# First Direct Assimilation of Lidar Water Vapor Mixing Ratio Profiles Into the WRF-DA System

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## Introduction

- Lidar data give continuous information on the thermodynamic structure of the atmosphere. Thus, they provide an improved representation compared to radiosondes which are just instantaneous.
- The lack of a suitable forward operator for the assimilation of water vapor mixing ratio profiles was a significant limitation of the WRF-DA system.
- This limitation has been overcome by modification of the atmospheric infrared sounding retrieval (AIRSRET) observation operator.
- Before, only relative humidity could be assimilated. Now, with the modified operator, direct assimilation of water vapor mixing ratio profiles is possible.
- Evaluation of the new operator is performed with observations from the temperature rotational Raman lidar (TRRL) and water vapor mixing ratio observations from differential absorption lidar (DIAL) of the University of Hohenheim.

## Experimental Design

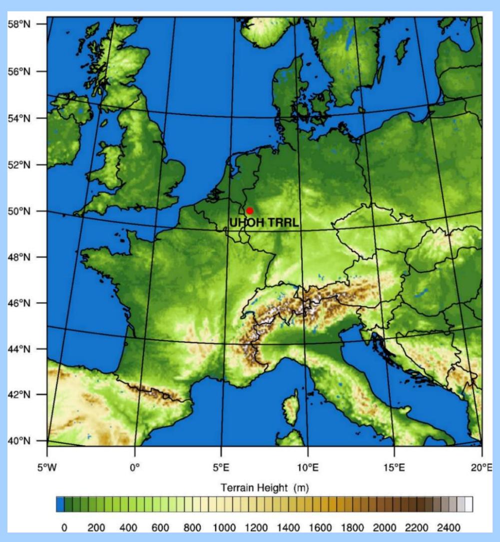

**Fig. 1:** Model domain

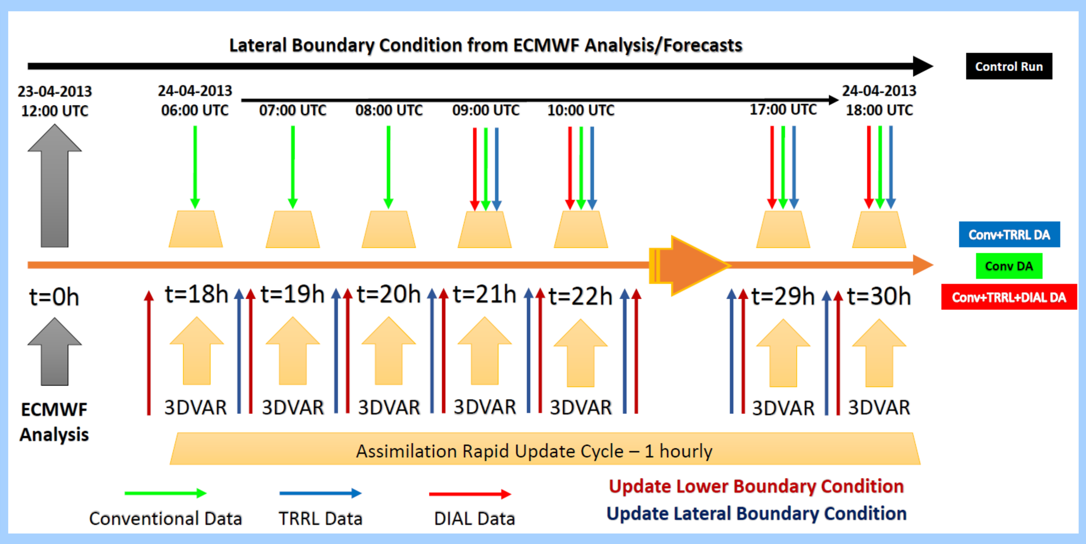


**Fig. 2:** Rapid update cycle (RUC) experiment

- WRF Version 3.8.1
- 856 x 832 – 2.5 km horizontal resolution
- 100 vertical levels up to 50 hPa with 27 levels within the PBL.
- B-Matrix computed from 58 forecasts of April 2013 by NMC method.
- Case study with well developed boundary layer and no clouds.

- Experiments conducted:
  1. Control Run - No data assimilated
  2. Conv DA - Conventional data assimilated
  3. Conv+TRRL DA - Conventional and TRRL data assimilated
  4. Conv+TRRL+DIAL DA - Conventional, TRRL, and DIAL data assimil.
- Rapid Update Cycle (RUC) was set up with hourly 3DVAR DA from 6:00 UTC to 18:00 UTC with a spin-up of 18 hours.
- TRRL data was assimilated with the radiosonde operator.

