Koninklijk Nederlands
Meteorologisch Instituut
*Ministerie van Infrastructuur en Waterstaat*

# ATLID cloud/aerosol retrieval approaches applied to ALADIN

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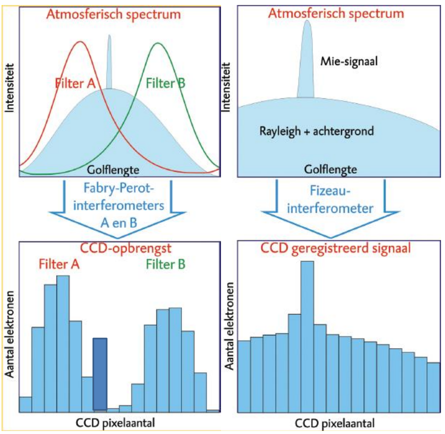
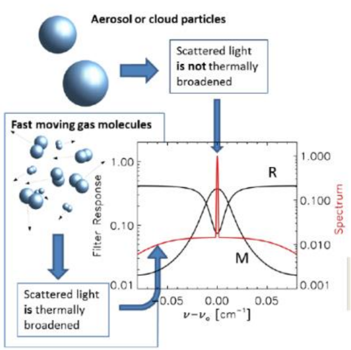
# Outline

- Brief Overview of ALADIN and ATLID
- The retrieval of Aerosol/Cloud extinction from Space. What are the issues and challenges ?
- Overview of EarthCARE (ATLID) approaches.
- How these concepts are being applied to Aeolus observations.
- Examples
- Summary and Outlook.

# ALADIN and ATLID are HSRL Lidars




ALADIN has two spectrometers and 3 channels

A Dual FP (RSP)
A Fizeau (MSP)

ATLID has one spectrometer and 3 channels

A single FP separating the Mie and Ray co-polar returns and a total cross-polar channel.

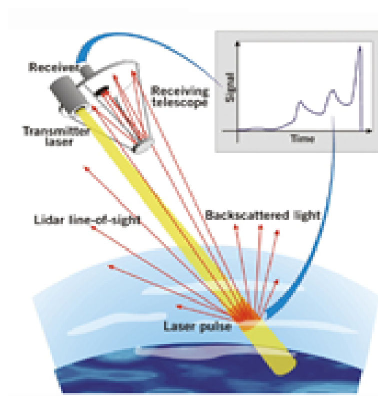
Power

$$P(z=\frac{ct}{2}) = \frac{C}{z^2}\left(\beta_{Ray}(z)+\beta_{Mie}\right)\exp\left[-2\int_0^z\left(\alpha_{Ray}(z')+\alpha_{Mie}(z')\right)dz'\right]$$

Attenuated backscatter

$$ATB = \frac{1}{C}z^2 P(z) = P(z=\frac{ct}{2}) = \left(\beta_{Ray}(z)+\beta_{Mie}\right)T^2(0,z)$$

$$\begin{pmatrix} ATB_{Ray,o} \\ ATB_{Mie,o} \end{pmatrix} = \begin{pmatrix} K_{Ray} & 0 \\ 0 & K_{Mie} \end{pmatrix}\begin{pmatrix} C_1 & C_2 \\ C_3 & C_4 \end{pmatrix}\begin{pmatrix} ATB_{Ray} \\ ATB_{Mie} \end{pmatrix}$$

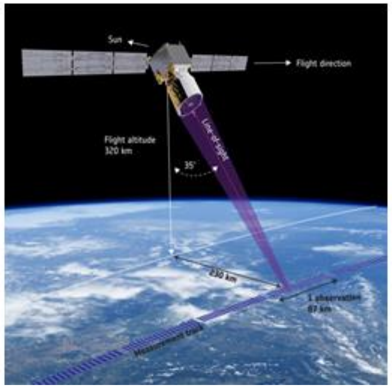



Invert

Profiles of the "True" separate Rayleigh and Mie attenuated backscatters

IF high enough SNR extinction and backscatter can be directly derived !

# ALADIN and ATLID




ALADIN

Optimized for winds

Large power-aperture product

But..

Low resolution

Low optical efficiency

Unfavorable set of cross-talk coefficients (which acts to lower effective SNR of retrieved pure Mie and Ray attenuated backscatters)

ATLID

Optimized for aerosols and clouds

100m(vert.) resolution
385 m (Hor.) resolution

High optical efficiency

Better cross-talk characteristics

ATLID should be (much) better for aerosol/cloud work…but Aeolus is actually flying !

# Issues and Challenges

-

**Space-borne lidar signals are noisy !.**

The standard Aeolus L2a aerosol product (the SCA) is (fundamentally) a variation of the usual direct (log derivative) approach for deriving extinction. **As such, it requires high SNR signals !**

Along-track averaging to increase the SNR is one solution. However, one can not mix "strong" (e.g. cloud) and "weak"(e.g. aerosols) returns and hope to get anything quantitatively useful ! The Aeolus standard approach does not screen before averaging.

**A strategy (based on ideas taken from ATLID developments) is to:**

1) Separate the `strong' and `weak' features at as high a horizontal resolution as possible.
2) Separately process and merge the strong and weak fields at different resolutions.

**This requires:**

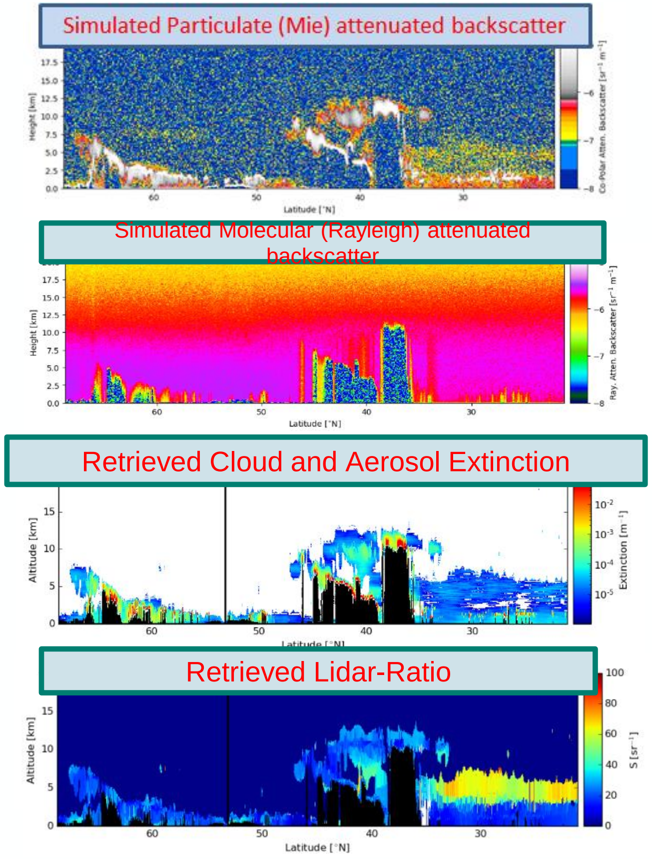
1) A high resolution mask
2) A quantitative retrieval approach than can be applied at difference scales which is robust to noise.

