Temperature and humidity profile retrievals from satellite (MTG-IRS) and ground-based (Microwave Radiometer) observations

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DWD — Deutscher Wetterdienst — Wetter und Klima aus einer Hand

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1. VITAL I, August 2024

Resolve, assess and compare summer daytime evolution of the ABL with state-of-the-art and novel observing systems:

- **U**ncrewed **A**ircraft **S**ystems (UAS)
- **M**icro**W**ave **R**adiometers (MWR)
- Ceilometer
- **W**ater **V**apor **DI**fferential **A**bsorption **L**idar (WV-DIAL)
- Doppler lidar
- Radiosondes

JOYCE platform during VITAL I with a range of ground-based remote sensing profilers (front) and in about 300 m distance the 124 m meteorological tower (red/white).
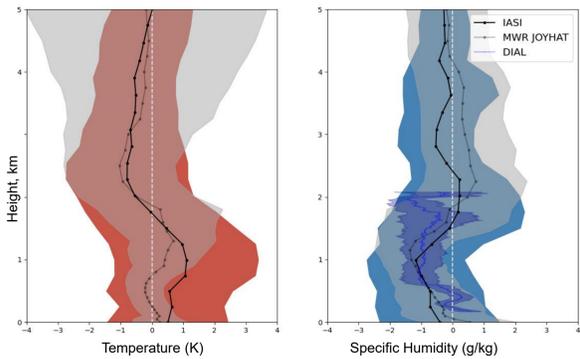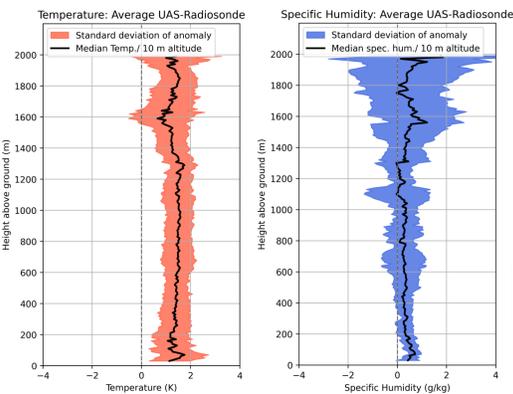

Synergy benefit is evident regarding the opposite STD behaviour with height

*Temperature and humidity retrieval bias and standard deviation from **IASI** (orange/blue, 35 cases), **MWR** (grey, 40 cases), and **DIAL** (dark blue, 40 cases) assessed against radiosondes during VITAL I campaign.*

In the lowest 2km UAS is superior to remotely sensed values

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Median difference and standard deviation of temperature and humidity profiles between radiosondes and UAS "Flik". 19 flights within 15 minutes between 13-19.08.25.

2. Outlook: VITAL II, Summer 2026

Regional profiler network, satellite synergy and cold pools

- **MTG-S IRS** scheduled for launch 07/2025: every 30 min, 6-8 km footprint
- How much can ABL profiles be improved through space-based and ground-based synergy?
- **VITAL II**: leverage use of novel and state-of-the-art satellite sounder observations in synergy with surface-based in-situ and remote sensing observations
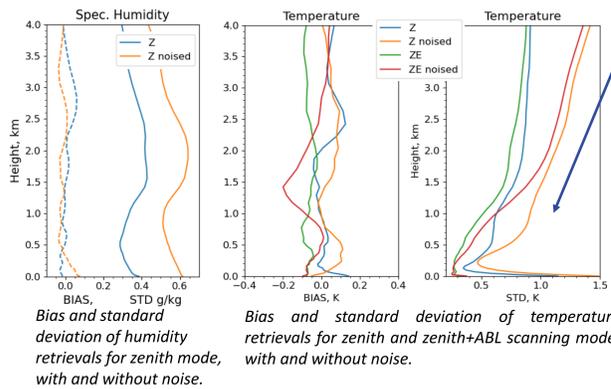
RMR: Rhineland Metropolitan Region

