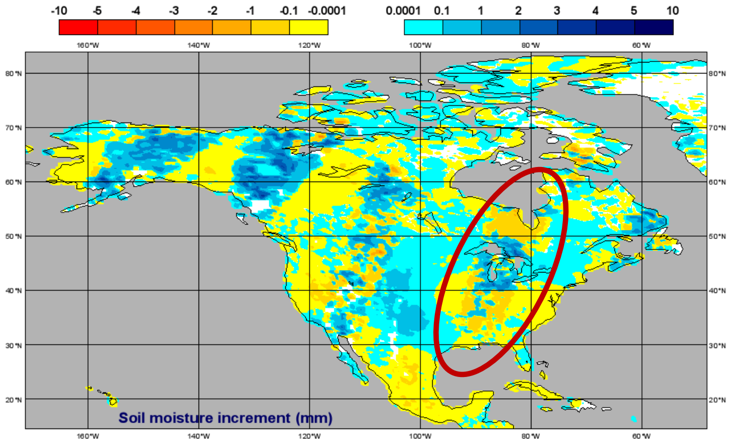
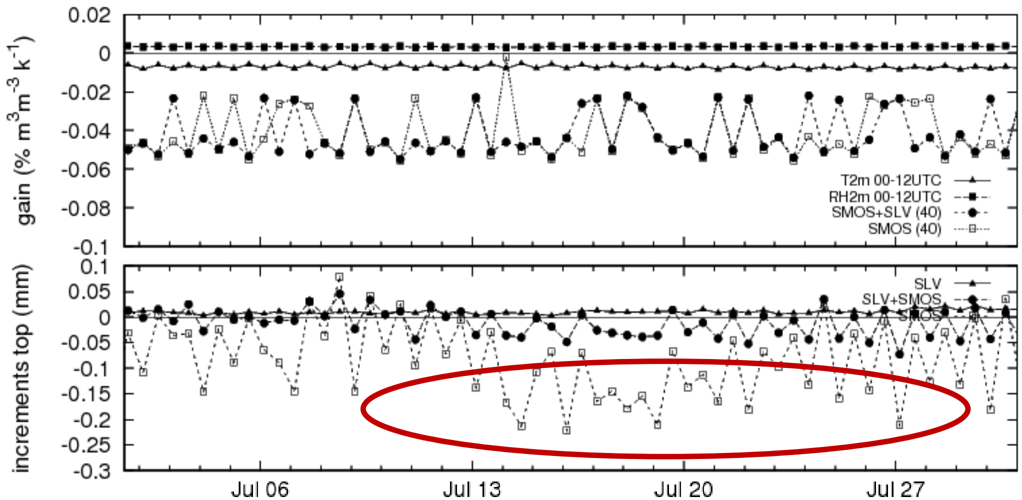
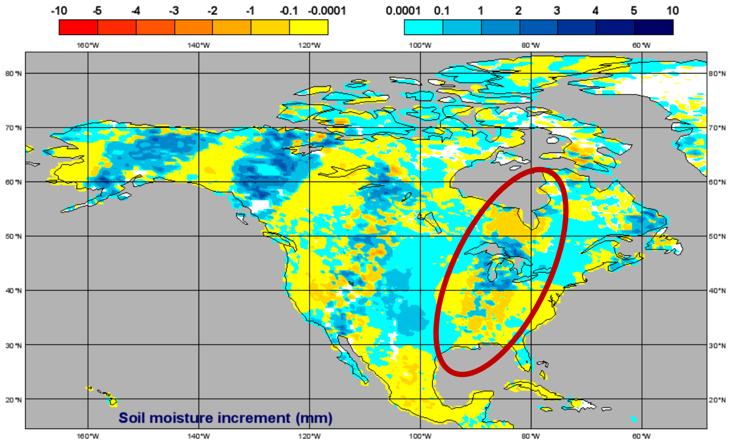
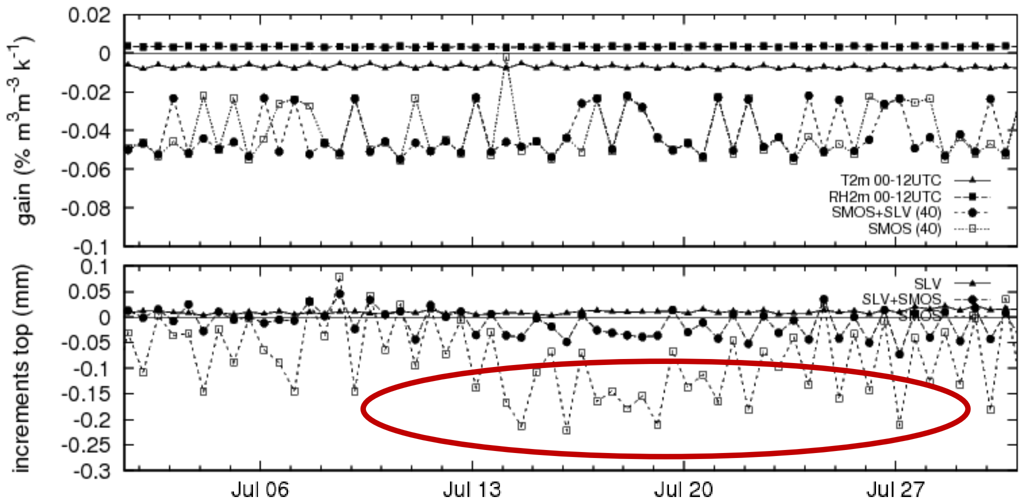




