Comparison of EarthCARE/ATLID, ICESat-2 and CALIPSO molecular and clouds measurements.

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Introduction

Context

EarthCare/ATLID *[1]* is expected to extend the record of spaceborne LiDAR clouds profiles to observe their variability and possibly changes in response to climate warming. Unfortunately, the CALIPSO/CALIOP mission *[2]*, launched in April 2006, stopped acquiring data in August 2023 before ATLID's launch.

ICESat-2/ATLAS LiDAR, launched in September 2018, is designed for surface altimetry *[3][4]*, but it has flown at the time of CALIOP and is flying at ATLID time.

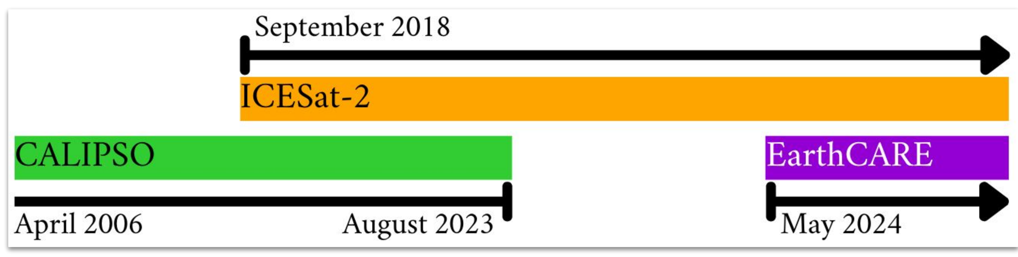

Fig.1: Timeline of satellites missions used in this study.

Motivation

Climate models predict that clouds properties such as cover, opacity and vertical distribution will change in response to global warming. To observe such changes with spaceborne LiDAR, more than 25 years of measurements are needed.

Goals

- Rely on ICESat-2 for satellite-to-satellite validation of ATLID.
- **Bridge the gap in cloud profile observations between CALIOP and ATLID using ICESat-2/ATLAS.**

Method

- **Usually precisely co-located acquisitions** (**500m and 5 minutes**) occur **at latitudes above 70°**. However for a period **≈ 6 weeks** each 8 months flyovers occur **between lower latitudes** as nodal lines are getting closer.
- We are studying 2025-01-01 to 2025-02-14 for EarthCARE/ICESat-2 and 2018-11-01 to 2018-12-14 for CALIPSO/ICESat-2.

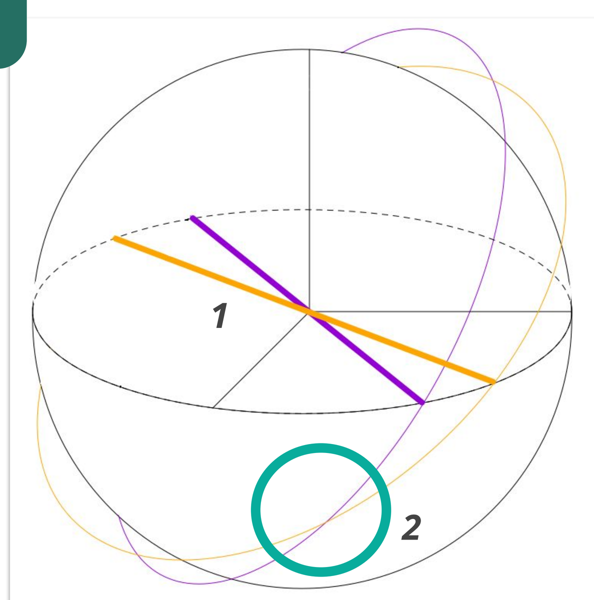

*Fig.2: Illustration of nodal lines (**1**) precession for orbit intersections(**2**).*