## Assimilated Observations

| Data | Conventional | | | | | | | TRRL | DIAL |
|---|---|---|---|---|---|---|---|---|---|
| Type | AMDAR | AMV | GNSS-ZTD | METAR | PROFL | SYNOP | TEMP | TEMP | AIRSRET |
| Number of observations | 1385-1883 | 1724-3117 | 1050-1076 | 264-339 | 50-57 | 1183-1361 | 0-26 | 1 | 1 |

**Tab. 1:** Observations assimilated

HOPE campaign lidar measurements on 24th April 2013

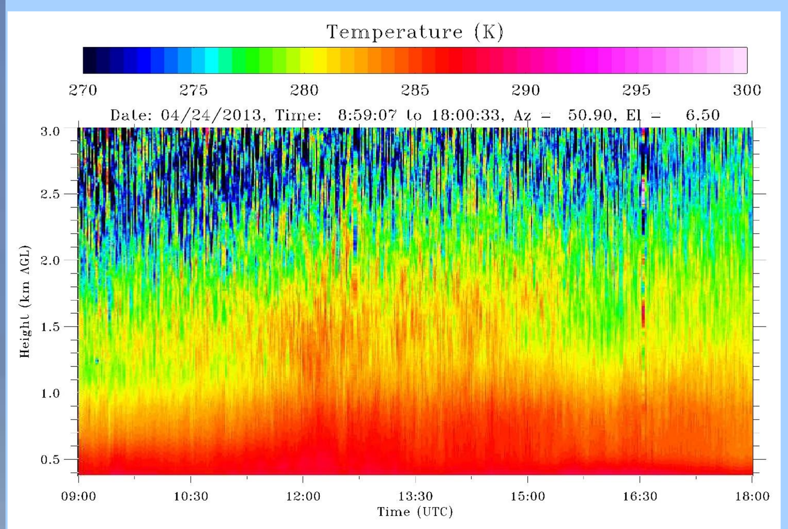


**Fig. 3:** UHOH TRRL temperature measurements.

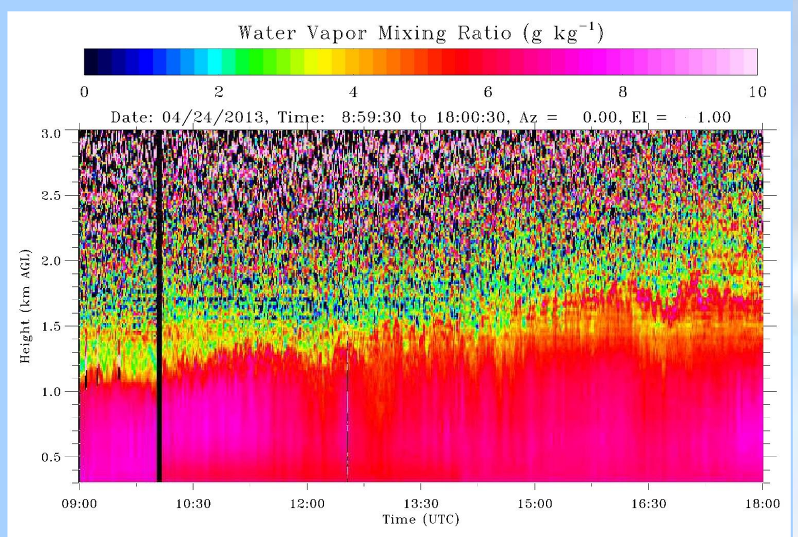


**Fig. 4:** UHOH DIAL WV mixing ratio measurements.

- TRRL observations were spatially smoothed with a running average of 108.75 m and then interpolated to 37.5 m resolution in heights of ~500 m to 3000 m above the lidar.
- DIAL observations were spatially averaged by Savitzky – Golay (SaGo) algorithm with a window length of 135 m up to 1500 m and a window length of 285 m till 3000 m distance from the lidar. The data were interpolated to every 30 m.
- The TRRL and DIAL data were finally averaged over a 20 minute window at each assimilation time step.
- The temperature error ranges from 0.7 K to 1.1 K at higher levels.
- The water vapor mixing-ratio error ranges from 0.1 g/kg to 1 g/kg, depending on altitude.
- 4 radiosonde observations at 09:00, 11:00, 13:00 and 15:00 UTC were used for verification but not assimilated.

