Evaluation of ASCAT-derived near-surface soil moisture by assimilation into the SIM model

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EUMETSAT H-SAF on Support to Operational Hydrology and Water Management

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15 March 2011, GSFC
ASCAT on MetOp

ASCAT:
- Real-aperture backscatter radar: C-band (5.255 GHz)
- MetOp launched late 2006 (data available from 2007)
- Observes $\sim 80\%$ of the globe each day (two overpasses)
- $0.25^\circ$ resolution

Soil moisture retrievals:
- Change detection approach, from TU-Wien (Wagner et al, 1999)
- Surface Degree of Saturation:
  - $SDS = (\theta - \theta_{\text{min}})/(\theta_{\text{max}} - \theta_{\text{min}})$
- Near-surface observation only, $\sim 1$ cm
- Operationally supported via EUMETCAST
  - Assimilated into ECMWF’s IFS
Evaluating the ASCAT SDS

- Comparison to in situ observations from SMOSMANIA
- Comparison to soil moisture from the SIM modeling suite over France
  - SAFRAN: atmospheric analysis $\rightarrow$ forcing for ISBA
  - ISBA: land-surface model $\rightarrow$ surface energy and moisture fluxes
  - MODCOU - hydrogeological model $\rightarrow$ routes moisture fluxes through river network
- Assimilation into SIM
  - Assimilate into near-real time SIM chain
  - Assess against delayed cut-off SIM chain (3000 additional observing stations)
    - More accurate SAFRAN forcing $\rightarrow$ more accurate surface hydrology
  - Test impact on simulations of soil moisture, fluxes, and river discharge
Comparison to SMOSMANIA in situ soil moisture
SMOSMANIA monitoring network

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Evaluation of ASCAT-derived near-surface soil moisture
Timeseries at SMOSMANIA sites

SDS (% of saturation) from in situ (black), SIM (red), ASCAT (blue)
<table>
<thead>
<tr>
<th></th>
<th>SIM / SMOSMANIA</th>
<th>ASCAT / SMOSMANIA</th>
<th>ASCAT / SIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( r_{abs} )</td>
<td>( r_{anm} )</td>
<td>RMSD (%)</td>
</tr>
<tr>
<td>SBR</td>
<td>0.81</td>
<td>0.72</td>
<td>19.0</td>
</tr>
<tr>
<td>URG</td>
<td>0.67</td>
<td>0.68</td>
<td>23.7</td>
</tr>
<tr>
<td>CRD</td>
<td>0.72</td>
<td>0.56</td>
<td>25.2</td>
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<tr>
<td>PRG</td>
<td>0.67</td>
<td>0.43</td>
<td>21.9</td>
</tr>
<tr>
<td>CDM</td>
<td>0.74</td>
<td>0.57</td>
<td>19.6</td>
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<tr>
<td>LHS</td>
<td>0.70</td>
<td>0.43</td>
<td>22.4</td>
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<td>0.71</td>
<td>0.56</td>
<td>22.1</td>
</tr>
<tr>
<td>MNT</td>
<td>0.62</td>
<td>0.56</td>
<td>24.0</td>
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<tr>
<td>SFL</td>
<td>0.73</td>
<td>0.47</td>
<td>20.4</td>
</tr>
<tr>
<td>MTM</td>
<td>0.61</td>
<td>0.54</td>
<td>31.2</td>
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<tr>
<td>LZC</td>
<td>0.73</td>
<td>0.69</td>
<td>18.4</td>
</tr>
<tr>
<td>NBN</td>
<td>0.66</td>
<td>0.56</td>
<td>20.3</td>
</tr>
</tbody>
</table>

\( r_{abs} \) - absolute correlation
\( r_{anm} \) - anomaly correlation (relative to 31-day moving average)
RMSD - Root Mean Square Difference
Comparison to SIM near-surface soil moisture
SIM & ASCAT correlations

$r_{abs}$
mean: 0.69
87% grids $> 0.6$

$r_{anm}$
mean: 0.62
77% grids $> 0.6$
Evaluation of ASCAT-derived near-surface soil moisture
Assimilation of ASCAT into SIM
Interactions between Surface, Biosphere, and Atmosphere (ISBA)

Three-layer force-restore model:

- $w_1$ - near-surface soil moisture bare soil evap., $\sim 1$ cm
- $w_2$ - root-zone soil moisture transpiration, $\sim 0.5-2$ m
- $w_3$ - deep-layer soil moisture deep layer storage, $\sim 1-3$ m

