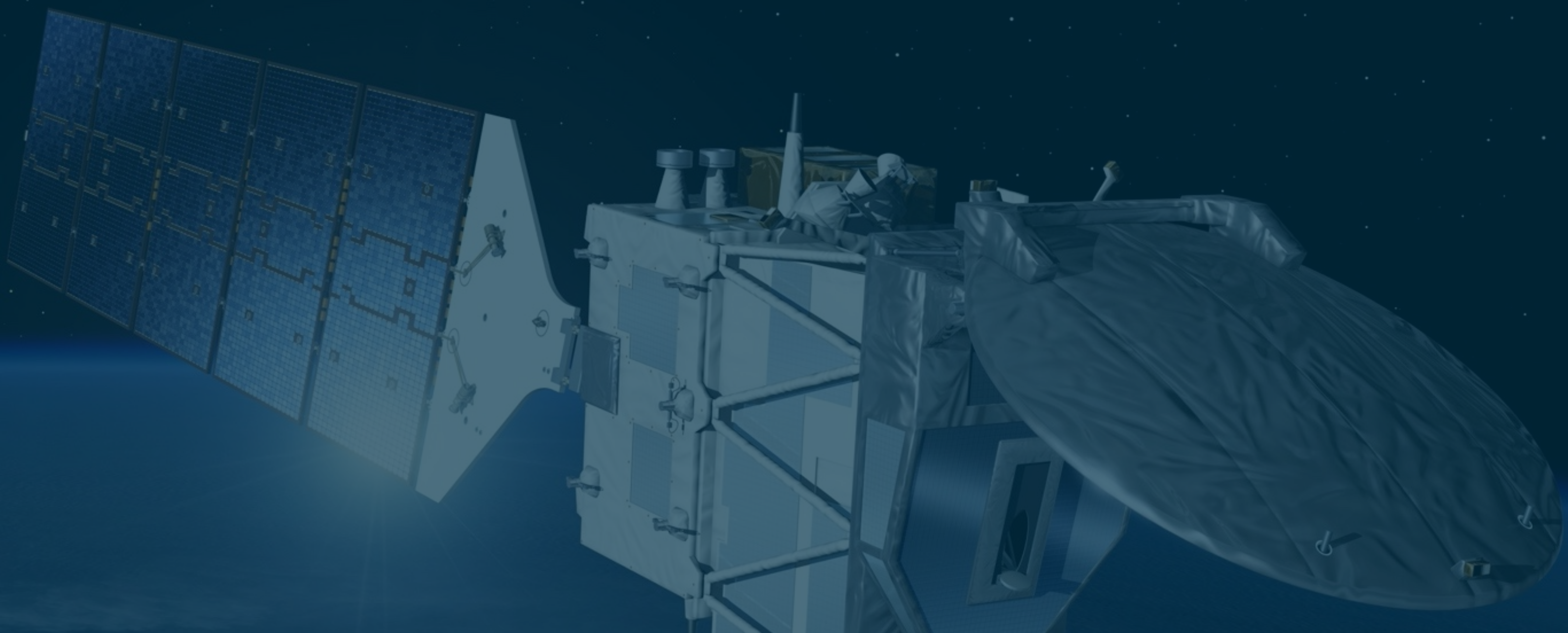


EarthCARE Level 2 Aerosol
26 May 2021

2nd ESA EarthCARE Validation Workshop

25-28 May 2021 (online)

Goal/Topic of this discussion

- What has been learned from previous aerosol validation campaigns?
- Imager validation is straight forward → AERONET → but what goes beyond the simple AERONET comparison?
- Common approaches / Strategies:
    - E.g. statistics of certain regimes /aerosol types compared to EarthCARE statistics vs. direct overpass comparisons
    - In-situ vs. remote sensing
- What are the key regions for certain aerosol types (lidar ratio, depolarization) and will we have Cal/Val sites available in each region (regional networking)?
- Are there gaps in this current Cal-Val group (could be regional but also topical)? → this can be used as input for campaign planning
- Will we have access to unpredictable aerosol types: like stratospheric smoke, volcanic ash, polar stratospheric aerosols?
- Is there model support for Aerosol Cal/Val, e.g. use of aerosols transport models such as CAMS?
- Satellite support for Aerosol Cal/Val, which other satellites could support our Cal-Val?

EarthCARE L2 Aerosol Retrievals

- L2 processor description (presentations are available here)
- L2 processor developers' needs (responses are available here)
- Notation: A- ATLID only, M- MSI only, AM- ATLID+MSI, ACM- ATLID+CPR+MSI

	Vertically integrated and layerwise (M-AOT, A-LAY, AM-COL)			Vertical profiles (A-PRO, ACM-CAP)	
	Quantity	**At nadir**	**Across-track**	**Quantity**	**At nadir**
Macrophysics	**Aerosol layer height/depth**	A-ALD, A-TC	AM-ACD	**Aerosol fraction**	A-TC, ACM-COM
	Aerosol layer classification	A-ALD, A-TC	AM-ACD	**Aerosol species**	A-TC, ACM-COM
Aerosol (per species)	**Aerosol optical thickness**	M-AOT, A-ALD, A-AER, A-EBD, ACM-CAP	M-AOT, AM-ACD	**Aerosol extinction**	A-AER, A-EBD, ACM-COM, ACM-CAP
	Layer-mean extinction-to-backscatter ratio	A-ALD		**Extinction-to-backscatter ratio**	A-AER, A-EBD, ACM-CAP*
	Layer-mean particle linear depolarisation ratio	A-ALD		**Particle linear depolarisation ratio**	A-AER, A-EBD
	Ångström exponent	M-AOT (670/865nm), AM-ACD (355/670nm)	M-AOT (670/865nm), AM-ACD (355/670nm)		

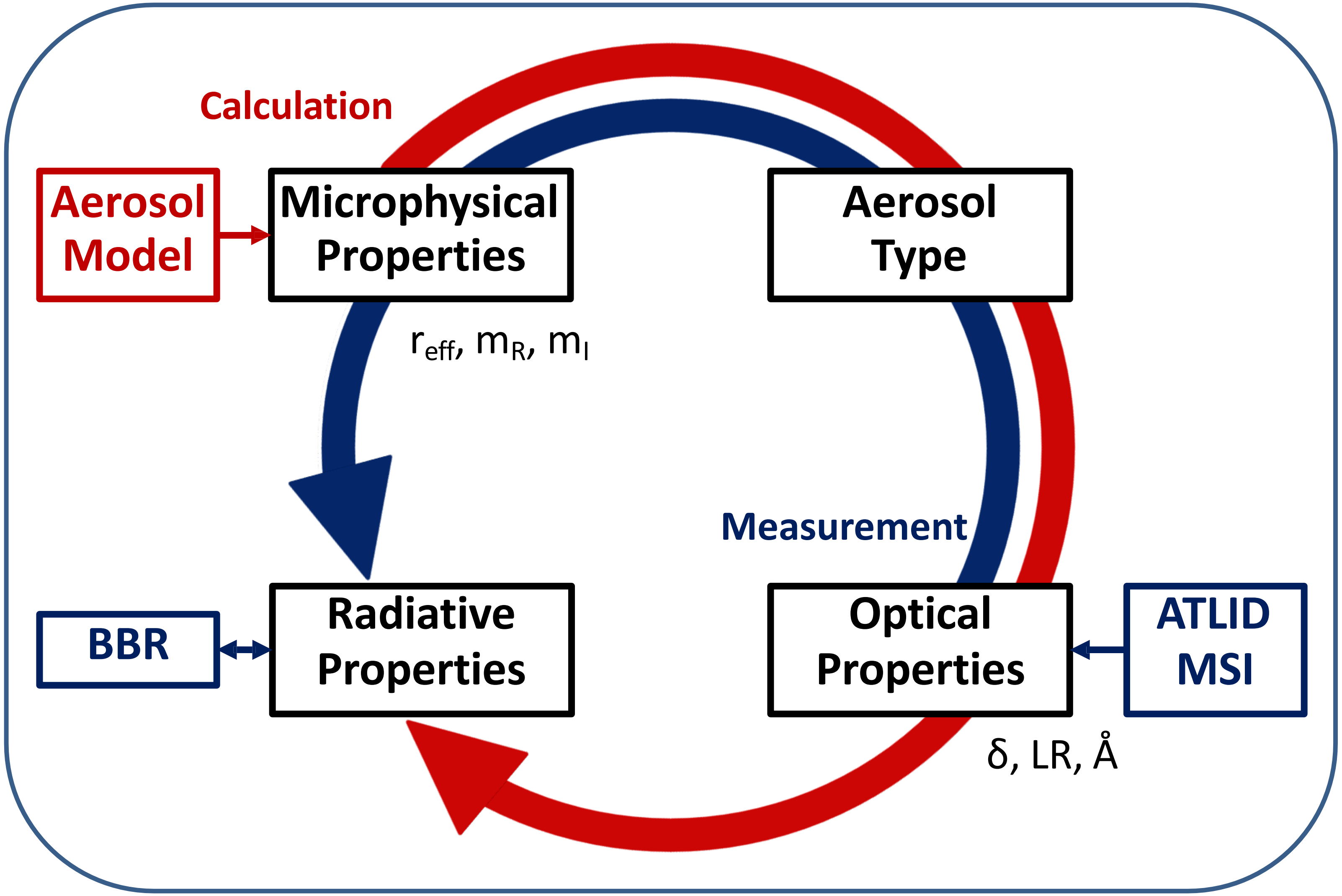
	Uncertainty	Locations/scenes/regimes	Measurements needed	Products
Macrophysics	Aerosol layer detection	• Multiple aerosol layers • Aerosol layers with strong internal structure • Attributing aerosol plumes at nadir to features in the across-track imagery	• Ground-based (& scanning?) and airborne lidars	A-ALD, AM-ACD, A-TC
	Aerosol/cloud discrimination	• Cloud embedded in aerosol layers	• Ground-based lidars	A-ALD, AM-ACD, A-TC
Aerosol	Large AOT uncertainties over land; sensitivity to aerosol classification	• Range of different land classes (biomes) & ocean • Range of different aerosol classes	• Ground-based, e.g. AERONET(-OC) • Ship-based sun photometers, e.g. MAN • Satellite imagers, e.g. MODIS, VIIRS, 3MI	M-AOT

