Cloud Macro-and Microphysical Properties as Coupled to Sea Ice Leads During the MOSAiC Expedition

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Abstract

This study presents the micro- and macrophysical cloud properties as a function of their surface coupling state with the sea ice during the wintertime of the MOSAiC field experiment. Cloud properties such as cloud base height, liquid- and ice water content have been previously found to have statistically distinguished features under the presence of sea ice leads (characterized by sea ice concentration, SIC) along downwind direction from the central observatory RV Polarstern. Those findings are mainly in an increase of liquid water content, and favored occurrence of low level clouds as contrasted to situations when the clouds are thermodynamically decoupled.

The present contribution is an update considering two recent developments in the liquid detection in clouds and in the detection of sea ice leads. First, radar and lidar-based cloud droplet detection approaches like Cloudnet (Illingworth et al. 2007, Tukiainen et al. 2020) using Arctic wintertime observations and applied to measurements by the Atmospheric Radiation Measurement mobile facility (ARM) instrumental suite on-board the RV Polarstern during MOSAiC.

Secondly, we explore a new sea ice lead fraction product based on sea ice divergence. Sea ice divergence is estimated from sequential images of space-borne synthetic aperture radar with a spatial resolution of 700 m. The lead divergence product, being independent of cloud coverage, offers the unique advantage to detect opening leads at high spatial resolution.

Statistics for the wintertime cloud properties based on the coupling state with the sea ice concentration and sea ice lead fraction will be presented as an approach to study Arctic clouds and their interaction with sea ice.

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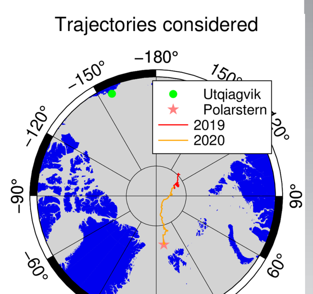
1.- Research Objectives

The study focuses on the observation of Arctic mixes-phase clouds and sea ice leads to address the following research questions:

- Are cloud properties influenced by the presence of sea ice leads?
- Does coupling/decoupling of clouds to moisture-layers impact the cloud's properties?



We focus is wintertime/early spring legs 1 to 3 of the *MOSAiC* expedition [1]. Instrumentation and data set are provided by the Atmospheric Radiation Measurement's (ARM) Mobile Facility 1 (AMF-1) and by the OCEANET-Atmosphere container from TROPOS.

2.- Coupling of Sea Ice and Clouds

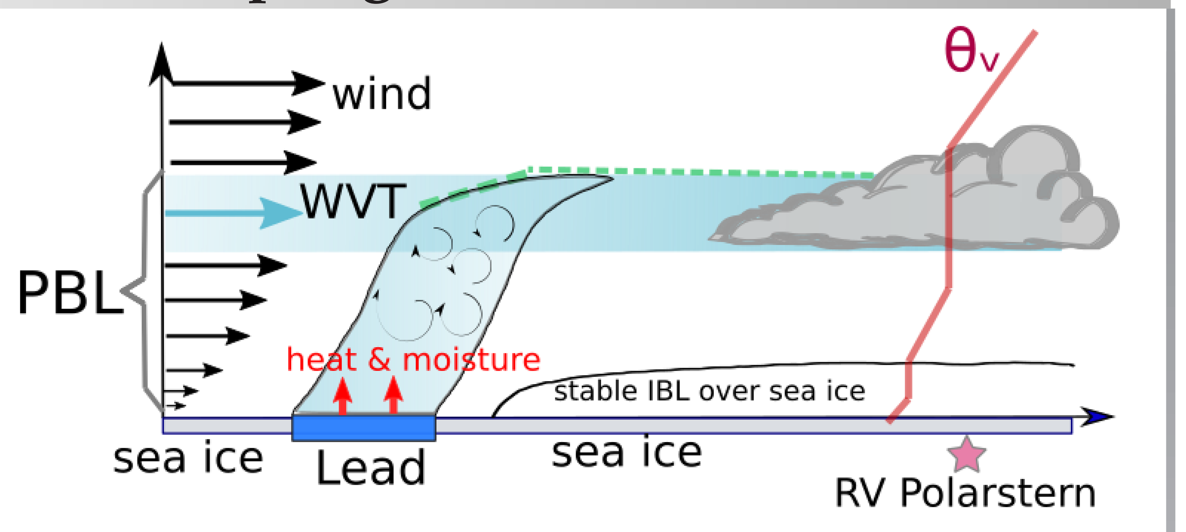


Figure 1: Sea ice interaction with observed clouds. Adapted from [7]

