Climatology of clouds containing supercooled liquid in the Western and Central Arctic

Pablo Saavedra Garfias[1], Heike Kalesse-Los[1], and Willi Schimmel[1]

[1]University of Leipzig

January 20, 2023

Abstract

Long-term measurements at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) at the North Slope Alaska (NSA) site in Utqiagvik, Alaska and from the Multidisciplinary drifting Observatory for the study of the Arctic Climate (MOSAiC) expedition are being used to study the climatology of clouds containing supercooled liquid (SCL) in the Western and Central Arctic. Classification of cloud hydrometeors in the liquid, ice or mixed phase of the cloud is determined by using the Cloudnet algorithm developed by the Finish Meteorological Institute. We apply the Cloudnet processing chain to a set of ground-based remote sensing measurements from the NSA site and the ARM mobile facility and the TROPOS shipborne atmosphere observation suite (OCEANET) on board of the RV Polarstern research vessel during MOSAiC. In order to accurately detect cloud droplets and SCL layers within mixed-phase clouds, Cloudnet relies on lidar observations. Lidars however suffer from total signal attenuation at a penetration optical depth of about three. Conversely cloud radars with their capability to penetrate multiple liquid layers can be used to expand the identification of cloud phase to the entire vertical column beyond the lidar signal attenuation height by using information of the cloud radar Doppler spectrum. The Leipzig Institute for Meteorology (LIM) recently developed a deep learning approach for reVealing supercOOled liquiD beyOnd lidar attenuatiOn (VOODOO) which benefits from the morphological features in cloud radar Doppler spectra to extract further information related to the existence of SCL using Cloudnet's target classification as supervisor. The current contribution presents a SCL climatology obtained using Cloudnet for the NSA site along with case-studies for MOSAiC where VOODOO results are contrasted with the standard Cloudnet outputs. Advantages and limitations of both methods will be presented to the scientific community.

UNIVERSITÄT LEIPZIG

Climatology of clouds containing supercooled liquid in the Western Arctic

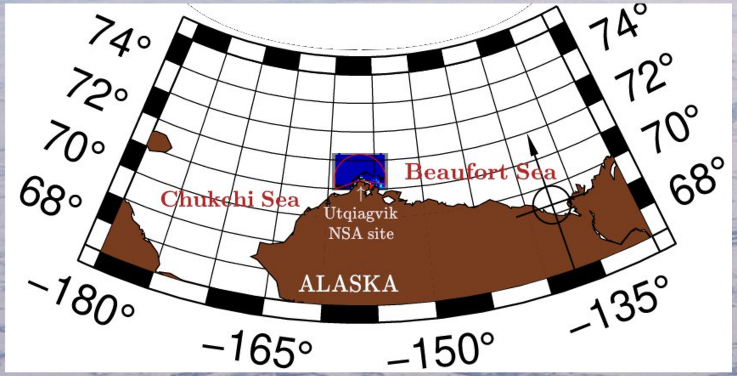
Pablo Saavedra Garfias, Willi Schimmel, Heike Kalesse-Los

Leipzig Institute for Meteorology
University of Leipzig
16th December 2021

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

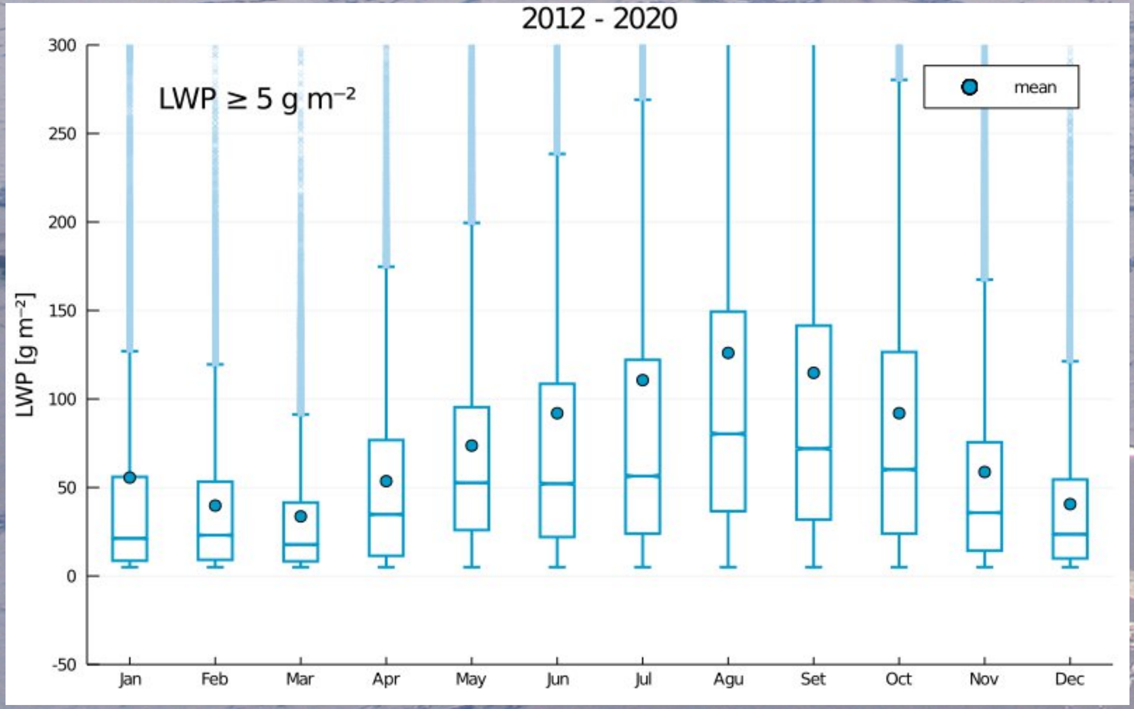
Session: A42F: Microphysical and Macrophysical Properties and Processes of Ice and Mixed-Phase Clouds: Linking in Situ, Remote-Sensing Observations and Multiscale Models

Arctic Cloud Climatology

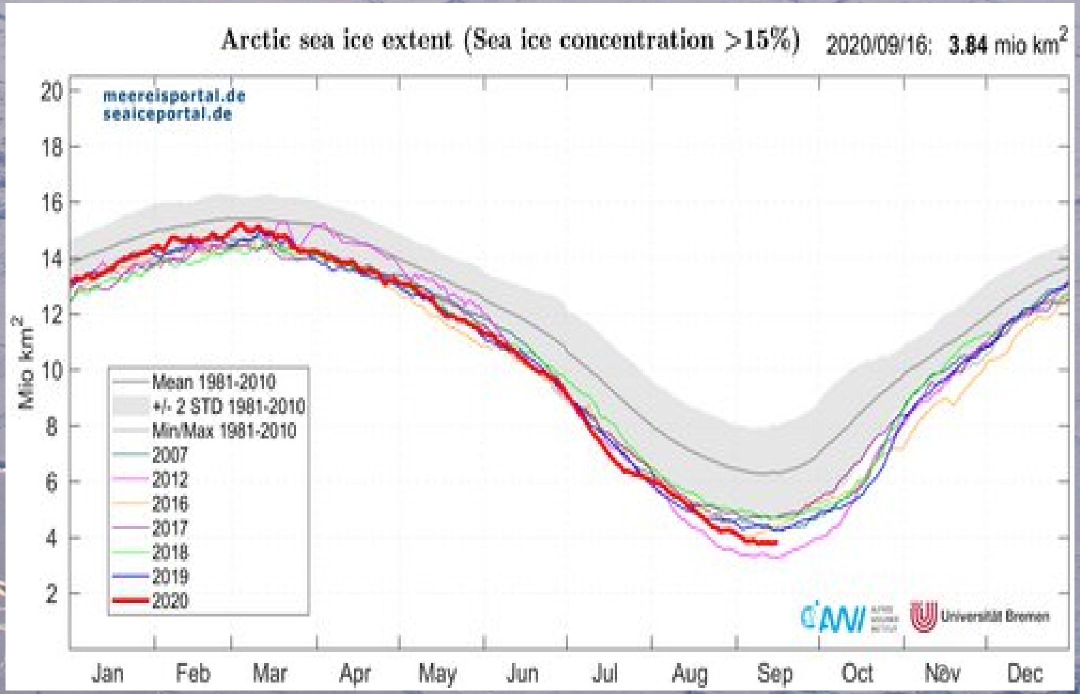


Yearly cycle of liquid-containing clouds in the Western Arctic resembles the annual Arctic Sea Ice Extend. Locally the relation between Sea Ice and Arctic clouds, particularly mixed-phase, is less understood.

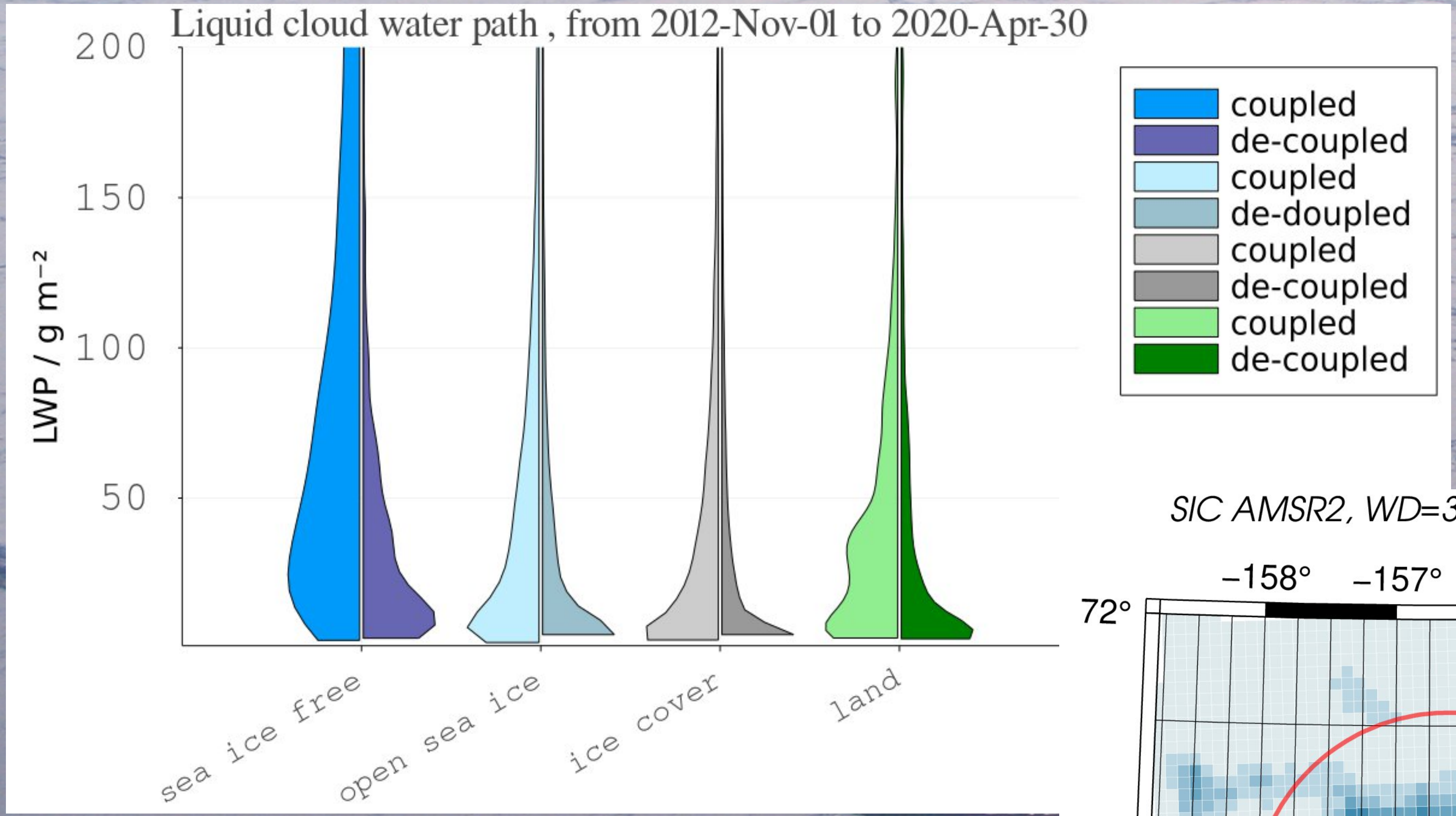
Liquid water path (LWP) at North Slope of Alaska

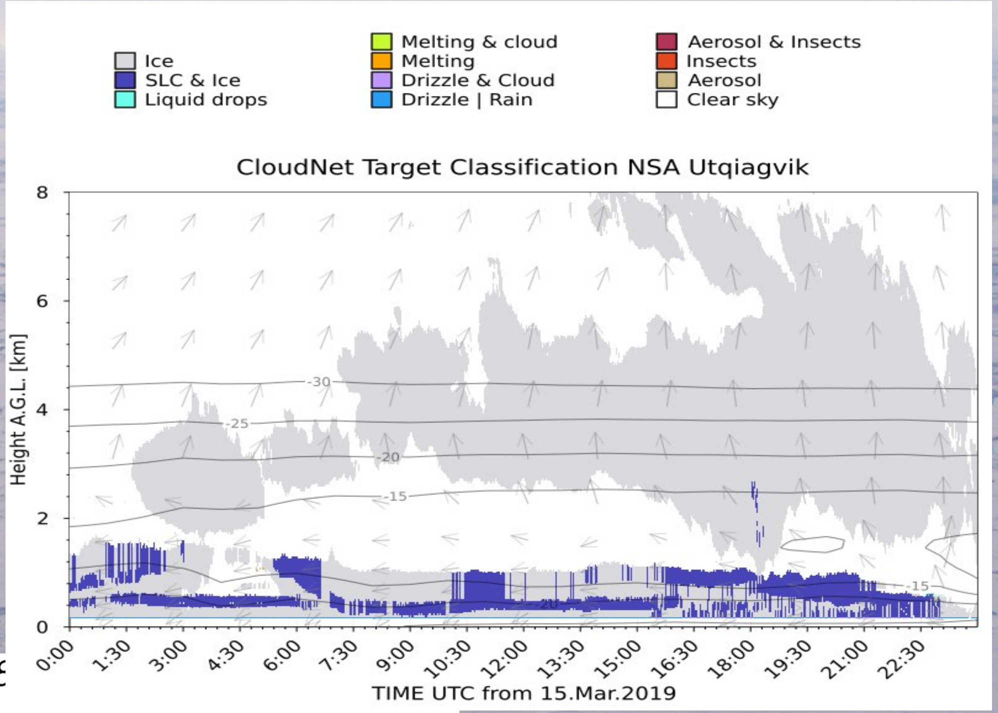


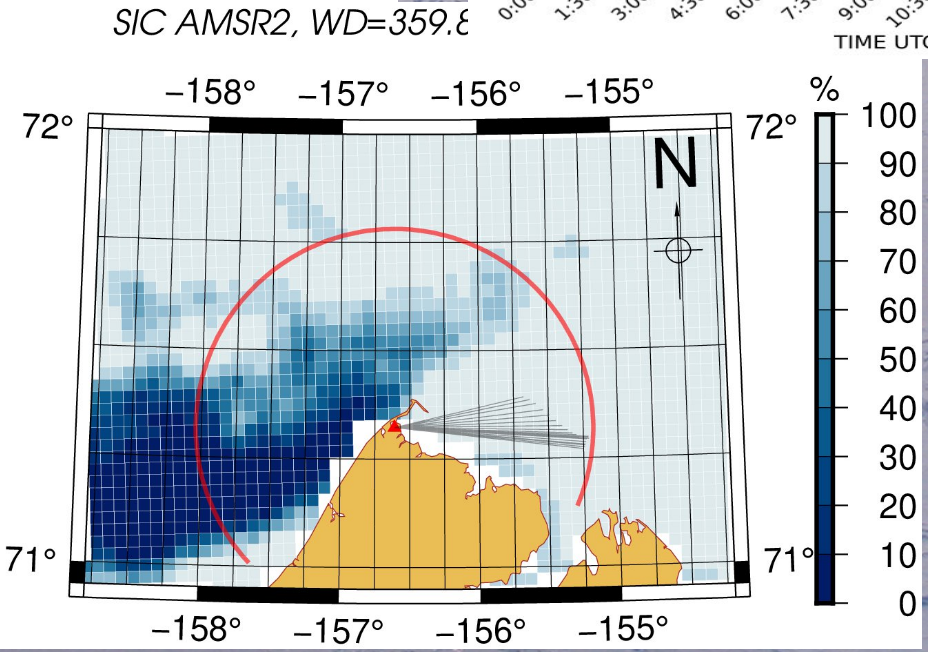
Arctic Sea Ice Exent (www.meericeporlat.de)



