ACTRIS | Centre for Aerosol Remote Sensing

Automatic low-power lidar and ceilometer (ALC) QA/QC measurements

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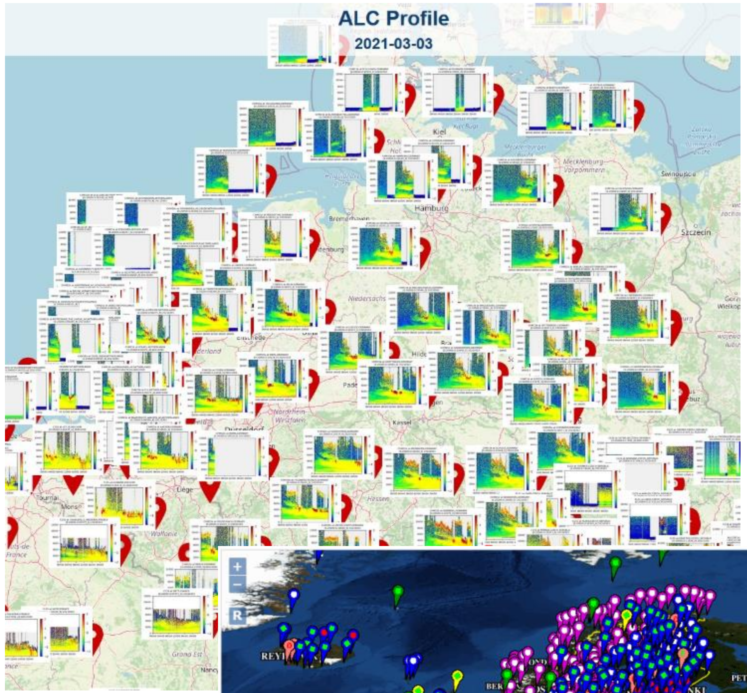
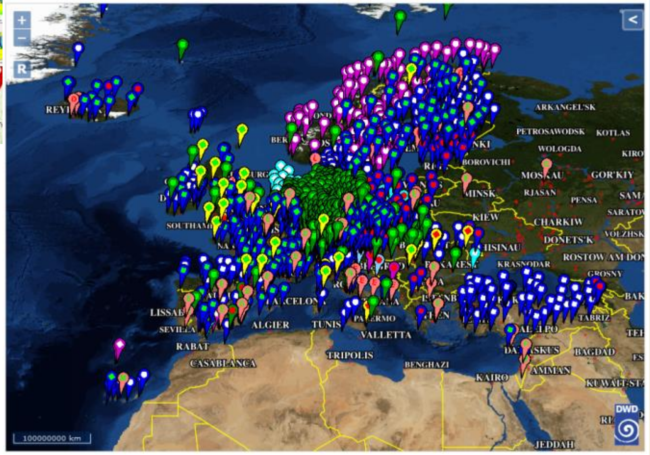
Bundesministerium für Bildung und Forschung
FONA Forschung für Nachhaltigkeit
Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit
Bundesministerium für Verkehr
ACTRIS CCRES
Deutscher Wetterdienst – Wetter und Klima aus einer Hand
DWD
LMU
MIM

CARS-ALC goals

- Running an evaluation testbed with instruments from different manufacturers together with AHL reference systems
  - Instrument characterization and formulation of SOPs
  - Development, application and testing of calibrations, corrections (e.g. overlap, dark measurement, water vapor absorption) and methods (e.g. ABL and layer detection)
  - Development of QA and QC methods (e.g. house keeping data monitoring, instrument calibration)
- Definition and contribution to workflows
  - Data flow with data centres
  - Labeling process with CRS NFs
- Based on the cooperation across ACTRIS CFs and a large user community → knowledge transfer and training

E-Profile





DWD Ceilomap

CARS-ALC instruments

CARS-ALC-LMU

Vaisala			Campbell Scientific	Lufft	
CL31	CL51	CL61	SkyVUEPRO	CHM15k	CHM8k
operation	operation	operation	operation	operation	operation

CARS-ALC-DWD

DROPLET	Lufft			Vaisala	
MiniMPL	CHM15k	CHM15k	CHM8k	CL51	CL61
operation	operation	operation	operation	operation	operation

Reference Device

Lidar: POLIS, AHL from ACTRIS-NF (2025/26)

EARLINET lidar RALPH

Dark measurements

Dark measurements

Why dark measurements?

- Lidar signals are affected by different noise sources which can be
  - External (e.g., solar radiation, moon, street lamps)
  - Internal (e.g., electronic)
- Solar background noise is a range independent component
- Electronic noise sources are instrument related and result in range dependent signal distortions
- Correcting for such lidar signal distortions is an important step in lidar data processing and usually done for aerosol high-power lidar (AHL) as part of QA/QC procedures
- For ALCs, only the background signal is corrected automatically in the device

→ Regular dark measurements and their necessity for ALCs are investigated within ACTRIS for signal post-processing

Dark measurements

Regular dark measurements

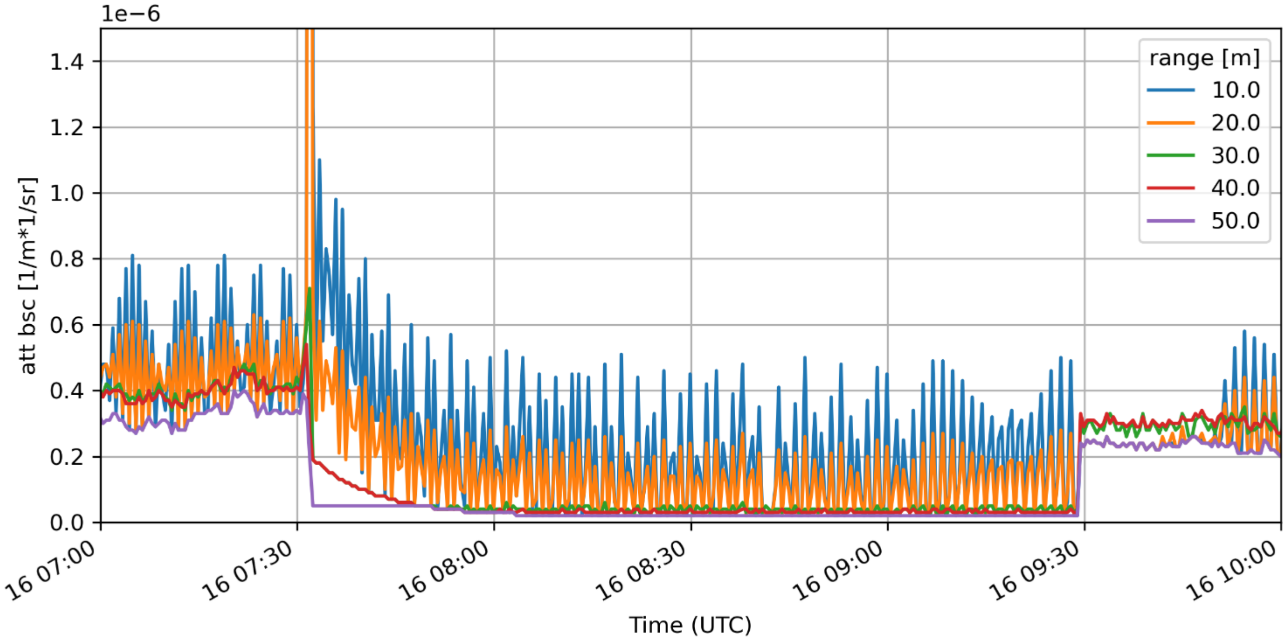
- How variable are the DMs over time?
- Is a correction needed for every instrument?
- Is a correction useful/possible?