## Summary

- The assimilation of DIAL water vapor mixing ratio data using the modified AIRSRET operator has a positive impact.
- The overall RMSE of the Conv+TRRL+DIAL DA water vapor mixing ratio compared to the DIAL observations is lower by 10 % compared to Conv+TRRL DA.
- The correlation of water vapor mixing ratio with temperature in the background error covariance matrix is evident from the single observation test.
- The 3DVAR RUC DA system improves the impact of the lidar observations progressively at consecutive assimilations.
- The extension of the WRF-DA system with the new forward operator for the assimilation of water vapor mixing ratio is extremely useful. It allows to make optimum use of high resolution lidar data which will help to improve our process understanding of PBL characteristics, clouds, and precipitation.

## Impact on Temperature and WV Mixing Ratio Profiles

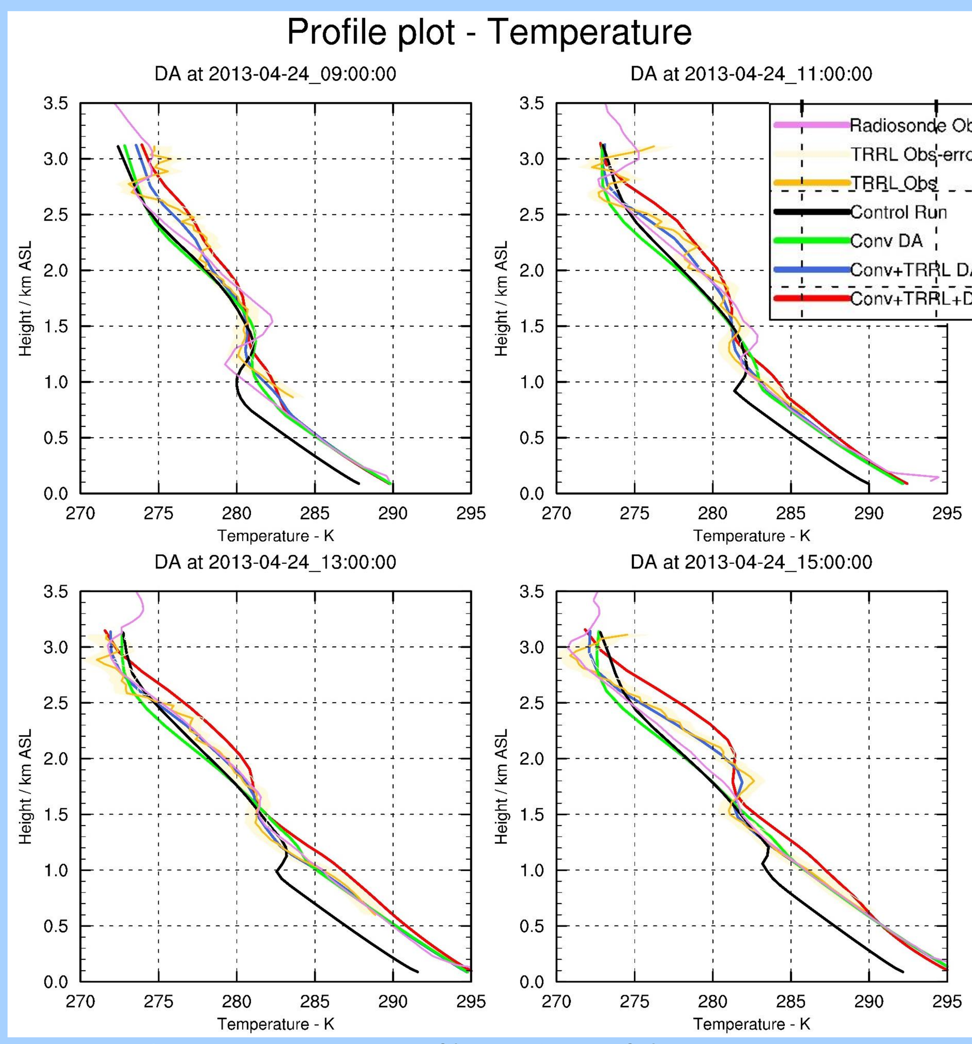


**Fig. 5:** Temperature profiles at times of the RS ascents

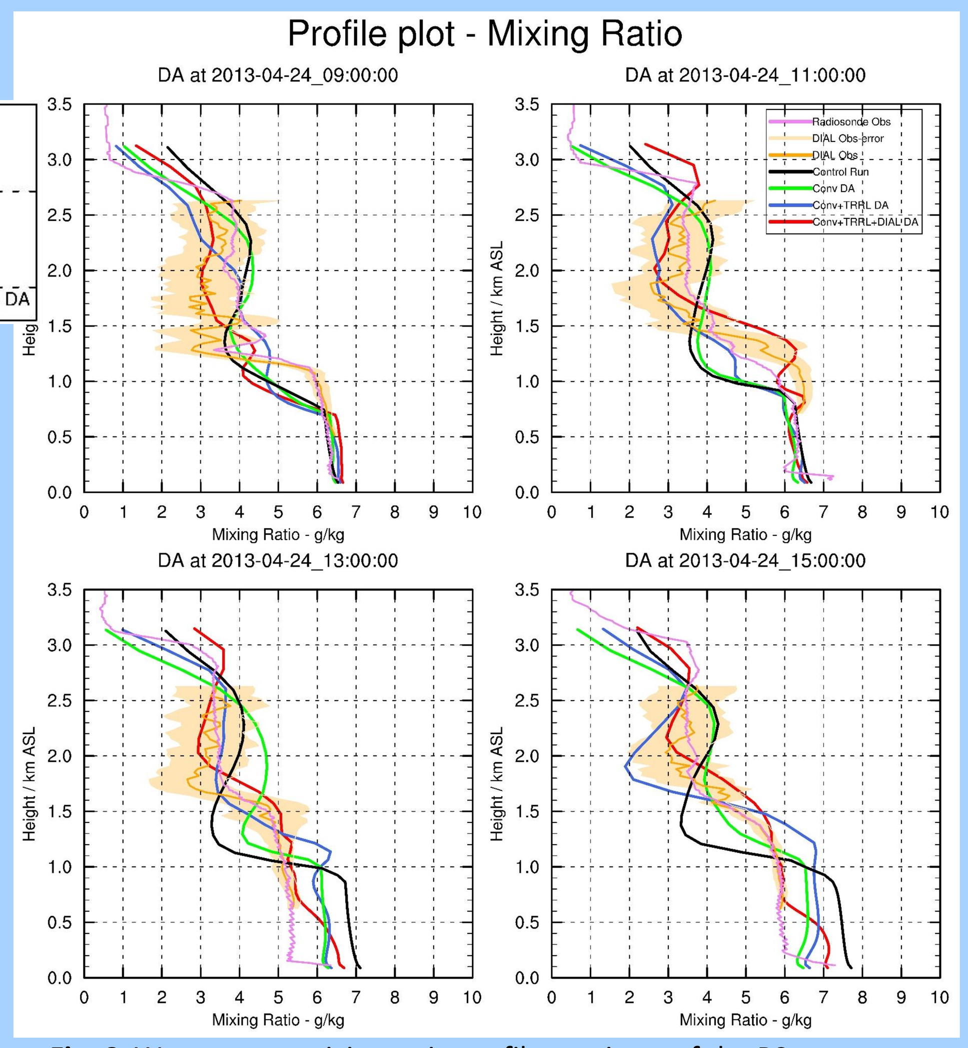


**Fig. 6:** Water vapor mixing ratio profiles at times of the RS ascents

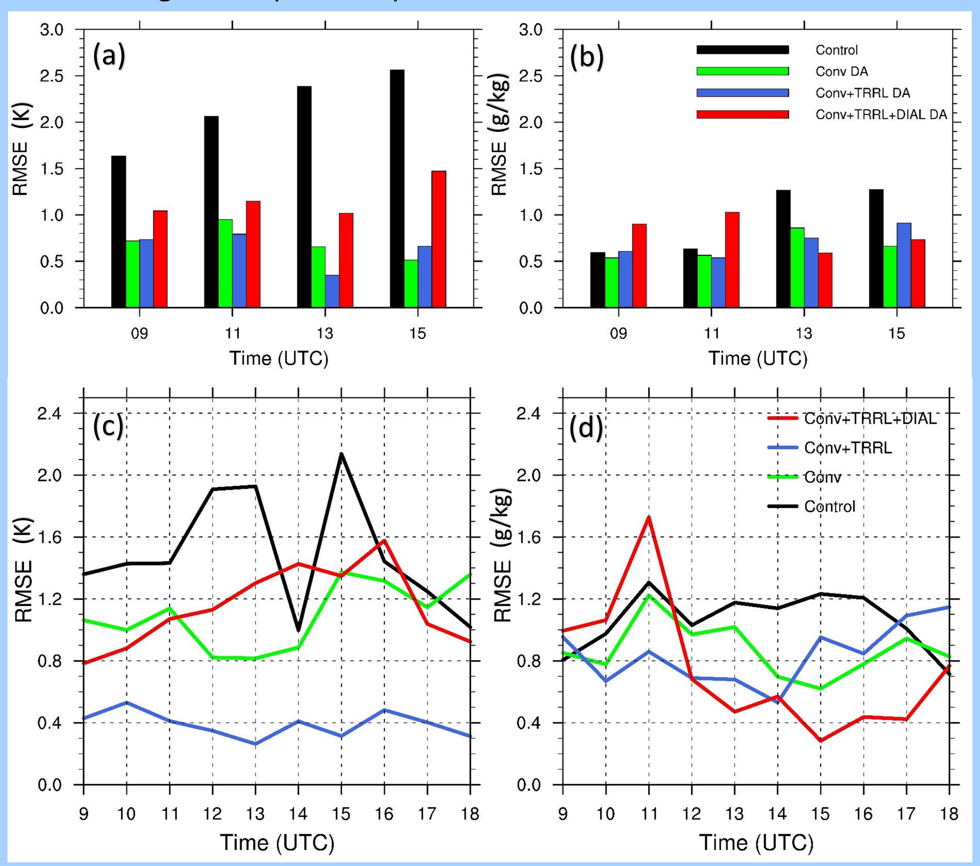


**Fig 7:** (a) RMSE of $T_{model}$ compared to RS Temperature, (b) RMSE of $Q_{model}$ compared to RS, (c) RMSE of $T_{model}$ compared to TRRL data, and (d) RMSE of $Q_{model}$ compared to DIAL data

