Evaluation of data impact in the mesoscale AROME 3D-Var system at Météo-France

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Outline

- Main features of the AROME forecasting system
- Observation usage for data assimilation
- Diagnostics:
  - Degrees of Freedom for Signal (Desroziers and Ivanov, 2001)
  - Reduction of error variance of estimation (Desroziers et al., 2005)
- Conclusions
Regional model AROME

- Spectral limited area non-hydrostatic model with explicit moist convection
- Heritage: ARPEGE and ALADIN NWP models – MESO-NH research model
- Operational at Météo-France since December 2008
- Horizontal resolution: 2.5 km
- 60 vertical levels (up to 1 hPa)
- 3D-Var assimilation (3h window)
- Coupling files: hourly forecasts from global model ARPEGE
- Forecast range: 30 hours
Illustration of data usage in 3D-Var (type 1)
Illustration of data usage in 3D-Var (type 2)
ARAMIS: French network of 24 Doppler radars

Radial wind

Relative humidity = F(reflectivity)
- Mean over 8 analyses per day
- Mean over 10 days in May 2010 (*fewer GPS*)

**DFS in AROME**

<table>
<thead>
<tr>
<th>DFS</th>
<th>DFS/p</th>
<th>Nombre d’observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synop</td>
<td>Airep</td>
<td>Bouee</td>
</tr>
<tr>
<td>8000</td>
<td>6000</td>
<td>4000</td>
</tr>
</tbody>
</table>

Legend:
- Geo. Tb
- Pol. Tb
- Scatt
- Pilot V
- Satob V
- Rad V
- Rad HU
- Temp V
- Temp q
- Temp T
- Bouee
- Airep V
- Airep T
- V10m
- Gpssol
- HU2m
- T2m
- pmcr
Reduction of error variance of estimation

- Analysis error covariance matrix (from linear estimation theory):
  \[ A = B - KHB \]

- Reduction of error variance of estimation:
  \[ r = Tr(B) - Tr(A) = Tr(KHB) \]

- When \( R \) is block-diagonal, \( r \) can be split between observational subsets \( i \):
  \[ r_i = Tr(K_iHB) \quad K_i = K\Pi_i^T\Pi_i \]

- A transformation \( L \) can also be applied: projection over a geographical domain, specific field or model level, specific norm, forecast model, ...
  \[ r = Tr(LKHB L^T) \]

- Estimation from a randomization technique proposed by Desroziers et al. (2005): differences between a reference analysis and analyses with perturbed observations
Some properties

- DFS has no dimension: global and synthetic measure of the informativity of observations on an analysis.

- $r$ has the dimension of the variance of a model field: comparison only for fields having the same dimension.

- When $\frac{\sigma_o}{\sigma_b}$ increases (observation weight decreases), DFS and $r$ are reduced.

- When background correlation lengths are increased:
  - DFS is reduced: each observation has less freedom to modify the background independently from the others.
  - $r$ is increased: each observation modifies the background and reduces the variance over a wider domain.
Validation of the computation

- In the optimal case:
  \[ r = Tr(B) - Tr(A) = Tr(KHB) \]

Prescribed Estimated from
Estimated from
an ensemble of analyses the proposed
method

\textbf{a)}

\begin{tabular}{c c c}
\hline
\textbf{Variable} & \textbf{Graph} \\
\hline
T & \includegraphics[width=0.3\textwidth]{T_graph} \\
q & \includegraphics[width=0.3\textwidth]{q_graph} \\
wind & \includegraphics[width=0.3\textwidth]{wind_graph} \\
\hline
\end{tabular}

\textbf{b)}

\begin{tabular}{c c c}
\hline
\textbf{Variable} & \textbf{Graph} \\
\hline
Pression (hPa) & \includegraphics[width=0.3\textwidth]{pressure_graph} \\
Variance (K^2) & \includegraphics[width=0.3\textwidth]{variance_graph} \\
Variance (m^2.s^{-2}) & \includegraphics[width=0.3\textwidth]{wind_variance_graph} \\
\hline
\end{tabular}
Observations having the largest contribution: surface data, AIREP, radar.
Day to day variability

Larger reduction during rainy periods coming from radar radial winds

Reduction de variance (K²)

Reduction de variance (kg².kg⁻²)

T 850-950 hPa

T 450-550 hPa

q 850-950 hPa

q 700-800 hPa

Geo. Tb
Pol. Tb
Scatt
Pilot V
Satob V
Rad V
Rad HU
Temp V
Temp q
Temp T
Bouee
Airep V
Airep T
V10m
Gpssol
HU2m
T2m
pmer

Toujours un temps d'avance
Dependency with analysis time

b) 12 UTC

c) 21 UTC

a) 00 UTC

METEOR FRANCE
Toujours un temps d'avance
Over sea, the variance reduction reaches only 25-30% of the total variance.
Summary

- Presentation of the convection-permitting model AROME with a RUC 3D-Var system (opérational at Météo-France since end 2008)
- Presentation of a posteriori diagnostics: DFS and reduction of error variance
- Observations having the most important impact at mesoscale: surface data (SYNOP + GPS), radar (wind and humidity), aircrafts
- Variability of reduction of error variance:
  - From day to day: stable except for radar observations
  - Contributing observations depend upon analysis time (AIREP vs. TEMP)
  - Dependency with surface type (land/sea)
- Spectral decomposition:
  - Reduction of error variance is maximum near the max of spectral variance (observations correct the most relevant scales)
  - For scales below 200 km only GPS and radar data contribute to the reduction of error variance
Conclusions: data usage at mesoscale

- Mesoscale data assimilation: need for observations with high spatial and temporal resolutions (AROME: 2.5 km / 3 hours => near future 1.25 km / 1 hour)
- Over Europe: largest data impact come from non-satellite observations including networks coordinated and supported by EUCOS and EUMETNET optional programmes:
  - Ground based GPS: E-GVAP
  - Aircraft reports: E-AMDAR
  - Radar winds and reflectivity: OPERA
- Needs: improved exchange of radar data (current OPERA status not sufficient) – Exchange of more SYNOP type surface observations. Diagnostics on observation error correlations: to increase spatial and temporal densities of observations (e.g. current radar thinning at 15 km)