ITINERIS

Training event “Atmospheric Remote Sensing observation: labs maintenance and methods”
Spectral Fluorescence Lidar Theory, Technique and Application

Jens Reichardt – jens.reichardt@dwd.de

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

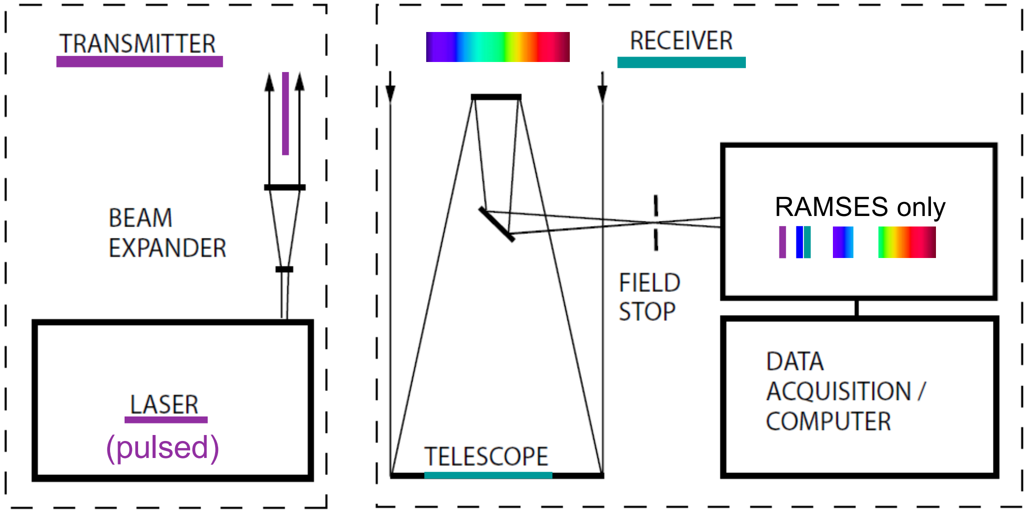
Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Overview

- What is a spectrometric lidar?
- RAMSES: Instrument and data analysis
- Spectral aerosol parameters
- Measurements: Biomass burning aerosol (BBA)
- Conclusions
- Brand new: ATLID intercomparisons

Spectrometric Lidar in a nutshell

„**LI**ght **D**etection **A**nd **R**anging“



- Cloud studies: Combined elastic and inelastic backscattering lidar quite popular
  (conventional, discrete receiver channels at selected wavelengths)
- RAMSES: The only *spectrometric* cloud and aerosol lidar
  (large number of spectrally closely spaced receiver channels; spectrum measured simultaneously)

Clarification: Spectrometric lidar

- ✓ (Large) number of spectrally closely spaced receiver channels

often, but not always, in combination with

- ✓ some conventional, discrete receiver channels at selected wavelengths.

- ✓ Full spectrum measured simultaneously, tunable spectrometers not considered here.

- ✓ Spectral remote measurements can be either range-resolved (PMT row), or range-integrated (gated CCD).

Applications

Wherever spectra of atmospheric response contain information not obtainable otherwise!

- Water Raman lidar (vapor, liquid, ice)
- Temperature Raman lidar (RR, VR)
- Fluorescence lidar (oil spills, vegetation, biodeterioration, bio hazards, atmospheric aerosols)
- Chemical composition lidar (aerosols, gases)

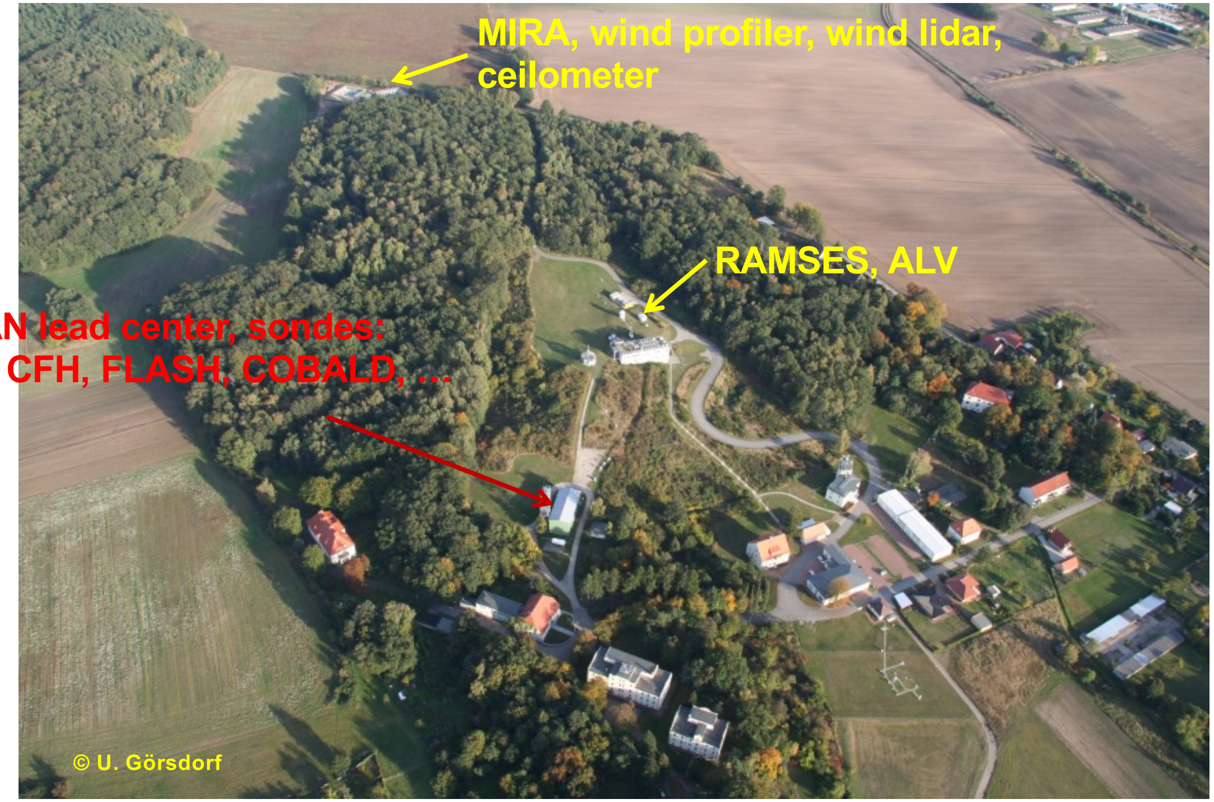
Lindenberg Meteorological Observatory

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

120 years of Meteorology (1905 - 2025)

Lindenberg Meteorological Observatory

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Pilotstation,
CLOUDNET,
BSRN,
ACTRIS…

State-of-the-art remote sensing instrumentation

RAMSES: Building

ALV (since 02/2025)

RAMSES

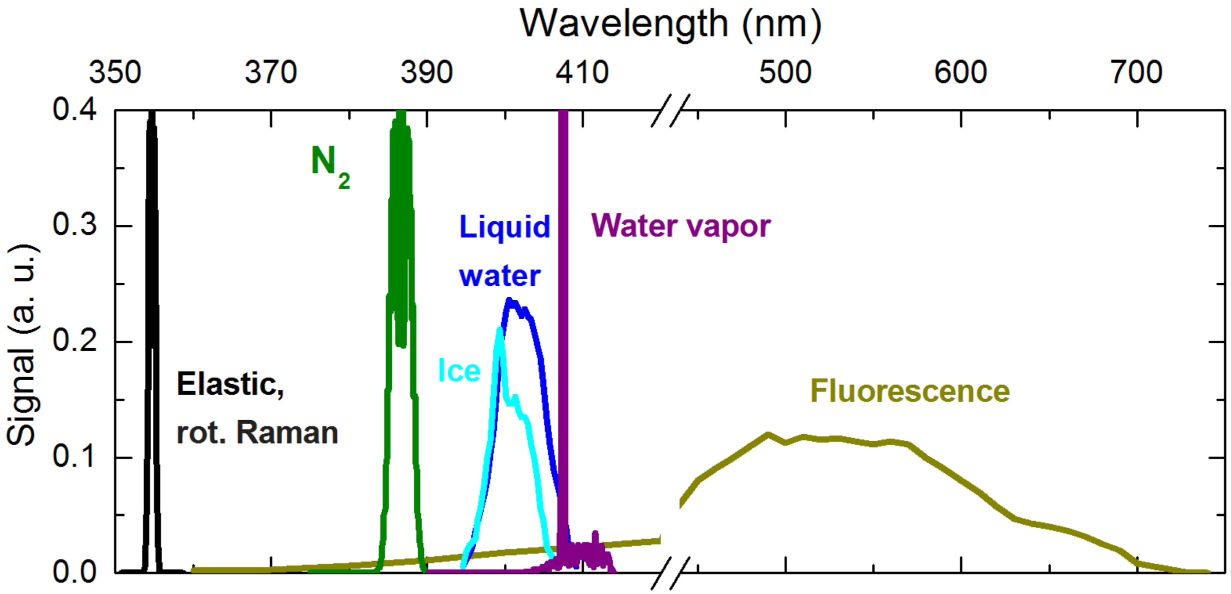
RAMSES: Instrument

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

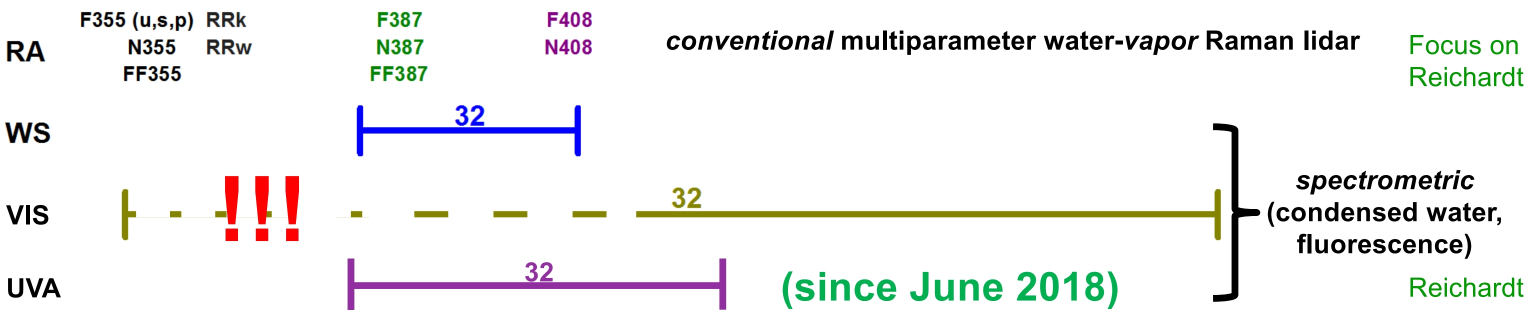
- „**R**aman lidar for **A**tmospheric **M**oisture **SE**n**S**ing“
- In operation since 2005
- Autonomous, 24/7
- Zenith-pointing
- Laser, transmitter:
  - Injection-seeded, frequency-tripled Nd:YAG laser
  - PRF=30 Hz, > 400 mJ UV pulse energy (transmitted; λ_L = 354.7 nm)
  - Tenfold beam expansion (eye safety)
- Receivers:
  - 30-cm near-range telescope, fiber-coupled; 3-channel polychromator OR 1-channel polychromator and UVA spectrometer (360 – 440 nm)
  - 80-cm far-range telescope, nonfiber-coupled; 9-channel polychromator OR 8-channel polychromator and water spectrometer (385 – 410 nm); VIS spectrometer (~380/440 – 750 nm)

RAMSES: Spectrometric fluorescence and Raman lidar

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Focus on clouds, IWC:
Reichardt (2012, 2014), Plakhotnik and Reichardt (2017, 2018), Rybka et al. (2021), Reichardt et al. (2022)



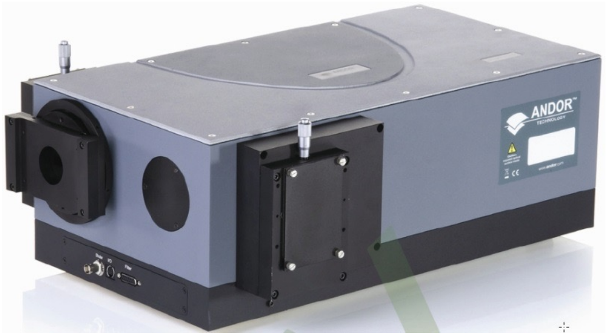
Focus on aerosol fluorescence:
Reichardt (2014), Reichardt et al. (2017, 2018)

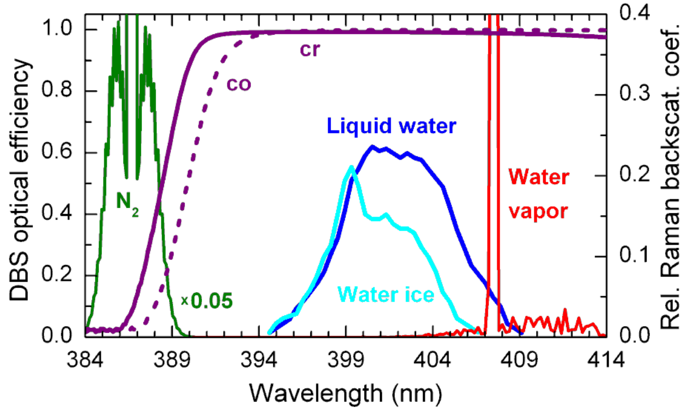
Reichardt et al. (2023a, 2023b, 2025)

RAMSES: Unique features

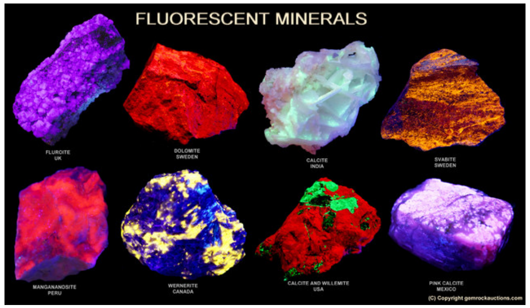
Water spectrometer: Measurement of all 3 water phases!!!

