Assessing EarthCARE Ability to Detect Polar Stratospheric Clouds Over Antarctica: Insights from Ground-Based Lidar Observations at Concordia Station

Bracci A.[1], Pasqualini F.[1], Roversi G.[1,2], Colao F.[3], Di Liberto L.[1], Snels M.[1]

[1] CNR - Institute of Atmospheric Sciences and Climate (CNR-ISAC), Rome, Italy; [2] Ca' Foscari University, Venice, Italy ; [3] ENEA, Frascati, Italy

Contact: a.bracci@isac.cnr.it

Polar Stratospheric Clouds and Their Role in Atmospheric Chemistry

Polar Stratospheric Clouds (PSCs) form in the **winter polar stratosphere** at altitudes between **15 and 25 km**, when temperatures drop below **195 K (-78°C)**. They play a crucial role in **ozone depletion**, **dehydration**, and **denitrification**, altering the stratospheric chemical balance.

PSCs provide surfaces for **heterogeneous reactions** that activate chlorine and bromine compounds, accelerating **ozone destruction** in early spring. They also contribute to **denitrification** by removing nitric acid from the gas phase, prolonging ozone loss conditions.

PSC Classification

PSCs are divided into two main types:

- **Type I PSCs (Nitric Acid Clouds)** (*195 K > T > 188 K*):
  - **Type Ia (NAT PSCs)**: Solid **Nitric Acid Trihydrate (NAT)** particles, which **depolarize lidar signals**.
  - **Type Ib (STS PSCs)**: Liquid **Supercooled Ternary Solution (STS)** droplets (H_2O, HNO_3, H_2SO_4), which do **not** depolarize lidar signals.
  - Externally mixed clouds with both NAT and STS are also common.
- **Type II PSCs (Water Ice Clouds)** (*T < 188 K*):
  - Composed of **pure water ice**, forming below the frost point.
  - Strongly **depolarize lidar signals** due to their crystalline structure.
  - Promote the most efficient **heterogeneous ozone depletion reactions**.

Why Are PSCs Important?

- **Trigger ozone depletion** by activating chlorine and bromine.
- **Drive denitrification**, enhancing ozone loss.
- **Modify stratospheric water vapor**, affecting climate processes.

Satellite lidars, like CALIOP in the past and EarthCARE ATLID now and in the future, are improving global PSC detection and characterization.

With CALIPSO decommissioned in 2023, **EarthCARE ATLID validation is crucial for accurate PSC climatologies and improved satellite-based atmospheric models.**

Why Validate EarthCARE ATLID with Ground-Based Lidar at Concordia?

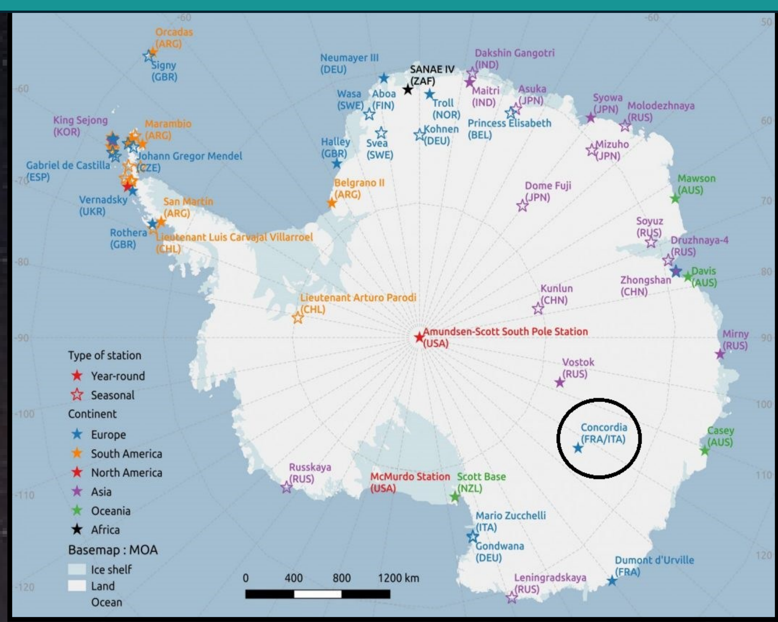
Concordia Station (75.1°S, 123.3°E), located on the **Antarctic Plateau at 3233 m altitude**, offers an **optimal site** for **PSC validation** due to:

- **Minimal tropospheric cloud cover** → Reduces interference in lidar measurements.
- **Stable position within the Antarctic polar vortex** → Ensures frequent and long-lasting PSC occurrences during Austral winter.
- **Continuous ground-based lidar observations since 2014** → Provides a reliable dataset for comparing **EarthCARE ATLID retrievals** with independent measurements.