Hybrid End-to-End Aerosol Classification (HETEAC)

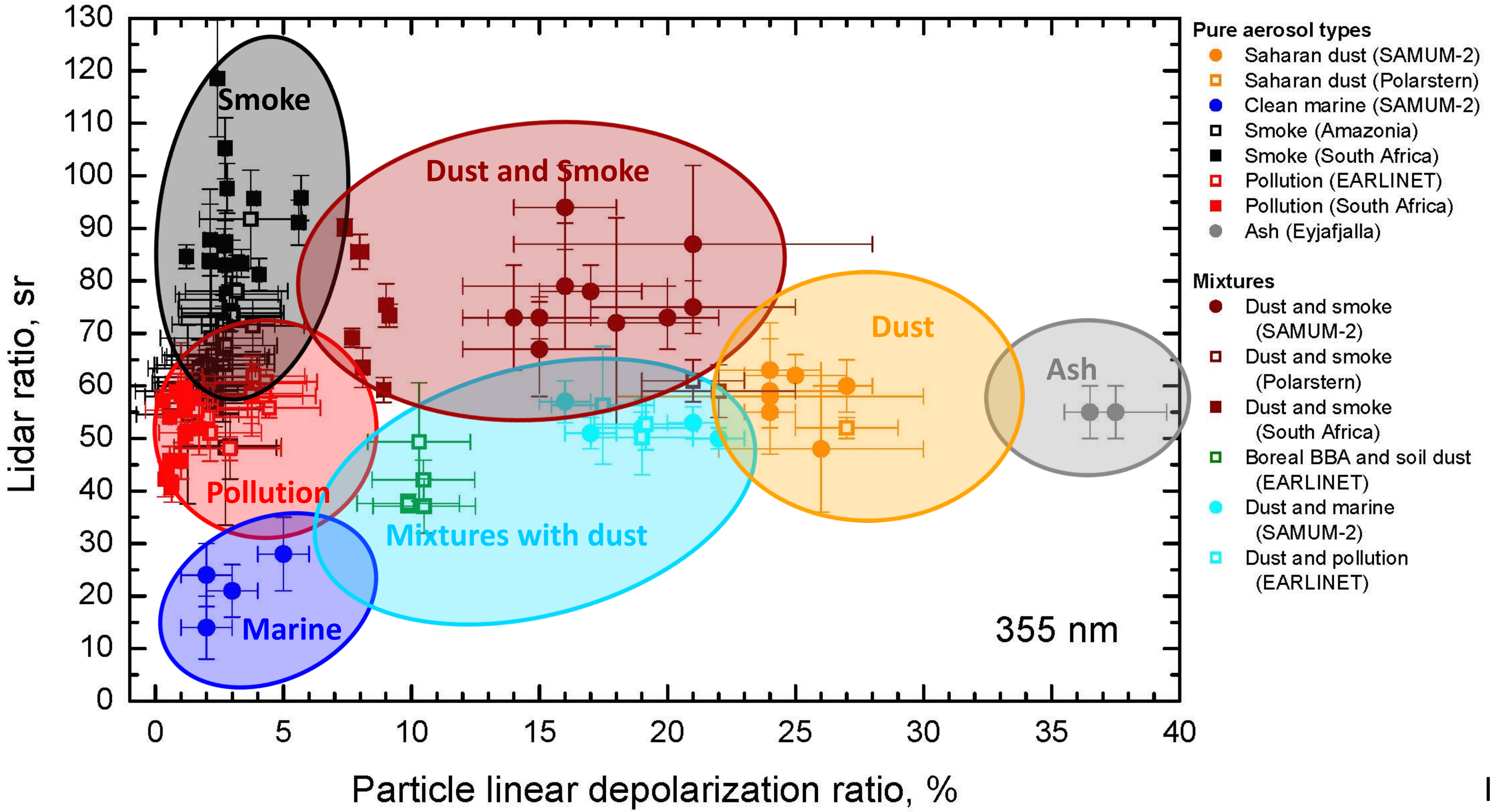
Aerosol model assumptions within the retrieval algorithms

Hybrid End-to-End Aerosol Classification

- **Aerosol classification** model developed for EarthCARE and implemented in ECSIM
- To connect **microphysical**, **optical** and **radiative** properties of pre-defined aerosol components
- 4 basic aerosol components with **prescribed microphysical properties** to calculate mixtures
- **Radiation closure for aerosol** from ATLID & MSI with BBR



