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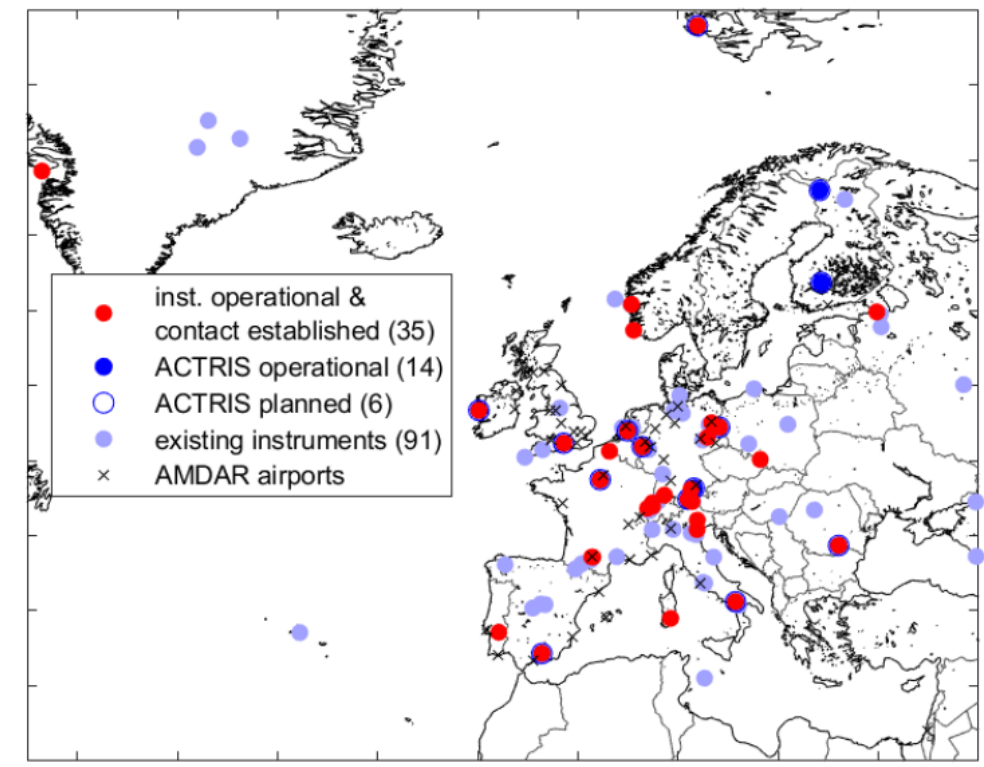
# NETWORK OPERATION OF GROUND-BASED MICROWAVE RADIOMETERS IN EUROPE: UNCERTAINTY ASSESSMENT AND CONSISTENT RETRIEVAL DEVELOPMENT

Bernhard Pospichal

With contributions from Tobias Böck, Tobias Marke, Moritz Löffler, Ulrich Löhnert

# Ground-based Microwave radiometer networks in Europe

- Ground-based microwave radiometers (MWR) have been operated in Europe for more than 20 years (mostly K- and V-Band instruments)
- More and more stations from various operators are running continuously throughout Europe
- Two initiatives aim for coordinated networks:
  - EUMETNET / E-Profile (operational met services)
  - ACTRIS (distributed research infrastructure)
- Challenges for network operation (calibration, data processing, retrievals, quality control, etc.)

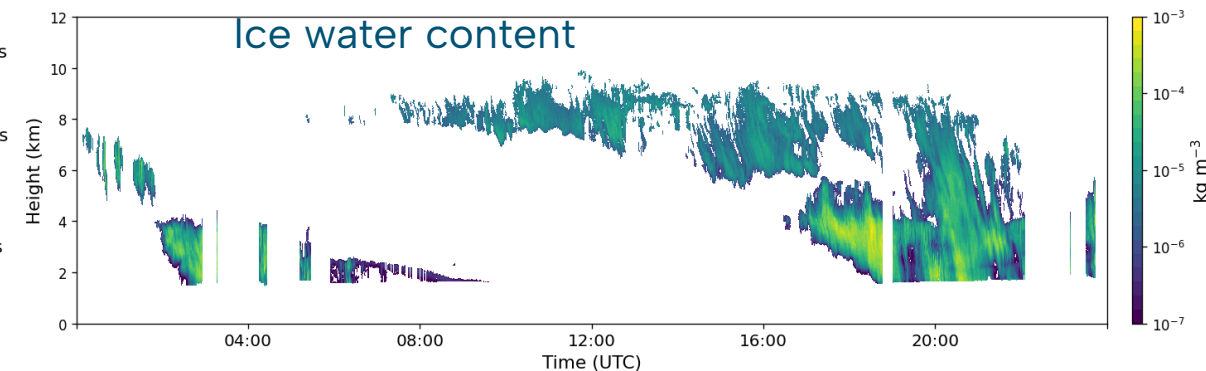
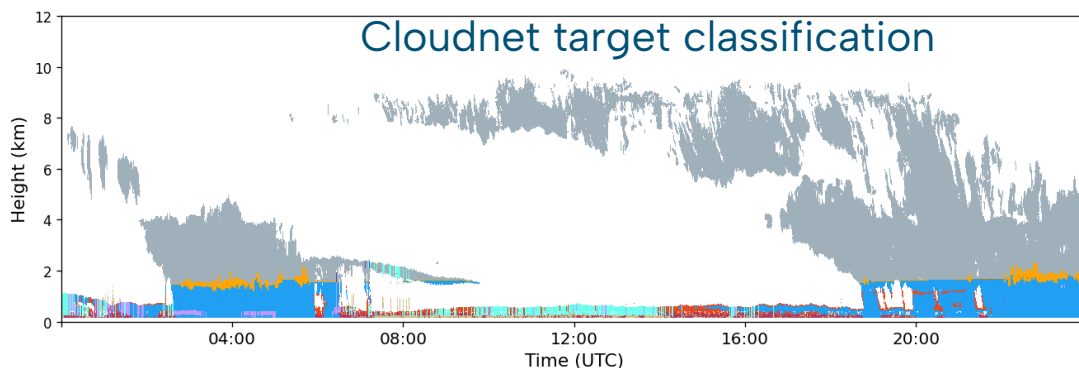


