Assimilation of ground-based rainfall observations in ECMWF’s global 4D-Var system

Philippe Lopez, ECMWF

Special thanks to P. Bauer, A. Geer, A. Fouilloux and D. Salmond (ECMWF)

- NCEP Stage IV (NEXRAD) rainfall data assimilation.
- SYNOP rain gauge assimilation.
- Summary and prospects.

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Direct 4D-Var assimilation of NCEP Stage IV rain data 
(Lopez 2011, MWR)

Observations:
• NCEP Stage IV radar + gauge precipitation product (4-km resol.).
• Data are averaged to model resolution prior to the assimilation.
• Domain: eastern USA.
• 6-hour accumulations are assimilated → smoother & more linear (4D-Var).
• Ln(RR_{6h}[mm h^{-1}]+1) transform (background departures closer to Gaussian).

Quality control:
• Obs rejected in regions with either rugged orography, surface snowfall or ducting.
• Only points that are rainy in both background and obs are assimilated.
• Fixed observation error: σ_o = 0.18 (in log-space).
• Variational bias correction applied (Dee and Uppala, 2009).

→ In ECMWF’s operations since 15 November 2011.
Direct 4D-Var assimilation of NCEP Stage IV rain data

- Improvement in short-range precipitation forecasts (up to 24h range).
- Impact on forecast scores for atmospheric parameters ($Z_T$ wind, RH):
  - neutral or slightly positive impact on the global scale.
  - some hint of a downstream positive impact over Europe and Asia.

\[ \Delta \text{RMSE North. Hemis. 500hPa wind} \]
\[ \Delta \text{RMSE Europe 500hPa temperature} \]
\[ \Delta \text{RMSE South. Hemis. 500hPa wind} \]
\[ \Delta \text{RMSE Asia 850hPa temperature} \]
Direct 4D-Var assimilation of SYNOP rain gauges
(Lopez 2012, MWR, submitted)

• Based on the developments made for radar rain data assimilation (e.g. possibility to assimilate accumulated rainfall obs.).

Observations:
• SYNOP station 6-hour precipitation accumulations.
• Data are superobbed to model resolution prior to the assimilation.
• Domain: extratropics (too large errors in the tropics?).
• $\ln(\text{RR}_{6h}\text{[mm h}^{-1}] + 1)$ is actually assimilated in 4D-Var.
Direct 4D-Var assimilation of SYNOP rain gauges

Quality control:
• **Obs rejected** in regions with **rugged orography, snowfall** or **strong winds**.
• All points that are **rainy in either background or obs** are assimilated.

• Crude parametrization of **representativity error** (seasonal variations).
• Fixed contribution from other sources: $\sigma_{other} = 0.05$ (in log-space).

• **Wind-induced error bias correction** (based on Nešpor and Sevruk, 1999):

• Fixed bias correction $BC = f(RR)$, for other sources of bias.
Direct 4D-Var assimilation of SYNOP rain gauges

Experimental set-up:

Two 4D-Var assimilation global experiments were run:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Resolution</th>
<th>Period</th>
<th>Observational coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERA_CTRL</td>
<td>T511 L91 (~40 km)</td>
<td>Apr-Jun 2011</td>
<td>SYNOP Psurf only</td>
</tr>
<tr>
<td>ERA_NEW</td>
<td>T511 L91 (~40 km)</td>
<td>Apr-Jun 2011</td>
<td>SYNOP Psurf + RGs (6h)</td>
</tr>
</tbody>
</table>

→ to mimic ECMWF’s future reanalysis of the early 20\textsuperscript{th} century.

→ to assess the potential impact of rain gauge assimilation when the coverage in other observations is sparse.

~ 600 rain gauge superobs were assimilated per 4D-Var cycle (every 12 h).
4D-Var assimilation of SYNOP rain gauges

Number of used RG superobs per 2° x 2° box and per 4D-Var cycle
T511 L91 experiment ERA_NEW (Apr-Jun 2011)
Results from pseudo-ERA experiments with RGs (1)

Forecast anomaly correlation (w.r.t. operational analyses) as a function of forecast range (0 to 10 days) (Apr-Jun 2011).

- **Z 500hPa Europe**
- **T 850hPa Europe**
- **Z 500hPa N. America**
- **T 500hPa N. America**

**Operations (all obs)**
**ERA_NEW (Ps + RGs)**
**ERA_CTRL (Ps only)**

→ Positive impact of RG assimilation, esp. over Europe.

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Results from pseudo-ERA experiments with RGs (2)

Correlation of short-range forecast 10.8 μm brightness temperatures with Meteosat-9 imagery over Europe (Apr-Jun 2011):

Higher correlations → improved spatial distribution of clouds when SYNOP RGs are assimilated.

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Summary and prospects

Ground-based precipitation radars:
- NCEP Stage IV 6-hourly rainfall accumulations are now assimilated in ECMWF’s operational 4D-Var.
- Plans: to use other radar networks (Europe, Japan, China,…) (issue of data policy).

Rain gauges:
- 4D-Var data assimilation of SYNOP 6-hour RG accumulations can have a significant positive impact on medium-range forecast scores when coverage in other observations is sparse.
- This might be beneficial in the context of future 20th century reanalyses.
- Plans: to test 4D-Var with 24h accumulations and relax screening of snowfall and tropical observations.
+ Hints of an improvement of surface analyses (e.g. soil moisture).