Experimental Basis for Aerosol Classification

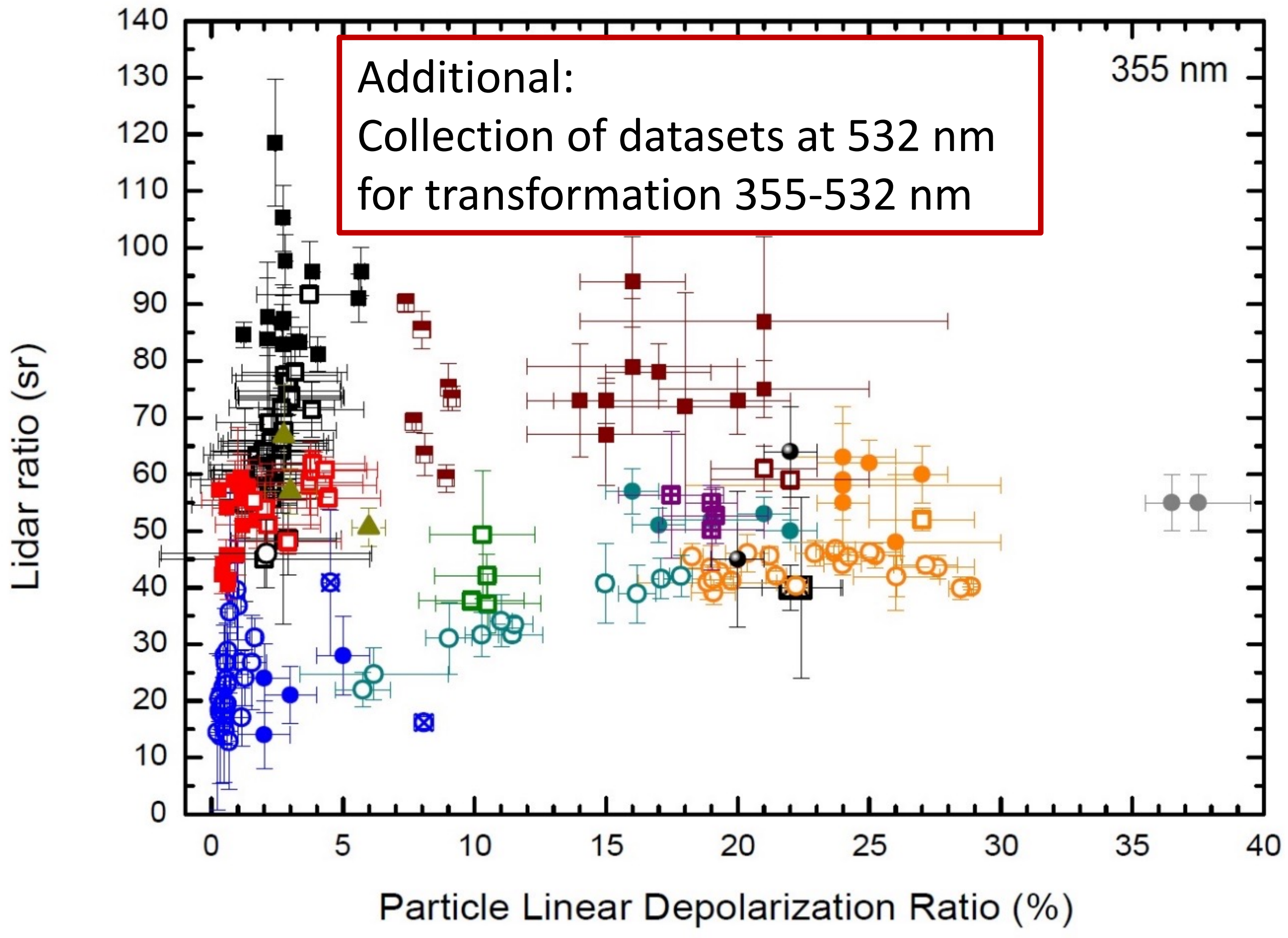


Illingworth et al., BAMS 2015

Recent updates

New datasets

Additional:
Collection of datasets at 532 nm
for transformation 355-532 nm

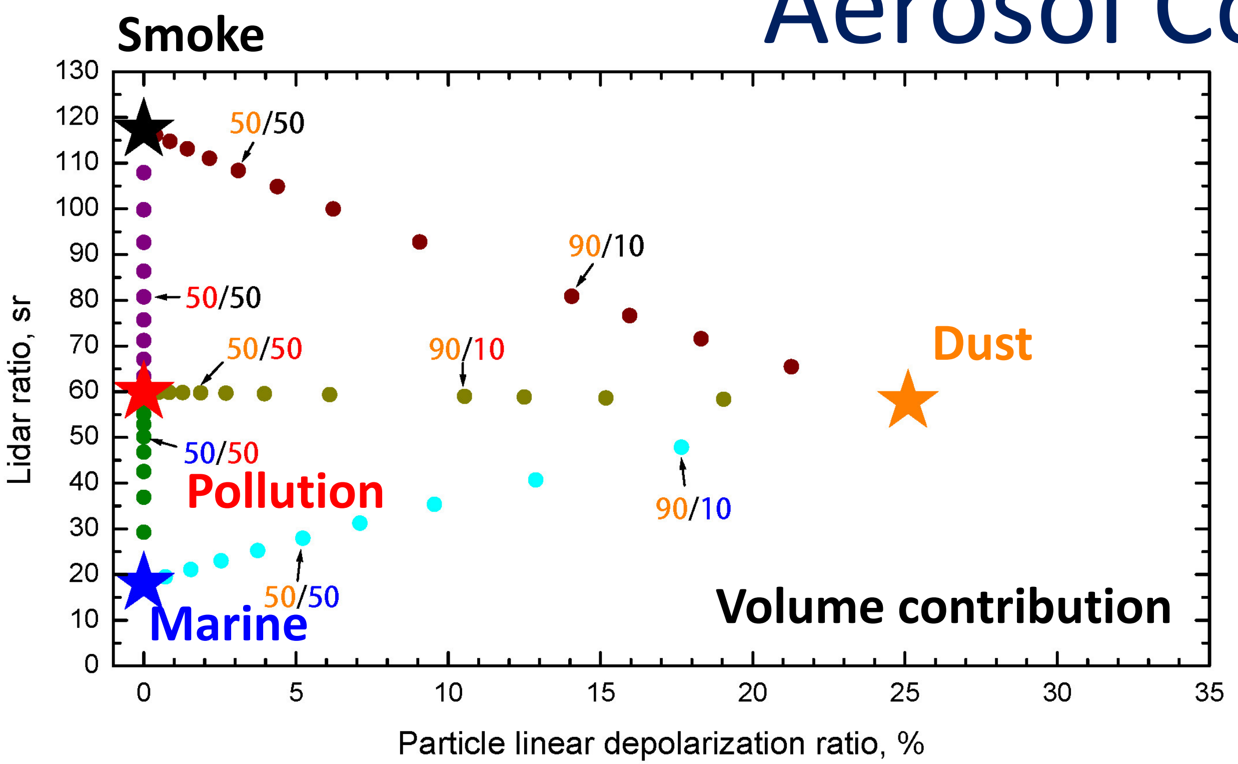


Continuously updated
(Athena Floutsi)

Pure aerosol types
- Smoke (Amazonia)
- Smoke (South Africa)
- Smoke (Central Europe)
- Smoke (Stratospheric)
- Aged smoke (Canadian and Siberian)
- Saharan dust (SAMUM-2)
- Saharan dust (Polarstern)
- Central Asian dust (CADEX)
- Clean marine (SAMUM-2)
- Clean marine (Polarstern)
- Dried marine (Polarstern)
- Pollution (South Africa)
- Pollution (EARLINET)
- Ash (Eyjafjalla)

Mixtures
- Central European background aerosol (Leipzig)
- Dust and smoke (SAMUM-2)
- Dust and smoke (Polarstern)
- Dust and smoke (South Africa)
- Saharan dust and African BBA
- Boreal BBA and soil dust (EARLINET)
- Dust and marine (SAMUM-2)
- MBL mixture (Polarstern)
- Dust and pollution (EARLINET)

Aerosol Components



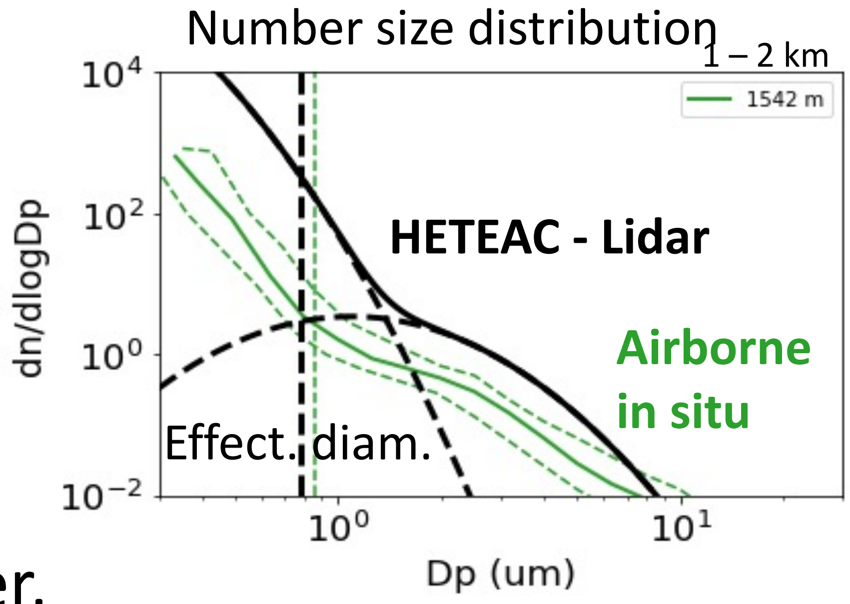
- 4 (pure) **aerosol components** to calculate mixing states
- Define **microphysical properties** for each component
- Calculate effective radius & refractive index of the **mixture**
  → Input for radiation calculation

	Dust Coarse mode	Sea salt Coarse mode	Pollution Fine mode	Smoke Fine mode
r_{eff}, µm	1.94	1.94	0.14	0.14
m_R (355 nm)	1.54	1.37	1.45	1.50
m_I (355 nm)	0.006	4.e-8	1.e-3	0.043
Shape	Spheroid	Spherical	Spherical	Spherical

Effective radius

Refractive index

Validation Needs for HETEAC



Good example: A-LIFE, Cyprus 2017

Validation by aircraft + lidar campaigns

Ideal:

Airborne aerosol in situ (small aircraft / UAV) within the aerosol layer (e.g., effective diameter, refractive index) combined with:

- Ground-based / airborne HSR lidar (2^{nd} aircraft) providing lidar ratio & depolarization ratio
- Bonus: Radiation measurements

Strong aerosol features (dust, pollution, smoke, marine) and mixtures

Validation approaches and strategies proposed

Ideas with respect to the Co-Location (*Matching of observations in place and time*):

- An analysis of representativeness of measurements will be done after the measurements have been taken, using model and satellite datasets
- Coincident and validated geostationary observations will be used as a comparison for the imager products
- Direct underpasses beneath the EarthCARE track will be performed during the airborne campaigns
- Coordinate with models (e.g. DREAM) for special runs during field campaigns
- The ground-based sites will follow the validation strategies developed by EARLINET and Cloudnet for previous missions (CALIPSO, Aeolus).
- Synergy is sought with EUMETNET E-Profile network of nearby (~10 km) profiling stations (AO proposal submission planned)
- CERES PSF size is bigger than BBR swath (maximum 18 km nadir) : Need to use MSI to improve matching
- Of more concern will be the biases introduced by conditional sampling arising from the difference in viewing geometry…
- Estimation of the effective impact of urban environment
- Focus on specific aerosol and cloud types

Validation approaches and strategies proposed

Ideas with respect to the use of statistical approaches:

- Long-term data sets from ground (networks like LALINET or single station like Lampedusa)
  - MPL-NET: Monthly, Annual, and Decadal diurnal averages of all product variables: →customized L3 products for EarthCARE validation, but altered for ideal sampling and targeted validation
  - Collocated measurements from the 3 experiments at different sites, analyze statistically and in relation to day/night differences and different aerosol types and cloud systems.
  - EarthCARE mean aerosol profiles against LIVAS-CALIPSO and Aeolus climatological profiles
  - Special attention to certain conditions, e.g. wave-clouds.
  - Deriving conclusions from ensembles of collocations
- Statistical anaylsis conducted from the aerosols measurements obtained during the long-duration balloon flights Strateole in the equatorial region around the tropopause
- Multiple scattering difference: modify the Monte Carlo simulation of CALIPSO so that it can provide accurate simulations for ATLID. Simulating depolarization ratio measurements of ATLID 355 nm water cloud backscatter and computing water cloud lidar ratios for various effective droplet sizes and variances. The analysis will be statistical and global scale in nature.
- Check of L2 products internally, i.e. with respect to viewing angle (MSI-AOD should statistically not have a swath dependence → MSI-☺)

Validation approaches and strategies proposed

Ideas with respect to the Wavelength dilemma:

- Using same wavelength:
  - ACTRIS/ LALINET : Operate lidars at multiple wavelengths, including 355 nm and depolarisation → who will measures 355 nm depolarisation?
  - The Hyytiälä station will be equipped with Vaisala CL61 ceilometer (includes depolarization @ 910.55 nm)
  - Specific non-network lidars at EarthCARE wavelength: UK, EVE polarization (linear and circular) lidar…
- Ideas for converting to EarthCARE wavelength
  - Aerosols profiles at 532 nm, when AERONET AOD are measured, can be extrapolated to 355 nm, using the AERONET co-located Angström exponent.
  - Expected wavelength dependence λ1 – λ0, will be tested with model simulations
- Extinctions are calculated from concentrations and size of the particles, considering typology & mean refractive index. Conducted (in the visible domain) at the wavelength of EarthCARE measurements→ type validation
- Multiple scattering difference: Modify Monte Carlo simulation algorithms developed for CALIPSO to provide accurate simulations for ATLID. This includes simulating depolarization ratio of ATLID 355 nm water cloud backscatter and computing water cloud lidar ratios for various effective droplet sizes and variances.