Rüfenacht et al., 2021

# ACTRIS – Aerosol Cloud and Trace Gases Research Infrastructure



- 6 main components (in-situ / remote sensing of Aerosol, Clouds and Trace Gases)
- > 20 European countries, more than 100 observational sites (+chambers)
- Many previous projects/networks were combined, official start in 2023
- MWR are part of CCRES (Centre for Cloud Remote Sensing)
- **Cloudnet**: Instrument synergy for providing cloud profiles for research purposes (Cloud radar, Ceilometer, **Microwave radiometer**, Doppler lidar, Disdrometer)



# Ground-based Microwave radiometer networks in Europe



## Focus of ACTRIS

- High quality product generation, focus on products around clouds/water cycle
- MWR: Statistical retrievals for products (IWV, LWP, T/RH/q-profiles)

## Instrumentation

- Mostly RPG-HATPRO instruments, in ACTRIS currently uniquely RPG.
- E-Profile also includes Radiometrics and Attex instruments

## Focus of EUMETNET/E-Profile

- Real-time data submission (~10 min latency) for nowcasting and data assimilation into weather forecast models (brightness temperatures)
- ID-Var retrievals, convective parameters

## ACTRIS MWR unit:

University of Cologne / JOYCE  
(U. Löhnert, B. Pospichal, T. Marke, ...)

## E-Profile coordination:

MeteoSwiss Payerne  
(A. Haefele, E. Sauvageot, ...)

# JOYCE – Jülich Observatory for Cloud Evolution



- Located in Jülich, Germany (~40km west of Cologne), operated by University of Cologne and Research Centre Jülich
- ACTRIS Cloudnet station since 2010
- > 20 years of microwave radiometry experience

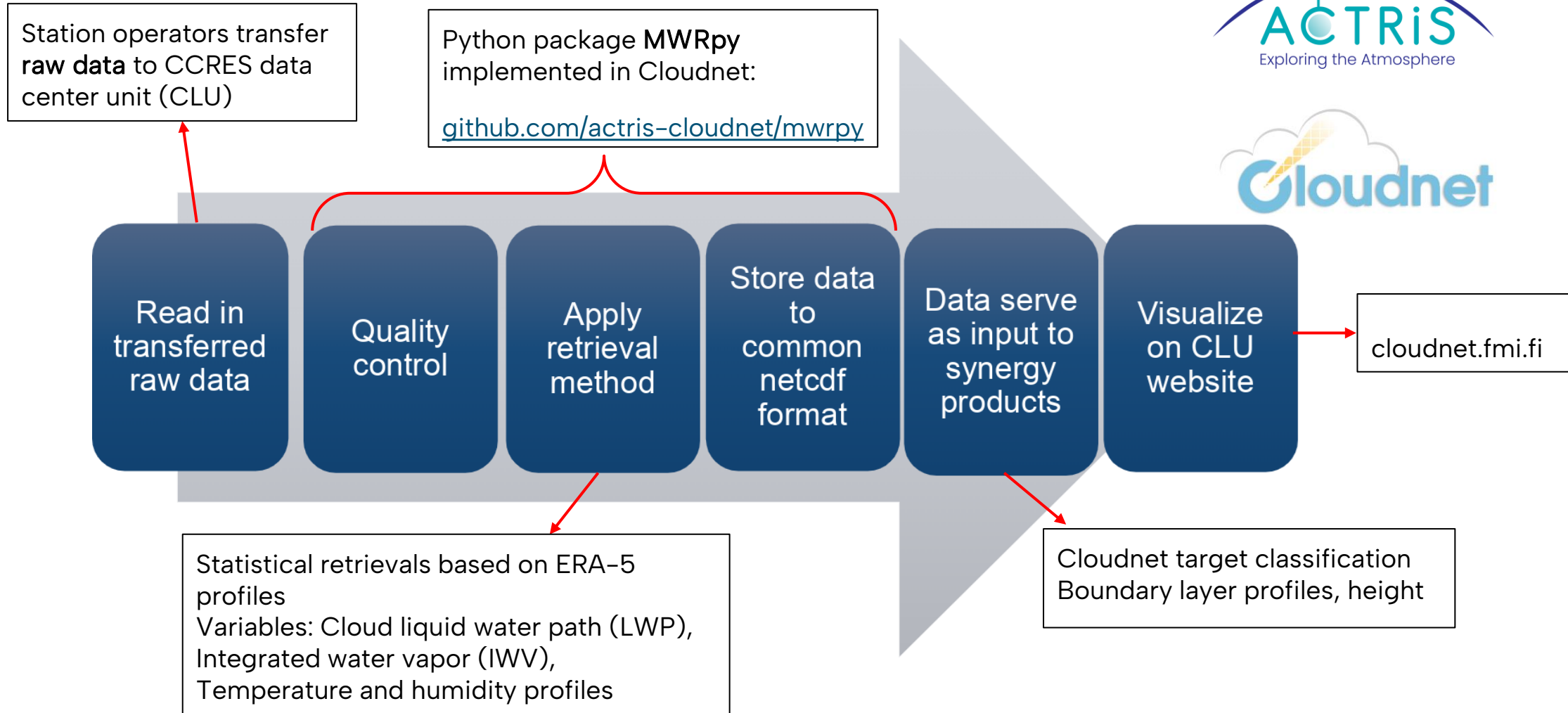
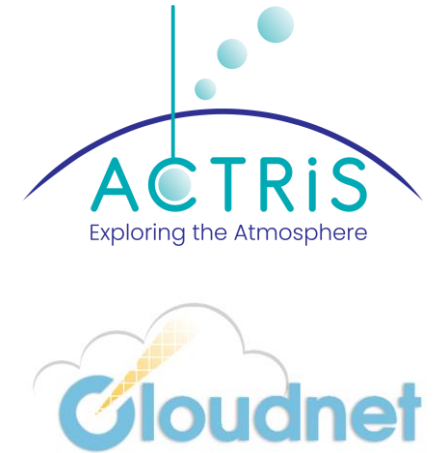
- **Science:** Cloud life cycle
- **Instruments:** Test and develop
- **Tools:** Inverse methods (“retrievals”)
- **Models:** Evaluation and data assimilation
- **Data:** Dissemination, standardization
- **Teaching:** PhD/MSc/BSc theses, excursions, summer schools, etc.

