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 (UHOH) 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 UHOH 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 of the TRRL observations and a prognostic variable in the model
- 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

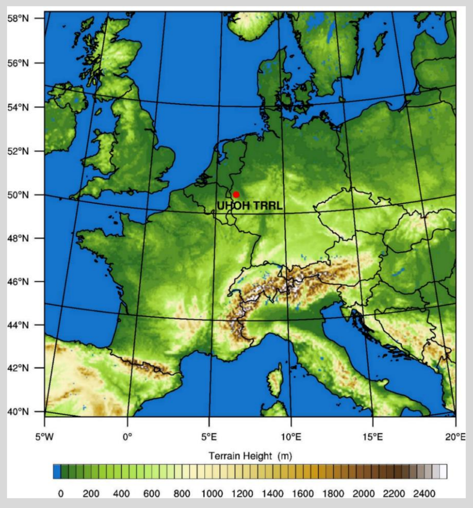

Fig. 1: Used domain.

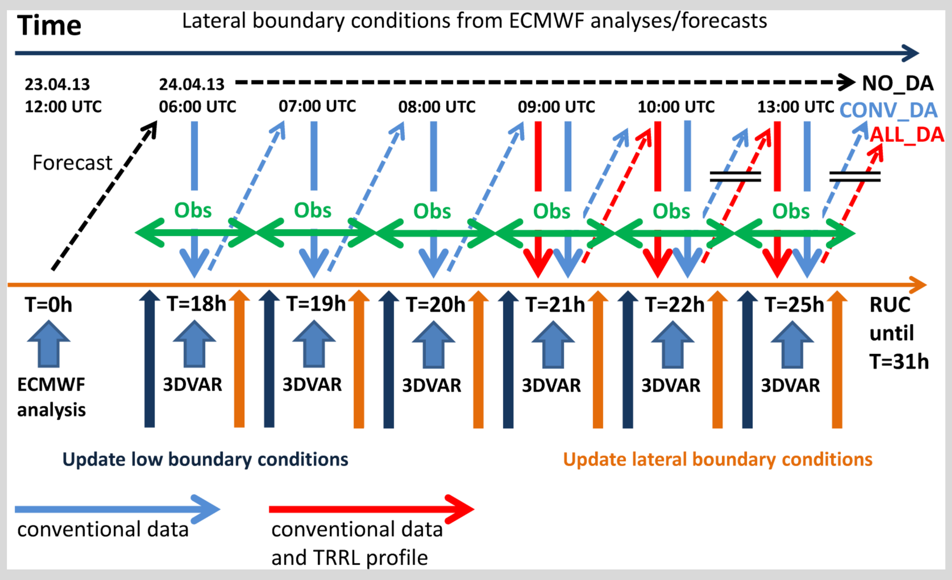

Fig. 2: Rapid update cycle approach with hourly 3DVARs.

- WRF Version 3.5.1
- 691 x 682 gridboxes at 3 km horizontal resolution
- 57 levels up to 50 hPa with 15 levels in the lowest 1.5 km
- B-Matrix calculated by the NMC Method for 62 forecasts of July 2012
- Radiation day with well developed convective boundary layer

- 3 different experiments: **ALL_DA** = TRRL and conventional data
  CONV_DA = conventional data
  NO_DA = no assimilated data
- Rapid Update Cycle with hourly 3DVARs [8]
- TRRL profiles assimilated with the radiosonde operator from ~500 m AGL to 3000 m AGL
- Smoothed with 109 m running average and reduced to one value each 37.5 m
- Hourly averaged TRRL profiles → statistical error from 0.01 K to 1.19 K
- 0.7 K chosen as observation error for the whole profiles

Tab. 1: Assmilated observations per 3DVAR .