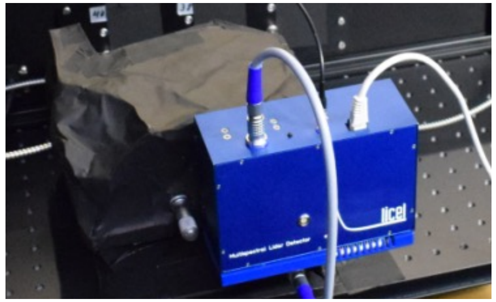
Hamamatsu H7260





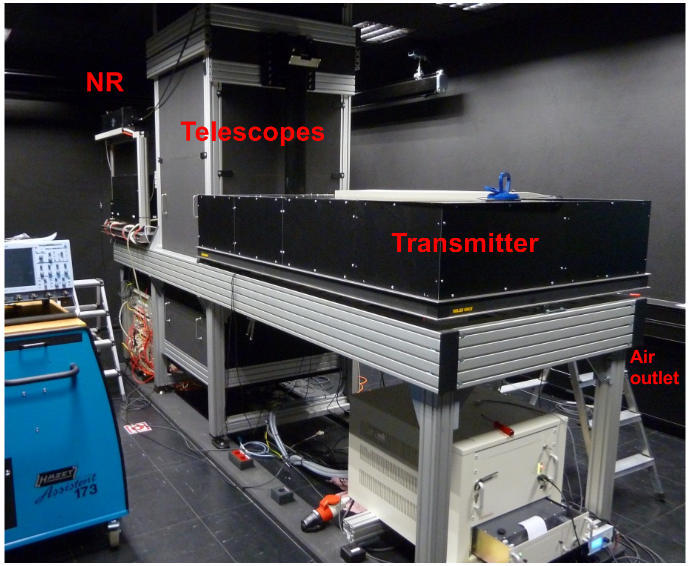
Fluorescence spectrometers: Measurement of (aerosol) fluorescence!!!

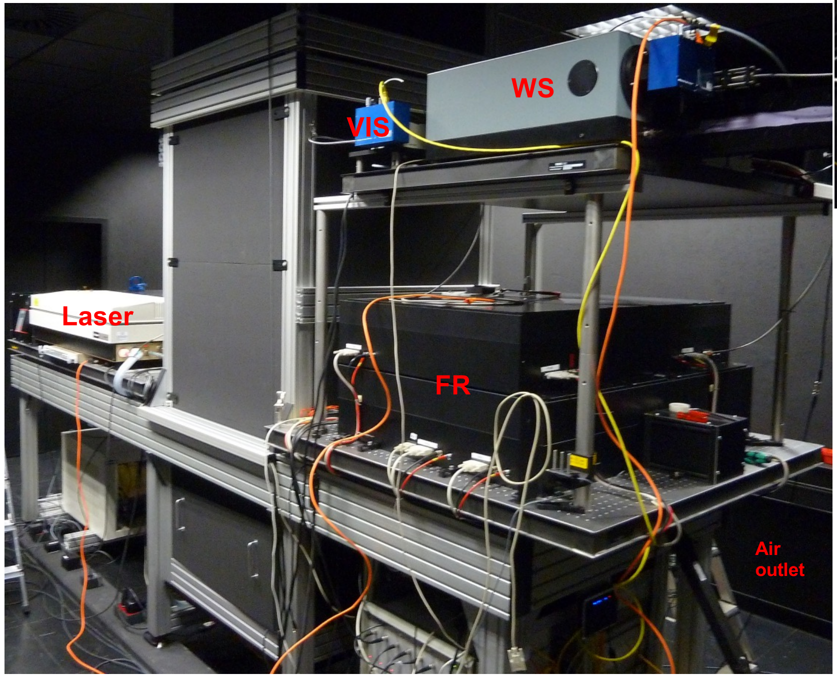


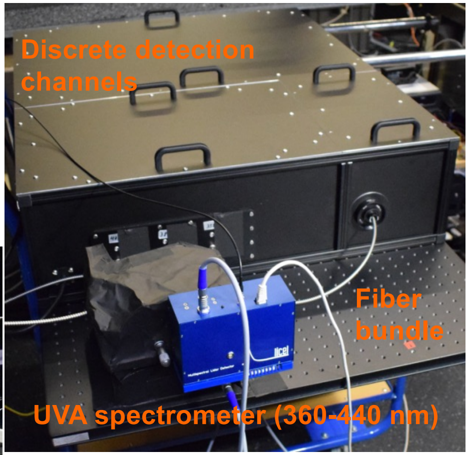


RAMSES: Instrument

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

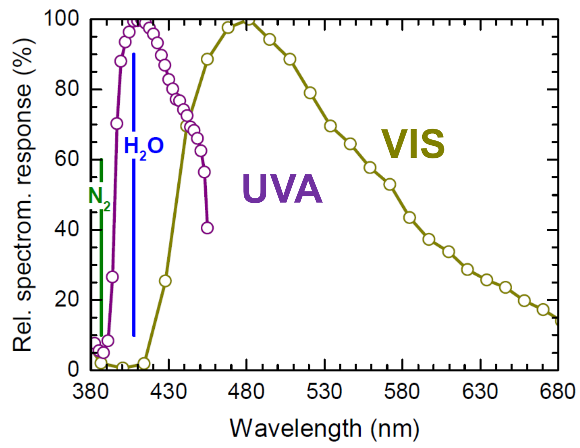






Data analysis: Spectrum processing

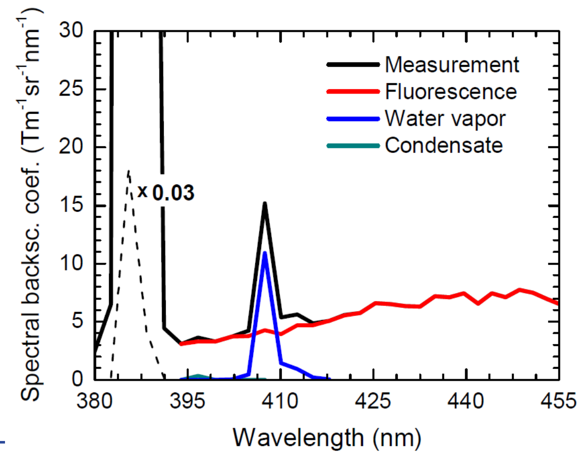
Calibration, step 1: Relative (UVA, VIS)



Calibration, step 2: Absolute (UVA), see Reichardt (2014)

Calibration, step 3: Fit VIS spectrum to UVA spectrum

Spectrum decomposition, see Reichardt et al. (2023a)

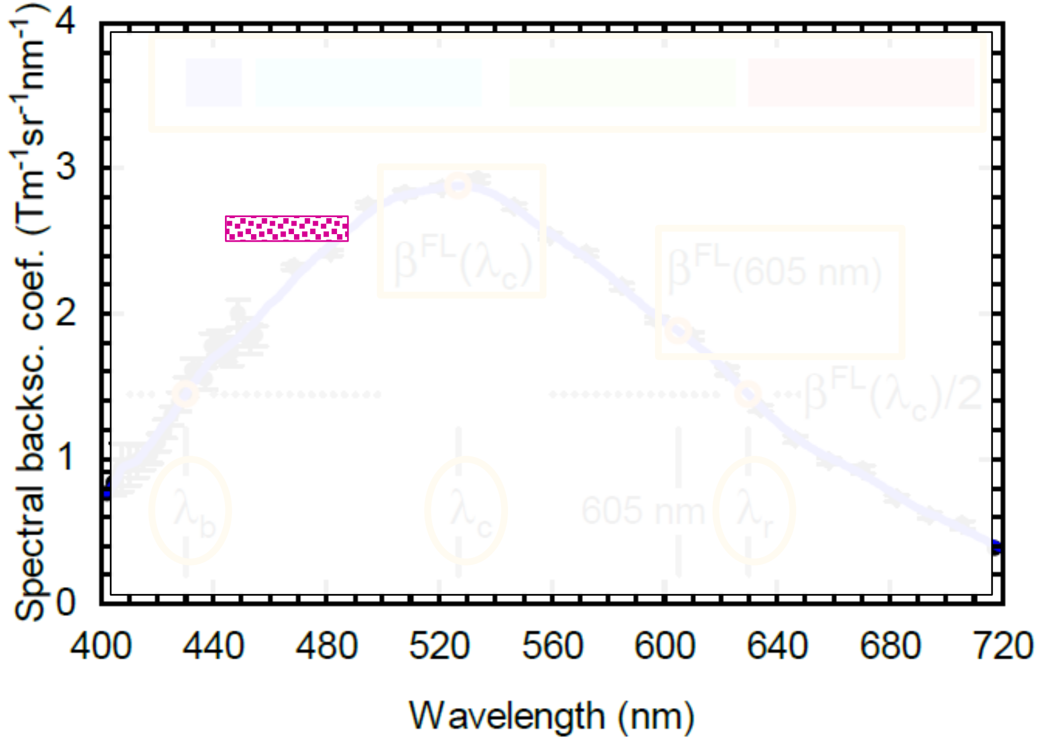


Spectral aerosol parameters

BTW:

What a lidar with a single fluorescence detection channel sees is…

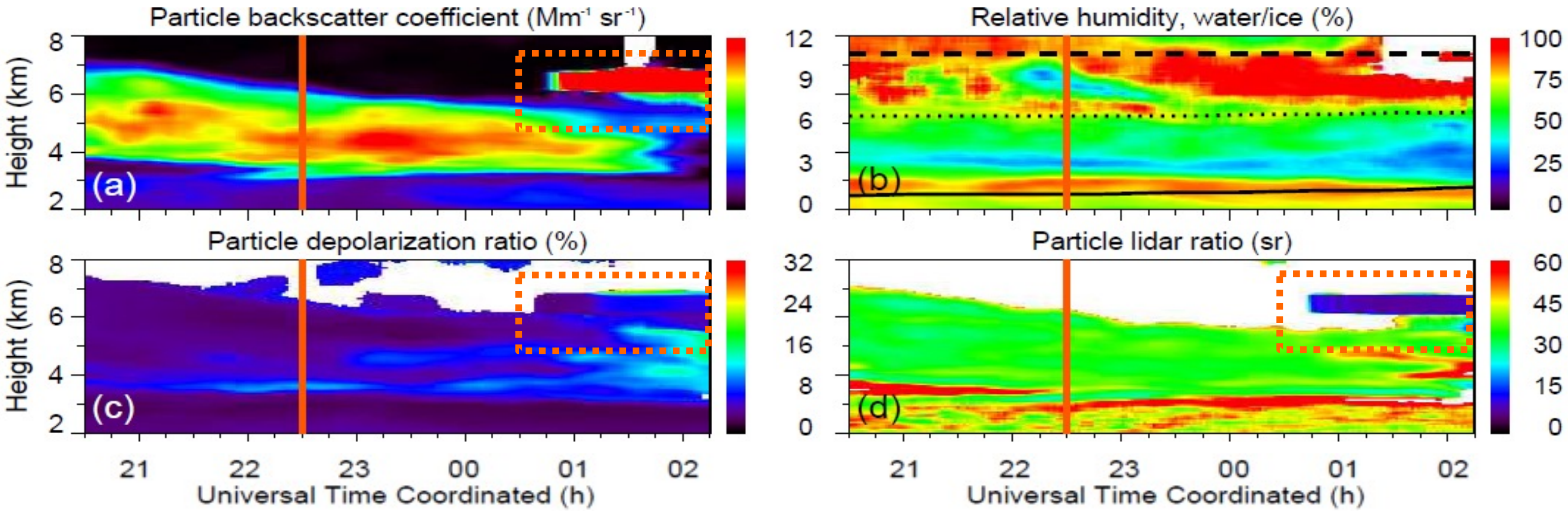
… THIS!



(BBA at 4.8 km around 01:15 UTC, 27 May 2023)

Biomass burning aerosol

General shape of the fluorescence spectrum



Case study: 04/05 July 2023

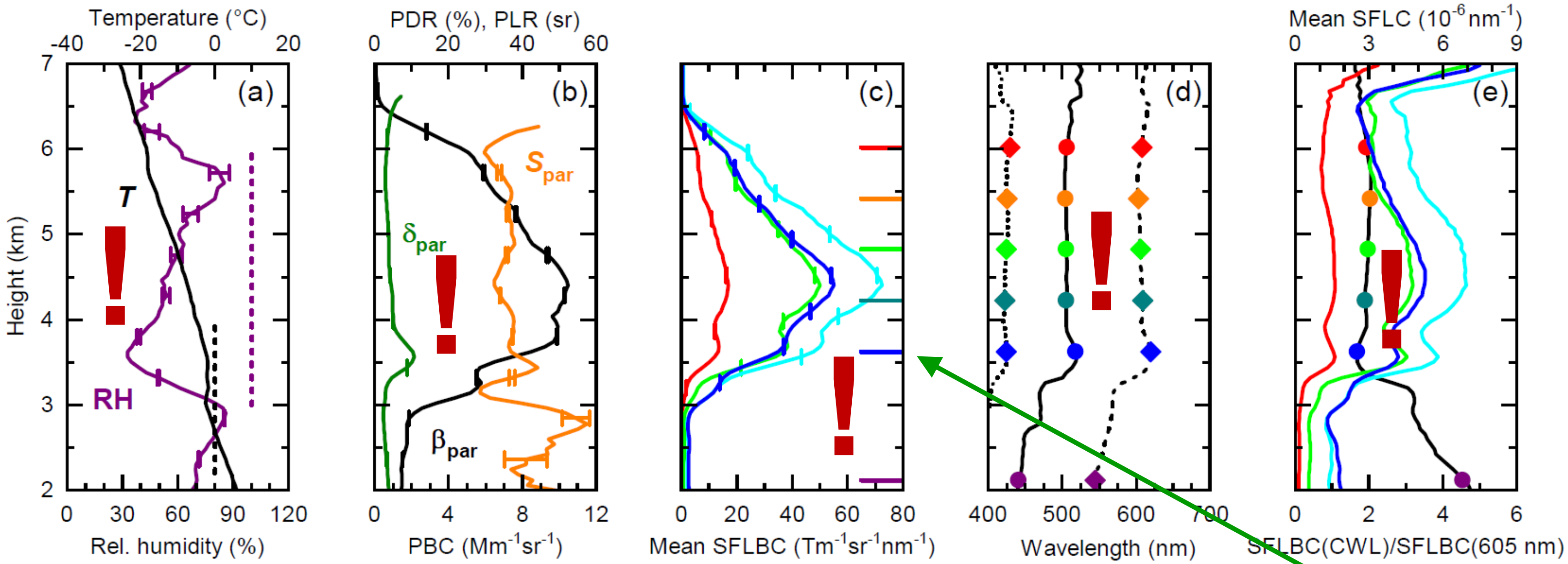
Fluorescence characteristics:

- **+ FL backscatter coefficient**
- **+ Spectral FL capacity**
- **+ Center wavelength**
- **+ Shoulder widths**
- **+ Skewness**

Let us look at the profiles at 22:30 UTC!

