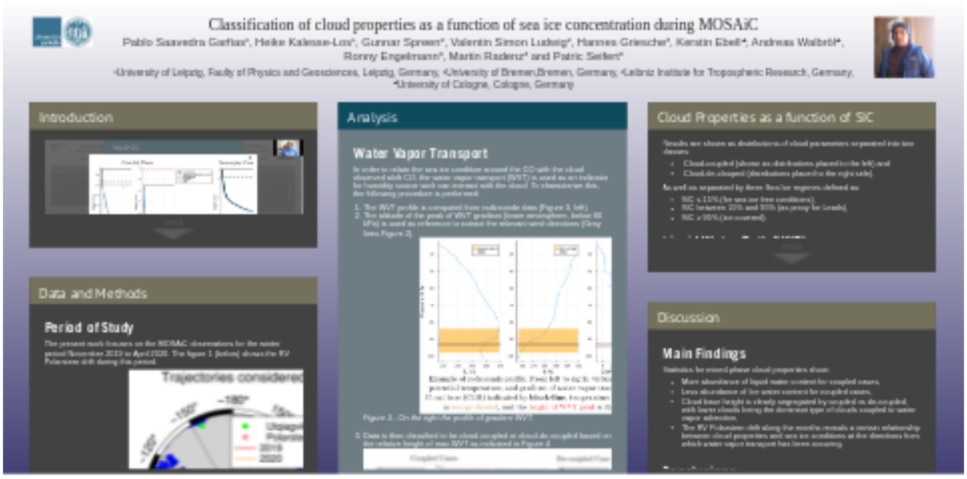
Classification of cloud properties as a function of sea ice concentration during MOSAiC



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INTRODUCTION

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As part of the (AC)3 Arctic Amplification project, we are studying the influence of specific sea ice conditions like the presence of leads on micro- and macrophysical cloud properties such as cloud altitude, thermodynamic phase, and their coupling state during the **MOSAiC** expedition.

Cloud properties are analyzed as a function of sea ice concentration (**SIC**) in the vicinity of the ground-based atmospheric remote-sensing observatory onboard the RV *Polarstern*.

Only sea ice conditions are analyzed where wind favored the transportation of air avobe the observatory.

Cloud microphysical properties are obtained from the **CloudNet** target classification algorithm which uses the atmospheric remote-sensing instrumentation suite provided by the US Atmospheric Radiation Measurement (**ARM**) mobile facility, the **TROPOS** ship-borne Atmosphere observation suite (**OCEANET**) and liquid water path retrievals by the University of Cologne.

Primarily, the classical Matlab-based **CloudNet** classifications retrieved by **TROPOS** are used. Furthermore, the recently released ARM "evaluation" Active Remote Sensing Clouds (**ARSCL**) data product for the Ka-band cloud radar is also evaluated by the new Python **CloudNet** version developed at the Finish Meteorological Institute. Discrepancies between those two **CloudNet** versions will be evaluated and reported as feedback for the **ARM** evaluation data set.

High resolution (1-km) merged **AMSR2-MODIS** satellite retrievals of Sea Ice Concentration by the University of Bremen are used as information for sea ice monitoring. The present contribution only exploits SIC data, however future studies will focus on **MOSAiC** specific products for the identification of leads.

Statistics for the cloud properties as a function of **SIC** will be presented as first approach to investigate the influence of sea ice conditions to central Arctic clouds.

DATA AND METHODS

Period of Study

The present work focuses on the MOSAiC observations for the winter period November 2019 to April 2020. The figure 1 (below) shows the RV Polarstern drift during this period.

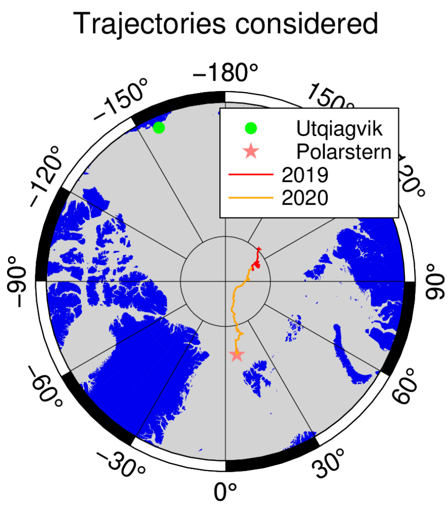


Figure 1.- RV Polarstern trajectory during the period considered.