Monostatic configuration	Bistatic configuration
Vaisala CL31 Vaisala CL51 Vaisala CL61 Campbell SkyVUE Pro	Lufft CHM8k Lufft CHM15k(x)
Dark measurement with optical termination hood from Vaisala - CL31/CL51 version - CL61 version	Dark measurement with telescope covered - e.g. cardboard or 3D-printed plate

Dark measurements

Method

- 1-2 hour of dark measurement
- Input: Attenuated Bsc.
  (calibrated, r², OVL-corr.)
- Average all profiles
- Attention:
  For the Vaisala CL51 for instance the signal settles in the first range bins for around 30 min
  → check signals before averaging
- Remove range correction
- Remove overlap correction



Dark measurements

Time series of DMs

CL61: - stable around zero above 2 km
- strong signal increase below

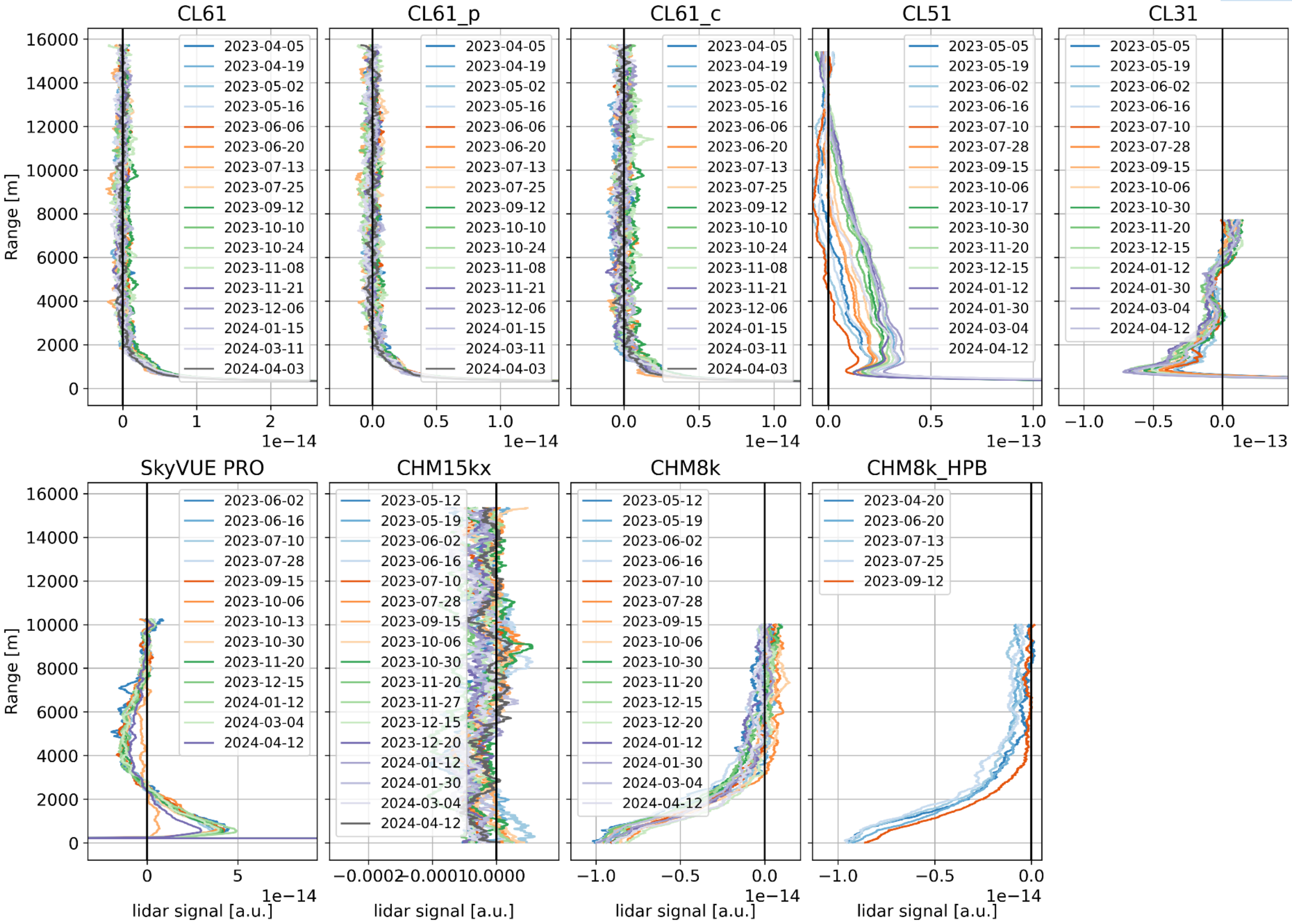
CL51: - very variable over time and height
- strong signal increase in near range

CL31: - stable over time but not height
- strong signal increase in near range

SkyVUE PRO: - stable over time but not height
- strong signal increase in NR

CHM15kx: - varying around zero → stable

CHM8k: - almost stable above 3-4 km
- signal decrease below



What is the signal strength of the DM compared to atmospheric measurements?

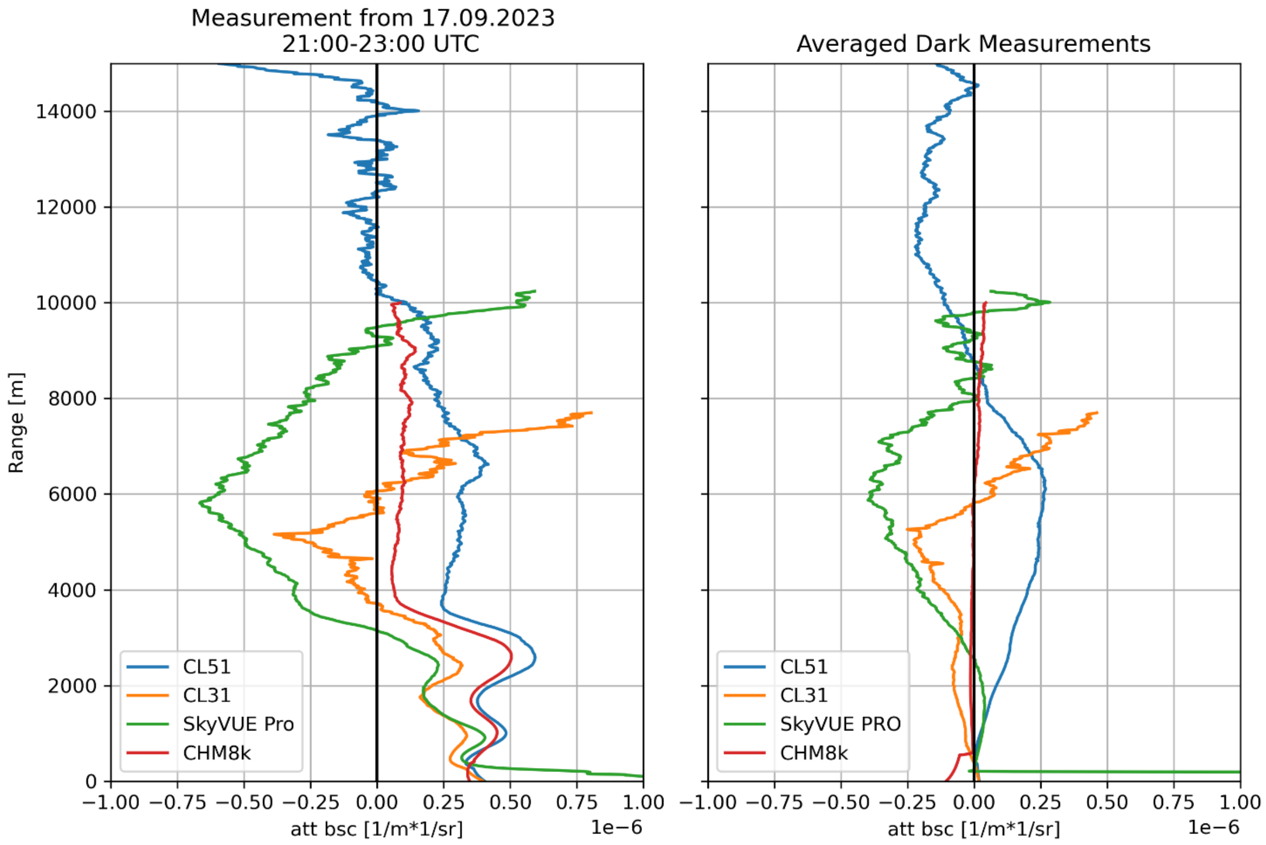
CL51: - signal strength of DM not negligible

