Combining the EKF soil analysis with a three dimensional variational upper-air assimilation for ALARO

Rafiq Hamdi, Annelies Duerinckx, Alex Deckmyn, Piet Termonia

Original idea by J-F. Mahfouf
1. Introduction

2. Surface assimilation only

3. Combination: surface and upper air assimilation

4. Summary & Future work
For the time being surface analysis are performed separately from upper air analysis. In theory a single analysis would be better but it is much more difficult to implement:

1) definition of $B$ between upper air and surface variables,

2) time scale evolutions may be different, ...

For the time being several surface analysis are used for different surface parameters (Soil temperature and Soil moisture, Snow, SST, Sea ice, ...)

Atmospheric analysis and several surface analysis are done separately and combined to provide the final analysis for the forecast.
Surface Analysis and upper air analysis

Observation pre-processing

Observation in ODB

Background (a forecast from the previous analysis)

Statistics (Background, Observations)

Minimization conf. 131

Screening conf. 002

Upper air analysis
3-D VAR

Surface analysis
Optimum Interpolation

CANARI analysis software
conf. 701

ANALYSIS

26th ALADIN-HIRLAM workshop, 4-8th April 2016   (4/26)
Question: Whether combining surface assimilation with upper-air assimilation has an added value compared to using either of them separately?

- Randriamampianina and Storto (2008) → improvement for short forecast range
- Schneider et al. (2009) → results more mixed
- Stanesic (2011) → positive for 2m T, RH and upper air RH
- de Rosnay et al. (2012) → EKF with 4D-Var operationally at ECMWF

- Duerinckx et al. (2016) focuses on new combination EKF+3D-Var tested with ALARO-0 coupled to SURFEX
Simulation set-up

Initial Conditions

<table>
<thead>
<tr>
<th></th>
<th>Atmosphere</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Loop (OL)</td>
<td>ARPEGE analysis</td>
<td>ARPEGE analysis</td>
</tr>
<tr>
<td>Optimum Interpolation (OI)</td>
<td>ARPEGE analysis</td>
<td>OI</td>
</tr>
<tr>
<td>Extended Kalman Filter (EKF)</td>
<td>ARPEGE analysis</td>
<td>EKF</td>
</tr>
<tr>
<td>3dVar+OL</td>
<td>3dVar</td>
<td>ARPEGE analysis</td>
</tr>
<tr>
<td>3dVar+Free run</td>
<td>3dVar</td>
<td>6h fc. from prev. run</td>
</tr>
<tr>
<td>3dVar+OI</td>
<td>3dVar</td>
<td>OI</td>
</tr>
<tr>
<td>3dVar+EKF</td>
<td>3dVar</td>
<td>EKF</td>
</tr>
<tr>
<td>3dVar+OI/EKF</td>
<td>3dVar</td>
<td>OI(soil temp.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ EKF(soil moisture)</td>
</tr>
</tbody>
</table>

Prognostic Variables:
- Soil moisture content: \( W_g \) and \( W_2 \)
- Soil temperature: \( T_s \) and \( T_2 \)

Observations:
- \( T_{2m} \) and \( RH_{2m} \)
- Interpolated to model grid with CANARI

- **ALARO-0**
- **SURFEX/ISBA 2-layer version**
- One year run for 2013
- 6-hour assimilation cycle
- Operational ALADIN-Belgium domain 4km resolution
- 181x181 grid point and 46 vertical levels
- OPLACE database for 2m T & RH
- OPLACE conventional observations: wind profiler, radiosonde, aircraft data and surface synoptic observations.
EKF for soil analysis

\[
x^a_t = x^b_t + BH^T (HBH^T + R)^{-1} [y^o_t - \mathcal{H}(x^b_o)]
\]

Kalman gain (weight)  Departure (error)

\[
\begin{align*}
y^o_t & \text{ Observations (T2m, RH2m)} \\
x^b_o & \text{ Model variables (Wg, W2, Ts, T2)} \\
\mathcal{H}(x^b_o) & \text{ Model counterpart of Observations (T2m, RH2m)}
\end{align*}
\]
\[ x_t^a = x_t^b + B H^T (H B H^T + R)^{-1} [y_t^o - \mathcal{H}(x_o^b)] \]

- \( \mathcal{H} \): observation operator
  - includes a model propagation
- \( H \): Jacobian of the observation operator
  - Calculated with finite differences
  - \( H_{i,j} = \frac{\delta y_{i,t}}{\delta x_{j,t_0}} = \frac{y_i(x + \delta x_j) - y_i(x)}{\delta x_j} \)
Coupled: used for the forecast