Orbital Characteristics[1]			
Parameter	*EarthCARE*	*ICESat-2*	*CALIPSO*
Sun-synchronous	Yes	No	Yes
Nodal precession speed (°/d)	0.99	0.27	0.99
Instrument Characteristics			
Parameter	*EarthCARE*()[2]	*ICESat-2*()[2]	*CALIPSO*
Wavelenght (nm) λ	355	532	532,1064
Pulse rep. frequency (Hz) PRF	51(25.5)	10×10^3 (25)	20
Vertical Resolution[3](m) at altitude level [km] Δz	$\begin{cases} 103 \forall z \in [0, 20] \\ 495 \forall z \in [20, 40] \end{cases}$	$30 \forall z \in [-0.25, 13.75]$	$\begin{cases} 300 \forall z \in [30.1, 40.0] \\ 180 \forall z \in [20.2, 30.1] \\ 60 \forall z \in [8.2, 20.2] \\ 30 \forall z \in [-0.5, 8.2] \\ 300 \forall z \in [-2.0, -0.5] \end{cases}$

[1] Derived from the NORAD TLE at study dates.
[2] Data per shot and summing over the number of shots used per product profile - 2 shots for EarthCARE and 400 for ICESat-2.
[3] Vertical resolution of products.

Table 1: Characteristics of the three satellites in this study.

500m - 5min colocated profiles

Satellite-to-satellite flyovers

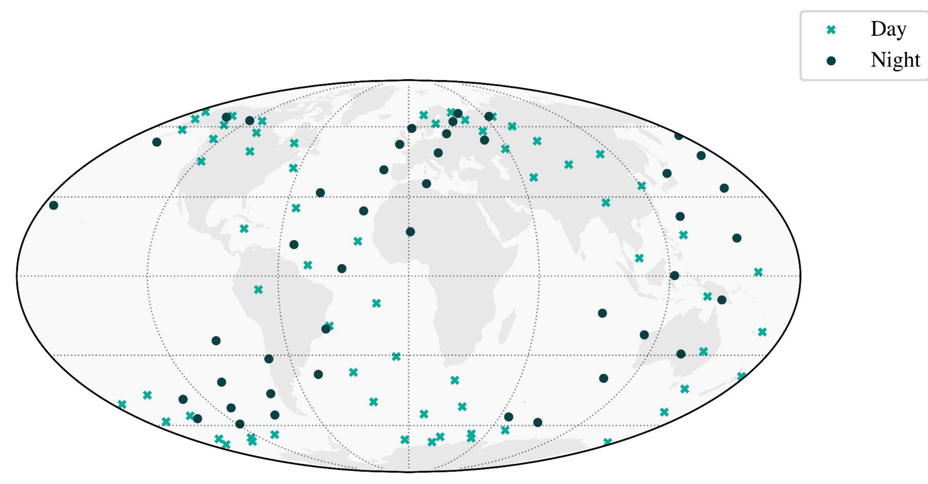

*Fig.3: **ICESat-2/CALIPSO flyovers from 2018-11-01 to 2018-12-14. Case A***

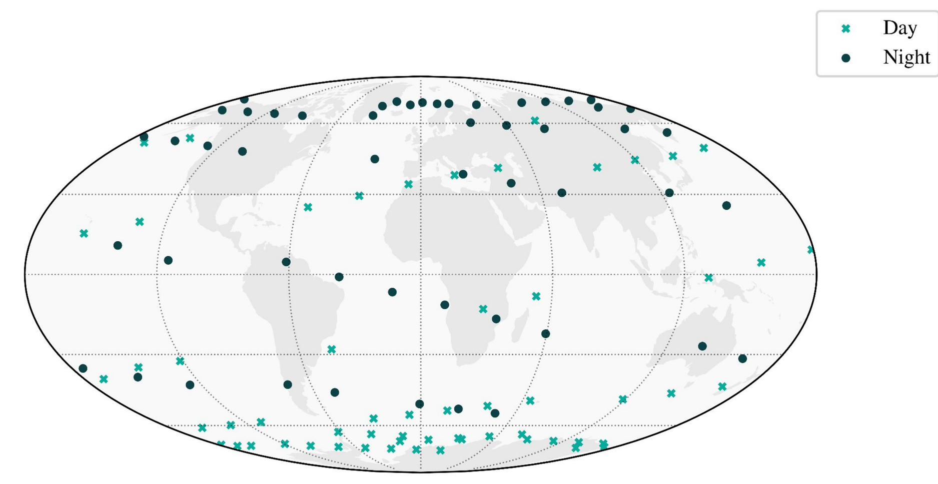

*Fig.4: **ICESat-2/EarthCARE flyovers from 2025-01-01 to 2025-02-14. Case B***

We obtain precise collocations at all latitudes, over land and oceans. For **Case A** (2018), 120 co-located measurements are found. For **Case B** (2025) , 115 co-located measurements are found.