CL31: - above 4 km with signal peaks in the DM
- not negligible

SkyVUE PRO: - strong negative peak between 3 and around 8 km
- not negligible

CHM8k: - DM signal strength much lower than atmospheric signal

→ Correction will improve the signal quality



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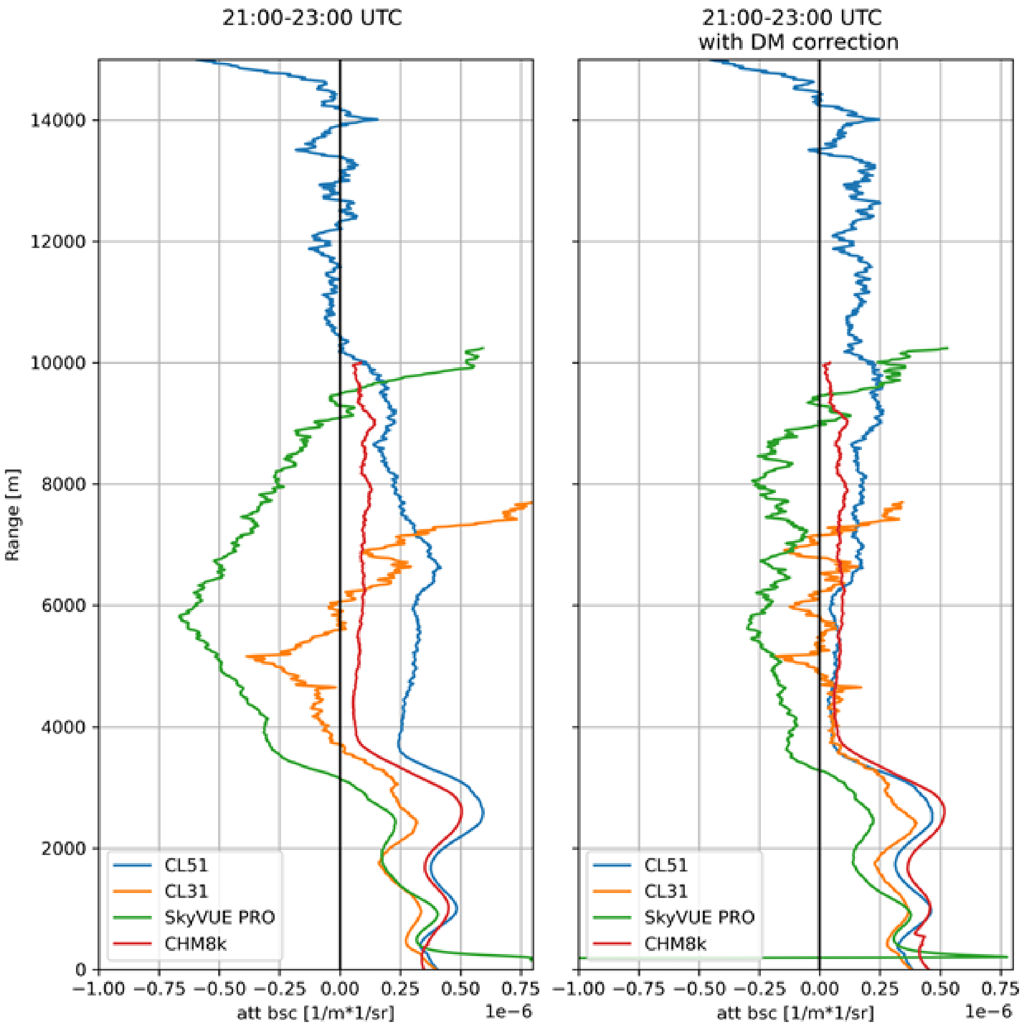
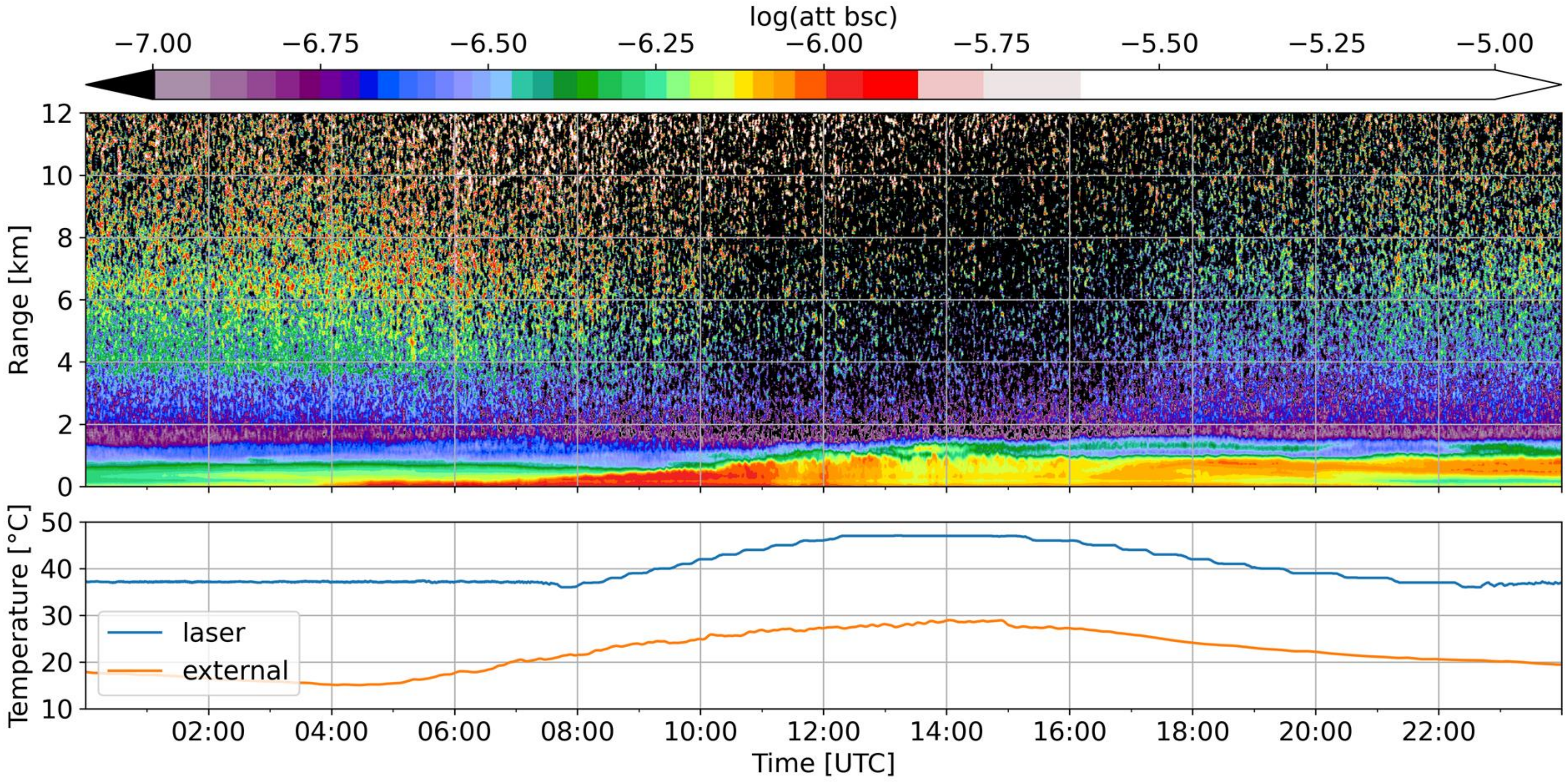
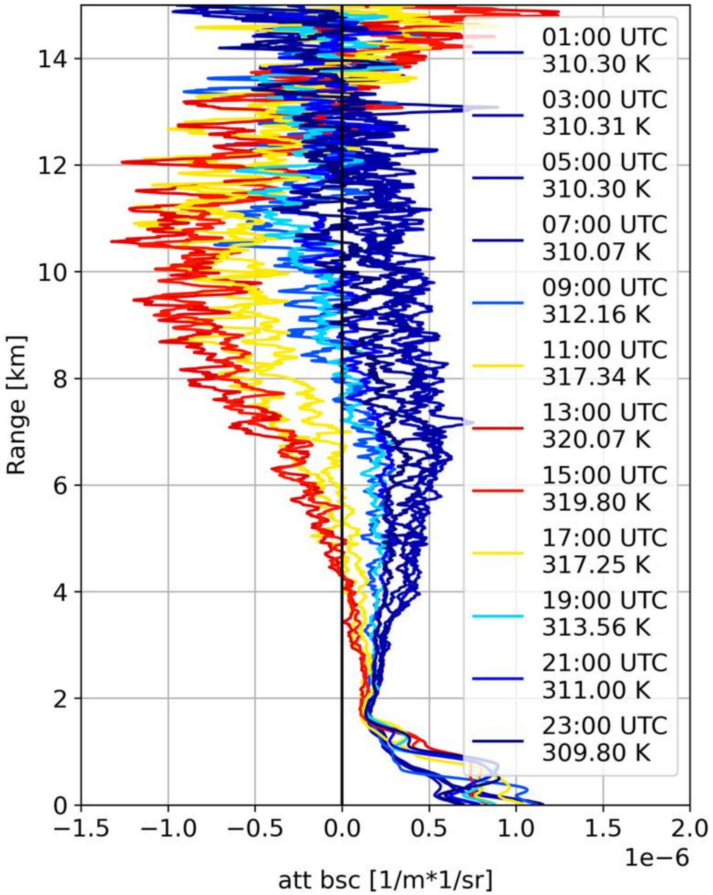
CHM8k: - DM signal strength much lower than atmospheric signal

→ Correction will improve the signal quality
But not yet perfect.