Daily sea ice lead fraction (LF) is obtained based on the divergence calculations from consecutive Sentinel-1 SAR scenes [4]. Sea ice concentration (SIC) is provided by the University of Bremen [5]. Fig. 2 summarizes the LF and SIC during *MOSAiC* wintertime.

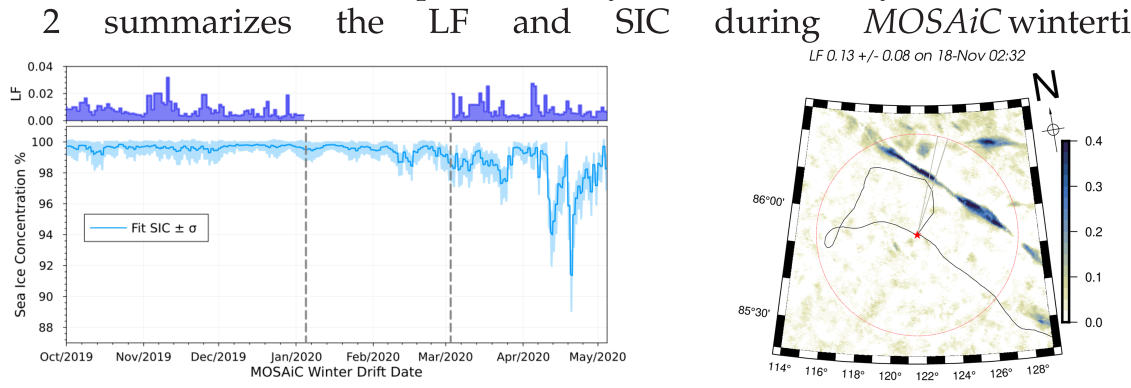


Figure 2: Left: LF and SIC, vertical dashed-grey lines mark the Sentinel-1 data gap. Right: case study 18 Nov 2019.

We relate sea ice lead fraction to cloud observations above RV *Polarstern* following:

- LF products is analyzed within 50 km around the RV *Polarstern* (red star in Fig. 2, right) with updated coordinates every minute.

- Sea ice - atmosphere coupling conceptual model

Vertical gradient of water vapour transport (∇WVT) is calculated from specific humidity q_v [g g^{-1}] and horizontal wind $\vec{v}_w$ [m s^{-1}] from radiosonde profiles, following

$$\nabla \mathrm{WVT} = -\frac{10^2}{g}\,|q_v \cdot \vec{v}_w|\,\frac{dP}{dz} \qquad (1)$$

The direction of maximum transport (see grey lines in Fig. 2) is used to relate LF with zenith observations at RV *Polarstern*.

- Planetary boundary layer height (PBLH)

Estimated via the bulk Richardson number 2, PBLH is used as top layer below which the maximum ∇WVT is localized:

$$Ri_b(z) = \frac{g}{\theta_v}\frac{\Delta\theta_v\,\Delta z}{(\Delta u)^2 + (\Delta v)^2} \qquad (2)$$

3.- Cloud-sea ice coupled case study 18th Nov 2019

Cloudnet target classification is used to determine cloud macro- and microphysical properties. Radiosondes are used to obtain information on the thermodynamic states of the atmosphere, e.g. θ_v, ∇WVT, wind vectors, and Ri_b.

- Synergy of the ship-based zenith observations are needed to apply the Cloudnet classification algorithm.