Coupled Clouds have larger Liquid Content



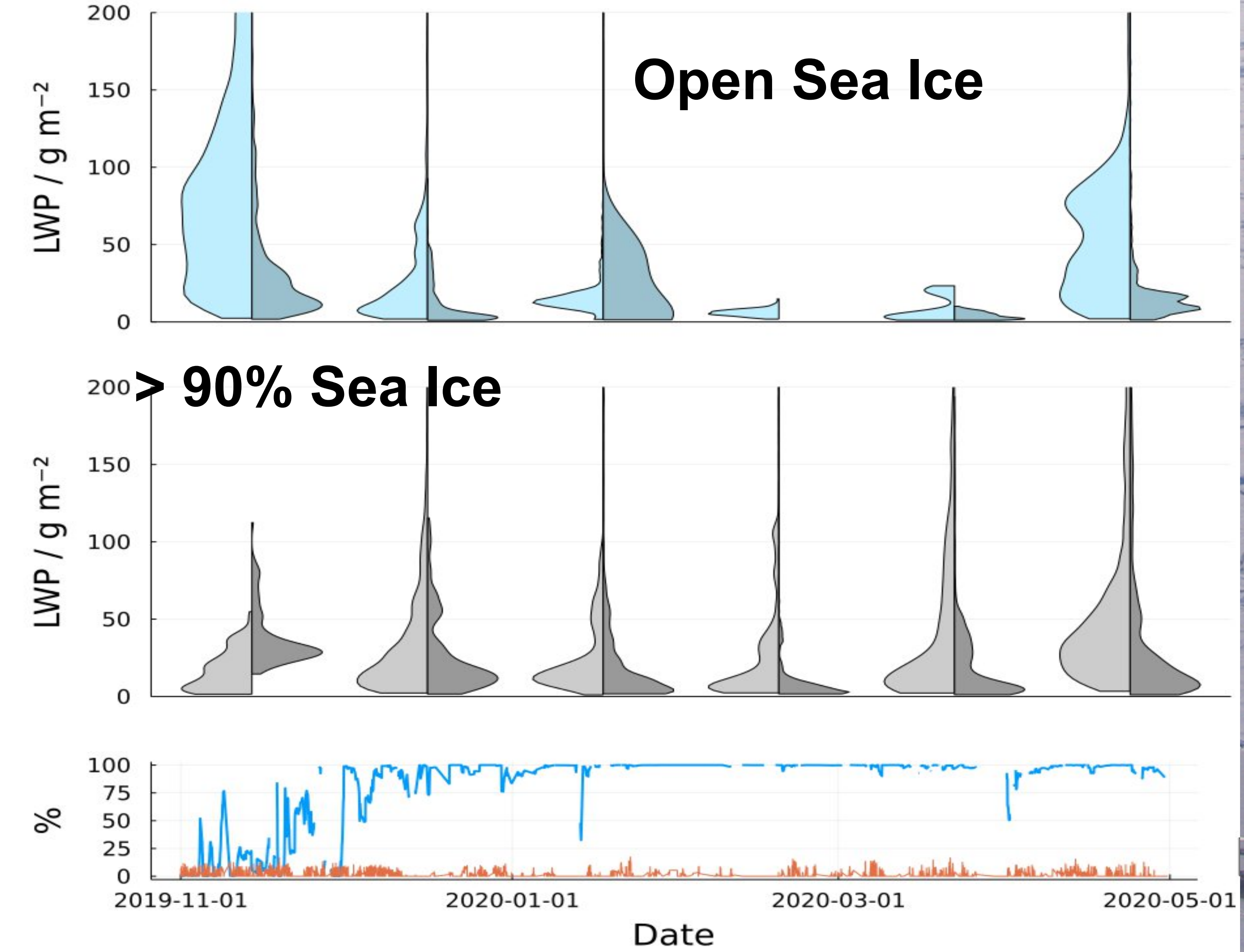


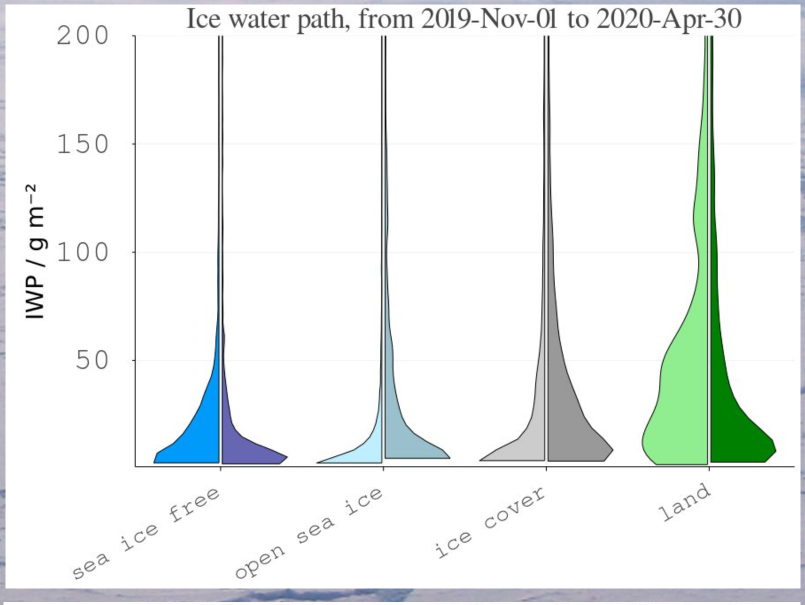


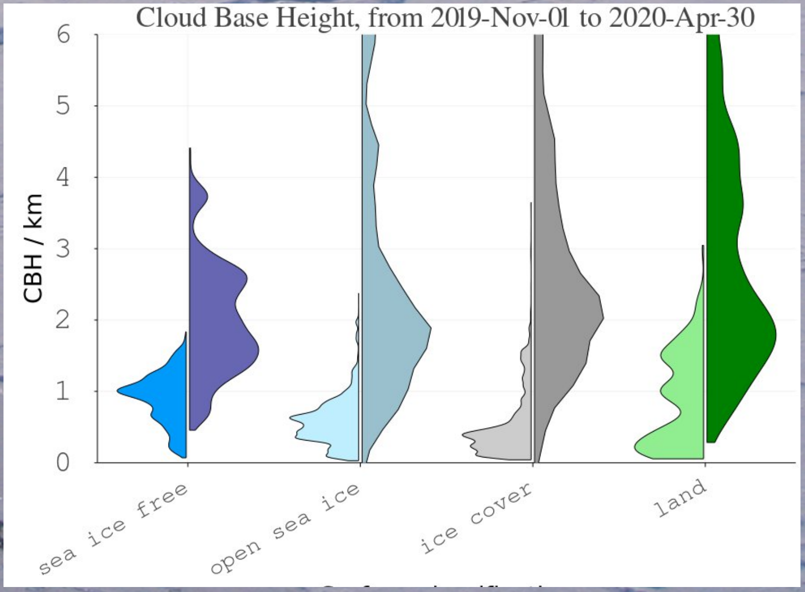
Coupled to the water vapor transport coming from a given direction

Coupled Clouds → lower Ice Content & lower Cloud base

Monthly variability reveals an entanglement of coupled clouds with sea ice.

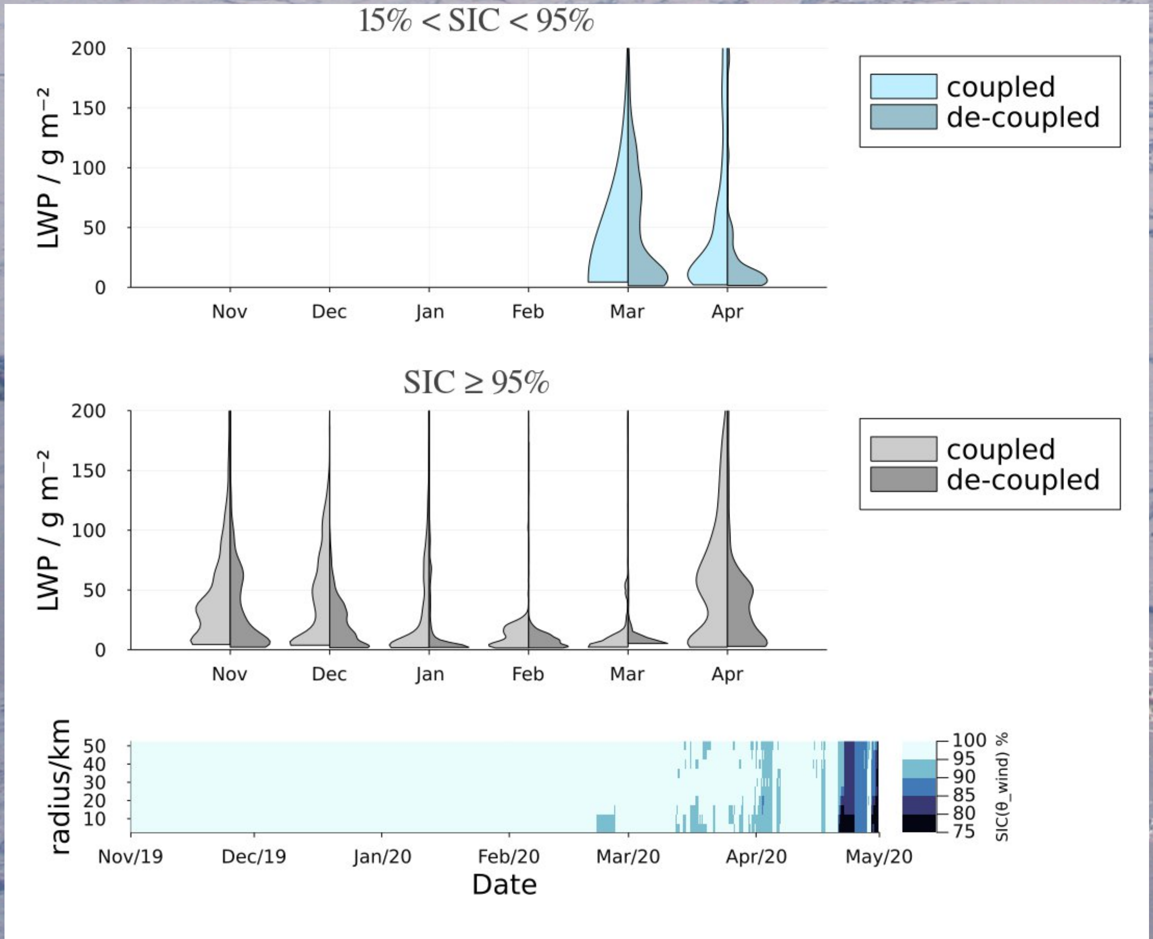






ArctiC Amplification:
Climate Relevant Atmospheric and SurfaCe Processes
and Feedback Mechanisms (AC)³

For the central Arctic visit eLighting poster: **C52C-08** on Fri. 17th.



Contact:

pablo.saavedra@uni-leipzig.de

/pablosaa @gasaapa

Climatology of clouds containing supercooled liquid in the Western Arctic

Pablo Saavedra Garfias, Willi Schimmel, Heike Kalesse-Los
contact: pablo.saavedra@uni-leipzig.de

Leipzig Institute for Meteorology
University of Leipzig
16th December 2021

UNIVERSITÄT LEIPZIG

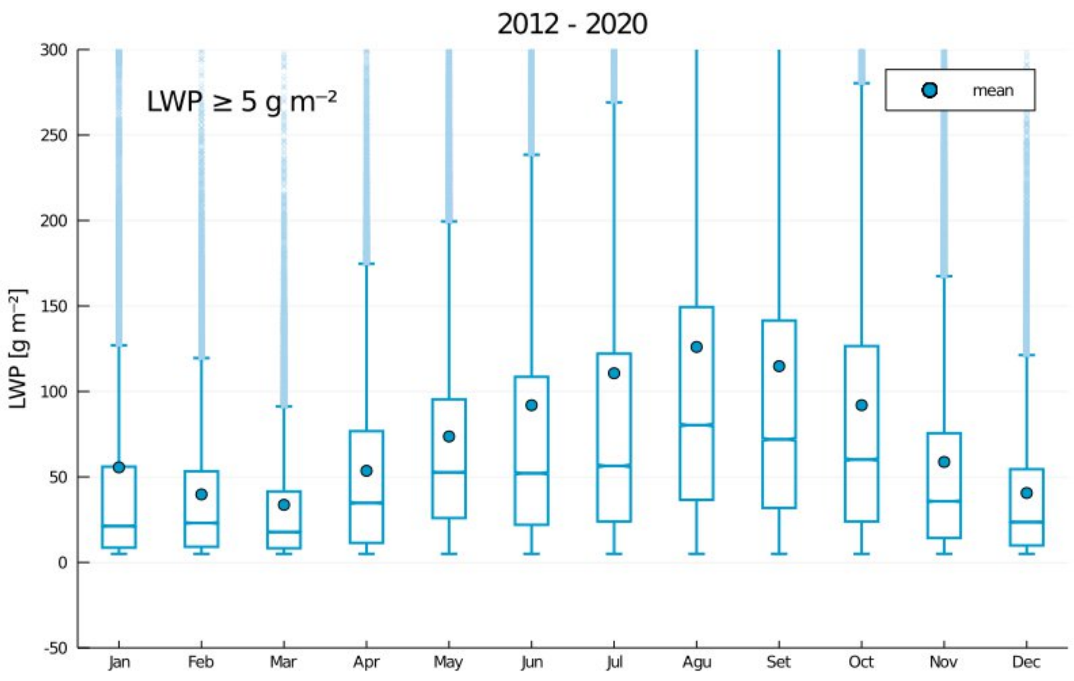
AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

Session: A42F: Microphysical and Macrophysical Properties and Processes of Ice and Mixed-Phase Clouds: Linking in Situ, Remote-Sensing Observations and Multiscale Models

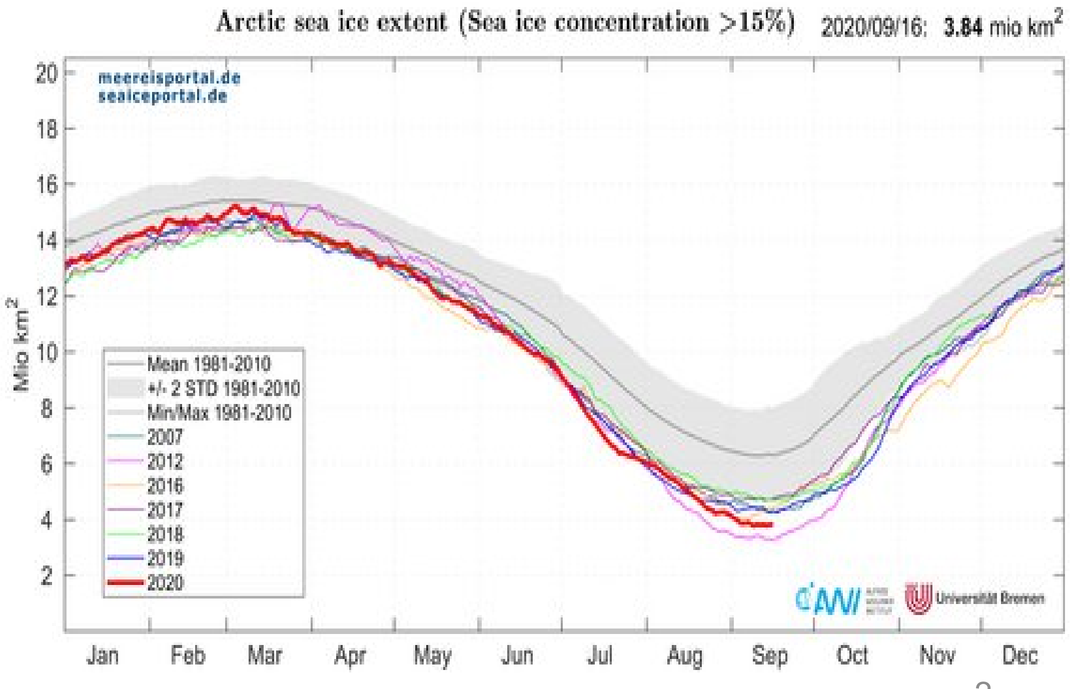
Arctic Cloud Climatology

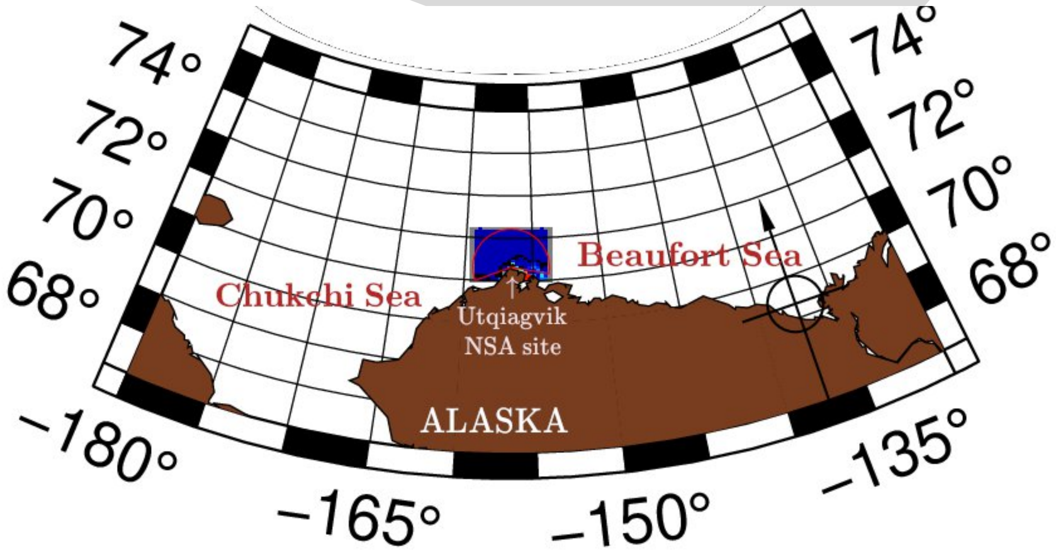
Yearly cycle of liquid-containing clouds in the Western Arctic resembles the annual Arctic Sea Ice Extent, with minimum of liquid water content corresponding to a maximum of Sea Ice Extent and vice versa. Locally the relation between Sea Ice and Arctic clouds, particularly SCLC, is not trivial and less understood.