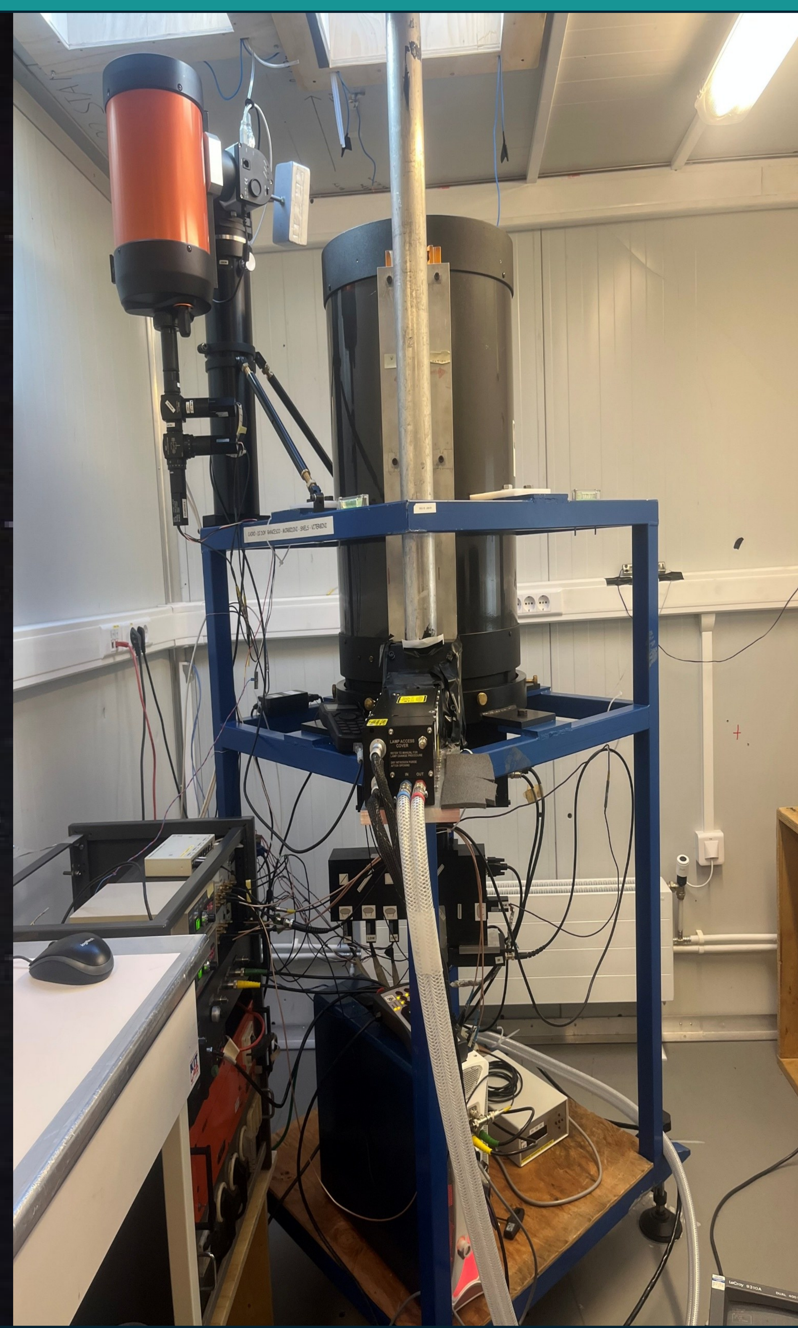
By comparing **ATLID observations** with Concordia **high-resolution polarization lidar**, we can:

- **Assess PSC detection accuracy** → Validate ability of ATLID to identify the occurrence, altitude.
- **Improve PSC classification algorithms** → Use polarization data to refine ATLID discrimination of **NAT, STS, and Ice PSC**.

The long-term lidar dataset from Concordia Station can represent a key reference for the validation effort of PSC detection and characterization.