# Network developments in the past

- COST actions in Europe (COST actions foster the exchange between European scientists. Several COST actions were relevant for the establishment of MWR networks and data processing:
- EG-Climet (2008-12), TOPROF (2013-17), PROBE (2019-24)
- Focus on MWR synergy products, uncertainty assessment, calibration tests, intercomparison campaigns, network operation, etc.

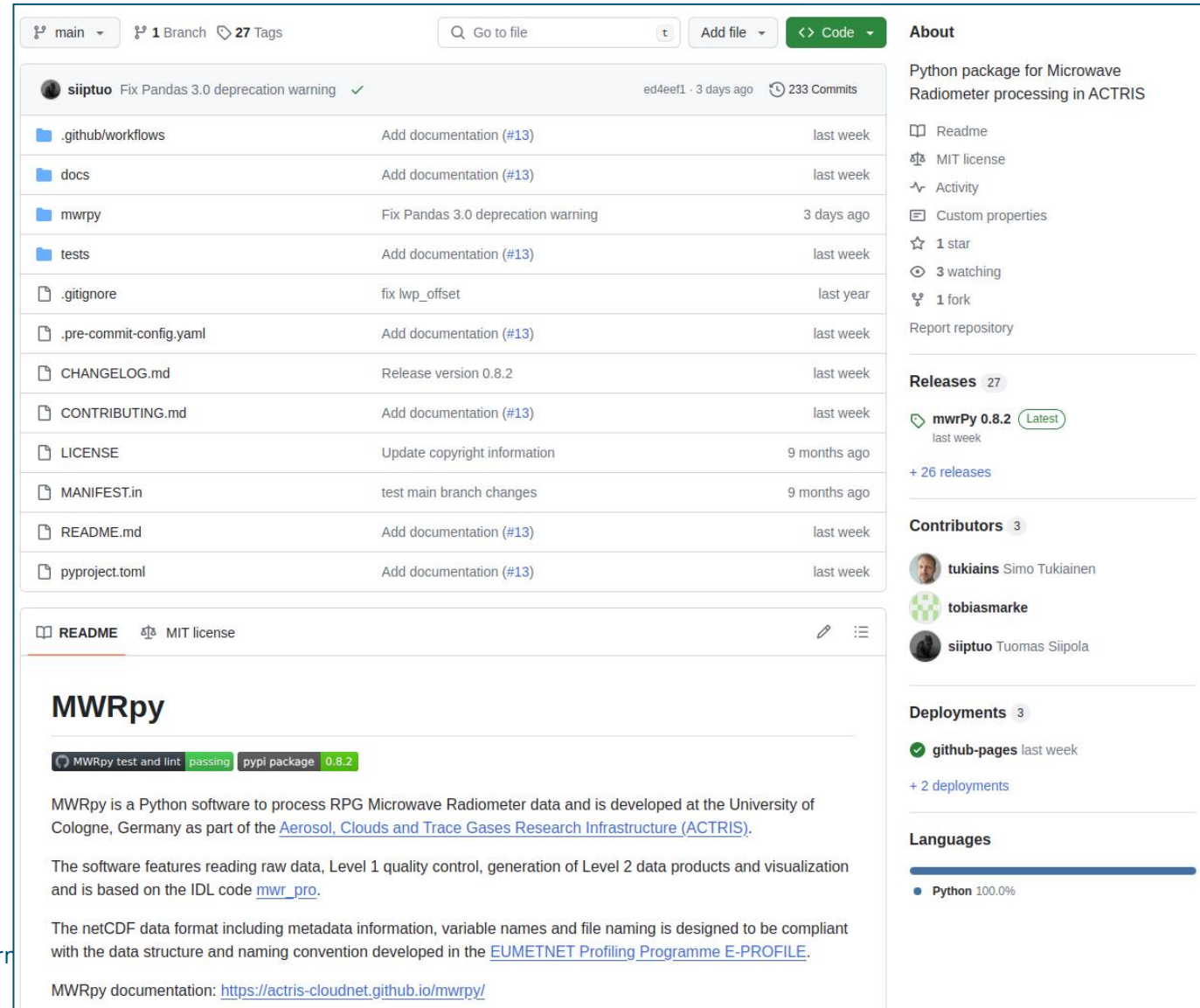


# Microwave radiometer processing in ACTRIS



# MWRpy processing software

- MWRpy is implemented in Cloudnet framework and maintained in Cloudnet's github repository
- Can be used as **stand-alone** software
- First experimental products are derived operationally for 8 stations
- Common statistical retrievals for level2 products under development (currently not harmonized yet)