aeolus DISC EARTHCARE

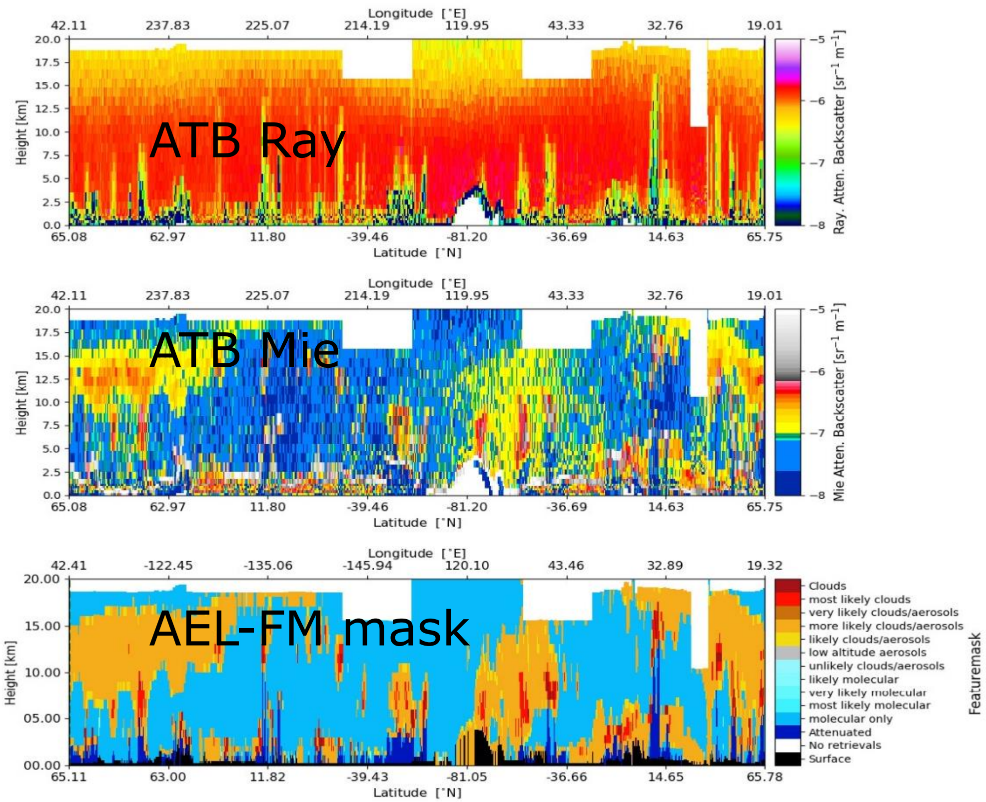
# AEL-FM and AEL-PRO

- **AEL-FM** and **AEL-PRO** are Aeolus algorithms based on EarthCARE developments (A-FM and A-PRO)
- **AEL-FM** provides a feature-mask at the **highest available resolution.**
- **AEL-PRO** is a **Multi-scale** Optimal-Estimation procedure for retrieving cloud/aerosol extinction and lidar-ratio(S).
  - The multi-scale approach is necessary in order to handle the SNR constraints and the physical size scale difference between clouds and aerosols.

A-PRO and A-FM have been developed and tested using extensive realistic simulations (example Right)…but they are only simulations. Aeolus has provided the opportunity to apply these algorithms to real data and benefit both missions !



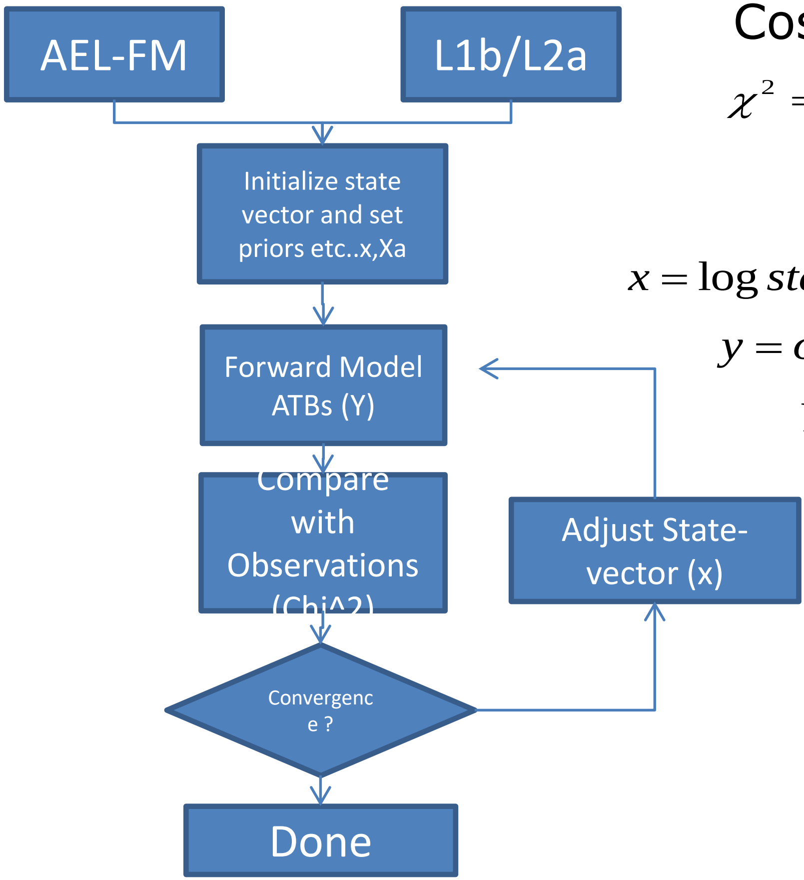
# Featuremask (AEL-FM)




Orbit 6180 (16 Sept 2019)

- Provides a mask on the highest resolution available.
- Uses image processing ideas to identify features in the signals.
  - Edge preserving filter (Hybrid median) to detect strong features.
  - Iterative smoothing together with signal probability histogram analysis in order to detect weak signal areas.
- Dynamic determination of noise thresholds.
  - Achieved by examining the signal+noise probability histograms