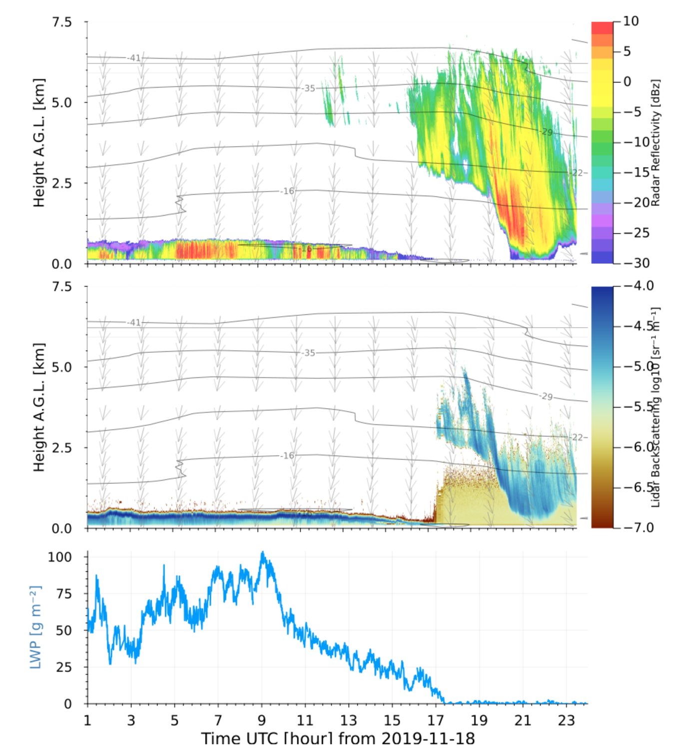


Figure 3: From top to bottom: ARM KAZR cloud radar reflectivity, ARM ceilometer backscattering coefficient, liquid water path from HATPRO microwave radiometer [2].

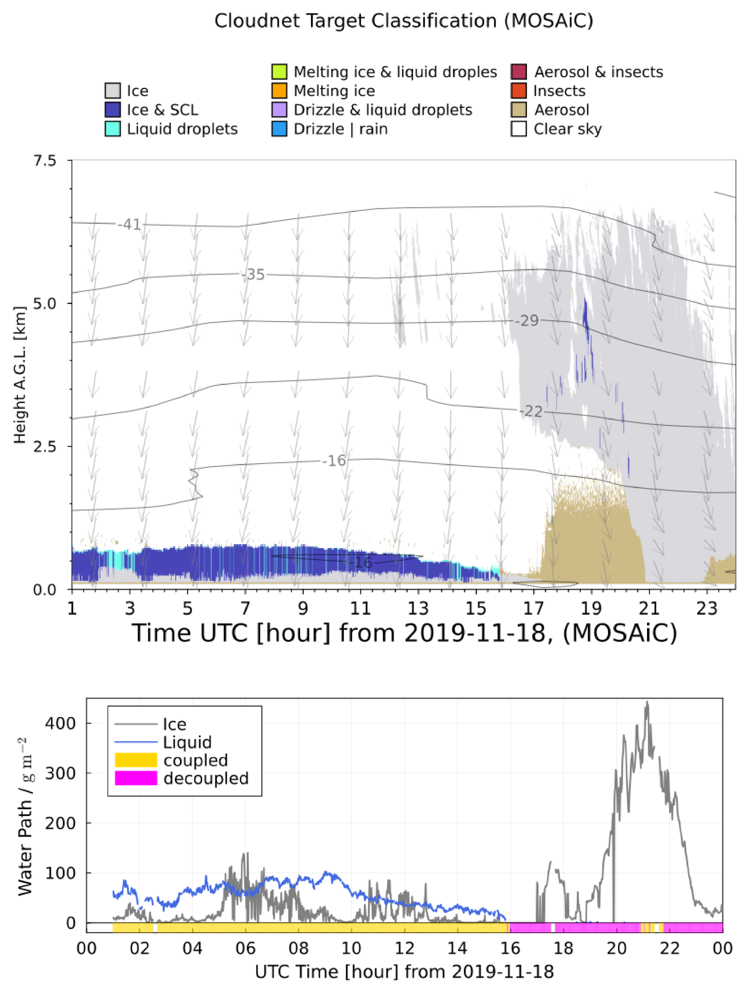


Figure 4: Top: Cloudnet classification from the measurements in Fig. 3. Bottom: LWP and IWP for the lowest layer detected. Note that only of mixed-phase clouds are considered.