Validation approaches and strategies proposed

Ideas with respect to synergistic products:

- Synergistic products at ACTRIS are already similar. Will be enhanced through combination of cloud and aerosol profiling at combined ACTRIS stations.
- Running our own retrievals combining more instruments than available on EarthCARE or using different wavelengths.
- GARRLIC/Grasp is intended to be used often
  - the inversion provides vertical distribution of aerosol concentration, fine and coarse mode refractive index (assumed constant vertically) and the fine and coarse mode size distributions. These inverted parameters are then used to compute aerosol extinction, backscatter and depolarisation profiles at any wavelength.
  - Development of GRASP retrieval for applying the same scheme in EarthCARE and in ground measurements

Validation approaches and strategies proposed

Ideas with respect to novel approaches:

- Fu-Liou-Gu model used to solve cirrus cloud radiative properties of single-layered cirrus clouds → Results from EarthCARE will be compared to similar TOA cloud-radiative effect (CRE) from MPLNET and historical CALIPSO dataset
- Use of Ocean surface return for AOD. Changes between ATLID and CALIPSO are straightforward (off-nadir angle, Fresnel reflectance coefficient of the ocean surface between 355 and 532 nm). Correction based on the polarization channel. Subsurface scattering should increase in the UV but this is not fully understood yet.
- We want to explore the possibility to use dual-field of view configuration on the EVE lidar system to estimate the multiple scattering factor from ground measurements.
- Involvement of other aerial platforms that incorporate simple instrumentation.
- Involvement of solar airplanes with lidar and radiometers (research task) – see https://skydweller.aero
- Influence of multiple scatter will be evaluated with model simulations; will then be included in lidar equation as a factor
- Automated precipitation detection has been incorporated into MPLNET processing (developmental-level) → Will be used to identify potential case studies for drizzle from CPR products

Selected parameters in need of validation

- Aerosol-cloud discrimination
- Layering (layer boundary detection)
- Extinction/AOD
- Lidar ratio
- Aerosol Depolarization
- Ångström parameter
- Aerosol Typing

Aerosol – Cloud discrimination

Needs: Aerosol – cloud – clear sky discrimination

Vertical (ATLID & ATLID+MSI)

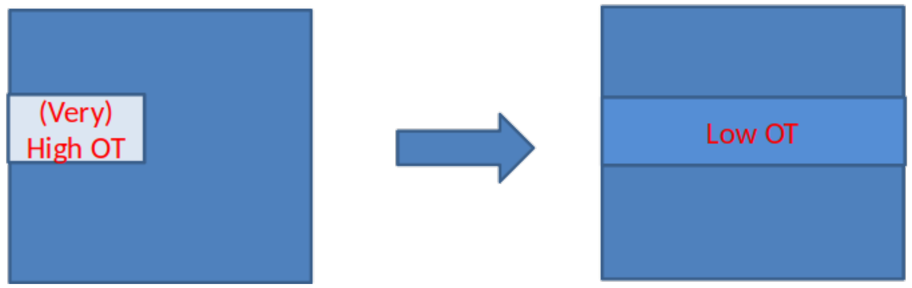
- Vertical feature detection (boundary detection), any lidar wavelength will do.
- Lidar + radar combination for detecting cloud boundaries (in case of aerosol above clouds), i.e. CloudNET, ACTRIS like.
- Close to the track (<10 km)

Horizontal context (MSI):
Validation of M-CM cloud mask flag “confident clear”

- Cloud edge detection vs aerosol (e.g. high spatial resolution imager cloud mask like Sentinel 2 (20m))
- Thick aerosol load vs thin cloud detection (e.g. higher spectral resolved imager cloud masks like VIIRS, MODIS and FCI (as MSI has limited channels for cloud detection)
- MSI’s viewing zenith angle dependency should be taken into account in validation (smile).

Note on averaging

- Mixing of strong (e.g. cloud) and weak (e.g. aerosol) returns is NOT desirable.
- Cloud returns get blurred out !
- Extinction profiles can become meaningless.



Layering

Needs: Layer boundary detection

Vertical (ATLID & ATLID+MSI)

- Vertical layering (boundary detection), any lidar wavelength will do.
  -Separation of layers by Lidar-ratio & Depolarization would be a bonus.
- Close to the track (<10 km)
- Planetary boundary layer height

Horizontal context (ATLID+MSI & MSI):
- Combination of 3D scanning lidar together with vertical layer products might enable a 3D description of any aerosol layers.
- flight patterns during airborne campaigns

- Will there be observations planned by teams to detect unpredictable aerosol types:
  stratospheric smoke, volcanic ash, polar stratospheric aerosols (& PSC)

Aerosol Extinction/Backscatter & AOD

Needs
- Extinction and Backscatter profiles at 355nm (ATLID) (or 532 with Ångström exponent)
- Ground-based or airborne lidar with Raman / HSRL capability
- Best in combination with sun photometer
- Distance to track < 100 km

- AOT at
  - 355 nm (ATLID-MSI synergy)
  - 670 nm (MSI, ATLID-MSI synergy)
  - 865 nm (MSI, ATLID-MSI synergy)

- Evaluation of Extinction/AOD error estimates provided by L2 processors

MSI Specific:
- Separation of AOTs over ocean and land (MSI)
- If possible, separation of AOT validation over land for different surface type (MSI)
- MSI’s viewing zenith angle dependency should be taken into account in validation (smile)
- Ground-based measurements (e.g. AERONET) as well as collocated satellite based imager AOTs (e.g. MODIS, VIIRS, 3MI) are essential in validation due to the narrow swath of MSI

Aerosol Lidar Ratio

Needs
- Profile at 355m (ATLID)
- Ground-based or airborne lidar with Raman / HSRL capability
- Different aerosol types (dust, marine, smoke, pollution, …)
- Distance to track < 100 km

- Will there be observations planned by teams to detect unpredictable aerosol types:
  stratospheric smoke, volcanic ash, polar stratospheric aerosols

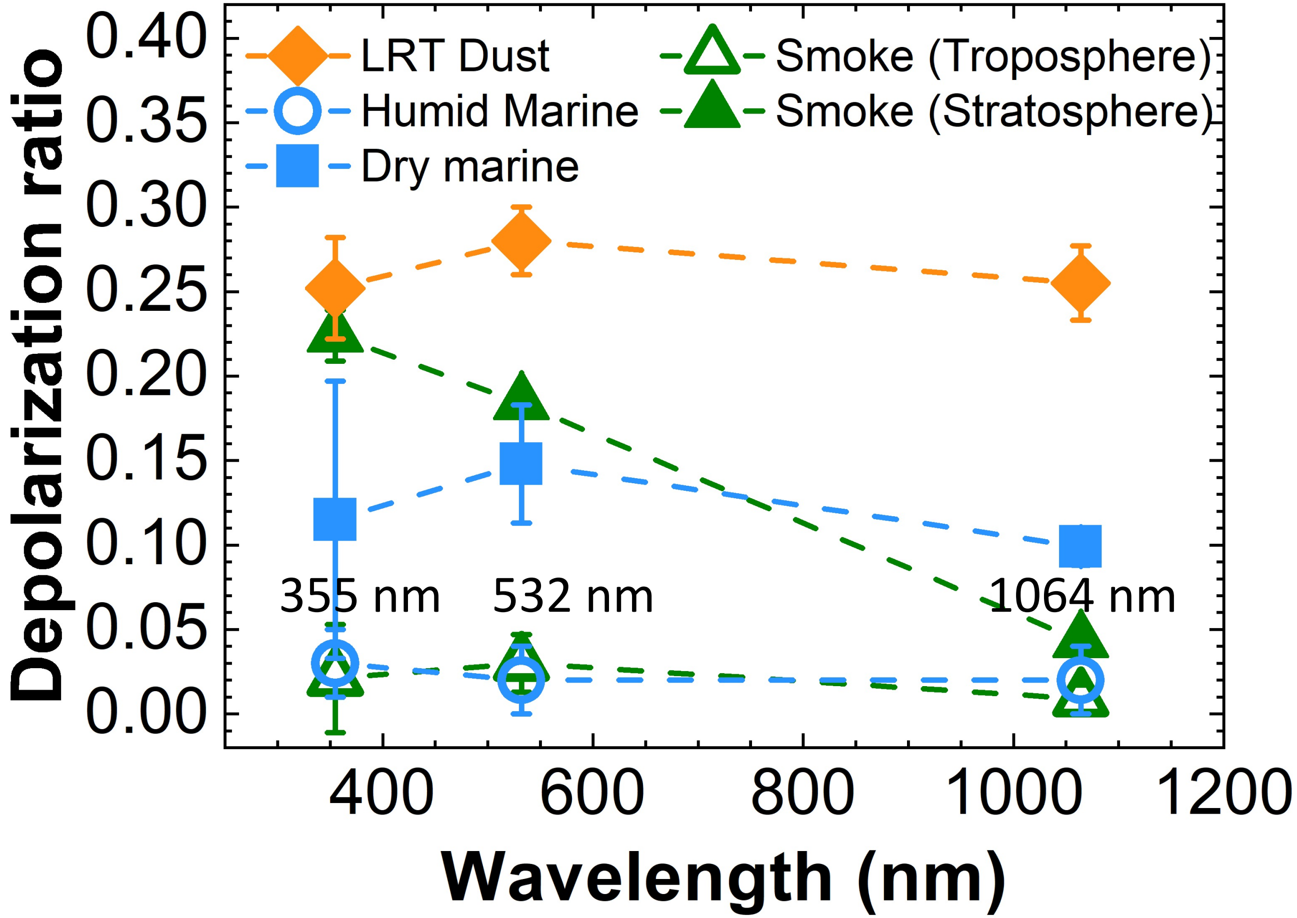
Depolarization

Needs

- Well calibrated lidar Depolarization profiles at 355nm (ATLID)
  - Depol. in free air
  - Depol. in Aerosol layers
  - Depol. in Cirrus clouds
  - Depol. of ocean surface return (AOD from surface backscatter)
- Different aerosol types (dust, marine, smoke, pollution, …)
- Distance to track < 100 km

- Will there be observations planned by teams to detect unpredictable aerosol types:
  stratospheric smoke, volcanic ash, polar stratospheric aerosols ?