# AEL-PRO (simplified structure)




Cost-function to minimize

$$\chi^2 = [(Y_i - y_i)]\left[C_{i,j}\right]^{-1}[(Y_i - y_i)]^t +$$
$$\left[(X_{i_a} - x_{i_a})\right]\left[C_{a,i_a,j_a}\right]^{-1}\left[(X_{i_a} - x_{i,a})\right]^t$$

$$x = \log state \;\; \text{var}\, iables = \log(\alpha_1 .......\alpha_{nz}, S_1....S_{nz}, Ra_1.....Ra_{nz}, C_{lid})$$

$$y = observations = (ATB_{Ray_1} .......ATB_{Ray_{nz}}, ATB_{Mie_1} ....ATB_{Mie_{nz}})$$

$$Y = Y(x) = \; forward \;\; modelled \;\; observations$$

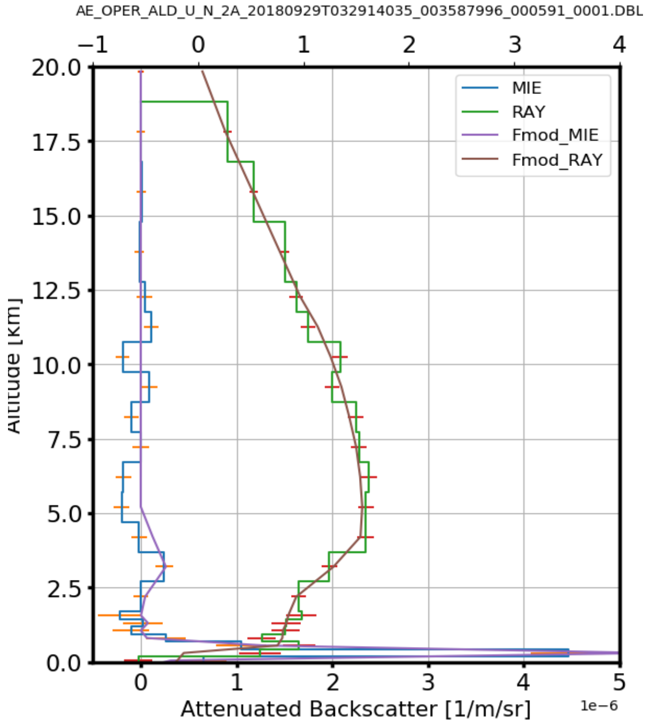
$$X_a = apriori \; values = \log(S_{a,1}....S_{a,nz}, Ra_{a,1}.....Ra_{a,nz}, C_{lid,a})$$

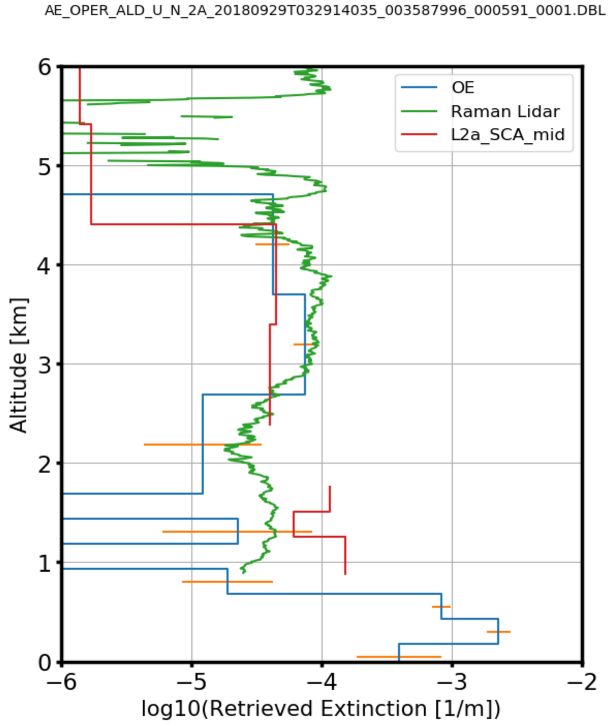
Two passes at different resolutions are performed:

-Low-res pass (aerosols + thin clouds)
-High-Res pass (clouds). Uses pass-1 results as input.

# Early Comparison with Ground-based Raman-Lidar observations

## 29-09-2018 Haifa



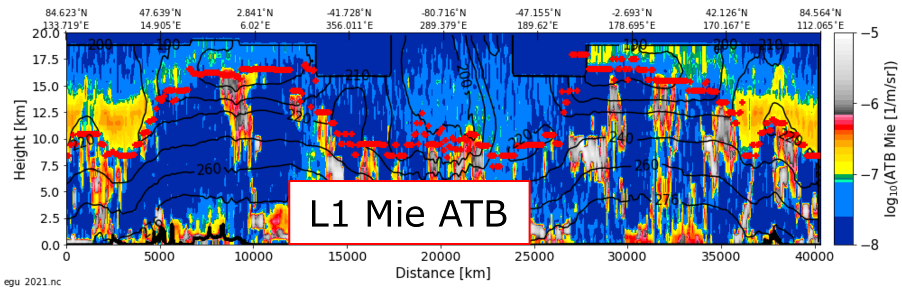



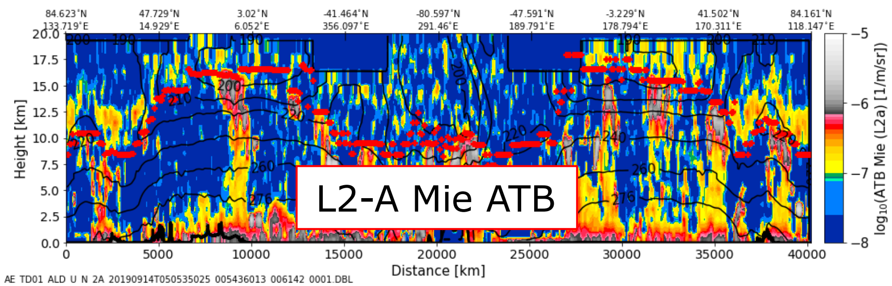

Raman lidar results from H. Baars (Tropos)

# In the past several months

- AEL-FM and AEL-PRO have been further adapted to Aeolus
- A method to generate less noisy attenuated cross-talk corrected Mie and Ray backscatters has been implemented.
- AEL-PRO speed increased due to use of analytical formulation of OE cost-function Jacobian.
- A correction procedure for beam-shape/obscuration effects on the Mie spectrometer ACCD signals formulated and implemented.
- AEL-FM and AEL-PRO have been applied to data from an Intensive Observation Period (IOP) from Sept 2019 (lots of smoke in the lower strat.)

