Gefördert durch:
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aufgrund eines Beschlusses des Deutschen Bundestages

How Aeolus Cal/Val helps to define validation protocols for space-borne aerosol profiling in the context of the EarthCARE mission

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On behalf of the EarthCARE Cal/Val Coordination Team

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History of spaceborne lidars

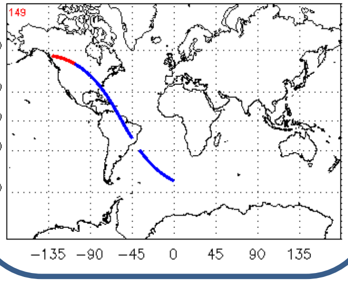
LITE

Lidar
In-space
Technology
Experiment

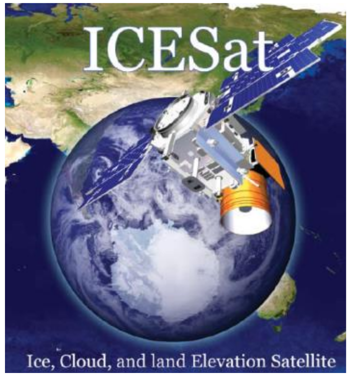
On Space Shuttle Discovery

September 1994

Fig. 1. The launch of Shuttle Discovery with LITE aboard. (Courtesy NASA KSC).



ICESat

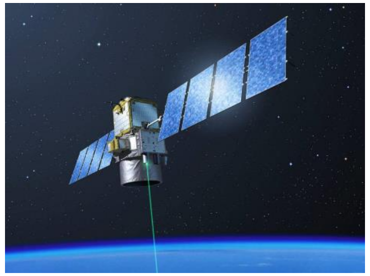


(aka: Laser Altimetry Mision)

Instrument: Geoscience Laser Altimeter System (GLAS) - sole instrument (532+1064 nm)

Jan 2003 – Feb 2010

CALIPSO

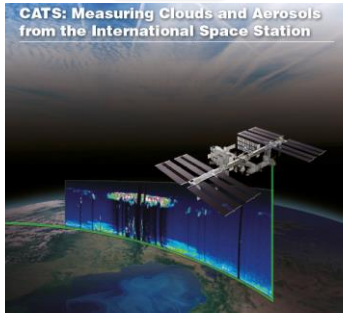


measures since 7 June 2006

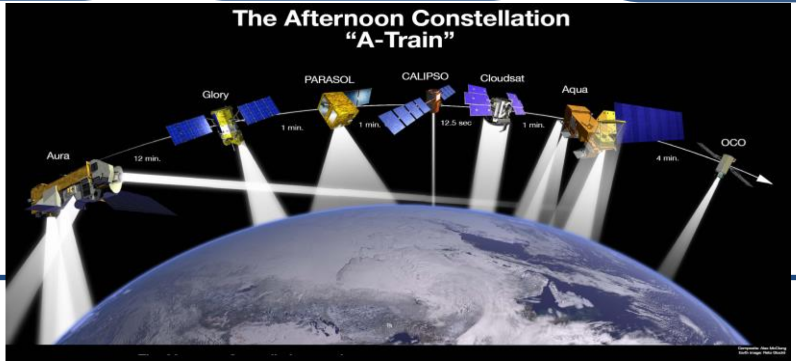
Elastic polarization lidar at 532 nm and 1064 nm

Part of the A-Train

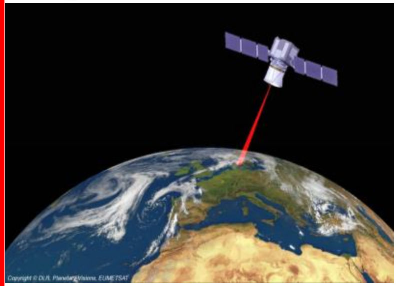
CATS



Calipso like payload onboard the **International Space Station (ISS) for** atmospheric aerosols and clouds profiling. Launched Jan 2015, duration 6 months.



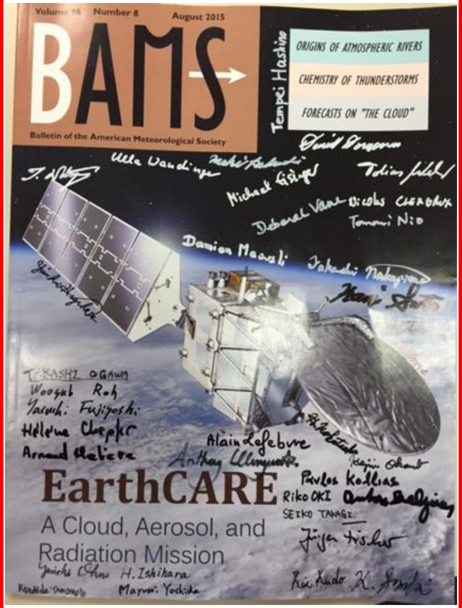
aeolus



Atmospheric Explorer for Observations with Lidar in Ultraviolet from Space
AEOLUS
Doppler lidar
@ 355 nm
pointing 35° off nadir

Launched Aug 2018

earthcare



Lidar+cloud radar+imager+broad band radiometer onboard one satellite

Launch in Autumn 2023?

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EarthCARE: Linking Clouds, Aerosol and Radiation

Science: Impact of Clouds and Aerosols on Radiation

Observations:

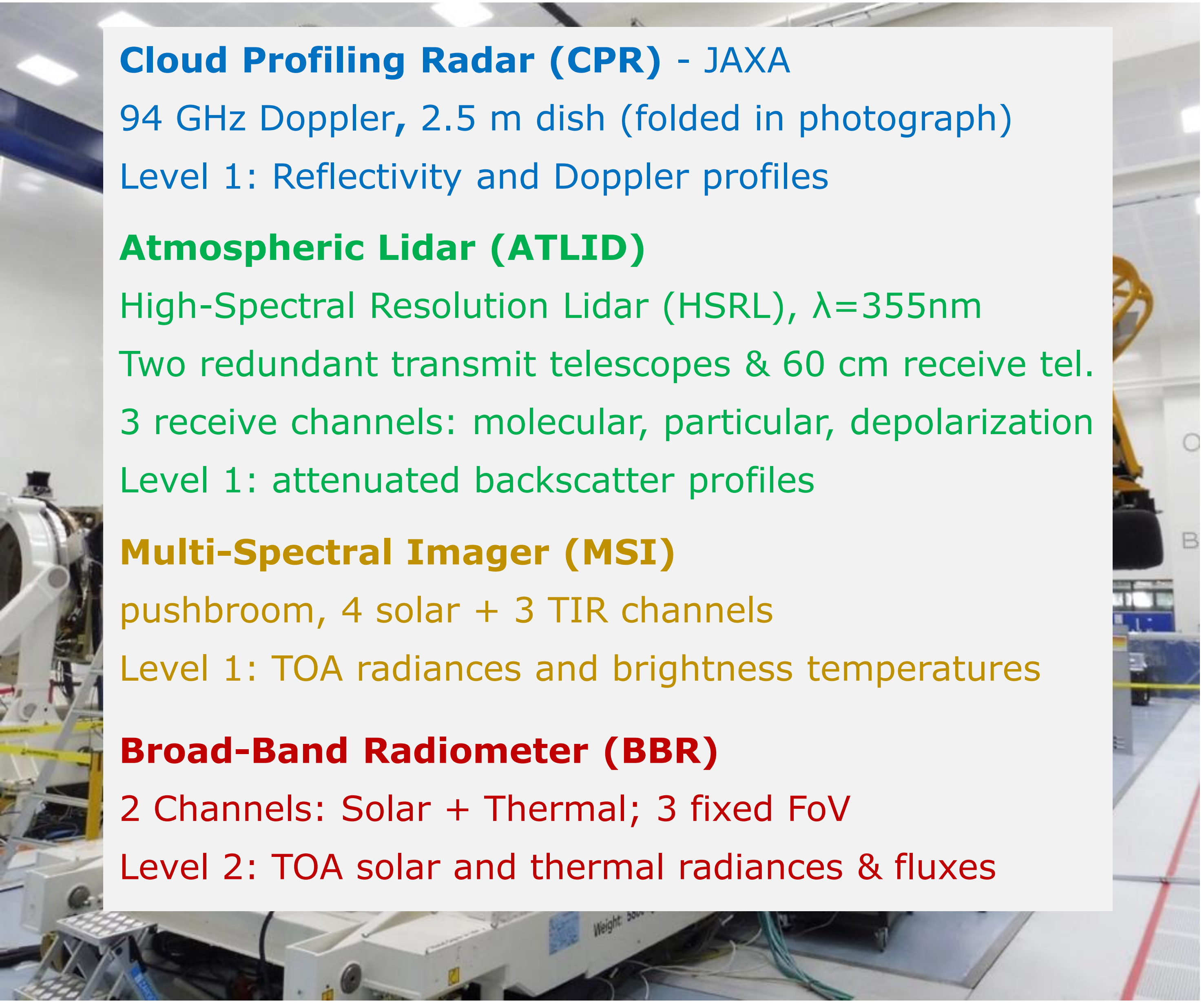
- Cloud profiles (ice, liquid, mixed), cloud coverage, precipitation
- Aerosol profiles
- Broad-band Solar & Thermal Radiation