Liquid water path (LWP) at North Slope of Alaska



Arctic Sea Ice Exent (www.meericeporlat.de)





This contribution focuses on the study of Arctic clouds using remote sensing observations at the Western Arctic DOE-ARM site in Utqiagvik, Alaska

The goal is to enrich our current understanding of how cloud properties and their climatology are influenced by different states of sea ice and areas of open ocean (polynyas and leads).

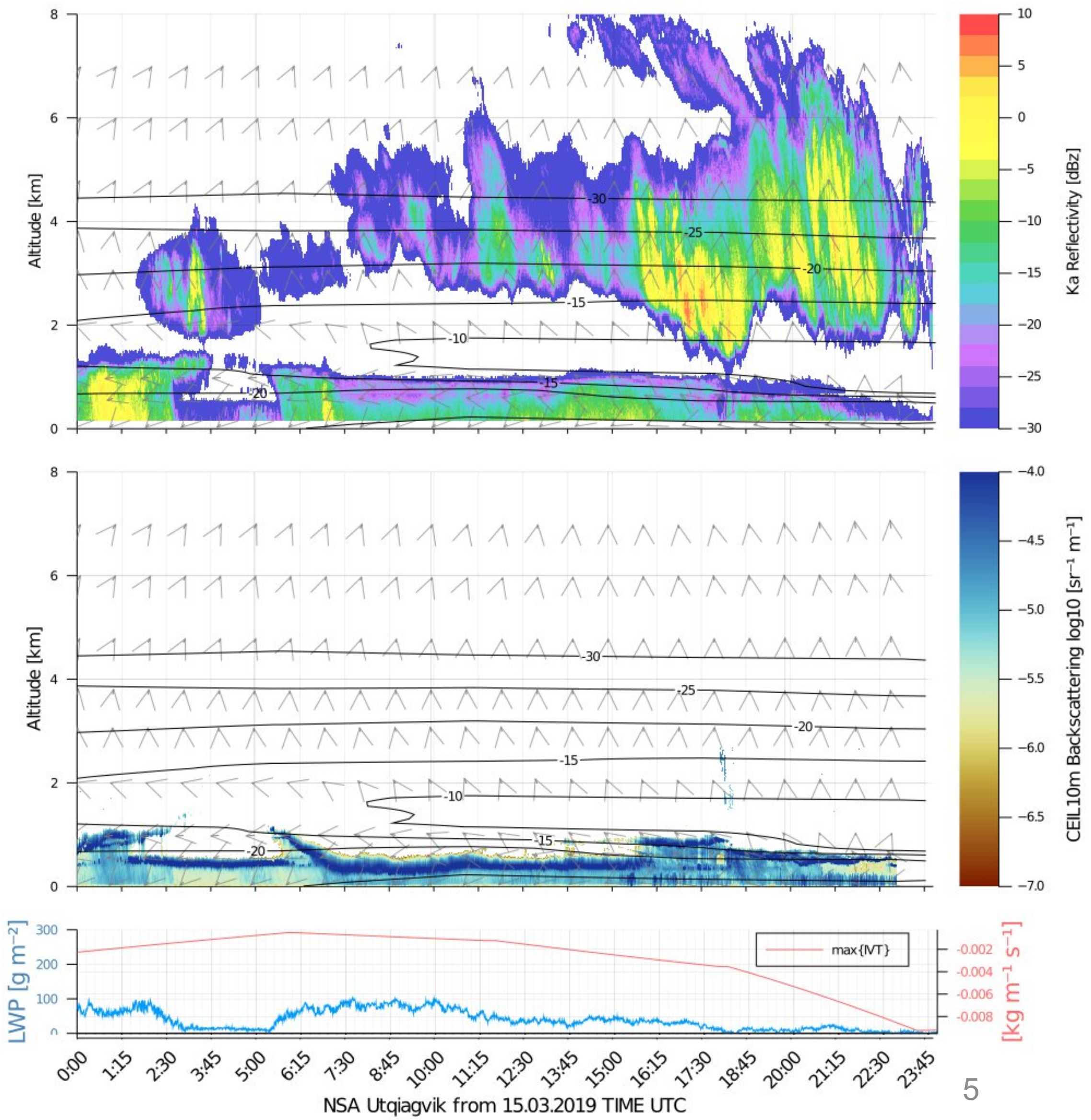
Instrumentation

The DOE-ARM North Slope of Alaska (NSA) site provides:

- KAZR ARCL: Vertically-Pointing Cloud Radar (35 GHz),
- CEIL10m: Vaisala Ceilometer (910 nm),
- HSRL: High Spectral Resolution Lidar (532 nm),
- MWR: Microwave radiometer (TB 22.2 & 31.4GHz, PW, LWP),
- INTERPOLATE SONDE : Radiosonde profiles interpolated between launches

Cloud observations by data synergy

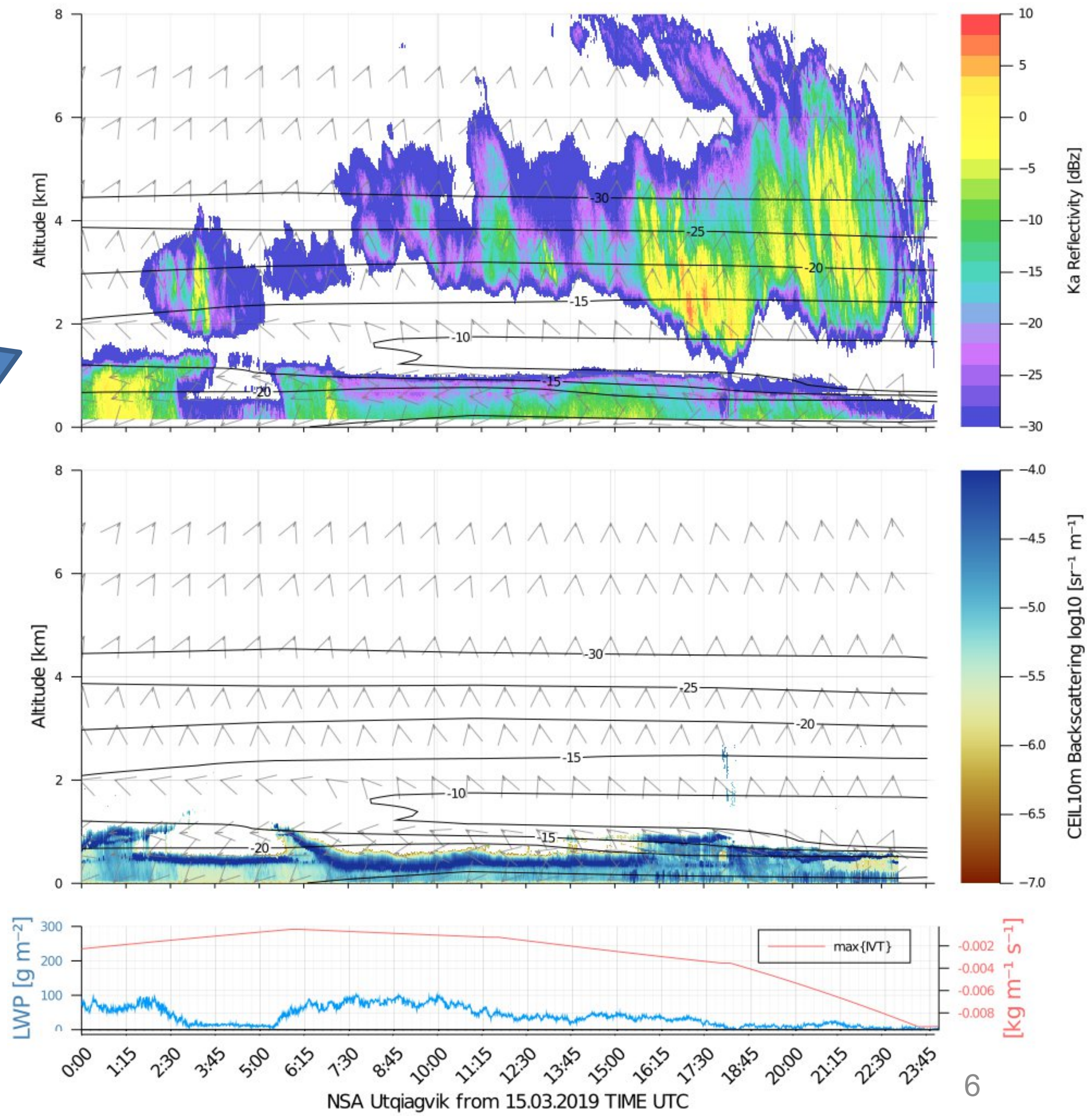
Liquid containing clouds are observed thanks to ARM remote sensing instrumentation.



Cloud observations by data synergy

Supercooled liquid clouds (SCLC) observed thanks to ARM remote sensing instrumentation

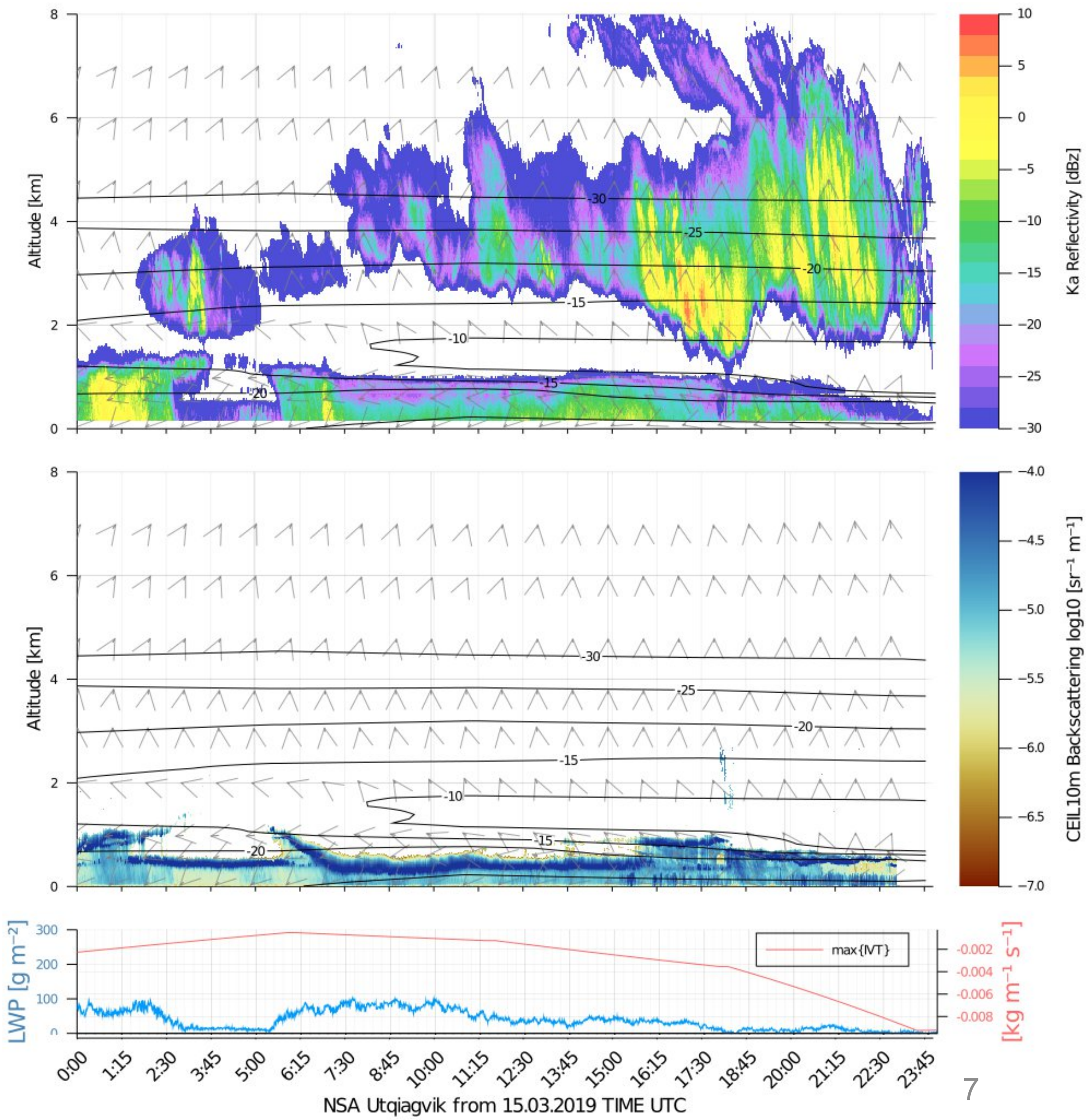
- KARZ cloud radar



Cloud observations by data synergy

Supercooled liquid clouds (SCLC) observed thanks to ARM remote sensing instrumentation.

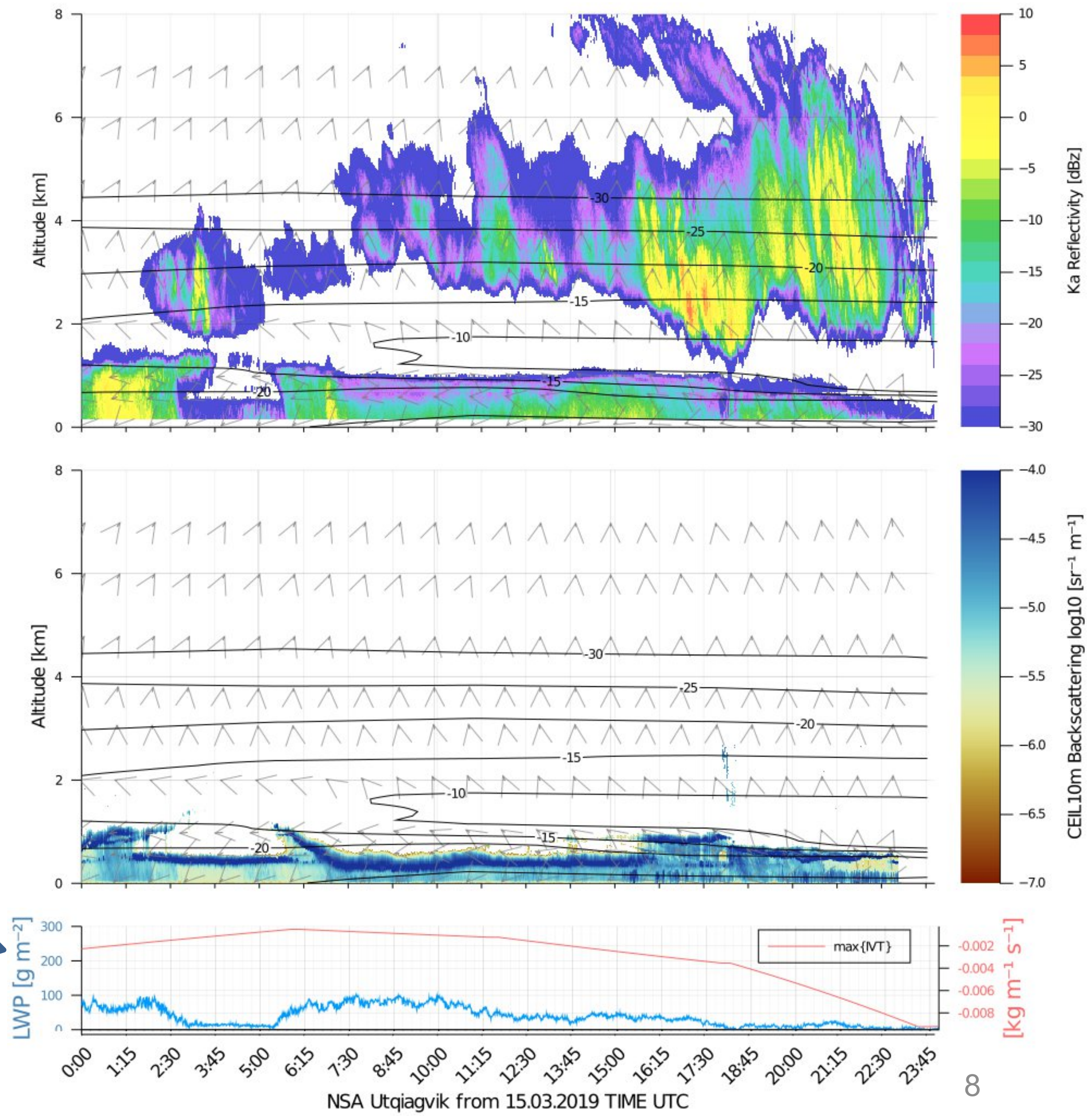
- KARZ cloud radar
- Ceilometer



Cloud observations by data synergy

Supercooled liquid clouds (SCLC) observed thanks to ARM remote sensing instrumentation.