Data Set	**Conventional Data**							**TRRL**
Type	AMDAR	AMV	GNSS-ZTD	METAR	PROFL	SYNOP	TEMP	TRRL
Number of Assimilated Observations / 3DVAR	1385 - 1883	1724 - 3117	1050 - 1076	264 - 339	50 – 57	1183 - 1361	0 – 26	1

- The conventional data were summarised in 1-hour observation windows and assimilated every full hour
- 4 Radiosonde (RS) ascents close to the UHOH TRRL were not assimilated and used additionally for verification

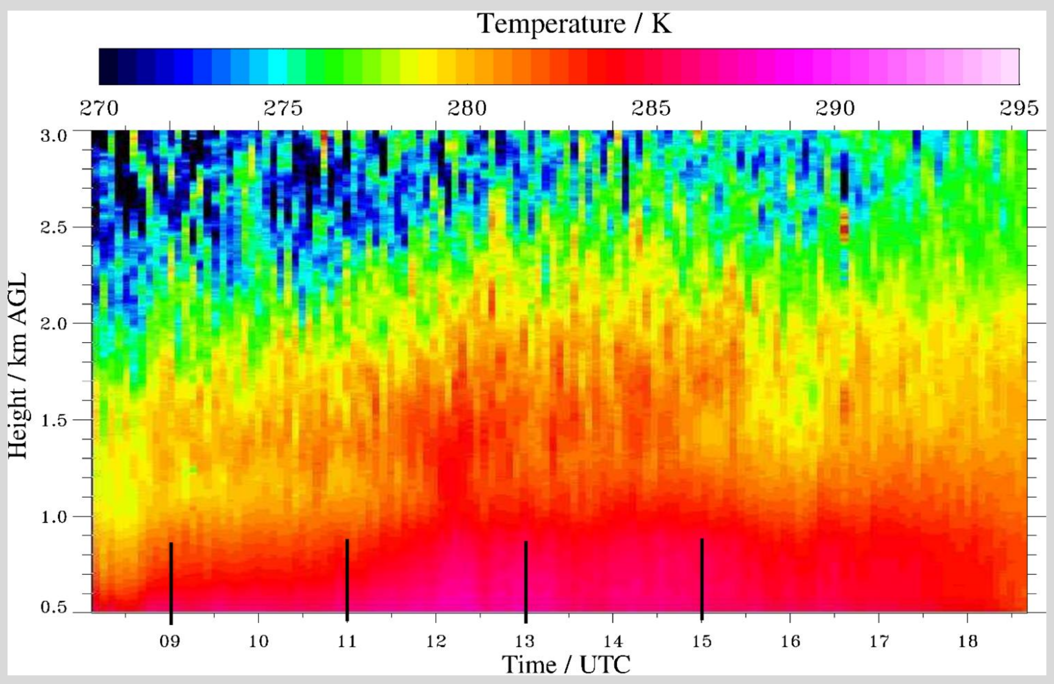

Fig. 3: Temperature observed with the UHOH TRRL during the assimilated day.

$$\sigma_{TRRL} \sim \frac{1}{\sqrt{\Delta z \Delta t}}$$

Eq. 1: Statistical error of the TRRL

Spatial resolution   Temporal resolution

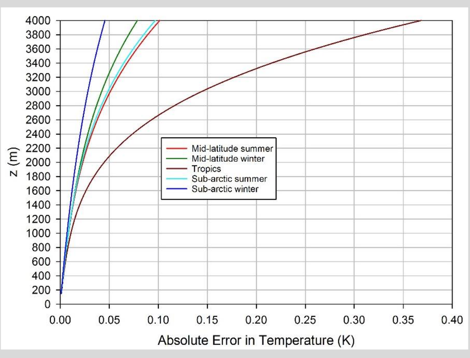

Fig. 4: Expected statistical errors for different standard atmospheres

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 Γ_{zi} in the entrainment zone was improved by 0.19 K (100m)$^{-1}$ 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_v was observed in the B-Matrix
- A network of TRRL and WVRRL could close the gap of high resolution lower tropospheric thermodynamic observations

