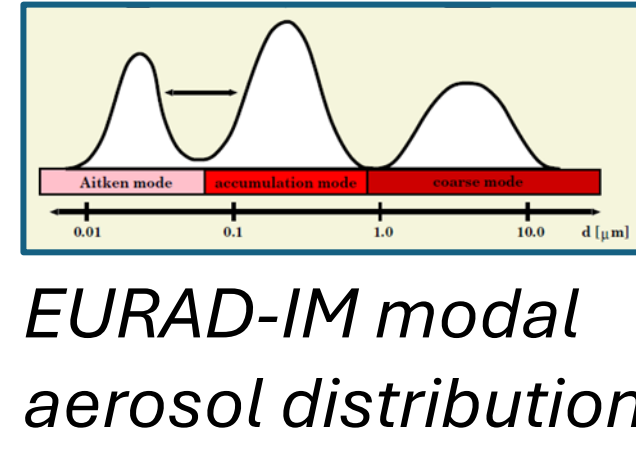


1. Motivation

- Chemical transport models, such as EURAD-IM, provide a 3D representation of atmospheric composition by simulating gas-phase chemistry and aerosols
- Direct comparison of modelled aerosol distributions with aerosol products from EarthCARE's ATLID enables validation during numerous European overpasses
- Data assimilation provides high spatio-temporally resolved analyses, well-suited for validating aerosol vertical profiles

2. EarthCARE observation operator

- EURAD-IM provides aerosol fields as mass and number concentrations
- To enable a comparison with EarthCARE ATLID aerosol extinction profiles, **an observation operator is required to convert modeled aerosol concentrations into extinction coefficients**
- Two conversion methods are explored:



Size-resolved optical formulation
Mie theory

$$\alpha = \alpha_{ait} + \alpha_{acc} + \alpha_{coa}$$

$$\alpha = \int_0^{D_{max}} \frac{\pi D^2}{4} Q_{ext} \cdot n(D) dD$$

α aerosol extinction coefficient
 D aerosol particle diameter
 Q_{ext} extinction efficiency factor
 n particle size distribution

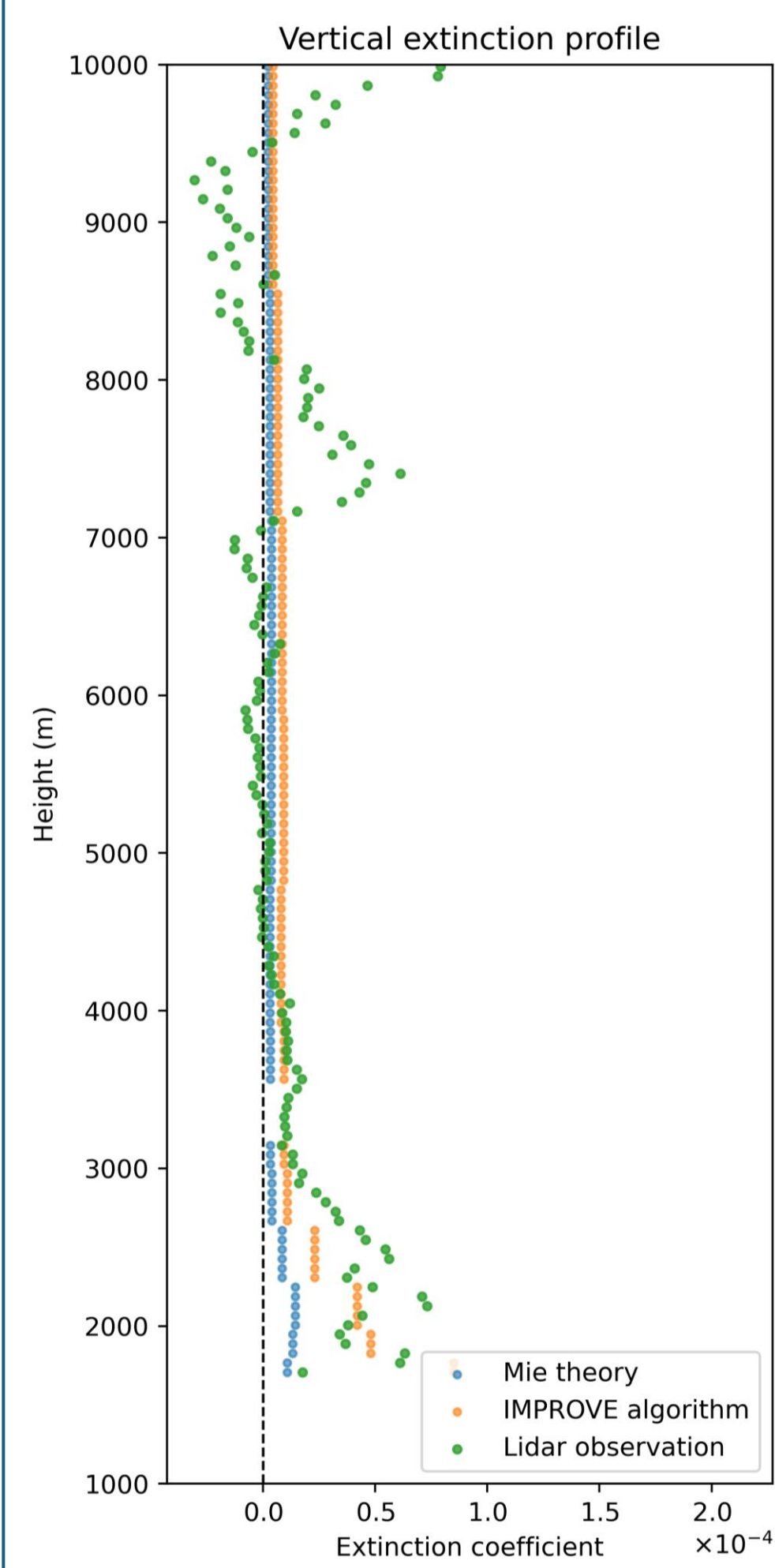
Empirical algorithm
IMPROVE (Pitchford et al., 2007)

