First Assimilation of Rotational Raman Lidar Temperature Data into WRF
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Introduction

• Lag of real time observations of the lower tropospheric temperature with sufficient vertical resolution to resolve temperature inversions [1, 2]
• Temperature Rotational Raman Lidar (TRRL) makes use of inelastic backscattered laser radiation to observe the atmospheric temperature continuously
• The boundary layer height and the inversion strength can be determined with TRRL
• The systematic error of the University of Hohenheim (UHH) TRRL is considerably less than 1K [3, 4]
• The statistical error scales with the spatial and the temporal averaging (Eq. 1)
• With averaging times of about 1 min and a spatial resolution of about 100 m, the noon time noise error of the UHH TRRL is less than 1 K up to 1500 m [5]
• No complex forward operator is necessary, as the temperature is a first level product
• No drift occurs in profiles observed by lidars
• With multiple ways of averaging and the good representativeness of the observations, lidar is very interesting for data assimilation [6, 7]

Experimental Setup

Fig. 1: Used dataset
• WRF Version 3.5.1
• 601 x 682 gridpoints at 3 km horizontal resolution
• 57 levels up to 500 hPa with 35 levels in the lowest 1.5 km
• B-Algorithm calculated by the HMC Method for 32 levels at 1 km resolution of July 2012
• Radiation day with well developed convective boundary layer

Fig. 2: Rapid update cycle approach with hourly 3DVARs
• 3 different experiments: ALL_DA = TRRL and conventional data
• CONV_DA = conventional data
• NO_DA = no assimilated data
• Rapid Update Cycle with hourly 3DVARs [9]
• TRRL profiles assimilated with the radiosonde operator from 500 m AGL to 3000 m AGL
• Smoothed with 10 m running average and reduced to one value each 37.5 m
• Hourly averaged TRRL profiles; \( \Delta_m \) = 0.5 K; shown as observation error for the whole profile

Tab. 1: Assimilated observations per 3DVAR

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Conventional Data</th>
<th>TRRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>AMDAR, AMV, GNSS-3D, METDA, PROFIL, SYNOP, TEMP</td>
<td>TRRL</td>
</tr>
<tr>
<td>Number of Assimilated Observations / 3DVAR</td>
<td>1383 – 1724 – 1000 – 264 – 50 – 57</td>
<td>1183 – 0 – 26</td>
</tr>
</tbody>
</table>

• The conventional data were summarised in 1-hour observation windows and assimilated each full hour
• 4 Radiosonde (RS) ascents close to the UHH TRRL were not assimilated and used additionally for verification of model results

Fig. 3: Temperature observed with the UHH TRRL during the assimilation day

Eq. 1: Statistical error of the TRRL
\[
\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (T_{\text{TRRL}}(i) - T_{\text{REF}}(i))^2}
\]

Fig. 4: Expected statistical errors for different atmospheric observations

Impact on the Temperature Profiles

Fig. 5: Temperature profiles for the four times RS ascents were available

Fig. 6: (a) RMSE of the T profiles (b) RMSE of T profiles

Tab. 2: Overall RMSE between 700 and 3000 m AGL between T_{\text{NO_DA}} and T_{\text{TRRL}}

<table>
<thead>
<tr>
<th>Method</th>
<th>RMSE (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONV_DA</td>
<td>0.8</td>
</tr>
<tr>
<td>NO_DA</td>
<td>0.01</td>
</tr>
<tr>
<td>TRRL</td>
<td>0.12</td>
</tr>
<tr>
<td>RS</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Summary

• RMSE to the TRRL profiles in ALL_DA half as large as in CONV_DA
• Boundary layer height \( z_i \) was improved by 50 m in the mean compared to CONV_DA
• The mean temperature Gradient \( T_{\Delta m} \) in the entrainment zone was improved by 0.19 K [100 m] compared to CONV_DA
• Impact of the TRRL data spreads flow dependant in between the 3DVARs in the rapid update cycle
• Correlation with the water vapour mixing ratio \( q_i \) was observed in the B-Matrix
• A network of TRRL and WVRRL could close the gap of high resolution lower tropospheric thermodynamic observations

Boundary Layer Height and Inversion Strength

Fig. 7: (a) RMSE of the T profiles compared to \( T_{\text{CONV}} \) and T_{\text{TRRL}}

Fig. 8: PBL height

Tab. 3: Statistical analysis of \( \Delta T \) and \( \Delta q \) assuming same subscripts as in Fig. 6

<table>
<thead>
<tr>
<th>Method</th>
<th>( \Delta T ) (K)</th>
<th>( \Delta q ) (g kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL_DA</td>
<td>0.12</td>
<td>0.01</td>
</tr>
<tr>
<td>CONV_DA</td>
<td>0.26</td>
<td>0.04</td>
</tr>
<tr>
<td>NO_DA</td>
<td>0.01</td>
<td>0.25</td>
</tr>
<tr>
<td>TRRL</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>RS</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Fig. 9: Temperature gradient at \( 10 \text{ m} \) in the entrainment layer

Spatial Impact and Correlations

Fig. 10: Temperature difference on model level 18, about 2.5 km AGL

Fig. 11: Cross sections of \( T \) and the water vapour mixing ratio difference \( q_i \)

References