Impact on the Temperature Profiles

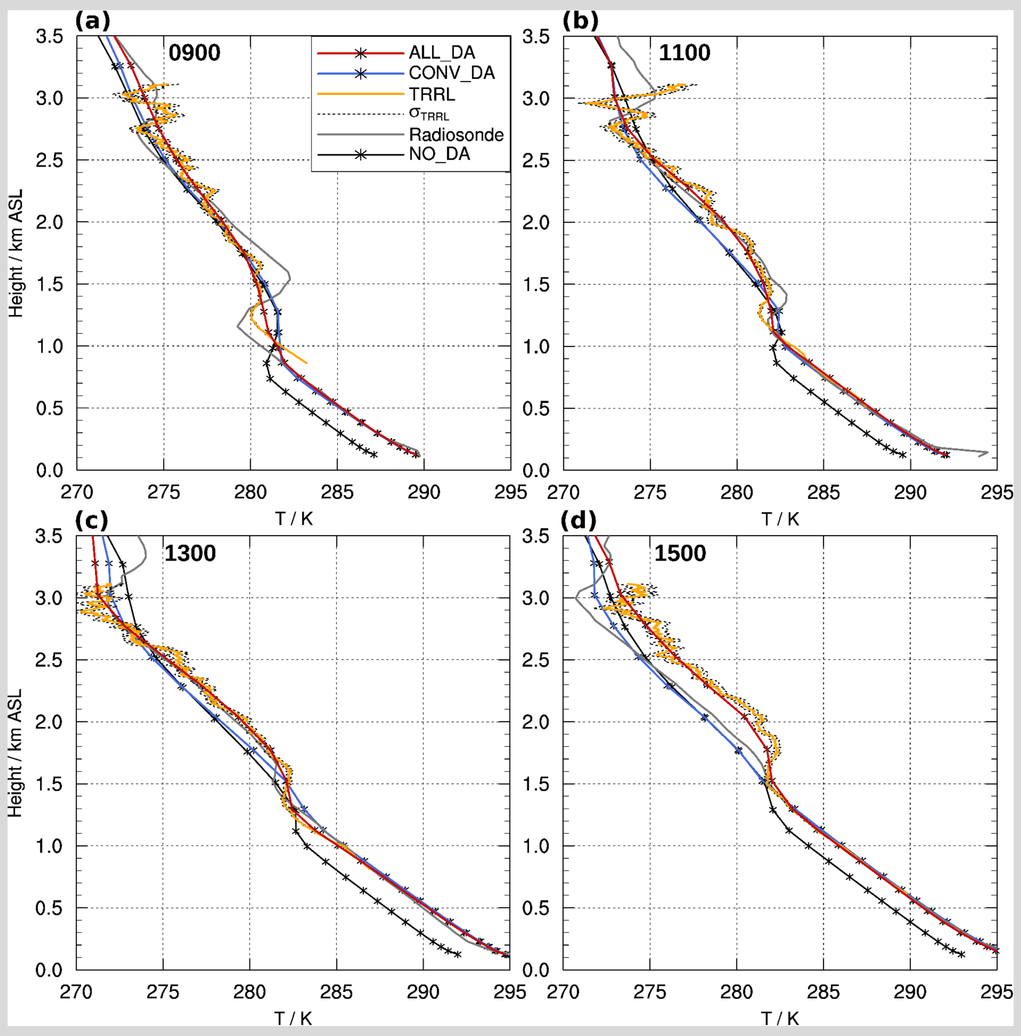

Fig. 5: Temperature profiles for the four times RS ascents were available

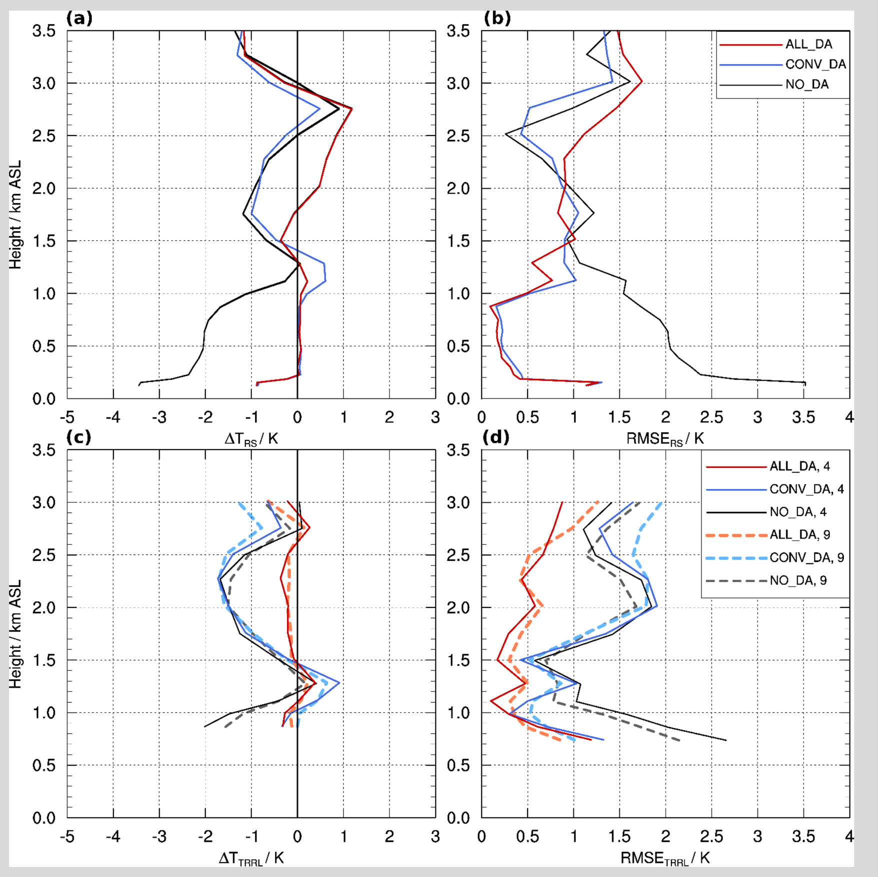

Fig. 6: (a) $T_{Model} - T_{RS}$ averaged over the 4 times RS ascents were available
(b) Root Mean Square Error (RMSE) of T_{Model} compared to T_{RS}