We need depolarization at 355 nm



- Spectral slope 355 – 532 nm depends on aerosol type
- Good aerosol typing and data base is necessary to transfer the depolarization ratio from 532 to 355 nm → additional uncertainties
- Dp355 is sensitive input in aerosol classification

Recommendation:
If possible, **upgrade your lidar** with **355 nm depolarization channel!**

Ideal: Depolarization ratio at 355 and 532 nm!

Haarig et al., ACP, 2017a,b, 2018, see also Burton et al., 2015, Hu et al., 2019, Hofer et al., 2020

Ångström parameter

- Should be considered as diagnostic quantity. Estimated from retrieved AOTs
- Ångström parameter (355 nm, 670 nm ATLID+MSI) and (670 nm, 865 nm MSI over ocean only)
- Ground and ship-based measurements (e.g. AERONET-OC, MAN) as well as collocated satellite-based imager Ångström parameters (e.g. MODIS, VIIRS, 3MI) are essential in validation due to the narrow swath of MSI

Aerosol Typing

Needs
- Aerosol typing following the HETEAC description
- Mixtures of specific aerosol main-types (when retrieved)

- Typing can originate from
  - Combination of lidar ratio and depolarization ratio at 355 or 532 nm
  - HSRL lidar measurements from a multi-wavelength system +depol. channel(s))
  - Airborne in situ / UAV in the aerosol layer (e.g., effective diameter, refractive index) (combined with lidar profiles for layer information if available)
- Different aerosol types (dust, marine, smoke, pollution) and mixtures
- Distance to track < 100 km

BACKUP Slides

Common practices applied to QC and calibration

- Many networks (ACTRIS, MPL-NET, AERONET, BSRN) have their **own, well established QC** and calibration approaches
- Some non-network stations follow ACTRIS QC's
- Only a few have not thought of any QA/QC yet, e.g.:
  - "Currently there is no convergence yet on common QA or (inter)calibration procedures for our instrument type"
  - This is something that we would work on with specific funding. Such actions are on hold at the moment
- Non-network instruments may follow different approaches, e.g.:
  - HALO Airborne instrumentation undergoes specific QC agreed for HALO campaigns
  - Occasional comparison of PSC measurements with neighbouring lidar (Esrange, 30km ENE)
  - Comparison with in-situ balloon measurements of cirrus

Aerosol Profile Retrievals

A-PRO

A-LAY

ACM-CAP

Processor	A-PRO (ATLID Profile processor)
Input Products	1. FeatureMask 2. ATLID L1 3. Auxiliary Met data
Output Products (reported on Joint standard Grid grid)	1. Aerosol and cloud optical properties. 2. Target Classification 3. Aerosol type

EARTHCARE

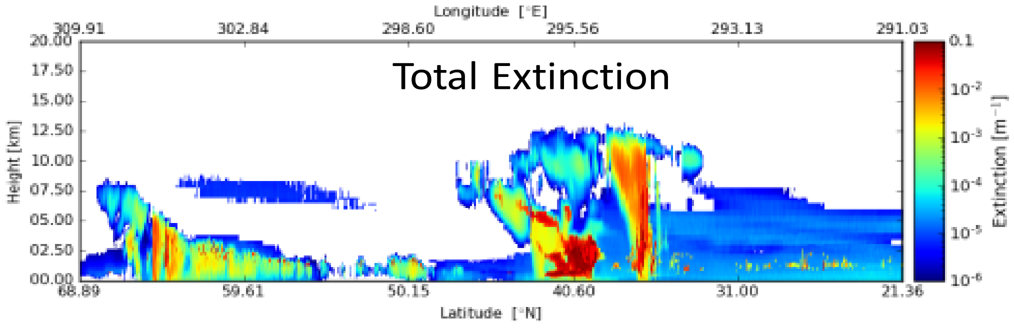
Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

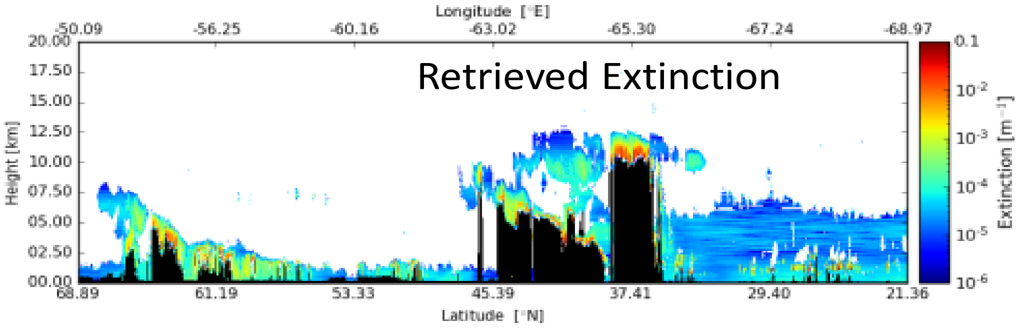
Brief Description

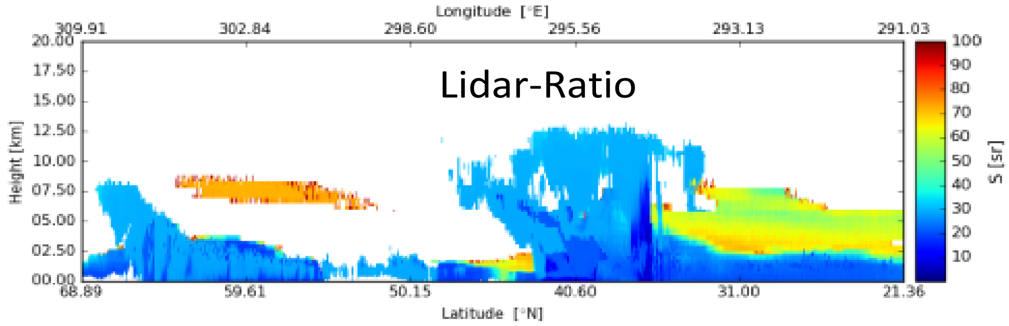
- **Two Step approach to deriving optical properties**:
  1. "Conventional" HSRL techniques applied to smoothed fields.
  2. High resolution "Optimal Klett-like" retrievals aimed at clouds.

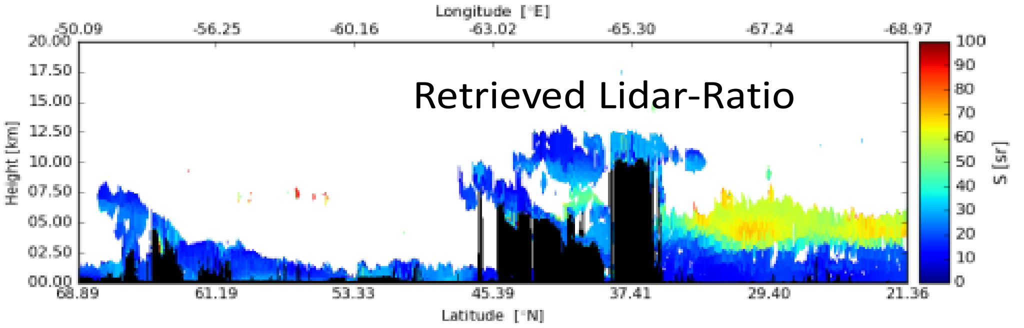
- Cloud/aerosol discrimination and aerosol typing based on using Backscatter thresholds as well as S and linear depolarization ratio.