SMOS DA impact experiments

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

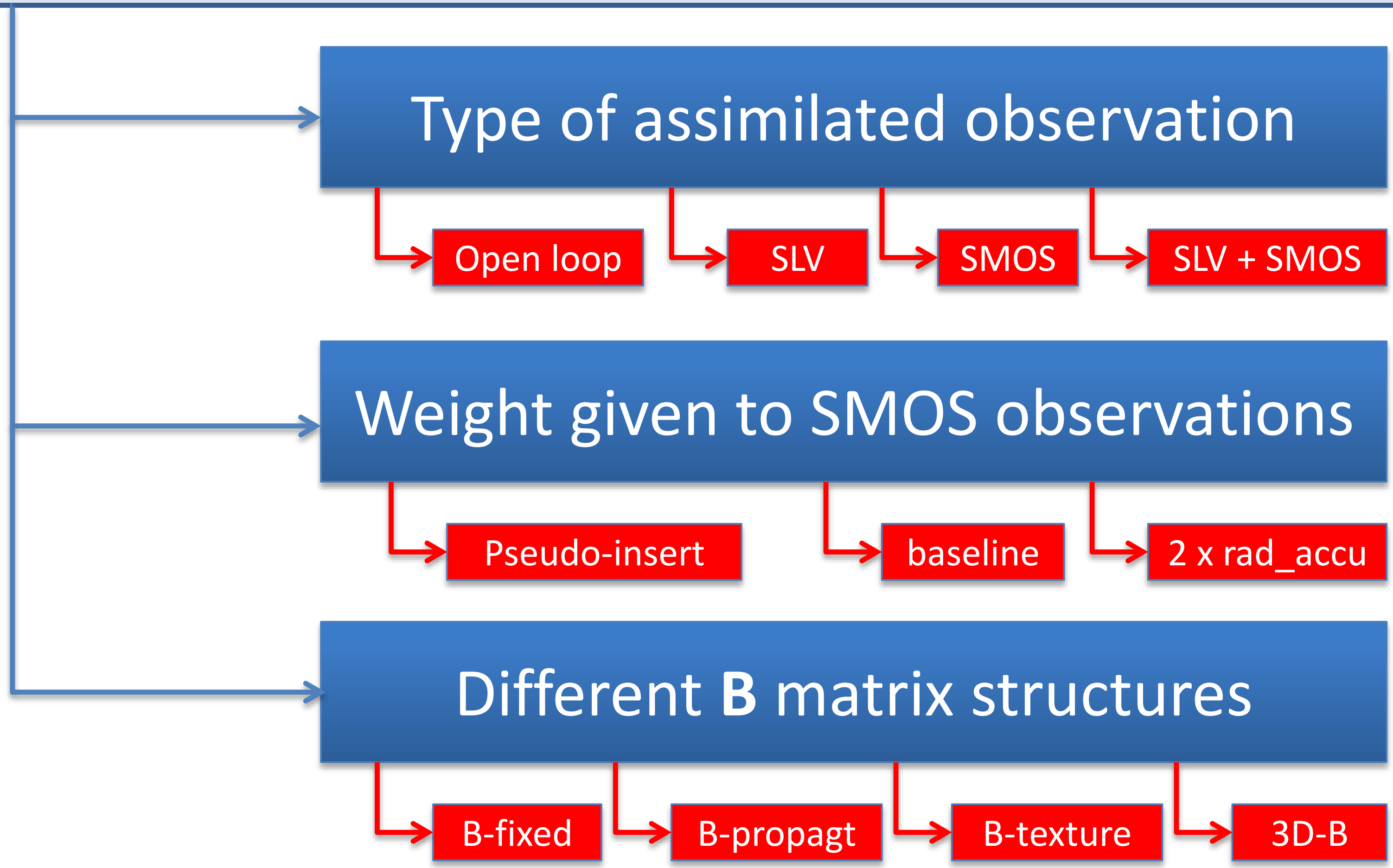




- The radiometric accuracy was used as best estimate of the SMOS observation error,
- The soil moisture background error is fixed to 0.01 m^3m^{-3} for all grid-points and layers

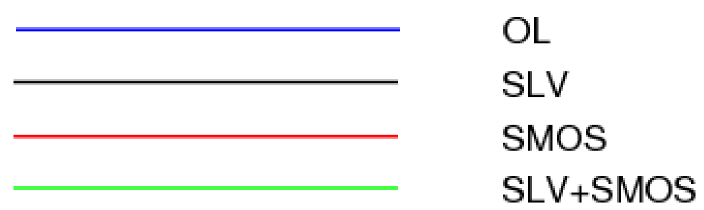
Sensitivity experiments

Investigate the effect of various types of assimilated observations, the assimilation approach and the observation (**R**) and background error (**B**) specification in the analysis of SM