Sea Ice Concentration

Data for Sea Ice Concentration (SIC) based on retrievals from MODIS and AMSR2 merged product at a resolution of 1 km provided by the University of Bremen for the years 2019, 2020 is used [1].

SIC is considered within a 50 km radius around the central observatory (CO). The figure 2 (below) highlights the event from 15 April 2020 where a 2.5 km wide north-south Lead opened about 25 km away from the CO within 24 hrs as reported by [7].

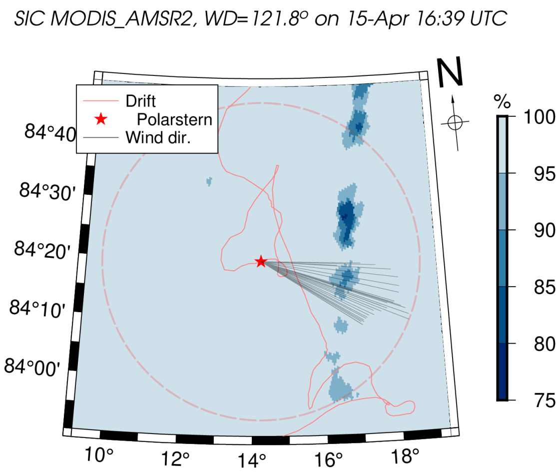


Figure 2.- SIC retrieved from MODIS-AMSR2 merged product. Dashed red circle indicates the 50 km radius considered for analysis. Light-red line depicts the RV Polarstern drift. Gray lines highlight the wind directions considered for analysis (see box Analysis point 5.).

Cloud Observations

The current contribution uses the instrument suit operated by:

OCEANET:

The Leipzig Institute for Tropospheric Research (TROPOS) performed atmospheric observations with the the Lidar Polly-XT, and a Hatpro-G5 microwave radiometer.

ARM Mobile Facility:

The DOE ARM mobile facility provides a large number of products, of relevance for this work are:

- Cloud radar KAZR, (GE, ME and ARSCL products)
- Vaisala ceilometer CL31 10m,
- Dual-frequency microwave radiometer RET product [8],
- Radiosonde Interpolated product.

Cloud Classification

The Cloudnet target classification algorithm [3] has been exploited to classify the observed cloud by its thermodynamic phase and liquid/ice water content. Two Cloudnet processing versions are currently available:

1. Legacy version, applied to OCEANET data and products provided by TROPOS [4],
2. Cloudnetpy version, software by ACTRIS [2] and applied only to a small subset of data (Nov., Dec. 2019) using only ARM data.

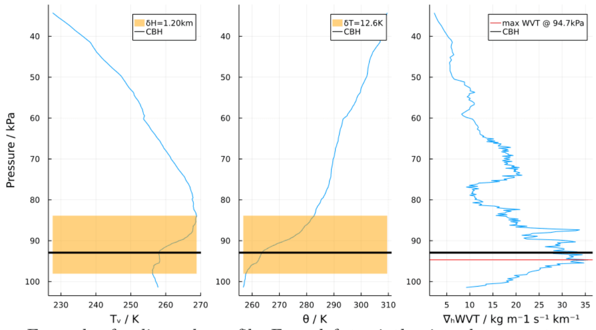
For this work, the main source for Cloudnet classification is the product from TROPOS.

ANALYSIS

Water Vapor Transport

In order to relate the sea ice condition around the CO with the cloud observed aloft CO, the water vapor transport (WVT) is used as an indicator for humidity source wich can interact with the cloud. To characterize this, the following procedure is performed:

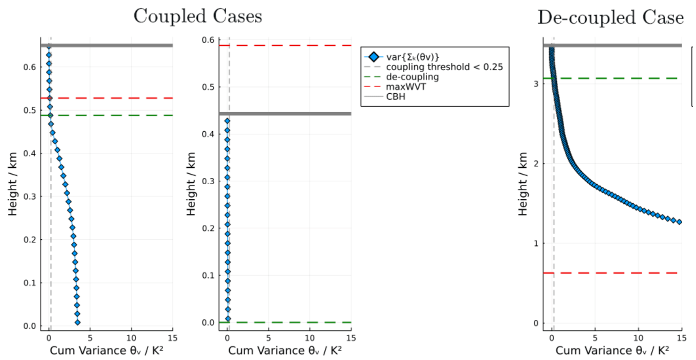
1. The WVT profile is computed from radiosonde data (Figure 3, left)
2. The altitude of the peak of WVT gradiant (lower atmosphere, below 60 kPa) is used as reference to extract the relevant wind directions (Gray lines Figure 2).