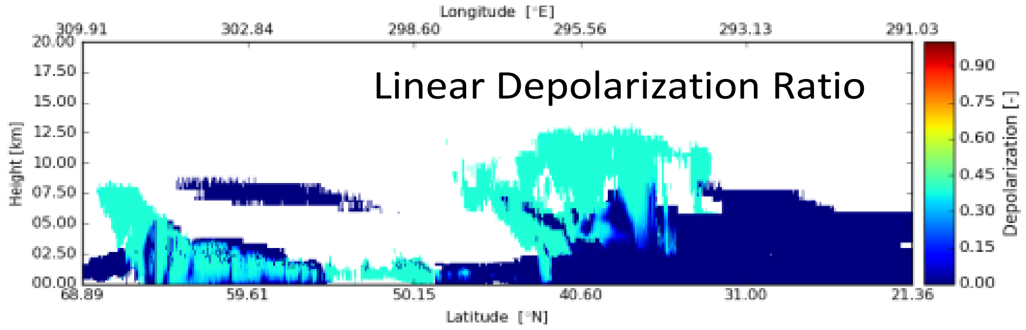
- Cloud phase determination via layer integrated backscatter-vs-integrated depolarization ratio.
- Aerosol type based on depol.-vs-lidar-ratio using the Hybrid End-to-End Aerosol Classification (HETEAC)

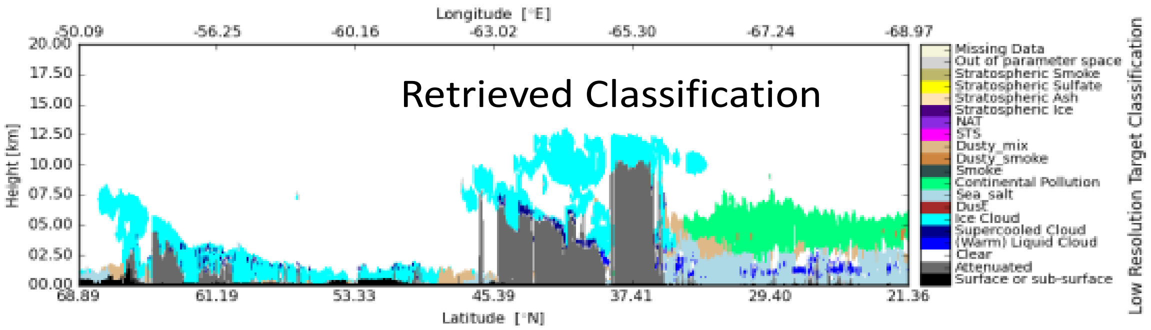

Total Extinction
Longitude [°E]
Latitude [°N]
Height [km]
Extinction [m⁻¹]


Retrieved Extinction
Longitude [°E]
Latitude [°N]
Height [km]
Extinction [m⁻¹]


Lidar-Ratio
Longitude [°E]
Latitude [°N]
Height [km]
S [sr]


Retrieved Lidar-Ratio
Longitude [°E]
Latitude [°N]
Height [km]
S [sr]


Linear Depolarization Ratio
Longitude [°E]
Latitude [°N]
Height [km]
Depolarization [-]

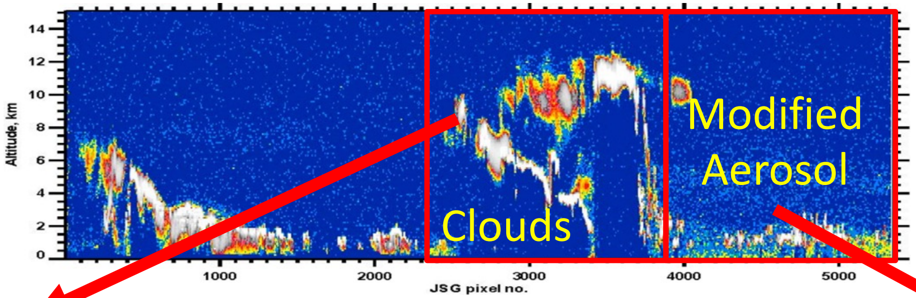

Retrieved Classification
Longitude [°E]
Latitude [°N]
Height [km]
Missing Data
Out of parameter space
Stratospheric Smoke
Stratospheric Sulfate
Stratospheric Ash
Stratospheric Ice
NAT
STS
Dusty_mix
Dusty_smoke
Smoke
Continental Pollution
Sea_salt
Dust
Ice Cloud
Supercooled Cloud
(Warm) Liquid Cloud
Clear
Attenuated
Surface or sub-surface
Low Resolution Target Classification

Processor	A-LAY (ATLID Layer processor)
Input Products	1. A-NOM 2. A-EBD, A-TC 3. X-MET, X-JSG
Output Products (reported on JSG grid)	1. Cloud top height and classification (A-CTH) 2. Aerosol layer descriptor (A-ALD) • **Aerosol layer boundaries** • **Aerosol layer mean optical properties** • Column, tropospheric and stratospheric AOT • Column aerosol classification probabilities

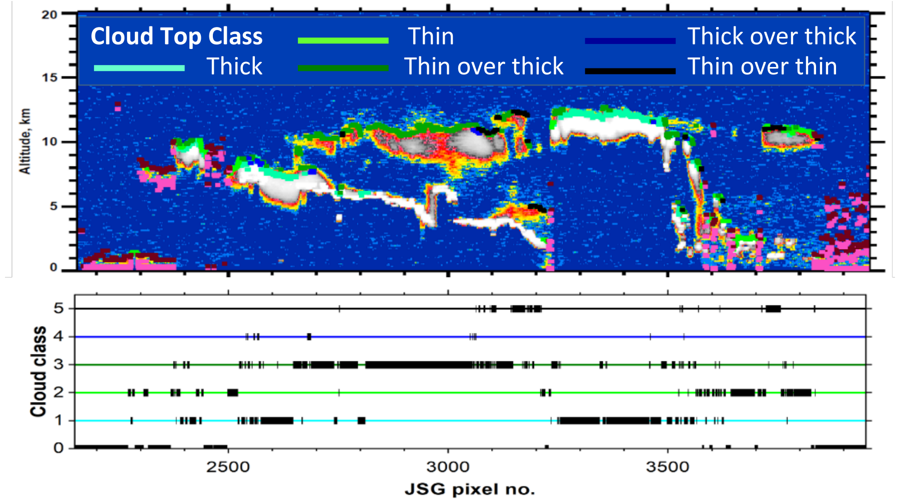
Brief Description

- **Wavelet Covariance Transform technique** combined with a threshold approach is **applied to the Mie co-polar signal** for cloud/aerosol discrimination and retrieval of
    1. **Cloud top height** and cloud top classification/layering information
    2. **Aerosol layer boundaries**
- Input from A-PRO is used to calculate layer-mean aerosol optical properties (extinction, backscatter, lidar ratio, depolarization ratio) and column/tropospheric/stratospheric aerosol optical thickness.
- The products are specifically designed to generate input for the synergistic ATLID-MSI Column processor.

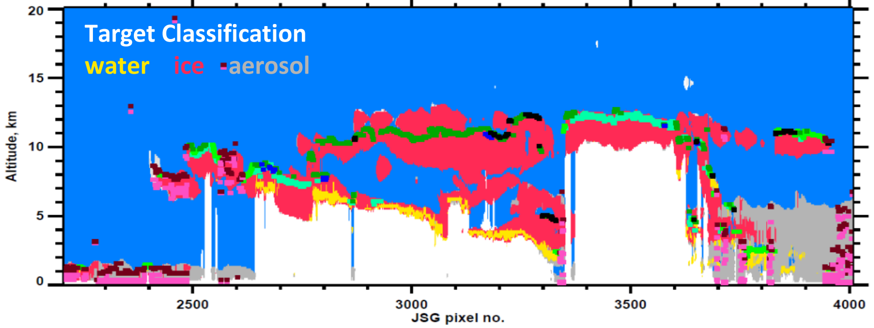
Simulated Particulate (Mie) Attenuated Backscatter



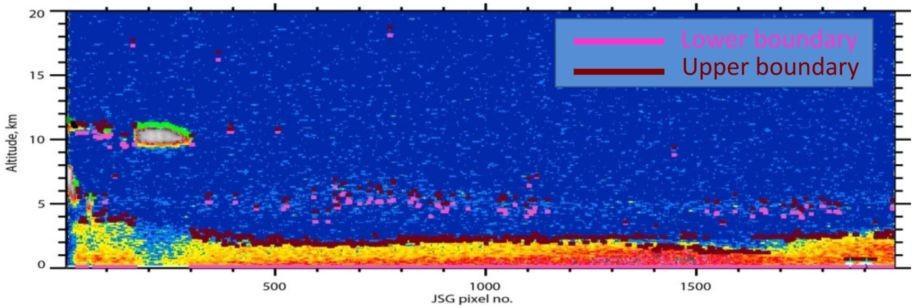
Retrieved Cloud Top Height and Class



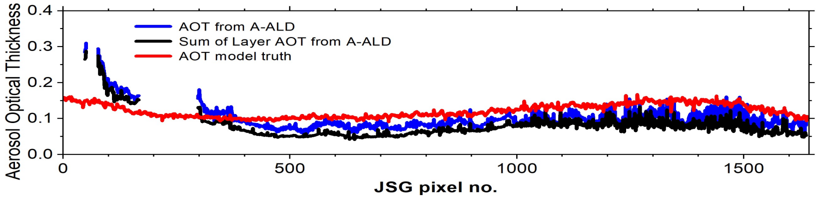
Comparison to A-TC



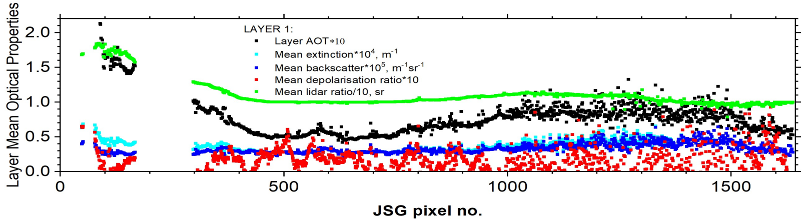
Retrieved Aerosol Layer Boundaries



Retrieved Aerosol Optical Thickness (355 nm)



Retrieved Layer-Mean Optical Properties (Layer 1)

