HErZ

Water Vapor Data Assimilation from Scanning Microwave Radiometers and Lidars

*Improving **Ico**sahedral **N**on-hydrostatic Model's (ICON) Analysis by Ground-Based Observations*

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1. Water Vapor within the Atmospheric Boundary Layer

Water Vapor (WV) plays a central role in weather and climate. Within the atmospheric boundary layer (ABL), WV strongly affects surface energy balance and atmospheric stability. Therefore an accurate representation of WV is essential for predicting **high-impact weather phenomena** such as:

- **convection and heavy precipitation**
- **fog**
- **droughts**

⇛ Improved WV observations and their assimilation into weather models are critical to **enhance forecast accuracy and lead time.**

Measurement System	Vertical Resolution	Accuracy (WV)	Frequency	Spatial Coverage
Radiosondes	10–100 m	≤ 5%	every 6 hrs	point/local
Raman Lidar	10–100 m	≤ 5%	1s–10min	point/local
DIAL	10–100 m	≤ 5%	1s–10min	point/local
MWR (zenith-pointing)	few 100 m–2 km	≈ 10%	5–10min	point/local
Satellite (IASI)	1 km	10%	6 h	global

Table 1: Observation properties for different instruments within the ABL; sources: Wulfmeyer et al. 2015; ESA: About IASI.

While satellite instruments provide great spatial and temporal coverage, they mostly **lack vertical resolution and accuracy within the ABL** and are often affected by clouds and the underlying surface.

Radiosondes are infrequent and **lack temporal and spatial coverage**. Zenith-pointing radiometers or lidars **lack spatial coverage.** Errors to be considered include instrument noise, forward modelling uncertainties, and errors due to **limited representativity** of observations relative to the model grid scale.

2. Observational Setup

A synergistic approach of zenith-pointing lidar measurements and **MWR slant path scans at low elevations ε (5°-10°)** is introduced.
For these elevations the MWR beam covers a **radius of 10-20 km** within a 2 km deep ABL (Figure 1).
Differential Absorption lidars (DIALs) will become operational within the German Weather Service's (DWD's) observational network within the LIDIA project. They provide highly resolved vertical profiles of WV.

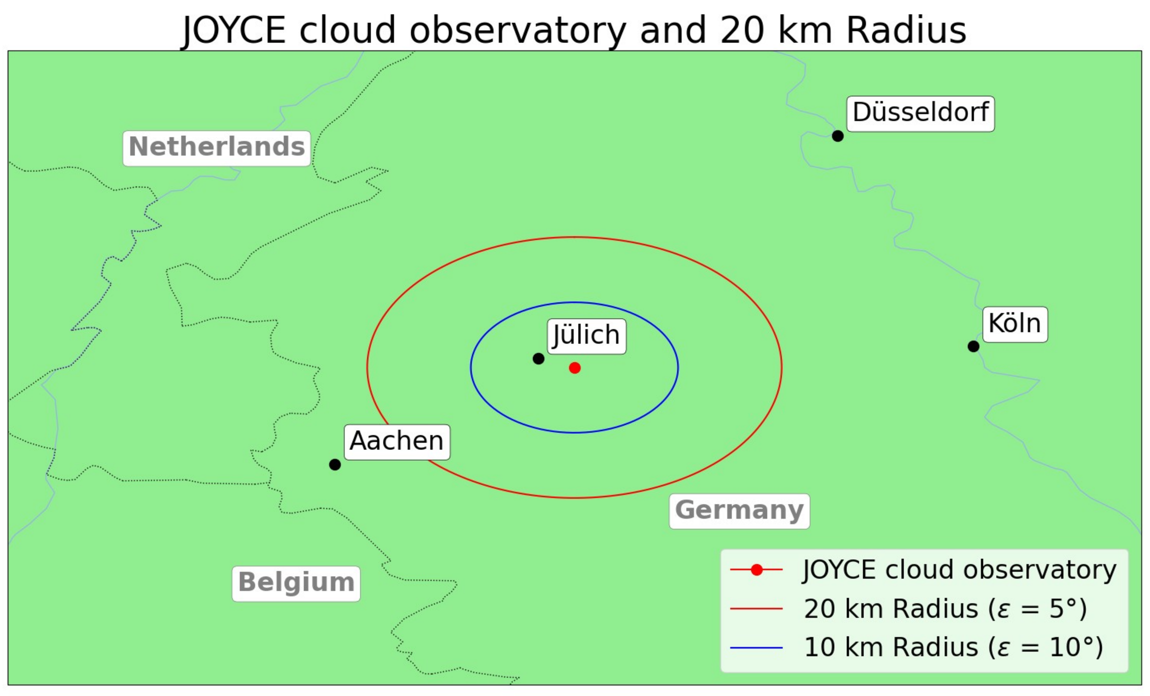

Figure 1: Cartopy-plot of JOYCE cloud observatory with 10/20 km radius.