Offline: used in the EKF to calculate the Jacobian
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Scores for 2m RH

2m Relative Humidity RMSE (Spring 2013) run 0

2m Relative Humidity RMSE (Summer 2013) run 0

2m Relative Humidity BIAS (Spring 2013) run 0

2m Relative Humidity BIAS (Summer 2013) run 0

(a) Spring 2013 (MAM)

(b) Summer 2013 (JJA)
Scores for 2m RH

2m Relative Humidity RMSE (Autumn 2013) run 0

2m Relative Humidity RMSE (Winter 2013) run 0

2m Relative Humidity BIAS (Autumn 2013) run 0

2m Relative Humidity BIAS (Winter 2013) run 0

(c) Autumn 2013 (SON)

(d) Winter 2012-2013 (DJF)
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Scores for 2m RH

2m Relative Humidity RMSE (Autumn 2013) run 0

2m Relative Humidity RMSE (Winter 2013) run 0

2m Relative Humidity BIAS (Autumn 2013) run 0

2m Relative Humidity BIAS (Winter 2013) run 0

(c) Autumn 2013 (SON)

(d) Winter 2012-2013 (DJF)
## Scores for precipitation

### Winter

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>A</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>OL</td>
<td>0.266</td>
<td>0.233</td>
<td>0.117</td>
</tr>
<tr>
<td>3D-Var+OL</td>
<td>0.267</td>
<td>0.278</td>
<td>0.121</td>
</tr>
<tr>
<td>3D-Var+free</td>
<td>0.279</td>
<td>0.281</td>
<td>0.128</td>
</tr>
<tr>
<td>3D-Var+OI</td>
<td>0.225</td>
<td>0.257</td>
<td>0.115</td>
</tr>
<tr>
<td>3D-Var+EKF</td>
<td>0.250</td>
<td>0.267</td>
<td>0.122</td>
</tr>
<tr>
<td>3D-Var+OIEKF</td>
<td>0.241</td>
<td>0.262</td>
<td>0.121</td>
</tr>
<tr>
<td>EKF</td>
<td><strong>0.212</strong></td>
<td>0.220</td>
<td><strong>0.114</strong></td>
</tr>
<tr>
<td>OI</td>
<td>0.214</td>
<td><strong>0.196</strong></td>
<td>0.115</td>
</tr>
</tbody>
</table>

### Summer

<table>
<thead>
<tr>
<th></th>
<th>S</th>
<th>A</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>OL</td>
<td>0.407</td>
<td>0.153</td>
<td>0.203</td>
</tr>
<tr>
<td>3D-Var+OL</td>
<td>0.427</td>
<td>0.232</td>
<td><strong>0.189</strong></td>
</tr>
<tr>
<td>3D-Var+free</td>
<td>0.552</td>
<td>0.339</td>
<td>0.226</td>
</tr>
<tr>
<td>3D-Var+OI</td>
<td>0.397</td>
<td>0.161</td>
<td>0.191</td>
</tr>
<tr>
<td>3D-Var+EKF</td>
<td>0.398</td>
<td>0.201</td>
<td>0.197</td>
</tr>
<tr>
<td>3D-Var+OIEKF</td>
<td>0.380</td>
<td>0.193</td>
<td>0.193</td>
</tr>
<tr>
<td>EKF</td>
<td><strong>0.363</strong></td>
<td>0.097</td>
<td>0.195</td>
</tr>
<tr>
<td>OI</td>
<td>0.369</td>
<td><strong>-0.007</strong></td>
<td>0.191</td>
</tr>
</tbody>
</table>
Summary:
1. The EKF runs are more successful in beating the Open Loop than the OI runs.

2. 3d-var is able to improve the 2m RH scores during the first 12h compared to Open Loop.

3. During winter, the combination of surface and atmospheric assimilation outperforms the runs with only surface assimilation or only upper-air assimilation.

4. During summer, the runs with only surface assimilation perform better than the runs with a combination of both.

5. Upper air scores using sounding indicate that the 3d-var is not able to get an equally well upper-air analysis as the ARPEGE interpolated atmosphere.
2m Relative Humidity RMSE (01–09 June 2014) run 0

2m Relative Humidity BIAS (01–09 June 2014) run 0
STAEKF

RMS Error (Superficial Soil Moisture Content - )

RMS Error (Mean Soil Moisture Content - )

Parametric Error (Absolute error in LAI - )