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

→ 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

Trenberth et al. (2007)
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 $x_a$:

$$x_a = x_b + K (y - H[x_b])$$

$x_b$ : background state vector,
$y$ : observation vector
$H$ : non linear observation operator
$K$ : Kalman gain matrix: $K = [B^{-1} + H^TR^{-1}H]^{-1}H^TR^{-1}$

**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

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

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

**Water holding capacity**

$= f(\text{soil texture})$

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<th>Layer</th>
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<th>Volume Range [m$^3$]</th>
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<tr>
<td>Layer 3</td>
<td>5%</td>
<td>0.008-0.02</td>
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</table>

SMOS Obs error:

**Config. 1**

$\sigma(T_B) = 6 + \text{rad_acc}$

($\sim 8.5 \text{ to } 10 \text{ K}$)

**Config. 2**

$\sigma(T_B) = 6 + \text{rad_acc}$

($\sim 8.5-10 \text{ K}$)

**Config. 3**

$\sigma(T_B) = 6 + 3\times\text{rad_acc}$

($\sim 13.5 \text{ to } 18 \text{ K}$)
L-band DA: background and observation errors

System configuration

- 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
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

- 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

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<thead>
<tr>
<th>USCRN</th>
<th>N</th>
<th>RMSD</th>
<th>corr</th>
<th>An_corr</th>
<th>ubRMSD</th>
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<td>0.69</td>
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<table>
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<td>0.071</td>
<td>0.800</td>
<td>0.670</td>
<td>0.048</td>
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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)

\[ \Delta_{\text{error}} T^{2m} \]

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

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)

\[TB^*_\text{SMOS} = a + b \ TB_{\text{SMOS}}\]
with
\[a = TB_{\text{ECMWF}} - TB_{\text{SMOS}} \left(\frac{\sigma_{\text{ECMWF}}}{\sigma_{\text{SMOS}}}\right)\]
\[b = \frac{\sigma_{\text{ECMWF}}}{\sigma_{\text{SMOS}}}\]

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

![Graph showing FG departure (Obs-Model) L-Band TBxx at 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 $\rightarrow$ 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

### Multi-year Global Evaluation

**Anomaly correlation**

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**RMSE**

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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$^3$m$^{-3}$)
- 40° 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 (30 degrees)
First Guess departure: Obs-Model (K)
23-28 Feb

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 trained on ECMWF soil moisture
   → No need for forward model, no bias correction

Collaboration ECMWF, ESA, CESBIO, Observatoire de Paris
Data Assimilation of SMOS Neural Network SM

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

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)

One year assimilation experiments in offline LDAS (forced by ERA-Interim)

- Sensitivity to observation errors → 13 experiments
  - Open Loop
  - SMOS NN SM $\sigma \times 1$
  - SMOS NN SM $\sigma \times 3$
  - SMOS NN SM $\sigma \times 9$
  - SMOS NN SM $\sigma \times 1 + T2m + RH2m$
  - SMOS NN SM $\sigma \times 3 + T2m + RH2m$
  - SMOS NN SM $\sigma \times 9 + T2m + RH2m$
  - ASCAT SM $\sigma \times 1$
  - ASCAT SM $\sigma \times 2$
  - ASCAT SM $\sigma \times 4$
  - ASCAT SM $\sigma \times 1 + T2m + RH2m$
  - ASCAT SM $\sigma \times 2 + T2m + RH2m$
  - ASCAT SM $\sigma \times 4 + T2m + RH2m$

→ 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 Network SM Forecasts verification 2012

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

Dew point temperature
RMSE normalized difference with OL
Data Assimilation of SMOS Neural Network SM Forecasts verification 2012

Impact:
Normalized change in rms of forecast error for T2m

SMOS NN SM $\sigma \times 1$ vs OL

SMOS NN SM $\sigma \times 3$ vs OL

SMOS NN SM $\sigma \times 3 + SLV$ 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/ESA Workshop on Using Low Frequency Passive Microwave Measurements in Research and Operational Applications

ECMWF | Reading | 4-6 December 2017

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)

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

Layer 1
(0-7 cm)

Layer 2
(7-28 cm)

Layer 3
(28-100 cm)

\[ x_a - x_b = K (y_0 - H [x_b]) \]