The screenshot shows the GitHub repository for MWRpy. At the top, it indicates the current branch is 'main', there is 1 branch, and 27 tags. A search bar and 'Add file' button are visible. The repository is owned by 'siiptuo' and has 233 commits. The file list includes:

File	Commit Message	Time
.github/workflows	Add documentation (#13)	last week
docs	Add documentation (#13)	last week
mwrpy	Fix Pandas 3.0 deprecation warning	3 days ago
tests	Add documentation (#13)	last week
.gitignore	fix lwp_offset	last year
.pre-commit-config.yaml	Add documentation (#13)	last week
CHANGELOG.md	Release version 0.8.2	last week
CONTRIBUTING.md	Add documentation (#13)	last week
LICENSE	Update copyright information	9 months ago
MANIFEST.in	test main branch changes	9 months ago
README.md	Add documentation (#13)	last week
pyproject.toml	Add documentation (#13)	last week

The README section is visible, showing the project title 'MWRpy' and a status bar with 'MWRpy test and lint' (passing) and 'pypi package' (0.8.2). The text describes MWRpy as a Python software for processing RPG Microwave Radiometer data, developed at the University of Cologne, Germany, as part of the ACTRIS infrastructure. It lists features like reading raw data, quality control, and visualization, and mentions its compliance with the netCDF data format and EUMETNET standards. The documentation link is provided as <https://actris-cloudnet.github.io/mwrpy/>.

The right sidebar contains repository statistics: 'About' (Python package for Microwave Radiometer processing in ACTRIS), 'Releases' (27, with the latest being 'mwrPy 0.8.2'), 'Contributors' (3: tukiains, tobiasmarke, siiptuo), 'Deployments' (3, with 'github-pages' last week), and 'Languages' (Python 100.0%).



Location

Hyytiälä x

Show all sites

Date

2024-04-08

Product

MWR multiple pointing x

MWR single pointing x

Show experimental products

Instrument

Select

Variable

Select

▶ ADVANCED

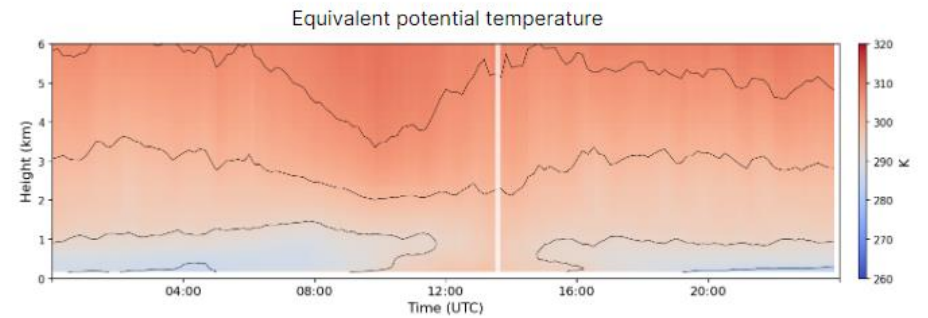
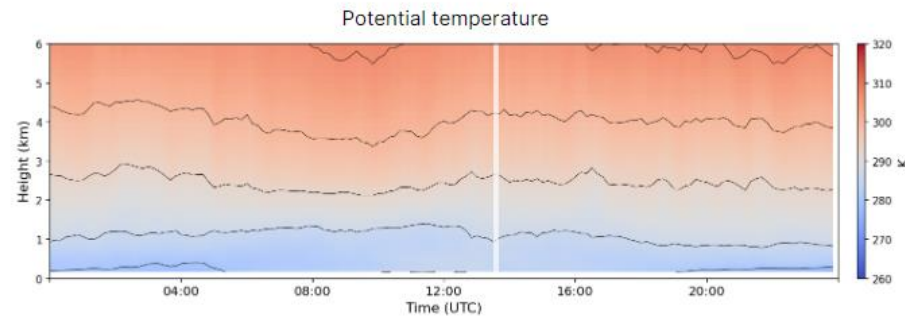
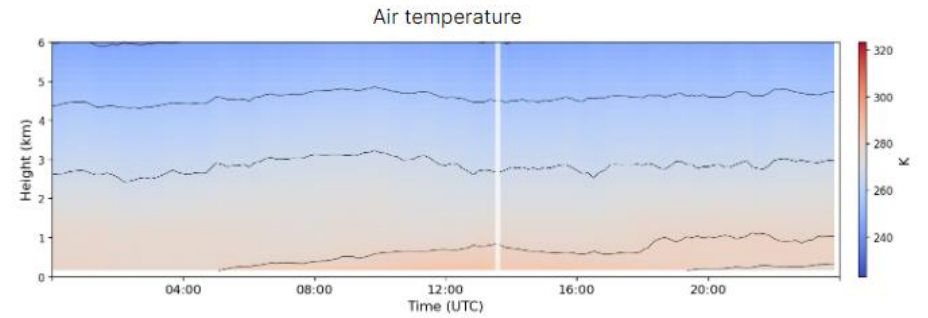
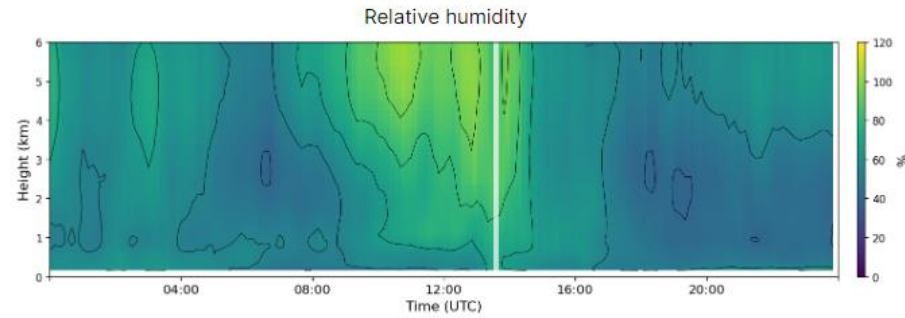
View in data search →