Example of radiosonde profile. From left to rigth: virtual temperature, potential temperature, and gradient of water vapor transport (WVT). Cloud base (CBH) indicated by **black-line**, temperature inversion depth in orange shaded, and the height of WVT peak with **red-line**.

Figure 3.- On the right the profile of gradient WVT.

3. Data is then classified to be cloud-coupled or cloud-de-coupled based on the relative height of max WVT as indicated in Figure 4.



Classification for Cloud copling: **Coupled** → when the max WVT height is found inside the mixing layer below cloud base (CBH) or in the cloud (left & middle). **De-coupled**→ max WVT height is below the cloud mixing layer (green dash line).

Figure 4.- Classification for cloud coupling.

4. After cloud coupling state is classified, only the wind direction profile is considered which lays within e.g. the altitude of WVT peak and de-coupling altitude. Otherwise within ∓100 m of WVT peak's height.
5. Selected wind direction are depicted in Figure 2 (gray lines) and SIC from only those directions are considered to extract a range-time SIC(θ_wind) along a 50 km range (Figure 5). The procedure is repeated for every observed atmospheric profile.

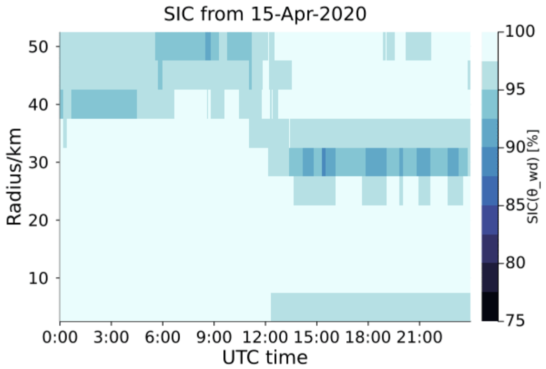


Figure 5.- Time series of SIC along 50km range extracted from wind direction identified from water vapour transport conditions (gray lines in Figure 2).

6. The dataset is then analyzed based on: coupling/de-coupling to the mixing layer below cloud base and the SIC condition obtained by point 5.
7. Cloud properties are obtained from the Cloudnet target classification and retrievals e.g. of ice water path (IWP), liquid water path (LWP) in mixed-phase cases (Figure 6) and cloud base height (CBH).

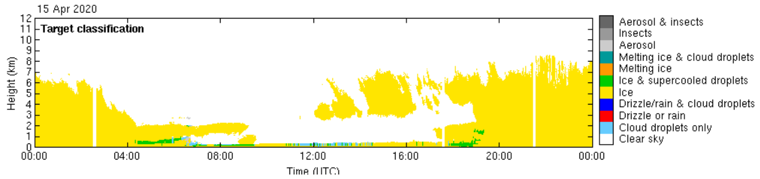


Figure 6.- Example of Cloudnet target classification for the 15th April 2020 case.

CLOUD PROPERTIES AS A FUNCTION OF SIC

Results are shown as distributions of cloud parameters separated into two classes:

- Cloud-coupled (shown as distributions placed to the left) and
- Cloud-de-clouped (distributions placed to the right side).

As well as separated by three Sea Ice regimes defined as:

- SIC ≤ 15% (for sea ice free conditions),
- SIC between 15% and 95% (as proxy for Leads),
- SIC ≥ 95% (ice covered).

Liquid Water Path (LWP)