Obs Error = Instr. Error x 1

Obs Error = Instr. Error x 2
Increments: SMOS NN

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

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
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<tbody>
<tr>
<td>(0-7cm)</td>
<td>(7-28cm)</td>
<td>(28-100cm)</td>
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</table>

\[ \text{Obs Error} = \text{Instr. Error} \times 1 \quad \text{m}^3/\text{m}^3 \]

\[ \text{Obs Error} = \text{Instr. Error} \times 3 \quad \text{m}^3/\text{m}^3 \]

\[ |\text{Inc}| < 0.1 \text{ m}^3/\text{m}^3 \]
Data Assimilation of SMOS Neural Network SM Validation soil moisture

<table>
<thead>
<tr>
<th>SM</th>
<th>Mean STD</th>
<th>Mean R</th>
<th>Mean Bias</th>
<th>Mean STD</th>
<th>Mean R</th>
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<td>-0.014</td>
</tr>
</tbody>
</table>

- SMOS SM $\sigma \times 1$
- SMOS SM $\sigma \times 3$
- SMOS SM $\sigma \times 9$
- SMOS SM $\sigma \times 1 + SLV$
- SMOS SM $\sigma \times 3 + SLV$
- SMOS SM $\sigma \times 9 + SLV$
- ASCAT SM $\sigma \times 1$
- ASCAT SM $\sigma \times 2$
- ASCAT SM $\sigma \times 4$
- ASCAT SM $\sigma \times 1 + SLV$
- ASCAT SM $\sigma \times 2 + SLV$
- ASCAT SM $\sigma \times 4 + SLV$

Open loop

SCAN Jordan Hydaprobe-Analog-(2.5-Volt)

$\rightarrow$ neutral impact of SMOS and ASCAT DA on soil moisture depending on site
<table>
<thead>
<tr>
<th>SM</th>
<th>Mean STD</th>
<th>Mean R</th>
<th>Mean Bias</th>
<th>Mean STD</th>
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<td>0.058</td>
<td>0.64</td>
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<td>0.037</td>
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<td>-0.002</td>
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<td>0.035</td>
</tr>
</tbody>
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Open loop
Humidity (whole 2012)

- R: SH -90° to -20°, 500hPa
- R: Tropics -20° to 20°, 500hPa
- R: NH 20° to 90°, 500hPa

- R: SH -90° to -20°, 850hPa
- R: Tropics -20° to 20°, 850hPa
- R: NH 20° to 90°, 850hPa

- R: SH -90° to -20°, 1000hPa
- R: Tropics -20° to 20°, 1000hPa
- R: NH 20° to 90°, 1000hPa

Forecast day

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
Temperature (whole 2012)

- T: SH −90° to −20°, 500hPa
- T: Tropics −20° to 20°, 500hPa
- T: NH 20° to 90°, 500hPa

- T: SH −90° to −20°, 850hPa
- T: Tropics −20° to 20°, 850hPa
- T: NH 20° to 90°, 850hPa

- T: SH −90° to −20°, 1000hPa
- T: Tropics −20° to 20°, 1000hPa
- T: NH 20° to 90°, 1000hPa

Forecast day

- 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
Humidity (3 months periods)

Jan--Mars

April-June
- ASCAT SM x1
- ASCAT SM x2
- ASCAT SM x4
- ASCAT SM x1 + T2m + RH2m
- ASCAT SM x2 + T2m + RH2m
- ASCAT SM x4 + T2m + RH2m

July-September

October-December
Humidity
(3 months periods)

Jan--Mars

April-June

July-September

October-December
Change in error in T (SMOSx3 (gj1) – OL (ggqa))
1-Jul-2012 to 29-Sep-2012 from 87 to 91 samples. Verified against 0.001.

T+12; 850hPa
T+24; 850hPa

T+36; 850hPa
T+48; 850hPa

T+60; 850hPa
T+72; 850hPa

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 0.001.

SMOS NN SM $\sigma \times 3$

$T2m + RH2m$
Change in error in T (ASCAT2 (gijw) – OL (gqa))
1-Jul-2012 to 29-Sep-2012 from 87 to 91 samples. Verified against 0.001.

ASCAT SM $\sigma \times 2$

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Change in error in T (ASCAT2+SLV (gjr3) – OL (ggqa))

1–Jul–2012 to 29–Sep–2012 from 87 to 91 samples. Verified against 0.001.

ASCAT SM σ x2
T2m + RH2m