[Reset filter](#)

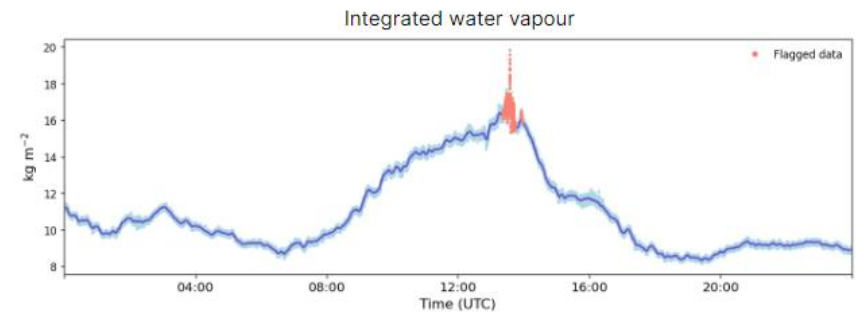
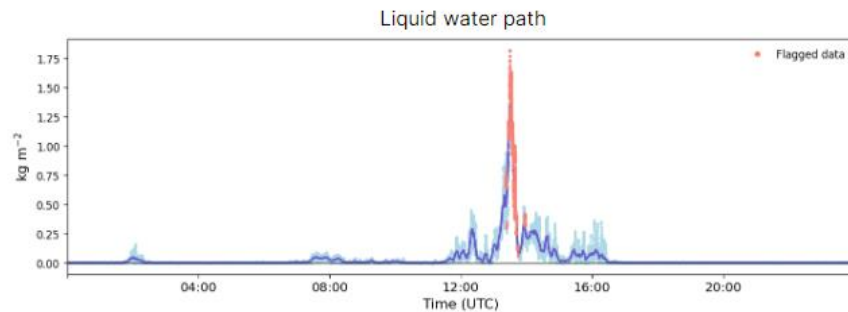
Visualisations for 8 April 2024

comparison view

Hyytiälä MWR multiple pointing Volatile Experimental



Hyytiälä MWR single pointing Volatile Experimental



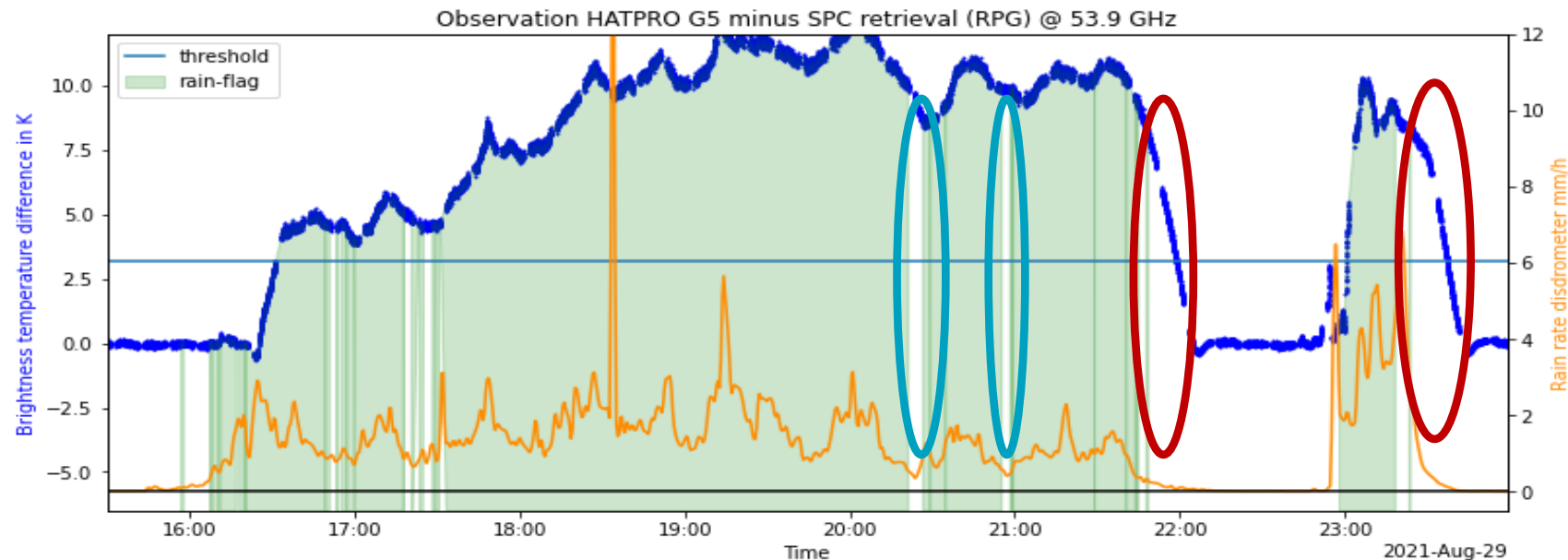
Relative humidity

Absolute humidity

# Uncertainty Assessment & Mitigation Strategy

- Develop standard procedure for error characterization
- Help operators determine uncertainties, perform system checks, and monitor stability to decide when and if an intervention is necessary
- Mitigation includes: frequent calibration, radome change