$$\alpha = 0.025 f_f [SO_4^{2-}] + 6.6 f_c [SO_4^{2-}] + 3.096 f_f [NO_3^-] + 6.579 f_c [NO_3^-] + 5.04 [ORG_f] + 10.98 [ORG_c] + 10.0 [EC] + 1.0 [SOIL_f] + 1.7 f_{SEAS} [SEAS] + 1.0 [COARSE]$$

α aerosol extinction coefficient
 f_f/c fine/coarse aerosol hygroscopicity
[] aerosol mass concentrations

3. Data assimilation in EURAD-IM

- To improve the EURAD-IM aerosol representation, EARLINET ground-based lidar extinction coefficients are assimilated
- Simulation setup: 9 km grid spacing, 300 s time steps
- 3D-variational data assimilation

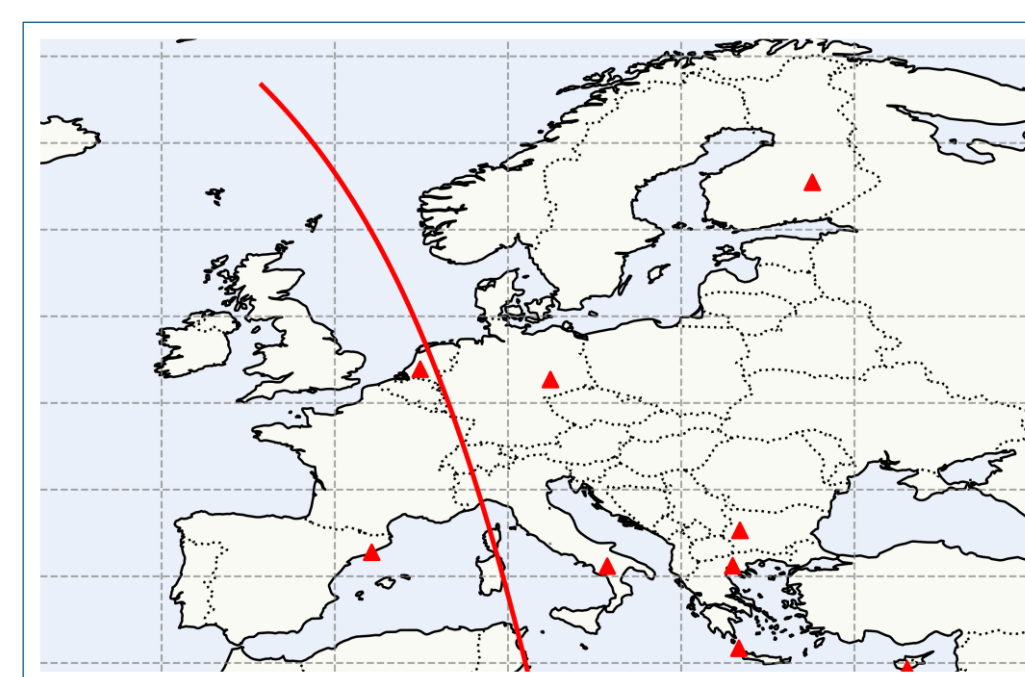


Comparison of a vertical aerosol extinction coefficient profile derived from ground-based lidar observations (green) with the model equivalent aerosol extinction coefficient using Mie theory (blue) and IMPROVE (orange).

