Long-term Analysis of Vertically Resolved Cloud Observations at Ny-Ålesund (Svalbard) using Self-Supervised Deep Learning

Climate change is particularly evident in the Arctic, where warming between 1979 and 2021 was almost four times faster than the global average (Rantanen et al., 2022). However, this temperature increase is not uniform across the region. For example, the Svalbard archipelago, situated in the warmest part of the Arctic, has experienced the most significant warming (Dahlke and Maturilli, 2017).

The role of clouds in the rapidly changing Arctic climate system, along with the underlying processes, remains a major area of investigation. While detailed cloud observations are crucial, there are few Arctic locations where continuous, high-resolution vertical cloud measurements are conducted. One such site is the German-French Arctic Research Base AWIPEV, located at the Ny-Ålesund Research Station in Svalbard. Since 2016, a 94 GHz cloud radar has been operational here as part of the Transregional Collaborative Research Centre TR172 on Arctic Amplification $(AC)^3$ (http://www.ac3-tr.de; Wendisch et al., 2023). Combined with existing remote sensing tools such as ceilometers and microwave radiometers, this setup enables continuous monitoring of clouds with high temporal and vertical resolution. This presentation will showcase key findings from these multi-year cloud radar observations.

At Ny-Ålesund, clouds are present 78% of the time, with the highest occurrence observed in low-level clouds between 0.5 and 1.5 km altitude. Pure liquid water clouds display a clear seasonal cycle, whereas mixed-phase clouds, containing both liquid and ice, are present throughout the year, averaging 42% of the time. These liquid-containing clouds significantly influence surface radiative fluxes, with an overall net warming effect of clouds of approximately 11 Wm^{-2}.

A novel approach to efficiently characterize the long-term observations of diverse cloud systems over Ny-Ålesund is by using a self-supervised deep learning framework. This framework is designed to learn the complex relationships within the sub-hourly, multi-scale measurements from radar collected from 2017 to 2021. During training, it captures the non-linear, orthogonal aspects of the clouds' vertical and temporal structure and distributions over the Ny-Ålesund column and extracts the essential low-dimensional features. Sensitivity tests are conducted by combining different measurements and observing the resulting changes in the extracted features. Analyzing this low-dimensional representation of the entire cloud measurement time series provides valuable insights into cloud evolution and its connection to environmental conditions.

Acknowledgment: We gratefully acknowledge the funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project Number 268020496 – TRR 172, within the framework of the Transregional Collaborative Research Center "ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms $(AC)^3$". We also acknowledge the support by AWIPEV for the project AWIPEV_0016.