Assimilation of land surface satellite data for Numerical Weather Prediction 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
- Crucial for near surface weather conditions, whose high quality forecast is a key objective in NWP

Land Surface Models (LSMs) prognostic variables:
- Soil moisture
- Soil temperature
- Snow mass, temperature, density

Land surface initialization
Important for NWP & Seasonal Prediction
Forecast Model: GCM including the H-TESSEL land surface model (coupled)

Data Assimilation → initial conditions of the forecast model prognostic variables
- 4D-Var for atmosphere
- Land Data Assimilation System
Introduction: Land Surface Data Assimilation (LDAS)

Snow depth
- Methods: Cressman (DWD, ECMWF ERA-I), 2D Optimal Interpolation (OI) (ECMWF, CMC, JMA)
- **Conventional observations**: *in situ* snow depth
- **Satellite data**: NOAA/NESDIS IMS Snow Cover

Soil moisture (SM)
- Methods:
  - 1D Optimal Interpolation (Météo-France, ALADIN and HIRLAM)
    Analytical nudging approach (BoM), EnsOI CMC
  - Simplified Extended Kalman Filter (EKF) (DWD, ECMWF, UKMO)
- **Conventional observations**: Analysed SYNOP 2m air relative humidity and air temp.
- **Satellite data**: EUMETSAT ASCAT soil moisture (UKMO, ECMWF),
  ESA SMOS brightness temperature development (ECMWF, UKMO, CMC),
  NASA SMAP development

Soil Temperature and Snow Temperature 1D-OI using analysed T2m as observation
**Snow data assimilation**

**Snow Model:** Component of H-TESSEL

(Balsamo et al., JHM 2009, Dutra et al., 2010)
- Snow water equivalent SWE (m), ie snow mass
- Snow density $\rho_s$, between 100 and 400 kg/m³

**Observations:**
- Conventional snow depth data: SYNOP and National networks
- Snow cover extent: NOAA NESDIS/IMS daily product (4km)

de Rosnay et al, ECMWF News Letter 143, Spring 2015

- Ongoing COST action on snow (HarmoSnow)
- GCW Snow Watch action on snow

**Data Assimilation Approach:**
Optimal Interpolation (OI) in oper IFS

de Rosnay et al, Survey of Geophysics 2014
Snow analysis: Forecast impact

**Revised IMS snow cover data assimilation**

**Impact on snow** October 2012 to April 2013 (using 251 independent observations)

**Impact on atmospheric forecasts**
October 2012 to April 2013 (RMSE new-old)

→ Consistent improvement of snow and atmospheric forecasts

de Rosnay et al., ECMWF NL 143, Spring 2015
Operational snow analysis: winter 2014-2015

Snow monitoring:

Soil Analysis in the IFS

NWP Forecast
Coupled Land-Atmosphere

T_2m RH_2m bg
SWVL1, SWVL2, SWVL3 bg
Jacobians, screen obs operator

Screen level analysis (OI)
T_2m RH_2m
\( \sigma^o_{T2m} = 2K \) \( \sigma^o_{RH2m} = 10\% \)

Soil Analysis (SEKF)
SWVL1, SWVL2, SWVL3
\( \sigma^o_{T2m} = 1K \) \( \sigma^b = 0.01 m^3 m^{-3} \)
\( \sigma^o_{RH2m} = 4\% \) \( \sigma^o_{ASCAT} = 0.05 m^3 m^{-3} \)

ASCAT SM OBS

ASCAT operational implementation
→ Operational soil moisture data assimilation: combines SYNOP and satellite data

Note: Only two NWP centres use satellite soil moisture in operations (UKMO and ECMWF)
ASCAT Soil Moisture data assimilation

Innovation (Obs-model)
25-30 June 2013

ASCAT (m³/m³)

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

Due to ASCAT

Due to SYNOP T2m and RH2m
ASCAT Soil Moisture data assimilation

Volumetric Soil Moisture increments (m³/m³) (accumulated)

Layer1 (0-7cm)
Layer2 (7-28cm)

ASCAT more increments than SYNOP at surface
SYNOP give more increments at depth
→ For 12h DA window, link obs to root zone stronger for T2m,RH2m than for surface soil moisture observations

Layer1:
Most increments due to ASCAT

Layer2:
Most increments due to SYNOP T2m & RH2m

Vertically integrated Soil Moisture increments (stDev in mm)

<table>
<thead>
<tr>
<th>Layer</th>
<th>SYNOP</th>
<th>ASCAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>0.68</td>
<td>1.43</td>
</tr>
<tr>
<td>Layer 2</td>
<td>1.48</td>
<td>0.68</td>
</tr>
<tr>
<td>Layer 3</td>
<td>4.28</td>
<td>0.46</td>
</tr>
</tbody>
</table>
ERA5 preparation
Assimilation of ASCAT reprocessed SM data

Surface data assimilation in the future reanalysis ERA5
Preparatory tests using operational and reprocessed data sets

<table>
<thead>
<tr>
<th></th>
<th>FG departure Mean m³m⁻³</th>
<th>FG departure StDev m³m⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL</td>
<td>0.013</td>
<td>0.05</td>
</tr>
<tr>
<td>REPROC</td>
<td>0.006</td>
<td>0.044</td>
</tr>
</tbody>
</table>