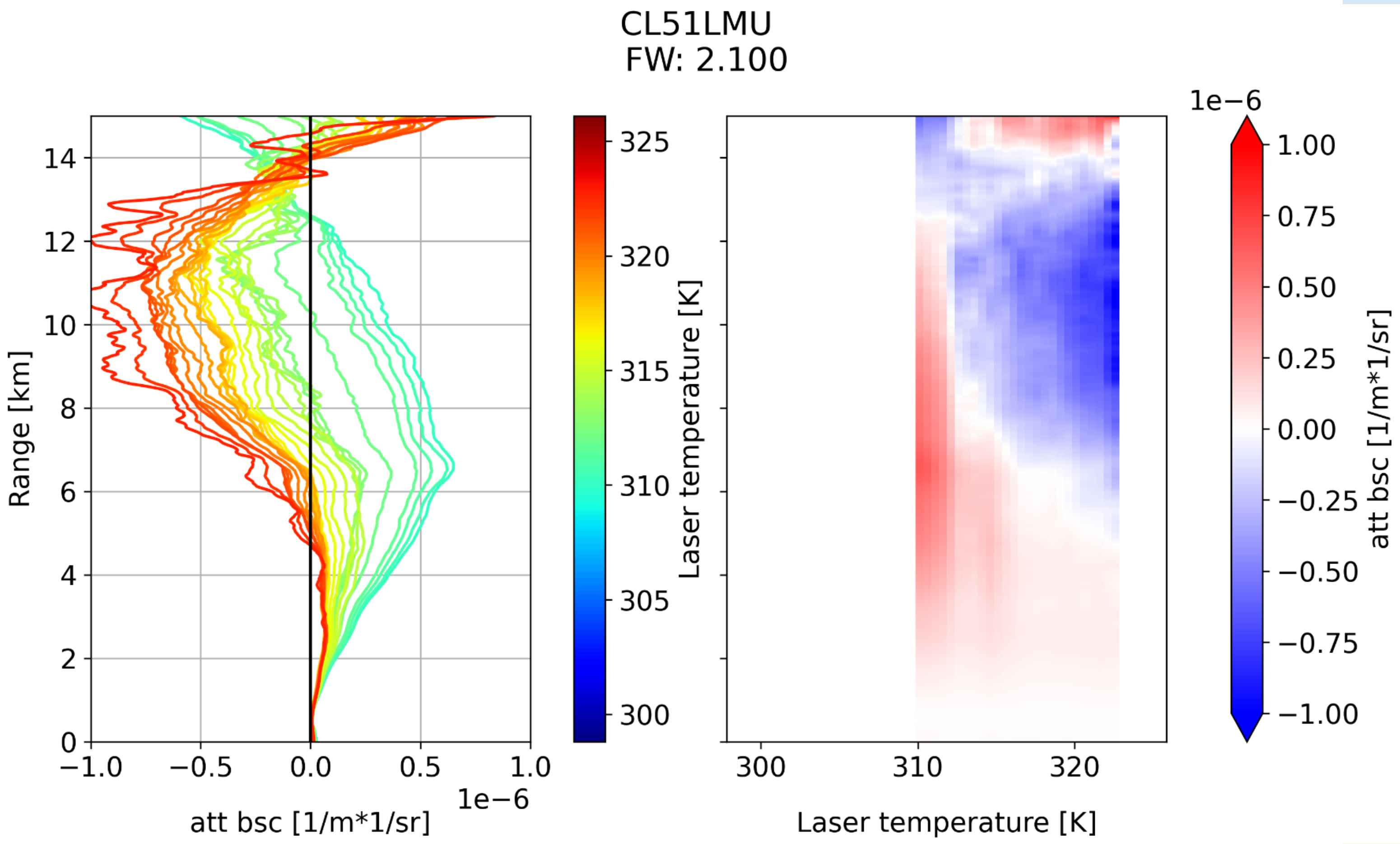
Vaisala CL51 – instrument temperature dependent signal





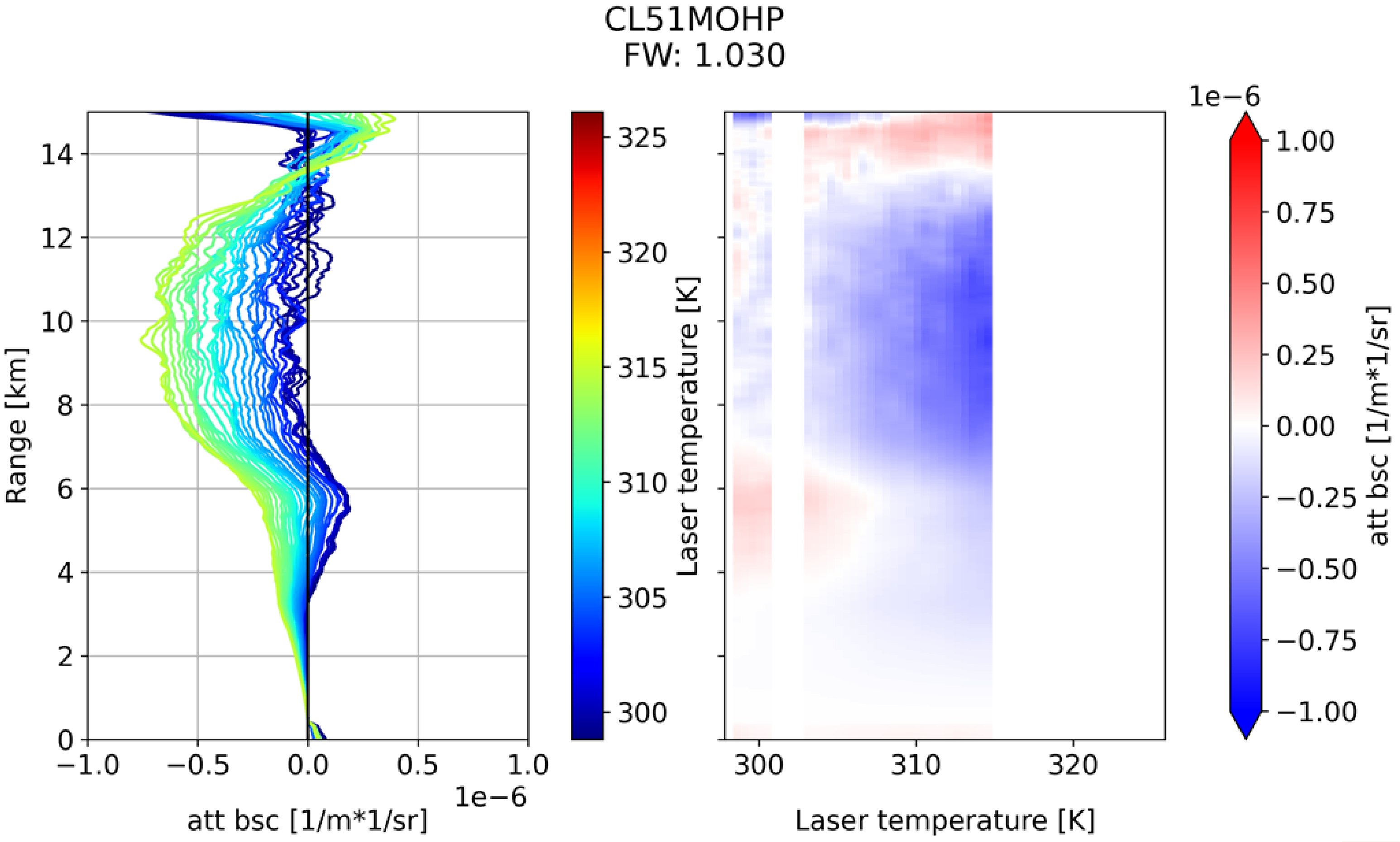
Vaisala CL51 – instrument temperature dependent signal

- Instrument is heated to stabilize the laser transmitter usually at 37°C in cold environments but is not cooled in hot conditions.
  Laser temperature is reported in the housekeeping data
- Only background signal originating from solar radiation is corrected in the ALC firmware
- Measurements from three other devices to check for a systematic problem of this ALC model
- Right: Example of Vaisala CL51 of ALC testbed at LMU, firmware version 2.100