Observations: $y = [w_1]$

Update vector: $x = [w_1, w_2]$
The Simplified EKF (1-D)

State forecast:

\[ x^b(t_i) = \mathcal{M}_{i-1}[x^a(t_{i-1})] \]

State update:

\[ x^a(t_i) = x^b(t_i) + K_i \left( y^o_i - \mathcal{H}_i[x^b(t_i)] \right) \]

Kalman gain:

\[ K_i = P_0 H^T_i \left( H_i P_0 H^T_i + R_i \right)^{-1} \]

- \( x^a \) - analyzed state vector
- \( x^b \) - background state vector
- \( y^o \) - observation vector
- \( P_0 \) - model background error matrix
- \( R \) - observation error matrix
- \( \mathcal{H} (H) \) - obs. operator (linearized)
- \( \mathcal{H} \) is a 24 hour ISBA forecast
Assimilation experiments

- Assimilate ASCAT SDS from January 2007 - May 2010 (SIM_ASCAT)
  - Used descending (early morning) overpass only
  - CDF-match ASCAT to SIM climatology (3.5 years)
- Assimilate into near-real time chain (SIM_NRT)
- Assess against delayed cut-off (climatological) chain (SIM_DEL)
Difference in $w_2$ from SIM_NRT & SIM_DEL

$r_{\text{abs}}$
mean: 0.95

$r_{\text{anm}}$
mean: 0.94

- Temporal behavior is very similar
- Very difficult for the assimilation to improve
Difference in $w_2$ from SIM\_NRT & SIM\_DEL

- $w_2$ bias (mm)
  - Mean: -13 mm

- RMSD (mm)
  - Mean: 18 mm

- Precip. bias (mm/year)
  - Mean: -100 mm/year

- Substantial negative bias in SIM\_NRT $w_2$
- Associated with precipitation bias
- Can assimilation correct this?
Impact on $w_2$

Mean daily $w_2$ (mm) - SIM_DEL (black), SIM_NRT (red), SIM_ASCAT (blue)

Bias / RMSD in $w_2$ (mm) - SIM_NRT (red), SIM_ASCAT (blue)

Net increment (mm / 3.5 years)

$w_2$ bias (mm)

Mean daily analysis increment (mm)
Impact on bias

$w_1$ (mm)

- Mean bias is reduced from -0.11 to -0.10 mm
  net reduction: 94% of grid-cells with ASCAT data

$w_2$ (mm)

- Mean bias is reduced from -13.3 to -7.9 mm
  net reduction at 89% of grids-cells with ASCAT data
Impact on RMSD

- Mean reduced from 0.283 to 0.279 mm reduction at 71% of grid-cells with ASCAT data
- Mean reduced from 18.1 to 17.6 mm reduction at 69% of grid-cells with ASCAT data
Impact on surface water balance

Water balance terms (mm/month) Difference from SIM_DEL (mm/month)

SIM_DEL (black), SIM_NRT (red), SIM_ASCAT (blue)
Impact on river discharge

Discharge ($m^3 day^{-1}$) from SIM_DEL (black), SIM_NRT (red), SIM_ASCAT (blue)
Discharge Ratio

Ratio = $Q_{sim}/Q_{ref}$

Mean increased from 0.68 to 0.76

Error in ratio decreased at 88% of stations
Nash-Sutcliffe Efficiency

\[ E = 1 - \frac{\sigma_{T=1}^T (Q_{\text{sim}}^t - Q_{\text{ref}}^t)^2}{\sigma_{T=1}^T (Q_{\text{ref}}^t - \bar{Q}_{\text{ref}}^t)^2} \]

- Mean increased from 0.62 to 0.68
- 82% of stations are improved
Conclusions

- The ASCAT SDS appears to provide an accurate observation of changes in near-surface soil moisture.
- Good temporal fit to in situ soil moisture observations at the SMOSMANIA sites.
- Good temporal fit to soil moisture simulated by SIM over France.
- Assimilation into SIM reduces the dry bias associated with the biased precipitation forcing.
  - Reduces the bias in the soil moisture, water budget, and river discharge.
  - ....but, is it doing this for the right reasons???
- Land-surface models are a valuable tool for evaluating novel remotely sensed soil moisture products.
For further details see H-SAF report: