Radar and lightning data assimilation: the impact of different setting options discussed for a heavy precipitation event occurred in Italy

R. C. Torcasio\textsuperscript{1}, S. Federico\textsuperscript{1}, S. Puca\textsuperscript{2}, M. Petracca\textsuperscript{2}, G. Vulpiani\textsuperscript{2}, L. Baldini\textsuperscript{1}, S. Dietrich\textsuperscript{1}

\textsuperscript{1} ISAC-CNR, via del Fosso del Cavaliere 100, 00133 Roma
\textsuperscript{2} Dipartimento Protezione Civile Nazionale Ufficio III - Attività Tecnico Scientifiche per la Previsione e Prevenzione dei Rischi, 00189 Roma
Very Short-term Forecast (VSF) configuration

8 forecast for every day, lasting 9 hours each. Each forecast consists of an assimilation period of 6 hours followed by a VSF period 3 hours long.
Lightning assimilation – 3DVar

A relative humidity pseudo-profile is generated when/where lightning is observed:

\[
RH: \begin{cases} 
NO\ DATA & z < z_{LCL} \\
100\% & z_{LCL} \leq z \leq z_{-25^\circ C} \\
NO\ DATA & z > z_{-25^\circ C}
\end{cases}
\]

This relative humidity pseudo-profile is assimilated by RAMS-3DVar once the relative humidity has been converted in water vapor mixing ratio:

\[
J(x) = \frac{1}{2} (x - x_b)^T B^{-1} (x - x_b) + \frac{1}{2} [H(x) - y_o]^T R^{-1} [H(x) - y_o]
\]

The background error matrix is computed by the NMC method which considers one month of simulations.
**Radar reflectivity data assimilation – 3DVar**

\[ y_{po}^U = \sum_i x_i^U \sum_j W_i \]

\[ W_i = \exp \left\{ -\frac{1}{2} [y_0 - h(x_i)]^T R^{-1} [y_0 - h(x_i)] \right\} \]

\[ J(X) = \frac{1}{2} (X - X_b)^T B^{-1} (X - X_b) + \frac{1}{2} [Y - H(X)]^T R^{-1} [Y - H(X)] \]

An example: 00 UTC 17/11/2019

RADAR CAPPI of the national radar composite at 2000m, 3000m, 4000m and 5000m are assimilated.

Caumont et al., 2010, Tellus 62A
Simulations considered for this case study

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
<th>Data assimilated</th>
<th>Model variable impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL</td>
<td>Control run</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>RAD</td>
<td>RADAR data assimilation</td>
<td>Reflectivity factor CAPPI (RAMS-3DVar)</td>
<td>Water vapour mixing ratio</td>
</tr>
<tr>
<td>LIGHT</td>
<td>Lightning data assimilation</td>
<td>Lightning density (RAMS-3DVar)</td>
<td>Water vapour mixing ratio</td>
</tr>
<tr>
<td>RADLI</td>
<td>RADAR + lightning data assimilation</td>
<td>Reflectivity factor CAPPI (RAMS-3DVar) + Lightning density (RAMS-3DVar)</td>
<td>Water vapour mixing ratio</td>
</tr>
</tbody>
</table>

**OBS**: observations

Forecasted and observed precipitation have been compared using the nearest neighborhood method employing a search radius of $2 \cdot \Delta x \cdot \sqrt{2} \sim 8.5$ km
Data assimilation impact on the precipitation forecast.

Positive aspects:
- Better precipitation forecast in southern Lazio for lightning and radar data assimilation
- Eastern shift of the precipitation pattern in northern Italy

Negative aspect:
- Tendency to overestimate rainfall in Lombardia (especially for radar reflectivity data assimilation)
The performance of RAMS@ISAC model has been evaluated using qualitative score (FBIAS, POD, ETS, FAR) computed from dichotomous contingency computed for all the 8 VSF of the 17 November 2019.
Conclusions

This case study shows the impact of lightning and radar reflectivity data assimilation on the very short-term forecast of RAMS@ISAC model for a case study reasonably predicted by the CTRL forecast. Both data are assimilated using 3DVar.

Despite the good performance of the CTRL forecast:
• lightning and radar reflectivity improve the forecast (ETS) up to 40 mm/3h and 30 mm/3h respectively, while for largest thresholds the impact is smaller;
• the result for the simulation assimilating both radar and lightning is similar to that for radar data assimilation.

The worsening of the performance of for LIGHT, RAD and RADLI at the largest thresholds is caused by the increase in false alarms.
All simulations with lightning and/or radar reflectivity data assimilation have a better POD in comparison with CTRL.

Acknowledgments: LINET data were provided by Nowcast GmbH (https://www.nowcast.de/) within a scientific agreement between H.D. Betz and the Satellite Meteorological Group of CNR-ISAC in Rome. This research was partially funded by the agreement between the Department of Civil Protection and ISAC-CNR.