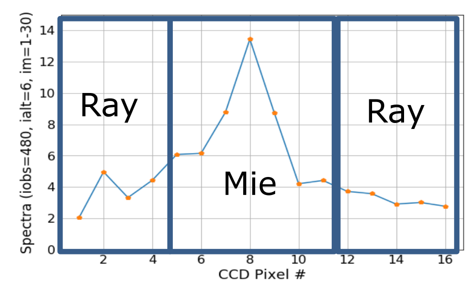
# An unexpected recent spin-off development: **ATB inputs from L1b spectrometer data**




The L1-b spectra is divided into Mie and Ray sections. X-talk between the sections is accounted for using a model of the Fizeau spectrometer.

The spectrometer response is corrected for beam-shape and obscuration effects using clear-air returns




A large improvement in SNR in the L1-B Mie ATB is apparent even though the photons in the Rayleigh spectrometer are not used at all !

Why ?

The final SNR depends not only on the SNR but also on the magnitude of the X-talk between the channels.

As it happens, the L1a set of cross-talk coefficients is much more favorable than those associated with the conventional (L2a) approach !

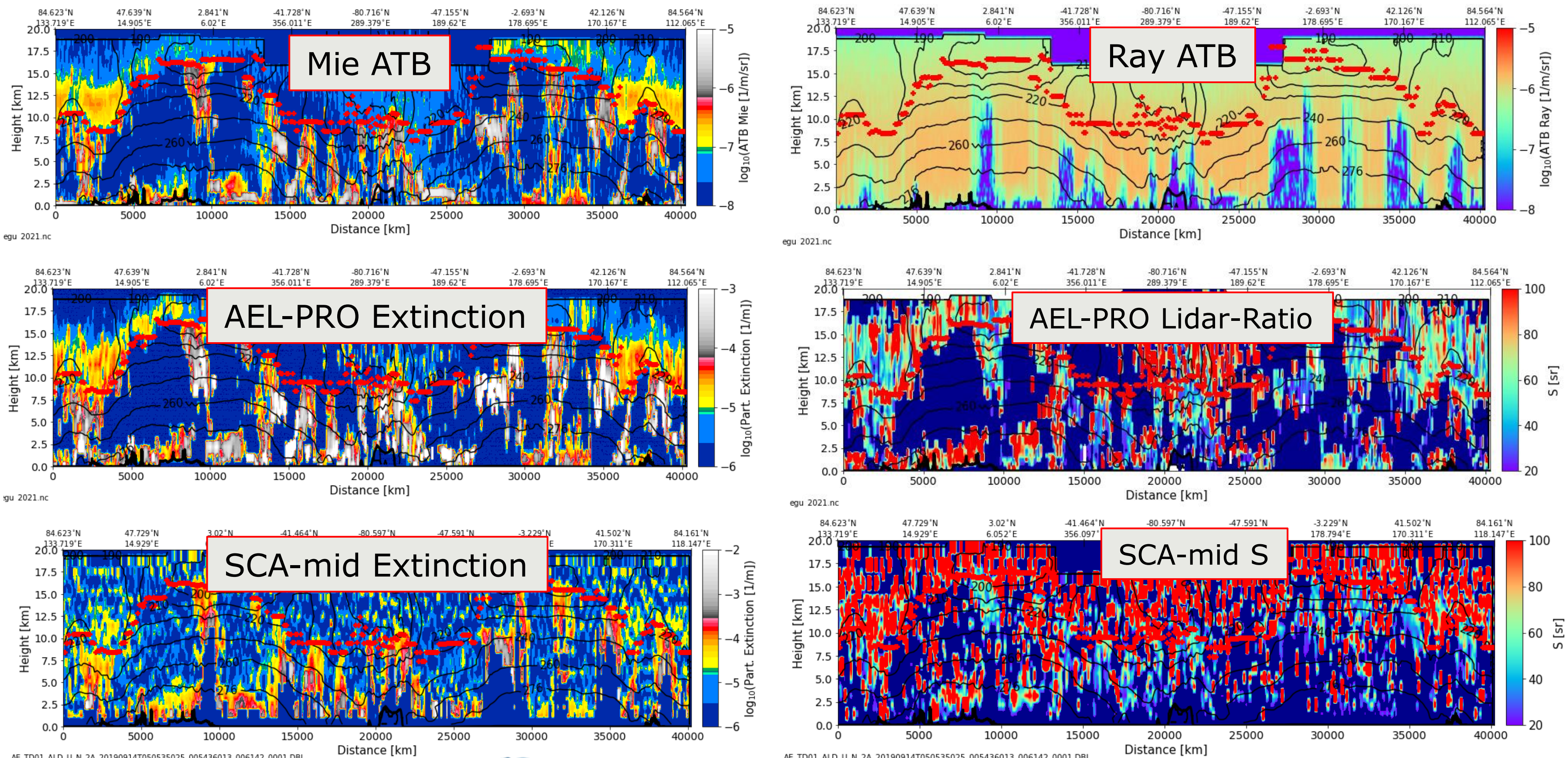
Note: For the Rayleigh backscatter a slight reduction in the SNR is realized. Work should continue on improving on the procedure by (re-)incorporating the Rayleigh spectrometer data.

# Sample recent results

September 2019: Lots of smoke in the lower stratosphere.