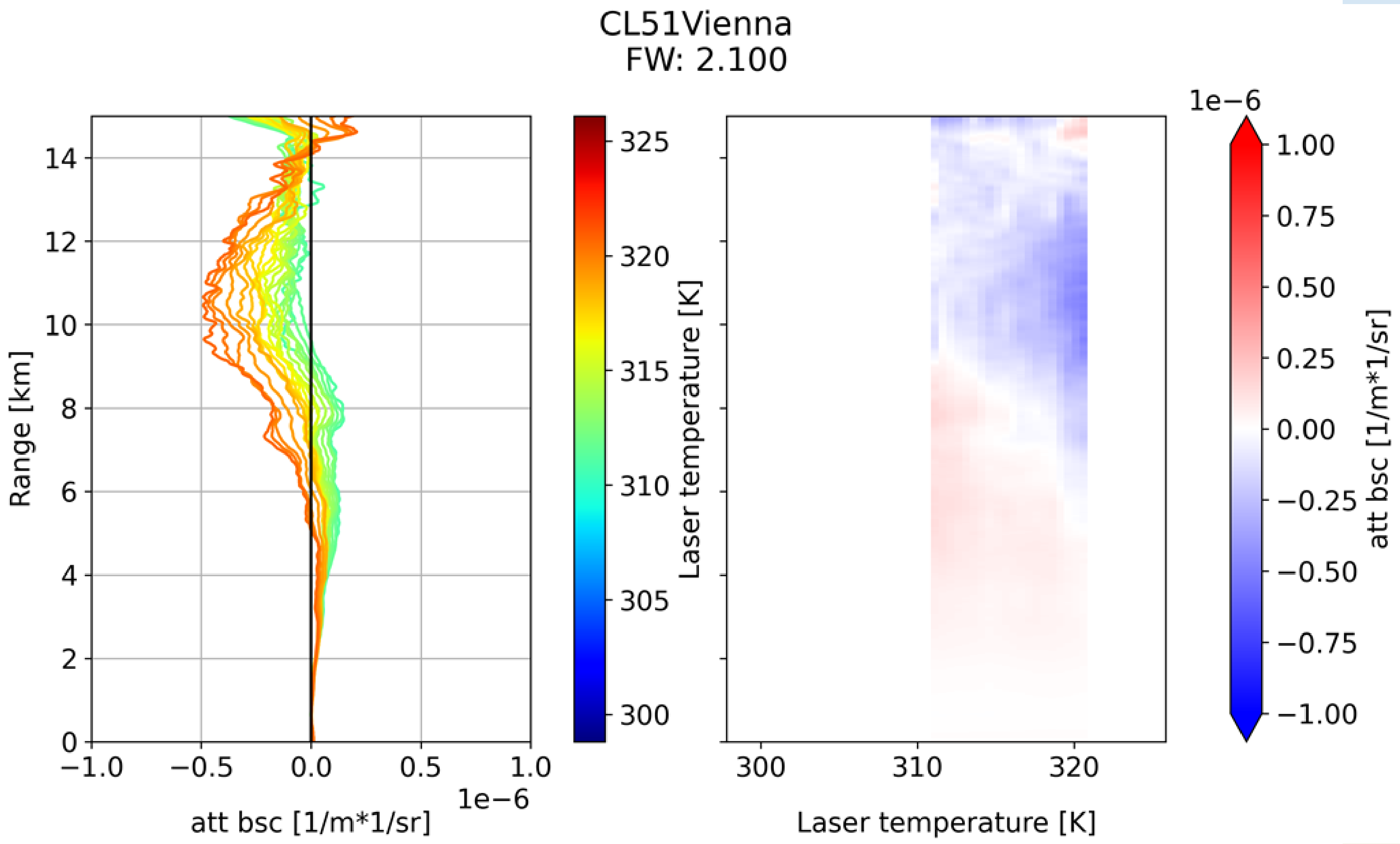
Vaisala CL51 – instrument temperature dependent signal

- **DWD ALC testbed Hohenpeißenberg**, firmware version 1.030 (special TOPROF version)
- Temperature range is lower compared to other devices. Stabilized at 27°C
- Clear temperature dependence



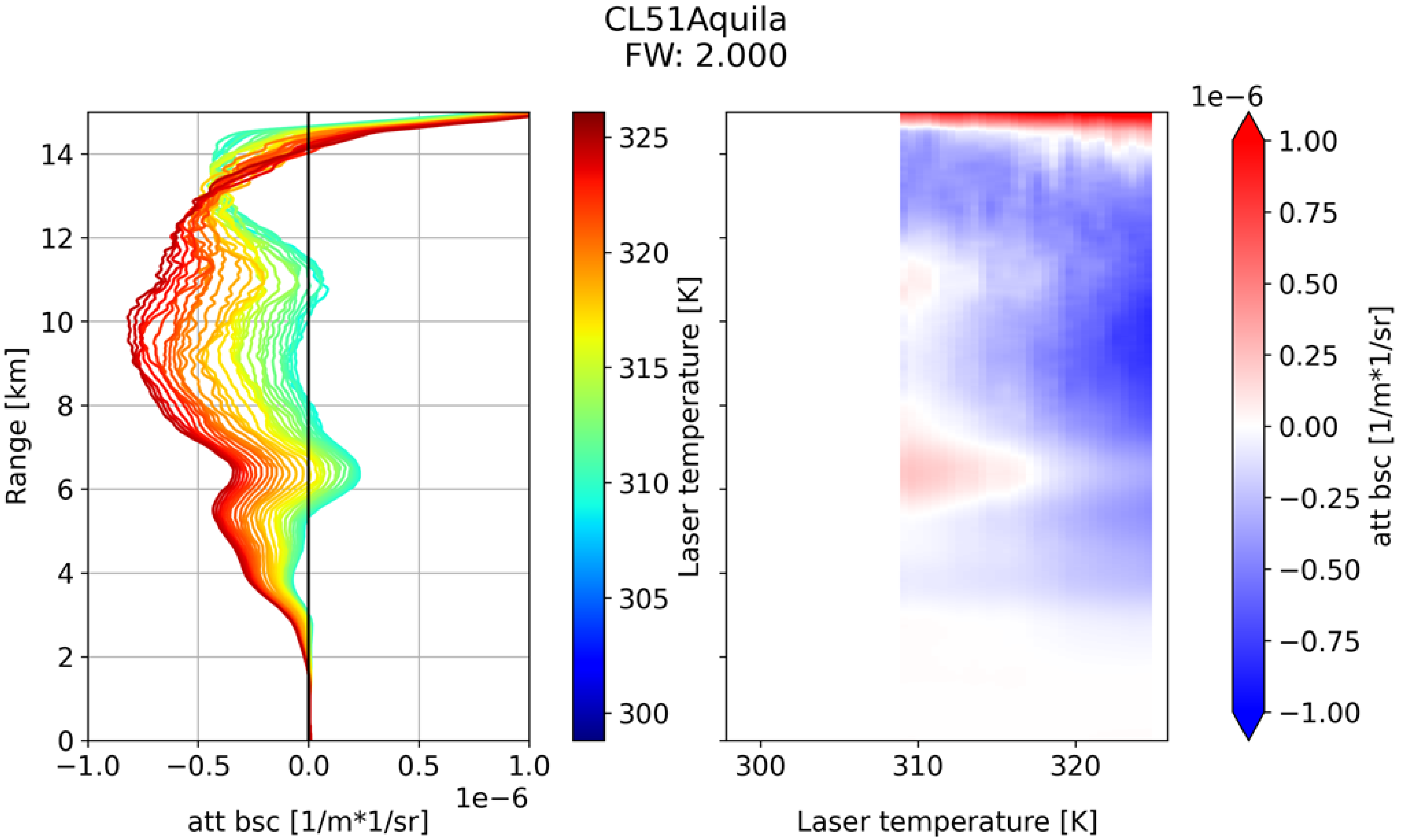
Vaisala CL51 – instrument temperature dependent signal

- **Geosphere Austria – Vienna,** firmware version 2.100 (courtesy of Alexander Hieden)
- Dark measurement provided covers a smaller temperature range
- Clear temperature dependence



