Sensitivity of soil moisture analyses to contrasting background and observation error scenarios

Joaquín Muñoz Sabater, Patricia de Rosnay, Clément Albergel and Lars Isaksen

European Centre for medium-Range Weather Forecasts (ECMWF), Reading, UK

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Introduction

Soil moisture is a crucial variable for numerical weather prediction (NWP). Accurate, global initialization of soil moisture is obtained through data assimilation systems. However analyses depend largely on the way observations and background errors are defined. In this paper a wide range of short experiments with contrasted specification of the observation error and soil moisture background were conducted. As observations, screen-level variables and brightness temperatures from the Soil Moisture and Ocean Salinity (SMOS) mission were used. The region of interest was North America given the good availability of in-situ observations. The impact of these experiments on soil moisture and the atmospheric layer near the surface were evaluated. The results highlighted the importance of assimilating sensitive observations to soil moisture for air temperature and humidity forecasts. The benefits on the soil water content were more noticeable with increasing the SMOS observation error and with the introduction of soil texture dependency in the soil moisture background error.

ECMWF Land Data Assimilation System (LDAS)

For each grid point, analysed soil moisture state vector x_a:

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

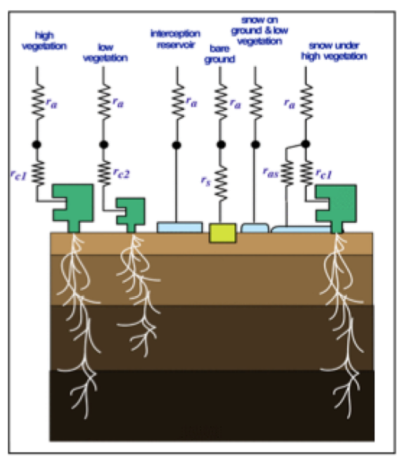
- x background soil moisture state vector,
- $\mathcal{H}$ non linear observation operator
- y observation vector
- K Kalman gain matrix, fn of H (linearsation of $\mathcal{H}$), P and R (covariance matrices of background and observation errors).

Used at ECMWF (operations and ERA5), DWD, UKMO

Observations used at ECMWF:

- Conventional SYNOP pseudo observations (analysed T2m, RH2m)
- Satellite MetOp-A/B ASCAT soil moisture
- SMOS Brightness temperature

The simplified EKF is used to corrects the soil moisture trajectory of the Land Surface Model



H-TESSEL land surface model (Balsamo et al JHM 2009), simplified EKF (de Rosnay et al. QJRMS 2013)

Soil Moisture and Ocean Salinity (SMOS)

SMOS ESA Earth Explorer mission (2009-present)

L-band (1.4 GHz) instrument. Optimal frequency for soil moisture remote sensing

Sun-synchronous, quasi-circular orbit at altitude 758 km. 06.00 hrs local solar time at ascending node. Three days revisit at Equator

Dual polarisation: H and V in the Earth reference, xx and yy in the antenna frame reference

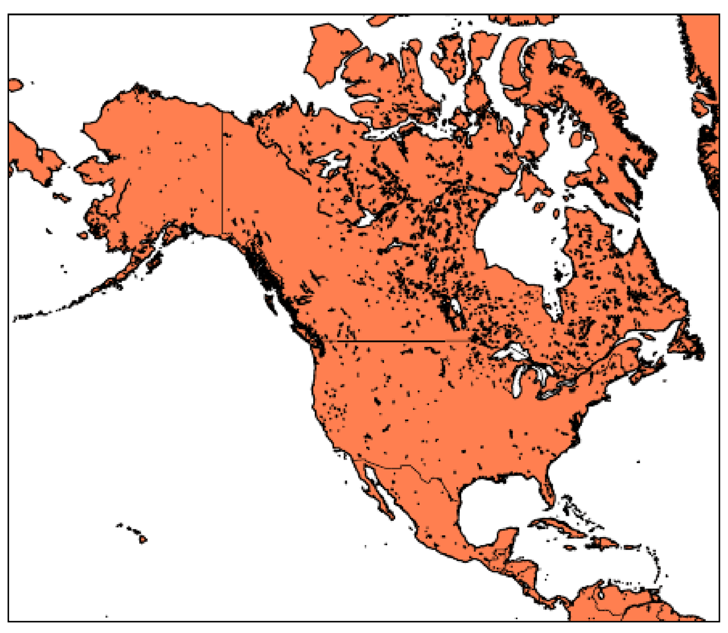
Multi-angular measurements 0 to 60°

ECMWF and ECCC: developments to use NRT SMOS Brightness Temperature (TB) data

→ Use observation operator to simulate L-band TB: Community Microwave Emission Modelling Platform (CMEM)

CMEM (de Rosnay et al JGR 2009, Drusch et al., JHM 2009), SMOS in the IFS (Muñoz Sabater et al.: IJRS 2011, TGRS 2014, GRSL 2012)

Numerical Experiments

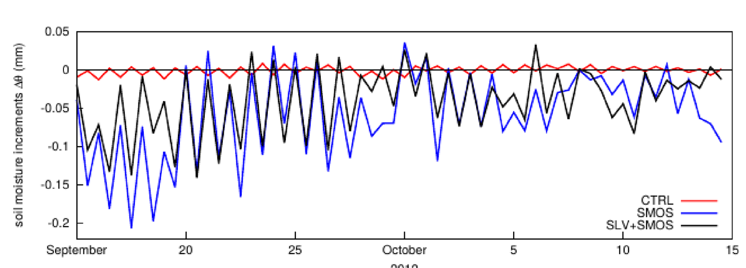


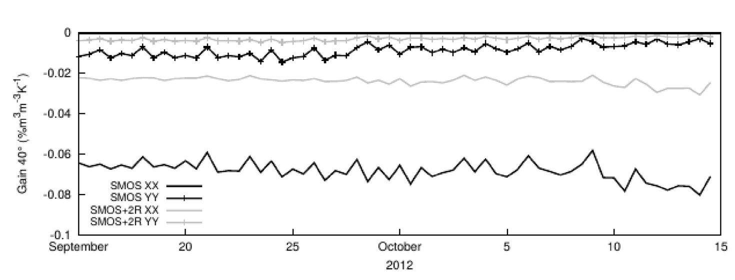
name	analysis	SLV	SMOS	σ_o^{SLV}	σ_o^{SMOS}	σ_b
OL	no	no	no	-	-	-
SLV	yes	yes	no	[1K,4%]	-	0.01
SMOS+SLV	yes	yes	yes	[1K,4%]	RA	0.01
SMOS	yes	no	yes	-	RA	0.01
SMOS-Bprop	yes	no	yes	-	RA	0.01
SMOS+PI	yes	no	yes	-	ϵ	0.01
SMOS+2R	yes	no	yes	-	2 x RA	0.01
SMOS-Btext	yes	no	yes	-	RA	$f(text)$
SMOS-3DB	yes	no	yes	-	RA	$f(text, depth)$

Region under study (left) for the experiments (right)

Two sets of NWP 1-month experiments are conducted (Sept-Oct 2012):
- Observations impact: OL (Open Loop), SLV (Screen level Variables) assimilation, SMOS and SLV assimilation, SMOS only assimilation.
- Sensitivity to error specifications: with SMOS assimilation and different values of the background and observations errors as detailed in the table.

Analysis Increments





Left: Time series of 12h area averaged analysis increments of the control SLV experiment and the SMOS+SLV (black) experiment for the top soil layer. Right: Averaged time series of the 40 degrees incidence angle gain component for the SMOS and SMOS+2R experiments.

Impact on Soil moisture

Validation against in situ soil moisture stations

- U.S. Climate Reference Network (USCRN) and the Soil Climate Analysis Network (SCAN) `http://www.wcc.nrcs.usda.gov/scan/`
- U.S. Climate Reference Network (USCRN) National from the Oceanic and Atmospheric Administration's National Climatic Data Center(Bell et al. JHM 2013)

	expt	USCRN MB	USCRN RMSD	USCRN R	USCRN ubRMSD	USCRN N	SCAN MB	SCAN RMSD	SCAN R	SCAN ubRMSD	SCAN N
0-7 cm	OL	-0.115	0.130	0.75	0.061	60	-0.062	0.104	0.74	0.083	86
	SLV	-0.115	0.130	0.76	0.061	60	-0.061	0.104	0.74	0.084	86
	SMOS+SLV	-0.097	0.121	0.76	0.072	60	-0.048	0.105	0.75	0.089	86
	SMOS	-0.089	0.115	0.67	0.073	60	-0.035	0.101	0.68	0.095	86
1-100 cm	OL	-0.089	0.096	0.74	0.036	37	-0.032	0.096	0.74	0.091	56
	SLV	-0.089	0.096	0.72	0.036	37	-0.031	0.096	0.70	0.091	56
	SMOS+SLV	-0.087	0.095	0.72	0.036	37	-0.030	0.096	0.72	0.091	56
	SMOS	-0.080	0.089	0.61	0.039	37	-0.024	0.099	0.61	0.096	56