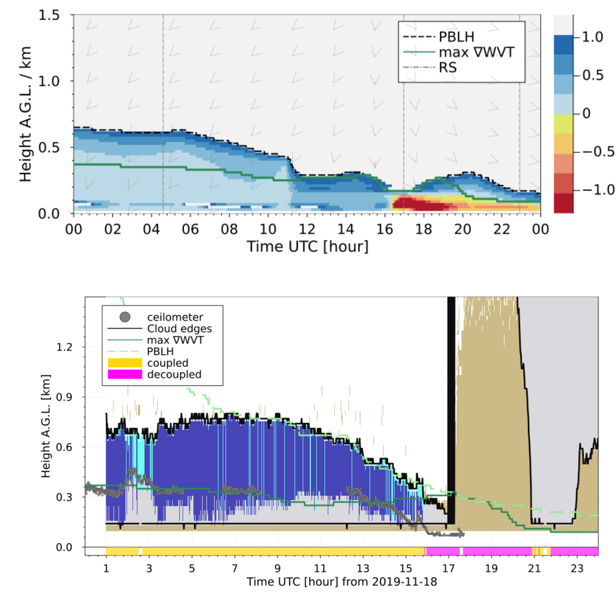


Figure 5: Top: Ri_b for lowest 1.5 km, PBLH critical Ri_b=1. RS denotes times of radiosonde launches. Bottom: Close-up of Fig. 4 with PBLH (dashed-light-green), max ∇WVT (green), and cloud bottom and top heights (black lines), and cloud base by the ceilometer (dotted-grey). Coupled status is shown along the x-axis.

The wind direction at max ∇WVT provides the relevant information to link sea ice LF to the cloud observation above RV *Polarstern*. LF is considered from a region determined by the wind direction with center at RV *Polarstern* to 50 km radius (grey lines in Fig. 2, right).

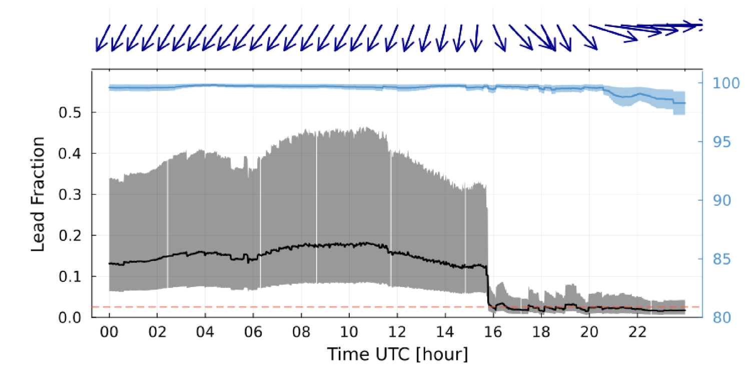
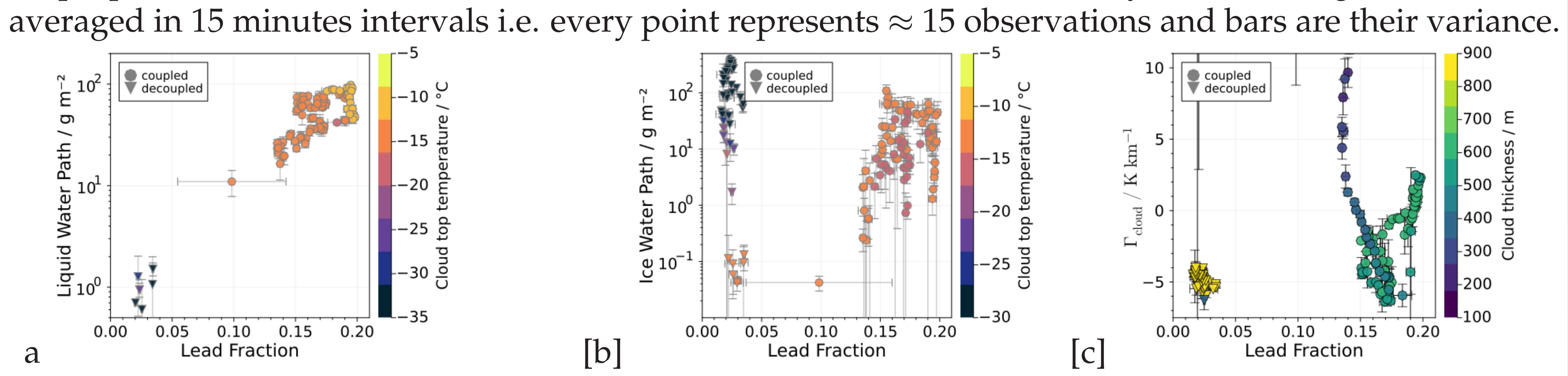