(c) T_{Model} –TRRL averaged over the 4 times RS ascents were available and over the 9 times TRRL data were assimilated
(d) Same as (c), but for the RMSE compared to the TRRL profiles

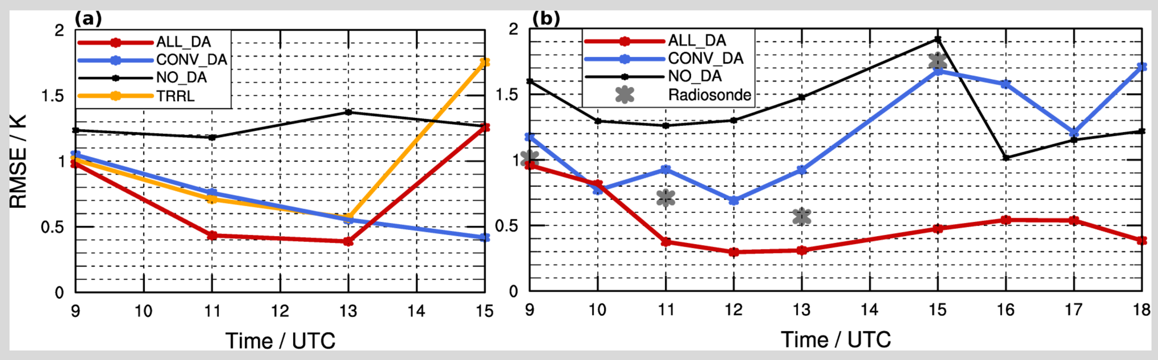

Fig. 7: (a) RMSE of the T_{Model} profiles compared to T_{RS} between 700 and 3000 m ASL.
(b) Same as (a) but compared to TRRL..

