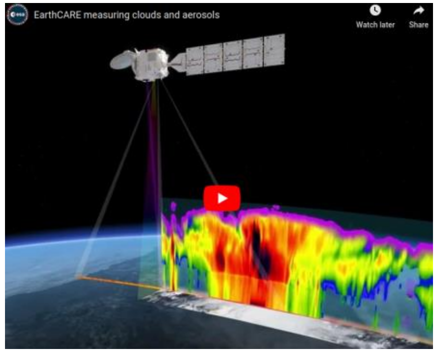
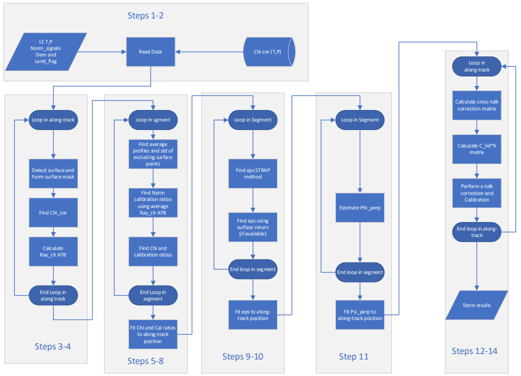


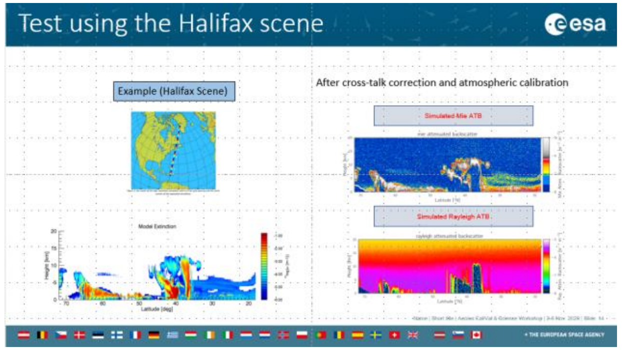
ATLID in-orbit crosstalk characterization.

D.P. Donovan, G-J van Zadelhoff (KNMI)

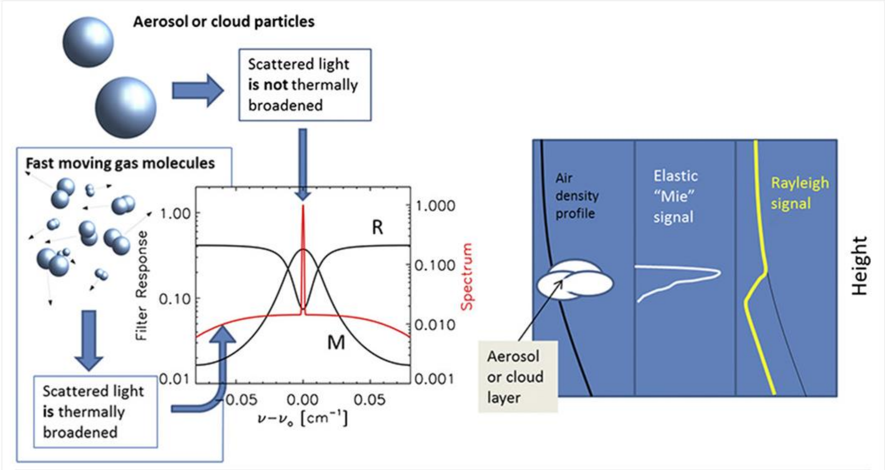
U. Wandinger, M. Haarig (Tropos)

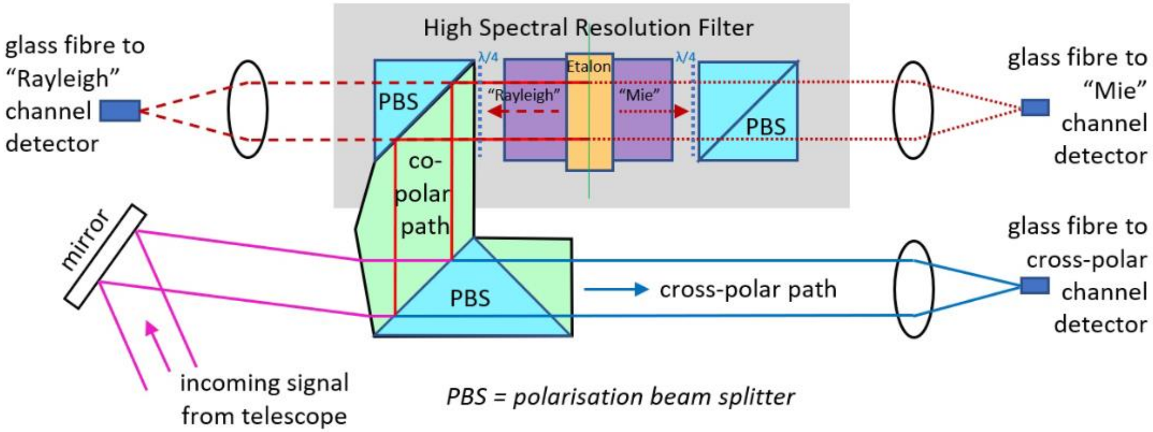
F. Marnas (ESA-ESTEC)





What is cross-talk ?





$$\begin{pmatrix} N_{Ray} \\ N_{Mie} \\ N_{Cro} \end{pmatrix} = \begin{pmatrix} C_{1,1} & 0 & 0 \\ 0 & C_{2,2} & 0 \\ 0 & 0 & C_{3,3} \end{pmatrix} \begin{pmatrix} B_{Ray} \\ B_{Mie,\parallel} \\ B_{Mie,\perp} \end{pmatrix}$$

This would be the idea case !

$$\begin{pmatrix} N_{Ray} \\ N_{Mie} \\ N_{Cro} \end{pmatrix} = \begin{pmatrix} C_{1,1} & C_{1,2} & C_{1,3} \\ C_{2,1} & C_{2,2} & C_{2,3} \\ C_{3,1} & C_{3,2} & C_{3,3} \end{pmatrix} \begin{pmatrix} B_{Ray} \\ B_{Mie,\parallel} \\ B_{Mie,\perp} \end{pmatrix}$$

But it is more like this !

Modeling the Instrument transfer function

What is measured

What one wants to know (the input atmospheric signals)

$$\begin{bmatrix} N_{Ray}^{cor} \\ N_{Mie}^{cor} \\ N_{Cro}^{cor} \end{bmatrix} = C_{lid} R(z)^{-2} \mathbf{M}_{\mathbf{det}} \mathbf{T}_{\mathbf{RX}} \begin{bmatrix} Ray_{inp} \\ Mie_{inp}^{\parallel} \\ Mie_{inp}^{\perp} \end{bmatrix}$$

$$\mathbf{T}_{\mathbf{RX}} = \begin{bmatrix} \tau_{Ray}(1+\delta_{Ray})^{-1}\left(T_{Ray}^{\parallel} + \delta_{Ray} T_{Ray}^{\perp}\right) & T_{Ray}^{\parallel}(1-T_{p}^{HSR}) & T_{Ray}^{\perp}(1-T_{p}^{HSR}) \\ (1-\tau_{Ray})(1+\delta_{Ray})^{-1}\left(T_{Mie}^{\parallel} + \delta_{Ray} T_{Mie}^{\perp}\right) & T_{Mie}^{\parallel} T_{p}^{HSR} & T_{Mie}^{\perp} T_{p}^{HSR} \\ (1+\delta_{Ray})^{-1}\left(T_{Cro}^{\parallel} + \delta_{Ray} T_{Cro}^{\perp}\right) & T_{Cro}^{\parallel} & T_{Cro}^{\perp} \end{bmatrix}$$

Some of these terms are expected to be “constant”, others not !