Satellite and Payload

- Sun-sync. orbit at 393 km, 14:00 hours descending node
- UV Lidar with high spectral resolution receiver
- W-band Cloud Radar with Doppler (contribution JAXA)
- Imager and Broad-Band Radiometer
- Launch 2023

Earth Explorer Mission implemented in cooperation with JAXA

EarthCARE: Instrumentation



Cloud Profiling Radar (CPR) - JAXA

94 GHz Doppler, 2.5 m dish (folded in photograph)

Level 1: Reflectivity and Doppler profiles

Atmospheric Lidar (ATLID)

High-Spectral Resolution Lidar (HSRL), λ=355nm

Two redundant transmit telescopes & 60 cm receive tel.

3 receive channels: molecular, particular, depolarization

Level 1: attenuated backscatter profiles

Multi-Spectral Imager (MSI)

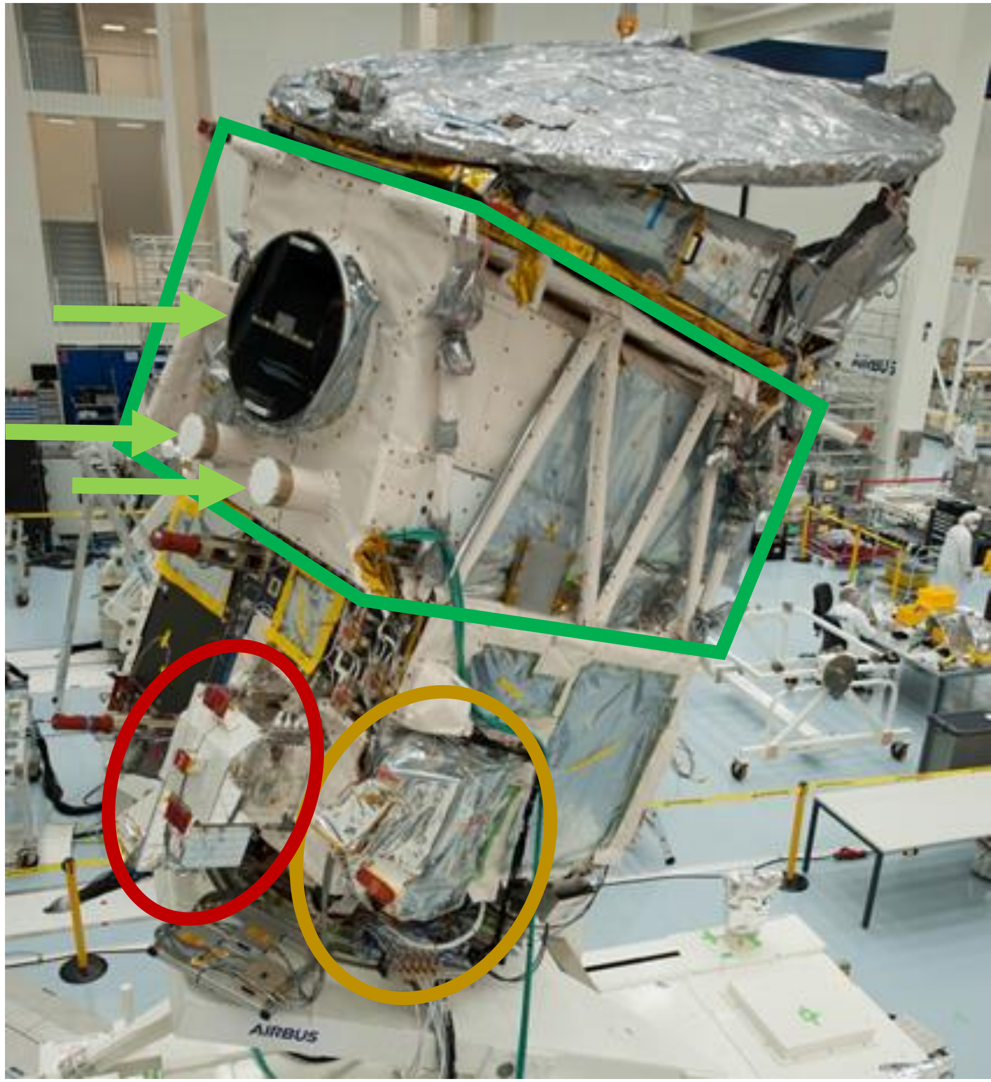
pushbroom, 4 solar + 3 TIR channels

Level 1: TOA radiances and brightness temperatures

Broad-Band Radiometer (BBR)