Case study: 04 July 2023, 22:30 UTC – profiles

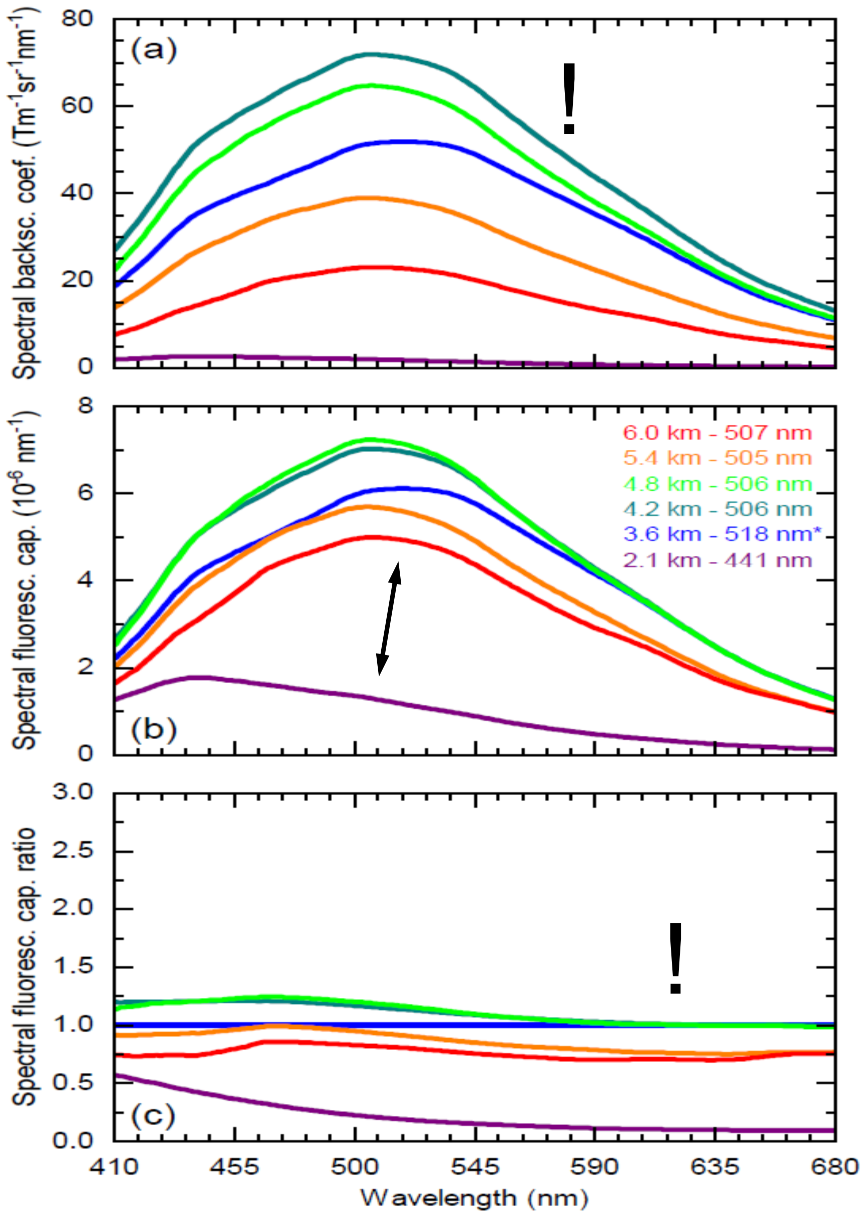
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Let us look at the fluorescence spectra at these heights!

BBA spectrum general shape

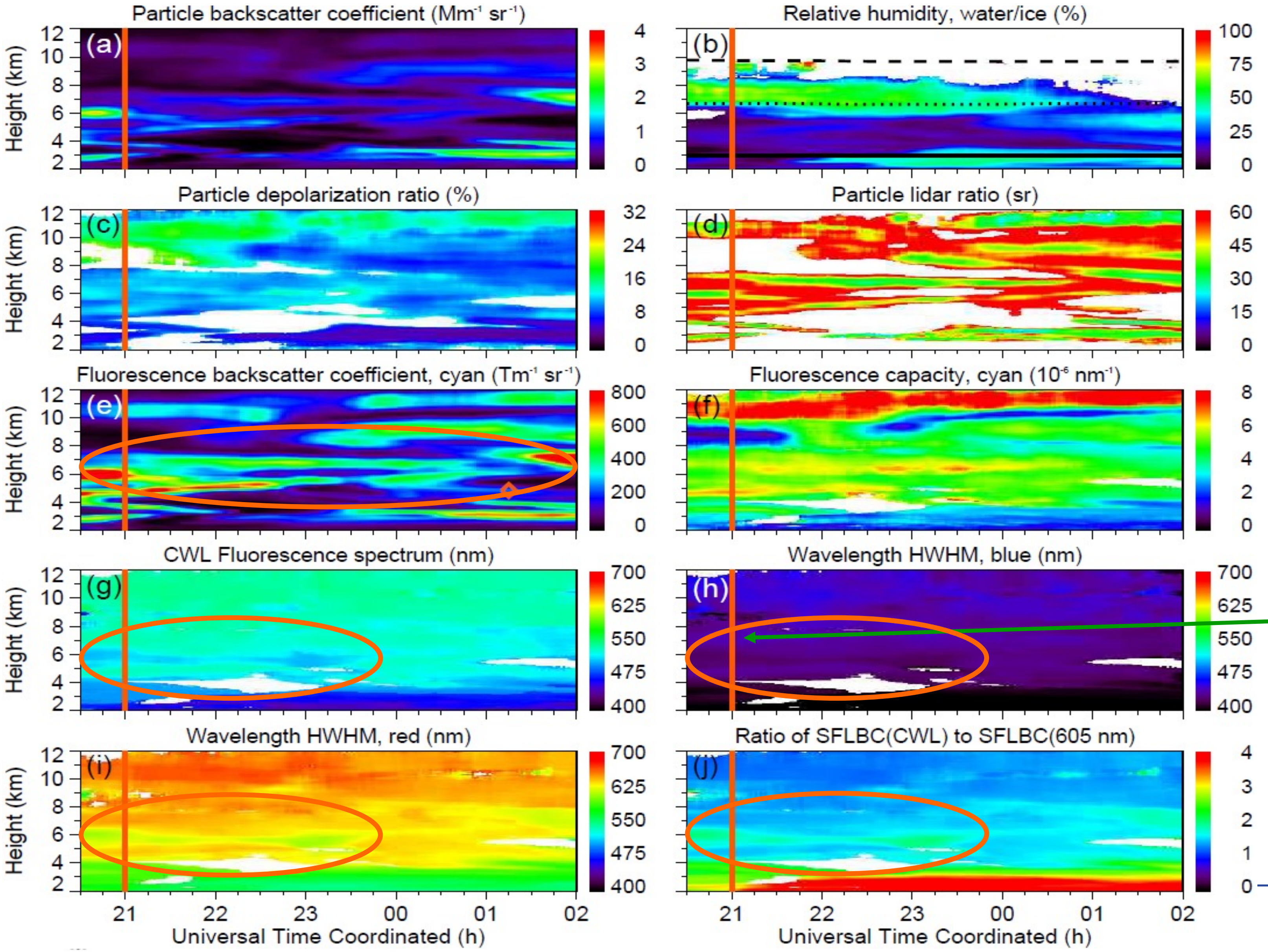
Different visualizations:



Biomass burning aerosol

Dynamics of the fluorescence spectrum

Case study: 26/27 May 2023



Fluorescence characteristics:

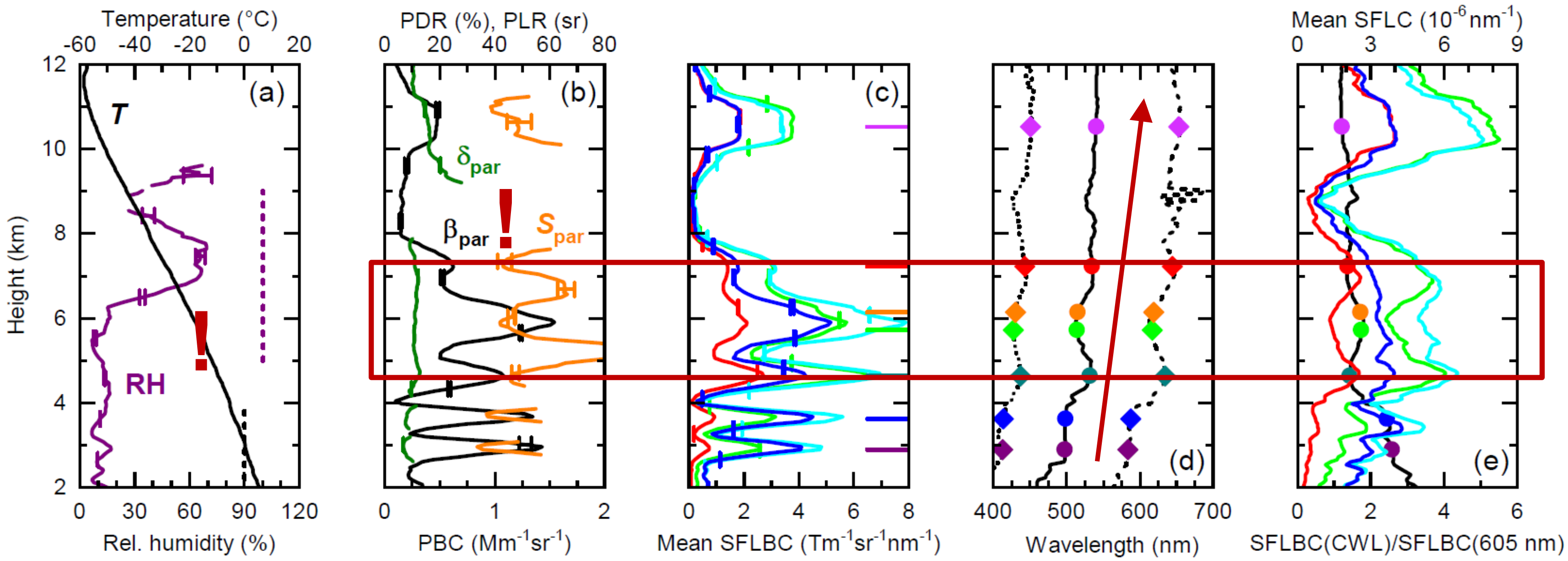
+ BBA filaments

+ Intensive properties highly variable

Let us look at the profiles at 21:00 UTC!

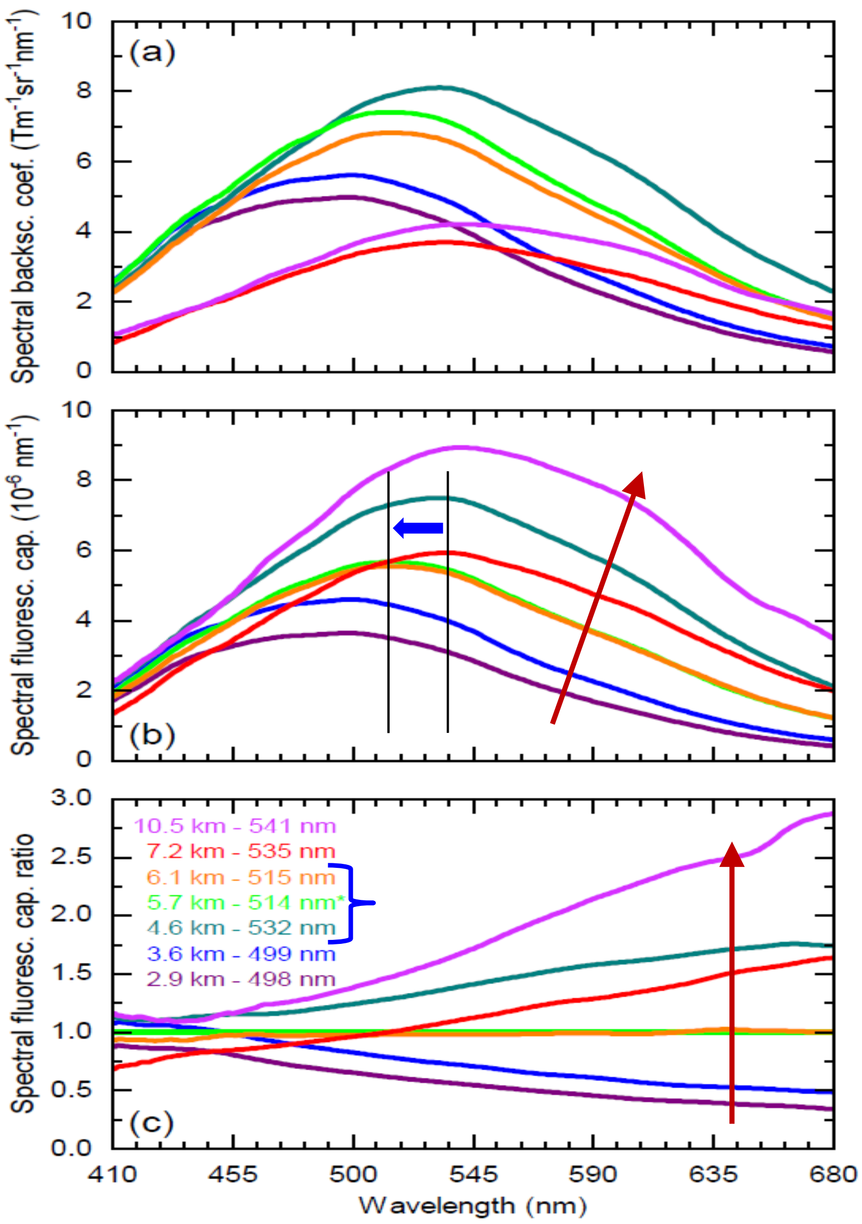
Case study: 26 May 2023, 21:00 UTC – profiles

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



BBA spectrum dynamics

Observations:

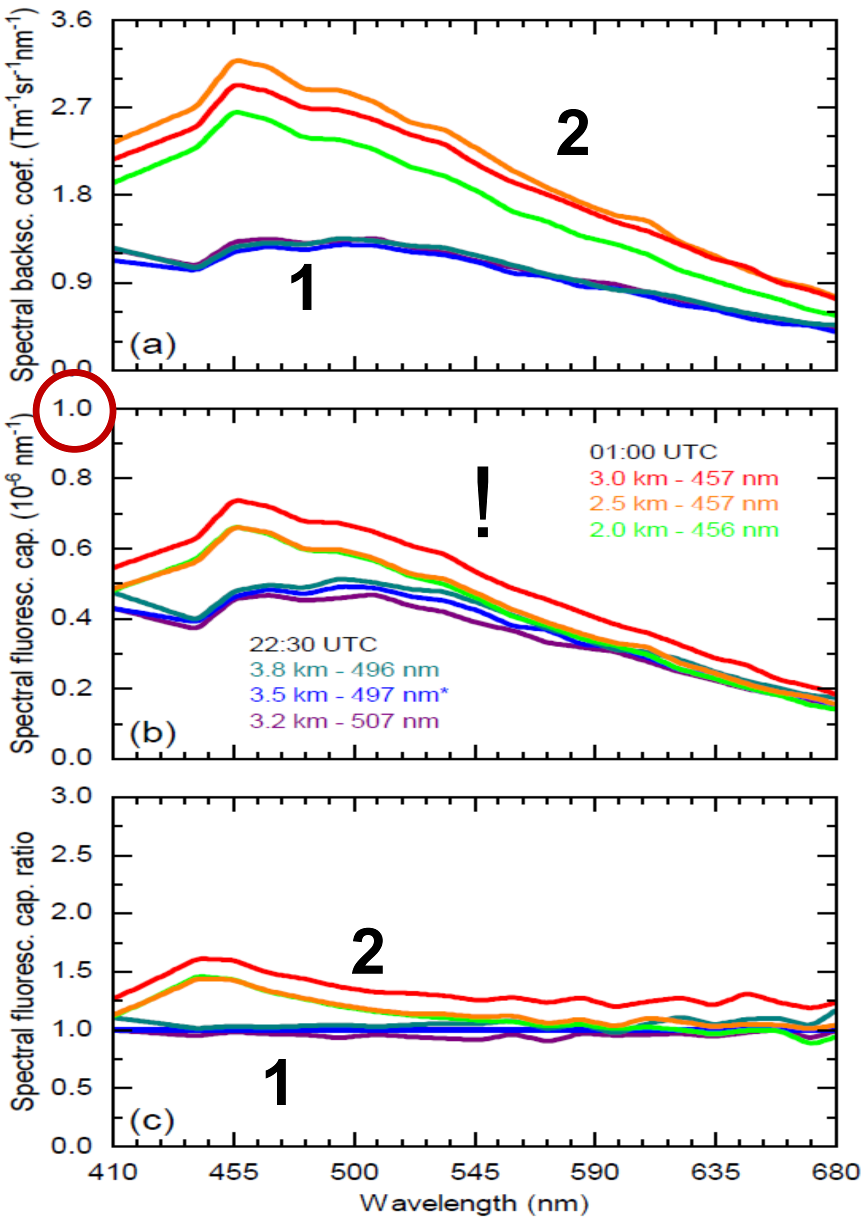


And what a difference the type of aerosol can make...

For comparison: Sahara dust spectra

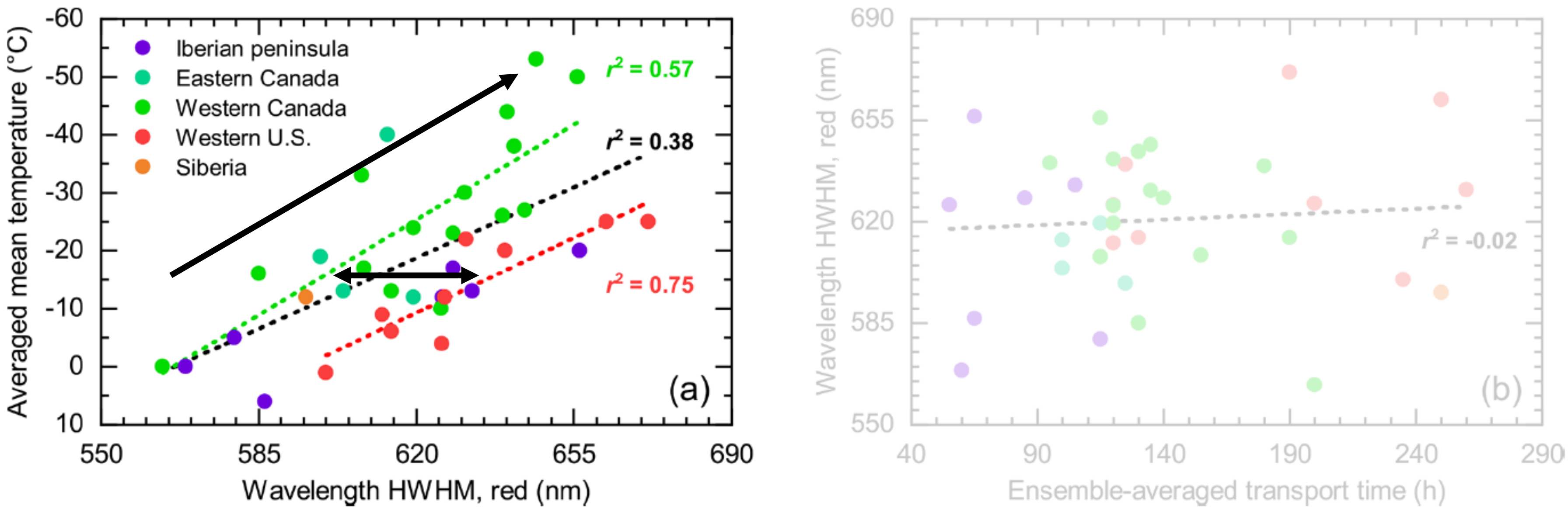
Case study: 22/23 February 2021, 22:30 & 01:00 UTC

Observations:



BBA spectrum: dependence on origin and transport

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



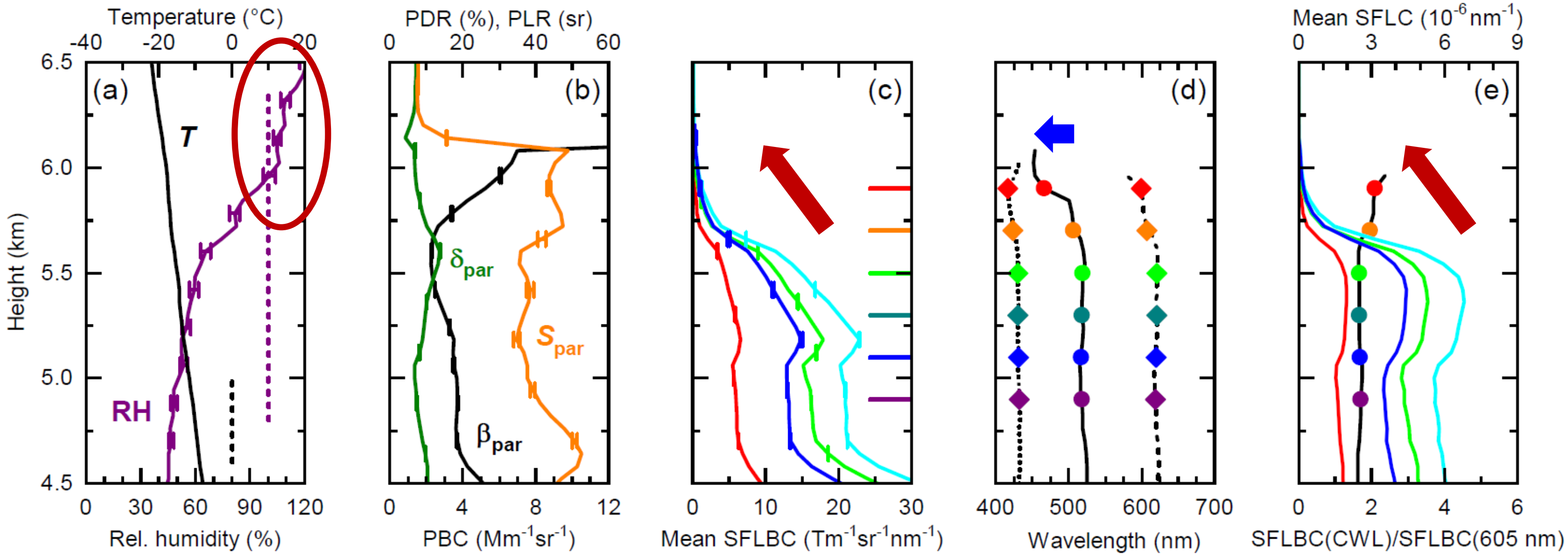
Biomass burning aerosol

Interaction with clouds

BBA interaction with clouds

Is there a way to prove that BBA and clouds actually *interact*?

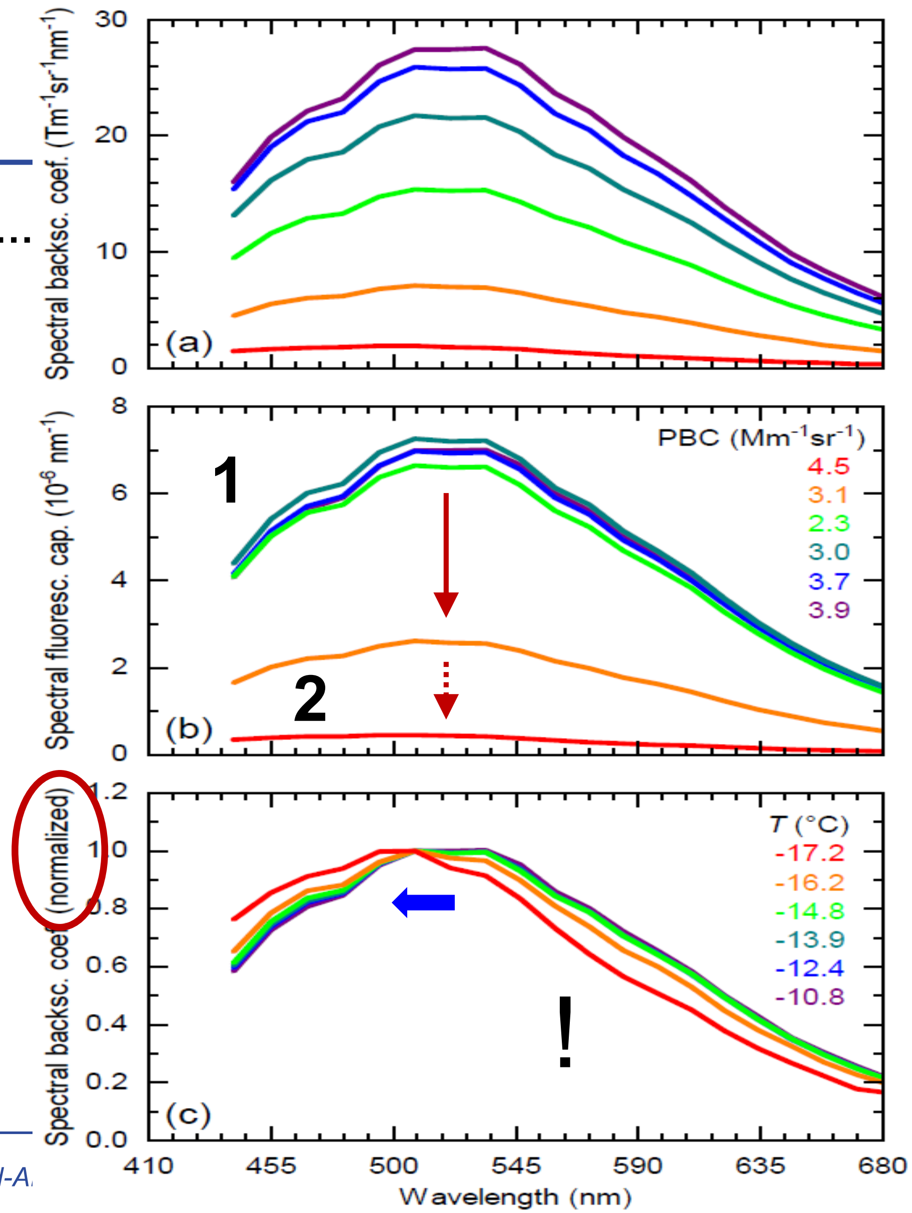
Case study: 05 July 2023, Altostratus – profiles



Case study: 05 July 2023, As – spectra

Challenging environment for spectrometric measurements…

Observations:



Conclusions

+ **RAMSES: Operational spectrometric fluorescence and Raman lidar with unsurpassed performance**

+ **Long-term observations of clouds and aerosols**

+ **Free troposphere: BBA most often observed (followed by Sahara dust)**

+ **Spectrometric fluorescence measurements provide insights into atmospheric aerosols and aerosol-cloud interaction that cannot be obtained with a limited number of discrete detection channels**

+ **BBA fluorescence spectra:**
    - **are broad and featureless with maxima between 500 and 550 nm**
    - **are nearly Gaussian in shape**
    - **differ significantly from those of Sahara dust and other aerosols (aerosol typing)**
    - **often exhibit a general trend to longer wavelengths (red shift) with height**
    - **can be layer-specific causing a blue shift of the spectrum**
    - **seem to correlate (weakly) with source region and atmospheric state, less with history and elastic optical properties**
    - **may be affected by cloud processing**

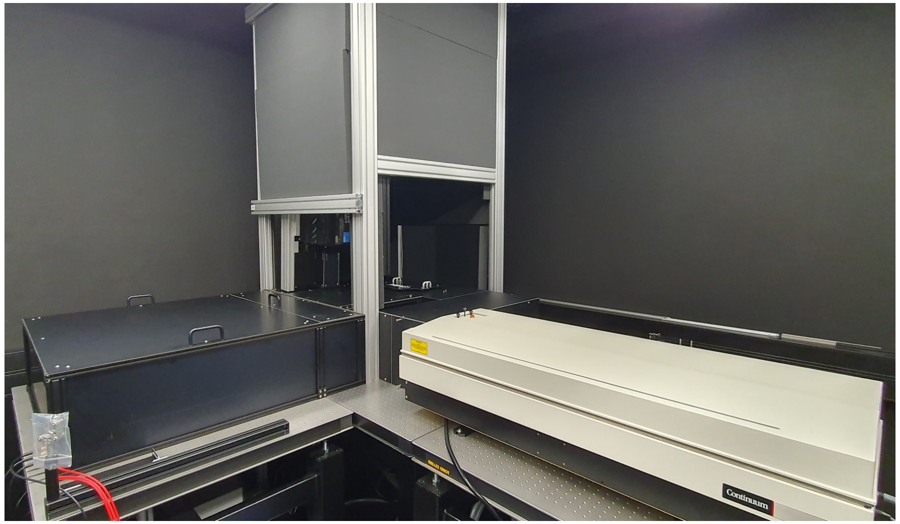
For more details see:

Reichardt, J., Lauermann, F., and Behrendt, O.: Fluorescence spectra of atmospheric aerosols, Atmos. Chem. Phys., 25, 5857–5892, https://doi.org/10.5194/acp-25-5857-2025, 2025.