And a good approximation to the correction Matrix is..

$$\mathbf{M}_{\mathbf{Crosstalk\_Cor}} = \mathbf{M}^{\mathbf{-1}}_{\mathbf{Crosstalk}} = \frac{1}{\mathrm{Det}(\mathbf{M}_{\mathbf{Crosstalk}})} \times$$

$$\begin{bmatrix} 1-\dfrac{T^{\parallel}_{Cro}T^{\perp}_{Mie}}{T^{\perp}_{Cro}T^{\parallel}_{Mie}} & \varepsilon\left(\dfrac{T^{\parallel}_{Cro}T^{\perp}_{Ray}}{T^{\perp}_{Cro}T^{\parallel}_{Ray}}-1\right) & \psi^{\parallel}\left(\varepsilon - K^{Cro}_{Crosstalk}\right) \\ \chi\left(K^{Ray}_{Crosstalk}\dfrac{T^{\perp}_{Mie}}{T^{\parallel}_{Mie}}\dfrac{(T^{\perp}_{Cro}\delta_{Ray}+T^{\parallel}_{Cro})}{T^{\perp}_{Cro}}-1\right) & 1 & \psi^{\parallel}\left(\chi K^{Cro}_{Crosstalk}-1\right) \\ \chi\psi^{\perp}\left(1-K^{Ray}_{Crosstalk}\dfrac{\left(T^{\perp}_{Cro}\delta_{Ray}+T^{\parallel}_{Cro}\right)}{T^{\parallel}_{Cro}}\right) & \psi^{\perp}\left(K^{Mie}_{Crosstalk}\dfrac{\left(T^{\perp}_{Cro}\delta_{Ray}+T^{\parallel}_{Cro}\right)}{T^{\parallel}_{Cro}}-1\right) & 1-\varepsilon\chi \end{bmatrix}$$

Where it has been assumed that

$$T^{\perp}_{Mie}\delta_{Ray} << T^{\parallel}_{Mie}$$

$$T^{\perp}_{Ray}\delta_{Ray} << T^{\parallel}_{Ray}$$

$$\frac{(1-T^{HSR}_{p})T^{\perp}_{Ray}(T^{\perp}_{Cro}\delta_{Ray}+T^{\parallel}_{Cro})}{\tau_{Ray}T^{\perp}_{Cro}(T^{\perp}_{Ray}\delta_{Ray}+T^{\parallel}_{Ray})} << 1$$

And where

$$\varepsilon = \frac{R_{Ray}T^{\parallel}_{Ray}(1-T^{HSR}_{p})}{R_{Mie}T^{\parallel}_{Mie}T^{HSR}_{p}} \qquad \chi = \frac{R_{Mie}T^{\parallel}_{Mie}(1-\tau_{Ray})}{R_{Ray}T^{\parallel}_{Ray}\tau_{Ray}} \qquad \psi^{\parallel} = \frac{T^{\perp}_{Mie}T^{HSR}_{p}R_{Mie}}{T^{\perp}_{Cro}R_{Cro}} \qquad \psi^{\perp} = \frac{T^{\parallel}_{Cro}R_{Cro}}{T^{\parallel}_{Mie}R_{Mie}T^{HSR}_{p}}$$

Useful to note that it is the ratios and not so much the absolute values that are most important.

$$K^{Cro}_{crosstalk} = \frac{T^{\perp}_{Ray}(1-Tp^{HSR})R_{Ray}}{T^{\perp}_{Mie}\cdot Tp^{HSR}\cdot R_{Mieco}}\ ,\ \mathrm{K}^{\mathrm{Ray}}_{\mathrm{crosstalk}} = \frac{\mathrm{Tp}^{\mathrm{HSR}}}{1-\tau_{\mathrm{Ray}}} \text{ and } \mathrm{K}^{\mathrm{Mie}}_{\mathrm{crosstalk}} = \frac{1-\mathrm{Tp}^{\mathrm{HSR}}}{\tau_{\mathrm{Ray}}}.$$

R-B scattering line shape is BOTH pressure and Temperature dependent !

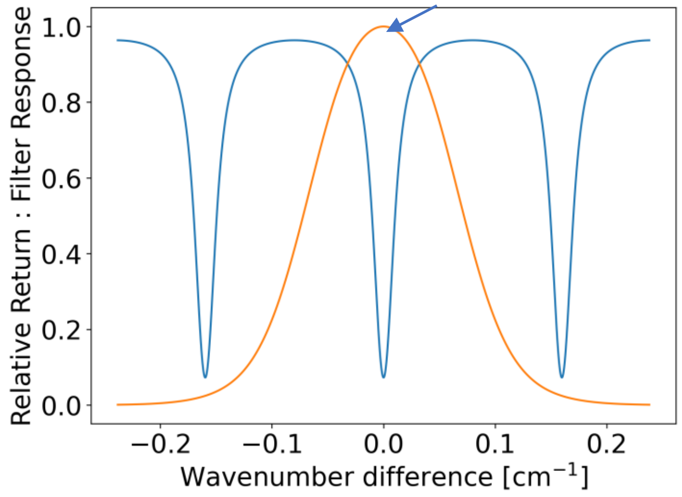


Figure 2: R-B spectrum at 300mb and 220 K (Orange).

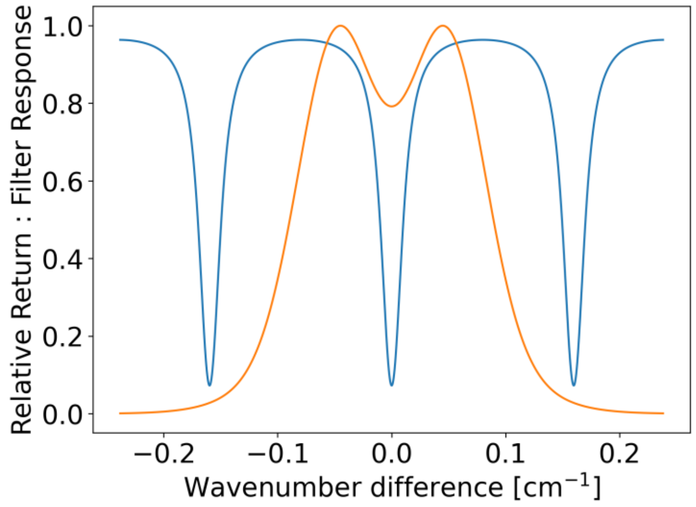


Figure 3: R-B spectrum at 1000mb and 245 K (Orange).

Simulation using Range of Temperatures and Pressures

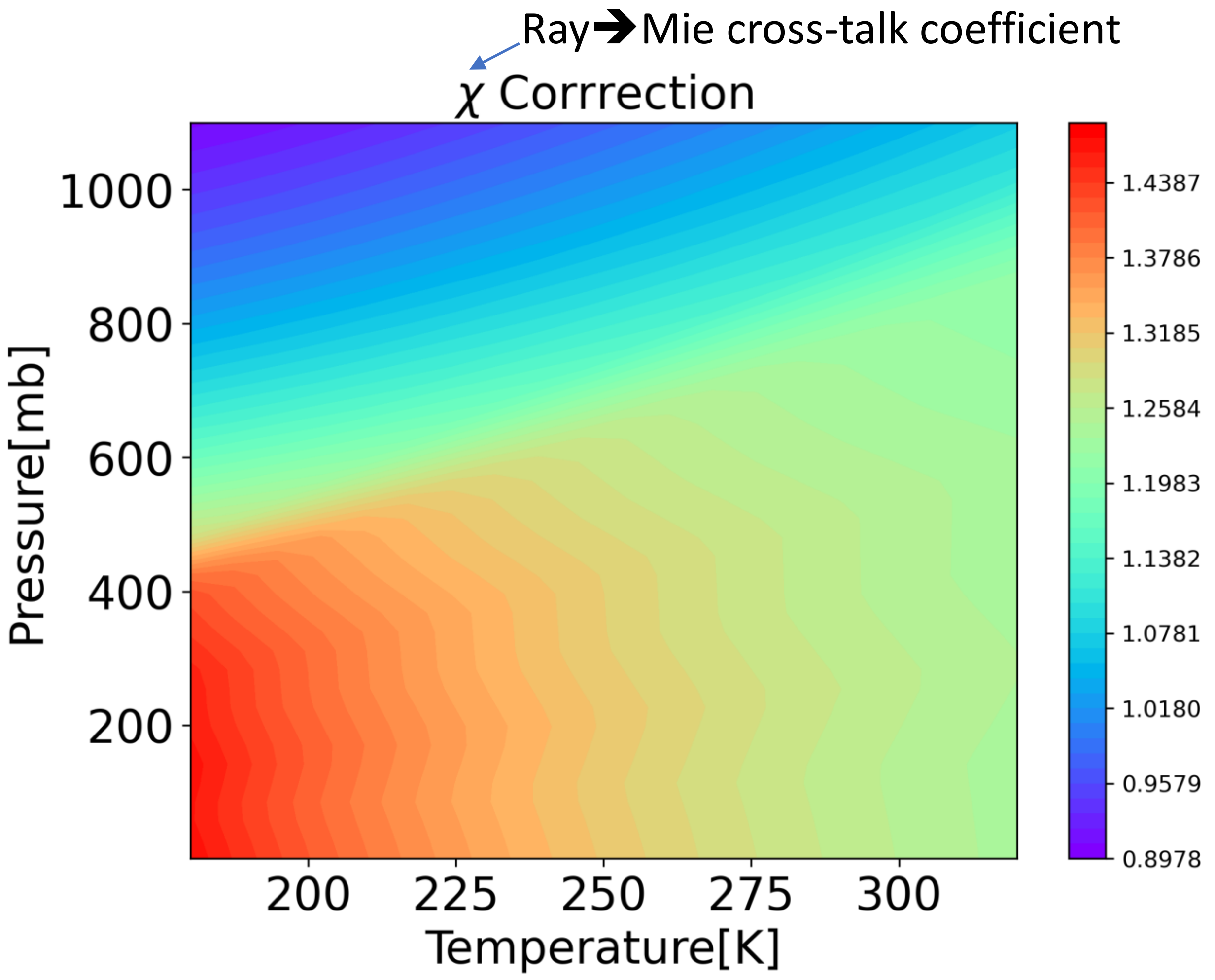


Figure 4: Chi correction factor with 300 mb and 220 K as the reference point.