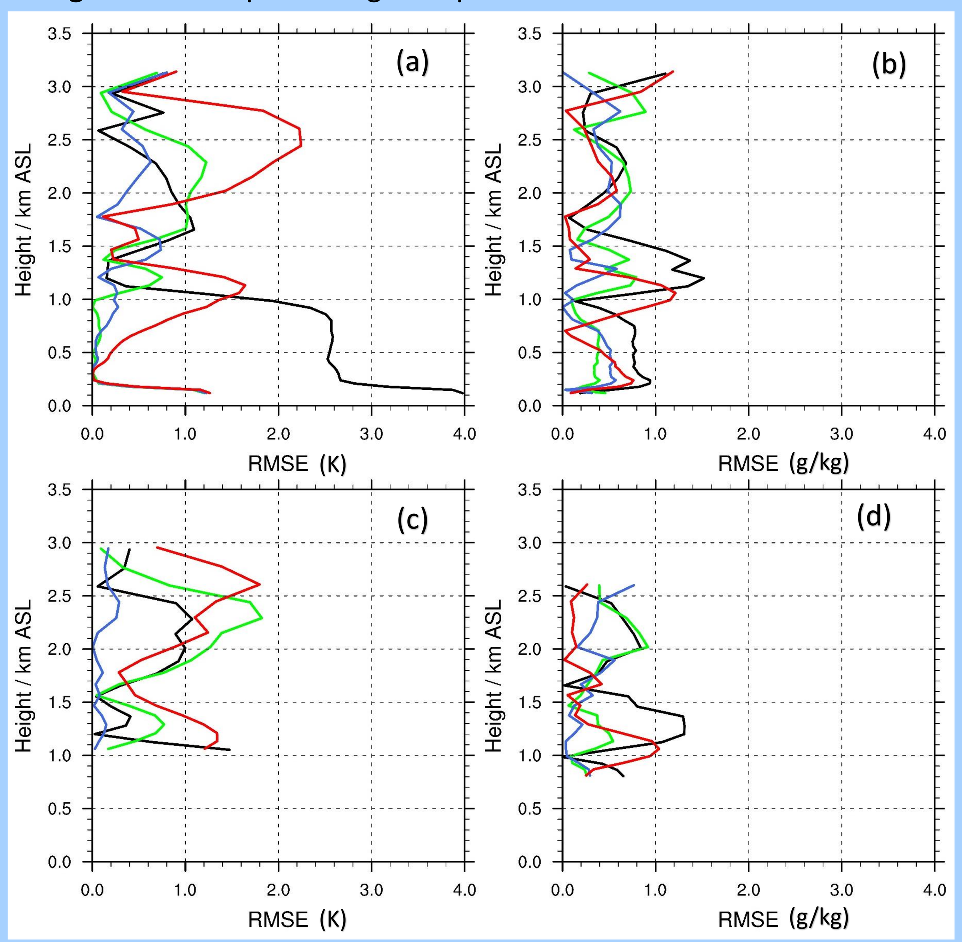


**Fig. 8:** Same as Fig: 7 but averaged over available profiles. (a) RMSE of $T_{model}$ compared to RS, (b) RMSE of $Q_{model}$ compared to RS, (c) RMSE of $T_{model}$ compared to TRRL, and (d) RMSE of $Q_{model}$ compared to DIAL