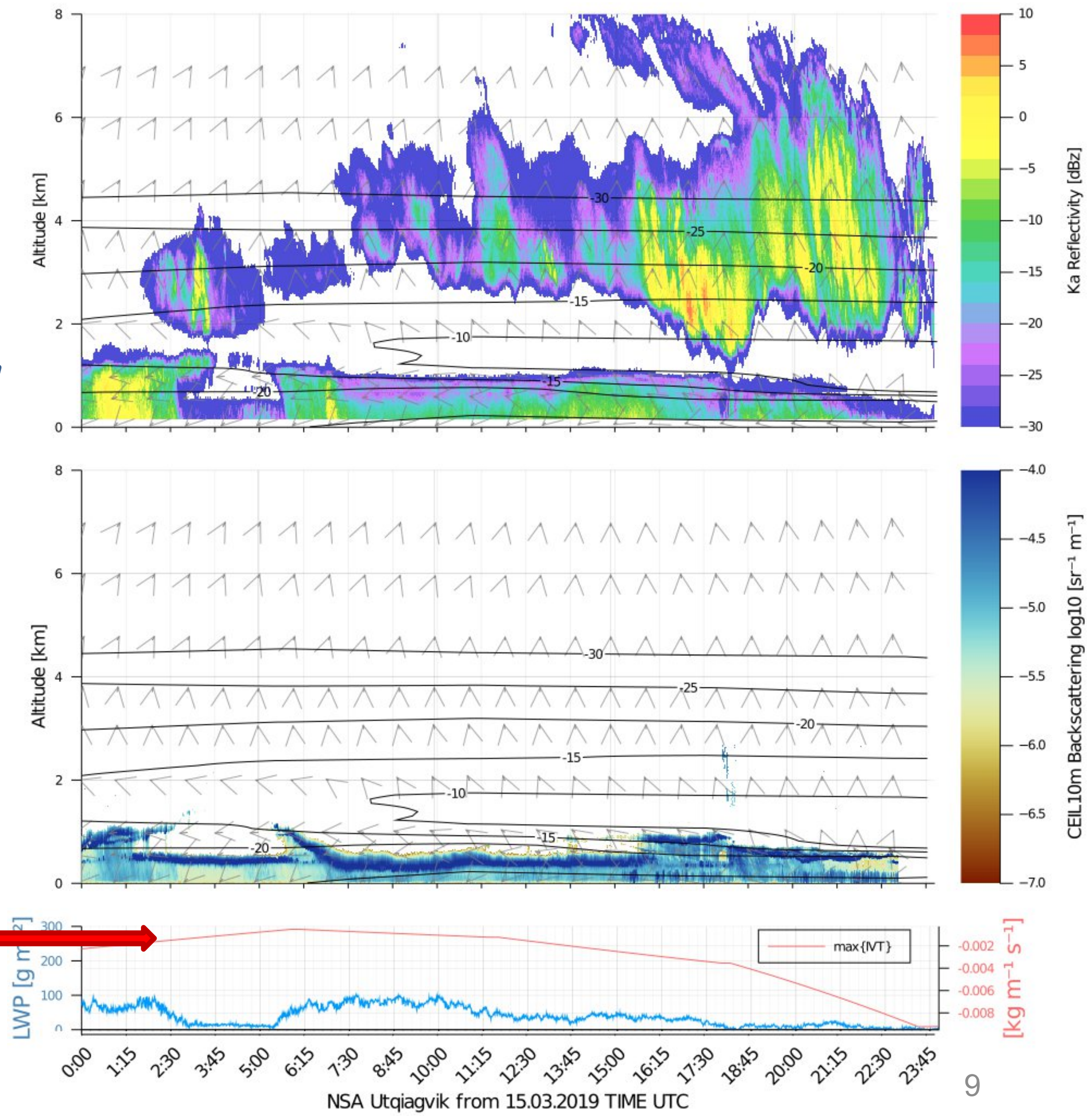
- KARZ cloud radar
- Ceilometer
- MW radiometer



Cloud observations by data synergy

Supercooled liquid clouds (SCLC) observed thanks to ARM remote sensing instrumentation.

- KARZ cloud radar
- Ceilometer
- MW radiometer
- Radiosonde (wind vectors, isotherms & WV transport)



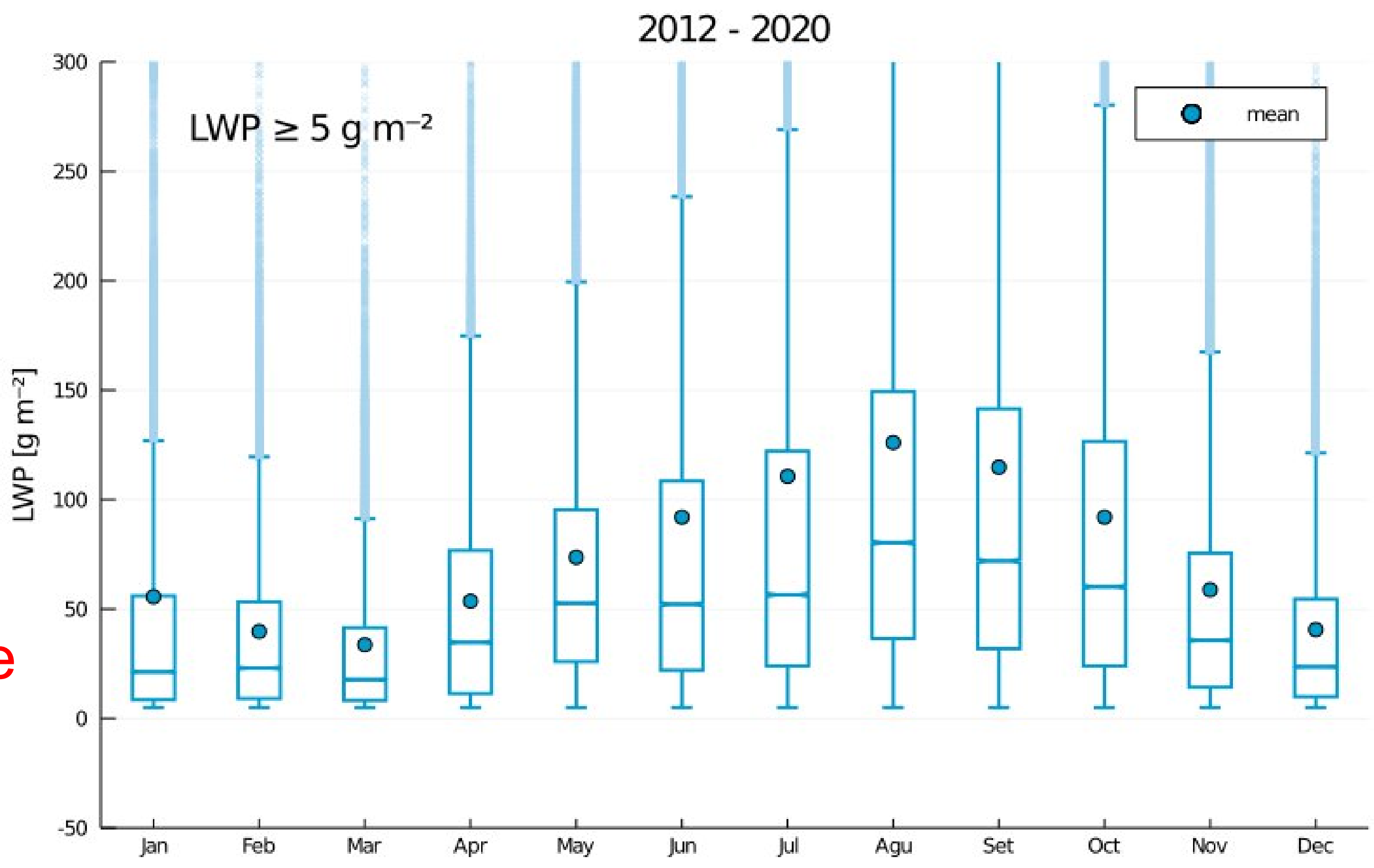
LWP climatology for Utqiagvik

MWR Liquid water path

All clouds above a minimum detectable threshold of LWP = 5 g m⁻² are included

and a maximum of 1 kg m⁻² to avoid liquid precipitating clouds

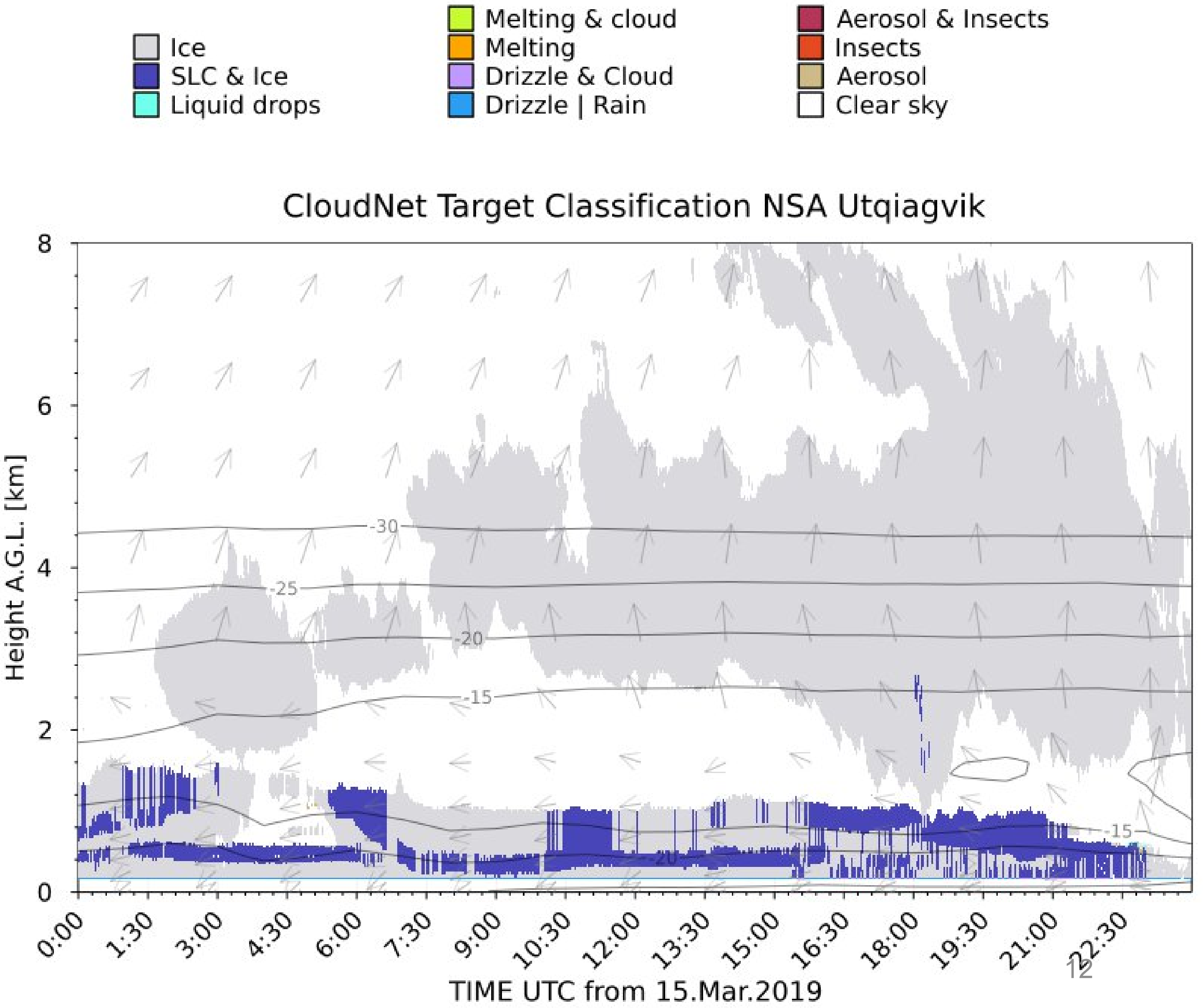
Additional sources of SCLC / Ice cloud detection and Sea Ice conditions are needed



SCLC Detection and Classification

- Cloudnet algorithm,
- Python version provided by the ACTRIS data centre node for cloud profiling (https://cloudnet.fmi.fi),
- Input data needed to be adapted to work with ARM instrumentation

SCLC Detection and Classification



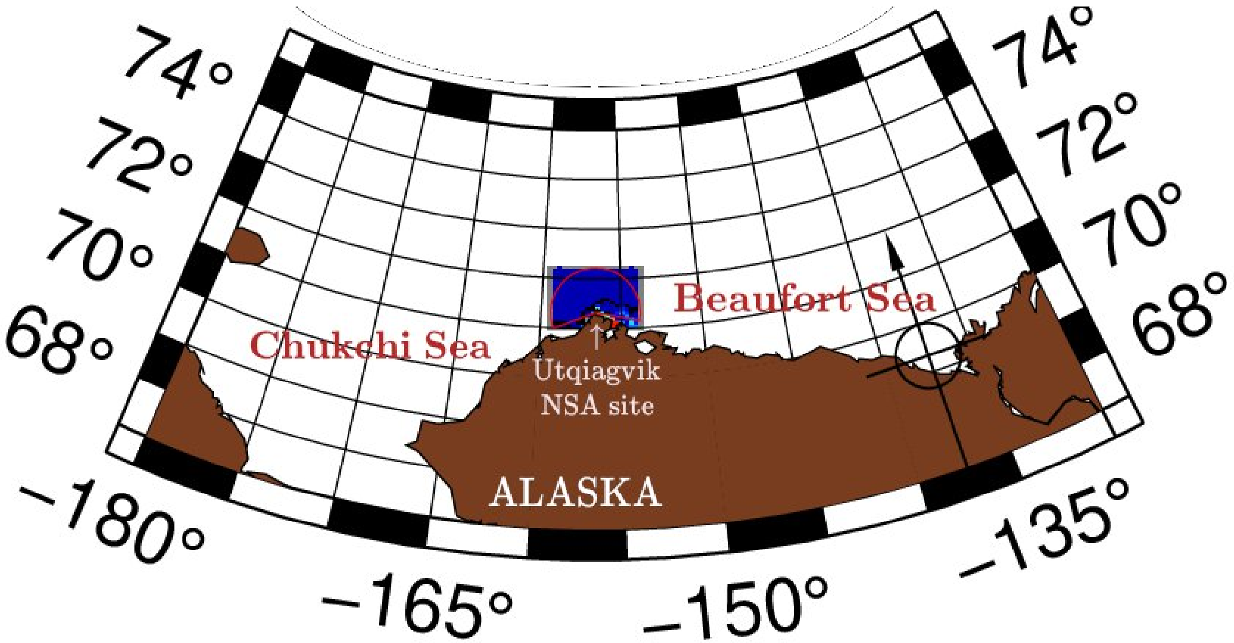
In addition to the classification, Cloudnet also provides retrievals for:

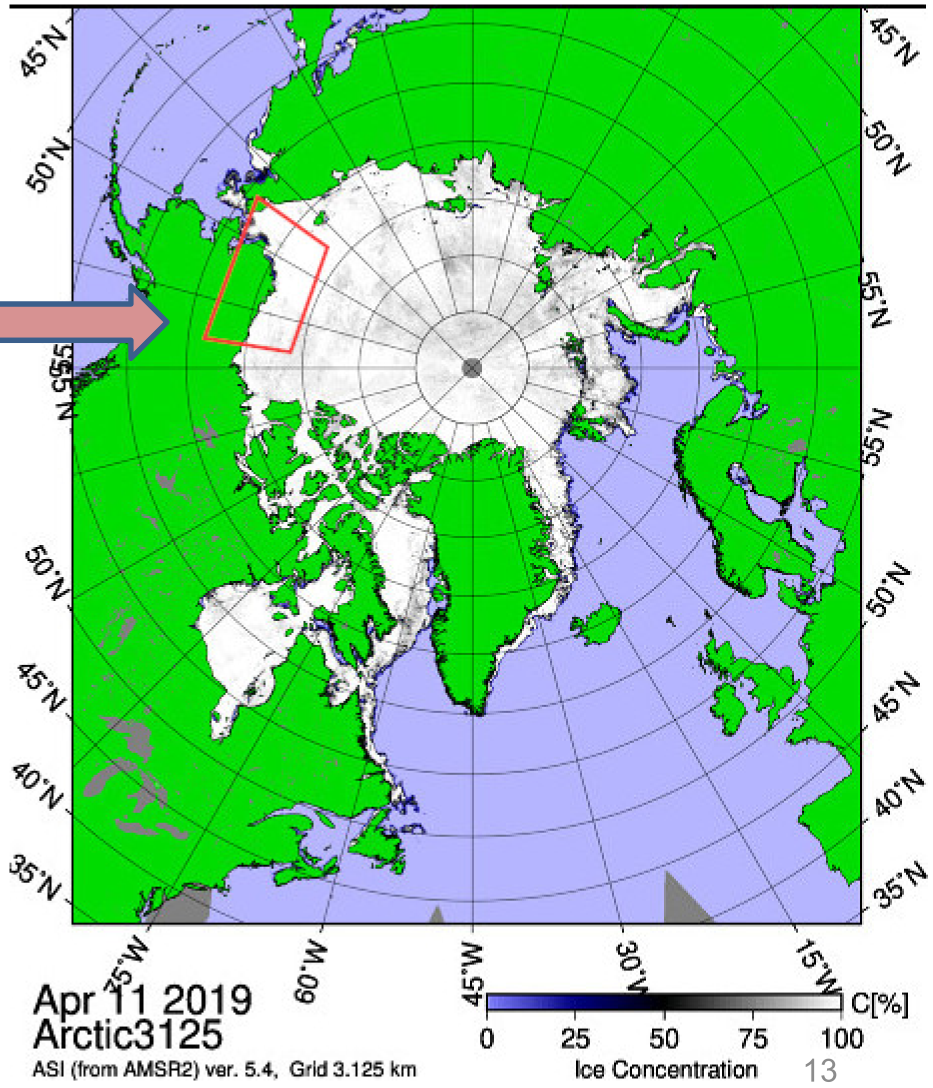
- Liquid water content (LWC),
- Ice water content (IWC),
- Drizzle