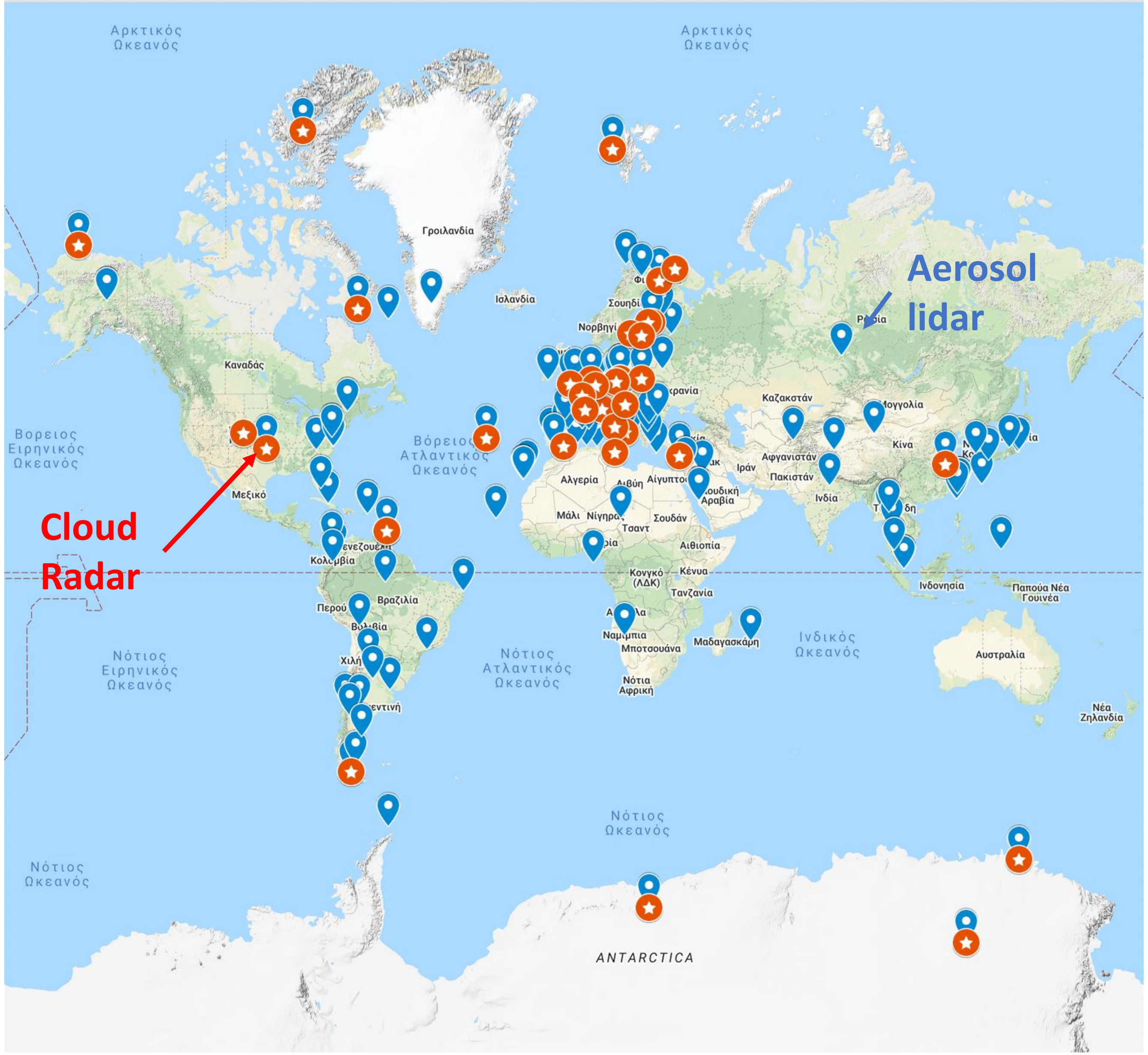
2 Channels: Solar + Thermal; 3 fixed FoV

Level 2: TOA solar and thermal radiances & fluxes



Photos courtesy Airbus

EarthCARE Cal/Val map



PLUS

- Airborne
- Ship-borne
- Satellite based
- Model

Huge validation effort…

→Coordination

EarthCARE Cal/Val preparation

- AO (Announcement of Opportunity) call in 2017
- ESA EarthCARE validation workshops in 2018 and 2021, each with ~250 participants

1st ESA EarthCARE Cal/Val Workshop Report
EC-RP-ESA-SYS-983
Bonn, Germany
13-15 June 2018
esa
European Space Agency

*> **30** AO proposals (**Cal/Val teams**)*
→adequate validation
***if full funding** is achieved*

2nd ESA EarthCARE Cal/Val Workshop Report
EC-RP-ESA-SYS-1229
Online Event
24-28 May 2021
esa
European Space Agency

Clear need for common protocols for cloud and aerosol profile validation

https://earthcare-val.esa.int

Involvement in EarthCARE Cal/Val is still possible →
rob.koopman@esa.int

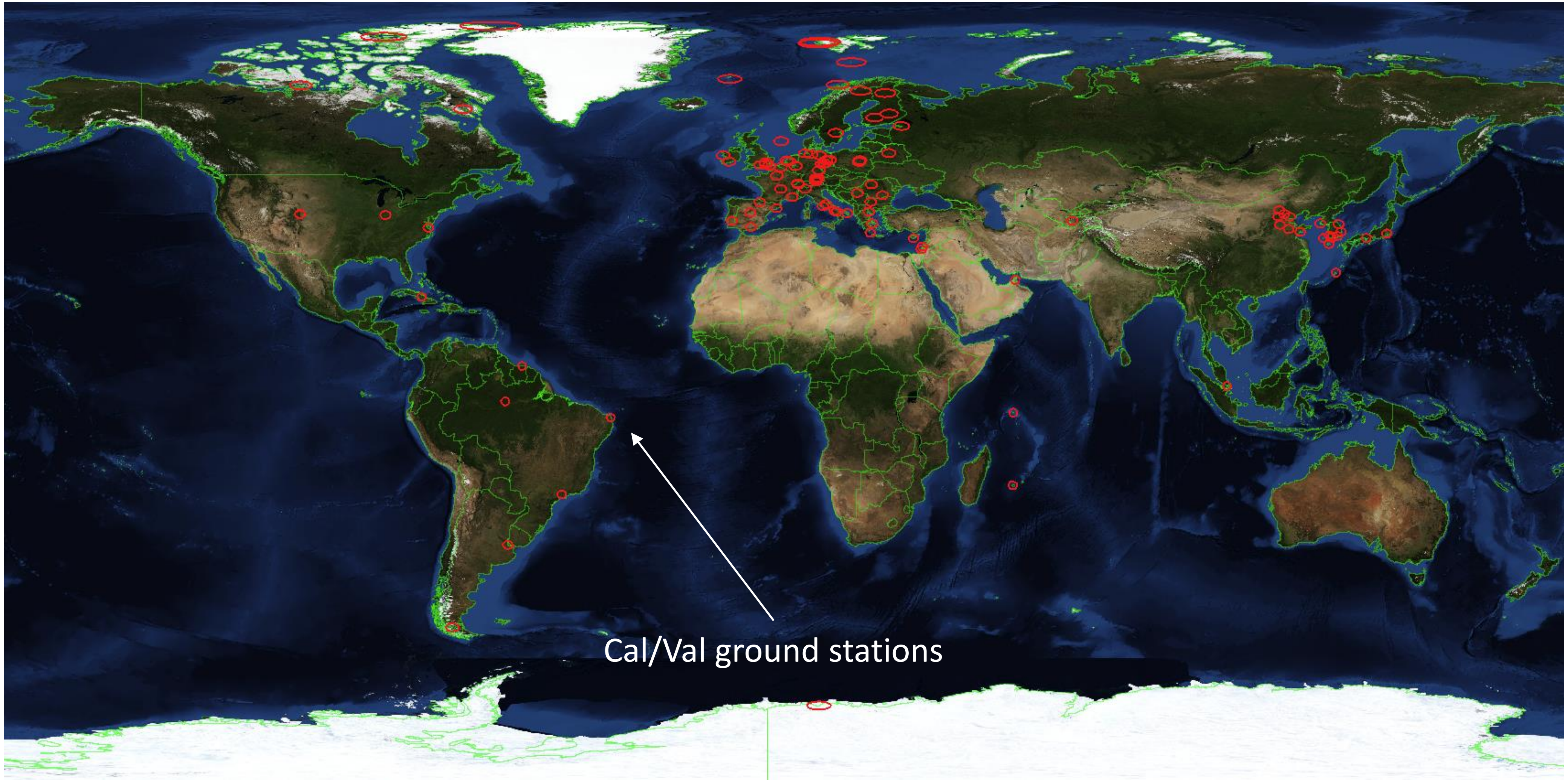
Some examples which have been discussed

- Wavelength conversion to 355 nm
  (or utilisation of correlative instruments with different wavelength)
- Orbital-suborbital attenuated backscatter – L1 validation
- 355 nm depolarization validation
- How to handle/mitigate daytime capabilities/limitations of ground-based lidars (especially RAMAN)
- Scene classification
- Statistical methods