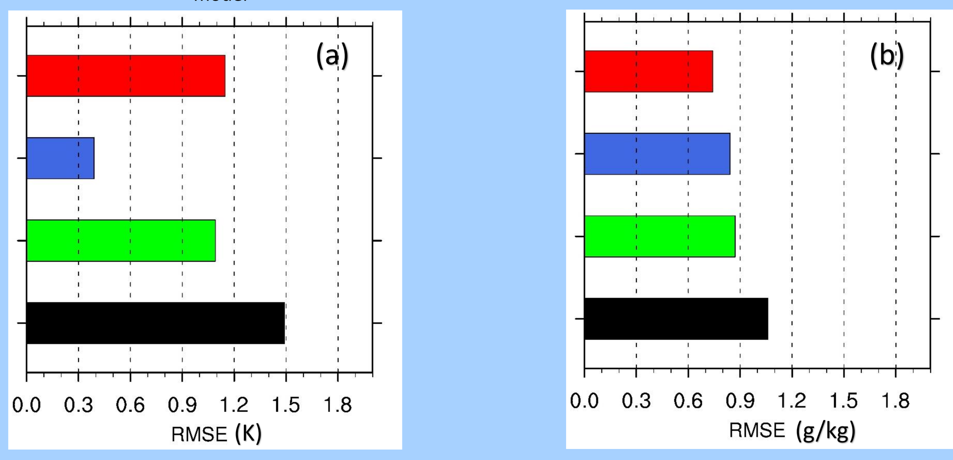


**Fig. 9:** (a) Overall RMSE of $T_{model}$ compared to TRRL
(b) Overall RMSE of $Q_{model}$ compared to DIAL

## Spatial Impact and Correlation

$$\Delta Q = Q_{\text{Conv+TRRL+DIAL}} - Q_{\text{Conv+TRRL}}$$

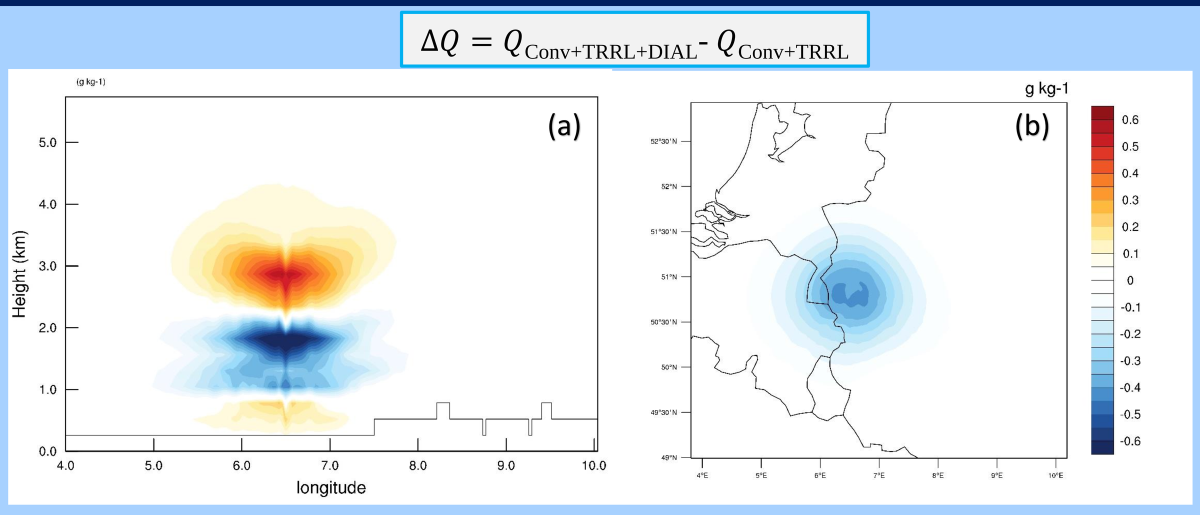


**Fig. 10:** (a) Cross-section of ΔQ at 09:00 UTC (b) Spatial plot of ΔQ at 850 hPa

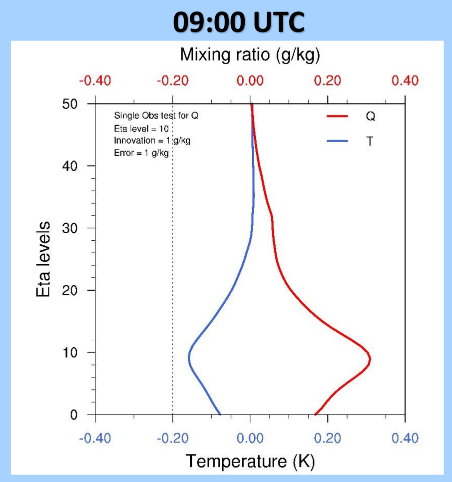