Sea Ice Concentration

- Daily Sea Ice concentration (SIC) retrieved from AMSR2 is provided by our collaborators from the University of Bremen https://seaice.uni-bremen.de

- SIC is then extracted for a region near NSA





SCLC Analysis for the NSA site

- Period of study: 2012 - 2020, Arctic winter November - April,
- Cloudnet product:
  - Hydrometeor classification
  - Ice water content (IWC), Ice water path (IWP)
- NSA direct product:
  - Radiometer Liquid water path (LWP)
  - Lidar cloud base height (CBH)
  - Radiosonde profiles for atmospheric thermodynamic properties
- Satellite product:
  - Daily SIC from AMSR2 @ 3.125 km resolution

Cloud observations as a function of SIC

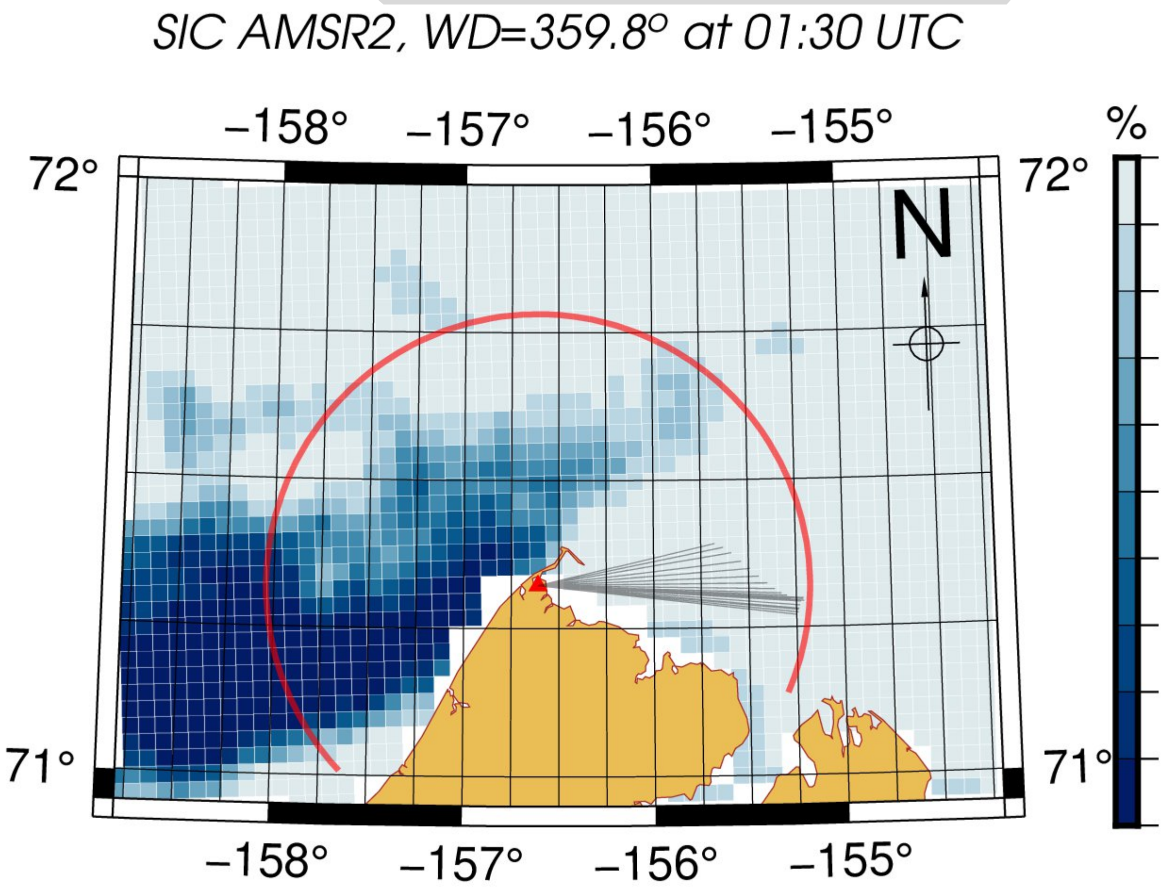
To relate the presence/absence of mixed-phase with the sea ice conditions, some assumptions need to be done:

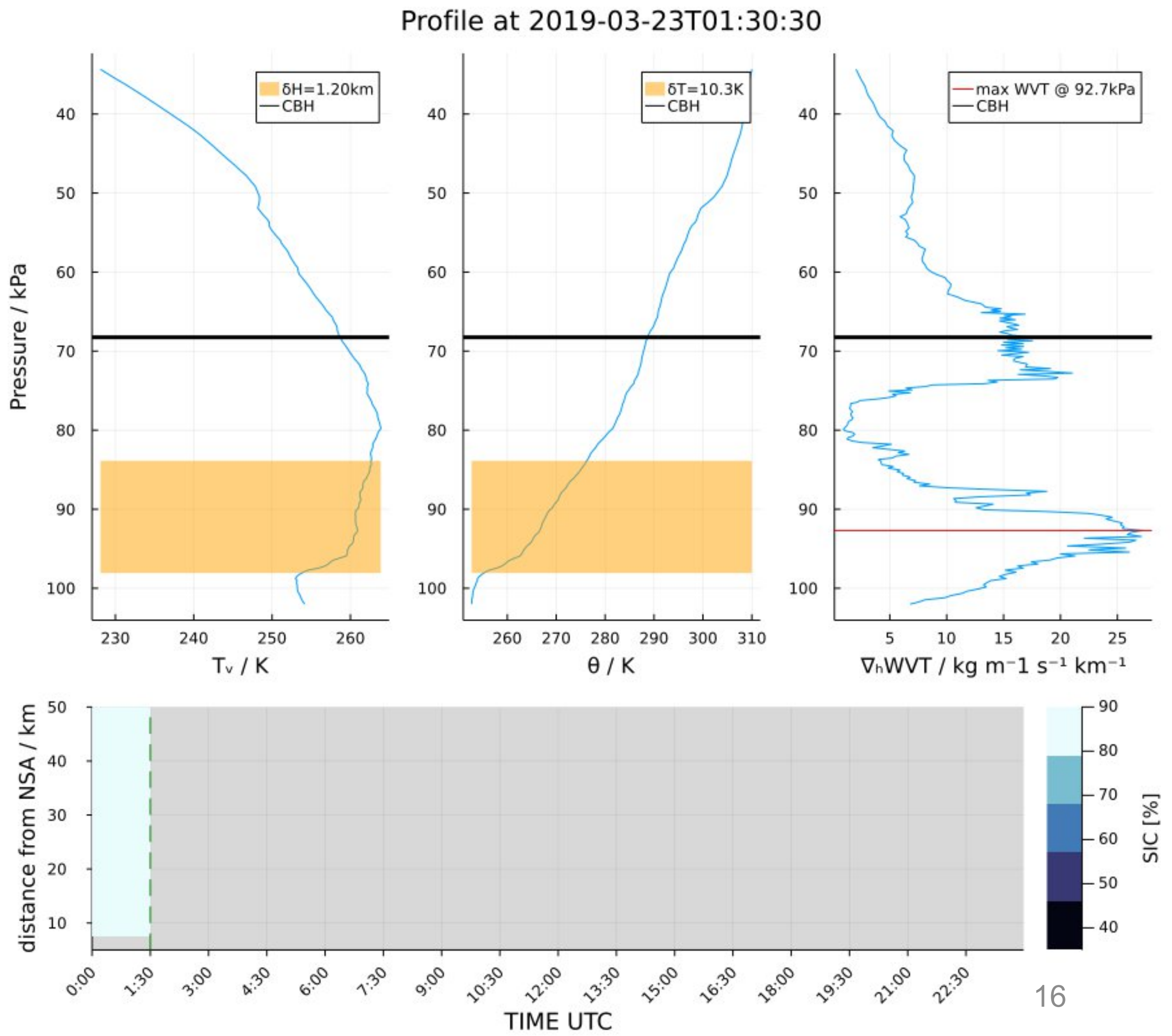
- Water vapor transport as a mechanism for the interaction within sea ice condition and mixed-phase clouds,
- Local sources of moisture e.g. polynya and leads can be related to the vertical observations by means of the gradient of water vapor transport:

$$\nabla WVT(z) = -\frac{1}{g}\left|q_v \cdot \vec{V}\right| \, dP$$

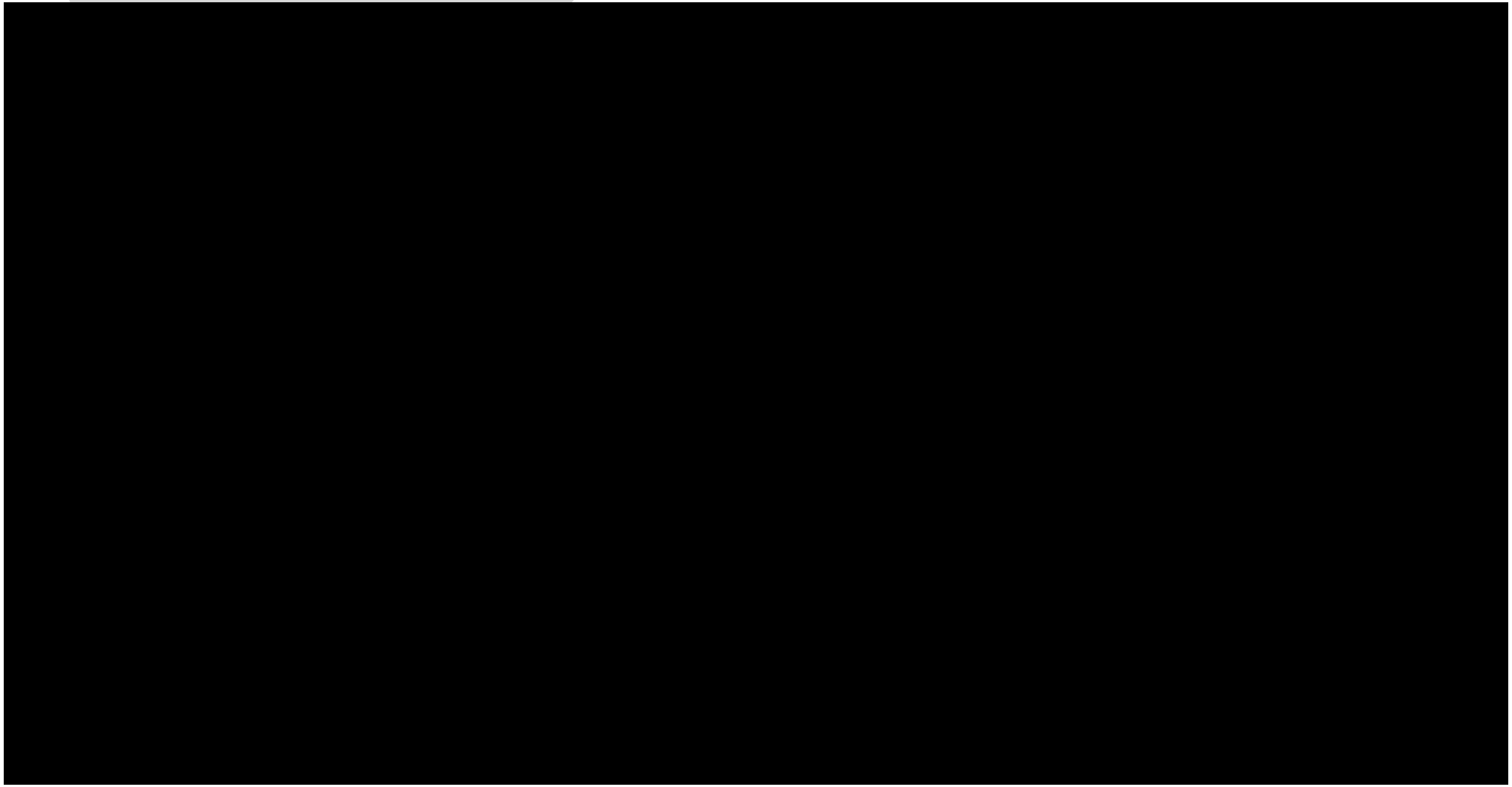
- Hypothesis: WVT in the lower atmosphere might interact with the cloud and modify its properties e.g. Ice and liquid water contend

