Review of satellite data usage for soil moisture analyses at ECMWF

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Introduction: Land Surface for Numerical Weather Prediction (NWP)

Land surfaces:

- **Boundary conditions** at the lowest level of the atmosphere
- **Processes**: Continental hydrological cycle, interaction with the atmosphere on various time and spatial scales
- **Strong influence on near surface weather conditions**, whose high quality forecast is a key objective in NWP

→ **Land surface processes modelling & initialization** are important for NWP at all range (short to seasonal)


Trenberth et al. (2007)
Forecasts Model: GCM including the H-TESSEL land surface model (fully coupled)

Data Assimilation ➔ initial conditions of the forecast model prognostic variables
- 4D-Var for atmosphere
- Land Data Assimilation System
Several Systems, including:

- **NWP (oper):** IFS (with 4D-Var and LDAS), 16km, version 41r1 (2015)
- **ERA-Interim:** IFS (with 4D-Var and LDAS), 79km, version 31r1 (2006)
- **ERA5 (next reanal.):** IFS (with 4D-Var and LDAS), 32km, version 41r2 (2016)
- **ERA-Interim-Land:** 79km
- **ERA5-Land:** HighRes TBD

**Data Assimilation** → initial conditions of the forecast model prognostic variables
- 4D-Var for atmosphere
- Land Data Assimilation System

**Forecast Model:** GCM including the H-TESSEL land surface model (fully coupled)

**Weakly coupled DA**

H-TESSEL LSM simulations forced by ERA

⇒ model only: no LDAS
ECMWF Land Data Assimilation System (LDAS)

**Soil moisture (SM)**

**Methods:**
- 1D Optimal Interpolation in ERA-Interim
- Simplified Extended Kalman Filter (EKF) for NWP and for ERA5

**Conventional observations:** Analysed SYNOP 2m air rel. humidity and air temp.

**Satellite data:** Scatterometer for NWP (ASCAT) & for ERA5 (ERS/SCAT & ASCAT)

SMOS brightness temperature in dvpt, research NASA SMAP

**Snow depth**

Methods: 2D Optimal Interpolation (OI) for NWP & for ERA5, Cressman interpolation for ERA-Interim

Observations: *in situ* snow depth and NOAA/NESDIS IMS Snow Cover

**Soil Temperature and Snow Temperature**

1D-OI using T2m analysis increments
Soil Analysis in the IFS

NWP Forecast
Coupled Land-Atmosphere

Soil Analysis (SEKF)
Soil Moisture L1, L2, L3

\[ \sigma^o_{T2m} = 1K \]
\[ \sigma^o_{RH2m} = 4\% \]
\[ \sigma^b = 0.01 \text{m}^3\text{m}^{-3} \]
\[ \sigma^o_{ASCAT} = 0.05 \text{m}^3\text{m}^{-3} \]

Screen level analysis (OI)

\[ \sigma^o_{T2m} = 2K \]
\[ \sigma^o_{RH2m} = 10\% \]

→ Operational soil moisture data assimilation: combines SYNOP and satellite data
ASCAT Soil Moisture data assimilation

Innovation (Obs-model)
25-30 June 2013

ASCAT (m³/m³)

Accumulated Increments (m³/m³)
in top soil layer (0-7 cm)

Due to ASCAT

Due to SYNOP T2m and RH2m

ASCAT Soil Moisture data assimilation

Accumulated Increments (m³/m³)
in top soil layer (0-7 cm)

Due to ASCAT

Due to SYNOP T2m and RH2m
Future ECMWF Re-analysis (ERA5)  
Assimilation of Scatterometer soil moisture data  
ERS/SCAT and MetOpA/B ASCAT

Use of EUMETSAT ASCAT-A reprocessed data (25km sampling)

<table>
<thead>
<tr>
<th></th>
<th>FG departure Mean $m^3m^{-3}$</th>
<th>FG departure StDev $m^3m^{-3}$</th>
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</thead>
<tbody>
<tr>
<td>Using NRT ASCAT</td>
<td>0.013</td>
<td>0.05</td>
</tr>
<tr>
<td>Using Reproc ASCAT</td>
<td>0.006</td>
<td>0.044</td>
</tr>
</tbody>
</table>

→ Reprocessed ASCAT has reduced background departure statistics both in mean and Stdev

ERA5 production (C3S) started (will be available end of 2017)

ASCAT surface soil moisture first guess departure (Obs-Model) in $m^3/m^3$ for JJAS 2014
**Evaluation of SM-DAS-2/H14**

Surface and root zone liquid soil moisture content

<table>
<thead>
<tr>
<th>Accuracy requirements for product SM-DAS-2 [R]</th>
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<tbody>
<tr>
<td><strong>Unit</strong></td>
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<td>Dimensionless</td>
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</table>

Scatterometer root zone soil moisture products based on data assimilation in dedicated LDAS suites

Observation (5cm) SM-DAS-2 (0-7cm)

200 stations across the USA
SMOS Forward modelling and Bias correction

- Comparison between ECMWF TB and SMOS NRT TB
- Consistent improvement of SMOS data at Pol xx and yy, for incidence angles 30, 40, 50 degrees
SMOS data assimilation in the IFS

Normalized change in rms of fc error:

- **Config.1**
- **Config.2**
- **Config.3**

Based on short experiments
Longer experiment under evaluation
New level 2 SMOS NRT Soil Moisture product based on Neural Networks

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 [link]
also on EUMETCAST and GTS

Comparison between L2 NRT and L2 v6.20 soil moisture

Evaluation against in situ stations (USCRN and SCAN)
→ median correlation of 0.71
Impact of soil vertical resolution for satellite soil moisture

Tests to investigate possible H-TESSEL soil resolution increase:
H-TESSEL top soil layer 0-7cm replaced by 3 layers 0-1cm, 1-3cm, 3-7cm

Impact on Anomaly Correlation with ESA-CCI satellite soil moisture

Anomaly correlation (1988-2014) measured with ESA-CCI soil moisture remote sensing (multi-sensor) product.
→ Provides a global validation of the usefulness of increase soil vertical resolution
Output from global ECMWF NWP land-surface forecast is fed into a routing model (Simplified LISFLOOD (JRC)) to produce flood forecasts – benefiting from all the improvements in the ECMWF Integrated Forecasting System (model and assimilation)!
Summary

- **ASCAT SM:** DA operational since May 2015 at ECMWF (also operational at UKMO, KMA)
- **L-band TB:** SMOS data assimilation in the IFS, SMAP Early Adopter
- **SMOS SM:** NRT (NN) processor implemented at ECMWF
- **Reanalyses:** ERA5 use of Scatterometer series ERS/SCAT and Metop ASCAT
- **Root zone retrieval from ASCAT (H-SAF):** H14 (NRT) and H27 Climate data record
- **Flood forecasts:** benefits from overall improvements in the ECMWF IFS, including soil moisture data assimilation.
- **Longer term development for satellite observations usage:**
  - Consistent snow and SM analyses
  - Integrated hydrological variables such as river discharges
  - Observation latency: crucial for NWP applications (<3h)
  - In situ data: essential for evaluation, importance of data exchange
Thank you for your Attention!

Useful links:

ECMWF LDAS:  https://software.ecmwf.int/wiki/display/LDAS/LDAS+Home
ECMWF SMOS:  https://software.ecmwf.int/wiki/display/LDAS/SMOS
ECMWF CMEM:  https://software.ecmwf.int/wiki/display/LDAS/CMEM

ECMWF Land Surface Observation monitoring:
https://software.ecmwf.int/wiki/display/LDAS/Land+Surface+Observations+monitoring