There is a clear need for common practise based on the lessons learned from previous missions

- Enhance **maturity** of **intercomparisons**
  (more quantitative vs presently rather qualitative)
- Enhance **thoroughness of statistical intercomparison** methods
  (dealing with sparse data, and with risks of bias)
- Guidance and knowledge transfer
- Obtain broader assessment of EarthCARE validation gaps by engaging **Aeolus**, CloudSat, CALIPSO, AtmOS communities

Aeolus Cal/Val



PLUS

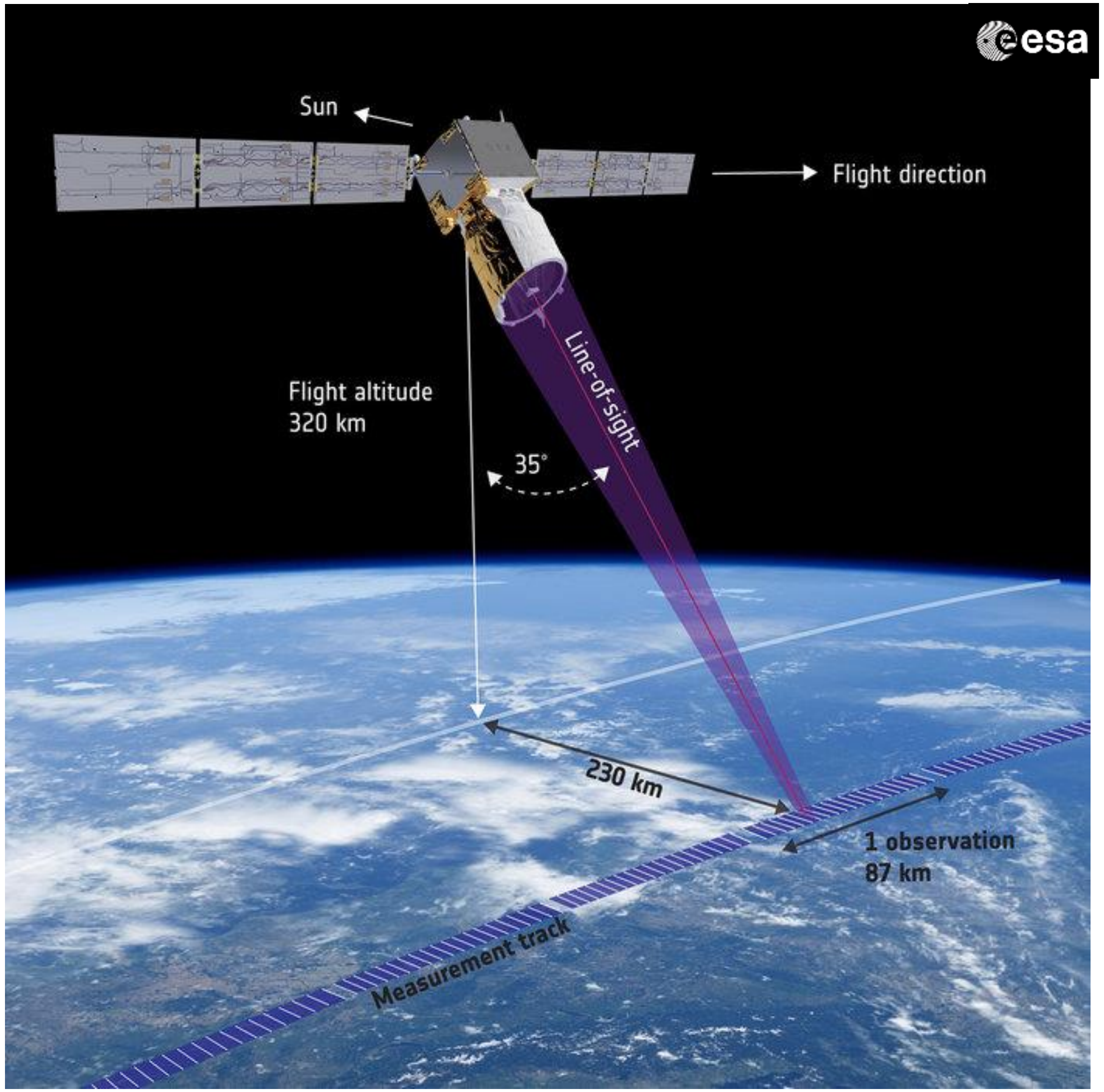
- Airborne
- Ship-borne
- Satellite based
- Model

Lessons learned for common protocols for best practice

Aeolus – the first wind lidar in space

- ESA Earth Explorer Mission
- First European lidar in space called Aladin
- **First lidar @ 355** nm in space
- **First HSRL** lidar in space
- Profiles of the **west-east wind component**
- Provides also **aerosol & cloud products**
- Intensive validation efforts needed

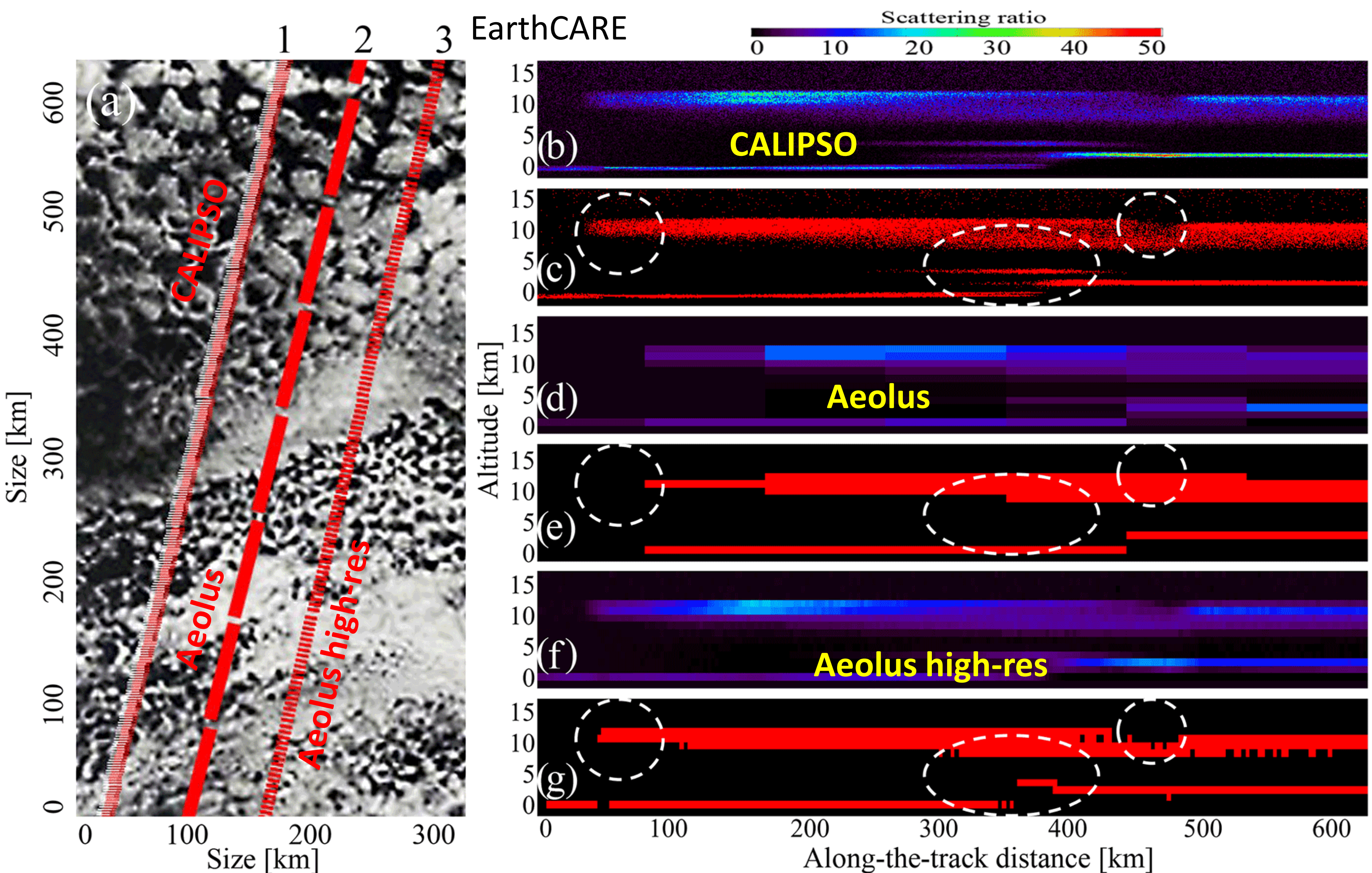
→ lessons learned for EarthCARE with ATLID