Need for monitoring !

- ATLID will be periodically tuned by scanning the laser wavelength to maximalize the Mie signal.
  - ➔Cross-talk will be minimized

- But what are the exact values and what happened between tuning operations and when is re-tunning necessary ?
  - ➔Need an effective means to monitor in orbit during normal operational mode !

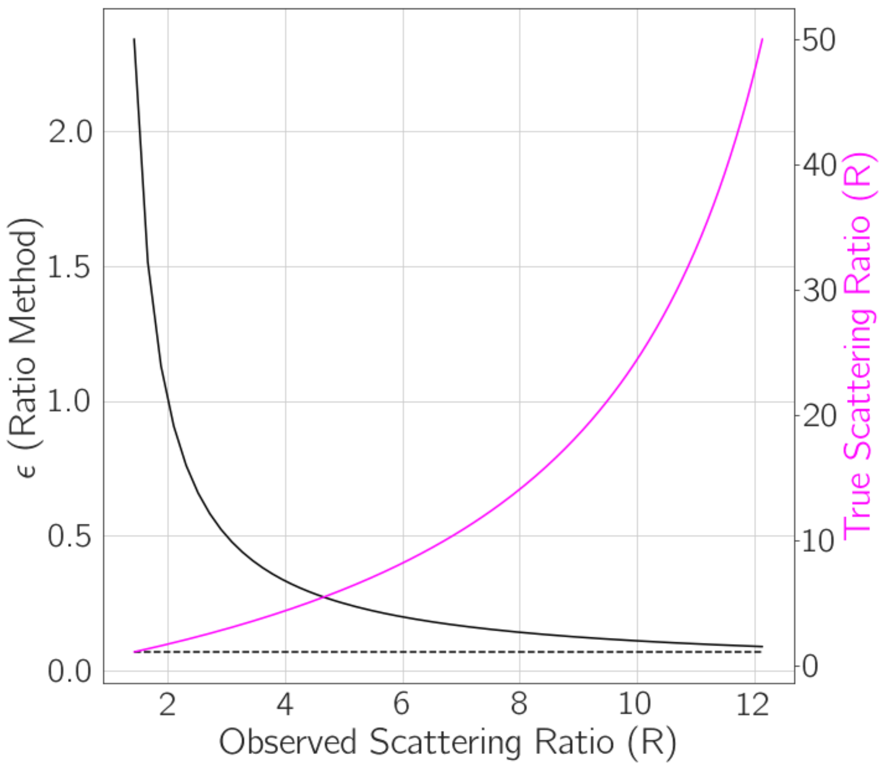
How to go about characterization and correction ?

1.	Use Aerosol free Signals (e.g. above 30 km)	Assume true value of ATB_{Mie} =0 Then ratio of Observed Mie/Ray yields χ (Ray ➔ Mie coefficient)
2.	?	Once we know and χ we need to find ϵ. How ?
3.	Use Aerosol free Signals (e.g. above 30 km and upper Trop)	Once we know ϵ and χ : Assume true value of ATB_{Mie} =0 and particle Depol=0 and using expected value of Ray Depol then the polarization cross-talk can be assessed.
4.	Use Aerosol free Signals (e.g. above 30 km)	Cross-talk corrected Relative signals can be absolutely calibrated !

Mie➔ Rayleigh cross-talk correction/assessment…..

- Ray➔ Mie (χ) coefficient can be accurately determined using high altitude (aerosol-free) signals.
- Mie➔Ray (ϵ) coefficient is more problematic.
  - If true Ray return is << true Mie return, then ϵ can be determined but..
    - Need to use suitably optically thick clouds !
      - Identification of suitable cloudy regions can be non-trivial as
        - Zero true Ray return ➔ attenuation ➔ bad SNR |!
    - **Can not use ocean returns !**
    - Thus
      - **A technique that can use a wide variety of clouds is necessary !**

Assume B_{Ray}=0 method is problematic for clouds



If Ray input is assumed to be zero:

➔ ϵ is given by the observed scattering ratio

But in reality

$$\epsilon = \frac{\chi + (R_t - 1) - (R_o - 1)}{(R_o - 1)(R_t - 1)}$$

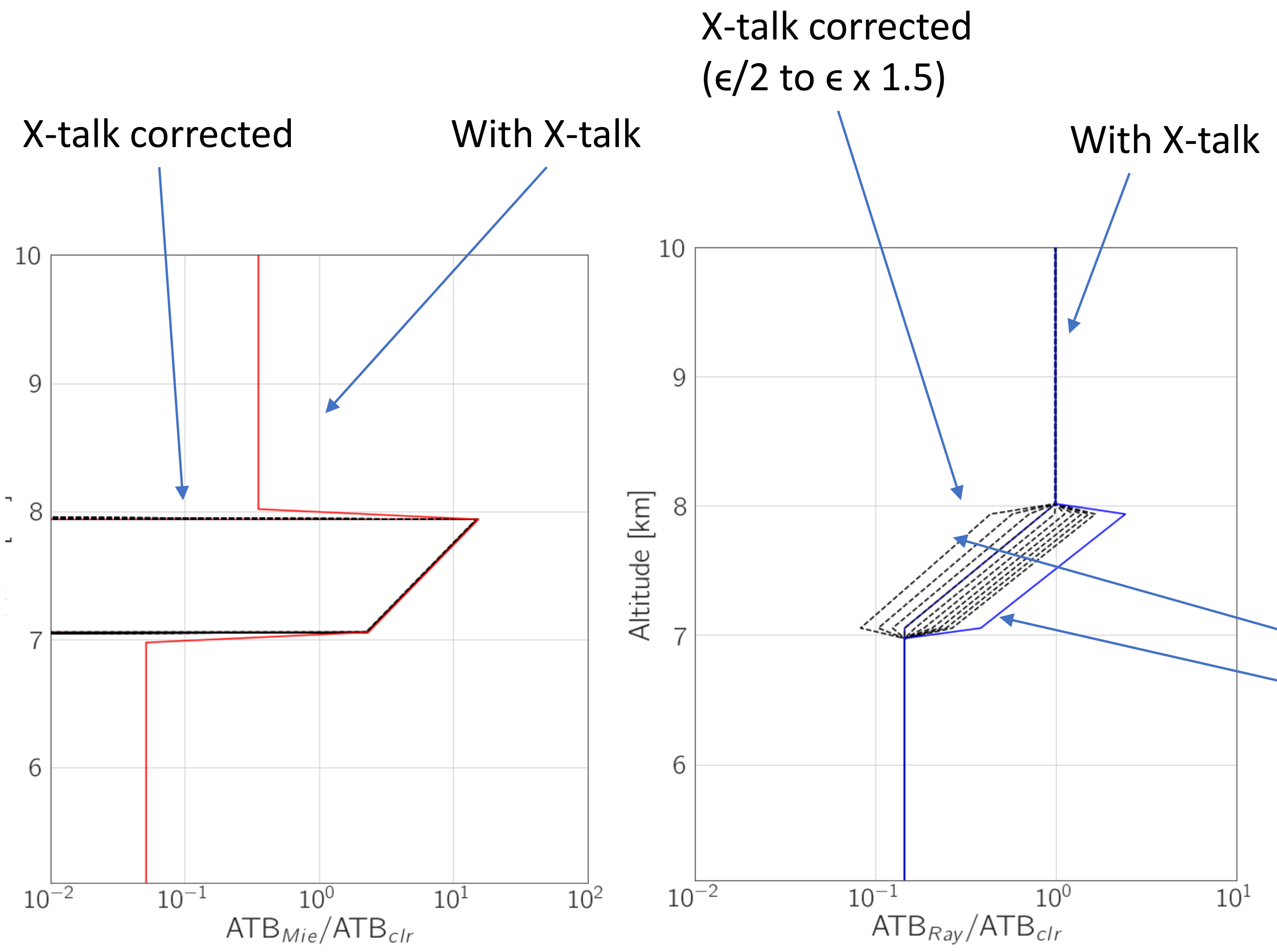
Convergence is slow !