~85 km
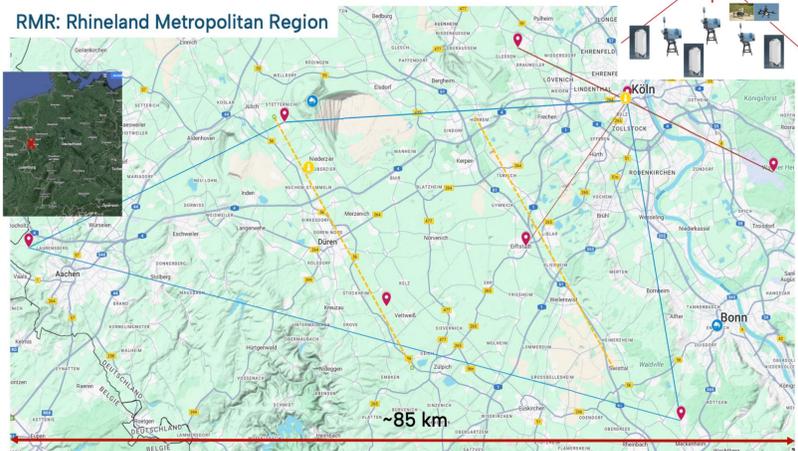
*Rhineland Metropolitan Region in western Germany: **red** markers indicate installed / designated profiling sites equipped at least with a **Doppler Lidar (DL)** and a **MicroWave Radiometer (MWR)**, partially enhanced by **WV-DIAL**. All profiling sites equipped with near-surface measurements. **Radiosondes** will be launched at Jülich, Cologne and Bonn. **UAS** profiling sites are planned for NW of Cologne and over the city during an Intensive Observation Period of two weeks (APOLLO). Additional surface-based data from regional networks will be acquired. When successfully launched, the **MTG-S IRS** (Infrared Sounder) instrument will provide continuous temperature and humidity profiles every 30 min with a horizontal spacing of ~6 km.*

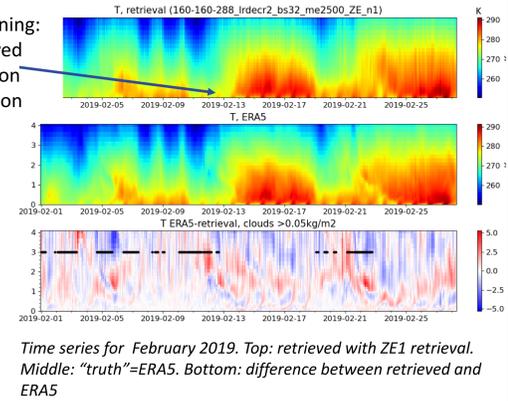## 3. NN retrievals from simulated MTG-IRS and MWR observations
Preliminary results

- ERA-5 reanalysis profiles for the JOYCE site for **2019-2021 (train/val), 2024 (test)**.
- MWR observations simulated with **MWRpy-ret** package (T. Marke)
- IRS observations simulated with **RTTOV14**
- **4 different MWR settings**: zenith measurements only and zenith with elevation measurements at 9 additional angles (30°-4.2°). Both noise-free and with random not correlated noise (0.5-0.2K)
- **Zn0, Zn1:** 14 channels between 23 -58 GHz
- **ZEn0, ZEn1:** 14 ch +9 angles*4 channels (54-58GHz)
- **IRS→** principal components (200)
- Fully connected **Neural networks** with 3 hidden layers (160 to 512 neurons)

NN retrieval from MWR observations

Bias and standard deviation of humidity retrievals for zenith mode, with and without noise.