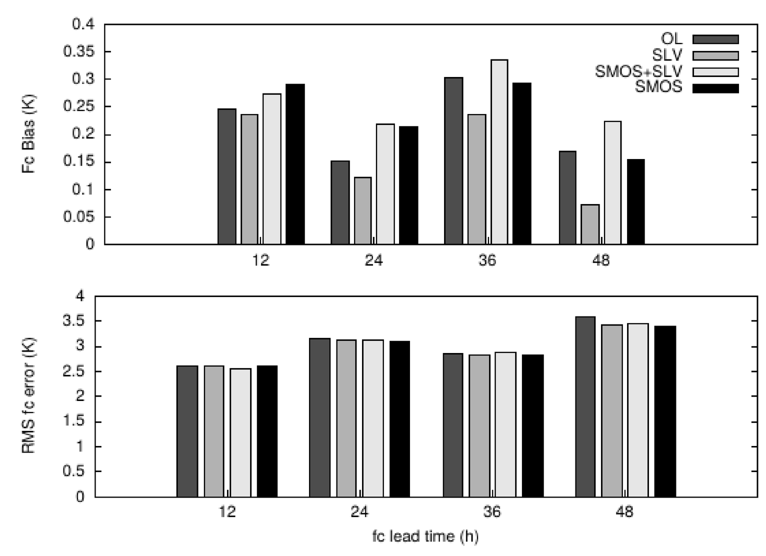
	expt	USCRN MB	USCRN RMSD	USCRN R	USCRN ubRMSD	USCRN N	SCAN MB	SCAN RMSD	SCAN R	SCAN ubRMSD	SCAN N
0-7 cm	SMOS+PI	-0.099	0.116	0.71	0.06	58	-0.051	0.106	0.68	0.093	83
	SMOS	-0.086	0.113	0.69	0.073	58	-0.032	0.101	0.69	0.096	83
	SMOS+2R	-0.096	0.117	0.74	0.067	58	-0.044	0.104	0.72	0.093	83
1-100 cm	SMOS+PI	-0.082	0.092	0.70	0.042	38	-0.029	0.095	0.67	0.09	62
	SMOS	-0.081	0.091	0.63	0.041	38	-0.025	0.095	0.58	0.092	62
	SMOS+2R	-0.081	0.091	0.70	0.041	38	-0.027	0.095	0.65	0.091	62

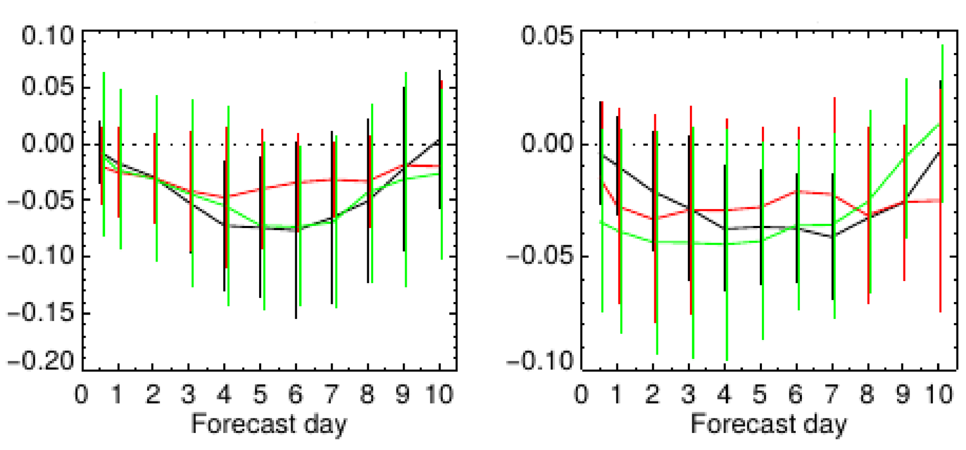
	expt	USCRN MB	USCRN RMSD	USCRN R	USCRN ubRMSD	USCRN N	SCAN MB	SCAN RMSD	SCAN R	SCAN ubRMSD	SCAN N
0-7 cm	SMOS	-0.085	0.109	0.70	0.068	64	-0.022	0.095	0.70	0.092	77
	SMOS-Bprop	-0.088	0.111	0.69	0.068	64	-0.025	0.095	0.70	0.092	77
	SMOS-Btext	-0.074	0.104	0.67	0.073	64	-0.015	0.094	0.66	0.093	77
	SMOS-3DB	-0.071	0.102	0.65	0.073	64	-0.016	0.094	0.64	0.093	77
1-100 cm	SMOS	-0.077	0.093	0.63	0.052	30	-0.013	0.090	0.64	0.089	48
	SMOS-Bprop	-0.076	0.091	0.65	0.05	30	-0.012	0.090	0.65	0.089	48
	SMOS-Btext	-0.077	0.092	0.66	0.05	30	-0.012	0.090	0.64	0.089	48
	SMOS-3DB	-0.076	0.092	0.71	0.052	30	-0.012	0.089	0.65	0.088	48