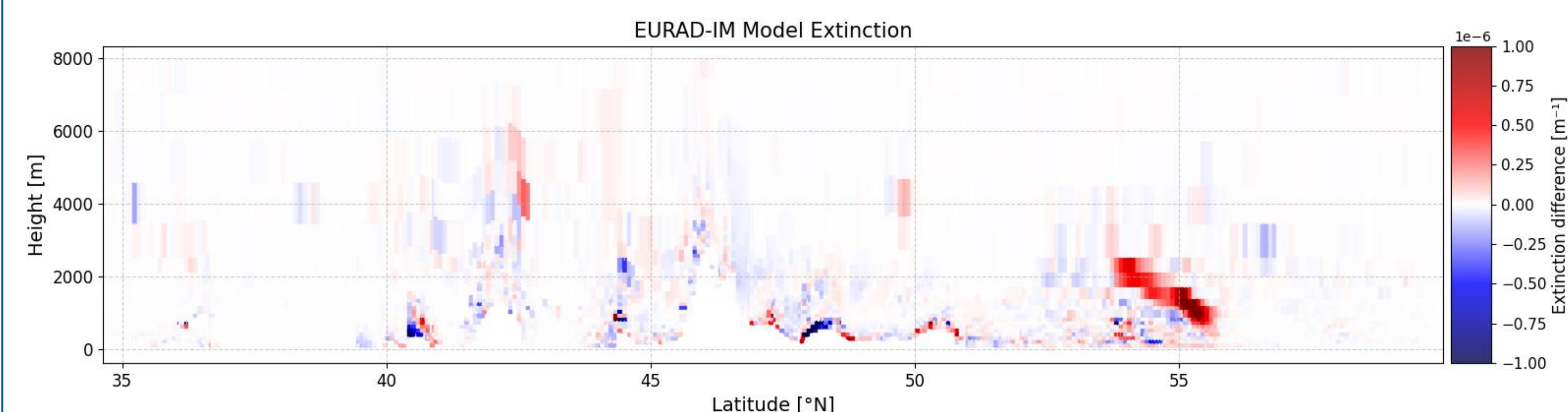
EURAD-IM System



JURECA-DC supercomputer (source: JSC).



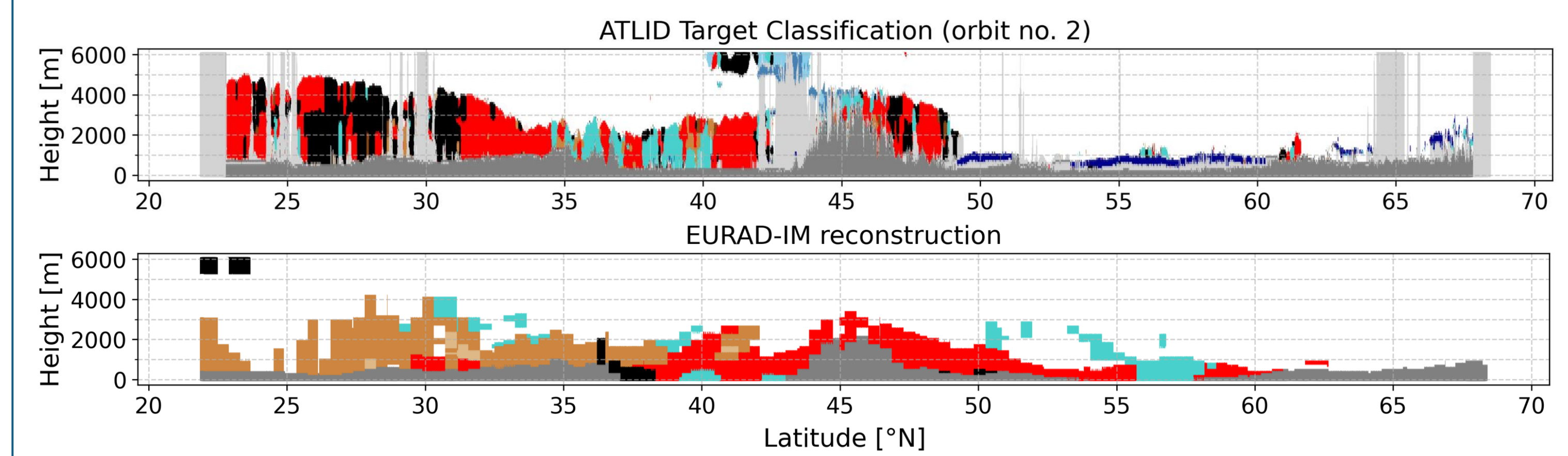
EarthCARE overpass on 13 June 2025 at 00:49 UTC and locations of assimilated ground-based lidar stations.