➔ Need optically thick clouds

➔Attenuation will be a problem !

Aside: Maybe the maximum observed scattering ratio from clouds can be used…but this is likely very noise…

Some simple modelling….



There are two main natural constrains that are relevant dictated by the physics of the lidar equation i.e.

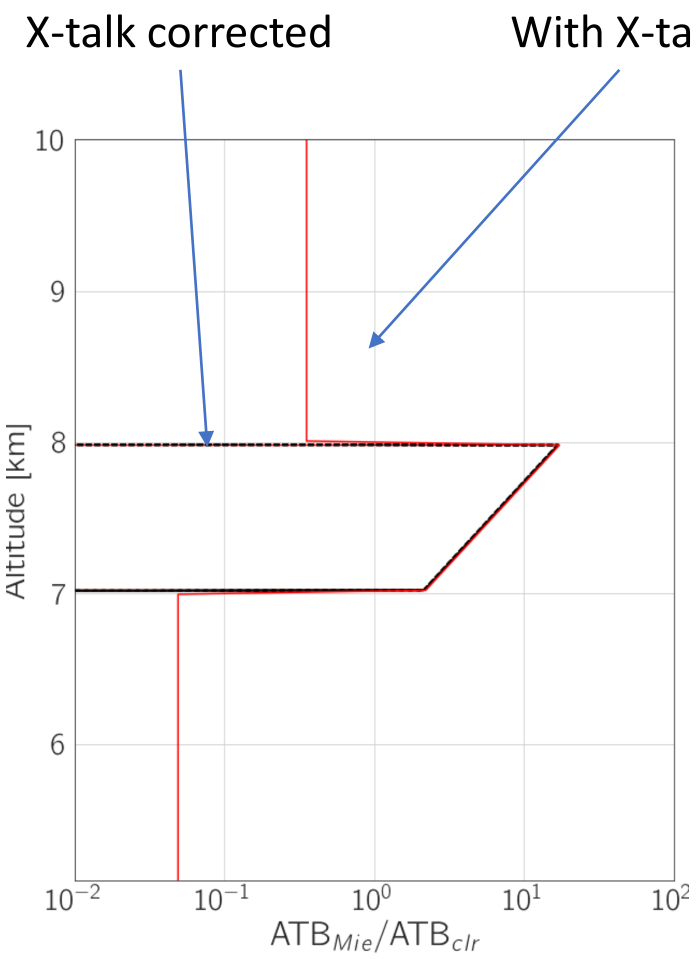
1. The Pure Ray ATB profile must be continuous at the layer boundaries
2. The Pure Ray ATB/atmos_den profile can not have a positive slope w.r.t. range from the lidar (eqiv. Negative slope with altitude).

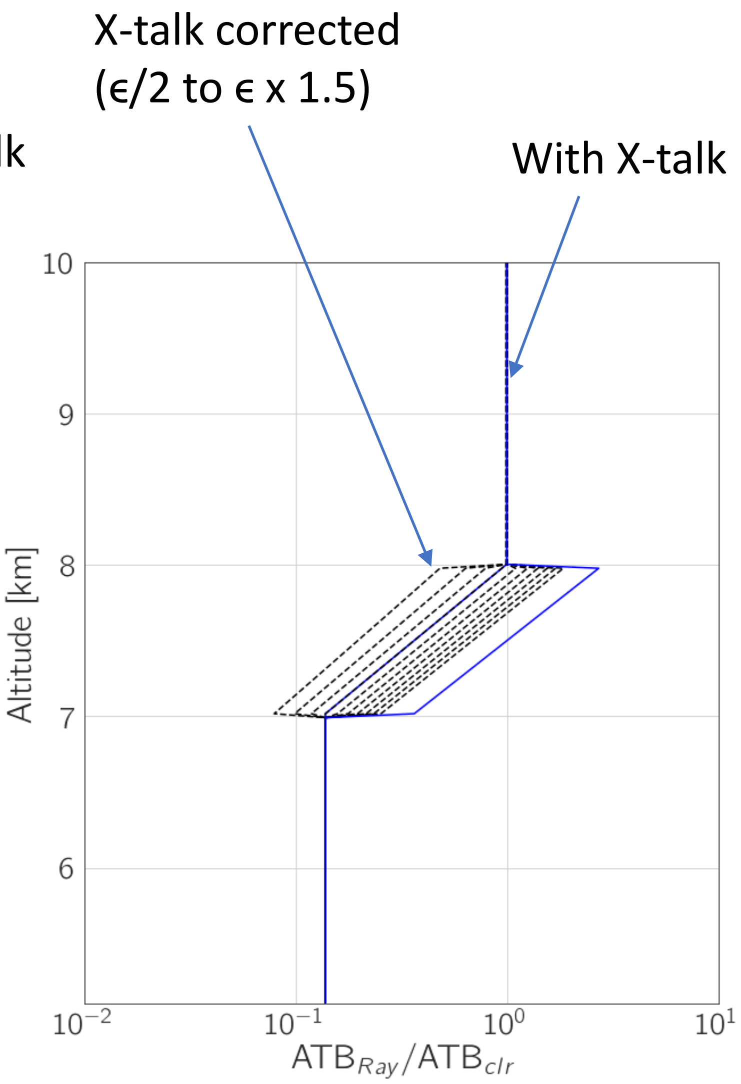
It is easy to see when one is
over-correcting or…
under-correcting

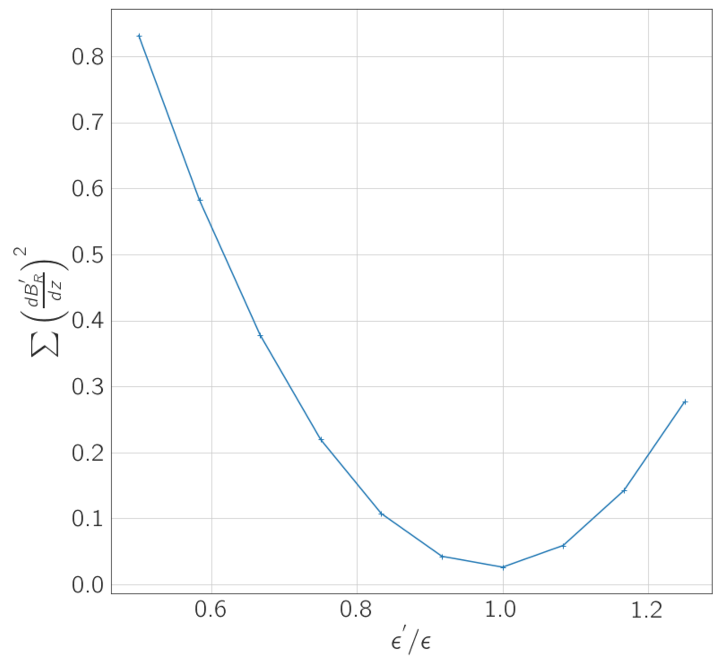
“Smoothest Rayleigh Path” (STRAP) method.

The (very-very close to) correct value of epsilon is the one which results in the ``shortest’’ path

``shortest’’ ➔ min variance in extinction profile ➔ smoothest path.







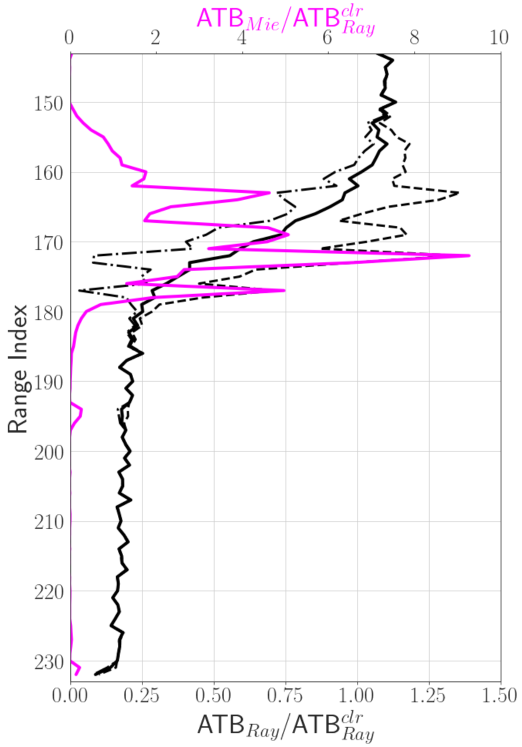
Why does STRAP work ? (a quantitative view)