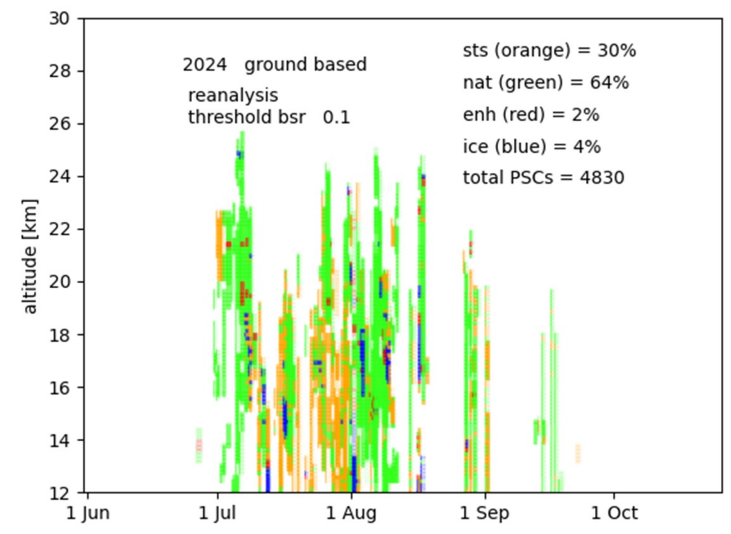


LASER SOURCE	Nd-YAG
Wavelength	1064nm - 532nm
Total Energy	200 mJ/pulse
Repetition Rate	10 Hz
TELESCOPE	
Strato-Tropo	diam: 355.6 mm
Tropo	diam: 152.4 mm
RECEIVER	
Strato-Tropo	1064nm - 608nm 532nm // (Hi-Low) - 532nm _|_ **Next Implementation: 355 // and _|_ (Matching ATLID- Planned 2025)**
Tropo	608nm - 532nm // - 532nm _|_
AQUISITION	Automated - Remote Controlled
DATA TRANSFER	Near Real time



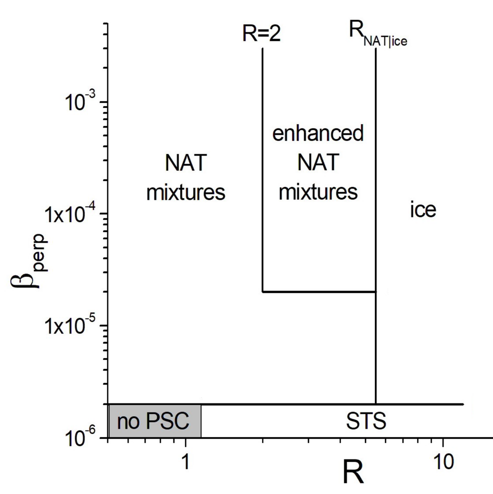
First Comparison of PSC Observations during the 2024 Austral Winter

Concordia Lidar Detection and Classification

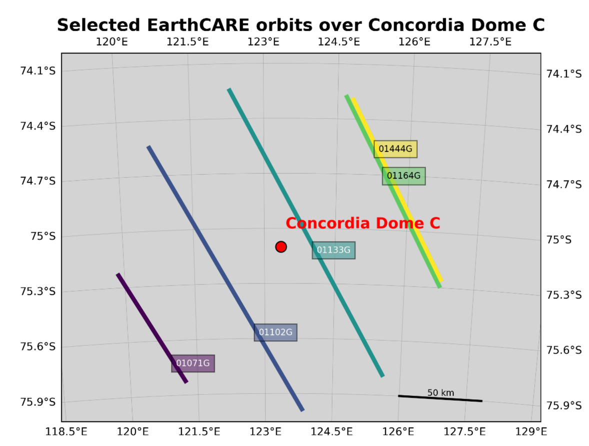


PSC detection, distribution, and classification at Concordia Station based on ground-based lidar observations with a **BSR threshold of 0.1**. PSC were detected from **1 Jul to mid September**, with **NAT** clouds being the dominant type throughout the period. The plot clearly shows the **seasonal variation in PSC**, with their altitudinal distribution ranging from **12 km to 26 km**. The year **2024** was marked by two sudden stratospheric warming (**SSW**) events which led to the disappearance of **PSC** in **mid-July** (upper stratosphere) and **mid-August**.

For detection and classification, an algorithm was used that follows the same approach and utilizes the same optical parameters as the **v2 CALIOP algorithm** for PSC. This algorithm combines the **Backscatter Signal Ratio (R)** and the **perpendicular backscatter coefficient** to classify the PSC effectively.



