Validation and impact assessment of ADM-Aeolus observations in the DWD global modelling system

Martin Weissmann
Hans-Ertel-Centre for Weather Research, LMU Munich

Alexander Cress, Roland Potthast
Deutscher Wetterdienst (DWD), Offenbach

Part of the proposal “Experimental Validation of ADM-Aeolus with the ALADIN Airborne Demonstrator (EVA4D)” by Reitebuch et al.
Proposed work for ADM-Aeolus Cal/Val:

- Estimation of representativity errors for validation with ground- and airborne observations from differences of high- and low-resolution regional COSMO simulations over Germany
- Assimilation of ADM-Aeolus observations in the experimental hybrid 3D-Var/LEKF global data assimilation system of DWD, sensitivity studies and assessment of systematic errors in collaboration with observational Cal/Val activities
- Impact assessment using data denial experiments and ensemble-based estimates of observation impact (EnFSO)

Relevant previous studies

- Assimilation of airborne wind lidar observations
- Ensemble-based estimates of observations impact
- Height assignment of cloud winds
Impact of A-TReC 2003 observations in ECMWF IFS (1)

Eight flights of DLR Falcon with scanning coherent 2-µm Doppler Wind Lidar (DWL) in 15 days

Example of observations, horiz. resolution ~10 km (shown: best example; average coverage ~30%)

Reduction of ECWMF forecast error for 500 hPa geopotential height with DWL
Impact of A-TReC 2003 observations in ECMWF IFS (2)

Reduction of mean forecast error over Europe in 15-day period

DWL has a larger observational error than radiosondes, but “volume” averages are more representative for the wind in the model grid box:

→ lower assigned error in DA
→ larger analysis influence
→ larger forecast improvement

Impact of T-PARC 2008 observations in ECMWF IFS and NRL NOGAPS

<table>
<thead>
<tr>
<th></th>
<th>NRL</th>
<th>EC IFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>assimilation</td>
<td>4D-Var</td>
<td>4D-Var</td>
</tr>
<tr>
<td>resolution</td>
<td>55 km</td>
<td>25 km</td>
</tr>
<tr>
<td>DWL processing</td>
<td>super-obs</td>
<td>thinning to</td>
</tr>
<tr>
<td></td>
<td>1.5° lat/lon</td>
<td>~63 km</td>
</tr>
<tr>
<td>DWL obs.</td>
<td>4368</td>
<td>9578</td>
</tr>
<tr>
<td>assigned error</td>
<td>1.8 m/s</td>
<td>1.5 m/s</td>
</tr>
<tr>
<td>an-increment</td>
<td>1.3 m/s</td>
<td>1.8 m/s</td>
</tr>
<tr>
<td>all obs. per day</td>
<td>3 million</td>
<td>18 million</td>
</tr>
</tbody>
</table>

T-PARC airborne DWL observations:
- Eight flights of DLR Falcon in 10 days
- Scanning coherent 2-µm DWL
- Observations near Typhoon Sinlaku

Larger weight at ECWMF
--> larger increment at location of DWL

Fewer observations in NRL analysis
--> larger analysis difference
Wind lidar impact on typhoon track prediction

**ECMWF:**
9% reduction of 12-120 h forecast error with DWL on one aircraft
8% with dropsondes from four aircraft

**NOGAPS:**
Neutral impact on typhoon track forecast
Synthetic bogus seems to limit impact of other observations
Experiment without bogus shows larger DWL impact, but very weak cyclone
**Adjoint forecast sensitivity to observations (per observation)**

**b) Mean relative contribution per observation**

<table>
<thead>
<tr>
<th>Observation Type</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>O3</td>
<td>0.00000</td>
</tr>
<tr>
<td>MTSAT-Rad</td>
<td>-0.00005</td>
</tr>
<tr>
<td>AMSU-B</td>
<td>0.00000</td>
</tr>
<tr>
<td>MHS</td>
<td>0.00005</td>
</tr>
<tr>
<td>AMSR-E</td>
<td>0.00010</td>
</tr>
<tr>
<td>SSM/I</td>
<td>0.00015</td>
</tr>
<tr>
<td>GPS-RO</td>
<td>0.00020</td>
</tr>
<tr>
<td>IASI</td>
<td></td>
</tr>
<tr>
<td>AIRS</td>
<td></td>
</tr>
<tr>
<td>AMSU-A</td>
<td></td>
</tr>
<tr>
<td>HIRS</td>
<td></td>
</tr>
<tr>
<td>SCAT</td>
<td></td>
</tr>
<tr>
<td>AMV GEO</td>
<td></td>
</tr>
<tr>
<td>TEMP/PILOT</td>
<td></td>
</tr>
<tr>
<td>DRIBU</td>
<td></td>
</tr>
<tr>
<td>DWL</td>
<td></td>
</tr>
<tr>
<td>AIRCRAFT</td>
<td></td>
</tr>
<tr>
<td>SYNOP</td>
<td></td>
</tr>
</tbody>
</table>

**d) Rel. contr. per obs., area 20-50 N, 120-160 W**

**ECMWF:**
- DWL impact similar to aircraft observations
- DWL impact lower than radiosondes (but more observations)

**NRL NOGAPS:**
- DWL has largest impact after retrieved TPW, synthetic bogus and scatterometer

Ensemble-based estimates of observation impact (1)

METHOD

\[ J(d') = \frac{1}{2} \left( |e_f^d|^2 - |e_f^{d-d'}|^2 \right) \]

\[ J'(d') \approx \frac{1}{2} \frac{1}{N-1} \sum_j (e_f^d + e_f^d)_j (Y_f^d)_j (Y_b^d W^d(j))^{\top} R(j)^{-1} d' \]

The method estimates the contribution of different observations to the reduction of forecast error (analogous to adjoint forecast sensitivity to observations)

No need for parallel (data denial) numerical experiments
Ensemble-based estimates of observation impact (2)

Ensemble information can be used to approximate the impact of various observations similarly to adjoint FSO

Reasonable agreement with data denial experiments

This is a powerful tool, but the calculation and interpretation requires caution (similarly to adjoint FSO)

Ongoing work on objective quality indicator for the reliability of estimates and verification with observations


Lidar-based height correction for Atmospheric Motion Vectors (AMVs)

• Correct AMV height with CALIPSO cloud top observations, treat AMVs as layer wind
• Lowest error when a AMVs are assigned to 120-hPa layer beneath CALIPSO cloud top observation
• AMV wind error 18% lower than with original discrete height
• AMVs represent a layer wind beneath the cloud top
• Is this because cloud structures propagate with the layer wind (not relevant for ADM-Aeolus observations)?
• Or is it because cloud motion at the cloud top doesn't represent the environmental wind at this layer, e.g. because vertical mixing in the cloud (relevant for ADM-Aeolus observations)?

Conclusions

- The assimilation of airborne DWL observations demonstrated a high impact and underlines the expectations for ADM-Aeolus
- Airborne DWL observations differ from ADM-Aeolus, but the studies underline the need for wind observations and the benefit of representative volume observations
- The period of the experiments is comparably short, but overall similar results for different campaigns, different models and different settings raise confidence in the results
- Ensemble information can be used to estimate the impact of observations similarly to the adjoint Forecast Sensitivity of Observations (FSO)
- Recent studies show that AMV winds represent winds in a layer wind beneath cloud top rather than winds at the cloud top level. Is this also true for ADM-Aeolus cloud returns or specific for AMVs that observe the shift of cloud structures instead of wind itself?