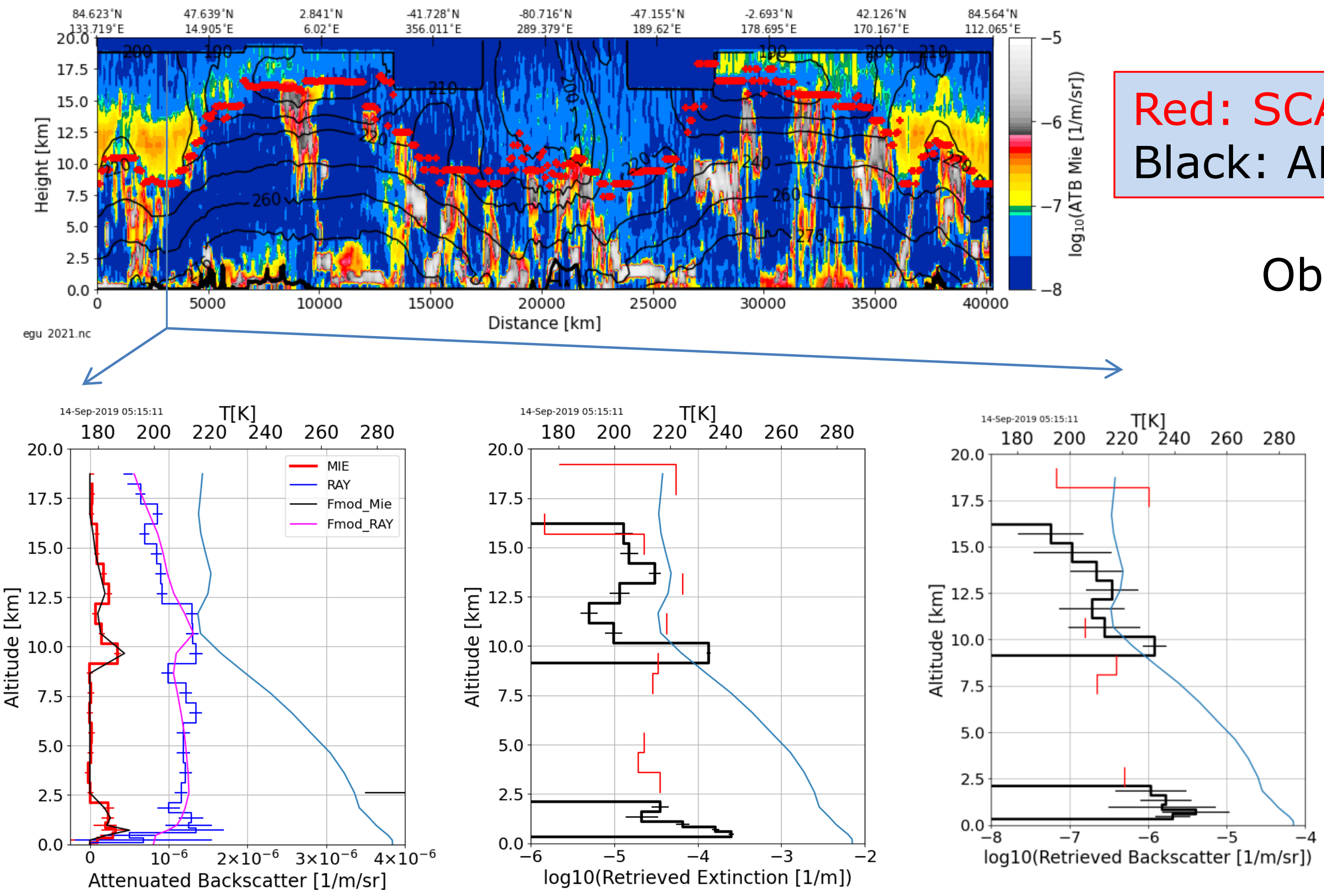
+ → Tropopause

Black contour lines → Temperature




AEL-PRO results are generally much more precise than the L2a product

AEL-PRO results tend to be much more precise (less noisy) than the current L2a




Red: SCA-Mid bin results
Black: AEL-PRO

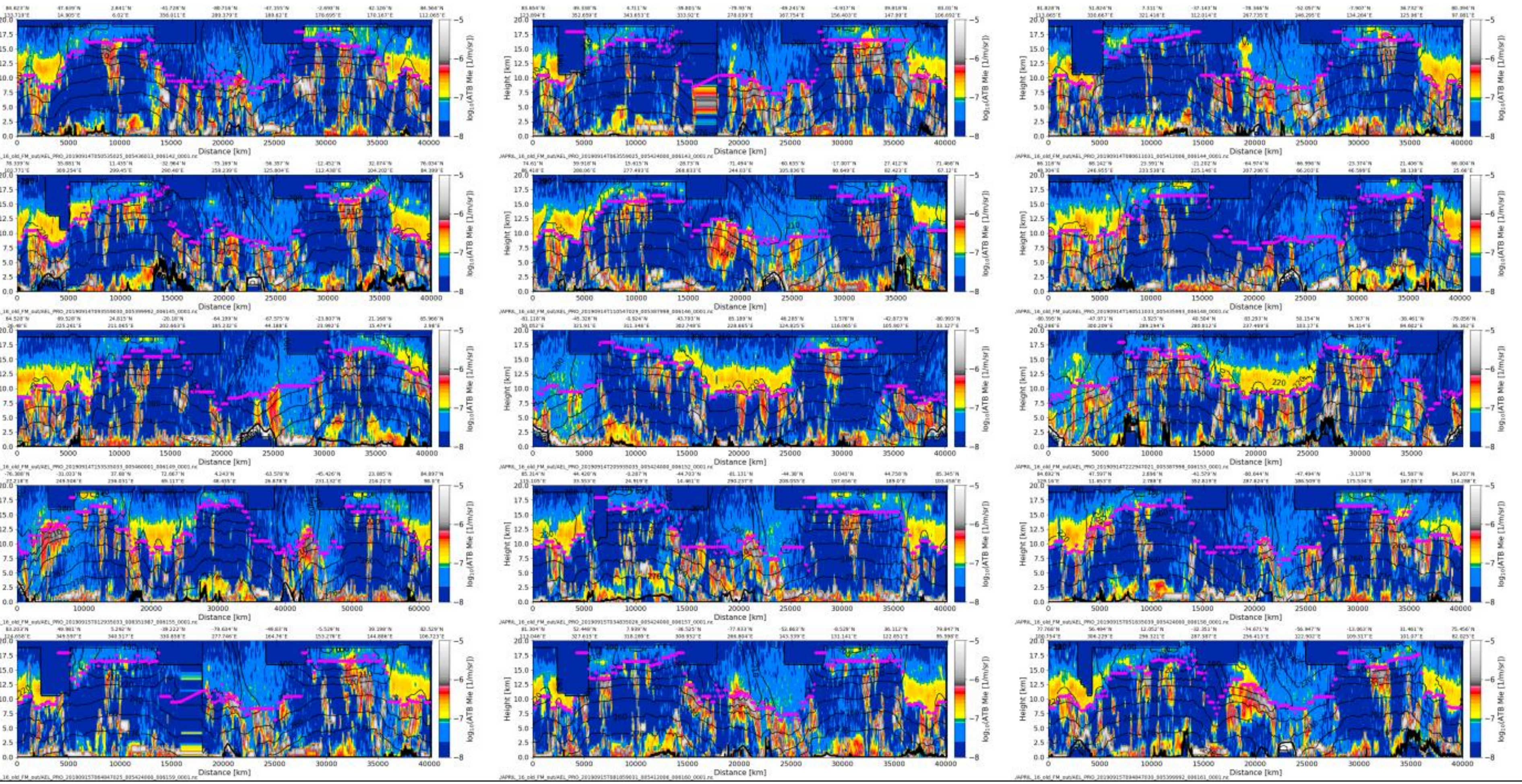
Obs#=48

Recently a week of data has been processed and is being used for evaluation/testing and comparison with other Aeolus aerosol/cloud products.