## Example: Wet radome detection




# MWR observation uncertainties

- External influences
  - Radome degradation
  - Obstacles
  - RFI (Radio frequency interference) from artificial sources
- Internal errors
  - Calibration Repeatability
  - Radiometric Noise
  - Drifts
  - Bias/ systematic Difference between Instruments

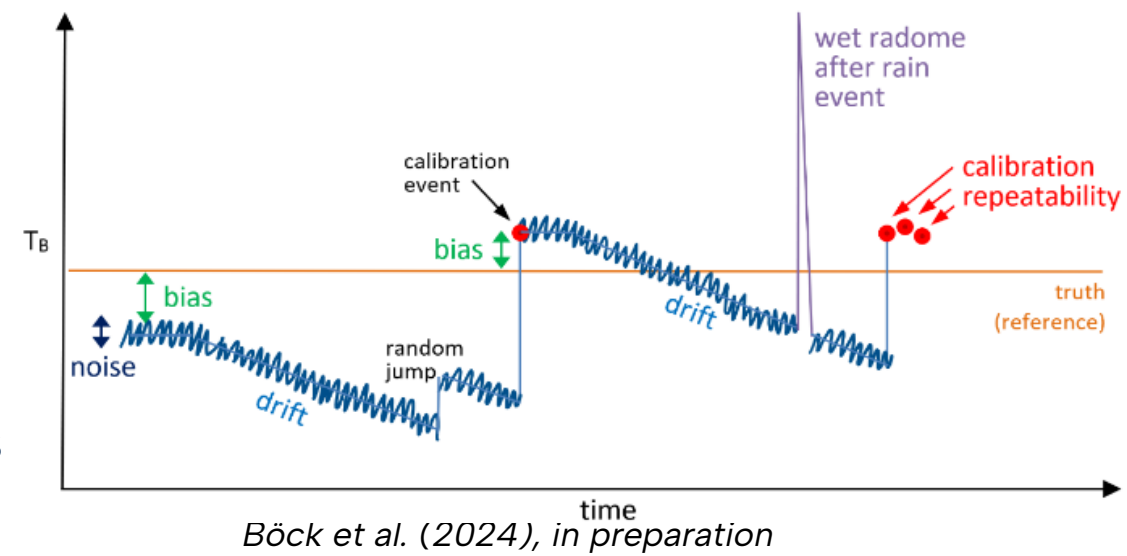



Atmos. Meas. Tech., 17, 219–233, 2024  
<https://doi.org/10.5194/amt-17-219-2024>  
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Atmospheric Measurement Techniques 

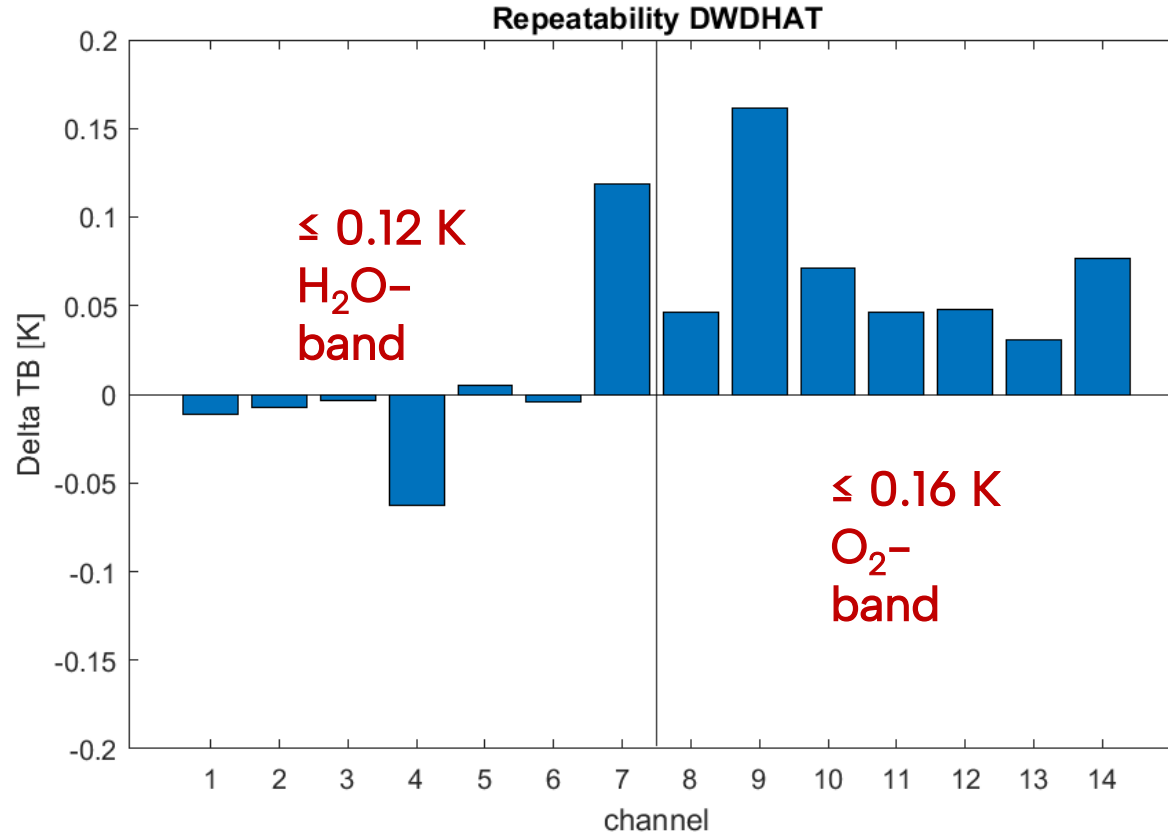
**Measurement uncertainties of scanning microwave radiometers and their influence on temperature profiling**