Impact of assimilation on soil moisture for different configurations of (left) the observing system, (middle) different observation errors, (right) different model background error specifications. For the first metre of soil, in-situ observations averaged at depth of 5, 10, 20, 50 and 100 cm are used.

Impact of the observing system on near surface weather forecasts

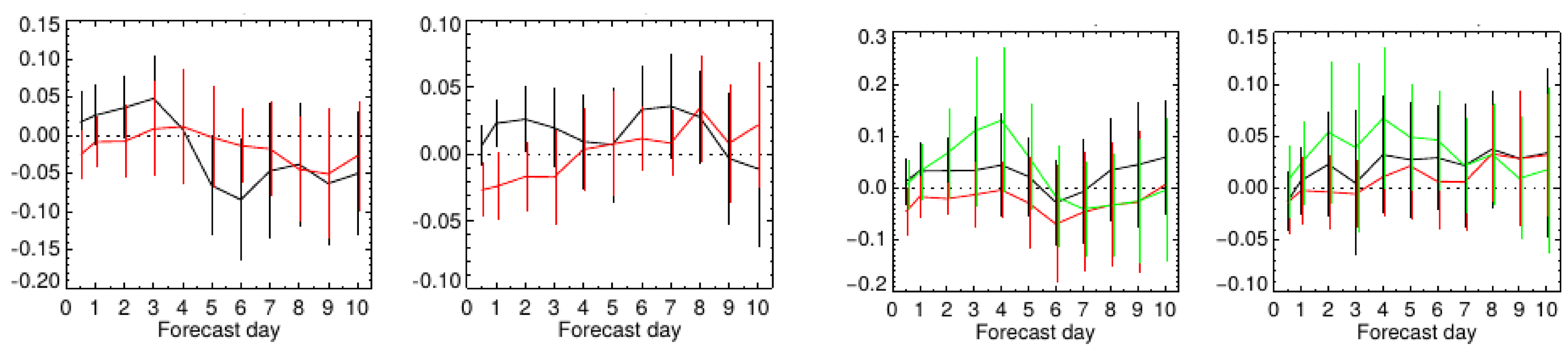
Validation against operational analyses





Left: averaged forecast biases and RMS forecast errors of 2 m dew point temp. compared to observations (SYNOP), as a function of the forecast lead time. Right: Near-surface air temperature (left panel) and air humidity (right panel) normalized RMSE forecast of SLV (black), SMOS (red) and SLV+SMOS (green) experiments compared to the control OL, as a function of the forecast lead time.

Impact of error specifications on near surface weather forecasts



Near-surface air temperature (left panel) and air humidity (right panel) normalized root mean square forecast error compared to the control SMOS experiment for: (left) SMOS+2R (red) and SMOS+PI (black) compared to the control SMOS experiment, (right) SMOS+Btext (red), SMOS+Bprop (black) and SMOS+3DB (green).

Summary

- Impact of soil moisture data assimilation for NWP with assessment of observing system, observation and model background error specifications
- Tests conducted in operational-like 1-month NWP experiments
- Atmospheric impact is limited to the closest layer to the surface
- Compared to the Open Loop, screen level data assimilation improves atmospheric forecast but it is neutral on soil moisture
- SMOS assimilation slightly reduces soil moisture RMSE but it slighlty degrades correlations
- Increased SMOS observations error specification for SMOS (to account for representativeness errors) has a slighlty positive impact on atmospheric forecasts
- Using a background error matrix as a function of soil texture and/or soil depth has a neutral impact on the near-surface forecast.
- Longer term experiments using the full observing system will be the topic of a follow-up paper with an exhaustive analysis of the meteorological impact due to the assimilation of SMOS TB.

Patricia.Rosnay@ecmwf.int