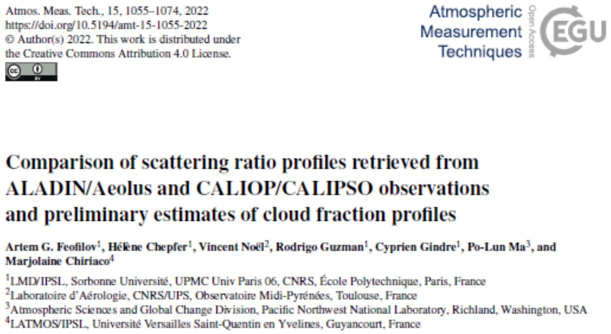


Some examples to be discussed
- Lessons learnt from Aeolus Cal/Val

- Wavelength conversion (or utilisation of correlative instruments with different wavelength)
- Orbital-suborbital attenuated backscatter – L1 validation
- 355 depolarization validation
- How to handle/mitigate daytime capabilities/limitations of ground-based lidars (especially RAMAN)
- **Scene classification**
- Statistical methods

Cloud contamination and representativeness problem → different for different missions




Atmos. Meas. Tech., 15, 1055–1074, 2022
https://doi.org/10.5194/amt-15-1055-2022

Atmospheric Measurement Techniques
Open Access
EGU

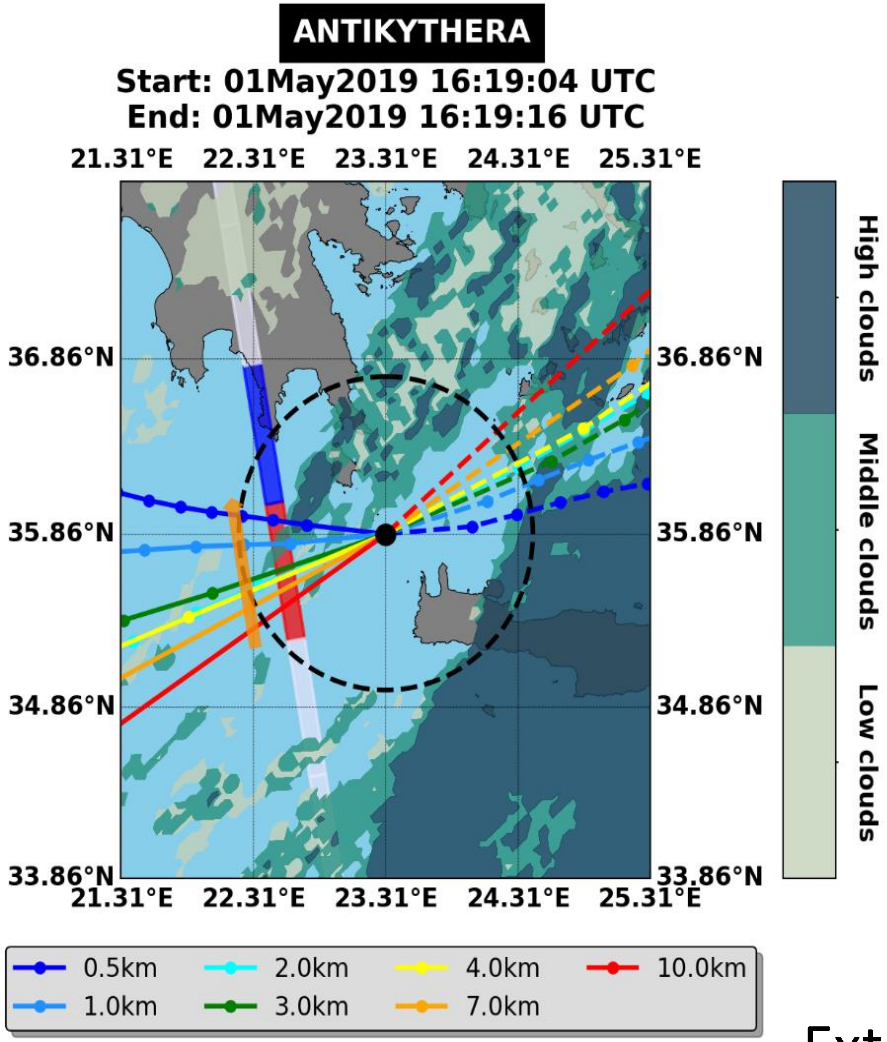
Comparison of scattering ratio profiles retrieved from ALADIN/Aeolus and CALIOP/CALIPSO observations and preliminary estimates of cloud fraction profiles

Artem G. Feofilov[1], Hélène Chepfer[1], Vincent Noël[2], Rodrigo Guzman[1], Cyprien Gindre[1], Po-Lun Ma[3], and Marjolaine Chiriaco[4]

[1]LMD/IPSL, Sorbonne Université, UPMC Univ Paris 06, CNRS, École Polytechnique, Paris, France
[2]Laboratoire d'Aérologie, CNRS/UPS, Observatoire Midi-Pyrénées, Toulouse, France
[3]Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, Washington, USA
[4]LATMOS/IPSL, Université Versailles Saint-Quentin en Yvelines, Guyancourt, France

