SMOS soil moisture data assimilation for operational numerical weather prediction

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Earth system approach

- Consistency of the infrastructure and coupling approaches across the different components
- Modularity to account for the different components in coupled assimilation
Current operational NWP system at ECMWF
weakly coupled land-atmosphere-wave and sea ice assimilation

→ Importance of the interface observations for consistent initialisation of coupled land-atmosphere forecasts
→ Soil moisture observations highly relevant for coupled assimilation
Soil moisture satellite observations

**Active microwave data:**

**ASCAT**: Advanced Scatterometer
C-band (5.6GHz) backscattering coefficient
EUMETSAT Operational mission

**Passive microwave data:**

**SMOS**: Soil Moisture & Ocean Salinity (2009-)
L-band (1.4 GHz) Brightness Temperature
ESA Earth Explorer, dedicated soil moisture mission

Data from **SMAP** (Soil Moisture Active Passive), NASA soil moisture mission, also available

ASCAT soil moisture ($m^3m^{-3}$)

Stdev(O-B) Sept. 2013

SMOS Brightness temperature (K)
Global mean comparison between SMOS TB and ECMWF TB for 2010-2016
SMOS continuous bias correction and long term monitoring

Consistent improvement of agreement between SMOS and ECMWF reanalysis from 2010 to 2016 at both polarisations

(de Rosnay et al 2019, RSE, in review)
SMOS TB assimilation
Atmospheric forecasts evaluation for MJJAS 2013

Muñoz Sabater et al 2019, QJRMS, in review
ESA level 2 SMOS NRT Soil Moisture product based on Neural Network (2016)

Designed by CESBIO/Estellus, Implemented by ECMWF

- Neural Network used to retrieve SMOS L2 SM from NRT brightness temperature
- Trained on SMOS L2 Soil moisture

→ NRT (4h latency) SMOS L2 SM

- Available in NetCDF, since March 2016 on ESA SMOS Online Dissemination service \[\text{https://smos-ds-02.eo.esa.int/oads/access}\]

Poster on Tuesday, South hall floor 0:
A4.13: EO for Hydrological Events Poster Session

L2 NRT vs L2 (v6.20) soil moisture
L2 NRT vs situ stations (USCRN, SCAN) R= 0.71

Rodriguez-Fernandez et al, HESS 2017
- Offline assimilation in H-TESSEL and initialisation of stand-alone atmospheric forecasts (2012)
- Reference H-TESSEL with no assimilation: Open Loop (OL)
- Impact on two-meter air temperature forecasts (JAS 2012)

→ Proof of concept of SMOS NN assimilation for NWP initialisation

Rodriguez-Fernandez et al, Remote sensing, in review, 2019
ECMWF level 2 SMOS Neural Network soil moisture (2018)

For data assimilation purposes

- NN Trained on ECMWF soil moisture
- SMOS soil moisture with no bias compared to ECMWF soil moisture
- NRT processing
- \( \rightarrow \) suitable for data assimilation
ECMWF level 2 SMOS Neural Network soil moisture compared to ERA5 e.g. in 2016

Bias

Comparison with the European Flood Alert System (EFAS) soil moisture

Lawrence et al. ESA report 2019, in prep
ECMWF Soil Analysis in IFS 46r1 (oper 11 June 2019)

Ensemble Data Assimilation (EDA)

EDA Jacobians
- T2m, RH2m
- & soil moisture
- Background

NWP Forecast Coupled Land-Atmosphere

Screen level analysis (2D-OI)
- \( \sigma_{T2m} = 2K \)
- \( \sigma_{RH2m} = 10\% \)

Soil Analysis (SEKF)
- SM1, SM2, SM3
- \( \sigma_{O_{T2M}} = 1K \)
- \( \sigma_{O_{RH2M}} = 4\% \)
- \( \sigma_{O_{ASCAT}} = 0.05m^3/m^3 \)
- \( \sigma_{b} = 0.01m^3/m^3 \)
- \( \sigma_{SMOS_{NN}} = 0.02+3\epsilon \)

Land initial conditions

in situ
- T_2m
- RH_2m

satellite
- ASCAT SM
- SMOS SM

SMOS Neural network

SMOS TB

ECMWF Soil Analysis in IFS 46r1 (oper 11 June 2019)
EDA SEKF and SMOS NN DA impact

- **Enhanced coupling:**
  - Use the EDA to compute the SEKF Jacobian
  - assimilate soil moisture from SMOS in coupled land-atmosphere forecasting system

- **Improved efficiency:**
  - CPU reduction (factor 3.6) from EDA SEKF, cost neutral for SMOS

Atmospheric impact (T2m)

Confidence range 95% with AR(2) inflation and Sidak correction for 8 independent tests

de Rosnay et al, in prep, 2019
SMOS neural network data assimilation: Fit between IFS first guess and independent observations (obs-model)

Aircraft humidity (JJA 2017)

Aircraft temperature (JJA 2017)

Improved fit in low troposphere
Evaluation of surface and root zone soil moisture against in situ data

More than 300 stations in US and Europe (SCAN, USCRN, SNOTEL and SMOSMANIA)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>surface</th>
<th>R root Zone</th>
<th>Ranom Surface</th>
<th>Ranom root zone</th>
<th>uRMSD surface</th>
<th>uRMSD root zone</th>
<th>Bias surface</th>
<th>Bias root zone</th>
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</thead>
<tbody>
<tr>
<td>CTRL (45r1)</td>
<td>0.617</td>
<td>0.65</td>
<td>0.518</td>
<td>0.428</td>
<td>0.052</td>
<td>0.031</td>
<td>0.06</td>
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<td>SMOS DA</td>
<td>0.609</td>
<td>0.667</td>
<td>0.507</td>
<td>0.443</td>
<td>0.052</td>
<td>0.030</td>
<td>0.058</td>
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<tr>
<td>SMOS+EDA (46r1)</td>
<td>0.623</td>
<td>0.64</td>
<td>0.521</td>
<td>0.421</td>
<td>0.051</td>
<td>0.029</td>
<td>0.055</td>
<td>0.052</td>
</tr>
</tbody>
</table>

Slight but consistent improvement of soil moisture with SMOS+EDA compared to CTRL
Summary and perspectives

- **Operational** SMOS Neural Network assimilation in the ECMWF IFS in IFS cycle 46r1 from June 2019
- **Research and development**: SMOS Neural network impact study on flood and fire forecasting for the Copernicus Emergency and Management Service (CEMS)

**FIRE**
- SMOS-NN soil moisture product will be used to identify dry lightning (ignition potential)
- SMOS-NN soil moisture product will be used to study the modulation of fire emissions
- SMOS biomass load product will be used to characterise the available fuel for burning

**FLOOD**
- Benchmarking SMOS Soil Moisture with Analysis and Re-Analysis Datasets
- SMOS Soil Moisture Initialisation in EFAS (Europe) & GloFAS (global) flood forecast systems
- Flood Susceptibility and the Role of Soil Moisture Excess