Vaisala CL51 – instrument temperature dependent signal

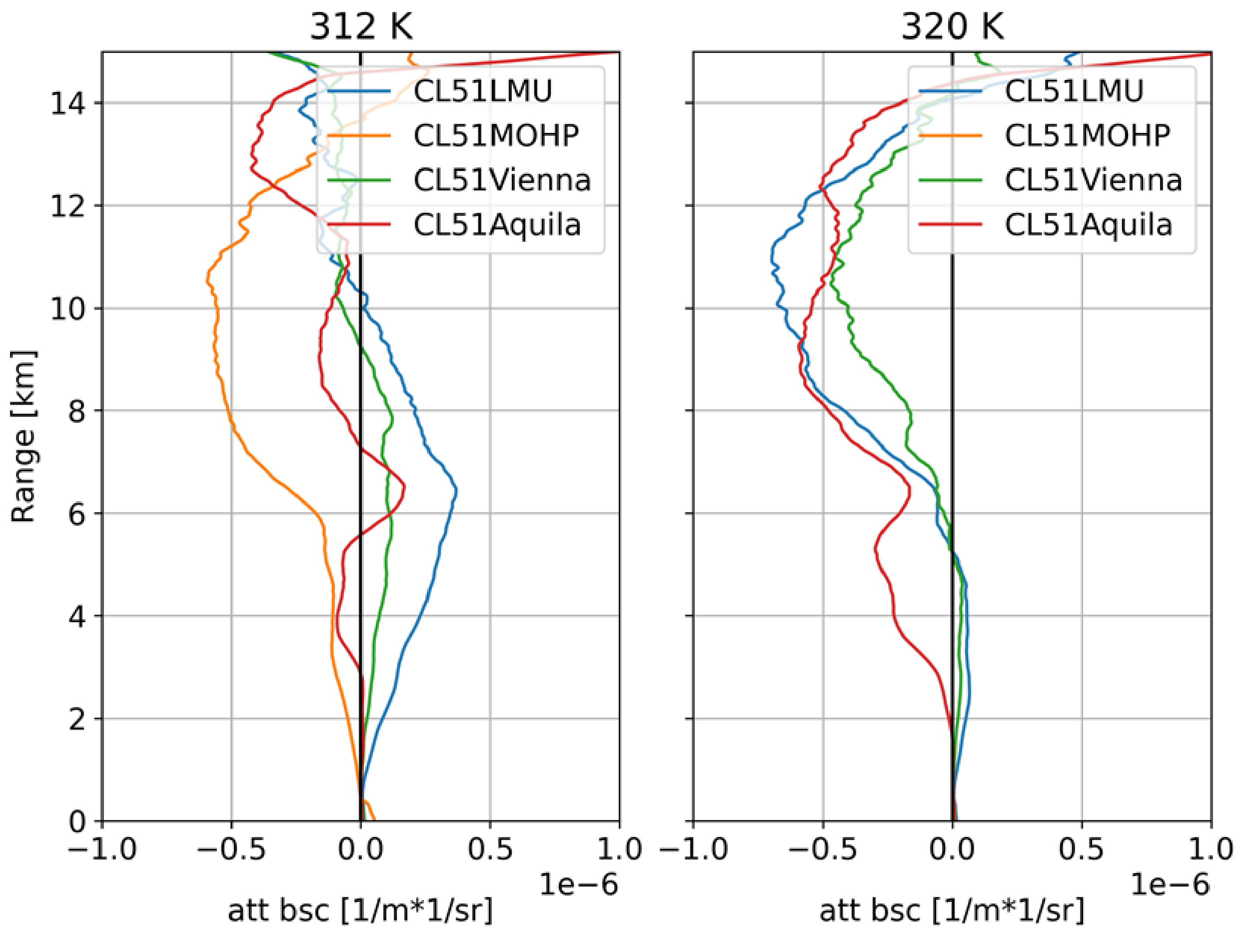
- **University of L'Aquila, Italy, ACTRIS N** firmware version 2.000 (courtesy of Andrea Balotti)
- Dark measurement covers a very large temperature range up to 326 K
- Clear temperature dependence



Vaisala CL51 – instrument temperature dependent signal

- Direct comparison of all CL51 at 312 K and at higher temperature at 320 K (note: CL51MOHP has no measurements at 320 K)
- Signal profile shapes are different at lower temperatures
- Signal profiles are better agreeing for higher temperatures

→ DMs have to be performed for every device

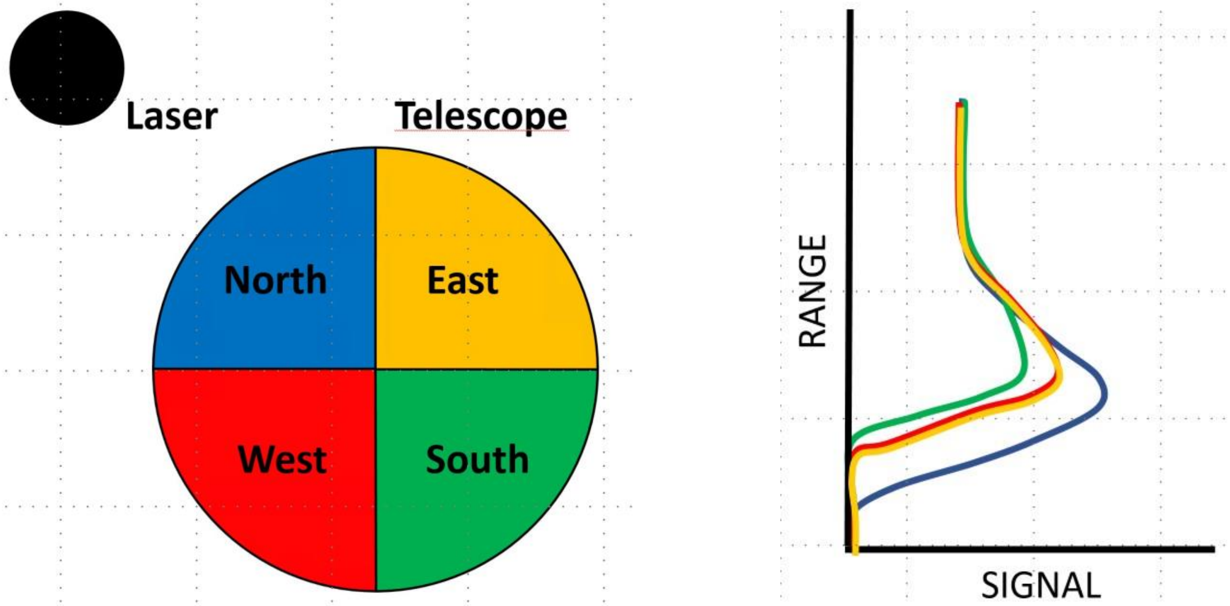


Telecover measurements

Theory of Telecover Test

The laser beam is seen first in the north sector of the telescope, resulting in a signal maximum at the lowest range compared to the other sectors. The east and west sectors should provide similar vertical signal profiles. The laser beam enters the south sector of the telescope's field-of-view last, yielding the lowest signal peak at the farthest range.

→ Measurement can be used to check the optical alignment between laser beam and telescope field-of-view and for assessing the height of complete overlap



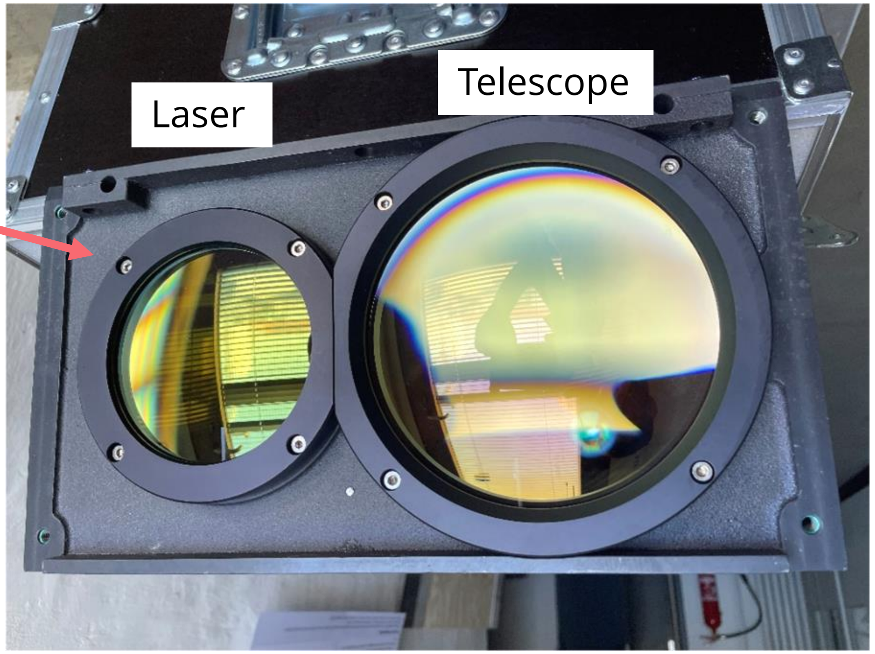
Freudenthaler, V., Linné, H., Chaikovski, A., Rabus, D., and Groß, S.: EARLINET lidar quality assurance tools, Atmos. Meas. Tech. Discuss. [preprint], 2018.