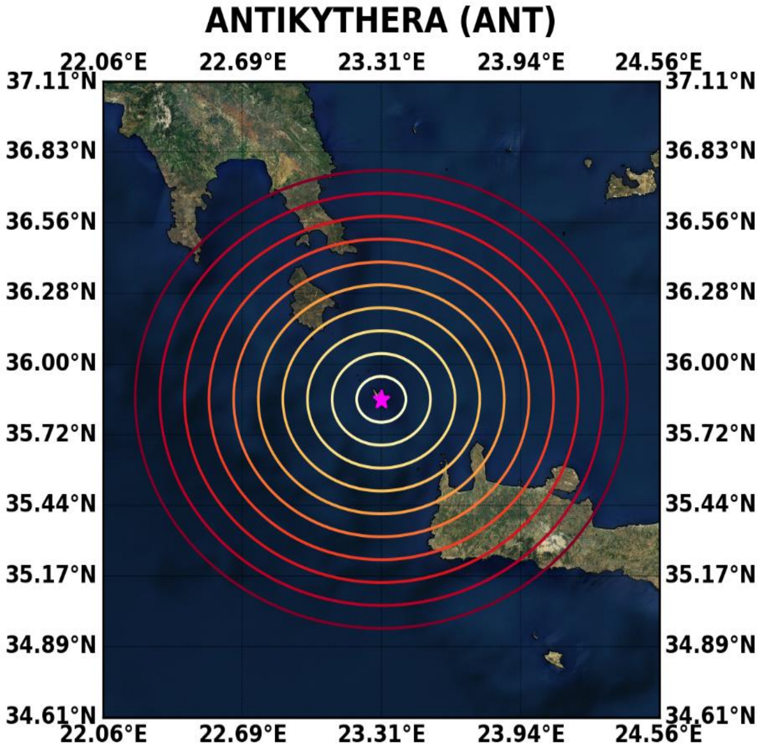
Feofilov, A. G., Chepfer, H., Noël, V., Guzman, R., Gindre, C., Ma, P.-L., and Chiriaco, M.: Comparison of scattering ratio profiles retrieved from ALADIN/Aeolus and CALIOP/CALIPSO observations and preliminary estimates of cloud fraction profiles, Atmos. Meas. Tech., 15, 1055–1074, https://doi.org/10.5194/amt-15-1055-2022, 2022.

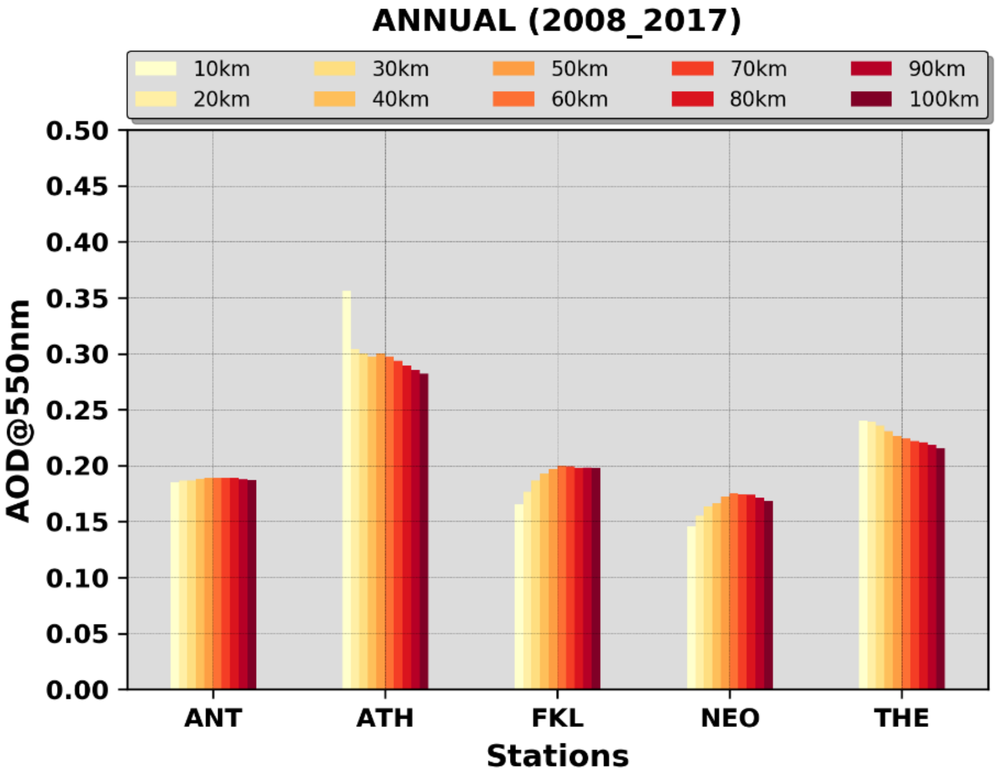
Cloud screening, scene classification essential



Extreme horizontal variability for both aerosols and clouds

Horizontal aerosol homogeneity within the 100 km circle



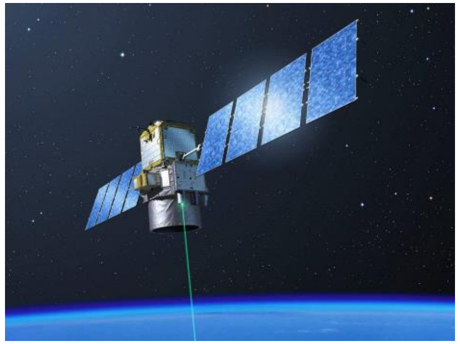


100 km for co-location radius is a recommendation and can be modified depending in station and scene

Some examples to be discussed
-- Lessons learnt from Aeolus cal/Val

- Wavelength conversion (or utilisation of correlative instruments with different wavelength)
- **Orbital-suborbital attenuated backscatter – L1 validation**
- 355 depolarization validation
- How to handle/mitigate daytime capabilities/limitations of ground-based lidars (especially RAMAN)
- Scene classification
- Statistical methods

Different space borne lidars – ground-based lidars

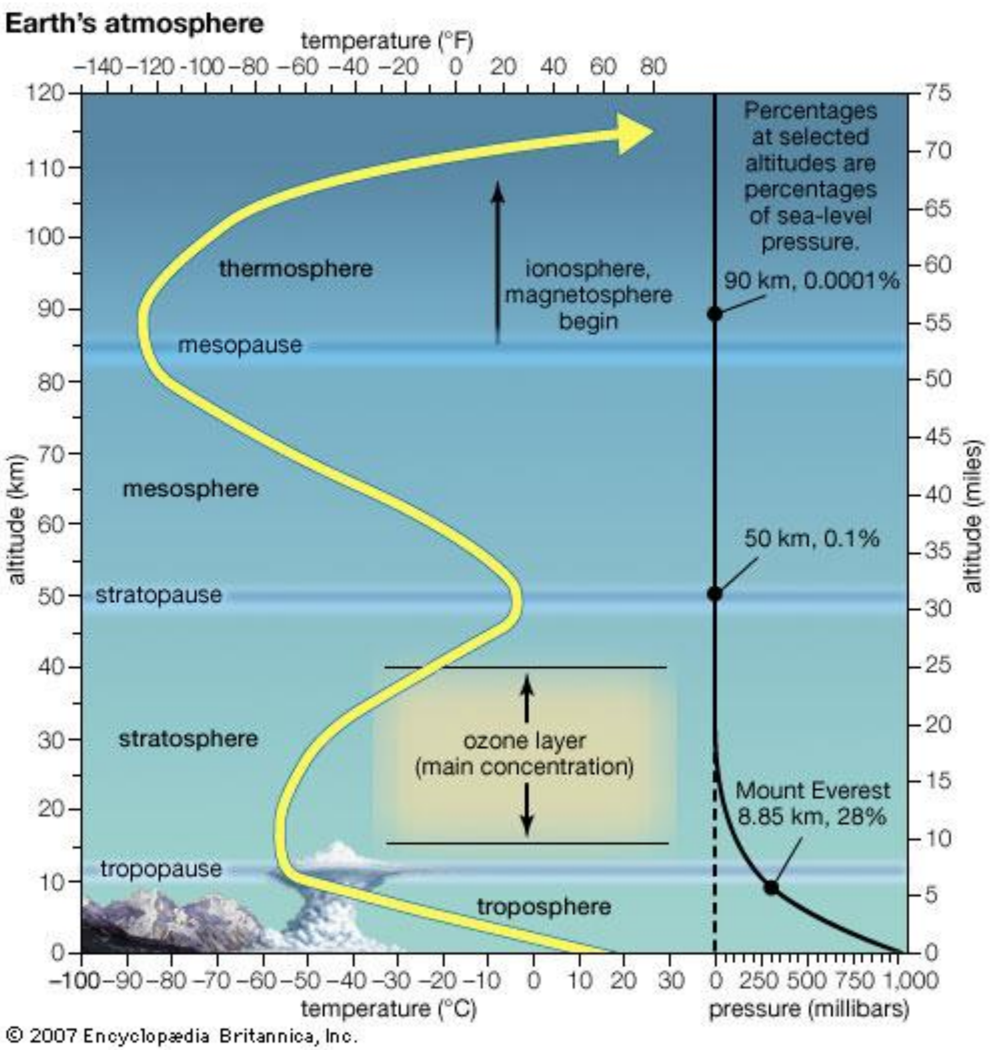


?