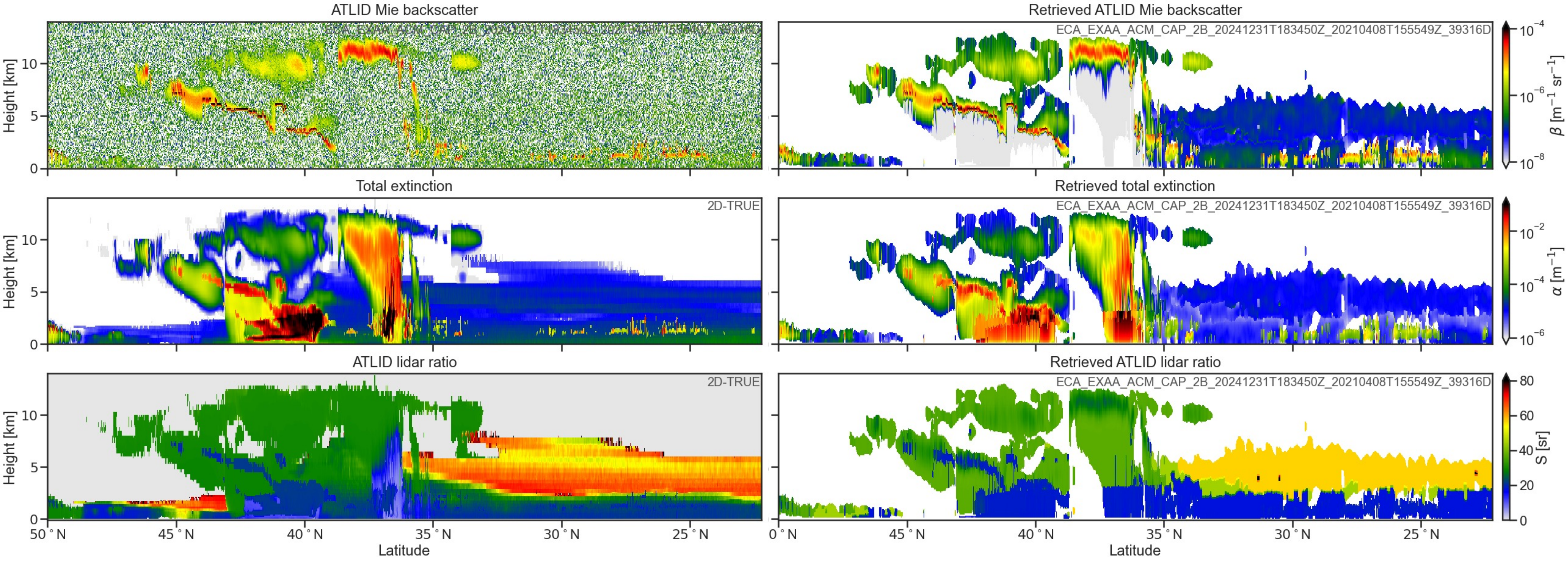


Processor	ACM-CAP Synergistic cloud, aerosol and precipitation retrieval from ATLID, CPR and MSI onboard EarthCARE
Input Products	A-EBD AC-TC C-FMR C-CD M-RGR X-MET
Output Products (reported on Joint standard Grid grid)	The algorithm retrieves the properties of clouds, aerosols and precipitation from the combination of nadir-pointing cloud radar, lidar and radiometer.

Brief Description

This product uses all the information to try to obtain the best possible estimate of cloud, aerosol and precipitation properties in any situation.

- The directly retrieved Aerosol variable: Aerosol total number concentration
- Derived from this are: aerosol extinction, aerosol mass content and aerosol median volume diameter (incl. their 1 sigma random error)
- Target classification comes from AC-TC and in case of aerosols come from A-PRO



ATLID Mie backscatter
Retrieved ATLID Mie backscatter
ECA_EXAA_ACM_CAP_2B_20241231T183450Z_20210408T155549Z_39316D
Total extinction
2D-TRUE
Retrieved total extinction
ECA_EXAA_ACM_CAP_2B_20241231T183450Z_20210408T155549Z_39316D
ATLID lidar ratio
2D-TRUE
Retrieved ATLID lidar ratio
ECA_EXAA_ACM_CAP_2B_20241231T183450Z_20210408T155549Z_39316D
Height [km]
0
5
10
50°N
45°N
40°N
35°N
30°N
25°N
0°N
Latitude
β [m^{-1} sr^{-1}]
10^{-4}
10^{-6}
10^{-8}
α [m^{-1}]
10^{-2}
10^{-4}
10^{-6}
S [sr]
0
20
40
60
80

Aerosol Imager Retrievals

M-AOT

Processor	M-AOT (MSI Aerosol Optical thickness processor)
Input Products	1. M-RGR (MSI regridded L1c product) 2. M-CM (MSI L2a cloud mask) 3. X-MET (ECMWF meteorological parameters on EarthCARE swath)
Output Products (reported on native MSI grid)	1. Aerosol optical thickness over land at 670 nm and over ocean at 670 nm and 865 nm; Ångström parameter (670nm, 865 nm) over ocean

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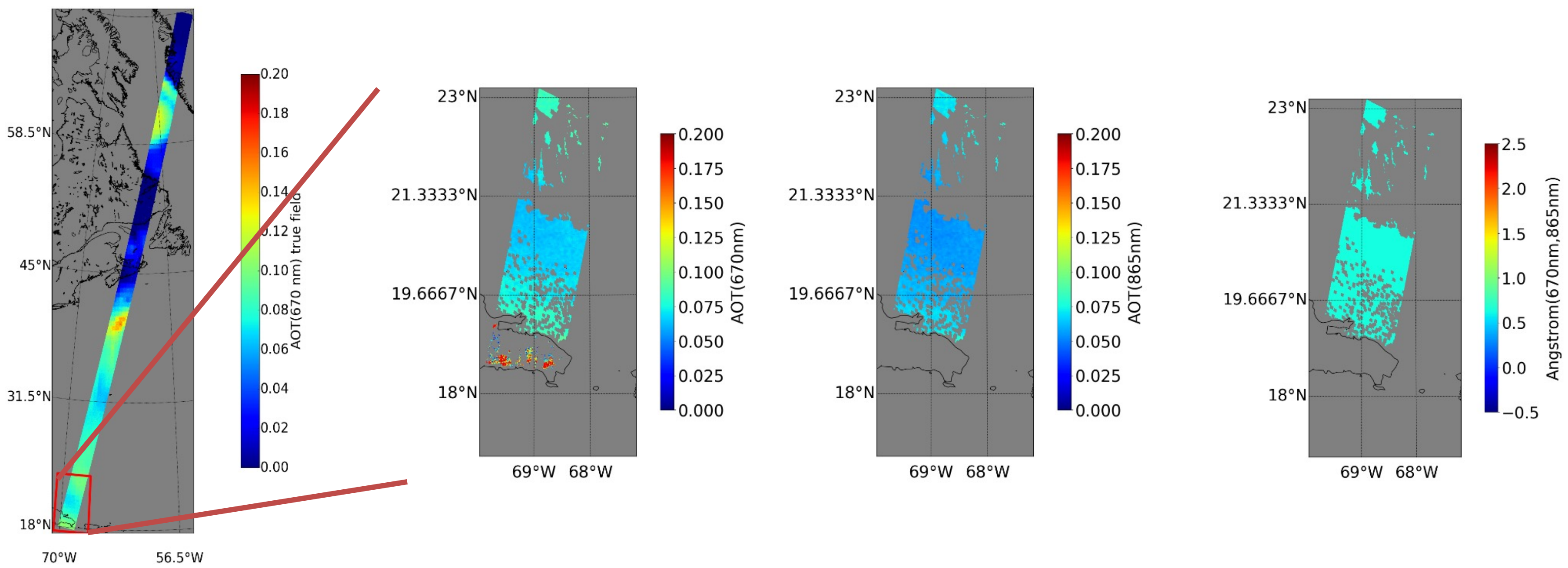
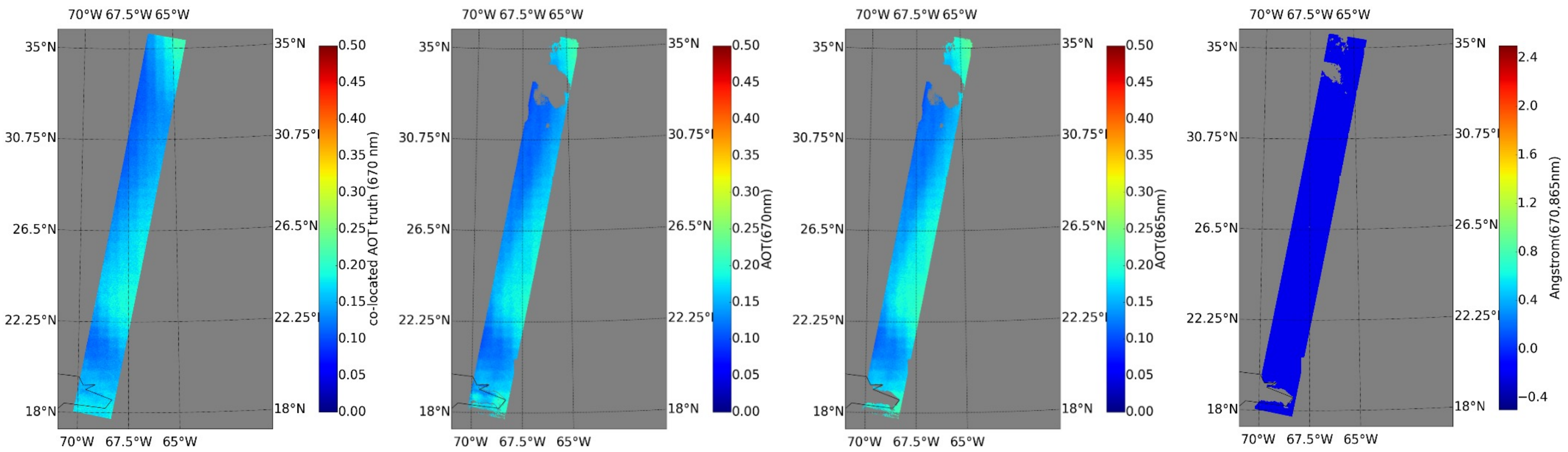
Brief Description