Aerosol extinction coefficient analysis increment (difference of simulations with and without data assimilation) following the assimilation of ground-based lidar observations along the EarthCARE flight track on 13 June 2025 at 00:49 UTC.

4. Validation of ATLID target classification (A-TC) and extinction coefficients (A-EBD)

A-TC: 5 November 2024

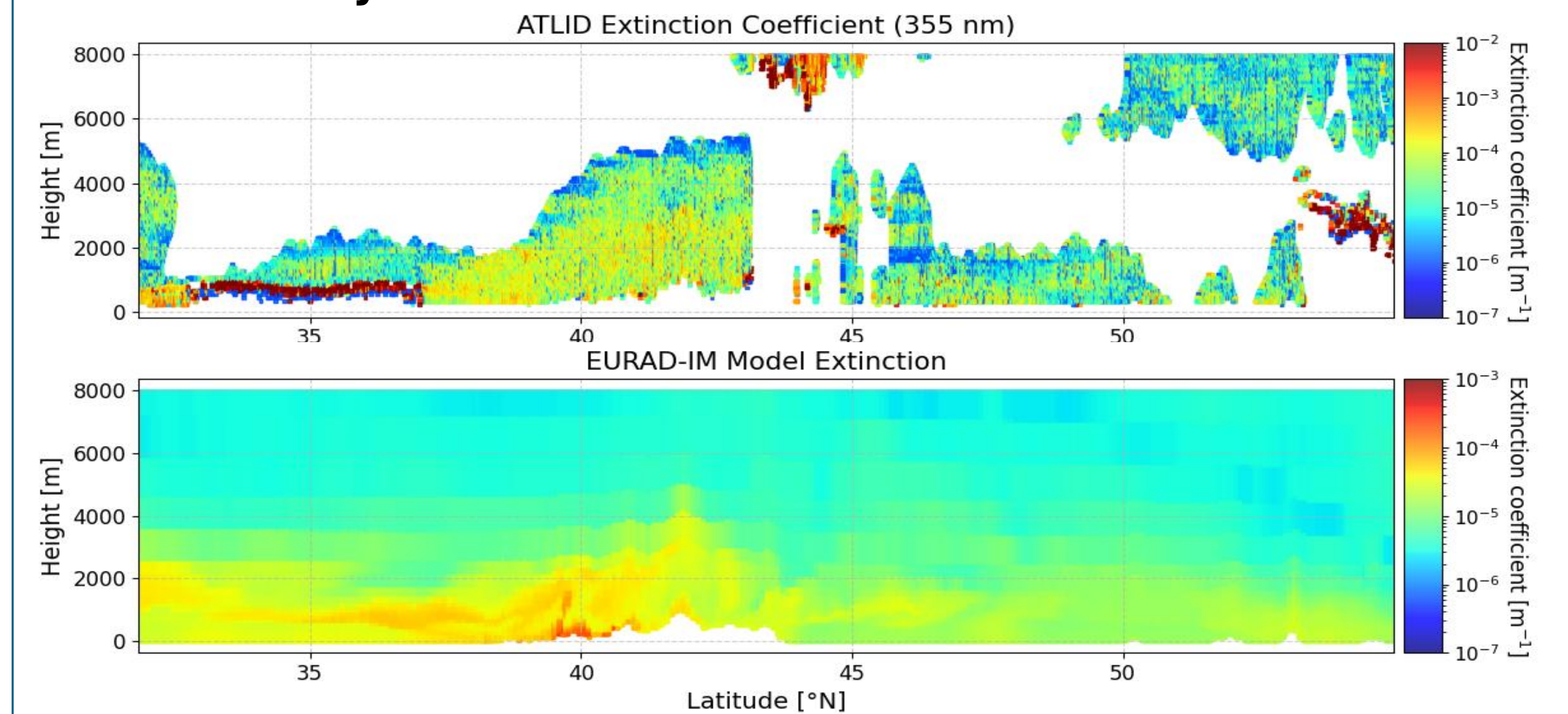


Legend for ATLID target classification:

- Clear
- Missing data
- Surface or sub-surface
- Warm liquid cloud
- Supercooled liquid cloud
- Ice cloud
- Continental pollution
- Sea salt
- Dust
- Dusty mix
- Dusty smoke
- Smoke

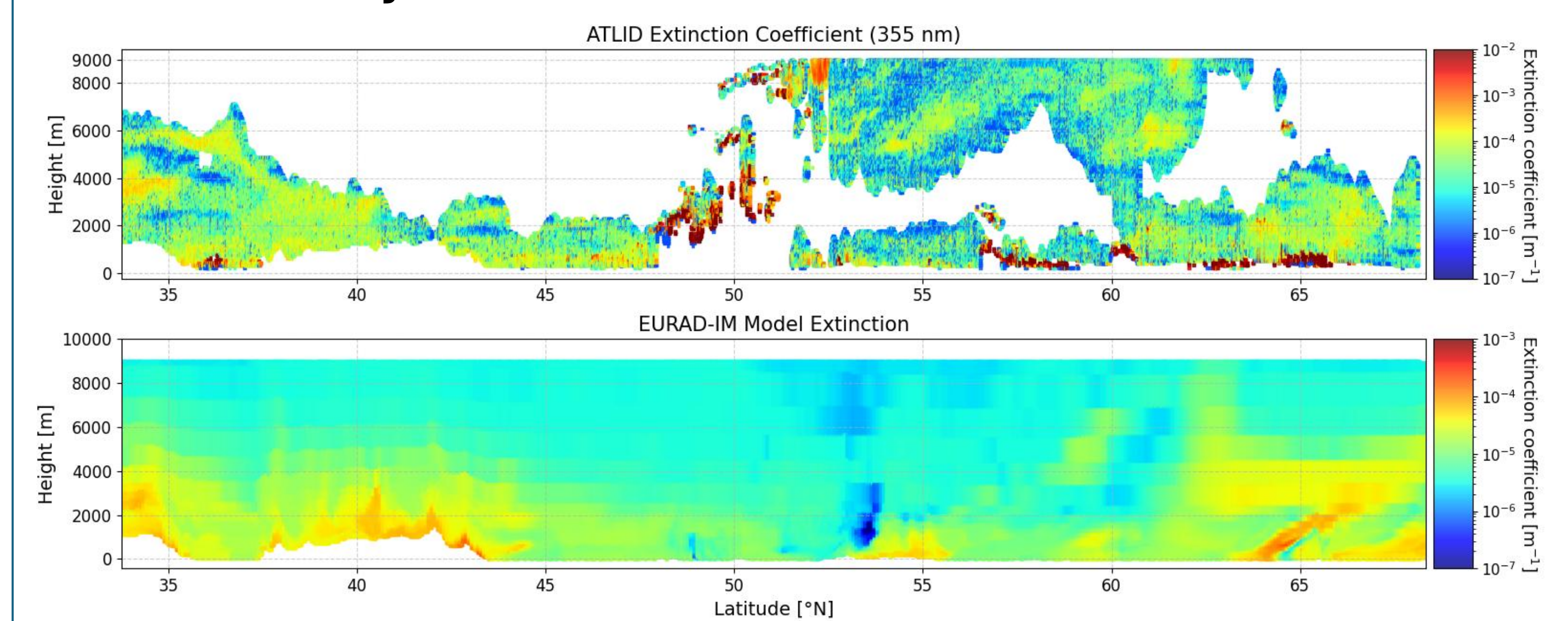
ATLID target classification (top) and reconstructed EURAD-IM target classification (bottom) on 5 November 2024 at 13:54 UTC.

A-EBD: 3 July 2025



ATLID extinction coefficient (baseline BA, top) and EURAD-IM predicted extinction coefficient (Mie, bottom) on 3 July 2025 at 14:46 UTC.

A-EBD: 16 July 2025



ATLID extinction coefficient (baseline BA, top) and EURAD-IM predicted extinction coefficient (Mie, bottom) on 16 July 2025 at 01:37 UTC.

5. Conclusion and future work

- Good agreement between modelled and observed aerosol distributions has been identified
- Further tuning of observation operator for precise validation of ATLID products is required
- Development of a machine learning based observation operator is foreseen to substitute complex radiative transfer calculations
- Assimilation of ground-based aerosol observations with 4D-var will further enhance the vertical and spatial distribution of aerosols enabling a more comprehensive validation and analysis framework

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