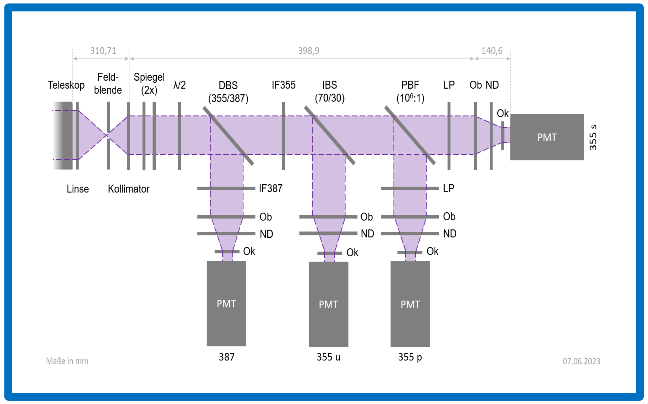
ATLID intercomparisons

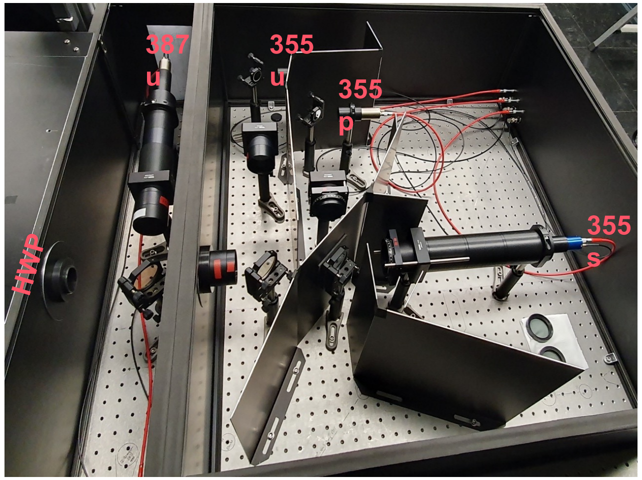
ALV (Atmospheric Lidar Validator)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

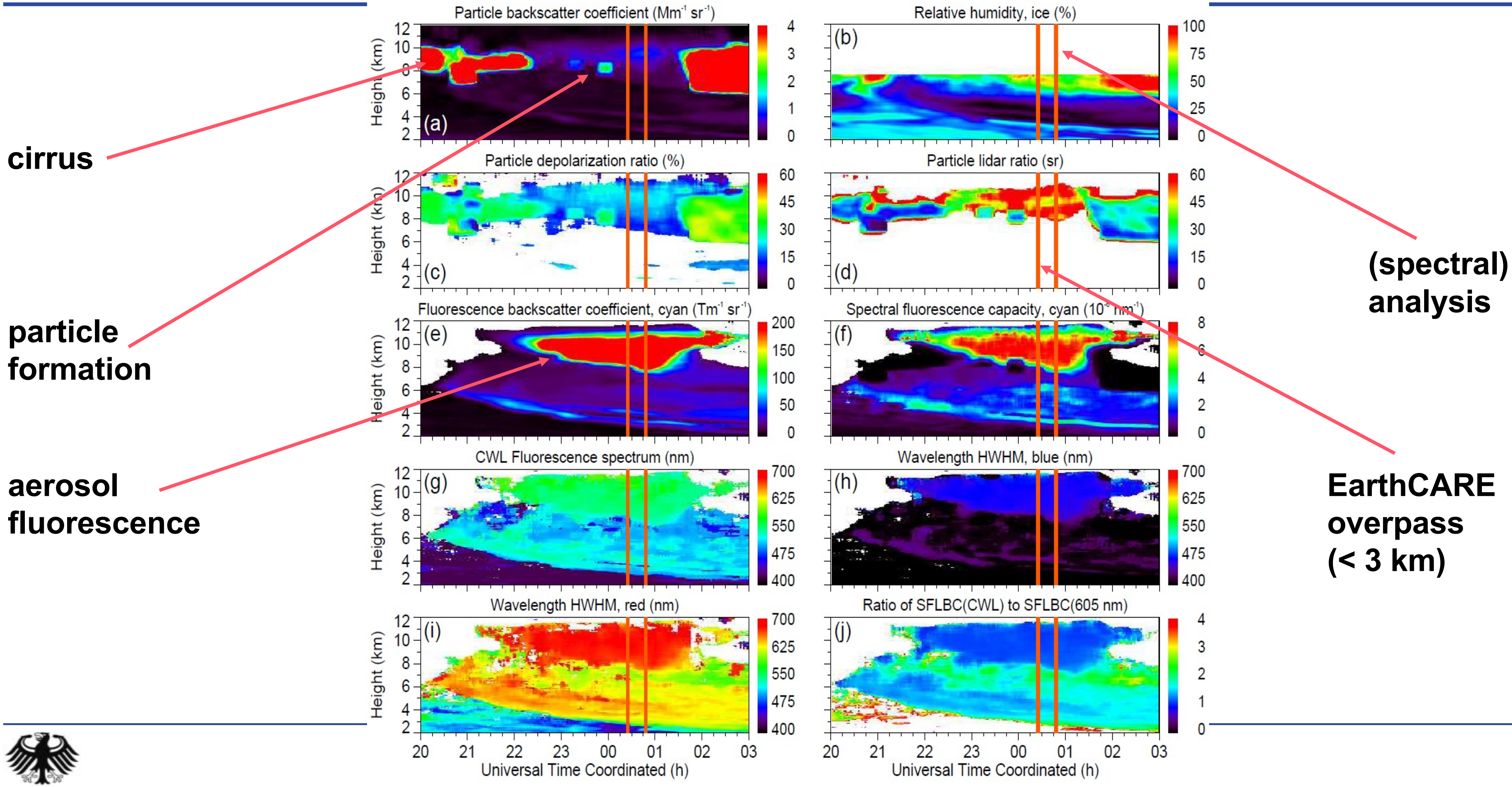


Ground-based equivalent of ATLID (tilted 3°)

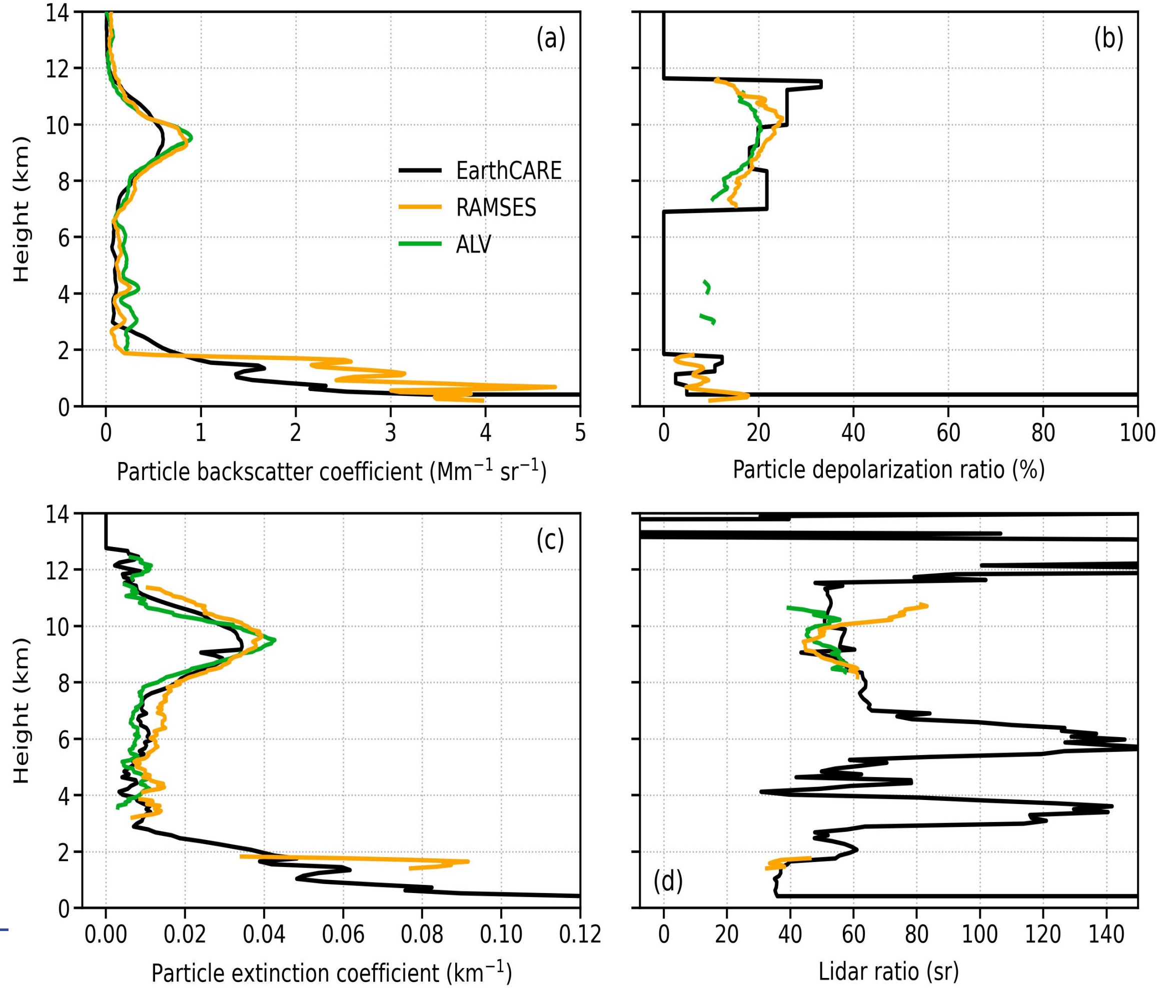




RAMSES measurement: 04/05 April 2025, mixed dust and BBA layer

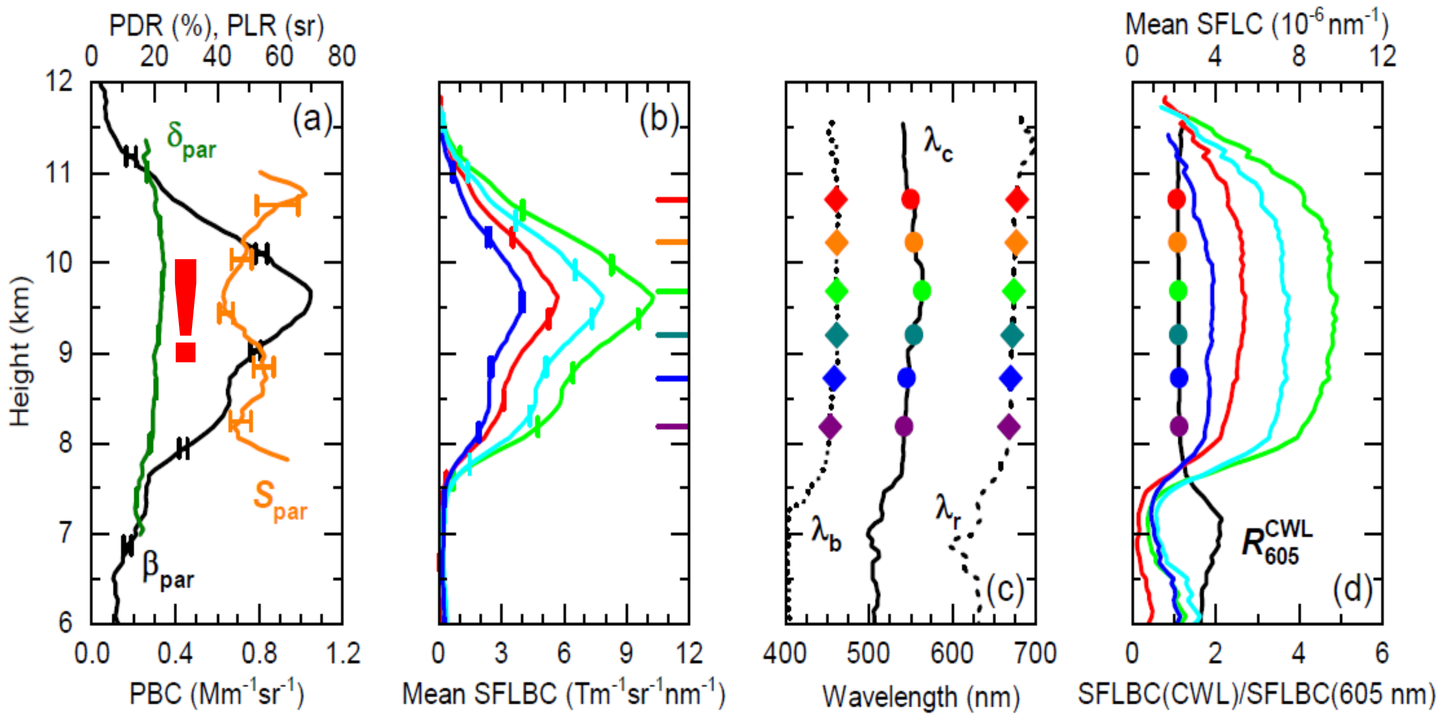


EarthCARE comparison: 05 April 2025, 00:25 UTC



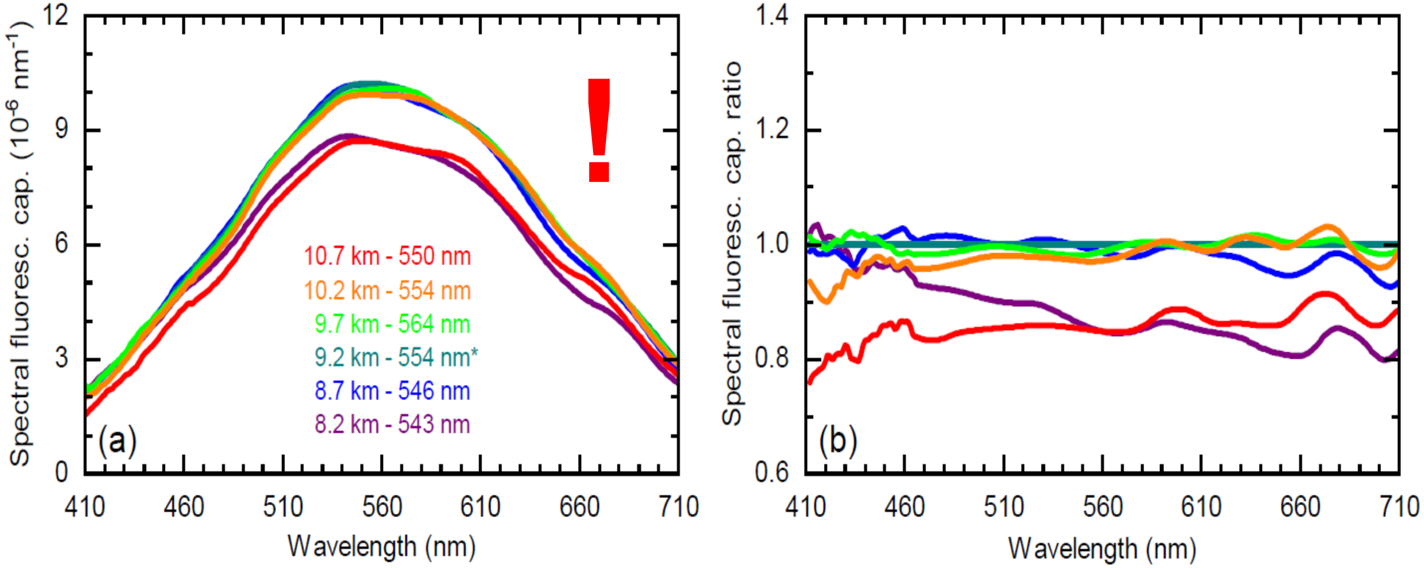
< 3 km

RAMSES measurement: 05 April 2025, 00:48 UTC – profiles



Elastic scattering properties of dust!