- Usage of TOA radiances that are corrected for gaseous absorption of water vapour and ozone, carbon dioxide and methane
- Optimal estimation based retrieval using Gauss-Newton approach
- Two separate forward operators for land and ocean surfaces both relying on LUT interpolation
  - Ocean algorithm: surface contribution simulated to be following Cox and Munk (1954)
  - Land algorithm: Lambertian reflector assumed; relying on prior information about the surface
  - HETEAC aerosol typing (Wandinger et al. 2016) used in order to ensure consistency within EarthCARE retrieval chain

Model AOT(670nm) field | AOT(670nm) | AOT(865nm) | Ångström (670,865nm)



Model AOT(670nm) field | AOT(670nm) | AOT(865nm) | Ångström (670,865nm)



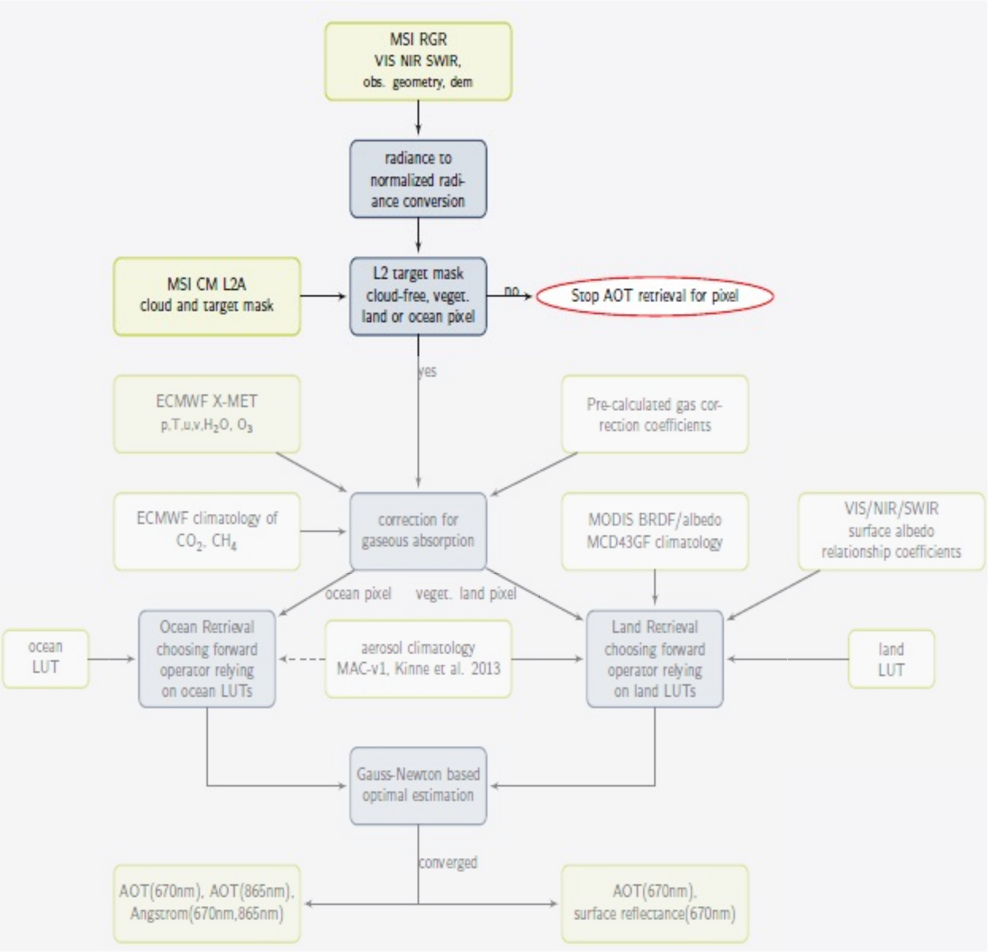
Underlying assumptions and priors

- De-coupling of weakly gases
- Climatological amounts of CO2 and CH4

- Ocean surface parameterization following Cox and Munk (1954) – wind speed from X-MET

- Lambertian surfaces over land using black sky albedo of MODIS MCD43 climatology as prior for SWIR-2

- Internal, 25 pre-defined mixings of HETEAC components in LUTs including the four pure HETEAC types
- Fixed vertical distribution of aerosol types according to Aerosol cci (Holzer-Popp 2013)
- Aerosol climatology (MAC v1 Kinne et al. 2013) used as prior and over land for fixed mixing of types



Known uncertainties

- Higher AOT uncertainties expected over land than over ocean due to the stronger TOA signal contribution of the surface than the aerosol
- Aerosol type assumption can lead to additional large uncertainties over land

Processor	AM-COL (ATLID-MSI Column processor)
Input Products	1. A-CTH, A-ALD 2. M-RGR, M-CM, M-COP, M-AOT 3. X-MET, X-JSG
Output Products (reported on JSG grid)	1. Synergistic cloud top height difference (AM-CTH) 2. Synergistic aerosol column descriptor (AM-ACD) • **Spectral aerosol optical thickness** • **Ångström exponent** • **Aerosol type**

EARTHCARE

TROPOS

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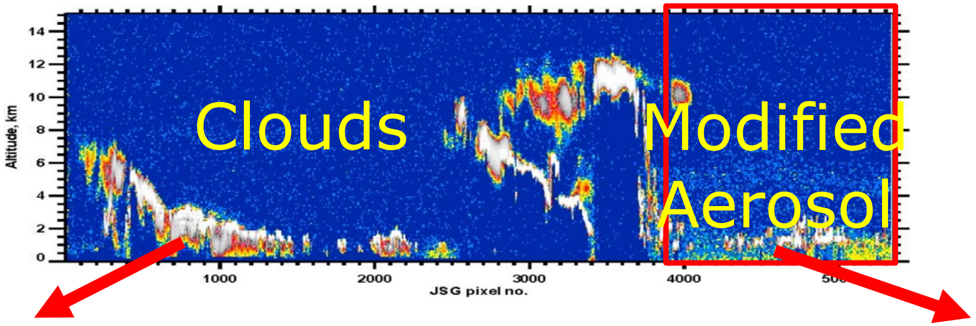
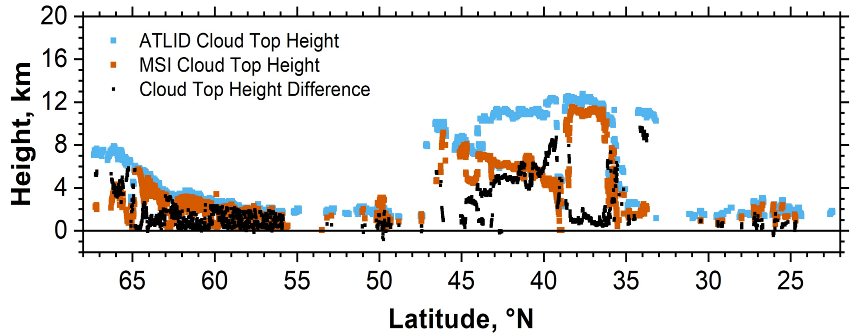
Brief Description

- Height-resolved information from ATLID is combined with MSI column products to retrieve
  1. Synergistic cloud top height information along and across track
  2. Synergistic aerosol column information along and across track
- Cloud classification from MSI is used to extrapolate CTH differences from ATLID track to MSI swath.
- ATLID AOT@355 nm is combined with MSI AOT@670 nm (over land and ocean) and AOT@865 nm (over ocean) to retrieve **Ångström exponent** and **estimate aerosol type.**
- Aerosol classification and homogeneity information from MSI is used to **extrapolate AOT@355 nm from ATLID track to MSI swath.**

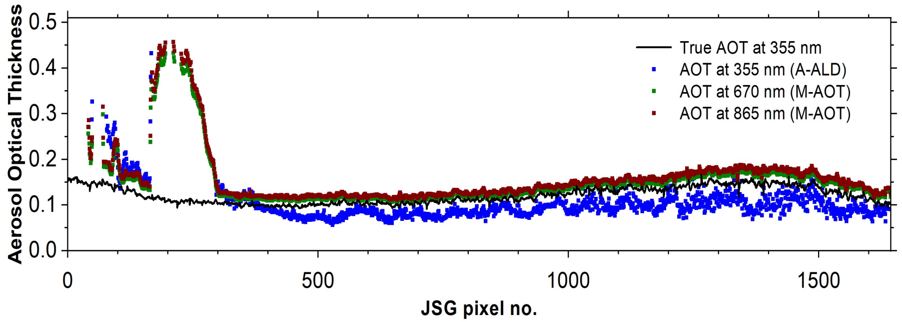
Simulated Particulate (Mie) Attenuated Backscatter



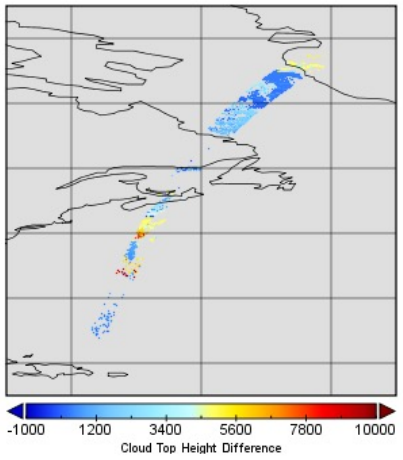
Retrieved Cloud Top Height Difference Along Track



Retrieved Spectral Aerosol Optical Thickness Along Track



Retrieved Cloud Top Height Difference Across Track



Retrieved Spectral Aerosol Optical Thickness Across Track