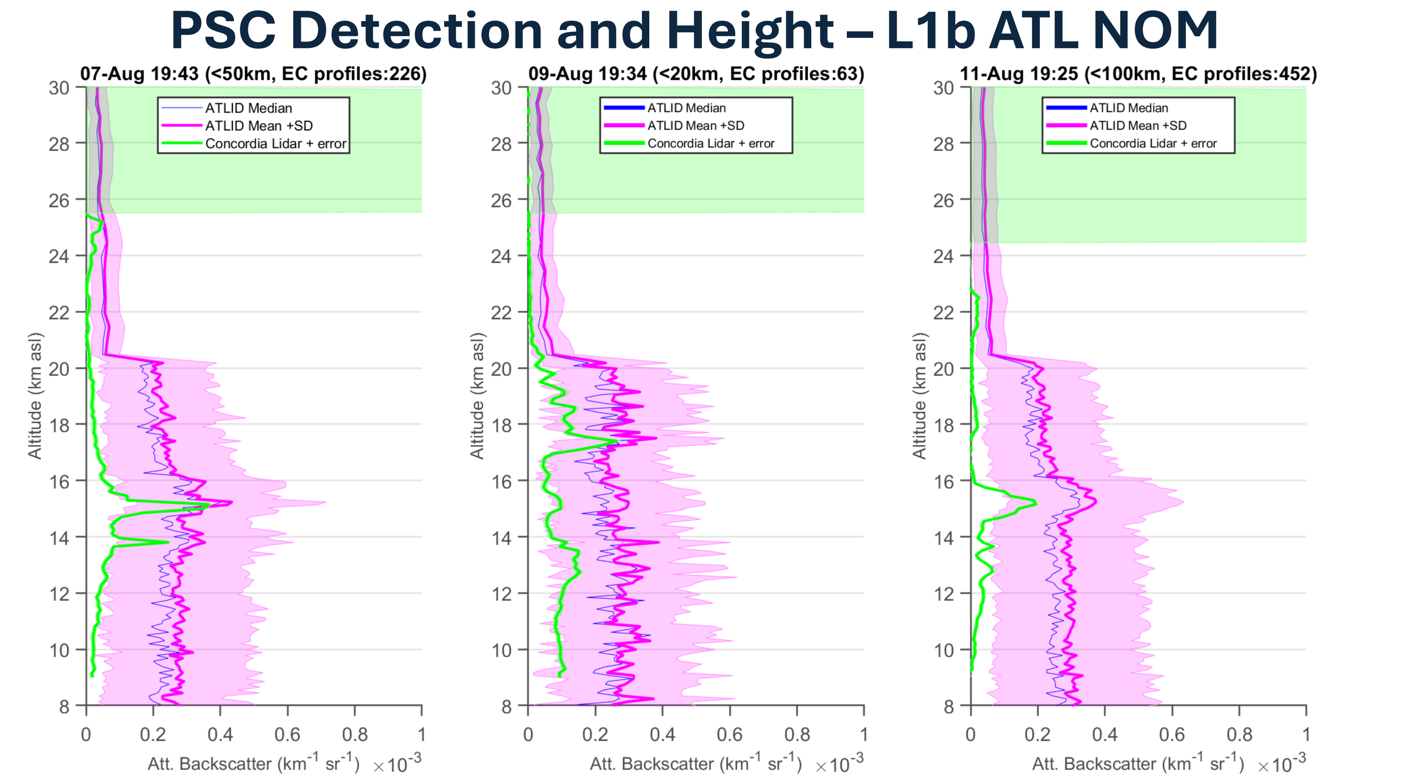
Validation of EarthCARE ATLID PSC Observations



Five overpasses with **PSC presence**, within a maximum distance of **100 km from Concordia**, were identified during the **2024 austral winter season**. The table presents the corresponding **dates, orbits,** and the **minimum distance from Concordia** for each overpass. Additionally, it includes the **baseline versions** of the **Level 1 and Level 2 products** used in this analysis.