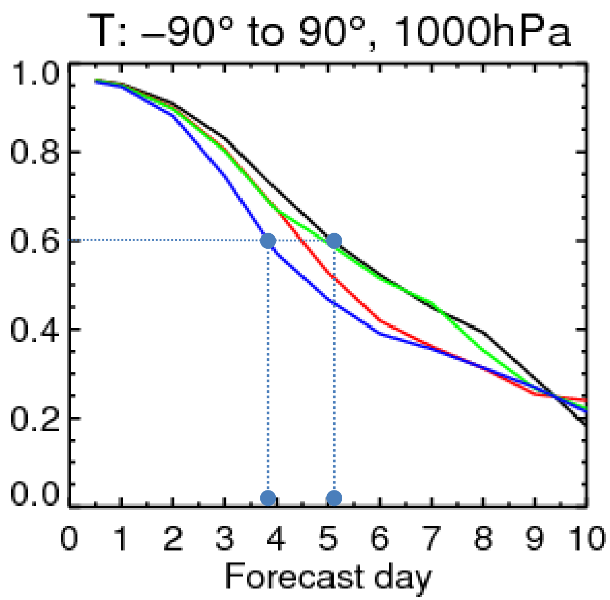


Atmospheric scores

Anomaly correlation of the forecast

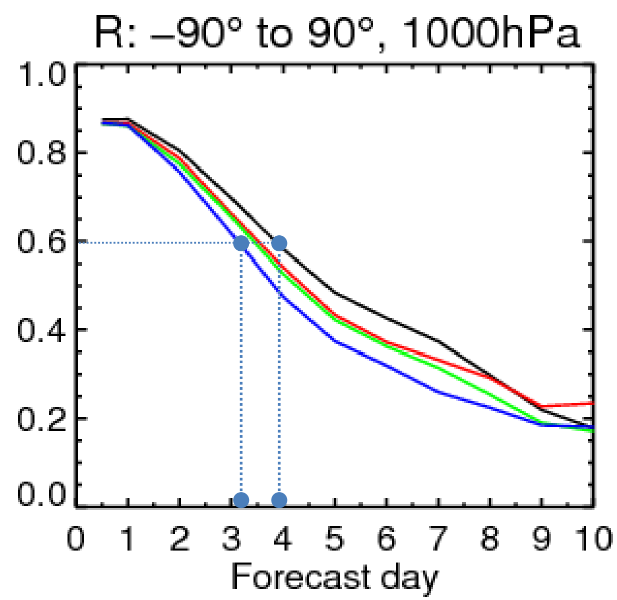


Temperature



> 1 day

Humidity



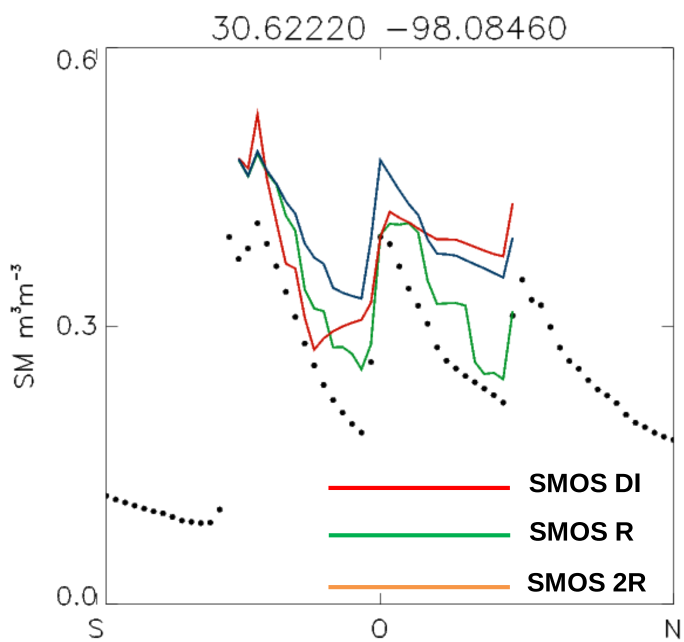
~ 1 day

Summer validation (JJA) ; top-layer (0-7 cm)

USCRN	Bias (m^3m^{-3})	RMSD (m^3m^{-3})	R	N
Direct Ins	-0.099	0.116	0.71	58
SMOS + R	-0.086	0.113	0.69	58
SMOS+2R	-0.096	0.117	0.74	58

SCAN	Bias (m^3m^{-3})	RMSD (m^3m^{-3})	R	N
Direct Ins	-0.051	0.106	0.68	83
SMOS + R	-0.032	0.101	0.69	83
SMOS+2R	-0.044	0.104	0.72	83

Only stations with significant correlation values
Confidence 95% (p-value < 0.05)

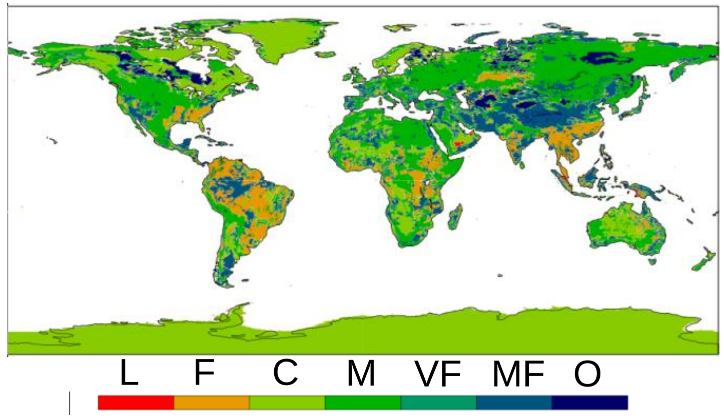


→ **Good impact of SMOS+2R in the root-zone (R)**

→ Doubling SMOS observation error and introducing soil texture information in the background error, in combination with SLV, could improve land and atmospheric scores in certain areas

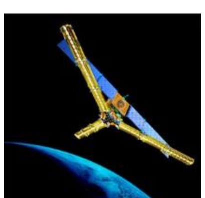
Preparation for operational use

Water holding capacity = *f*(soil texture)