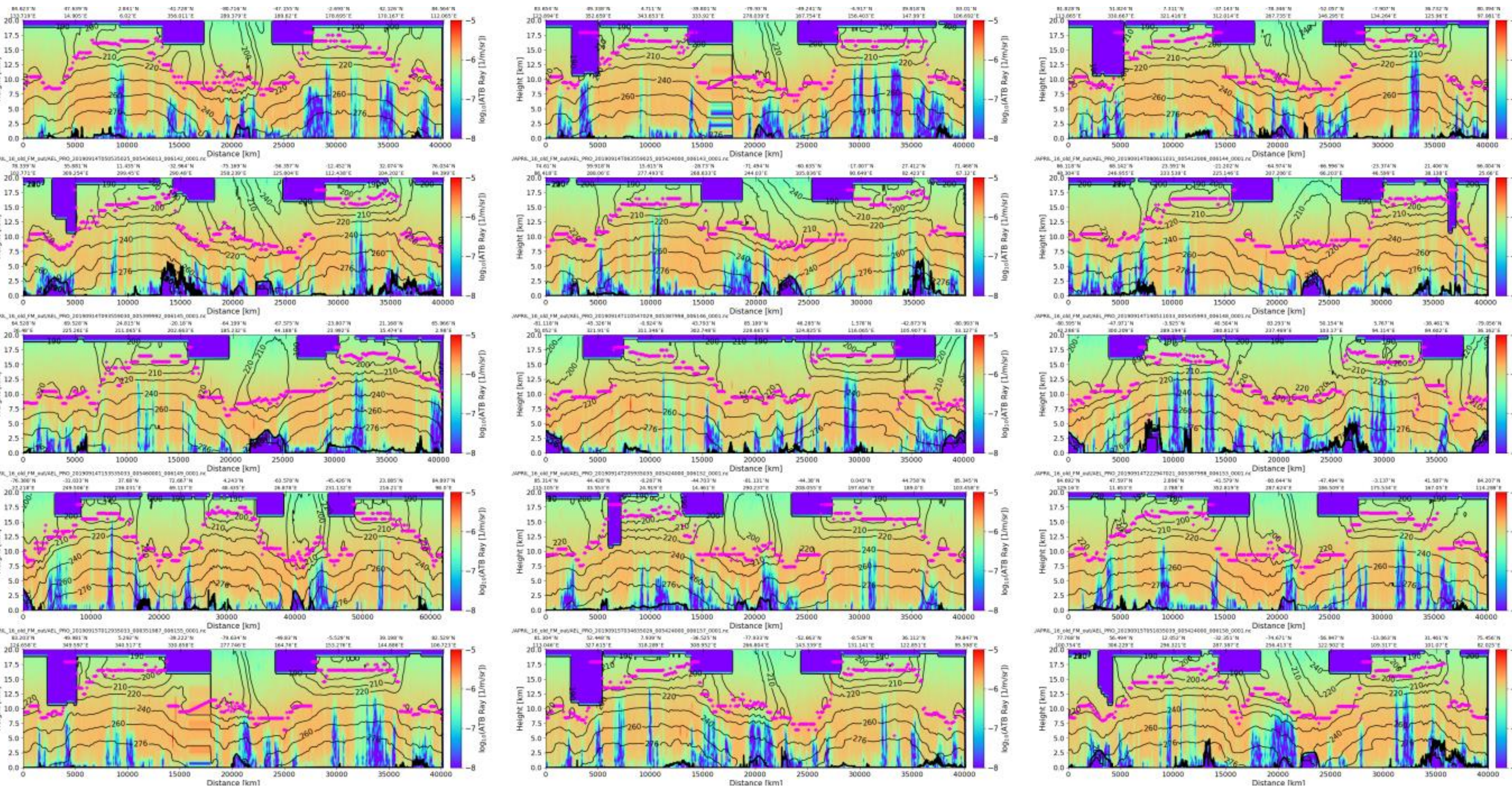
First results indicated the need to take beam-shape/obscuration effects on the Mie Spectrometer ACCD into account. A correction procedure has been devised and has been applied.