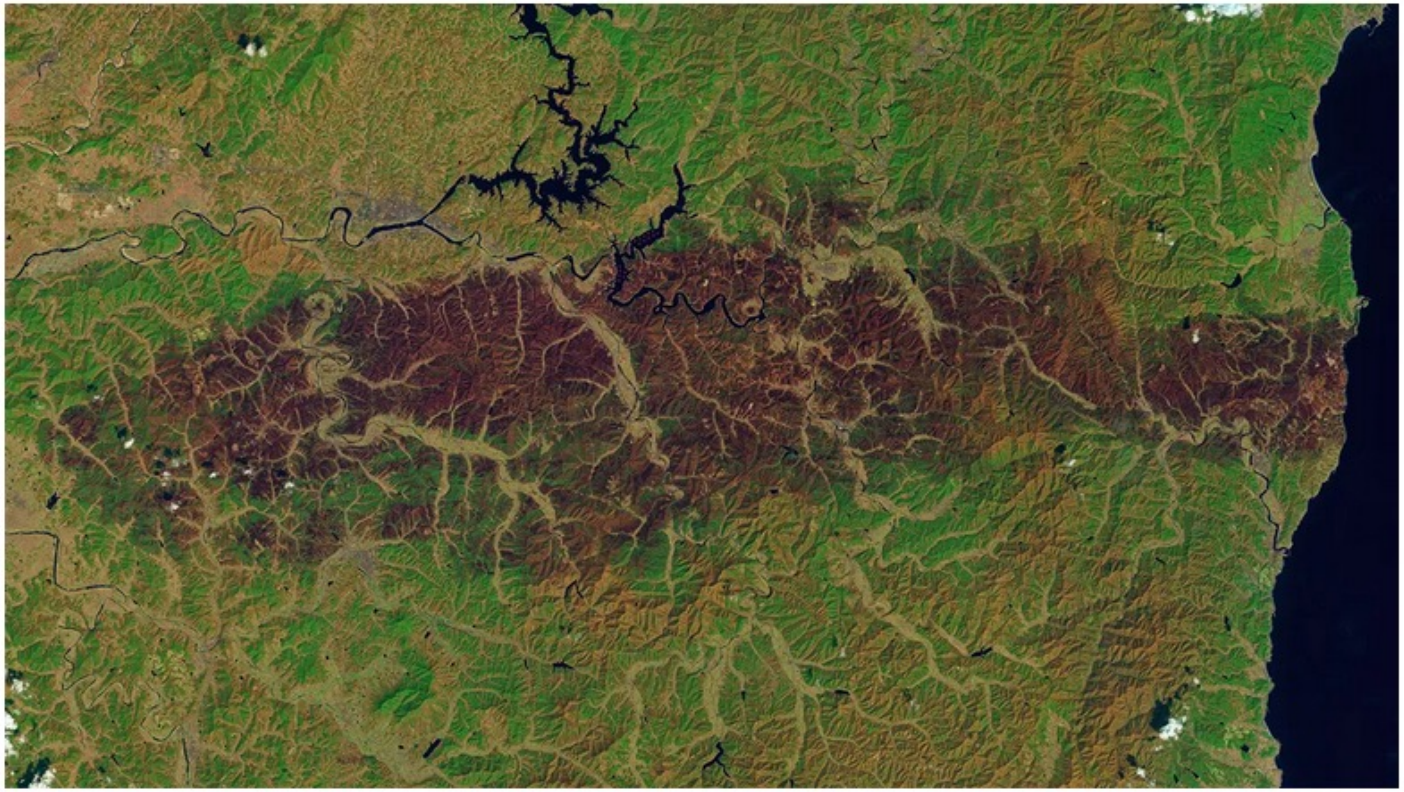
RAMSES measurement: 05 April 2025, 00:48 UTC – FL spectra



Inelastic scattering properties of BBA!

Source: Most likely mixture of Gobi Desert dust and South-Korean BBA

ənst
Hand



South Korea's March 2025 wildfires burned more than 100,000 hectares. Formerly, the country's worst wildfire season on record occurred in 2000, in which a total of 26,000 hectares burned. Credit: NASA Earth Observatory image by Lauren Dauphin, using Landsat data from the U.S. Geological

Citation: Dieckman, E. (2025), Climate change heightened conditions of South Korean fires, *Eos, 106,* https://doi.org/10.1029/2025EO250170. Published on 30 April 2025.

EarthCARE comparison: A-TC (baseline AE, orbit 4840, frame B)

Wetterdienst
na aus einer Hand
DWD

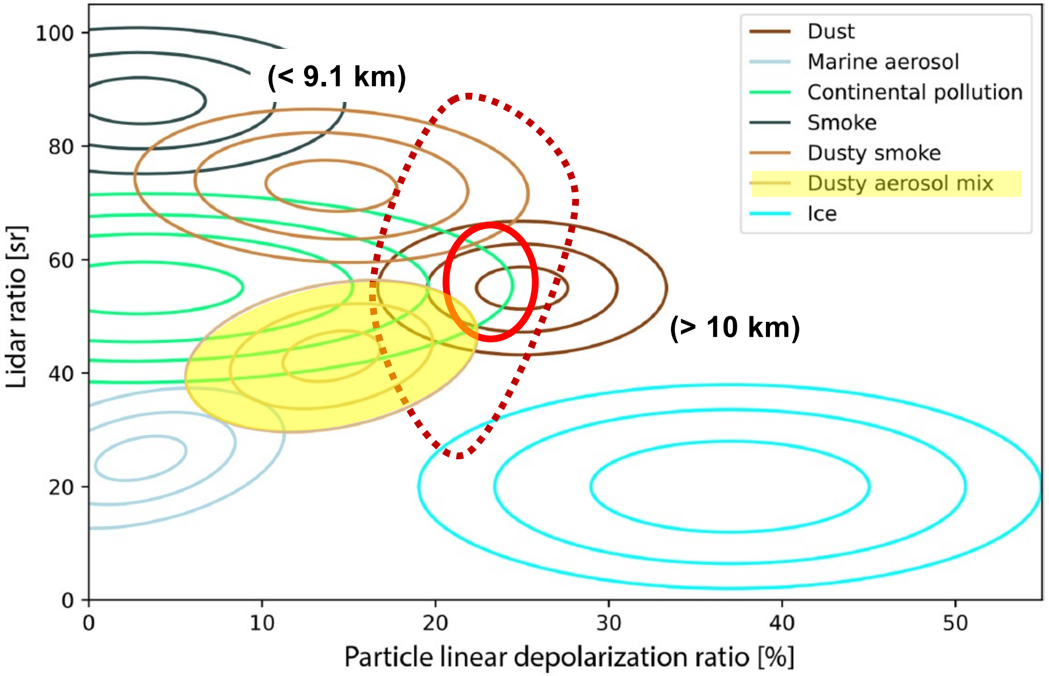
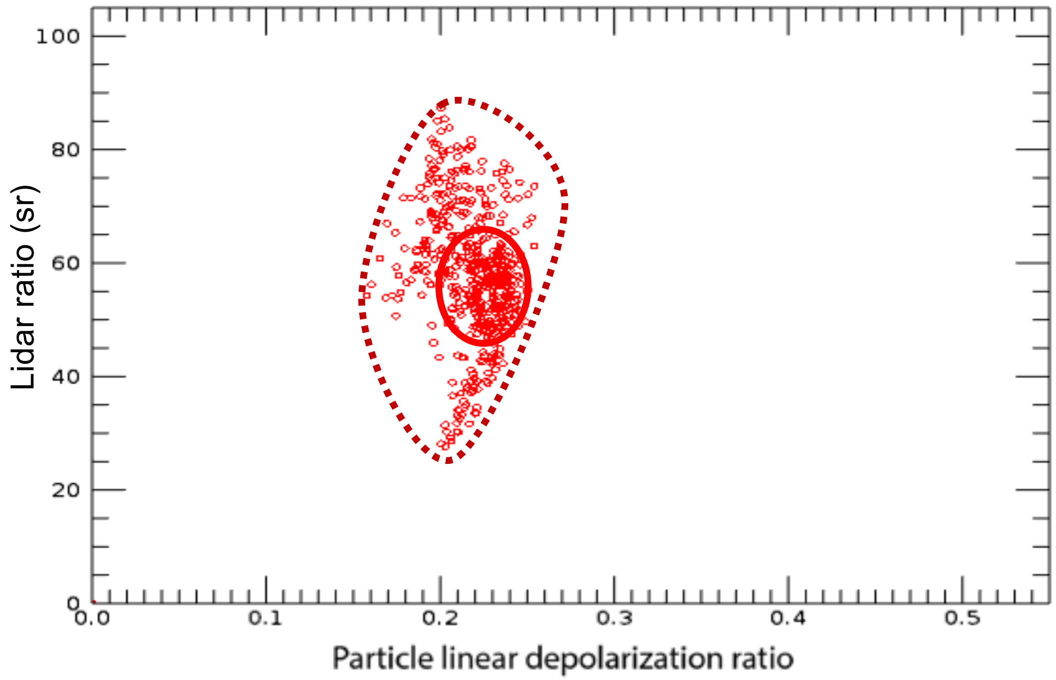


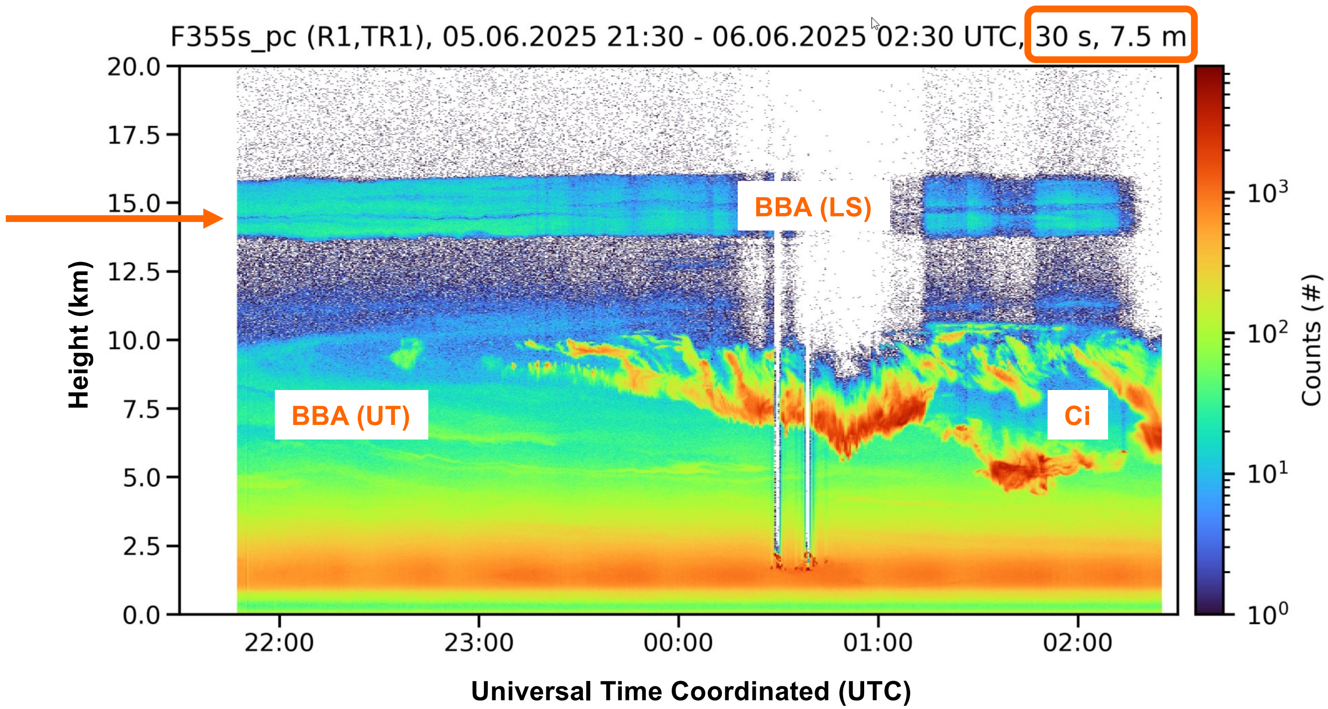
Figure 9. Schematic representation of the S–δ probability distribution functions used to determine the aerosol-related elements of the A-TC product.

