Evaluation of remotely sensed and modelled soil moisture products using global ground-based in situ observations

C. Albergel(1), P. de Rosnay(1), G. Balsamo(1), J. Muñoz-Sabater(1), C. Gruhier(2), S. Hasenauer(3), L. Isaksen(1), Y. Kerr(2), W. Wagner(3)

[1] European Centre for Medium-Range Weather Forecasts (ECMWF)
[2] Centre d'Etudes Spatiales de la BIOsphère (CESBIO)
[3] Institute of Photogrammetry and Remote Sensing (IPF)
Importance of soil moisture

- Key variable in land surface analysis
  - Controls hydrological processes (runoff, evaporation, transpiration…)
  - Impacts plants growth and carbon fluxes

- Obtaining soil moisture estimates
  - Land surface modelling
  - Remote sensing (e.g. ASCAT, SMOS)
  - Combining land surface modelling and remote sensing through data assimilation
Soil moisture from remote sensing

- Provides quantitative information about the water content of a shallow near surface layer (e.g. ASCAT, SMOS)
- Main variable of interest for applications such as meteorological modelling and hydrological studies is the root-zone soil moisture
- Accurate retrieval requires to account for physical processes

SM-DAS-2 : Root zone retrieval based on Data Assimilation
ASCAT SM data assimilation: SM-DAS-2

ECMWF Atmospheric conditions

SYNOP T2m RH2m

EKF Soil Moisture Analysis

SM-DAS-2: Soil Moisture Profile

SM-OBS: ASCAT Surface SM

4 layers: 0-7cm, 7-28 cm, 28-100 cm & 100-289cm

H-SAF CDOP: SM-DAS-2 Production chain
# Evaluation of 3 soil moisture products

<table>
<thead>
<tr>
<th>Soil Moisture data set</th>
<th>Type</th>
<th>Soil layer depth (cm)</th>
<th>Spatial resolution</th>
<th>Number of stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF SM-DAS-2</td>
<td>NWP analysis</td>
<td>0-7</td>
<td>~25 km (T799)</td>
<td>Global product</td>
</tr>
<tr>
<td>ASCAT</td>
<td>Remotely sensed product</td>
<td>C-band, ~0.5-2</td>
<td>~25 km</td>
<td>Global product</td>
</tr>
<tr>
<td>SMOS level 2 product</td>
<td>Remotely sensed product</td>
<td>L-band, ~5</td>
<td>~40 km</td>
<td>Global product</td>
</tr>
</tbody>
</table>

- **ASCAT**: NRT data and disseminated to NWP community via EUMETSAT
- **SMOS**: level 2 product, i.e. SSM, produces at CESBIO
In situ SSM: 252 stations available in 2010
Clément Albergel September 2011

SM-DAS-2 ASCAT SMOS

REMEDHUS (Spain) 0.79 0.57 0.52
OZNET (Australie) 0.82 0.80 0.74
SMOSMANIA (France) 0.83 0.52 0.44
Clément Albergel September 2011

Soil Moisture data set

Correlation [-]

<table>
<thead>
<tr>
<th>Soil Moisture data set</th>
<th>Correlation [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCRS-SCAN (US)</td>
<td>0.65 0.48 0.51</td>
</tr>
</tbody>
</table>

Graphs a) b) c) show correlation plots for different soil moisture data sets: SM-DAS-2, ASCAT, and SMOS. The correlation coefficients are indicated in the table.
<table>
<thead>
<tr>
<th>Level of correlation</th>
<th>NCRS-SCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SM-D</td>
</tr>
<tr>
<td>Inadequate (%)</td>
<td>R&lt;0.2</td>
</tr>
<tr>
<td>Poor (%)</td>
<td>0.2&lt;R&lt;0.5</td>
</tr>
<tr>
<td>Fair (%)</td>
<td>0.5&lt;R&lt;0.7</td>
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<tr>
<td>Good (%)</td>
<td>R&gt;0.7</td>
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Comparison of the Anomaly time-series soil moisture data set

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<tr>
<td></td>
<td>SM-D</td>
</tr>
<tr>
<td>Winter</td>
<td>0.70</td>
</tr>
<tr>
<td>Spring</td>
<td>0.65</td>
</tr>
<tr>
<td>Summer</td>
<td>0.53</td>
</tr>
<tr>
<td>Autumn</td>
<td>0.62</td>
</tr>
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</table>

- Representativeness of local rainfall could induce discrepancies when compared to coarse resolution products.
- Assimilation of rain-gauge rainfall accumulation is an ongoing activity.