Cloud observations as a function of SIC



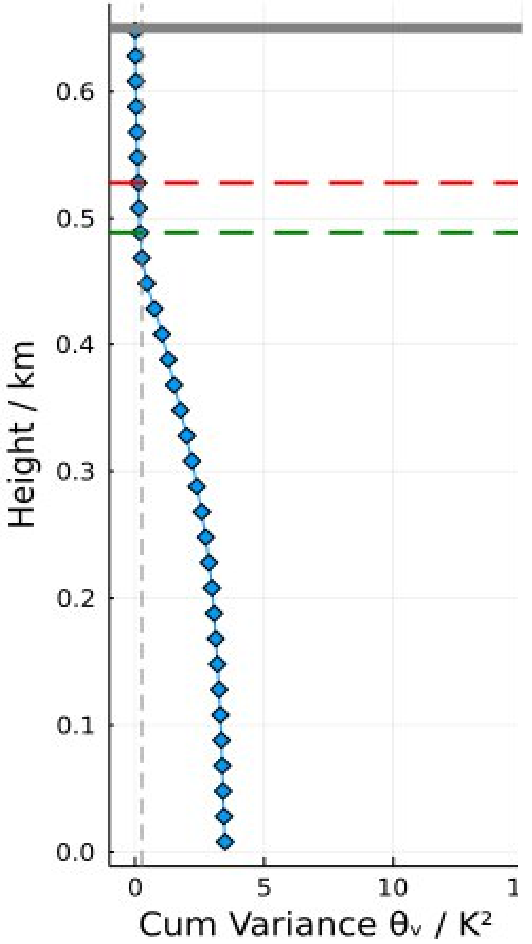


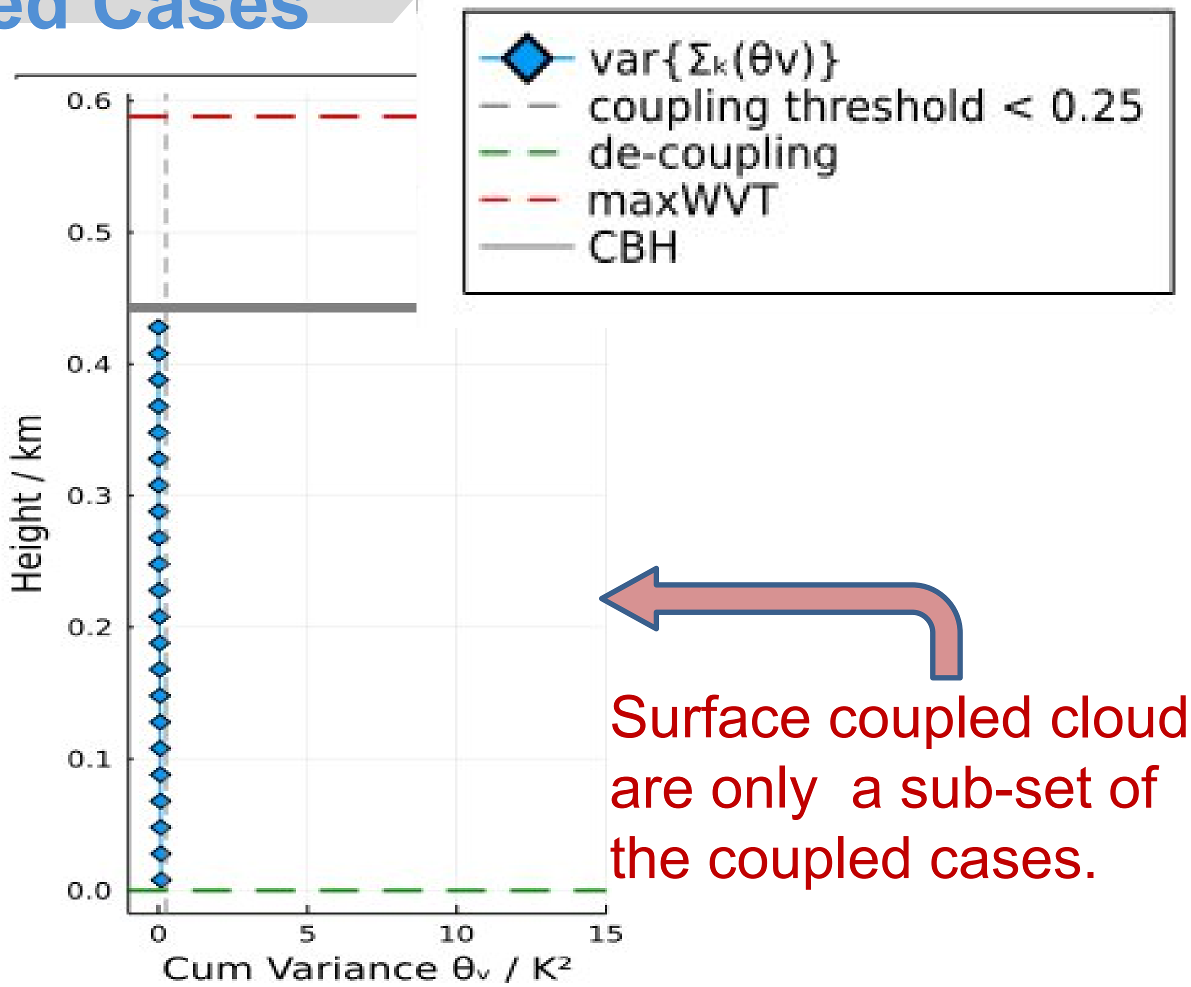
Cloud observations as a function of SIC



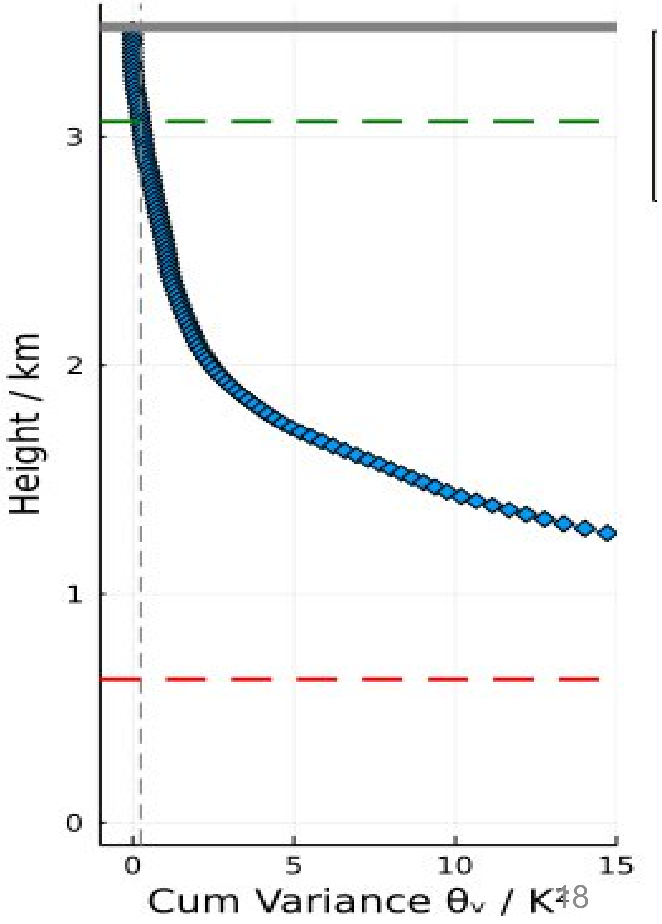
Coupling Cloud with Water Vapor Transport

Coupled Cases





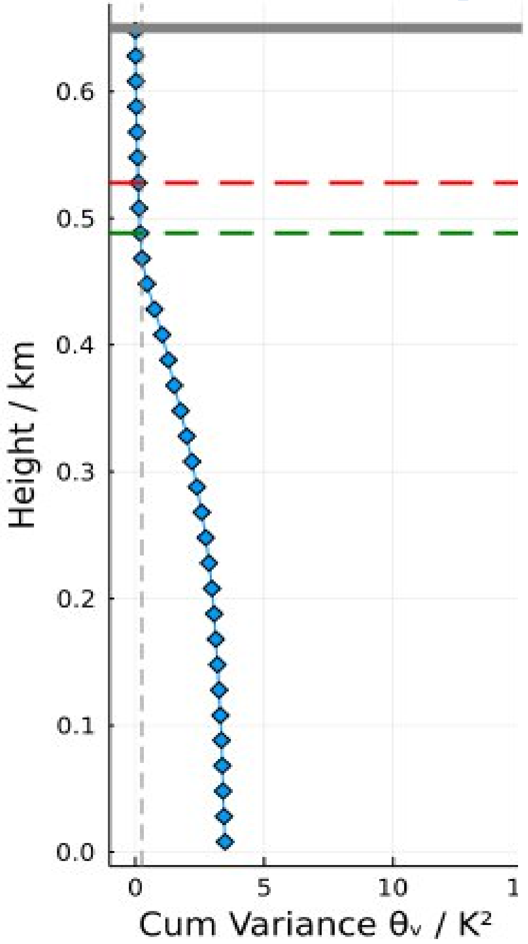
De-coupled Cases

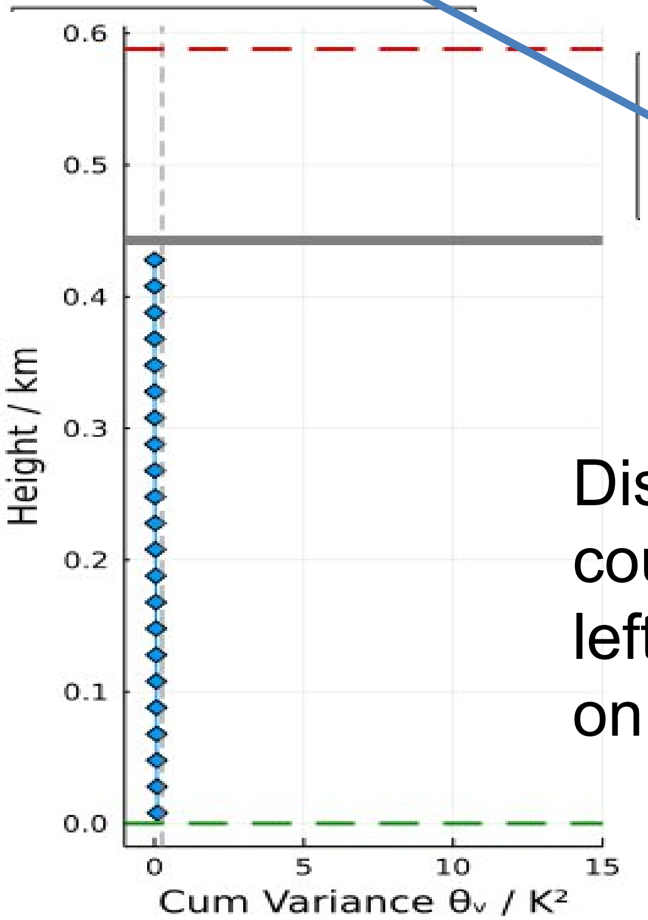


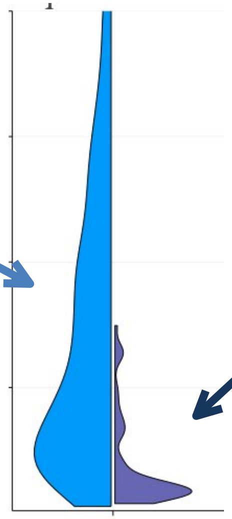
Surface coupled clouds are only a sub-set of the coupled cases.

Coupling Cloud with Water Vapor Transport

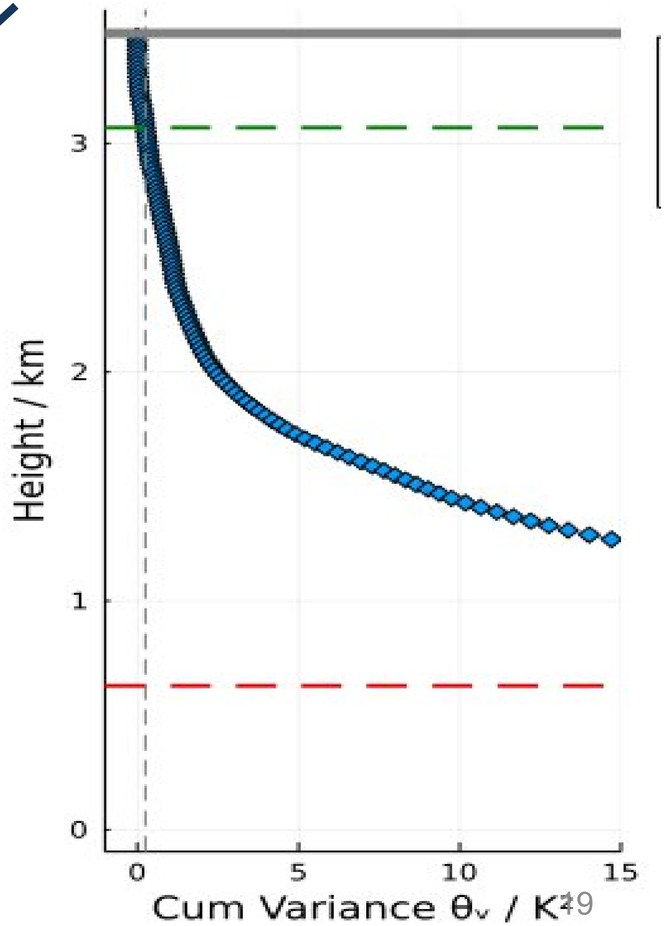
Coupled Cases





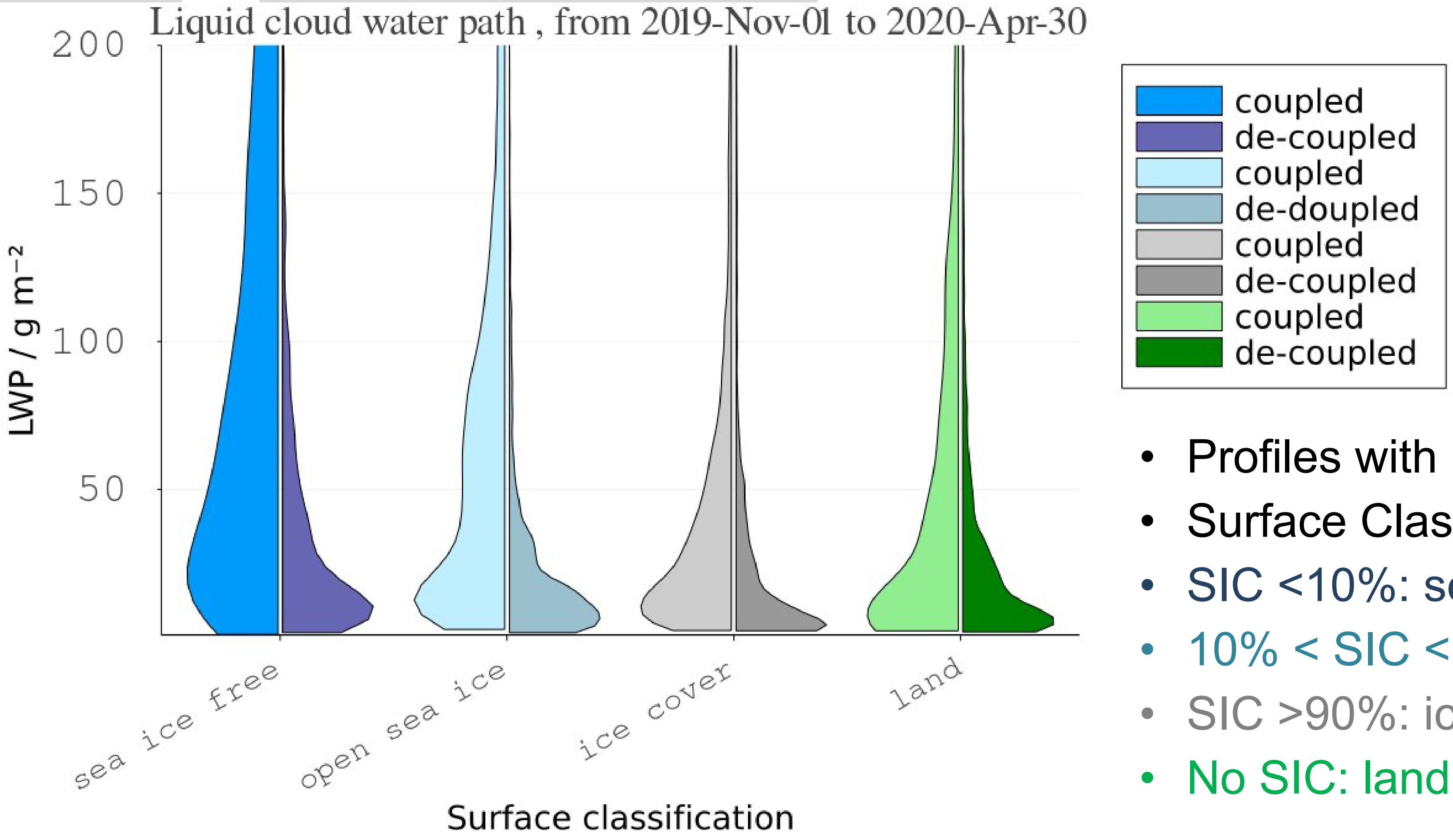


De-coupled Cases



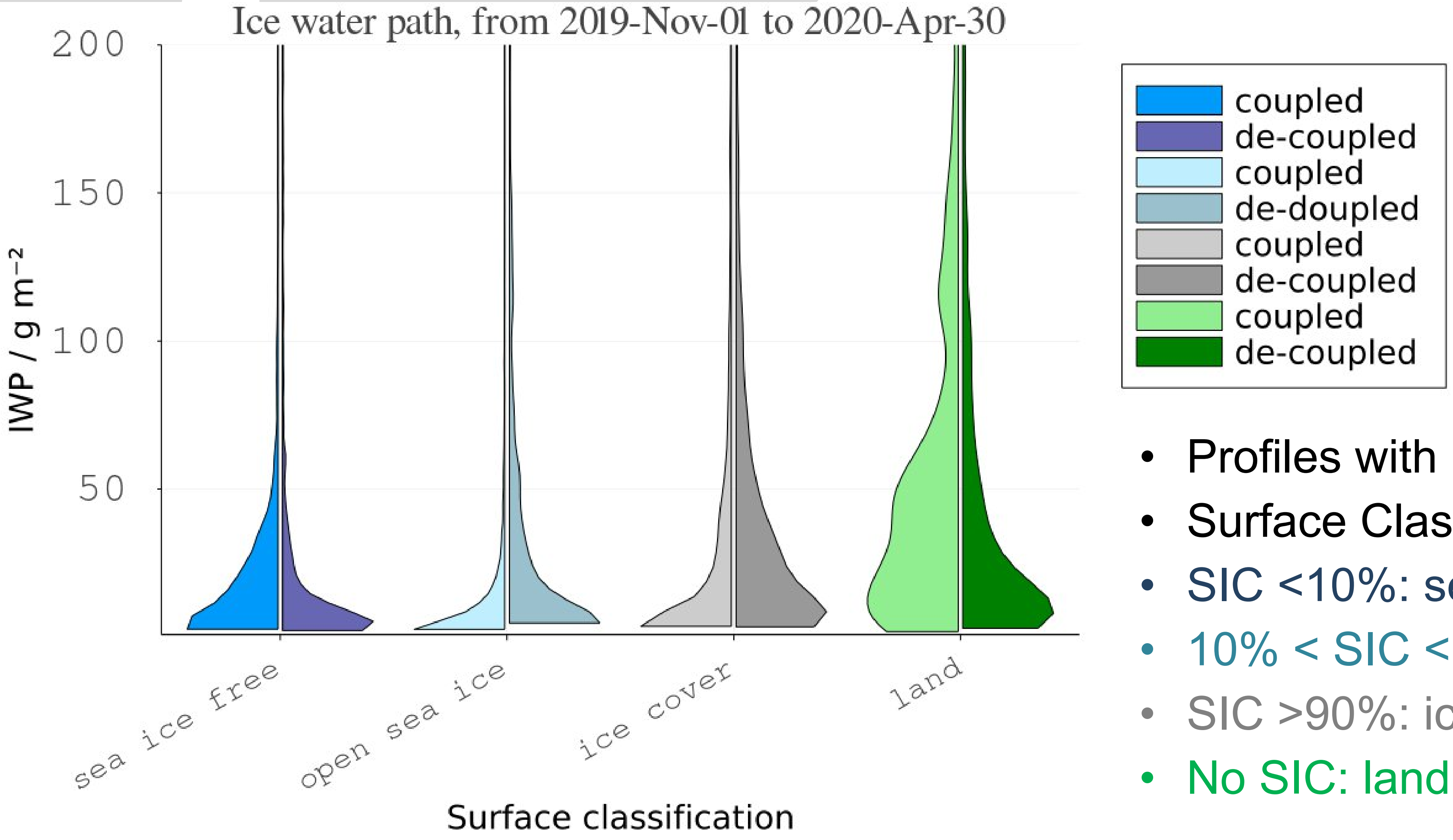
Distributions will show coupled cases on the left, and de-coupled on the right