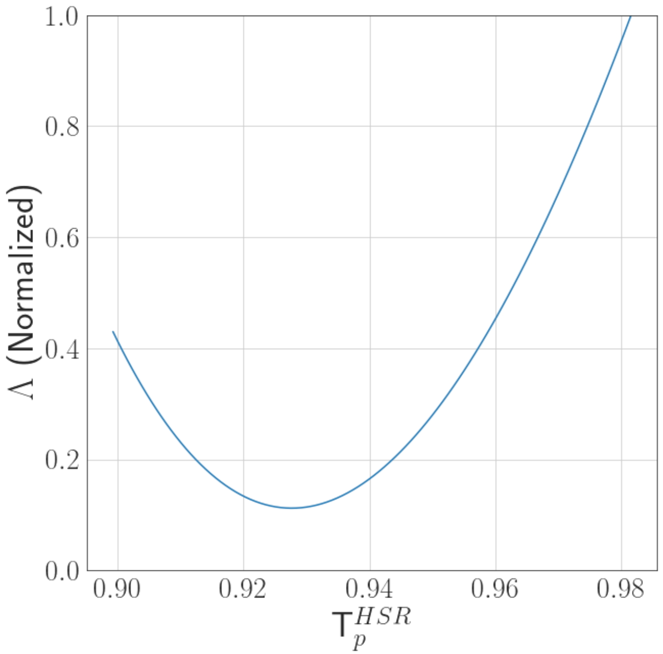
$$\Lambda = \sum_i \left(\frac{dB_R^{rat}}{dz} \right)^2$$

Ratio of trial x-talk corrected Ray channel to expected clear-air return

Minimize with respect to epsilon (equiv. Tau_ray)

Result is not exact…but very close to exact

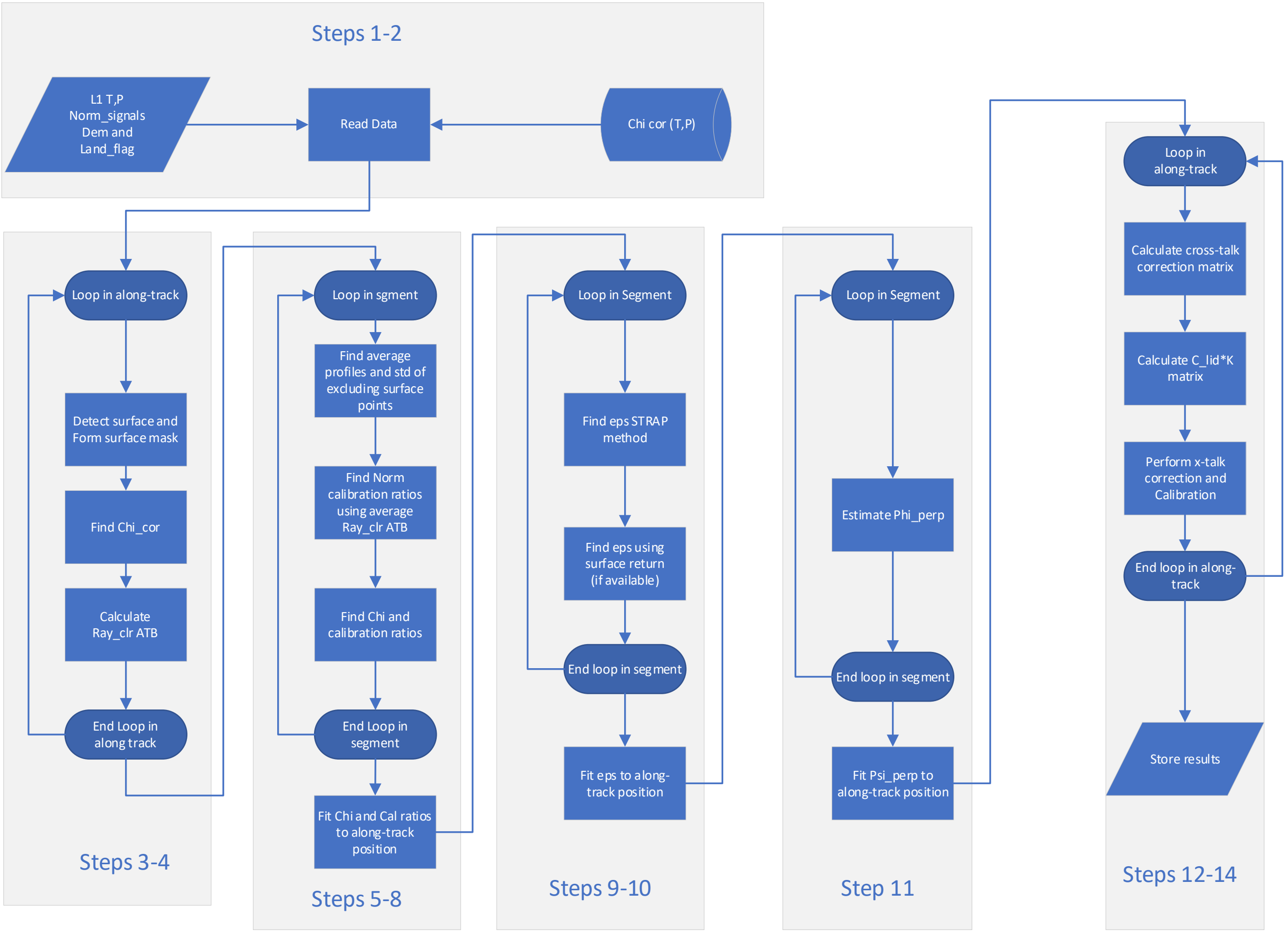




In fact, it can be shown that, in general, finding the minimum leads to a value of epsilon a little different from the true value (less than 0.2 % error typically)

$$(\epsilon - \epsilon') = \frac{\sum_i \left(B_R^{rat,t}\right)^2 \alpha_M \left(\frac{dR_s}{dz} - 2(R_s - 1)\alpha_s \right)}{\sum_i \left(B_R^{rat,t}\right)^2 \left(\frac{dR_s}{dz} - 2(R_s - 1)\alpha_s \right)^2}$$

Numerator tends to be much smaller than the denominator.



- Divide the frame into the desired number of segments
- Simple average of the ATBs (before x-talk correction)
- Average the data horizontally using Ray above 30 km to determine initial calibration coefficients and χ.
- Land-surface detection ➔ Masked average of Mie signal ➔Direct eps determination of ϵ
- Determination of ϵ using the STRAP technique
- Appropriate along-track smoothing/interpolation of χ and ϵ values. Taking account uncertainties and a-priori values.
- Examine Clear-air areas to assess polarization x-talk and calibration.

Test using the Halifax scene

Example (Halifax Scene)

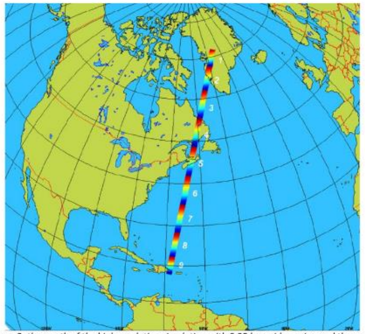
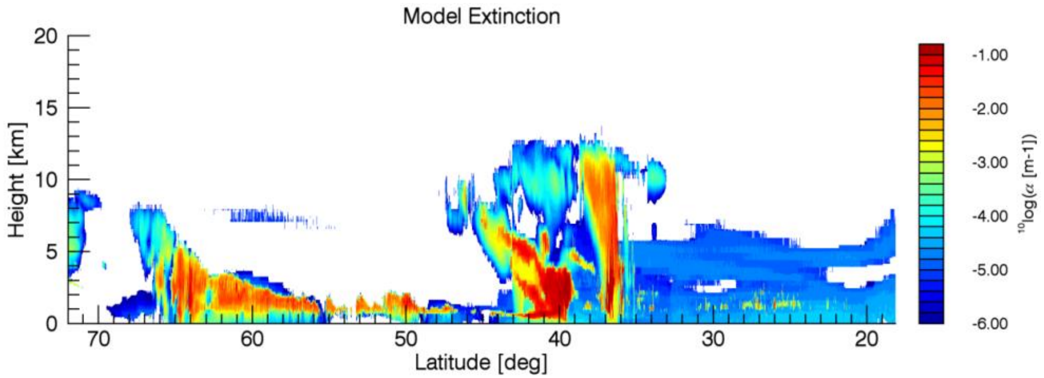
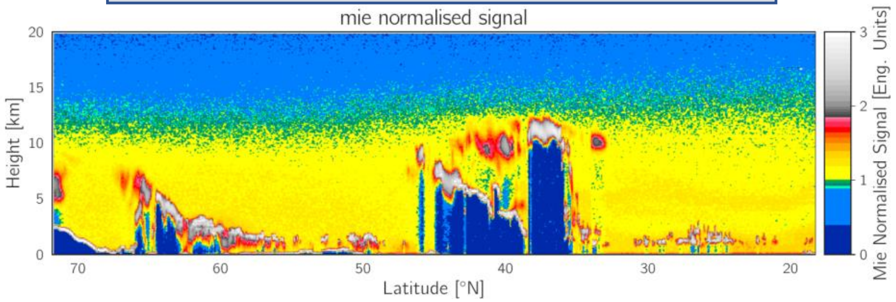


Figure 2: the swath of the high resolution simulation with 0.25 km grid-spacing and the seven section of the separated simulation.