Analysis

In situ
Global evaluation

- Good performances of the three products to capture surface soil moisture annual cycle as well as short term variability

- Results particularly encouraging over the Oznet network
  - does not seem to be affected by RFI
  - dense vegetation canopies → reduced sensitivity to soil moisture
  - land use is predominantly agricultural → significant fraction of bare soil and/or of dry vegetation

<table>
<thead>
<tr>
<th>Soil Moisture data set</th>
<th>Correlation [-]</th>
<th>Bias [-]</th>
<th>RMSD [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SM-D</td>
<td>ASC</td>
<td>SMO</td>
</tr>
<tr>
<td>All stations</td>
<td>0.70</td>
<td>0.53</td>
<td>0.54</td>
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Towards a root zone soil moisture product

- ECMWF SSM, good correlations, high biases and RMSD
- Spatial variability of in situ SSM very high and differences in soil properties could imply difference in the mean and the variance on SSM
- The true information content of modelled SSM not relies in their absolute magnitudes but in their time variation, i.e. the time-integrated impact of antecedent meteorological forcing

Good level of correlation of ECMWF SSM is supportive of the development of a root zone soil moisture index
Use of ASCAT within the EKF

- Small/Neutral impact of ASCAT SSM assimilation
- ASCAT required that the data are rescaled to the model climatology (CDF matching, Scipal et al., 2008)
- Improved CDF matching is expected, with H-TESSEL corrected from precipitation errors
- New ASCAT data processed by EUMETSAT (lower product noise level, 18/08)

There is room for improvement!
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Statistical comparison

- ‘Classic’ scores: R, bias, RMSD
- Normalised standard deviation \( SDV = \frac{\sigma_{analyse}}{\sigma_{in\ situ}} \)
- Centred RMSD normalised by in situ standard deviation \( E^2 = \frac{(rmsd^2 - Bias^2)}{\sigma^2_{in\ situ}} \)
- R, SDV and E are usually represented on Taylor diagram

(Taylor, 2001)
Taylor Diagram

- SDV is displayed as a radial distance (1)
- R as an angle in the polar plot (2)
- E is the distance to the ‘In situ’ point (3)
Implementation of the EKF (1)

- Using the EKF instead of OI significantly improved the soil moisture analysis
- The use of ASCAT SSM does not show any improvements
### Land surface model evolution

**TESSEL**
- Van den Hurk et al. (2000)
- Viterbo and Beljaars (1995)
- Viterbo et al. (1999)
- Up to 8 tiles (binary Land-Sea mask)
- GLCC veg. (BATS-like)
- ERA-40 and ERA-I scheme

**Hydrology - TESSEL**
- Balsamo et al. (2009)
- Global Soil Texture (FAO)
- New hydraulic properties
- Variable Infiltration capacity & surface runoff revision

**NEW SNOW**
- Dutra et al. (2010)
- Revised snow density
- Liquid water reservoir
- Revision of Albedo
- and sub-grid snow cover

**NEW LAI**
- Boussetta et al. (2010)
- BARE GROUND
- EVAPORATION
- FLAKE
- Mironov et al. (2010), Dutra et al. (2010), Balsamo et al. (2010)
- Extra tile (9) to account for sub-grid lakes

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Land surface data assimilation evolution

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<td><strong>OI screen level analysis</strong>&lt;br&gt;Douville et al. (2000)&lt;br&gt;Mahfouf et al. (2000)&lt;br&gt;Soil moisture analysis based on&lt;br&gt;Temperature and relative humidity analysis</td>
<td><strong>Revised snow analysis</strong>&lt;br&gt;Drusch et al. (2004)&lt;br&gt;Cressman snow depth analysis using&lt;br&gt;SYNOP data improved by using&lt;br&gt;NoAA / NSEDIS Snow cover extend data</td>
<td><strong>Structure Surface Analysis</strong>&lt;br&gt;<strong>OI snow analysis and high resolution NESDIS data (4km)</strong>&lt;br&gt;<strong>SEKF Soil Moisture analysis</strong>&lt;br&gt;Simplified Extended Kalman Filter&lt;br&gt;Drusch et al. (2009), de Rosnay et al. (2011)&lt;br&gt;METOP-ASCAT</td>
<td><strong>SMOS</strong></td>
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- SEKF (Simplified Extended Kalman Filter) surface analysis
- Use of active microwave data (ASCAT soil moisture product)
- Use of passive microwave SMOS data (Brightness Temperature product)
- New snow analysis and use of NOAA/NESDIS 4km snow cover product
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