-Reprocessed ASCAT soil moisture:
Reduced background departure statistics both in mean and Stdev

Ongoing tests to use ERS reprocessed soil moisture DA
→ ERA5 will assimilate scatterometer soil moisture for 1991-present

Also use the reprocessed IMS snow cover 4km product (2004-present)
EUMETSAT H-SAF soil moisture

Scatterometer root zone soil moisture based on data assimilation

H14/SM-DAS-2: NRT product operational since July 2012
H27/SM-DAS-3: Thematic Data Record SCAT root zone soil moisture for 1992-2014

Based on Surface-only Land Data Assimilation System:
Assimilation of ASCAT reprocessed data and screen level analysed T2M, RH2M

Albergel et al.
Evaluation of SM-DAS-2/H14
Surface and root zone liquid soil moisture content

Accuracy requirements for product SM-DAS-2 [R]

<table>
<thead>
<tr>
<th>Unit</th>
<th>Threshold</th>
<th>Target</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensionless</td>
<td>0.50</td>
<td>0.65</td>
<td>0.80</td>
</tr>
</tbody>
</table>

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

200 stations across the USA
SMOS Forward modelling and Bias correction

- **CMEM: ECMWF Community Microwave Emission Modelling Platform** → produce reanalysed ECMWF SMOS TB for 2010-2013
- Comparison between ECMWF TB and SMOS reprocessed data
- **Consistent improvement of SMOS data** at Pol xx and yy, for incidence angles 30, 40, 50 degrees

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de Rosnay et al, in prep RSE

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**Anomaly correlation**

![Graph showing anomaly correlation over polarisation (x or Y) and incidence angle (30, 40, 50)]

**RMSE**

![Graph showing RMSE over polarisation (x or Y) and incidence angle (30, 40, 50)]
Preparation for operational assimilation of SMOS $T_B$

**CTRL (operational system)**: $T^{2m}$, $RH^{2m}$, ASCAT

**Observation error ($R$):**
- $T^{2m} \Rightarrow \sigma(T_{2m}) = 1 \text{ K}$;  $RH^{2m} \Rightarrow \sigma(RH_{2m}) = 4\%$;
- ASCAT $\Rightarrow \sigma(SM_{ASCAT}) = 0.05 \text{ m}^3\text{m}^{-3}$
- SMOS $T_B \Rightarrow \sigma(T_B) = 6 + p \cdot \text{rad\_acc K}$

**Background error ($B$):**

<table>
<thead>
<tr>
<th>Depth</th>
<th>$\epsilon$</th>
<th>Water Content</th>
<th>$\text{m}^3\text{m}^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-7 cm</td>
<td>$20%$ WHC</td>
<td>$0.03-0.08$</td>
<td></td>
</tr>
<tr>
<td>7-28 cm</td>
<td>$10%$ WHC</td>
<td>$0.015-0.04$</td>
<td></td>
</tr>
<tr>
<td>28-72 cm</td>
<td>$5%$ WHC</td>
<td>$0.008-0.02$</td>
<td></td>
</tr>
</tbody>
</table>

**Config.1**
- $p=1 \sim [8.5-10] \text{ K}$

**Config.2**
- $p=1 \sim [8.5-10] \text{ K}$

**Config.3**
- $p=3 \sim [13.5-18] \text{ K}$

Muñoz-Sabater et al.
SMOS data assimilation impact on atmospheric scores

Normalized change in rms of fc error:

**SH- extratropics**

**Tropics**

**NH- extratropics**

**Configuration 3**

Muñoz-Sabater et al.
An official ESA Near-Real-Time product based on Neural Networks

NRT prototype designed and evaluated by CESBIO (Rodriguez-Fernandez et al.)

SMOS NRT SM vs SMOS L3 SM:
Average temporal correlation = 0.8

Average stats vs USDA SCAN in situ measurements better than SMOS L3

<table>
<thead>
<tr>
<th>Input</th>
<th>STD</th>
<th>R</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>NN</td>
<td>0.049</td>
<td>0.55</td>
<td>-0.024</td>
</tr>
<tr>
<td>SMOS L3</td>
<td>0.064</td>
<td>0.50</td>
<td>-0.026</td>
</tr>
</tbody>
</table>

NRT operational implementation in progress at ECMWF (Muñoz-Sabater et al.)

- A SM product very similar to the current operational one but in Near-Real-Time
- ESA product distributed by GTS and EUMETCAST

More information in the poster by Rodriguez-Fernandez et al.
Summary

• Most NWP centres analyse soil moisture and/or snow depth
• Satellite data used for snow cover and soil moisture analyses
  • Snow: NOAA NESDIS/IMS 4km snow cover data (multi-sensor product). No Snow Water Equivalent products used for NWP (yet)
• Soil moisture: ASCAT operational since May 2015 at ECMWF.
• SMOS TB: preparation and tests for NWP, SMAP developments
• SMOS SM: NRT processor implementation
• Observation latency: crucial for NWP applications (<3h)
• Longer term development for satellite observations usage:
  - Use of MW data to analyse snow depth
  - Integrated hydrological variables such as river discharges
Thank you for your Attention!

Contact: Patricia.Rosnay@ecmwf.int

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