CTRL: SLV + 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}



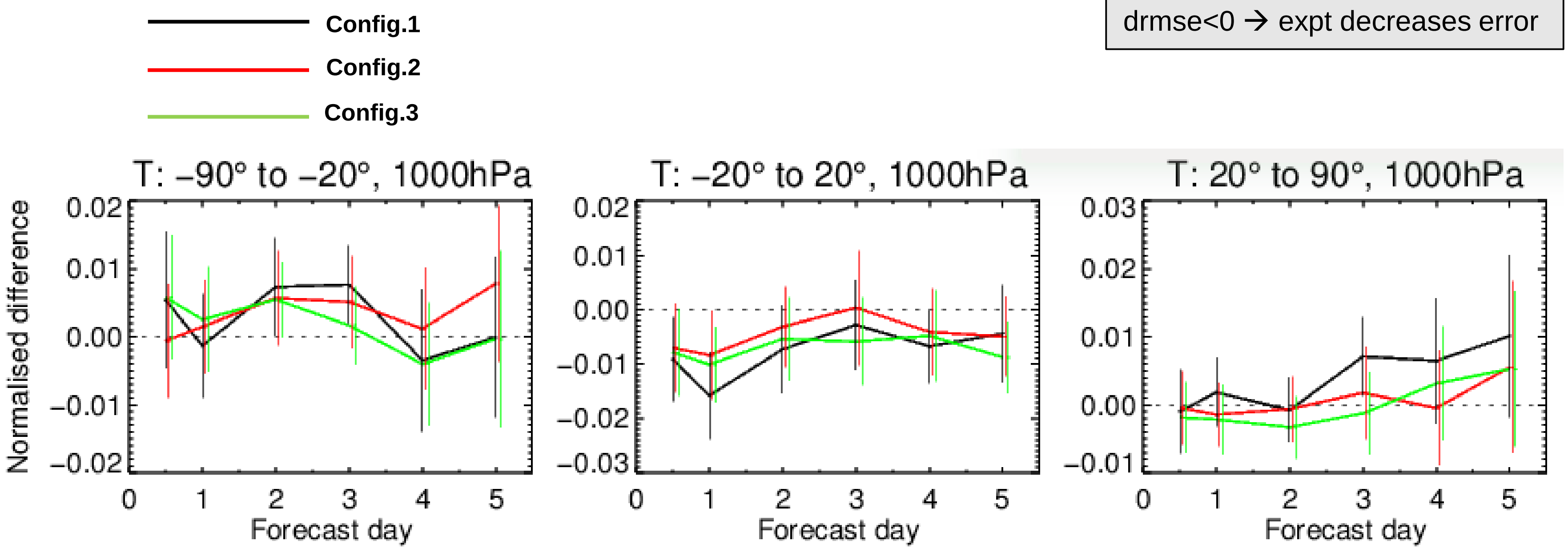
	Config.1	Config.2	Config.3
	$\sigma(T_B)$= 6 + rad_acc ~ [8.5-10] K	$\sigma(T_B)$= 6 + rad_acc ~ [8.5-10] K	$\sigma(T_B)$= 6 + 3xrad_acc ~ [13.5-18] K

Atmospheric scores

Normalized change in rms of fc error: $\text{drmse} = \frac{RMS(e^{SMOS}) - RMS(e^{CTRL})}{RMS(e^{CTRL})}$; $e^{EXPT} = fc^{EXPT} - an^{REF}$, $e^{CTRL} = fc^{CTRL} - an^{REF}$