Statistics for LWP winter 2019-2020



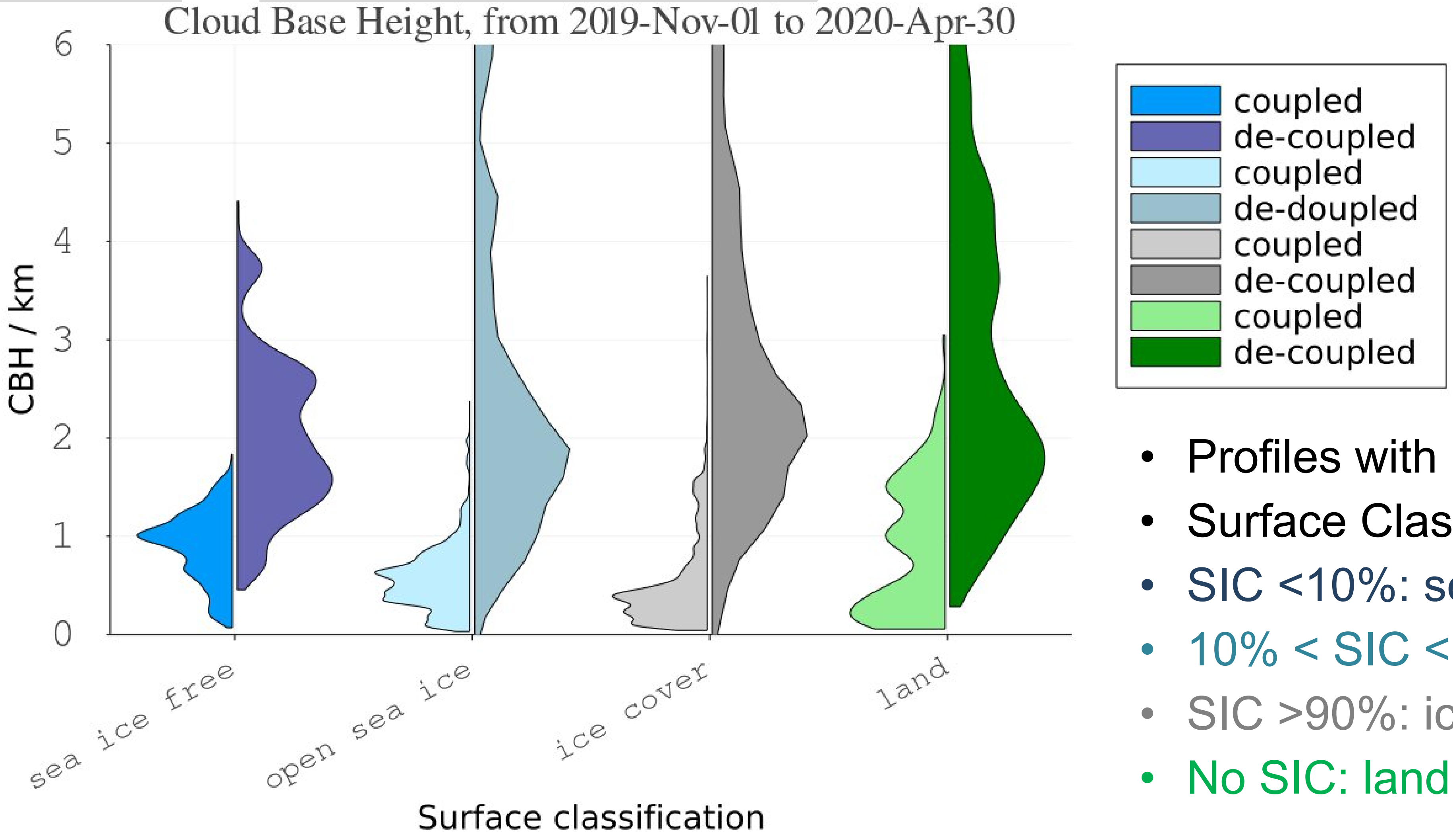
- Profiles with mixed-phase clouds
- Surface Classification function of SIC
- SIC <10%: sea ice free,
- 10% < SIC < 90%: open sea ice
- SIC >90%: ice cover
- No SIC: land

Statistics for ICE Clouds winter 2019-2020



- Profiles with mixed-phase clouds
- Surface Classification function of SIC
- SIC <10%: sea ice free,
- 10% < SIC < 90%: open sea ice
- SIC >90%: ice cover
- No SIC: land

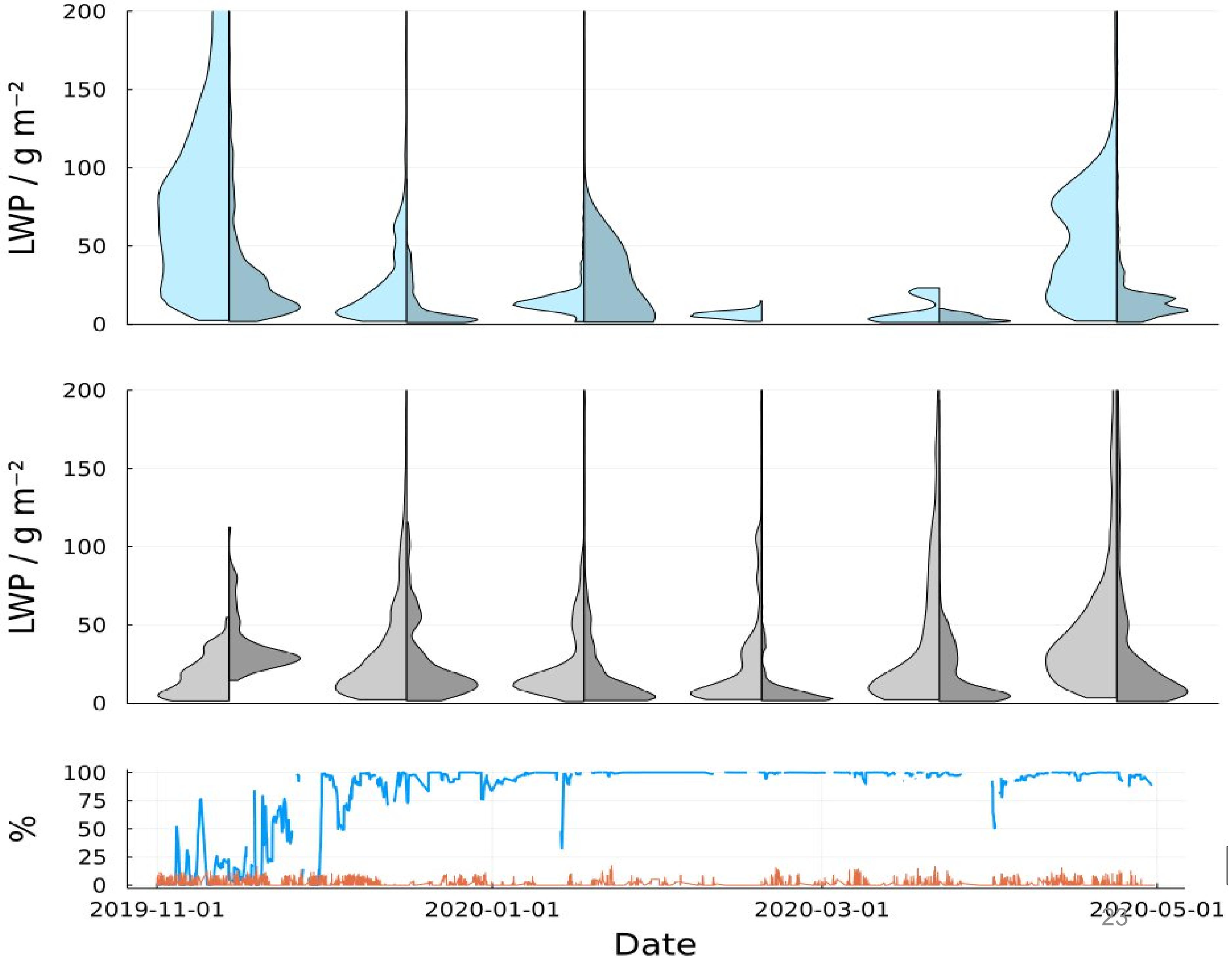
Statistics for Clouds base height winter 2019-2020



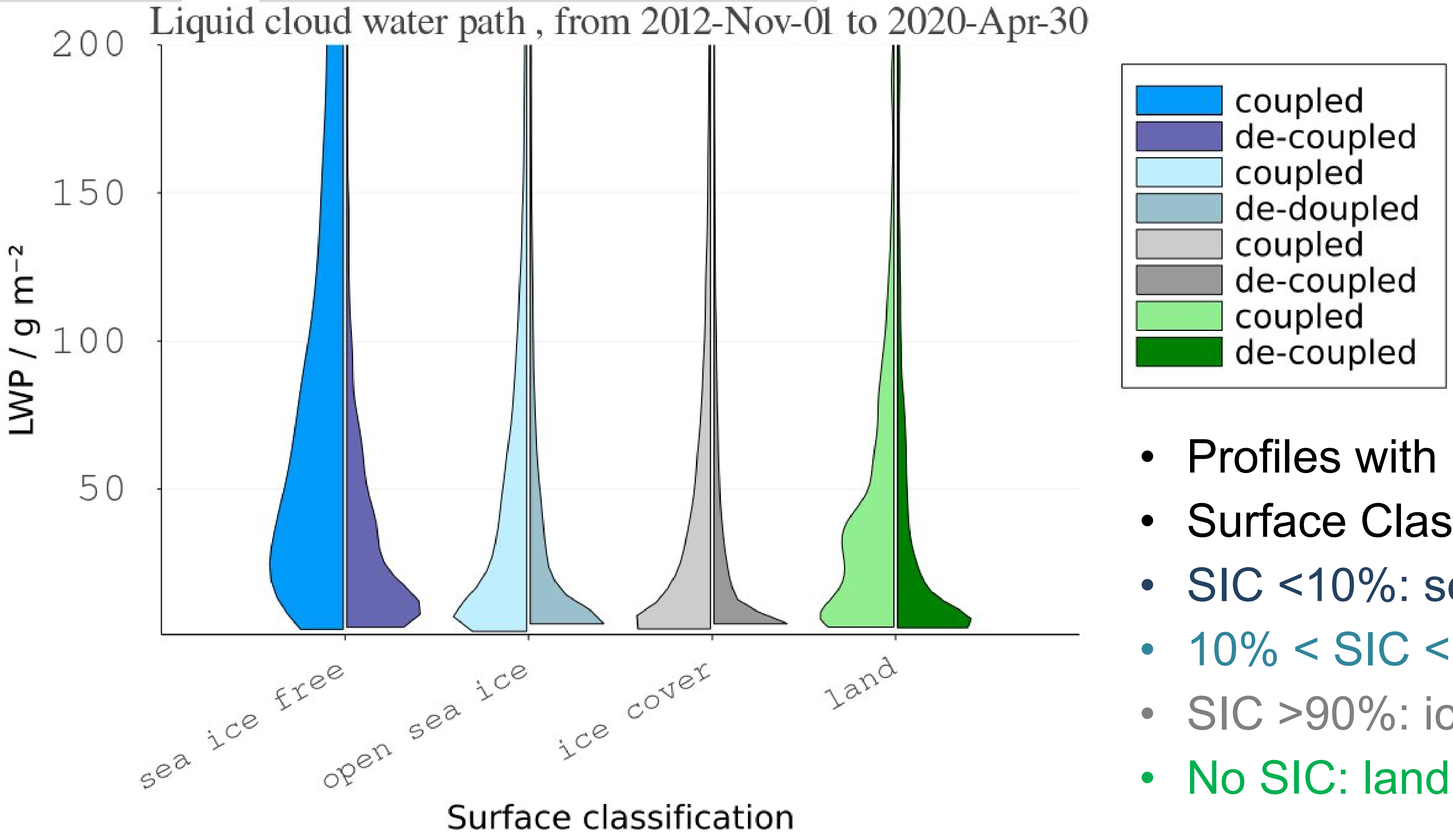
- Profiles with mixed-phase clouds
- Surface Classification function of SIC
- SIC <10%: sea ice free,
- 10% < SIC < 90%: open sea ice
- SIC >90%: ice cover
- No SIC: land

Monthly Statistics for LWP

- Open Sea Ice cases:
- Sea ice cover
- SIC time series (blue), % of SCLC (red)



Statistics for LWP 2012 to 2020



- Profiles with mixed-phase clouds
- Surface Classification function of SIC
- SIC <10%: sea ice free,
- 10% < SIC < 90%: open sea ice
- SIC >90%: ice cover
- No SIC: land

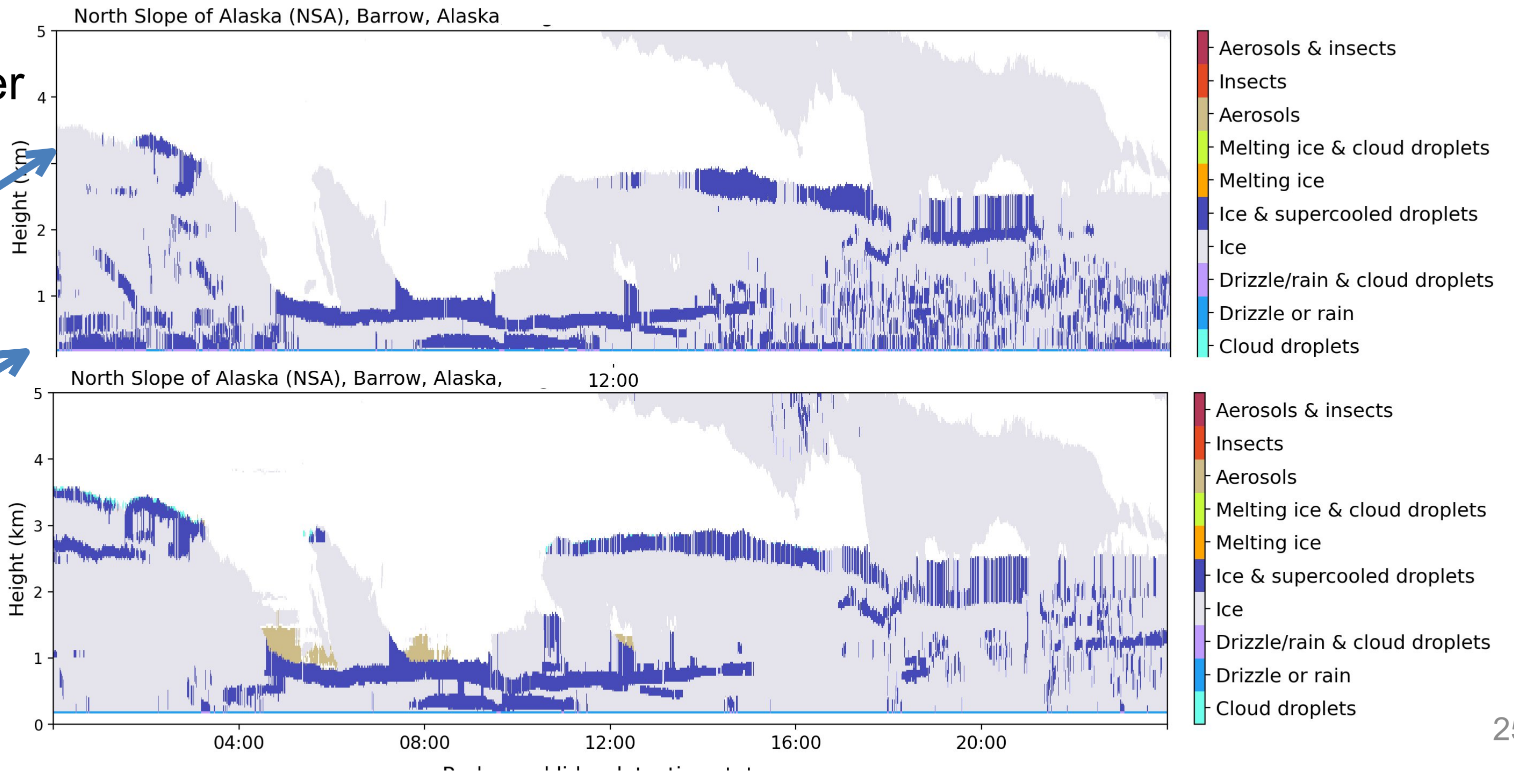
Limitations

- Problem: Cloudnet classification can only detect liquid below the Lidar attenuation. Thus SCLC are potentially missed.
- Solution #1: High power Lidars can penetrate some cloud layer but the instrument availability is poor (HSRL in NSA only from 2014-2019)