Figure 6: LF extracted from Fig. 2 (right) based on 1-minute wind direction at the max ∇WVT. For reference the wind vectors at max ∇WVT (top panel) and SIC for the same region is also shown in light-blue (right y-axis).

From Fig. 6 the 1-minute LF statistics can be related to the corresponding micro- and macrophysical properties of clouds derived from Cloudnet. In order to reduce variability the following results are averaged in 15 minutes intervals i.e. every point represents ≈ 15 observations and bars are their variance.



a [b] [c]

Figure 7: [a] mean single cloud layer LWP vs. LF (black-line in Fig. 6) with colour-coded cloud top temperature. [b] Same but for IWP of same cloud layer. [c] Γ_{cloud} as defined in Eq. 3 vs. LF with colour-coded cloud thickness.

$$\Gamma_{\mathrm{cloud}} = \frac{\Delta T}{\Delta H} = \frac{T_{top} - T_{base}}{CTH - CBH} \qquad (3)$$

Fig. 7 [c] shows the gradient of cloud temperature defined as Eq. 3. The most negative Γ_{cloud} are close to a moist adiabatic lapse-rate. Positive values indicate a temperature inversion at cloud top.

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4.- Statistical Results

Based on the analysis in Box 2 & 3 and applied to the whole wintertime data from Nov 2019 to April 2020, the following results are found:

- Cloud coupling classification: criteria based on the virtual potential temperature θ_v and location of maximum $\nabla\, WVT$ below PBLH. The θ_v is analyzed to classify cases where the WVT is coupled or decoupled to the cloud mixing layer.