Attenuated backscatter measured from ground and space is not the same

→ **Level one comparison is challenging**

→ **Even though one measures at the same frequency**



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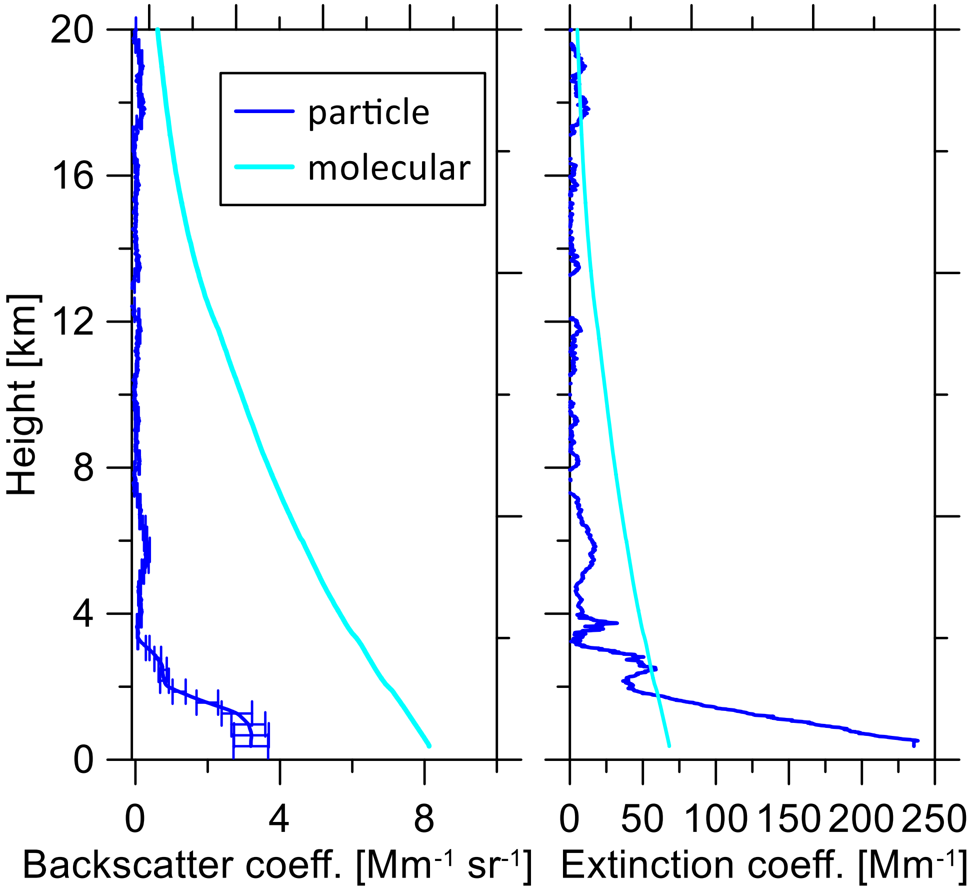
Example at 355 nm

$$AttBSC(R) = \frac{(P^{\lambda}(R) - P_{BG})R^2}{C_{sys}^{\lambda} O^{\lambda}(R)} = [\beta_{par}^{\lambda}(R) + \beta_{mol}^{\lambda}(R)] \exp\left\{-2\int_0^R [\alpha_{par}^{\lambda}(r) + \alpha_{mol}^{\lambda}(r)]\mathrm{d}r\right\}$$

PollyXT_TROPOS; Leipzig, Germany, 27 March 2020. 1830-1930 UTC

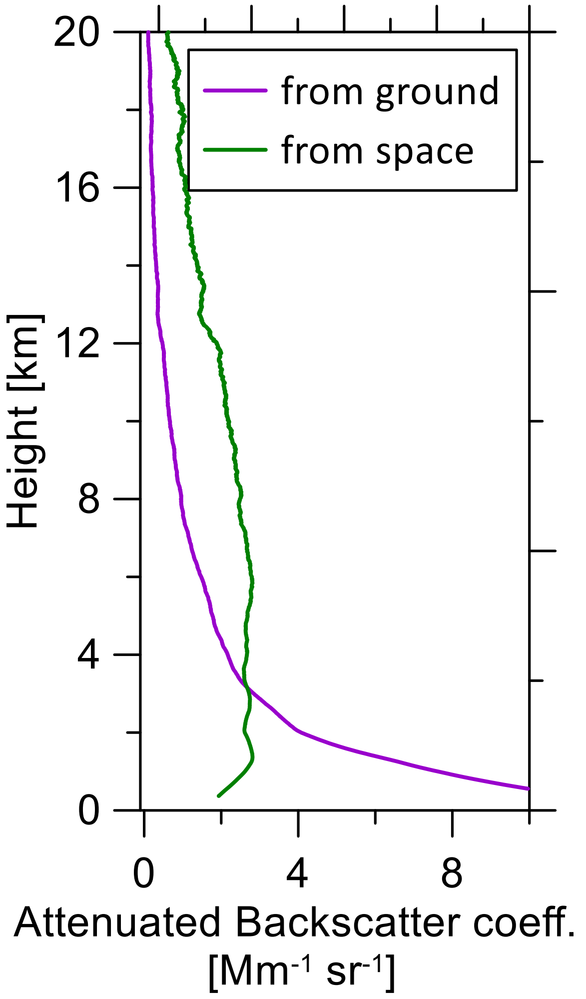


from ground: z1=0 km
from space: z1= 20 km

With measured backscatter and extinction profiles from ground one can calculate the attenuated backscatter from space!