Bias and standard deviation of temperature retrievals for zenith and zenith+ABL scanning mode, with and without noise.
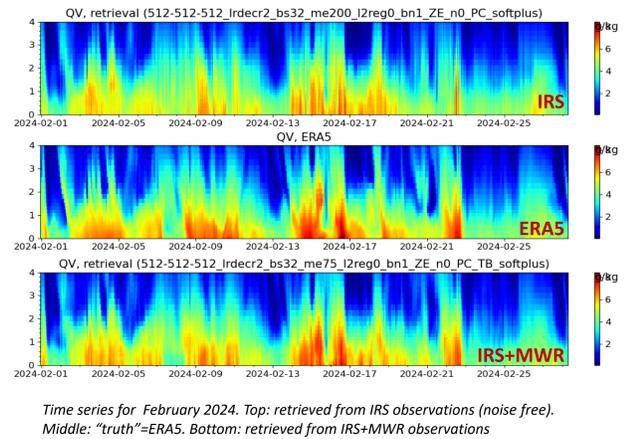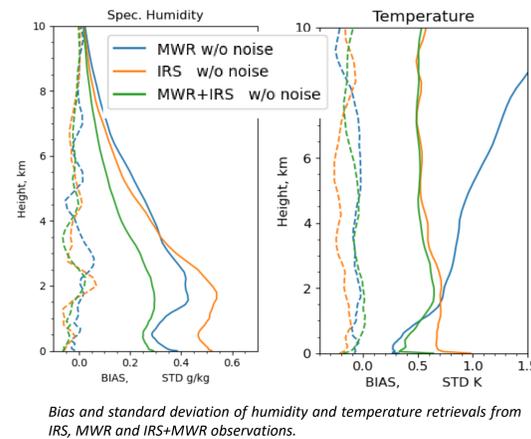
ABL scanning: Improved inversion detection

Time series for February 2019. Top: retrieved with ZE1 retrieval. Middle: "truth"=ERA5. Bottom: difference between retrieved and ERA5

NN retrieval from IRS+MWR observations

*Bias and standard deviation of humidity and temperature retrievals from IRS, MWR and IRS+MWR observations.*

Time series for February 2024. Top: retrieved from IRS observations (noise free). Middle: "truth"=ERA5. Bottom: retrieved from IRS+MWR observations

4. NN explainability → Try to explain the feature impact

- **Deep NN→** weights of the first layer do not give insight into the impact of channels on predictions.
- Feature importance is non-linear:
  - multiple layer transformations→ feature that appears unimportant in the first layer might become crucial in the later layers
  - Non-linear activation functions (here ReLU)
- Interactions between features
- Input is normalized→ weights alone do not directly indicate importance

→ Use **SHAP** to calculate SHAP values:

> **SHAP** assigns each feature an importance value for particular prediction
> **Positive SHAP**: feature increases the predicted value
> **Negative SHAP**: feature decreases the predicted value
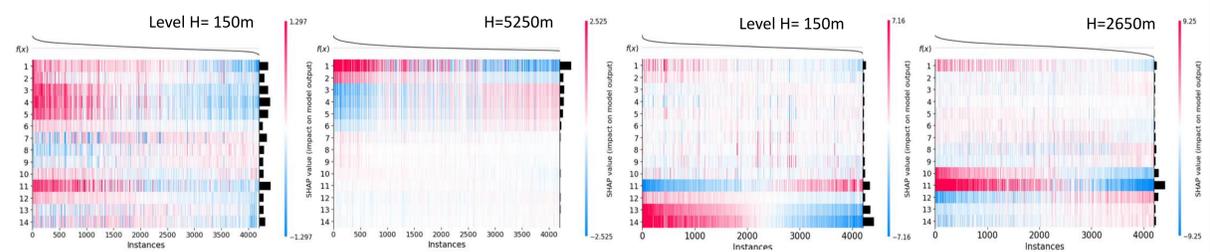
SHAP values of 14 channels and humidity at level 5 (150m, left) and level 40 (5250m, right) for the validation dataset (4200 samples). Sorted by the sum of the SHAP values over all features for particular prediction (black line) from positive to negative.

Same as left but for temperature retrieval ZEn1 and height level 5(150m, left) and 30 (2650m), right.

5. Outlook

- Application of developed retrievals to real MWR (IRS) observations
- Preparations for OSE experiments with ICON-LAM→ assimilation of retrieved atmospheric profiles during VITAL II