Tobias Böck, Bernhard Pospichal, and Ulrich Löhnert  
Institute for Geophysics and Meteorology, University of Cologne, 50923 Cologne, Germany



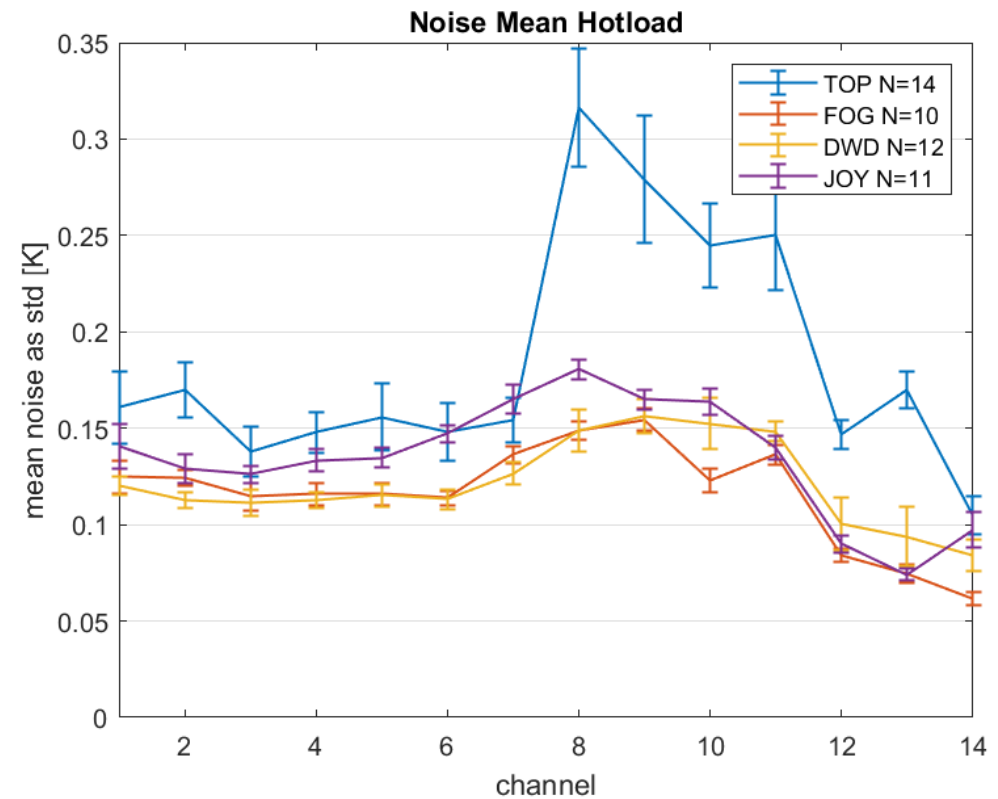
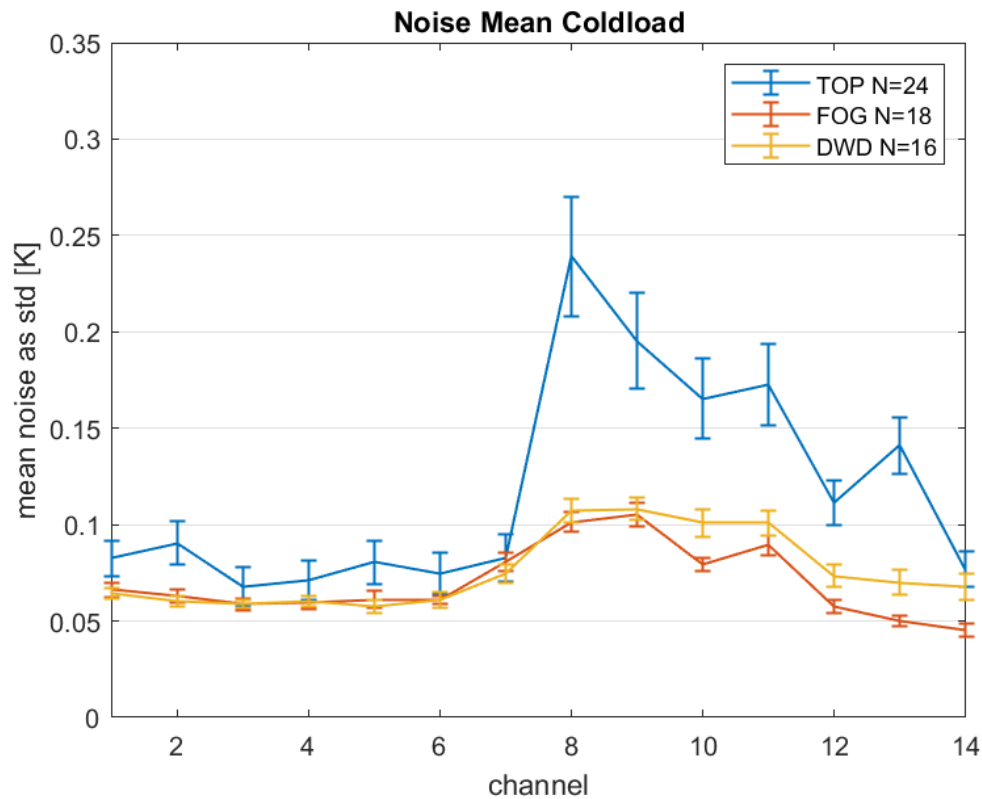
# Calibration Repeatability

## Differences at Zenith between Calibrations compared to a reference



- Is influenced by the quality of the calibration
- Can only be measured this way when there are at least two MWRs on the same site simultaneously (not feasible for regular operators)
- Meaningful values can only be achieved with the same conditions for each calibration (same day, same weather, same target,...)