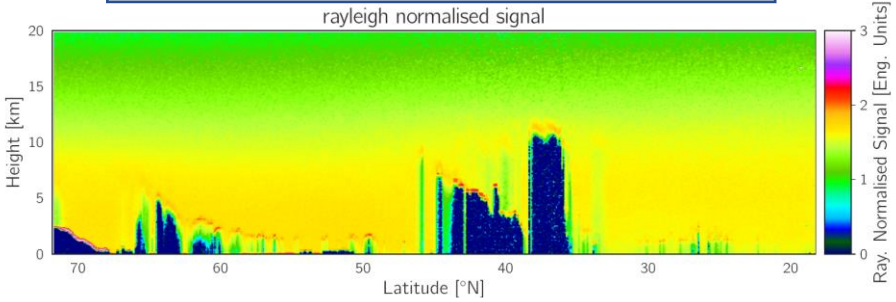


Step before cross-talk correction and atmospheric calibration

Simulated Mie channel normalized signal



Simulated Rayleigh normalized signal



Test using the Halifax scene

Example (Halifax Scene)

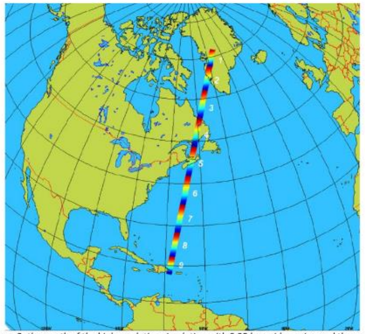
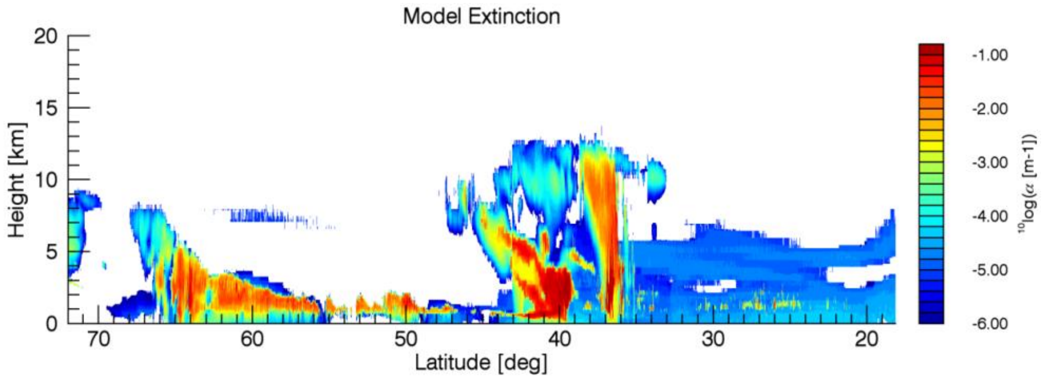
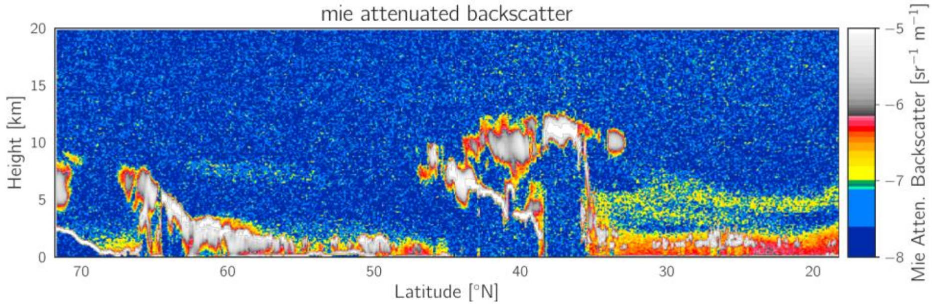


Figure 2: the swath of the high resolution simulation with 0.25 km grid-spacing and the seven section of the separated simulation.