Tab 2: Overall RMSE between 700 and 3000 m ASL between T_{Model} compared to T_{RS} and TRRL

	$RMSE_{RS,4}$ / K	$RMSE_{TRRL,4}$ / K	$RMSE_{TRRL,9}$ / K
ALL_DA	**0.8**	**0.6**	**0.6**
CONV_DA	**0.7**	1.2	1.2
NO_DA	1.3	1.5	1.5
TRRL	1.1		
RS		1.1	

Boundary Layer Height and Inversion Strength

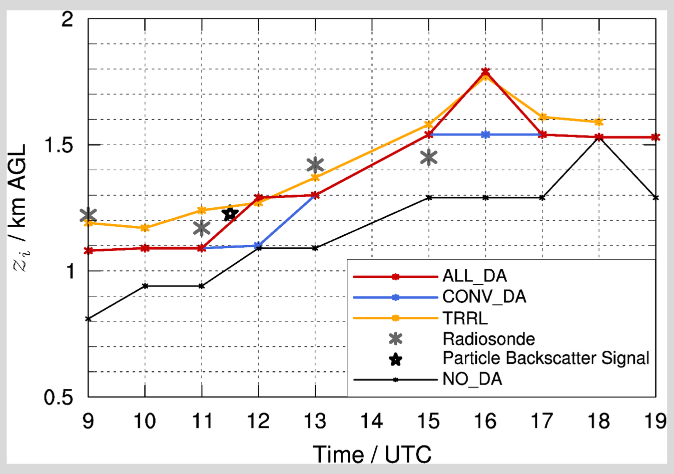

Fig. 8: PBL height z_i →

- Particle Backscatter Signal → z_i determined with a different method by the UHOH TRRL
- largest positve gradient of θ

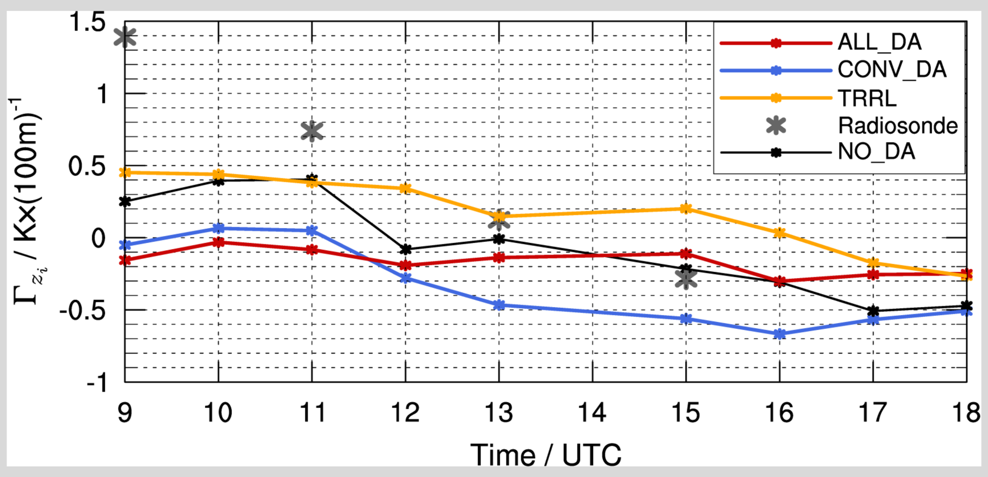

Fig. 9: Temperature gradient at z_i (Γ_{zi}) in the entrainement layer

Tab. 3: Statistical analysis of z_i, same subscripting as in Figure 6

	$\overline{z_{i,4}}$ / m	$\overline{z_{i,9}}$ / m	$RMSE_{RS,4}$ / m	$RMSE_{TRRL,4}$ / m	$RMSE_{TRRL,9}$ / m
ALL_DA	1250	1360	**110**	**100**	**80**
CONV_DA	1250	1310	**110**	**100**	120
NO_DA	1030	1110	300	320	300
TRRL	1350	1420	80		
RS	1320			80	