drmse>0 → expt increases error

drmse<0 → expt decreases error

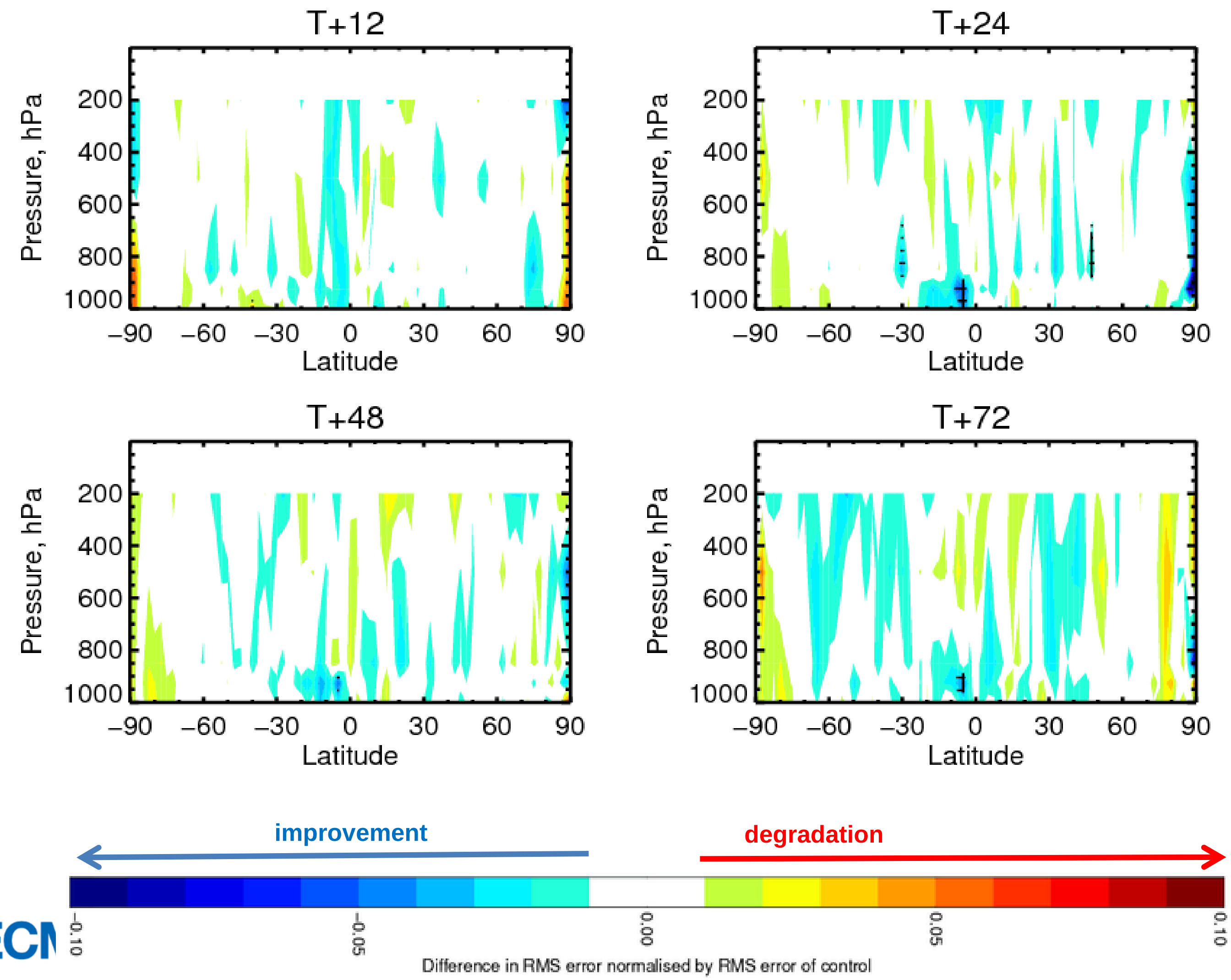


SH- extratropics *Tropics* *NH- extratropics*

- Neutral impact
- For air humidity, some significant improvement, around 1% for config3

Atmospheric scores

Configuration 3



Conclusions and remarks

- SMOS data successfully integrated into the ECMWF coupled land-atmospheric forecasting system and land data assimilation scheme,

- Seasonal summer expts (with baseline observation and background error) show that, compared to the op. system, the SMOS signal tends to dry out the soil (in average),

  → Positive results in terms of shallow, root-zone soil moisture analysis and forecasts,
  → But limited atmospheric impact (with some degradations)

- Several diagnostics and sensitivity experiments show that several components of the assimilation system can and should be adjusted in order to optimize the use of SMOS information in the coupled land-atmospheric forecasting system,

  → The integration of SMOS T_B in the ECMWF operational LDAS is plausible and it is a current extended objective,
  → Testing over long-term periods is needed to include SMOS data in the operational system,