Some examples follow……

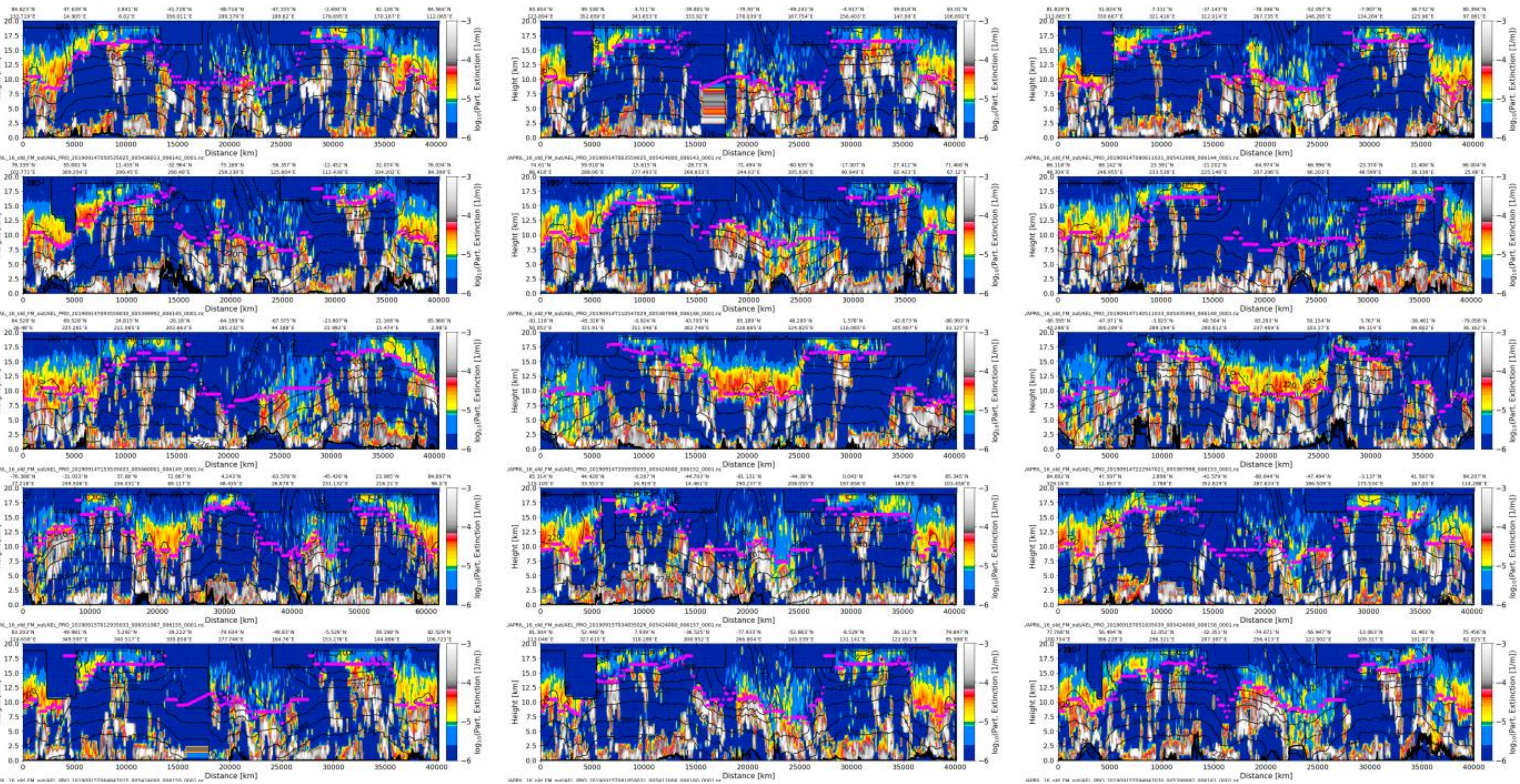
# Mie ATB



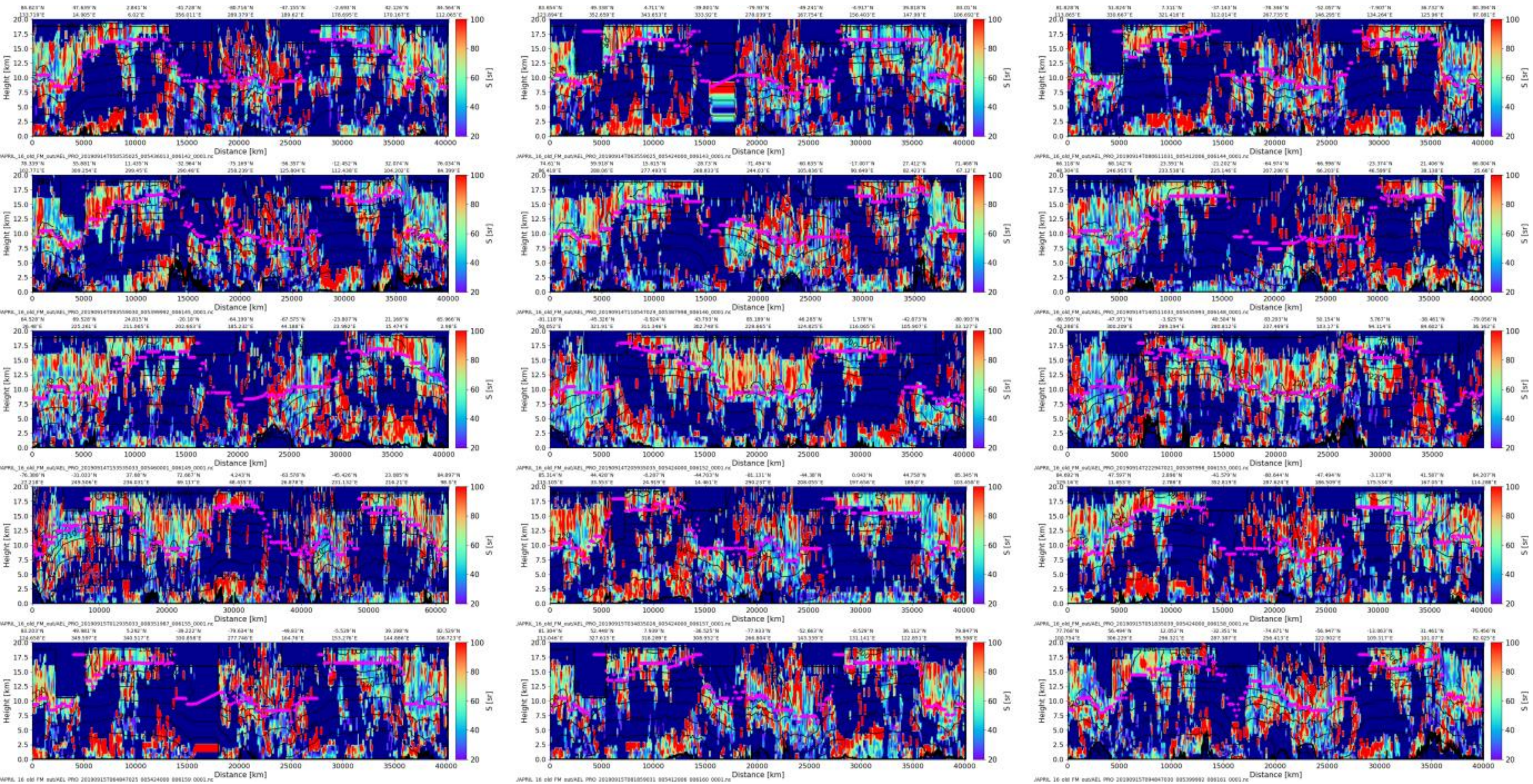
# Ray ATB



# Extinction



# Extinction/Backscatter ratio (S)

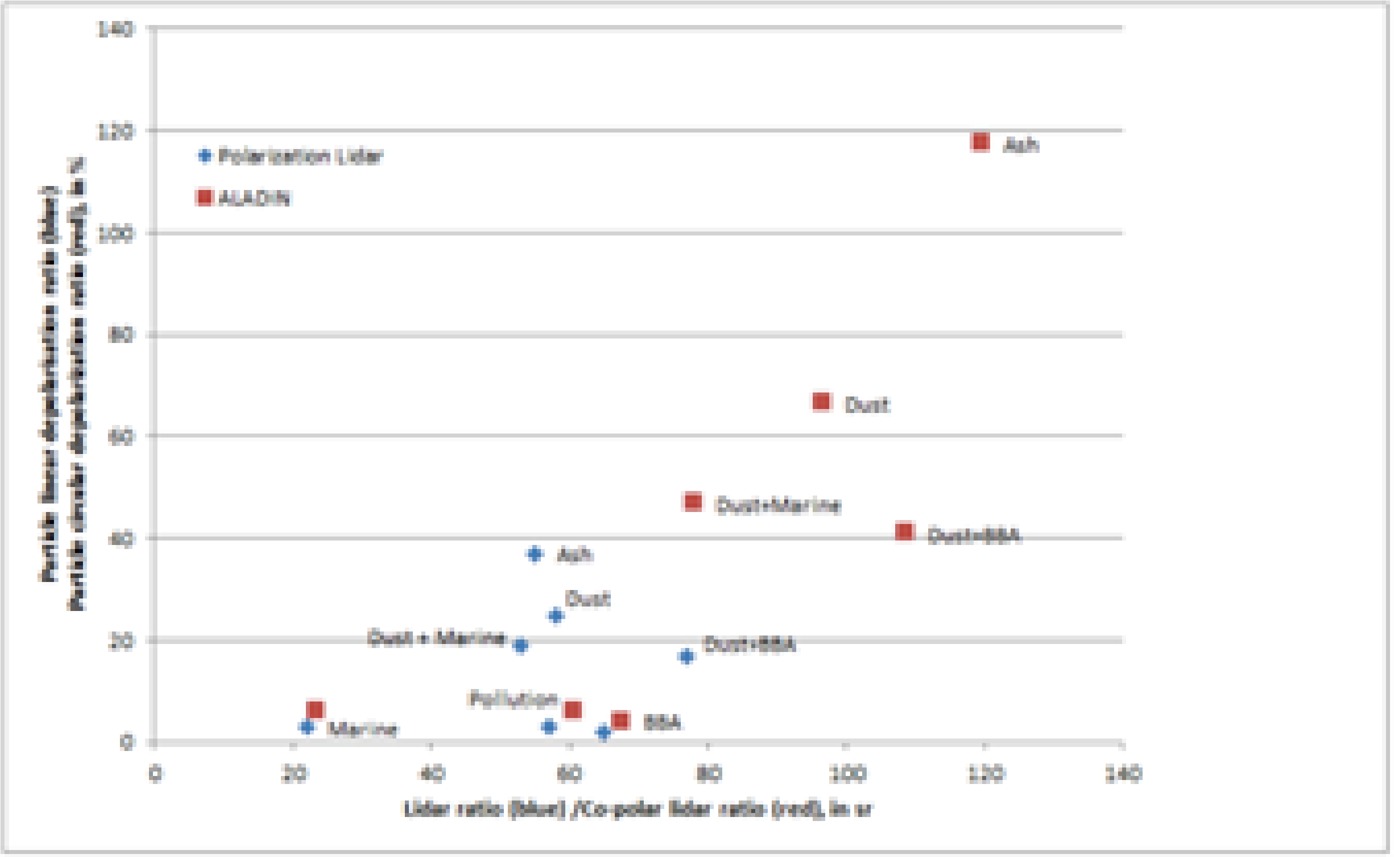


# Summary and Outlook

- The application of ATLID inspired techniques to Aeolus is very promising !
- Lots of work still to do though.
  - Impact of priors, classification strategy, surface effects, code speed, validation etc..
- Using MSP only gives better results for Mie ATBs (somewhat degraded for Ray ATBs). Further improvements (bringing the RSP data back into play) are likely.

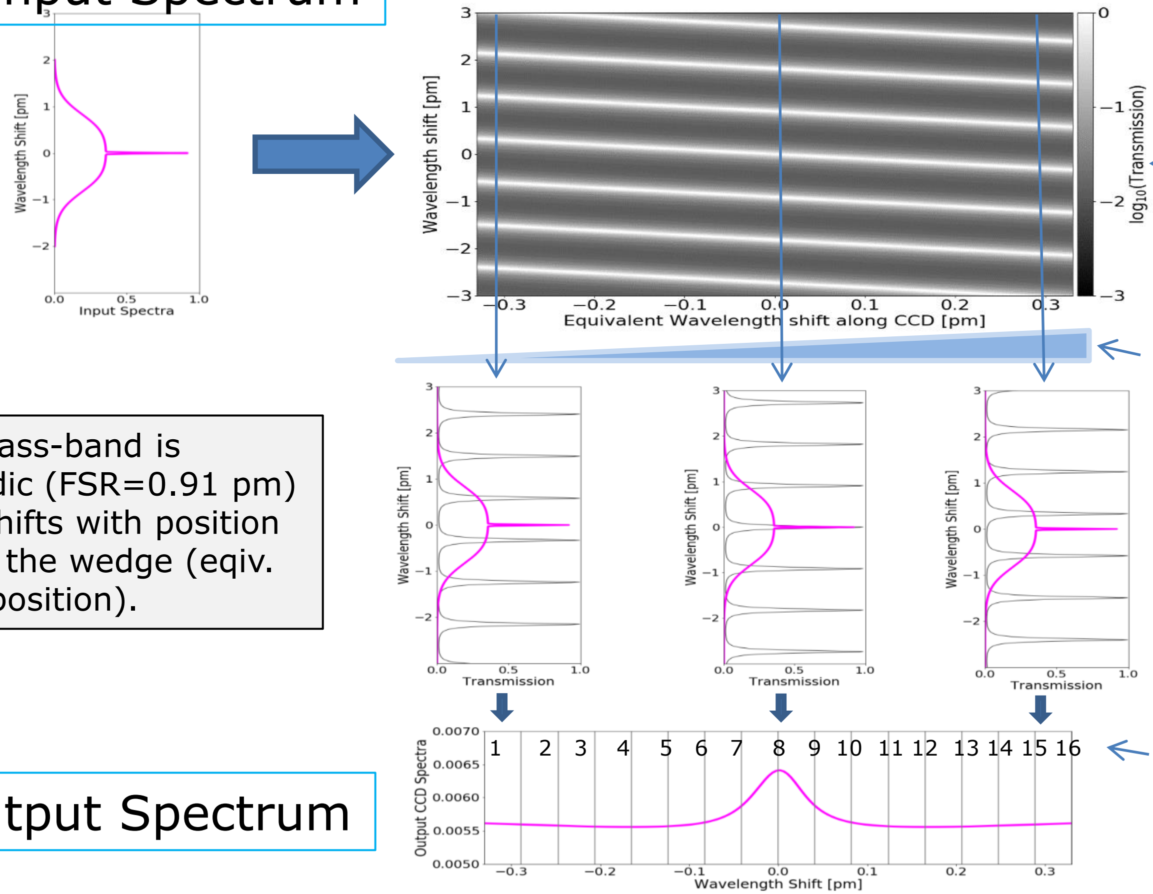
- AEL-FM and AEOL-PRO are being further improved/adapted to Aeolus and are being implemented into the processing chain.

# Extra Slides


Polarization Lidar
ALADIN
Ash
Dust
Dust+Marine
Dust+BBA
Ash
Dust
Dust + Marine
Dust+BBA
Pollution
BBA
Marine
Lidar ratio (blue) /Co-polar lidar ratio (red), in sr

# The Fizeau (Mie) Spectrometer

## Input Spectrum




The Fizeau Response function is 2D and depends on both the Wavelength and the Wedge-Position

Fizeau Wedge

The pass-band is periodic (FSR=0.91 pm) and shifts with position along the wedge (eqiv. CCD position).

$$\text{FSR} = \Delta\lambda = \frac{\lambda^2}{2h}.$$

Plate separation

ACCD Column

## Output Spectrum

aeolus DISC