HIRES-APP

Water Vapor Data Assimilation from microwave radiometers and lidars into DWD's ICOsahedral Non-hydrostatic (ICON) model

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
Hans-Ertel-Zentrum für Wetterforschung

Improved weather forecast by synergistic Water Vapor assimilation from lidar and MWR slant path!

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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. Accurate representation of WV is therefore 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.**

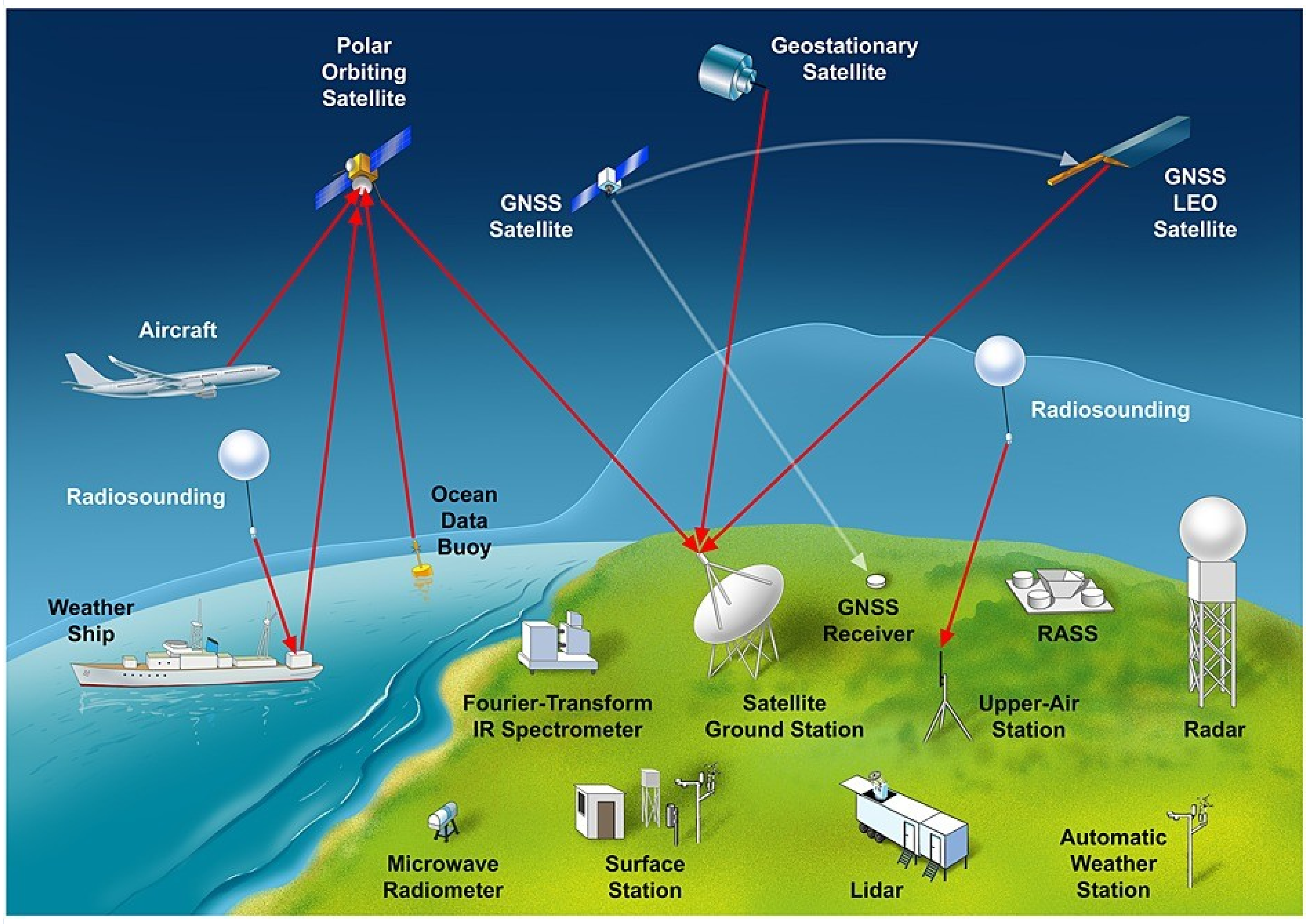

Figure 1: The Global Observing System; source: Wulfmeyer et al., 2015.

2. Observational gap within the Boundary Layer

There is an observational gap, when it comes to WV measurements within the ABL. While satellite instruments provide great spatial and temporal coverage, they mostly **lack vertical resolution and accuracy**, if clouds do not prevent any measurement within the lower troposphere at all. Radiosondes and ground-based instruments on the other hand give more accurate and better resolved WV-profiles, but are point measurements that **lack spatial coverage**.