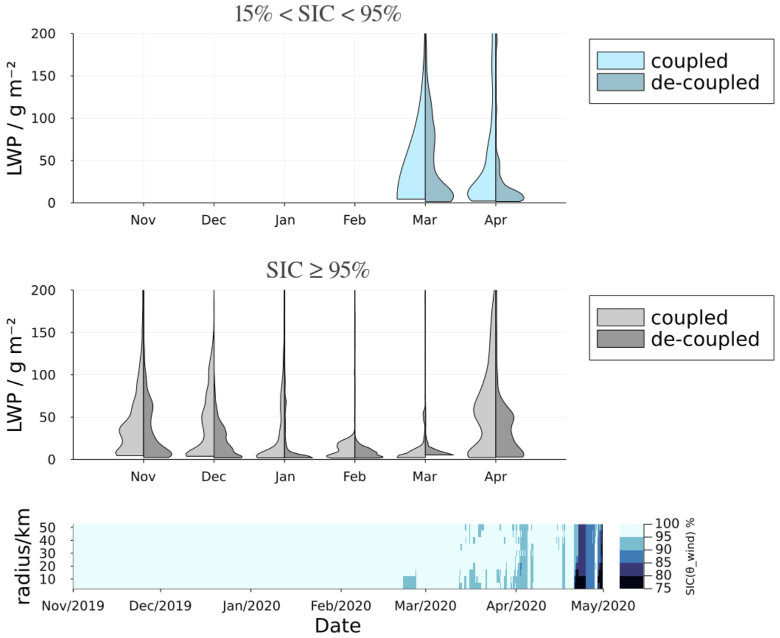


*Figure 7.- **Top:** LWP distributions for coupled (left side) and de-coupled (right side) to the WVT height and for cases with large open Sea Ice sectors. **Middle:** same as top but for cases with large Sea Ice concentration. **Bottom:** The SIC as a funcion of wind direction for the whole period of study.*

Ice Water Path (IWP)

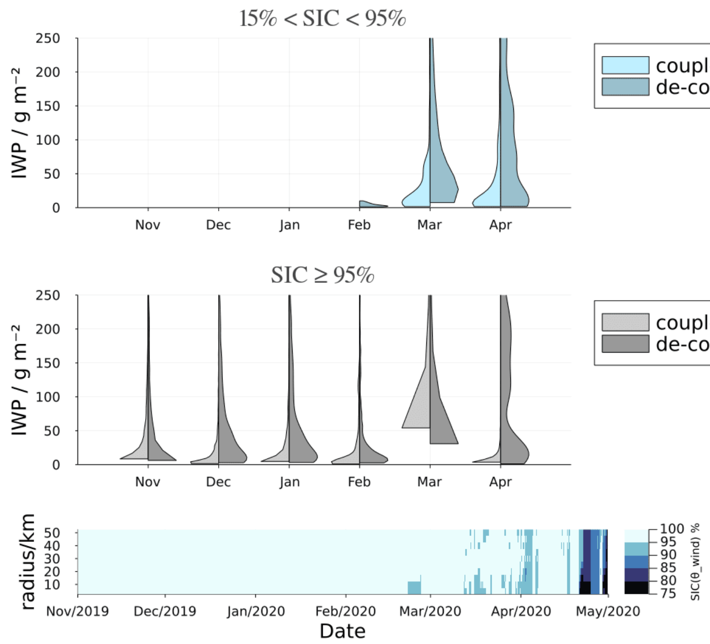


Figure 8.- Same as figure 7 but for the Ice water path obtained from the Cloudnet product.

Cloud Base Height (CBH)

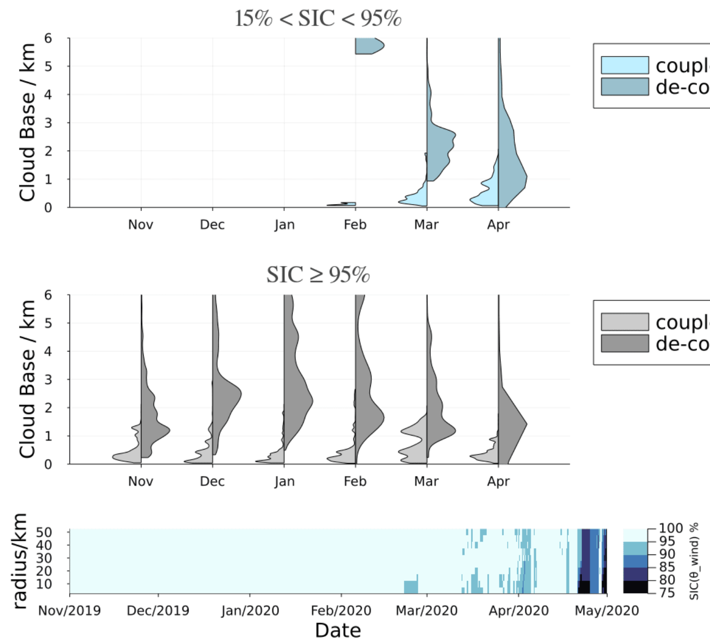


Figure 9.- Same as figure 7 bur for Cloud base height measured by the lidar.

DISCUSSION

Main Findings

Statistics for mixed-phase cloud properties show:

- More abundance of liquid water content for coupled cases,
- Less abundance of Ice water content for coupled cases,
- Cloud base height is clearly segregated by coupled vs de-coupled, with lower clouds being the dominant type of clouds coupled to water vapor advection,
- The RV Polarstern drift along the months reveals a certain relationship between cloud properties and sea ice conditions at the directions from which water vapor transport has been occuring.