3. Towards Direct Assimilation: Forward Model Evaluation

In former studies MWR zenith-pointing data have been assimilated indirectly as mixing ratios (Caumont et al., 2016) or directly as brightness temperatures (Vural et al., 2023). For the planned **direct assimilation of slant path observations forward operators of MWR** are needed, e.g.:

- **RTTOV-gb** (DeAngelis et al., 2016)
- **ARMS-gb** (Shi et al., 2025)

As Figures 2 and 3 show these fast radiative transfer algorithms can reasonably well **simulate MWR observations from an atmospheric profile**:

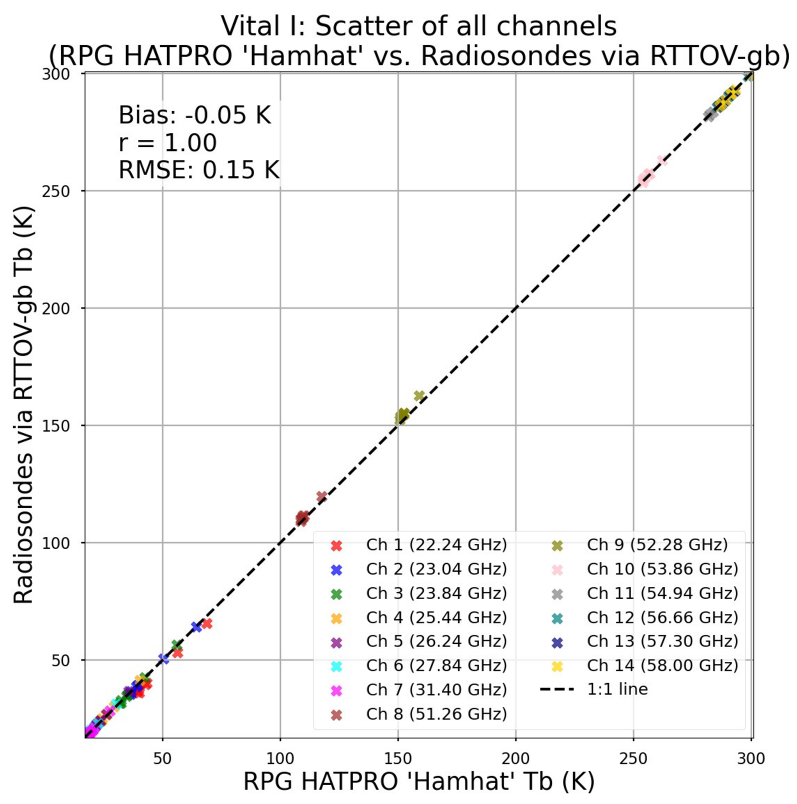

Figure 2: Zenith-pointing MWR plotted against simulated brightness temperatures from RTTOV-gb (all instrument channels)

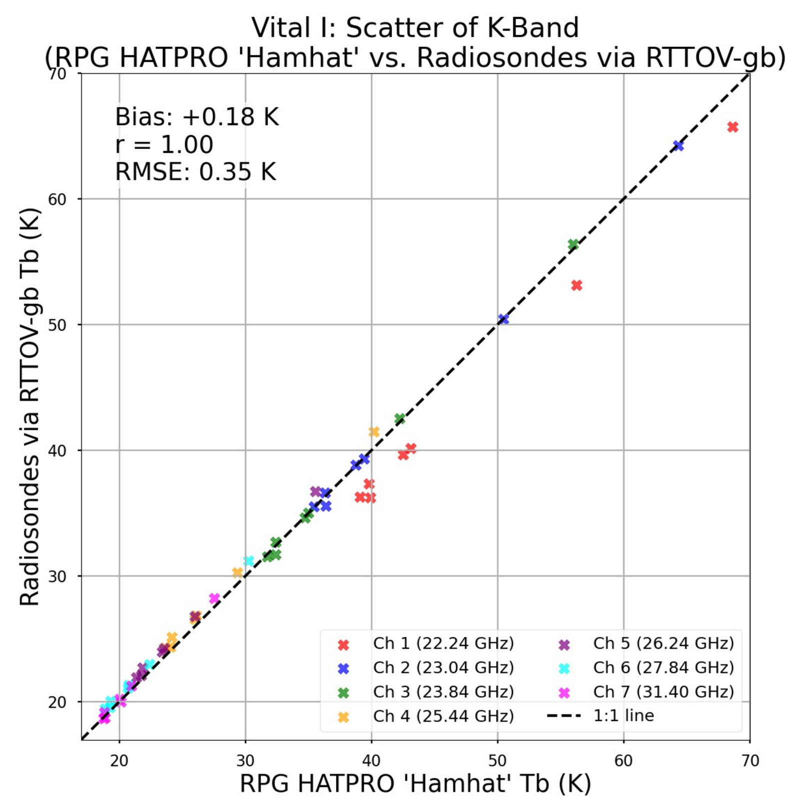

Figure 3: Zenith-pointing MWR plotted against simulated brightness temperatures from RTTOV-gb (K-Band only)

⇛ However, these algorithms have **barely been evaluated for elevations below 10°**!

4. Outlook

Using MWR slant path measurements is a fairly new approach. Necessary prerequisites for their assimilation into ICON-D2 are:

1. Extract slant path profiles from ICON-D2 first guess fields

2. Evaluation of brightness temperatures generated by forward operators for slant path (compared to Line-by-Line models)

3. Correction of additional errors in slant path measurements

4. Assimilation experiments and observation impact evaluation

⇛ By bridging the observational gap in the ABL, this project aims to lay the foundation for more reliable and timely forecasts of **high-impact weather events**.

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Gordon-Research conference, Lewiston (ME/USA), 21st-25th of July 2025