Lufft CHM8k and CHM15k

Bi-axial configuration which allows to perform a telecover test by covering one of four sections.

Lufft CHM8k (left) and CHM15k (right)

Inside view of the housing with telescope (right) and laser (left)

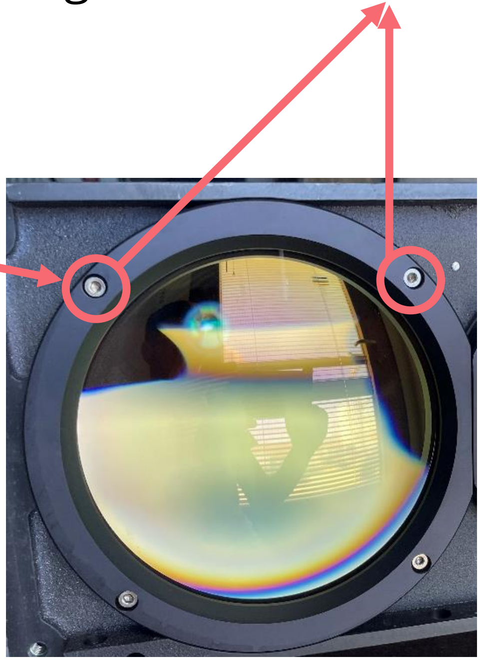


View on top of the laser optical module (LOM)

Developments

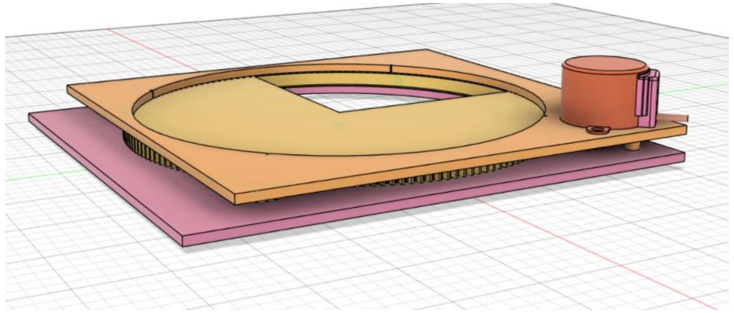
Four 3D-printed templates for N, E, S and W sector

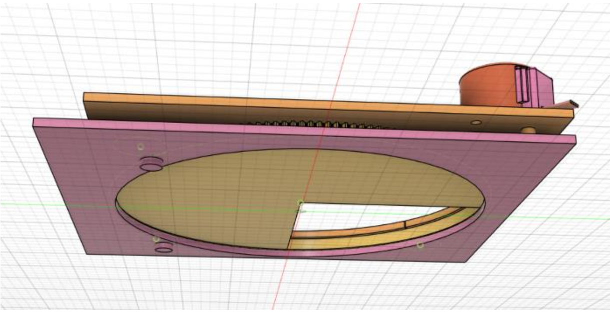
- Ina created four plates for covering the telescope
    - Model created with CAD software and then printed in 3D
    - Fits on the CHM8k and CHM15k and can be held in position using the two screw holes

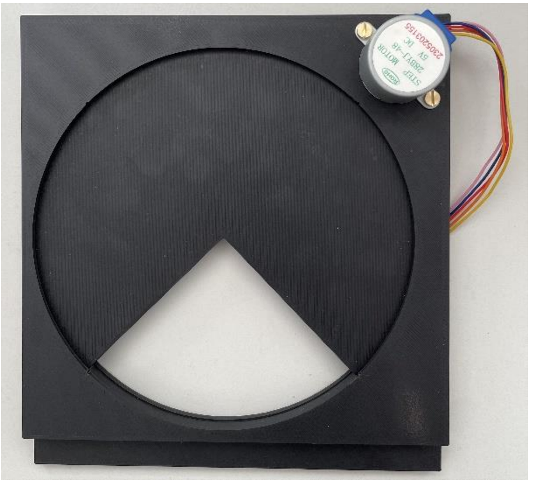


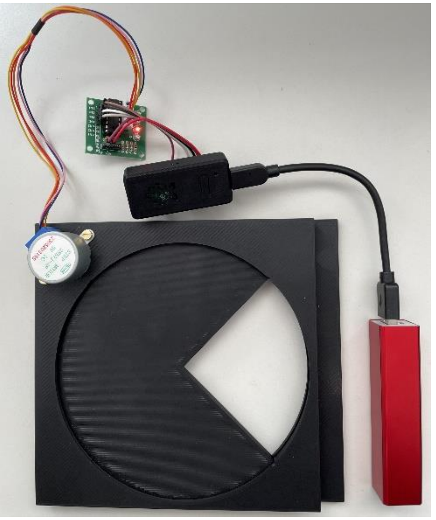
Improvement with an automatic motorized telecover tool

- Manual templates require to open the inner housing each time to change the sector
  → problem in cold weather: heater turns on and off
- Automatic rotation of template requires to open only once at the beginning
- Impractical for multiple measurement cycles for taking atmospheric variability into account



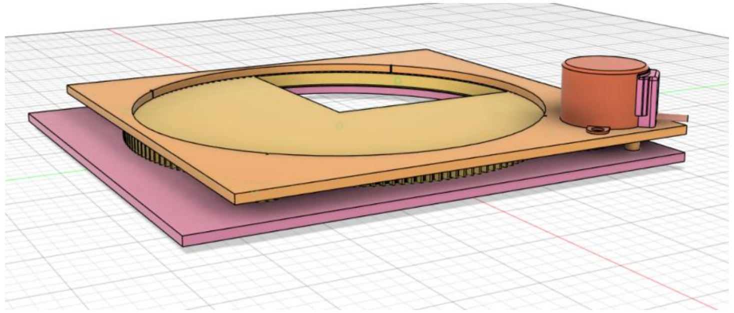


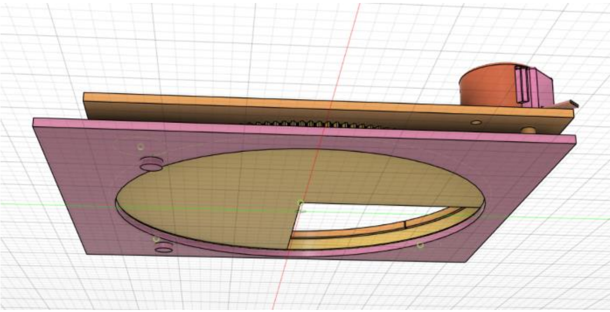


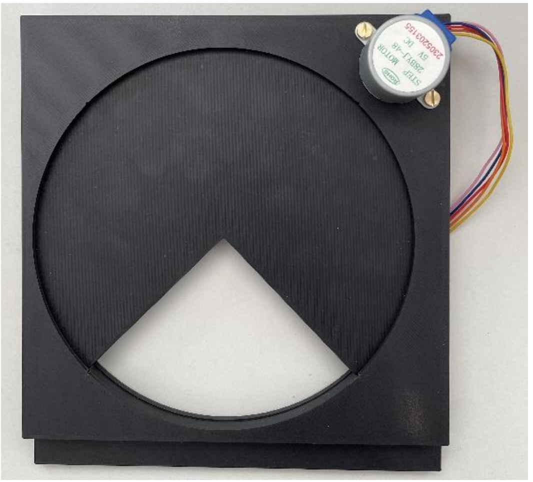


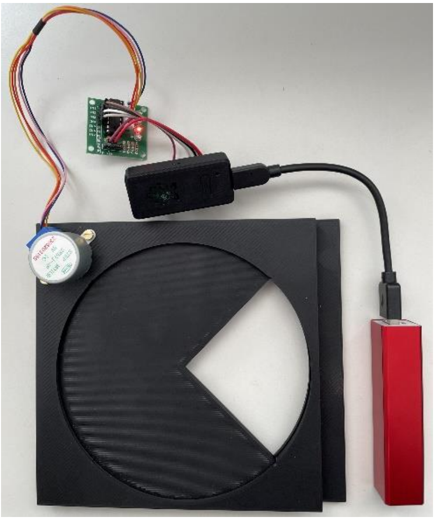
Improvement with a automatic motorized telecover tool