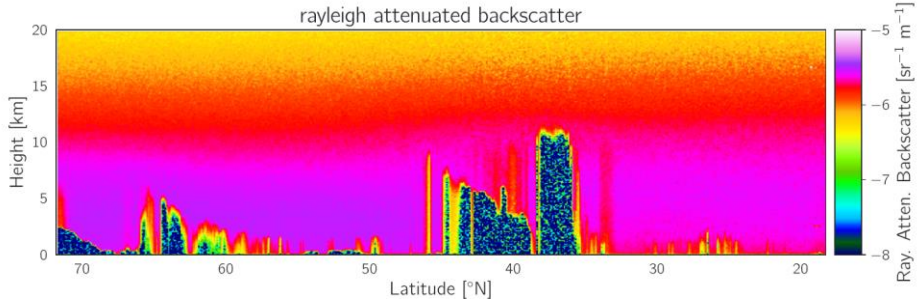


After cross-talk correction and atmospheric calibration

Simulated Mie ATB



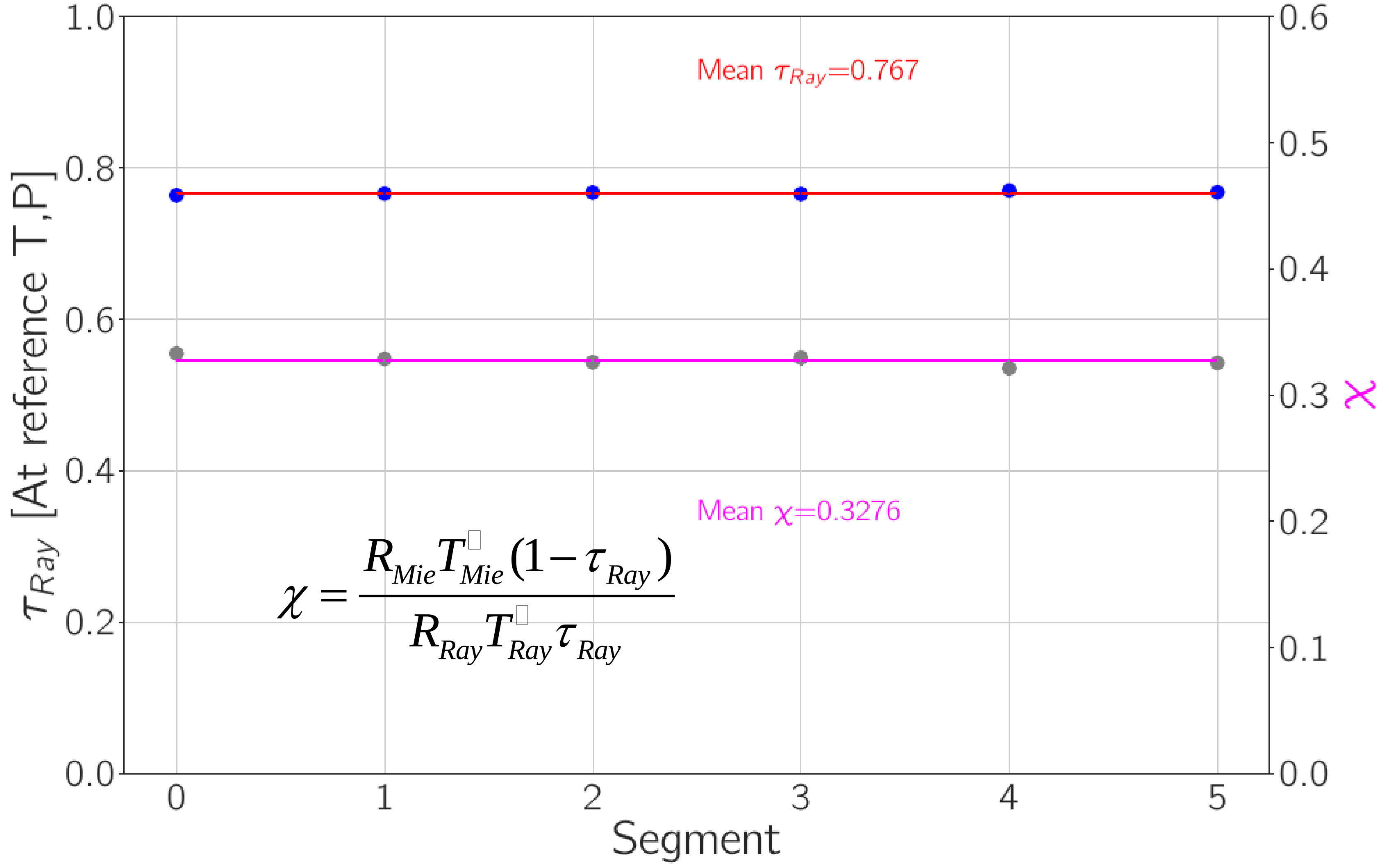
Simulated Rayleigh ATB



Ray ➔ Mie cross-talk

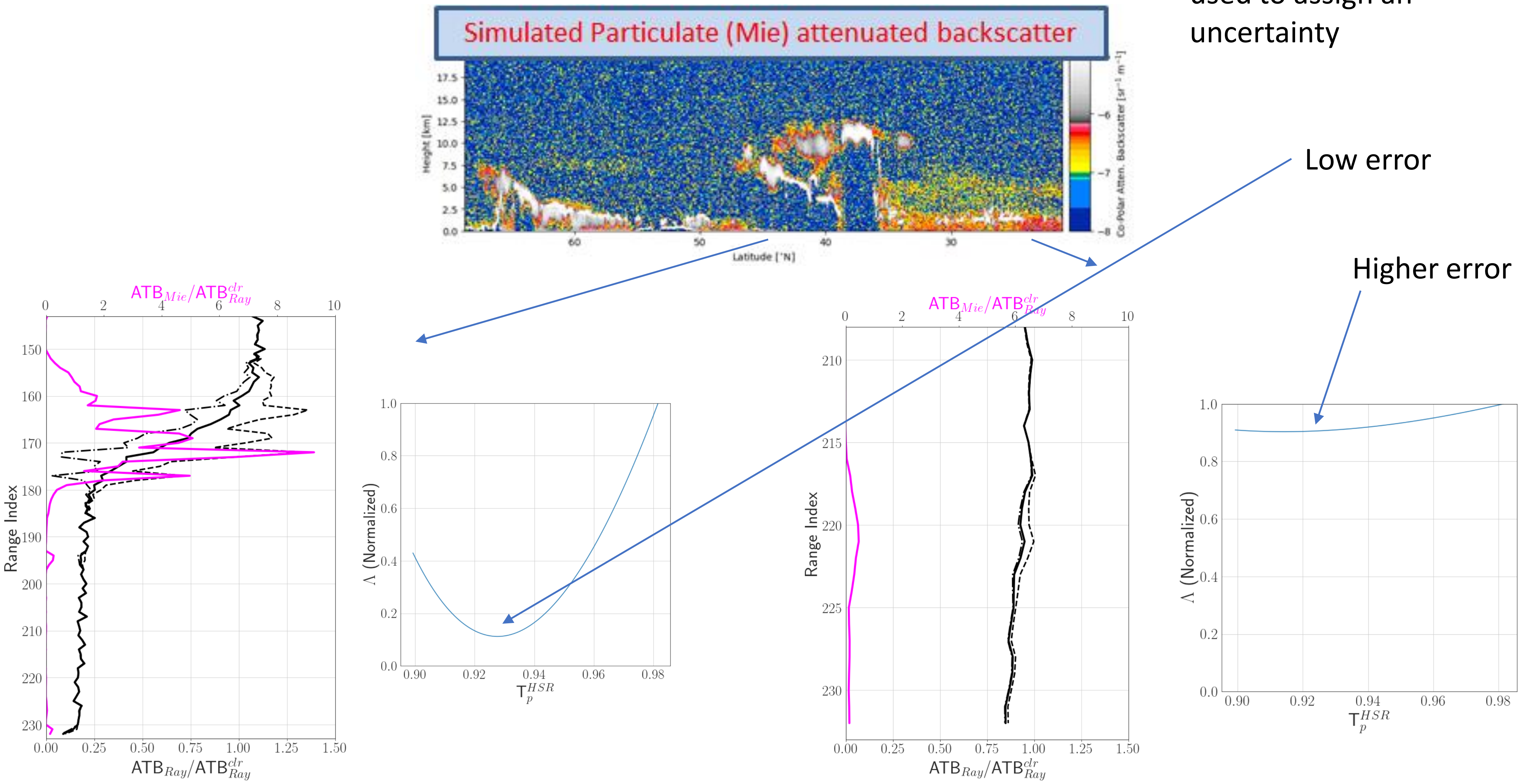
Ratio of Mie and Ray channels above 30 km can be used as a pure Ray input

This allows the Ray➔Mie cross-talk to be assessed.