- Ground based:
  Signal maximum ~ ground
- Space borne:
  Signal maximum (Aeolus) at 7 km

For Level 1 validation, you need Level 2 products from ground



But multiple scattering is not addressed with this simple approach

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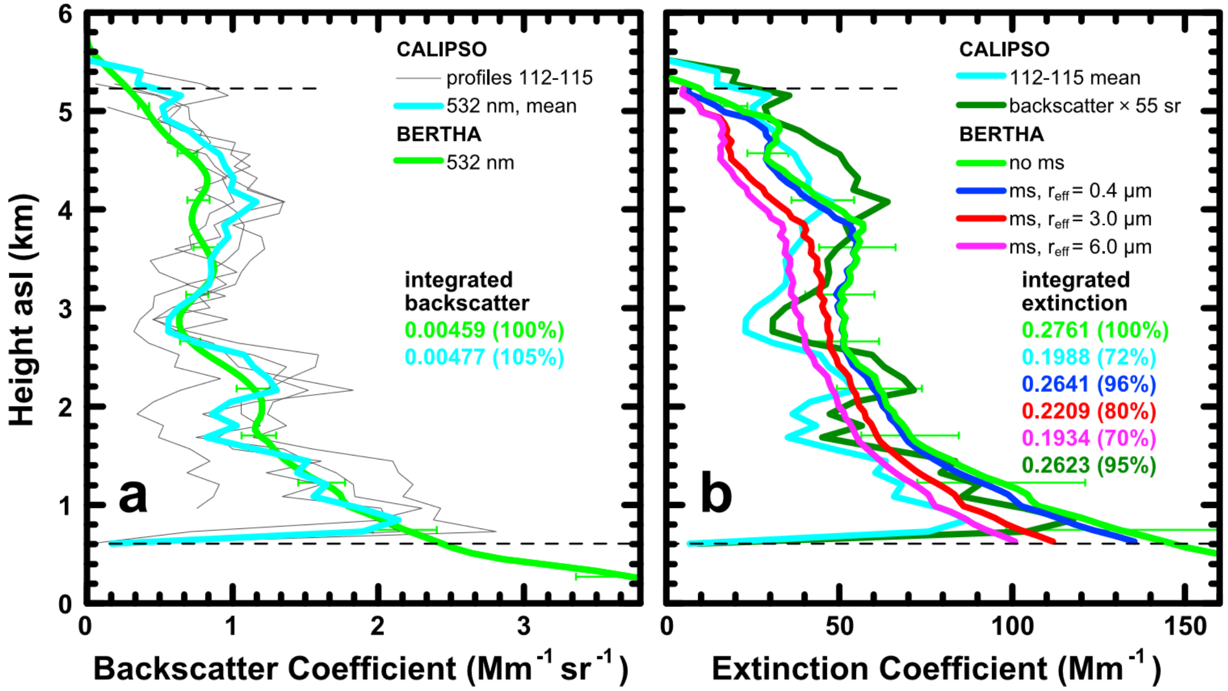
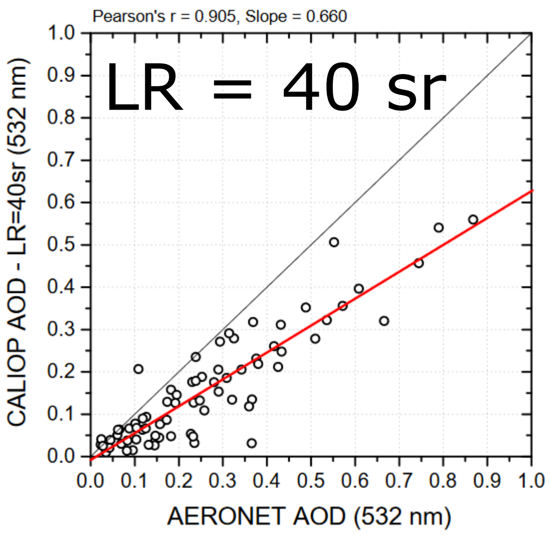
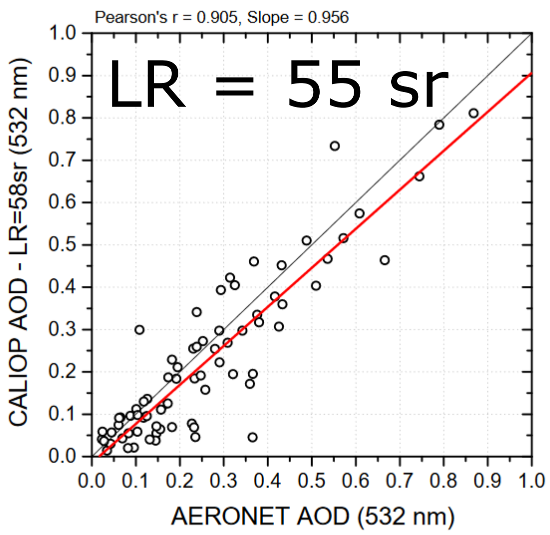
Heritage from previous Cal/Val

Underestimation of extinction and optical depth by 25%–35%.







Amiridis et al., ACP, 2013

Wandinger et al., 2010

Impact of multiple-scattering effect for **CALIPSO**

How to come to a (CEOS) validation protocol for

Aerosol profile
Cloud & precipitation profiles ?

- Community consensus on approaches for
  - Data acquisition strategies
  - Data intercomparison methods/strategies (remember examples given)
  - Combining remote sensing and in-situ measurements.
- But, not mandatory: Different approaches can and should co-exist
- But should be unambiguously distinguished when interpreting results

The way forward

- Expert group currently forming
- Use expertise from existing projects (FRN4radar, DIVA, CARDINAL etc.)
- Identify important open issues (where no common practice is available yet).
- For some topics, contributions may lead to the development of **scientific code** which will be made publicly (like e.g. attenuated backscatter issue).
- Lessons learnt from Aeolus (scene classification, backward trajectories, co-location exercises, Aerosol typing?) → Will be of great interest for EarthCARE
- Contribution from Aeolus community strongly desired

Initial version of the best practice at EarthCARE launch

You are very welcome to contribute in formulation of best practise:

Email to Rob.Koopman@esa.int, Stephanie.Rusli@esa.int, elmarinou@noa.gr, baars@tropos.de

EarthCARE Cal/Val preparation

living planet symposium BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

- Dedicated EarthCARE sessions at Living Planet Symposium May 2022:

living planet symposium | BONN 2022 draft overview programme 16/03/2022

Scientific Programme | Thursday 26

	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7
8:30-10:10	B2.06 EarthCARE ReadyFor Launch	A9.04 Mass Balance of the Cryosphere - Session on Results	C4.02 HAPS – High-Altitude Pseudo Satellites	B8.08 Copernicus Sentinel Expansion Missions - New capabilities for the Copernicus 2.0	A3.06 Biomass monitoring	C1.07 ML4Earth: Machine Learning for Earth	C1.04 AI4EO applications for Land and Water
10:40-12:20	A1.09 EarthCARE: Preparing for the Scientific Mission Exploitation to Quantify the Impact of Clouds and Aerosols on Radiation	A9.04 Mass Balance of the Cryosphere - Session on Results	A7.06 EO for monitoring water quality and ecological status in inland waters	B8.09 Copernicus Sentinel Extension Missions/Next Generation	A3.06 Biomass monitoring	C1.07 ML4Earth: Machine Learning for Earth	C1.04 AI4EO applications for Land and Water
13:30-15:10	A5.05 Monitoring Anthropogenic Greenhouse Gas Emissions from Space	A9.04 Mass Balance of the Cryosphere - Session on Results	A7.06 EO for monitoring water quality and ecological status in inland waters	A3.12 Forest Monitoring	E5.07 Copernicus International Cooperation – Building infrastructure for the world	C2.01 Towards a Digital Twin of the Earth - advances and challenges ahead	C5.03 Open Source Science, toolboxes and Jupyter technologies in EO
15:40-17:20	A1.04 Greenhouse Gases	A9.04 Mass Balance of the Cryosphere - Session on Results	A7.06 EO for monitoring water quality and ecological status in inland waters	A3.12 Forest Monitoring	E5.07 Copernicus International Cooperation – Building infrastructure for the world	C2.01 Towards a Digital Twin of the Earth - advances and challenges ahead	C5.03 Open Source Science, toolboxes and Jupyter technologies in EO

<u>**Poster in A1.09**</u>

Defining validation protocols for space-borne aerosol and cloud profile products