Tab. 4: Statistical analysis of Γ_{zi}, same subscripting as in Figure 6

	$\overline{\Gamma_{zi,4}}$ / m	$\overline{\Gamma_{zi,9}}$ / m	$RMSE_{RS,4}$ / m	$RMSE_{TRRL,4}$ / m	$RMSE_{TRRL,9}$ / m
ALL_DA	-0.12	-0.20	0.86	0.44	0.30
CONV_DA	-0.26	-0.39	0.86	0.58	0.53
NO_DA	0.10	-0.11	0.60	0.25	0.28
TRRL	0.30	0.17	0.56		
RS	0.49			0.56	

Spatial Impact and Correlations

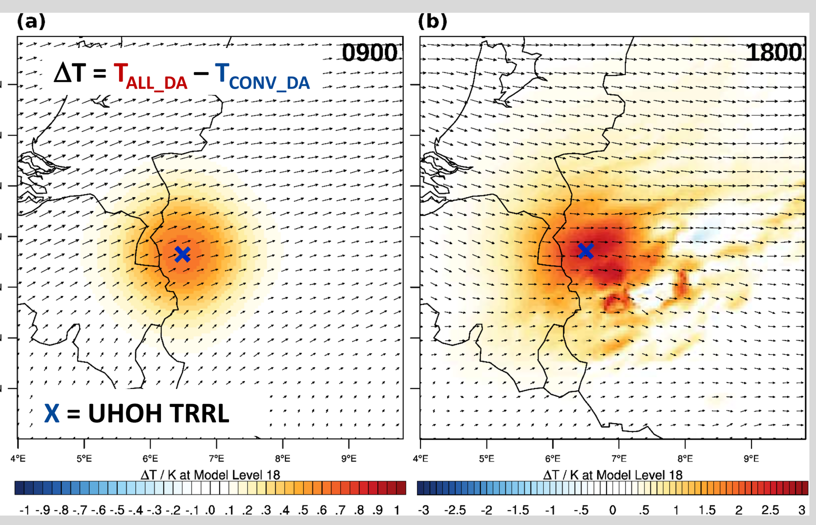

Fig. 10: Temperature difference on model level 18, about 2.5 km ASL

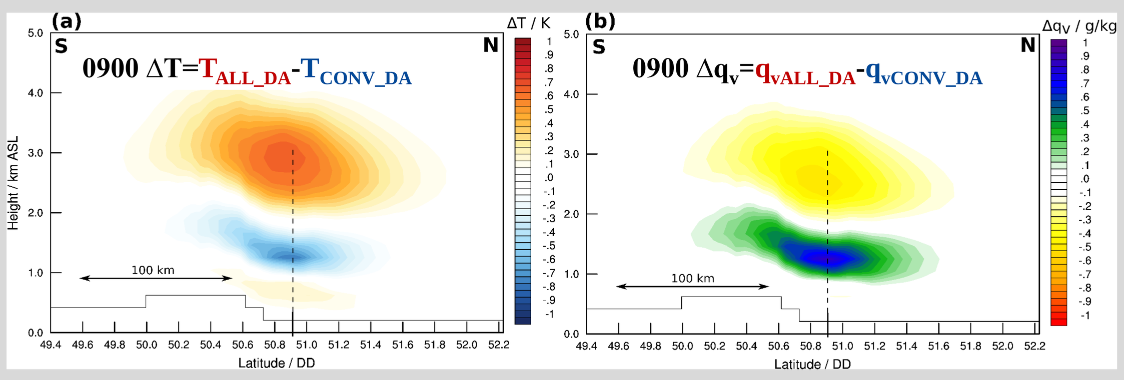

Fig. 11: Cross sections of ΔT and the water vapour mixng ratio difference Δq_v

References

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