# Radiometric Noise



- N indicates the number of 3–5 min observation intervals on the cold- or hotload
- Noise does not change over time and is independent of calibrations events
- Operator cannot influence noise but can and should monitor it

# Summary Instrument Errors

Manufacturer's claims:

→ absolute TB uncertainty 0.25 K

→ noise 0.10 to 0.25 K

## Results Overview (for Gen5 HATPROs):

Type of Error	Typical Error Values K-band (H <sub>2</sub> O)	Typical Error Values V-band (O <sub>2</sub> )	Determined via	Can error be influenced by handling?	How to reduce Error?	Should be determined by the operator
Calibration Repeatability	≤ 0.12 K	≤ 0.16 K	Changes in zenith reference measurements after two immediate consecutive calibrations	yes	Quality of calibration	no
Mean Noise Levels (cold load – hot load) (1s)	≤ 0.11 K – 0.18 K	≤ 0.27 K – 0.35 K	Standard deviation	no	Not possible; instrument specific	yes
Drifts (indicated by cold load jumps)	usually ≤ 0.4 K (up to 1.8 K)	usually ≤ 1.0 K (up to 2.8 K)	Differences at cold load after calibration	yes	Frequency of calibration	yes
Mean Biases	≤ 0.16 K or ≤ 0.5 K – 1.2 K	≤ 0.7 K or ≤ 0.5 K	Zenith measurement differences between two MWRs	yes	Quality of calibration	no
Radome weathering	>> 2 K	>> 2 K	Observation minus SPC-retrieval in channel 10	yes	Replace radome frequently, filter data	yes

# MWR quality control / data flagging

Quality flags derived and applied for Level 1 data (also provided in level 2 product files)

Bit 1: `missing_tb`

Bit 2: `tb_below_threshold`

Bit 3: `tb_above_threshold`

} TB values are being checked

Bit 4: `spectral_consistency_above_threshold` ➡ Comparison: retrieved & observed TB

Bit 5: `receiver_sanity_failed` ➡ Receiver & ambient target stability + noise diode status

Bit 6: `rain_detected` ➡ Rain sensor / wet radome detected

Bit 7: `sun_in_beam` ➡ Calculate sun & moon position for site location (relevant for scans)

Bit 8: `tb_offset_above_threshold` ➡ OmB monitoring

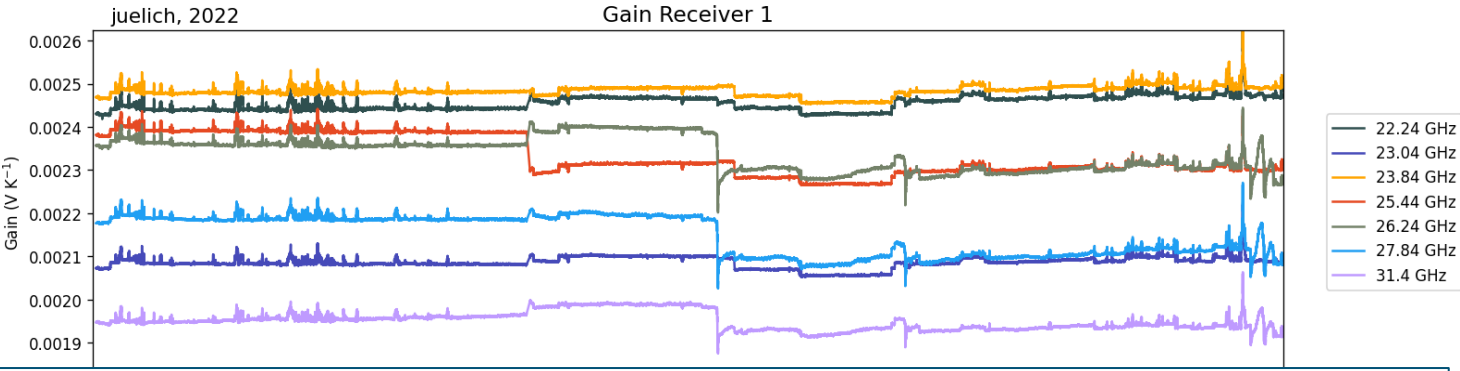
# MWR quality monitoring

## Long term data quality monitoring and assessment

- Detection of malfunction possible in operational use
- Required to have instrument logbook in ACTRIS network
- Observation minus background monitoring

## Centralized housekeeping data (HKD) monitoring in development

- Includes instrument type specific thresholds and alert settings



status	no rai	no rai	no rain	no	no	no	no	no ra	no	no	no	no
Rain	no rai	no rai	no rain	no	no	no	no	no ra	no	no	no	no
Dew blower status	high	high	hig hig	lo high	high	hi	high	hi hi	high	high	hi	lo
Boundary layer mode	active	active	active	active	active	active	active	active	active	active	active	active

# Summary / Outlook

- Ground-based microwave radiometer networks in Europe (ACTRIS / Cloudnet, E-Profile) being implemented with centralized data processing
- 30–50 stations throughout Europe, standard operation procedures
- Applications, current developments:
  - Software tools for processing and data quality control
  - Development of new synergy products (BL profiles, BL height, cloud profiles)
  - Development of methods to determine error budget for each instrument
  - Retrieval intercomparison campaigns
  - Data assimilation becoming operational (MeteoSwiss, Deutscher Wetterdienst)
  - Future efforts for MWR in GRUAN (GCOS Reference Upper-Air Network)