**Fig. 11:** Single observation test for Q

$$\Delta T = T_{\text{Conv+TRRL+DIAL}} - T_{\text{Conv+TRRL}}$$

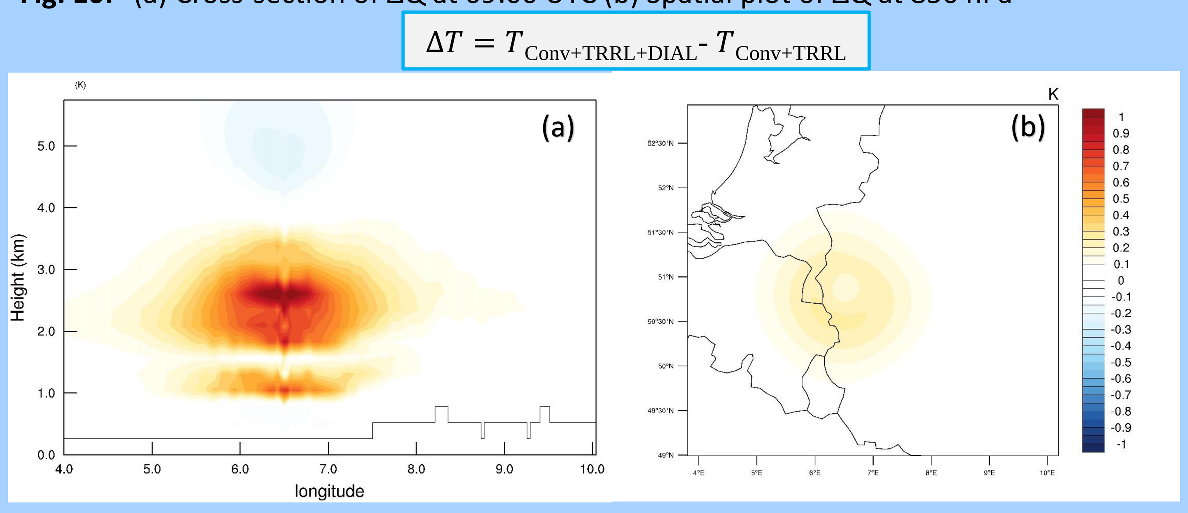


**Fig. 12:** (a) Cross-section of ΔT at 09:00 UTC (b) Spatial plot of ΔT at 850 hPa

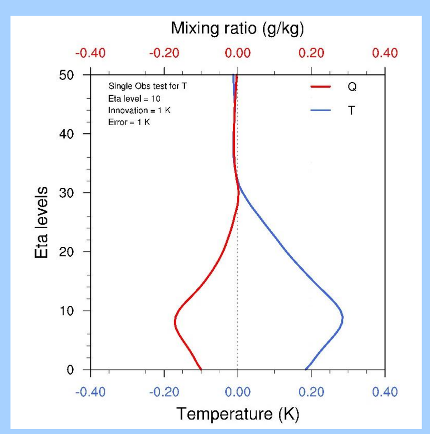


**Fig. 13:** Single observation test for T

## References


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