- Technical development
  - 3D-printable tool was developed as CAD model in Fusion 360 tailored to the geometry of Lufft ALCs
  - Fully automated coverage of the telescope quadrants using a stepper motor rotating the template
  - Control and measurement time storage by using a Raspberry Pi Pico microcontroller
    → efficient post-processing
  - Programmable duration of each sector and number of measurement cycles



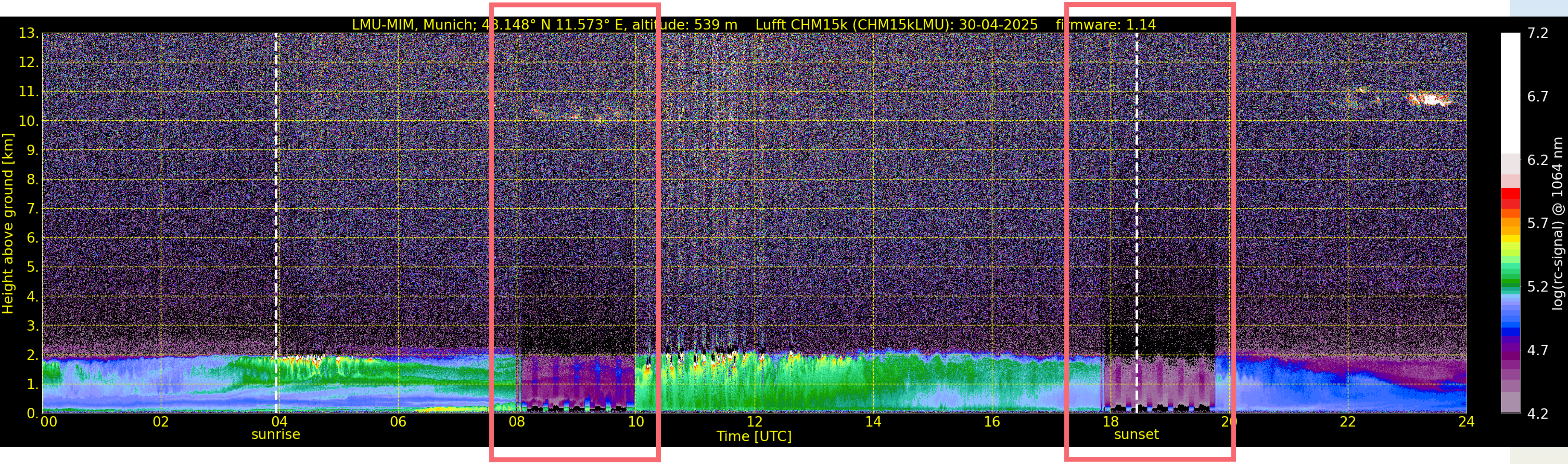






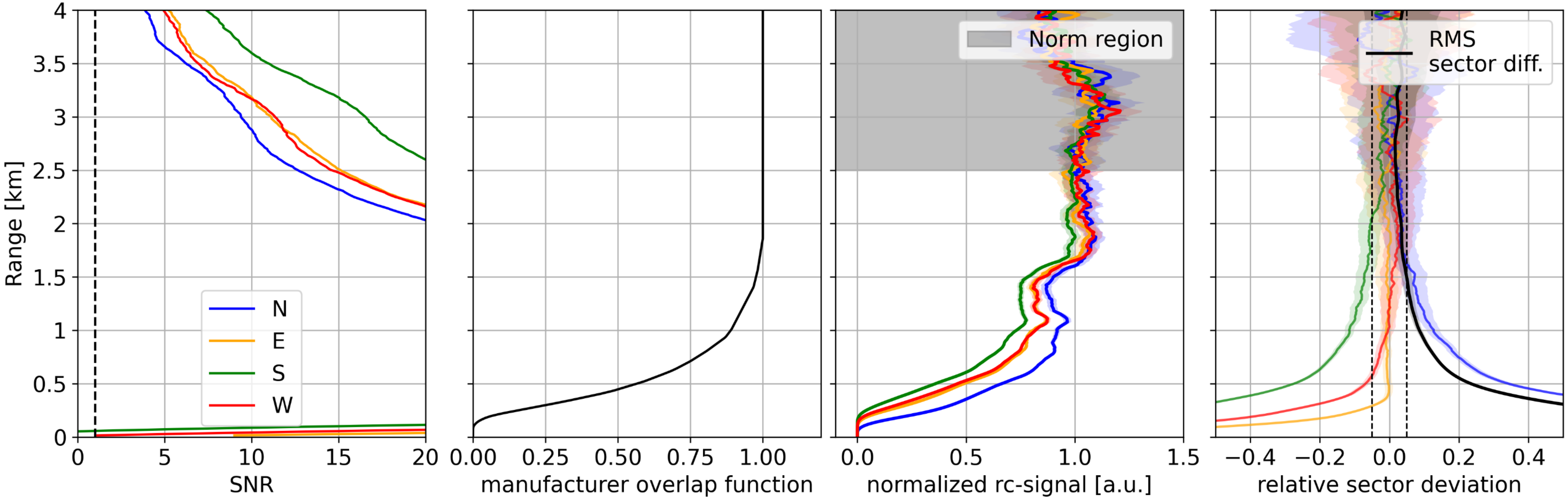
Telecover measurements with Lufft devices

Example for LMU CHM15k



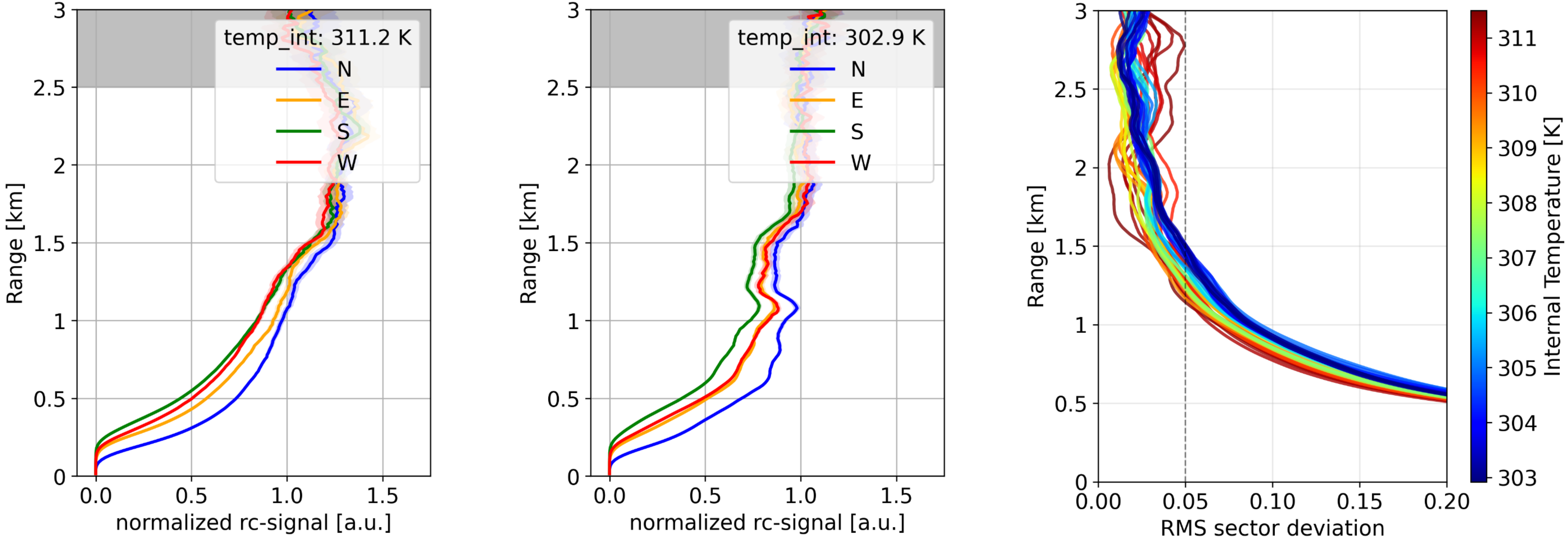
Telecover measurements with Lufft devices

Example for LMU **CHM15k**



Telecover measurements with Lufft devices

Temperature dependent overlap of **CHM15k** determined with telecover test



Now it's time for practice!