Finding similar profiles

ICESat-2 profiles measured in Case A flyovers that are the more similar as possible to profiles acquired by ICESat-2 during Case B flyovers give an insight into the possibility of gap bridging using ICESat-2. These profiles are identified using Angle Mapper, Pearson correlation and RMSE.

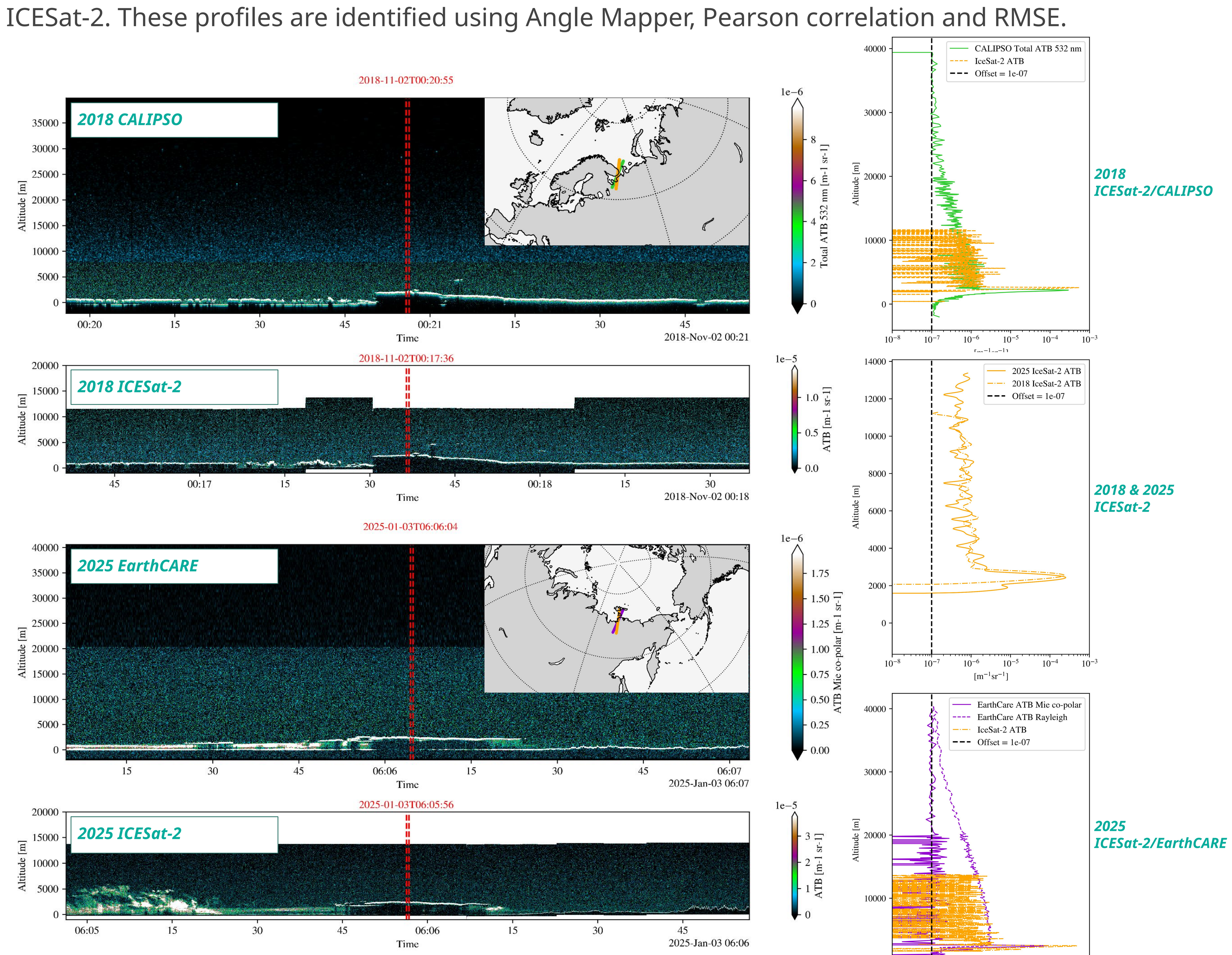

*Fig.5: Two case studies with similar profiles : **2018-11-02 00:20 and 2025-01-03 06:06**. On the middle right-panel the 2018 and 2025 ICESat-2 profiles (filtered) are superimposed.*

Preliminary Cloud Altitudes

Find altitude of the first cloud detected (or surface if clear-sky) using a Canny filter analysing ATBs gradient (ΣΛ = 0.92) *[5]* .

Our method is independent of the retrieval algorithms used by each satellite for layer classification.

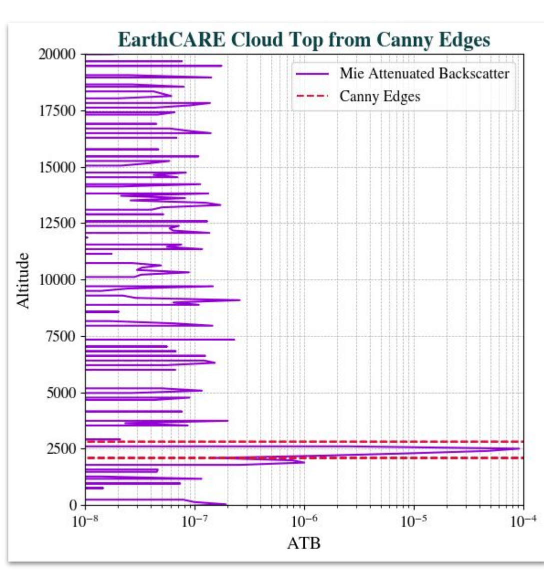

Fig.6: Cloud altitude retrieved in EarthCARE 2025-01-03 profile.

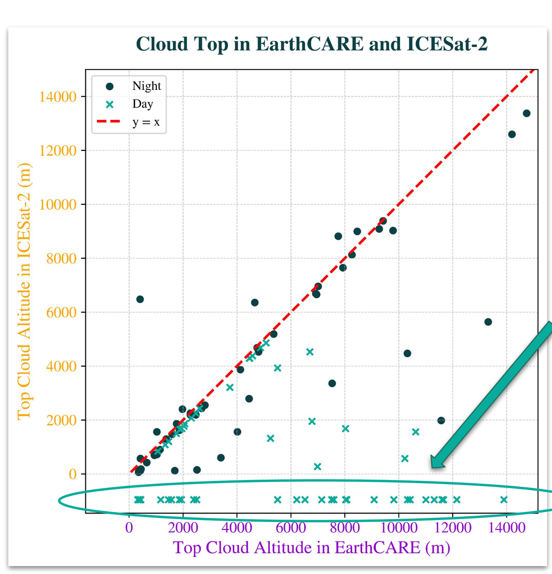

Fig.7: Global retrieving for all EarthCARE / ICESat-2 flyovers

This method is applied to all flyovers of ICESat-2/CALIPSO **Case A** (2018) (not shown here) and ICESat-2/EarthCARE **Case B** (2025) presented here.

Molecular signal above the first cloud

- **Measured molecular signal above the first cloud** detected with the method shown opposite. EarthCARE (EC) Rayleigh channel is noted AMB_{EC} and ICESat-2 ATB is noted AMB_{IS2} .
- **Theoretical molecular signal AMB (λ, θ)** derived from pressure and temperature *[6]*.
- Molecular signal consistency between EarthCARE and ICESat-2 measurements using a ratio expected to give Q ≈ 1.

$$Q = \frac{\mathrm{AMB}_{EC} - \mathrm{AMB}_{IS2}}{\mathrm{AMB(355nm, 3°)} - \mathrm{AMB(532nm, 0°)}}$$

Applied to all **Case B** we found Q=0.94 for nighttime and Q=0.79 for daytime, the latter being affected by undetected clouds. For **Case A**, Q cannot be applied, but we found a similar agreement between measurements and theory.