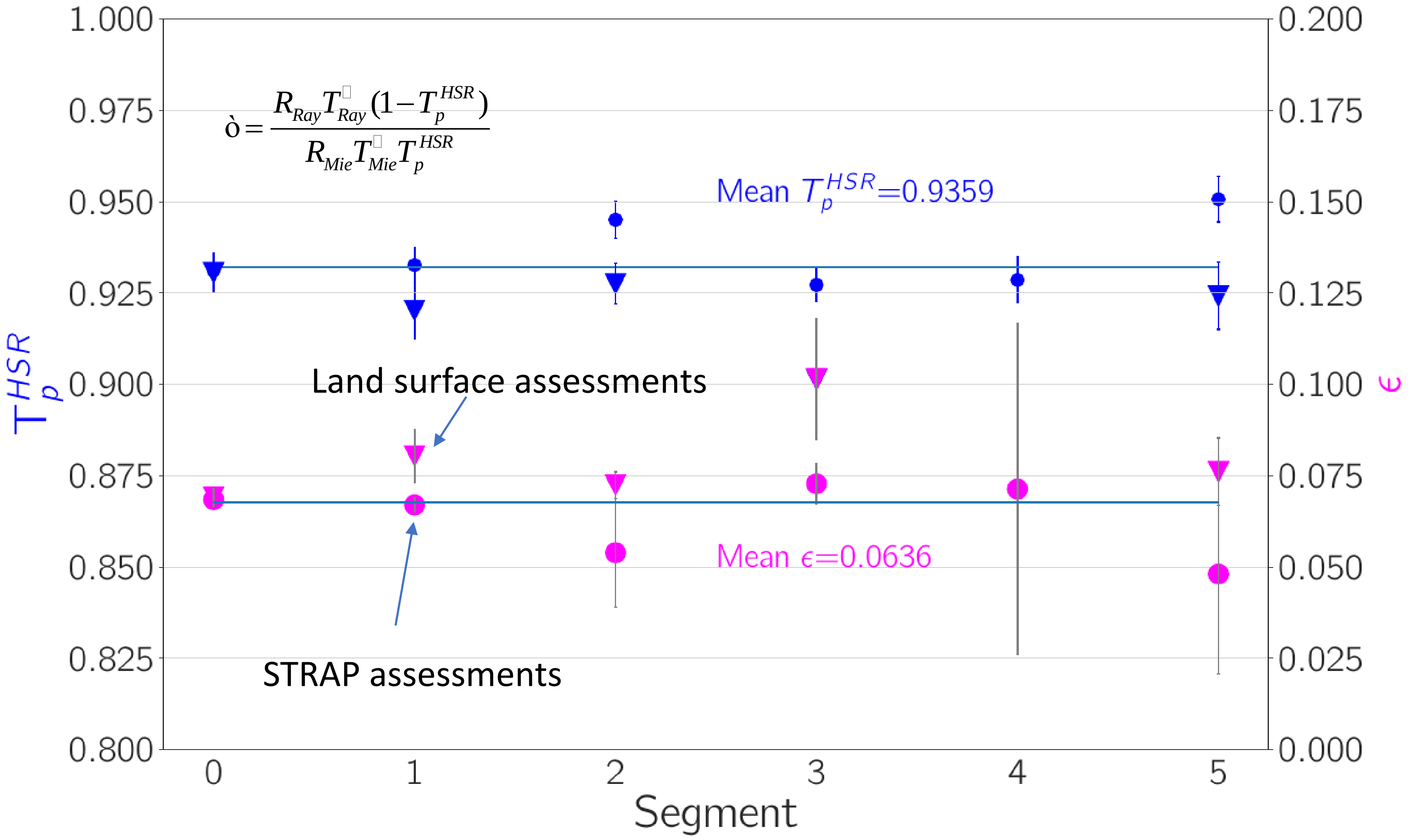


Best Path approach results

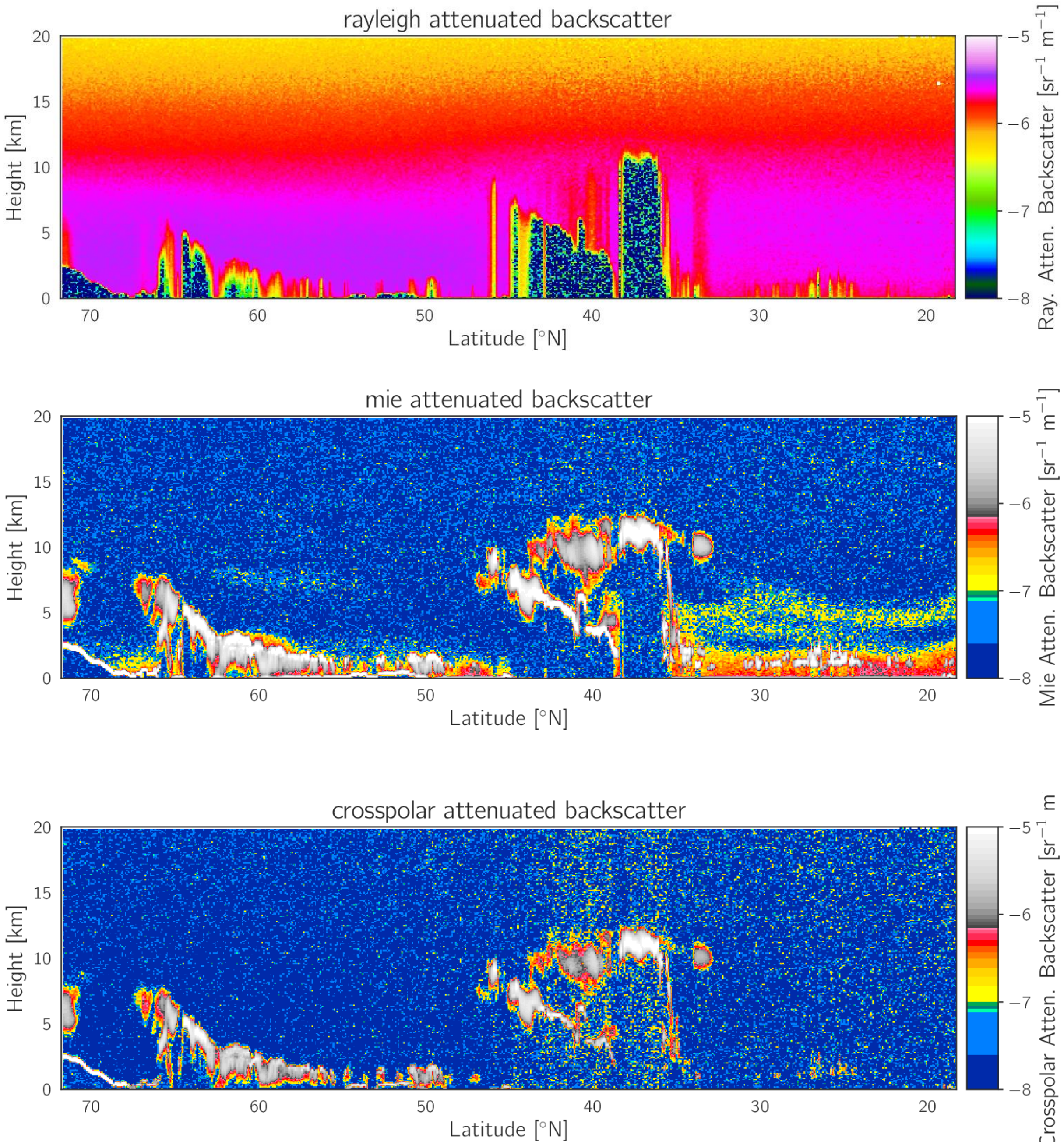
Curvature around minimum is being used to assign an uncertainty



Combined STRAP assessments (circles) and land-return based assessments (Triangles)

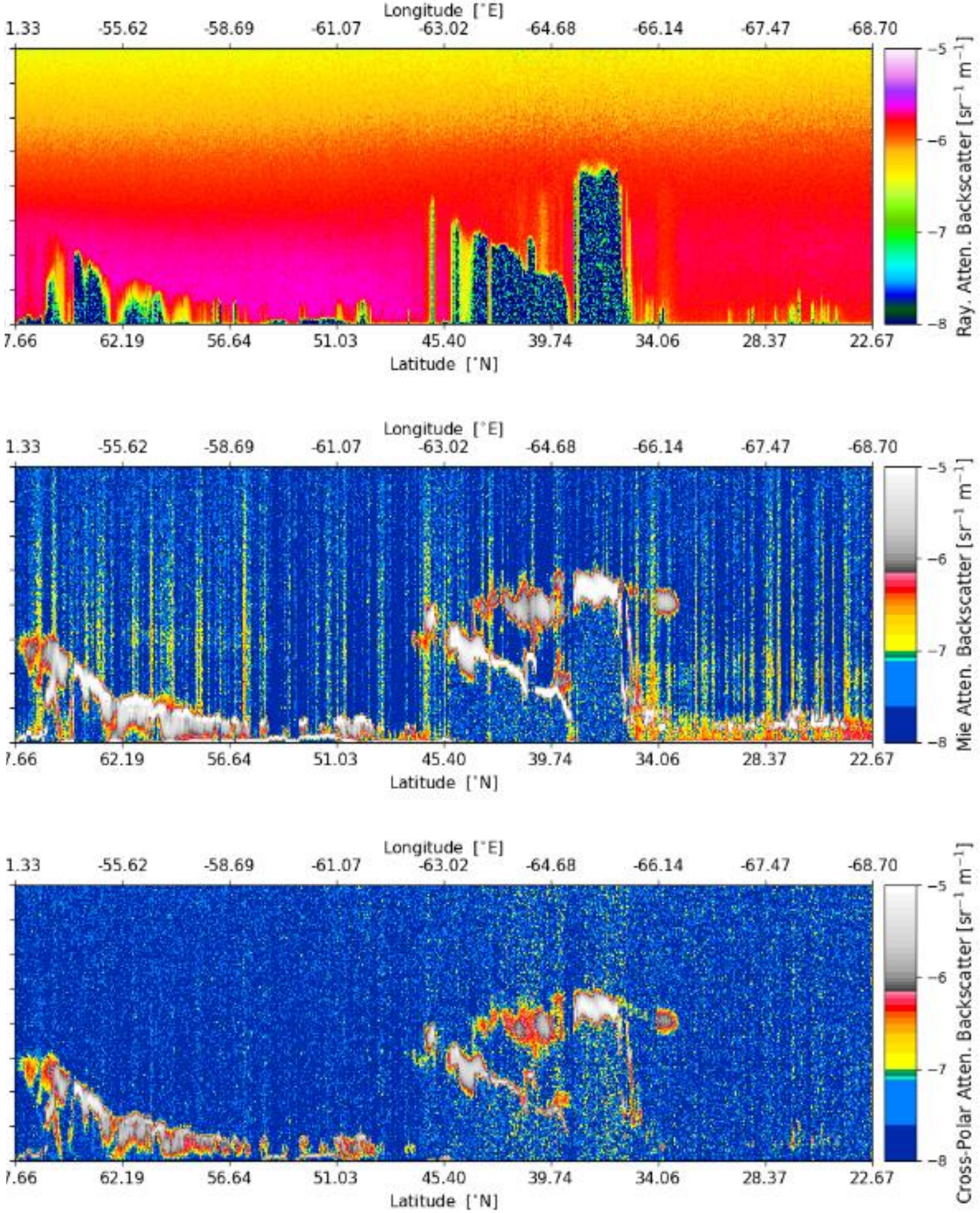


Now !



Reprocessing Halifax scene
Attenuated backscatter :

ECGP: Earlier !



Summary and Outlook

- Problems with the L1 ATLID processor were noticed late…but not too late !
- Innovative robust methods were developed.
- ATBD and working prototype code have bee delivered to ESA for implementation

- **Further monitoring can be done (likely at L2) !**
  - Use of background solar signals above suitable targets could help with the Depol characterization.
  - Assessing the relationship between layer depol and layer integrated attenuated backscatter in water clouds (borrowing a Calipso technique).

L1-ATLID Calibration and Crosstalk Correction (ECGP-L1 ATLID Delta/Post-Processor) ATBD

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Version 0.4

Oct. 27, 2023

Contents

ATBD and prototype working Python application recently delivered to ESA !