Wandinger et al. (2023)



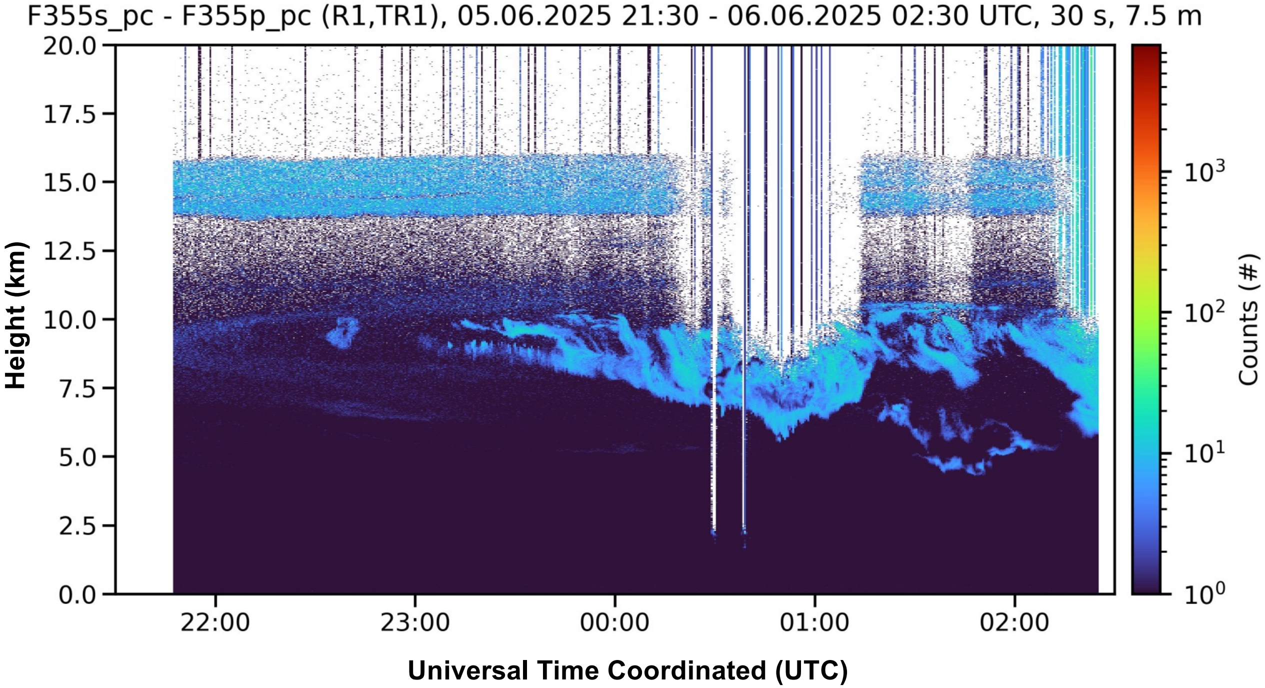
RAMSES: 9 – 10 km, 00:20 – 01:22 UTC

RAMSES measurement: 05/06 June 2025, stratospheric BBA



- Aerosol layer between 13.5 and 16 km (also intriguing aerosol structures in the free troposphere)
- Clearly in the stratosphere, clearly BBA (fluorescence); this time from North America

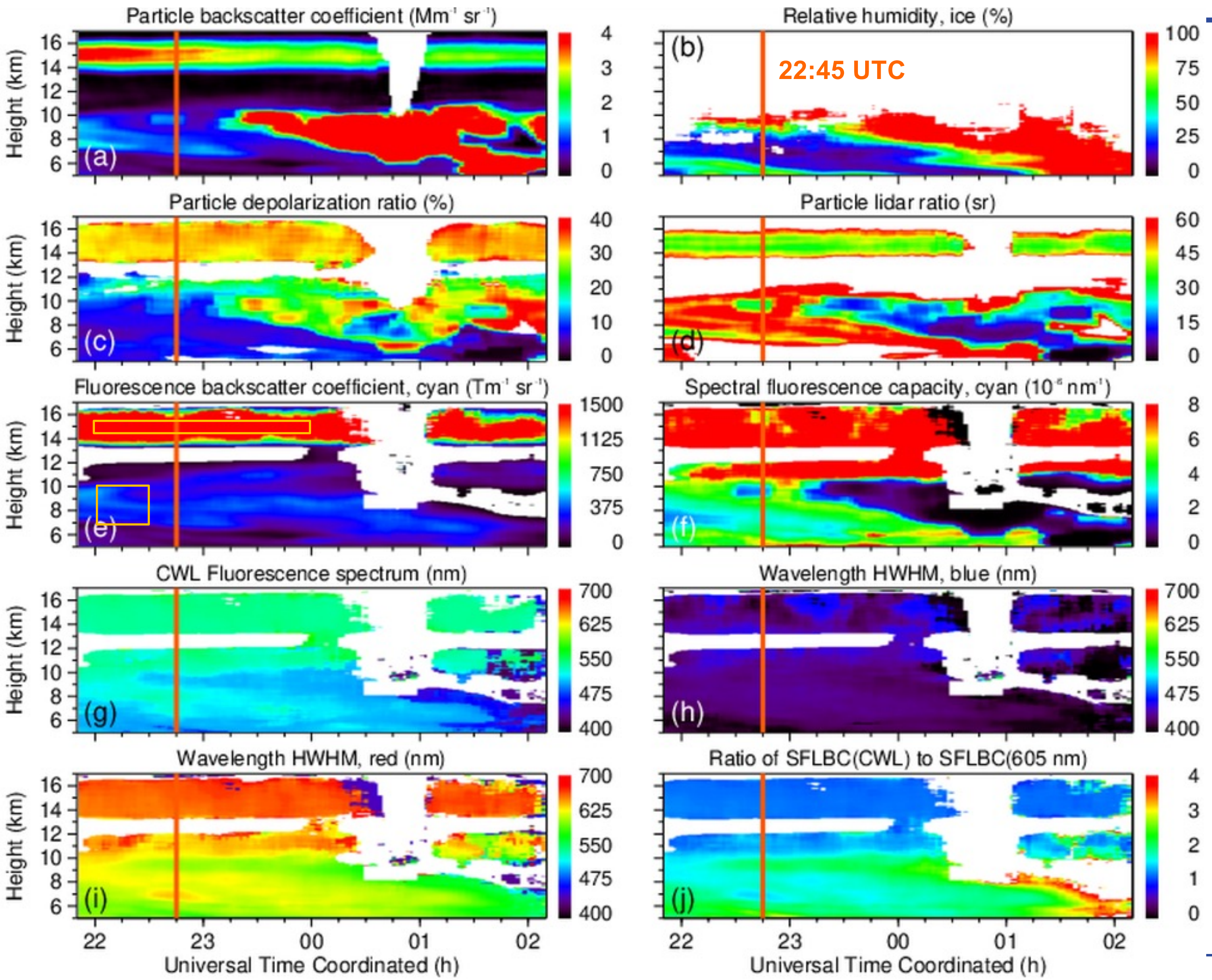
RAMSES measurement: 05/06 June 2025, stratospheric BBA



- High depolarization, comparable to cirrus cloud (note: in high free troposphere already lower)

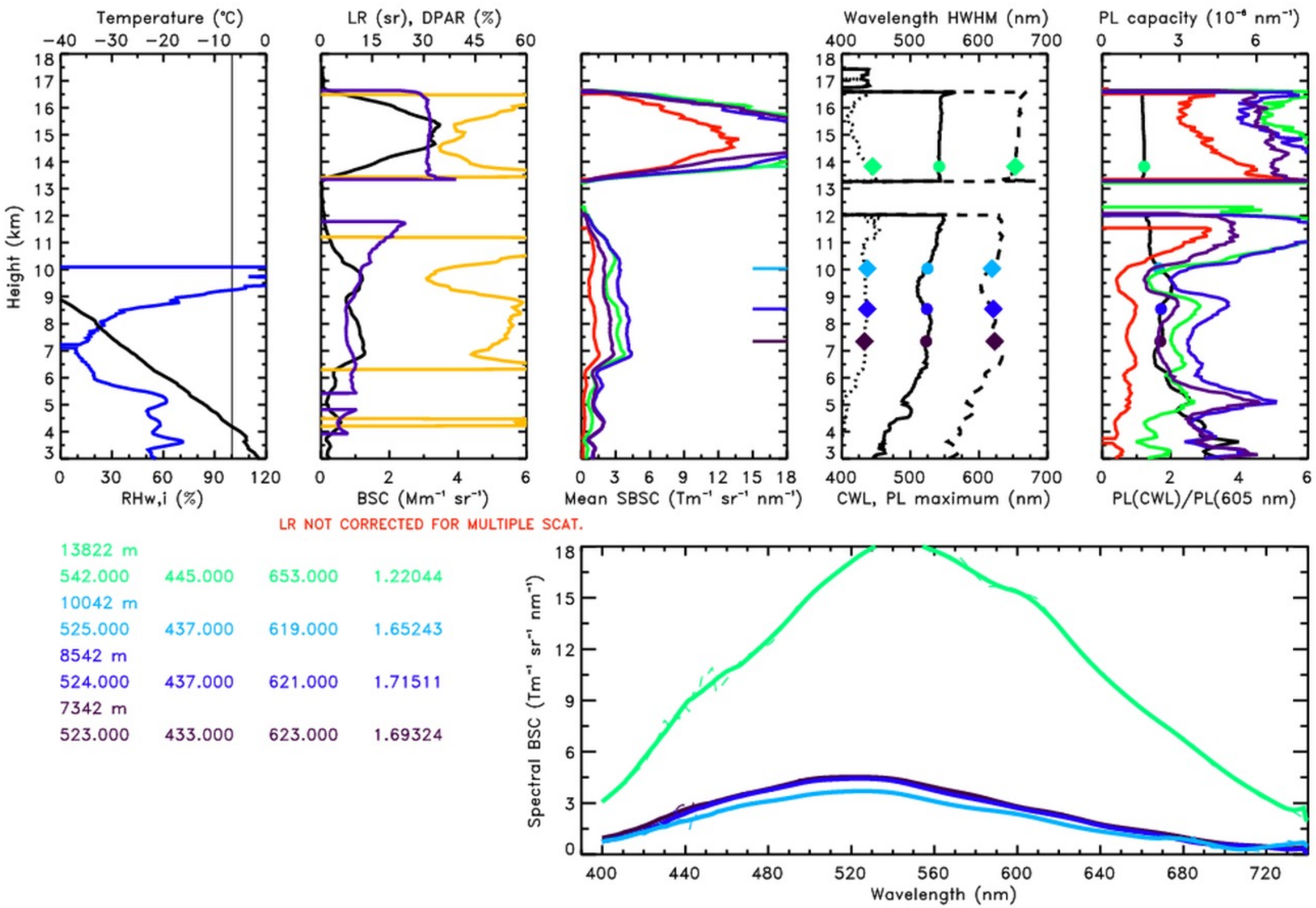
RAMSES measurement: 05/06 June 2025

· Wetterdienst
ima aus einer Hand



RamDA_v3a:
00: 20 min
01: 64 min
02: 20 min, NA

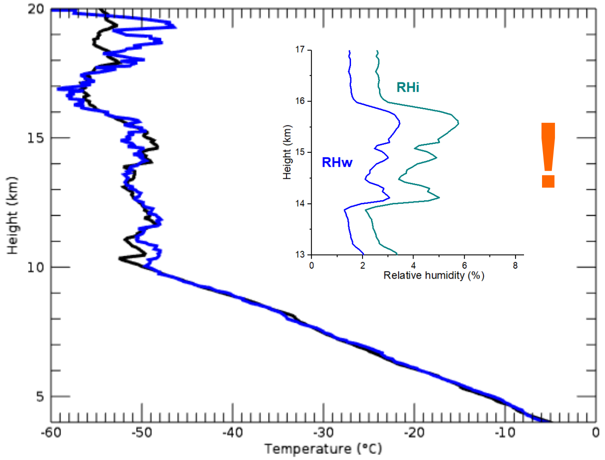
RAMSES measurement: 05/06 June 2025, 22:45 UTC – profiles

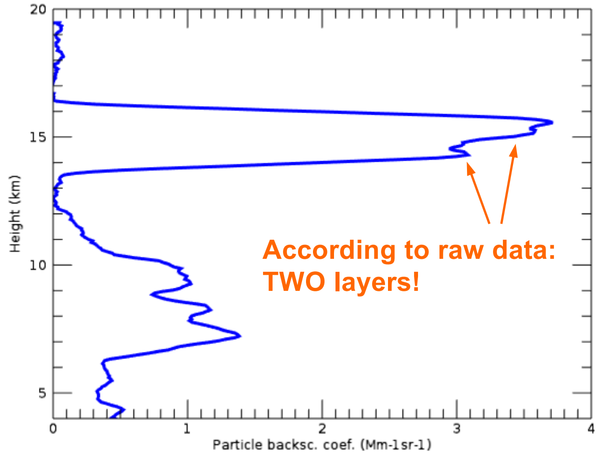


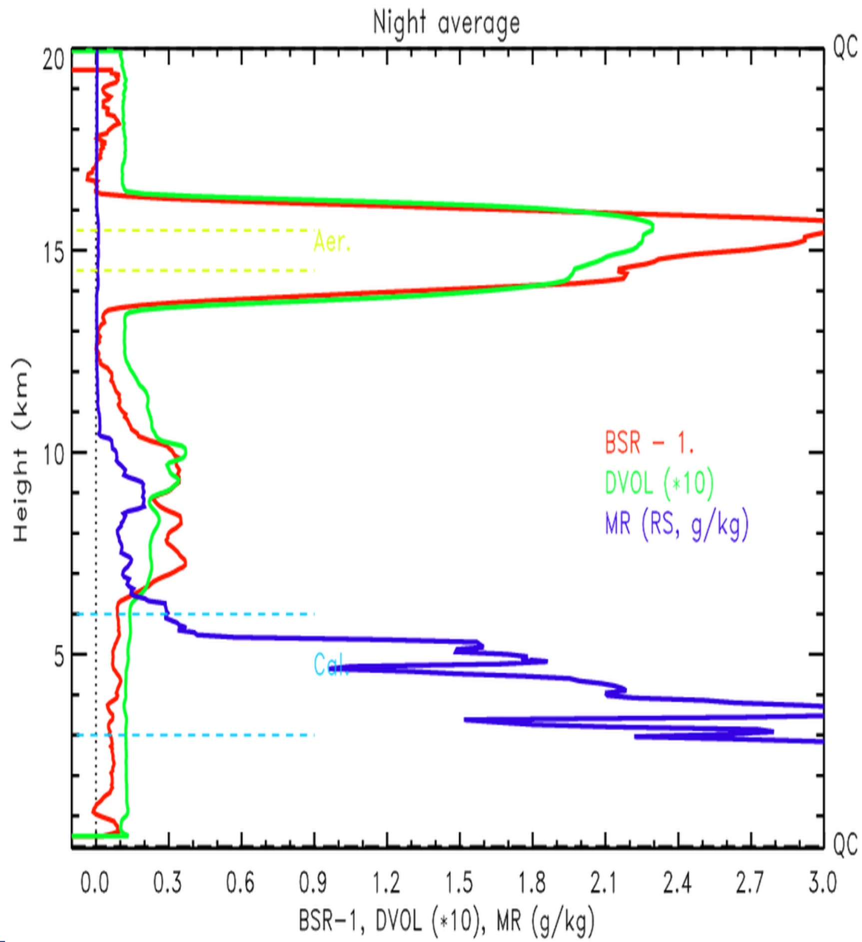
RamDA_v3a:
02: 20 min

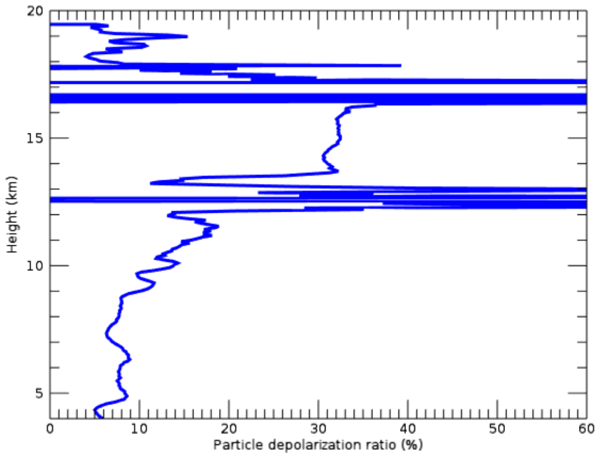
RAMSES measurement: 05/06 June 2025, 82-min average