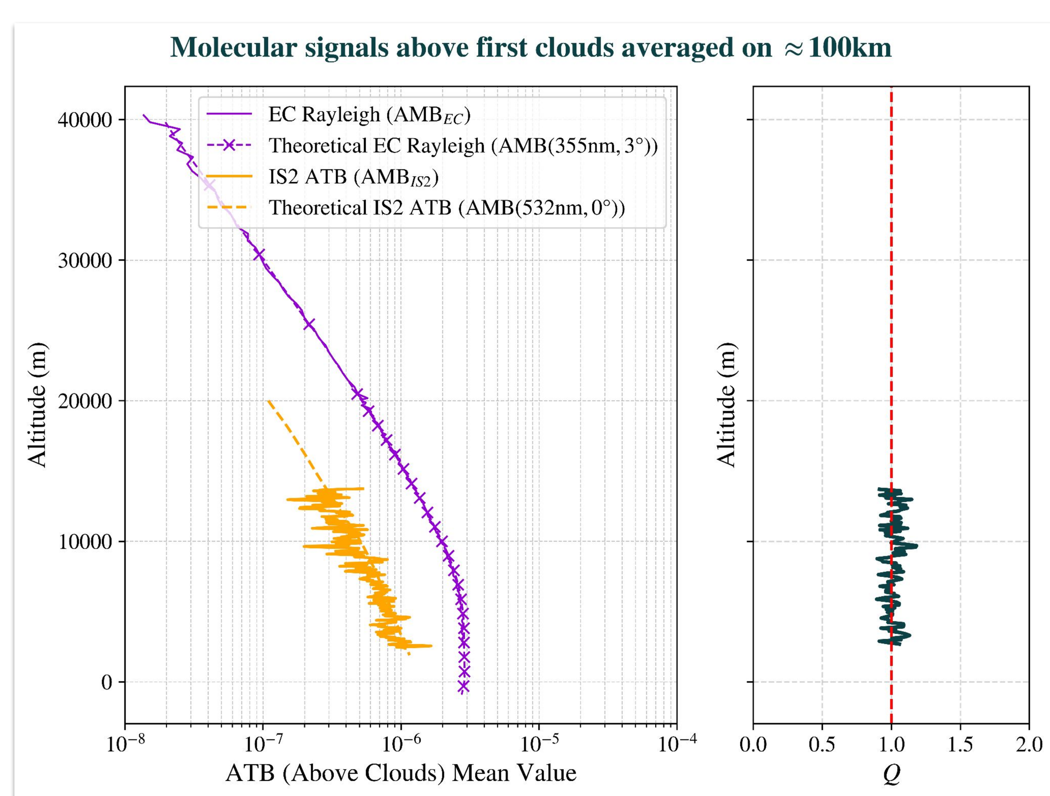

Fig.8: Measured and theoretical mol. signals and Q coeff. for the EarthCARE and ICESat-2 case study 2025-01-03.

Perspectives

- We found precise collocations at all latitudes between ICESat-2 and CALIPSO (2018) as well as between ICESat-2 and EarthCARE (2025).
- Preliminary comparison shows consistency in molecular profile and altitudes retrieved.
- *Perspectives* : Satellite-to-satellite flyovers will be used to bridge the gap between EarthCARE and CALIPSO, as they may be used as constraints on which we are confident about our physical understanding.

References:

[1] T. Wehr et al. In: Atmospheric Measurement Techniques (2023).
[2] David M. Winker et al. In: Journal of Atmospheric and Oceanic Technology (2009).
[3] Stephen P. Palm et al. In: Earth and Space Science (Aug. 2021).
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[5] John Canny. In: IEEE Transactions on Pattern Analysis and Machine Intelligence (1986).
[6] R. T. H. Collis and P. B. Russell. In: Laser Monitoring of the Atmosphere. Ed. by E. David Hinkley. Springer Berlin Heidelberg, (1976).

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