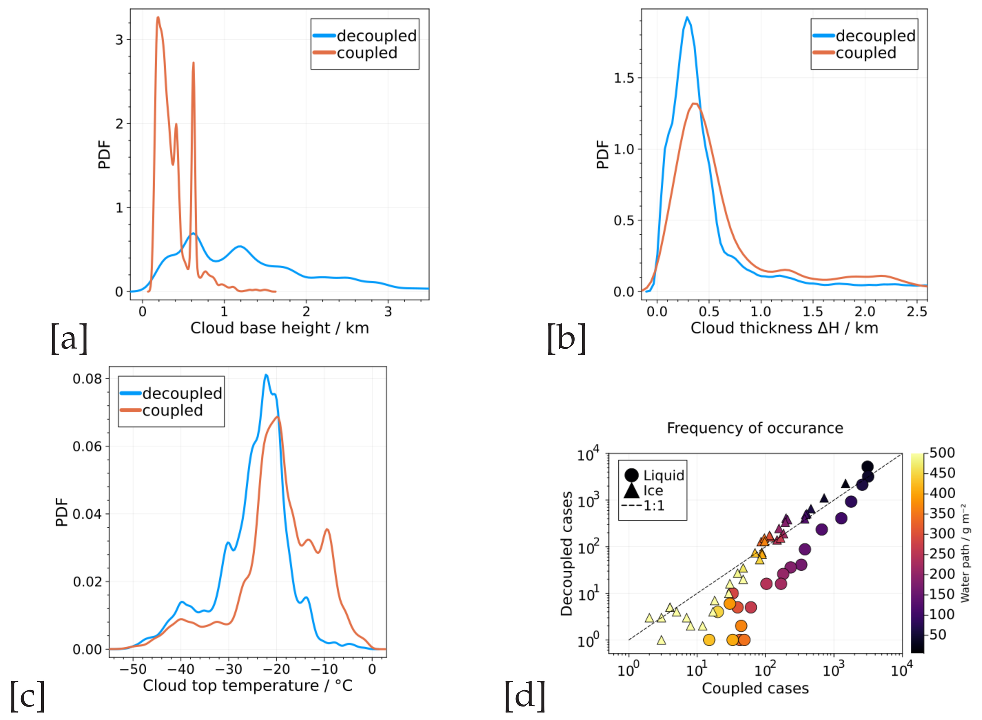

Figure 8: PDF for cloud-base height [a], -layer thickness [b], -top temperature [c], and [d] number of occurrences of coupled (red) and decoupled (blue) observations.

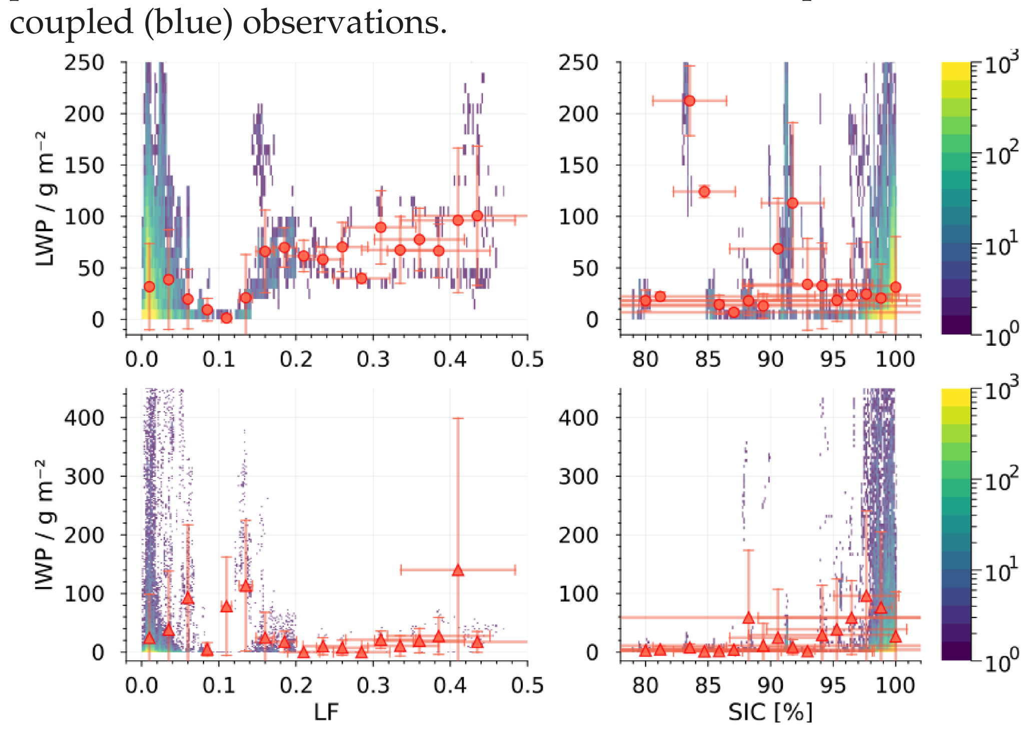

Figure 9: Statistics for LWP vs LF (top left) and LWP vs SIC (top right), and IWP vs LF (bottom left) and IWP vs SIC (bottom right)

5.- Conclusions

- Relating cloud observations with LF upwind with water vapour transport as conveying mechanism for the coupling as a plausible approach,
- When Leads are present, coupled clouds with larger LWP are more frequent,
- Increasing of LWP with LF (decreasing of SIC),
- Ice water shows no clear relation with sea ice LF or SIC,
- Cloud top temperature is warmer and cloud layer thicker for coupled obs.,
- Confirmation that coupled clouds are mainly low level clouds (similar for Utiqiaġvik, Alaska [6]),

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