Date	Orbit	Min. Distance	Baseline L1 and L2 Products
5 August	01071G	92,41 km	AC (only L1)
7 August	01102G	38,40 km	AC (only L1)
9 August	01133G	17,95 km	AC (only L1)
11 August	01164G	76,72 km	AC
29 August	01444G	79,32 km	AC

PSC Detection and Height – L1b ATL NOM

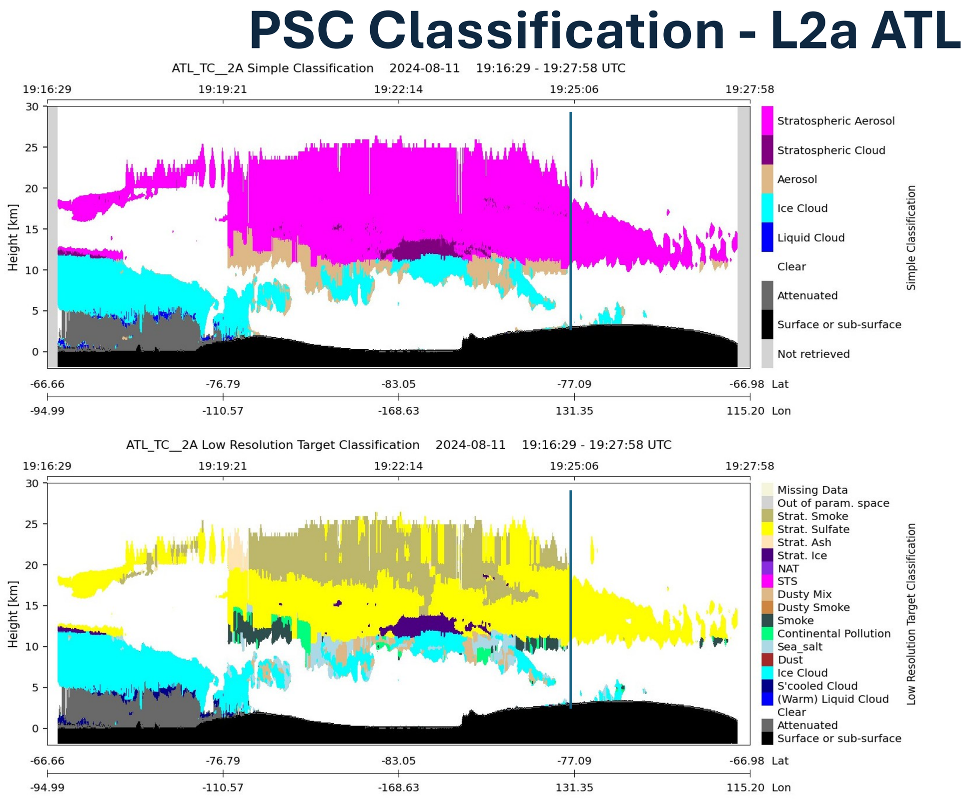


Comparison of attenuated backscatter signal from the **Concordia lidar** (green) with **ATLID data** (pink). For Concordia, **16 profiles** (2 minutes each, totaling **32 minutes**) were averaged around the overpass time. For EarthCARE, different averaging methods were tested based on the **minimum overpass distance** from Concordia, as shown in the table. The **number of EC profiles** and **maximum distance considered** are displayed in the figure.

ATLID aligns well with PSC detection of Concordia, matching both the **intensity** (considering wavelength differences) and **altitude** of the PSC layer, even in cases of overlapping layers (e.g., **07-Aug**).

Some comparison days fall before **ATLID optimal settings** for correlative measurements. Combined with limited cases due to the **early PSC season start**, this suggests that further analysis is needed in the next **Antarctic winter season** to build a more robust dataset and gain deeper insights into PSCs over Antarctica.

PSC Classification - L2a ATL TC



Classification results for **ATLID L2 data** on **11-Aug: Simple Classification** (top) and **Low Resolution Target Classification** (bottom). The vertical lines indicate the overpass time over Concordia Station.

While signal detection appears accurate, classification is more challenging. **ATLID** detects the signal but likely considers it too weak to be identified as a **PSC**, classifying it as **Stratospheric Aerosol** and **Stratospheric Sulfate**.

In contrast, the **Concordia lidar**, previously compared with **CALIPSO**, identifies the signal as **PSC** with **STS characteristics**, using **CALIPSO classification scheme**.

Understanding the **thresholds for stratospheric aerosol and cloud classification** and the **target classification in the ATL_TC product** is crucial for improving the comparison between the **Concordia lidar** and **ATLID**. This knowledge enhances **classification accuracy** and **PSC detection**. **Investing in this area** is essential for **EarthCARE validation**, improving **data interpretation** and supporting future **PSC studies and validation efforts**.

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