- More research into the bias correction approach and the quality control of the assimilated observations should further refine the assimilation system.

  → Infuence in extended range forecasts?

Thanks for your attention !

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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

Sensitivity experiments

Investigate the effect of various types of assimilated observations, the assimilation approach and the observation (**R**) and background error (**B**) specification in the analysis of SM

- USA → best place for availability of observations and "cheaper" experiments,
- Period: 15 Sept- 14 Oct 2012 → recharge period, good variability of soil moisture,
- Full coupled land-atmospheric system,
- 3 angles (30, 40, 50), 2 polarisations (XX, YY), AF-FOV, RFI flag,
- Physics of cy40r1,
- Reduced observing system for the upper-air atmosphere; ATOVS, GBRAD and NEXRAD observations used to limit number of observations, and still reasonable atmospheric constrain.

- **R**: $\sigma(T^{2m})$ =2 K; $\sigma(RH^{2m})$=10%; $\sigma(SMOS)$≈rad_acc K
- **B**: $\sigma(sm_{(0\text{-}7)\ cm}) = \sigma(sm_{(7\text{-}28)\ cm}) = \sigma(sm_{(28\text{-}100)\ cm}) = 0.01\ m^3m^{-3}$
- **Q**: $\sigma(sm) = 0.01\ m^3m^{-3}$