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
Geostationary Satellites	> 1 km	10–20%	15 min	continental/global
Polar-Orbiting Satellites	1 km	10%	12h / daily (SSO)	global

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

3. The proposed synergistic observation approach

Zenith-pointing microwave radiometer (MWR) have been assimilated as retrieved WV-profiles (Caumont et al., 2016) or directly as brightness temperatures (Vural et al., 2023) with positive forecast impact in the past.
Here a synergistic approach of zenith-pointing lidar measurements and **MWR slant path scans at low elevations (5°-10°)** is introduced. For these elevations the MWR beam covers a **radius of 10-20 km** within a 2 km deep ABL.
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.

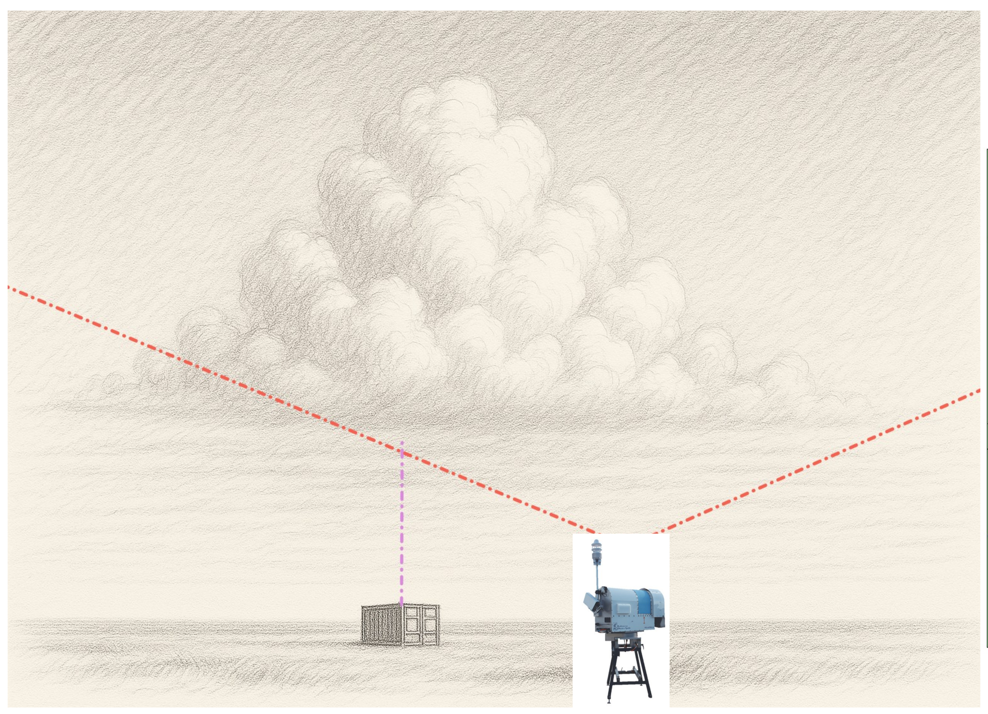

Figure 2: AI-generated schematic of synergistic measurement with MWR slant path scans and zenith-pointing lidar.

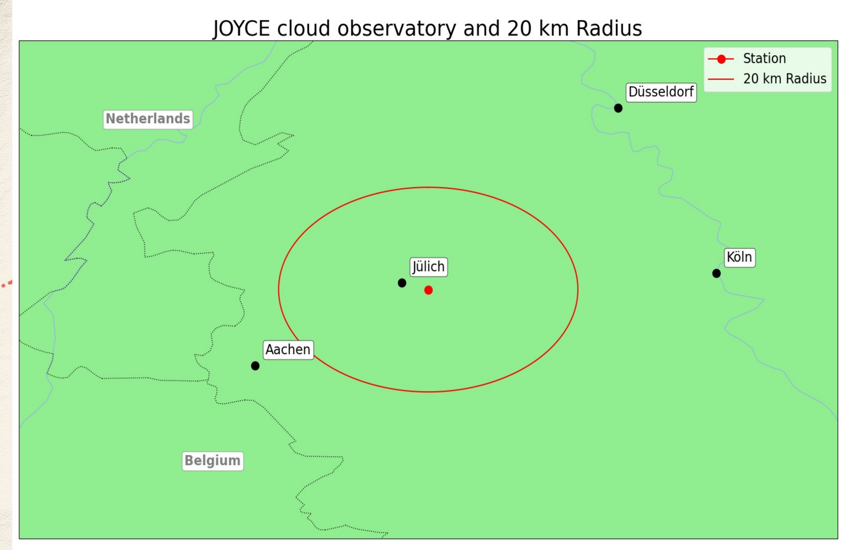

Figure 3: Cartopy-plot of JOYCE cloud observatory with 20 km radius.

4. Direct Assimilation approach for MWR slant path

Within ICON-D2's data assimilation framework, DIAL profiles of WV can be assimilated alongside MWR slant path brightness temperatures. The direct assimilation needs a forward operator H to simulate observations from model data, e.g.:

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

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

5. Next steps of research project

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

1. **Implementation of forward operators for slant path brightness temperatures.**
2. **Evaluation of forward operators for slant path**
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.

References

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