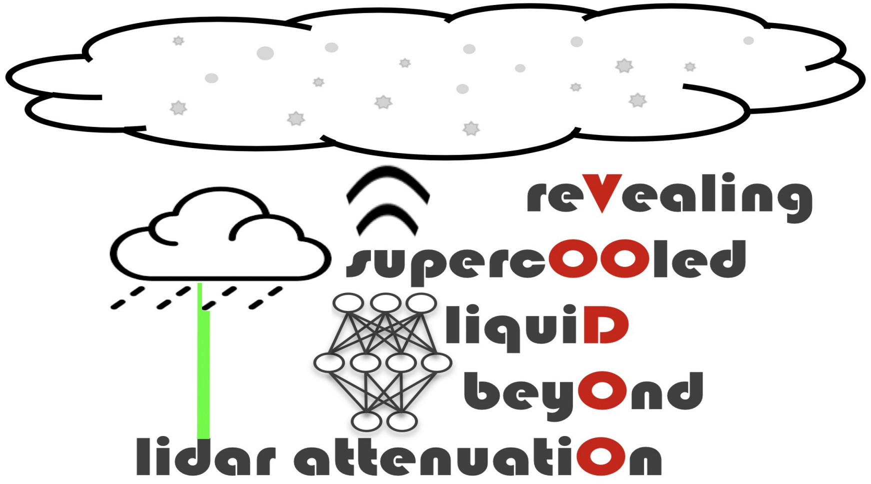
Ceilometer

- Missed detection
- sensitivity to detect small cloud droplets

HSRL



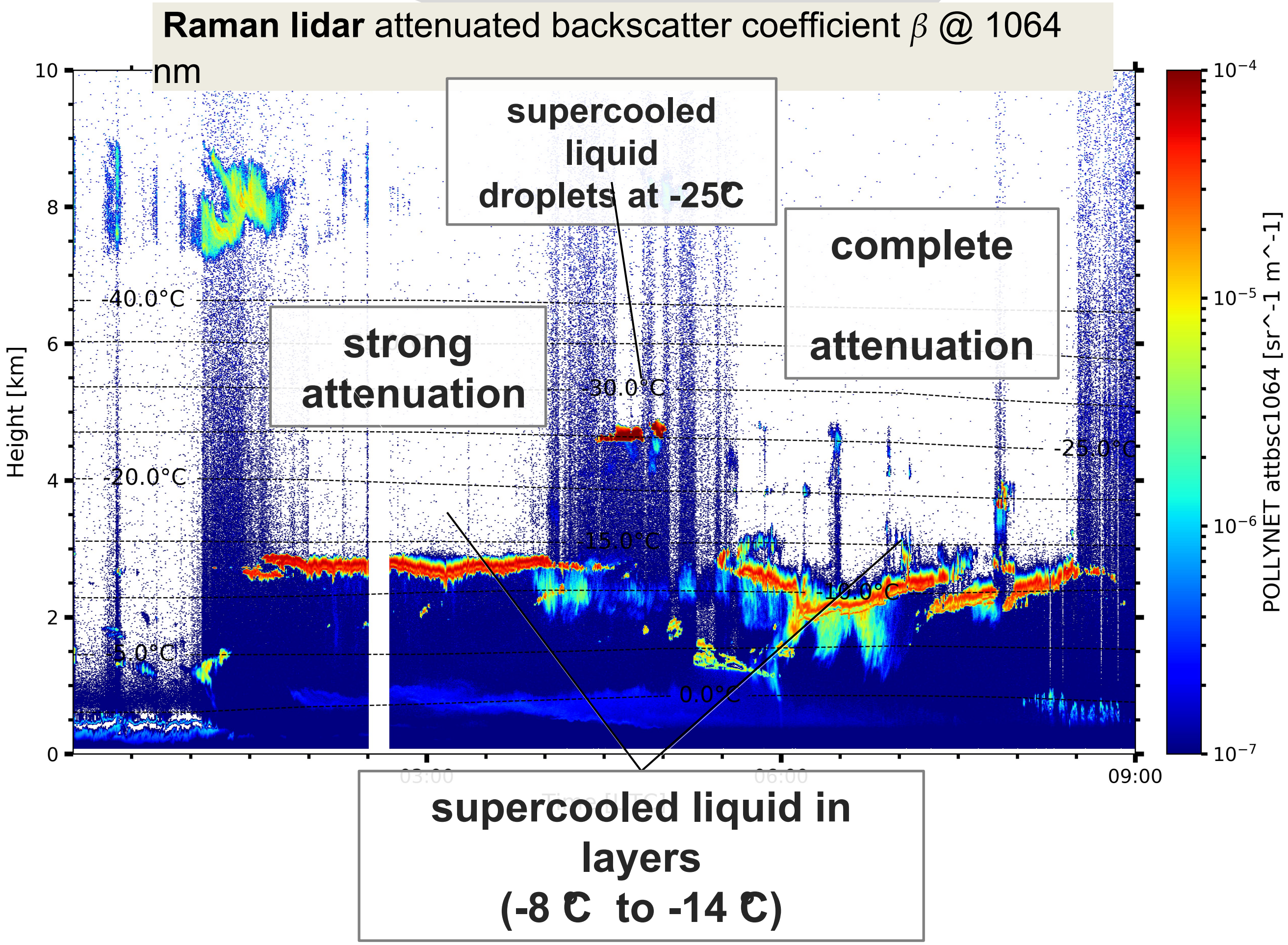
Detection with Cloud Radar Solution #2:

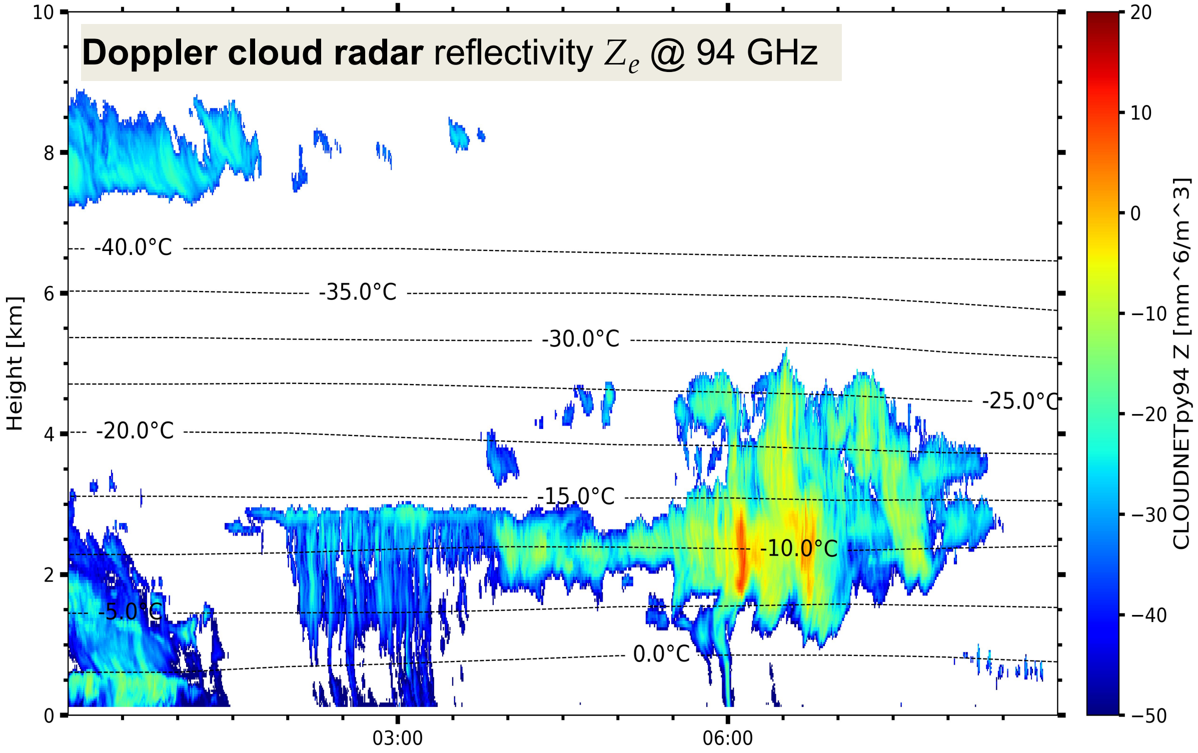


- VOODOO — A deep learning approach for detecting supercooled liquid beyond Lidar attenuation.
- **Application of Willi Schimmel PhD work to NSA data set.**

Reliable detection of liquid water only possible with valid Lidar signal.

Punta Arenas, Chile: 1st August 2019

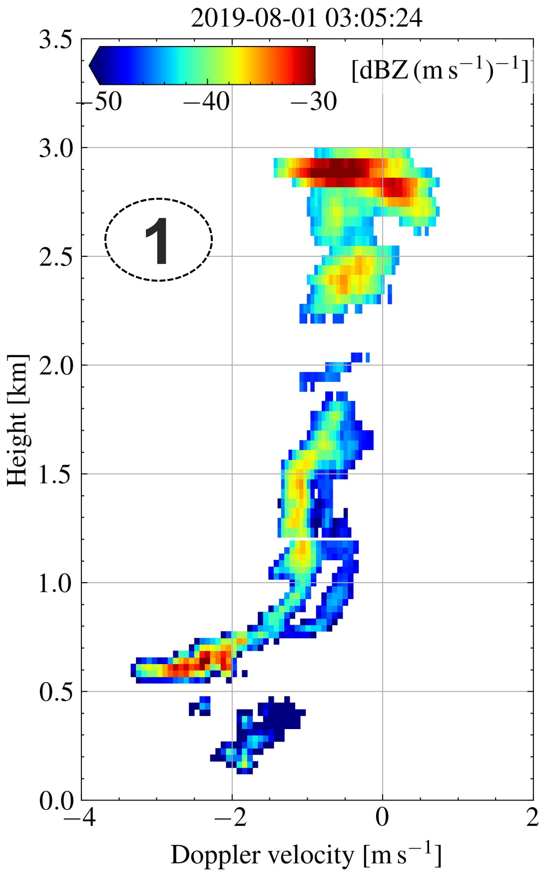


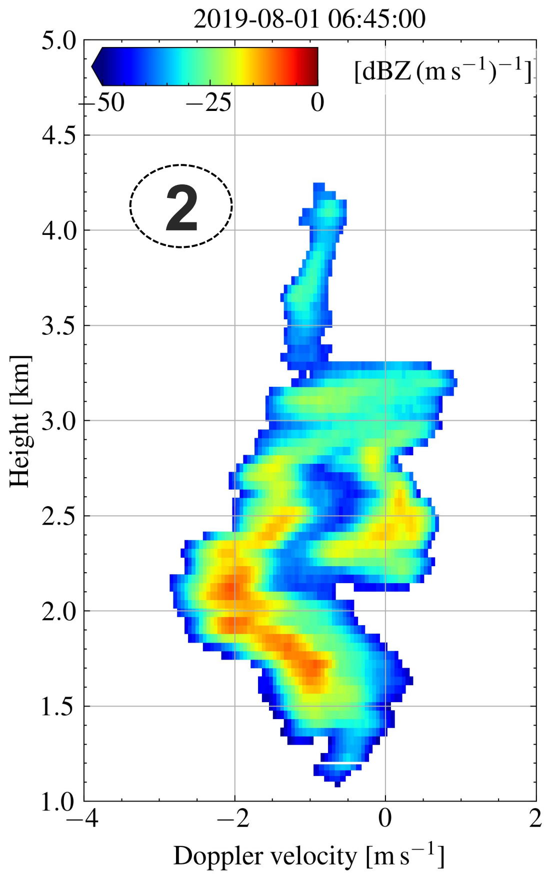


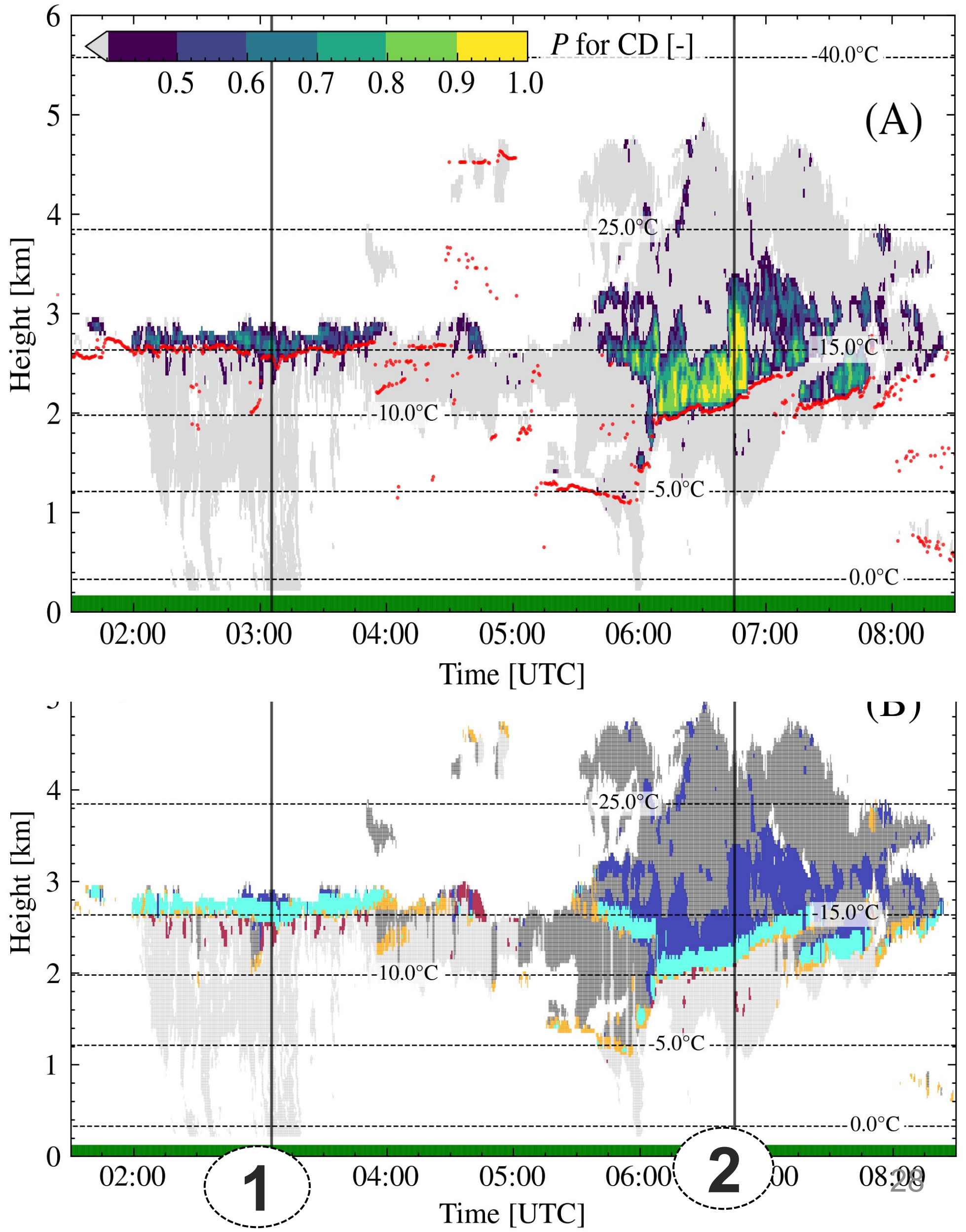
Detection by Radar Doppler spectrum

Cloud detection above Lidar attenuation

- stratiform liquid clouds,
- multi-layer mixed-phase clouds,







Conclusions

- **Water vapor transport can be a good parameter to relate presence/absence of mixed-phase clouds with Sea ice conditions**,
- Classical approach of selecting only Cloud surface coupling is not valid when WVT still present above inversion layer,
- Statistics for mixed-phase clouds show:
  - ➢ More abundance of cloud water content for coupled cases,
  - ➢ Less abundance of Ice water content, except for Land & Ocean,
  - ➢ Cloud base height is clearly segregated by coupled vs de-coupled, with lower clouds being the dominant type of clouds coupled to water vapor advenction,
  - ➢ There is a large monthly variability, revealing a certain entanglement with particular sea ice conditions present during the month.

Conclusions

- Water vapor transport can be a good parameter to relate presence/absence of mixed-phase clouds with Sea ice conditions,
- **Classical approach of selecting only Cloud surface coupling is not valid when WVT still present above inversion layer**,
- Statistics for mixed-phase clouds show:
  - More abundance of cloud water content for coupled cases,
  - Less abundance of Ice water content, except for Land & Ocean,
  - Cloud base height is clearly segregated by coupled vs de-coupled, with lower clouds being the dominant type of clouds coupled to water vapor advenction,
  - There is a large monthly variability, revealing a certain entanglement with particular sea ice conditions present during the month.

Conclusions

- Water vapor transport can be a good parameter to relate presence/absence of mixed-phase clouds with Sea ice conditions,
- Classical approach of selecting only Cloud surface coupling is not valid when WVT still present above inversion layer,
- **Statistics for mixed-phase clouds show:**
  - More abundance of cloud water content for coupled cases,
  - Less abundance of Ice water content, except for Land & Ocean,
  - Cloud base height is clearly segregated by coupled vs de-coupled, with lower clouds being the dominant type of clouds coupled to water vapor advenction,
  - There is a large monthly variability, revealing a certain entanglement with particular sea ice conditions present during the month.

Thank you for your attention

Contact:

pablo.saavedra@uni-leipzig.de

/pablosaa

@gasaapa