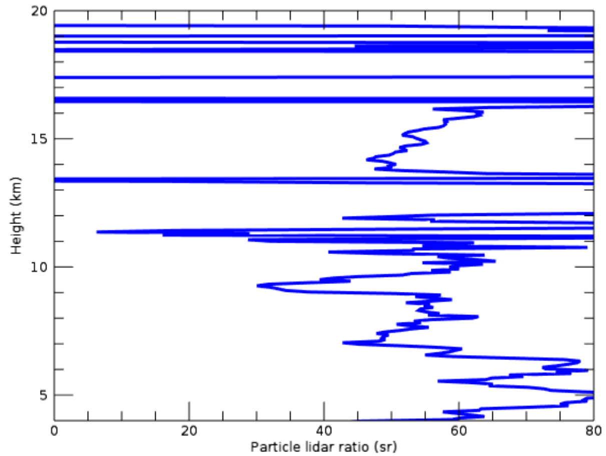
Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD







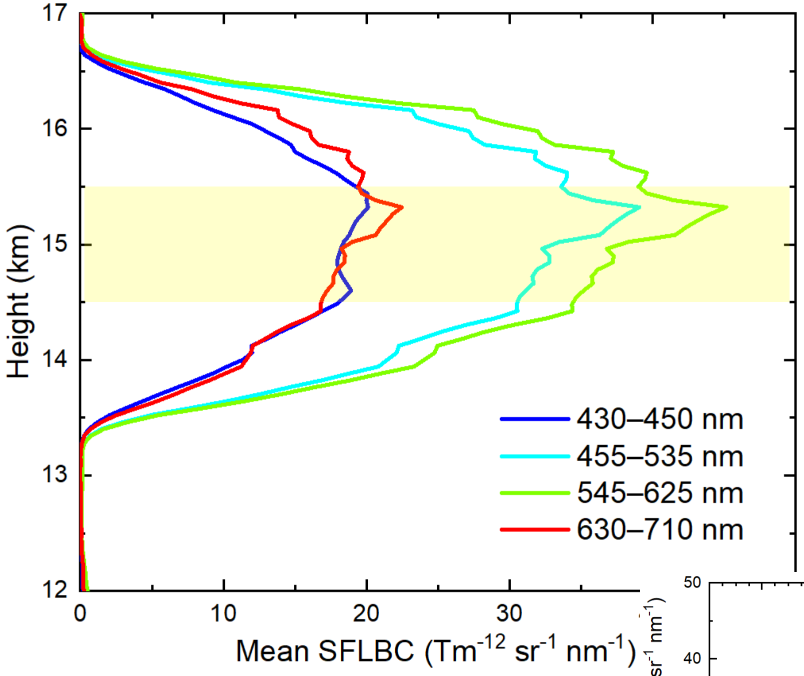


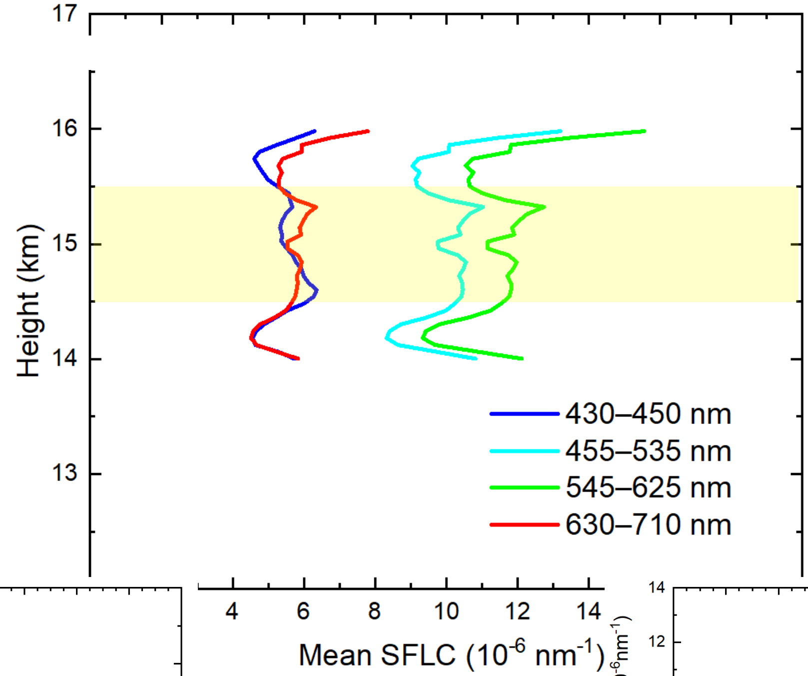


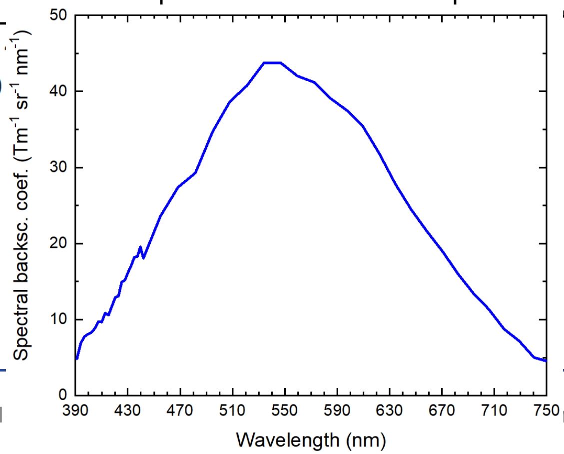
RAMSES measurement: 05/06 June 2025, 82-min average

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

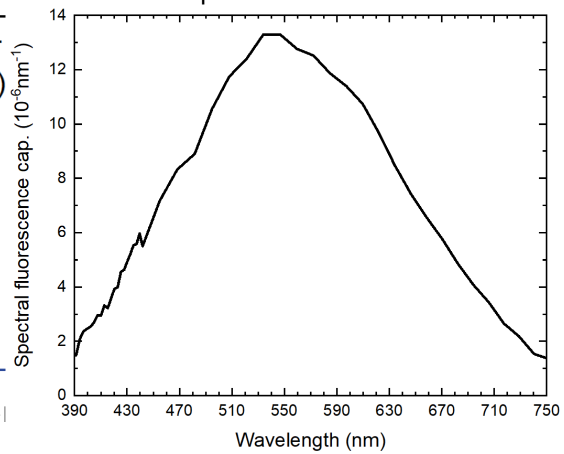
DWD







14.5-15.5 km



EarthCARE comparison: HETEAC (A-TC)

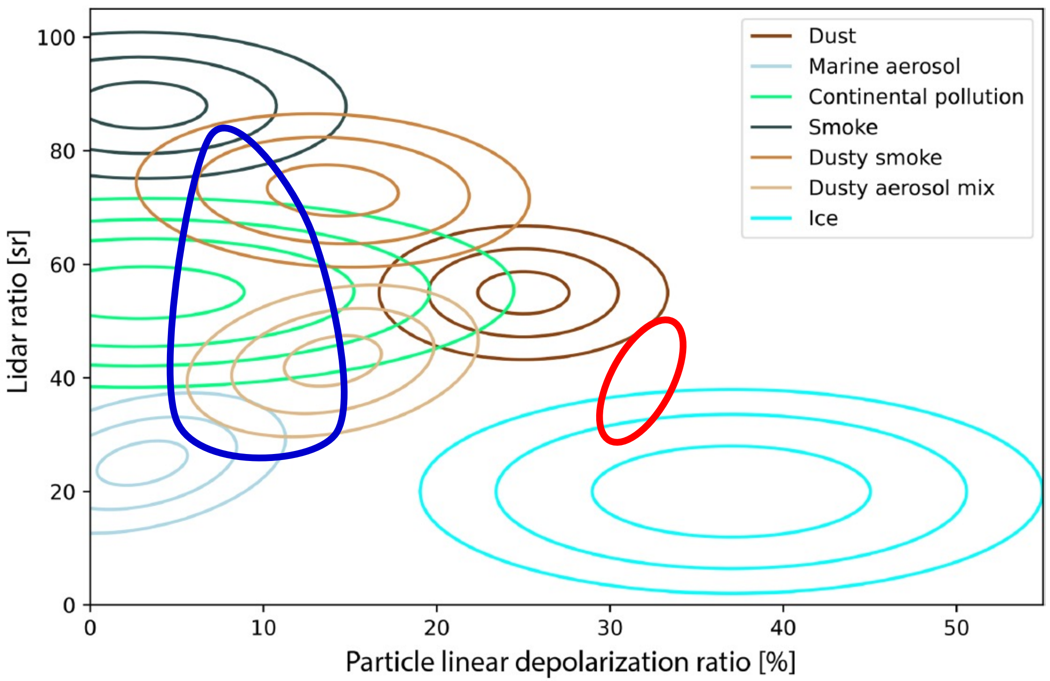
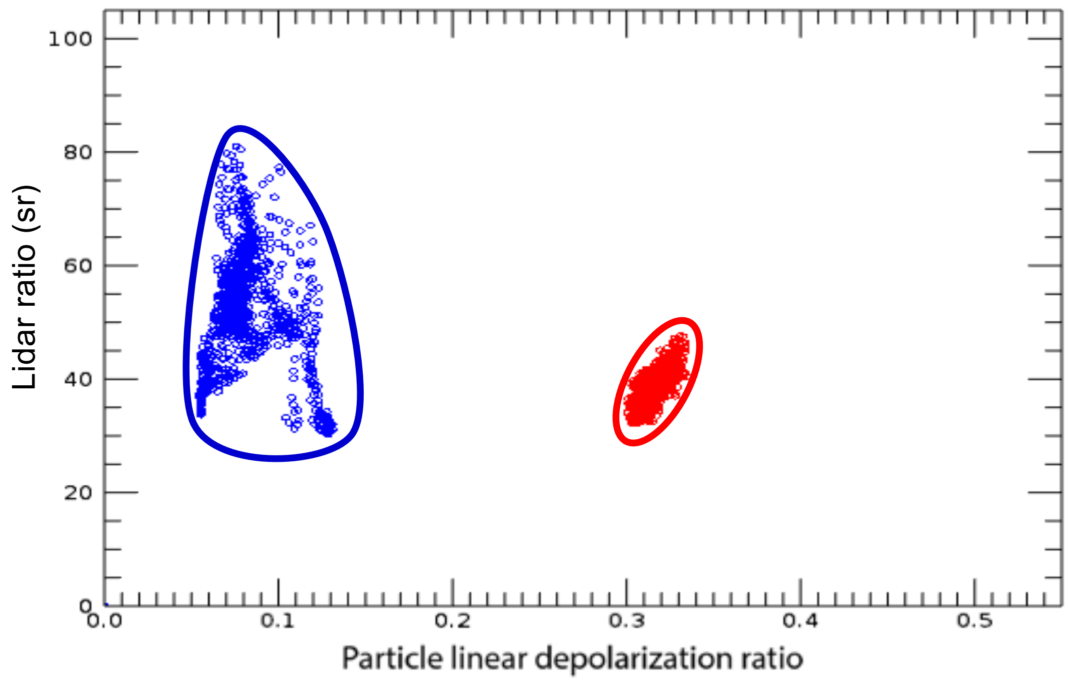


Figure 9. Schematic representation of the S–δ probability distribution functions used to determine the aerosol-related elements of the A-TC product.

Wandinger et al. (2023)

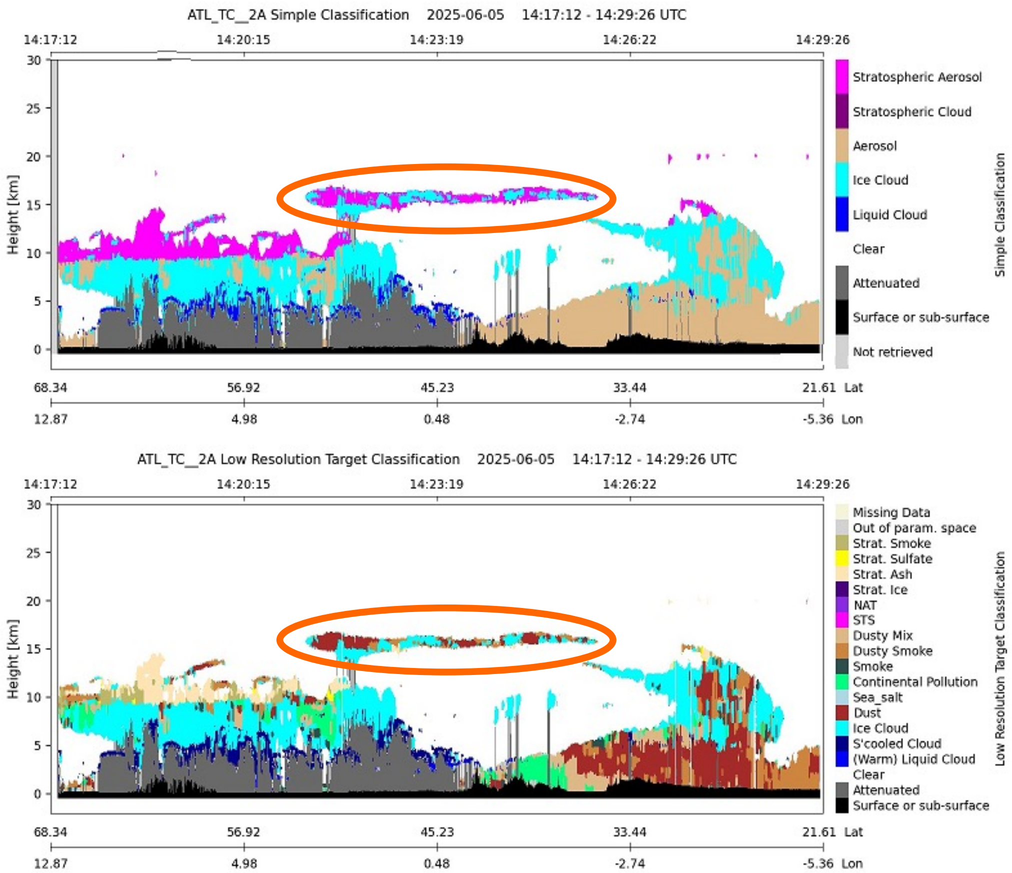


20-min data points:
BBA (UT)
BBA (LS)

EarthCARE comparison: A-TC

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- A-TC results dubious (again)
- Probably misled by high depolarization (and low lidar ratio)



Thanks for your attention!

Questions?