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Thank you!
Early developments

- At ECMWF, work on the assimilation of ground-based precipitation radar data started in 2005, taking advantage of the developments for satellite microwave imager observations in rainy regions (Mahfouf, Marécal, Moreau, Bauer, Geer, Lopez).

- First, an indirect 1D+4D-Var approach was tested with NCEP Stage IV hourly radar + gauge rain product over the USA:

\[ \text{1D-Var} \rightarrow \text{TCWV pseudo-obs} \rightarrow \text{4D-Var} \rightarrow \text{Analysis} \]

- Slightly positive impact on both analyses and forecast scores (up to 24h range only).

- Limited impact \( \Leftarrow \) competition with other observations (TEMP, SYNOP).

- Some limitations of 1D+4D-Var were identified \( \Rightarrow \) try direct 4D-Var instead.
1D+4D-Var assimilation of NCEP Stage IV rain data  
(Lopez and Bauer, 2007, MWR)

Three global assimilation experiments (20 May - 15 June 2005; T511 L60):

CTRL = all standard observations (ECMWF operational 4D-Var).
CTRL_noqUS = CTRL – no moisture obs over US (from SYNOP, TEMP, satellites).
NEW_noqUS = CTRL_noqUS + NCEP Stage IV hourly rain rates over US (1D+4D).

Mean differences of TCWV analyses at 00UTC

CTRL_noqUS − CTRL

| No moisture obs. over USA → strong drying (down to −5 kg m⁻²) |

NEW_noqUS − CTRL_noqUS

| Radar data assimilated “on their own” cancel most of the drift. |

→ Rain data alone can have a substantial positive impact on analyses and forecasts.

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Asymmetry of rain analysis increments

Statistics of direct 4D-Var assimilation of NCEP Stage IV data over eastern half of the USA in April-May 2009 (T511 L91; CY35R2).

Always easier to reduce precipitation than to increase it during assimilation, mainly as a result of the limiting effect of saturation.
Direct 4D-Var assimilation of NCEP Stage IV rain data

Short-range precipitation forecast is significantly improved.

12h-accumulated precipitation FC 00Z+12

April-May 2009

Equitable Threat Score

0-12h Precip. Equitable Threat Score
20090401-20090531

False Alarm Rate

0-12h Precip. False Alarm Rate
20090401-20090531

Sept-Oct 2009

Equitable Threat Score

0-12h Precip. Equitable Threat Score
20090901-20091031

False Alarm Rate

0-12h Precip. False Alarm Rate
20090901-20091031
Direct 4D-Var assimilation of NCEP Stage IV rain data
Impact on precipitation FC as a function of FC range (6-72h)

Sept-Oct 2009 average
(CY35R2; T511 L91 ≈ 37 km)

Filled symbols indicate significant differences (at 95% level)

**Precipitation (mm/day) 20090901-20091031**

- CTRL
- NEW
- NEXRAD

**Precipitation RMSE (mm/day) 20090901-20091031**

- CTRL
- NEW

**Precipitation Bias (mm/day) 20090901-20091031**

- CTRL
- NEW

**Precipitation Correlation 20090901-20091031**

- CTRL
- NEW

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Impact of NCEP Stage IV assimilation on 12h forecasts of precipitation. Sept-Oct 2009 average (T511 L91 ≈ 40km)

NCEP Stage IV observations

CTRL – NCEP Stage IV

NEW – NCEP Stage IV

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Fitted curves of relative wind-induced error (%) against measured rain rate and wind speed at gauge top for Mk2 and Hellmann gauges:

- Hellmann larger than Mk2 gauge in size ⇒ stronger undercatch.
SYNOP rain gauge height above ground (m)

- **No info**
- **0.3 - 0.4**
- **0.4 - 0.5**
- **0.5 - 0.6**
- **0.6 - 0.7**
- **0.7 - 0.8**
- **0.8 - 1**
- **1 - 1.1**
- **1.1 - 1.2**
- **1.2 - 1.3**
- **1.3 - 1.5**
- **1.5 - 2**
- **2 - 3**
Results from pseudo-ERA experiments with RGs (3)

0-6h precipitation forecast scores against SYNOP RG themselves: Equitable Threat Score (ETS) and False Alarm Rate (FAR) (Apr-Jun 2011).

- **ETS Europe**
- **ETS USA**
- **ETS China**

- **FAR Europe**
- **FAR USA**
- **FAR China**

→ 4D-Var “precipitation analysis” is successful.

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Results from pseudo-ERA experiments with RGs (4)

Comparison of top-layer soil moisture analyses (6-hourly) with in-situ NCRS-SCAN observations over the USA (from Clément Albergel)

Statistics over 101 stations

<table>
<thead>
<tr>
<th></th>
<th>ERA_CTRL</th>
<th>ERA_NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correl.</td>
<td>0.615</td>
<td>0.644</td>
</tr>
<tr>
<td>Bias</td>
<td>-0.060</td>
<td>-0.058</td>
</tr>
<tr>
<td>RMSD</td>
<td>0.128</td>
<td>0.124</td>
</tr>
</tbody>
</table>

(Bias and RMSD in m$^3$ m$^{-3}$)

Higher correlations $\rightarrow$ improved spatial distribution of soil moisture when SYNOP RGs are assimilated.