Conclusions

- Classical approach of selecting only Cloud surface coupling might not be valid when water vapor transport is still present above inversion layer,
- Water vapor transport can be a good parameter to relate the influence of certain Sea Ice conditions to the properties of mixed-phase clouds.

Classification Algorithm Caveats

For the results presented here, only the Cloudnet target classification as preliminary product provided by TROPOS [4] has been used.

It is important to note that as the data is being further processed, the classification might change. To illustrate this point, Figure 10 highlights an example where the recently released preliminary ARM data for MOSAiC has been used to apply the ACTRIS Cloudnet algoritm [2] and compared to the state-of-the-art classification by TROPOS [4].

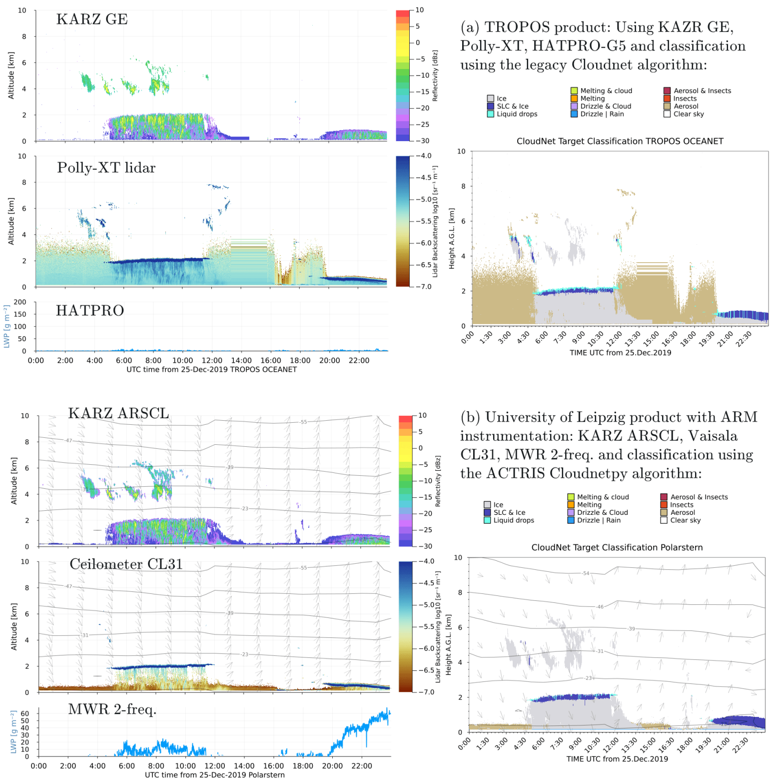


Figure 10.- Comparisons of Cloudnet input data and target classification products from the case of December 25th 2019. Note how the classification is sensitive to the quality of input data and the algorithm itself.

AUTHOR INFORMATION

For similar study but applied to the Western Arctic site NSA in Utqiagvik, watch my presentation in session A42F, contribution 7 on Thursday 16th December from 10:15 to 10:20 CT.

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ABSTRACT

As part of the (AC)³ Arctic Amplification project, we are studying the influence of specific sea ice conditions like the presence of leads or polynyas on micro- and macrophysical cloud properties such as cloud fraction, altitude, thickness, thermodynamic phase, and their coupling state with respect to the underlying surface during the MOSAiC expedition's legs 1 to 3. Micro- and macrophysical properties of surface-coupled clouds are analyzed as a function of sea ice concentration (SIC) in the vicinity of the ground-based atmospheric remote-sensing observations onboard the RV Polarstern. Only situations are analyzed where wind favored the transportation of air from location where open sea ice is detected.

Cloud microphysical properties are obtained from the CloudNet cloud target classification algorithm which uses the atmospheric remote-sensing instrumentation suite on board of RV Polarstern provided by the US Atmospheric Radiation Measurement (ARM) mobile facility, the TROPOS ship-borne Atmosphere observation suite (OCEANET) and liquid water path retrievals by the University of Cologne. Primarily, the classical Matlab-based CloudNet classifications retrieved by TROPOS are used. Furthermore, the recently released ARM "evaluation" Active Remote Sensing Clouds (ARSCL) data product for the KA-band cloud radar is also evaluated by the new Python CloudNet version developed at the Finish Meteorological Institute. Discrepancies between those two CloudNet versions will be evaluated and reported as feedback for the ARM evaluation data set.

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