Do sea ice conditions have a measurable influence on snowfall? A study based on MOSAiC wintertime observations

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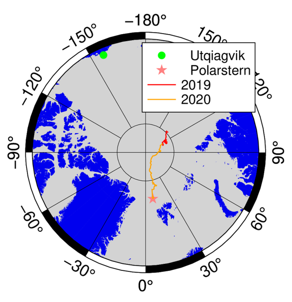
1.- Research Objectives

Arctic mixed-phase clouds have been found to change properties under the presence of sea ice leads [1]. Here we extend the study by analysing snowfall rates to address the following research questions:

- Is snowfall rate influenced by the presence of sea ice leads?
- In which way does the coupling/decoupling of clouds to moisture-layers impact the precipitation?



Of main interest is the wintertime/early spring legs 1 to 3 of the *MOSAiC* expedition [2]. 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.

The period of study ranges from November 2019 to April 2020, where sea ice leads are the most active in the central Arctic.

2.- Coupling of Sea Ice and Clouds

Daily sea ice lead fraction (LF) is obtained from space-borne observations based on the divergence calculations from consecutive Sentinel-1 SAR scenes [5]. Fig. 1 summarizes the LF and sea ice concentration (SIC) during the period of interest.

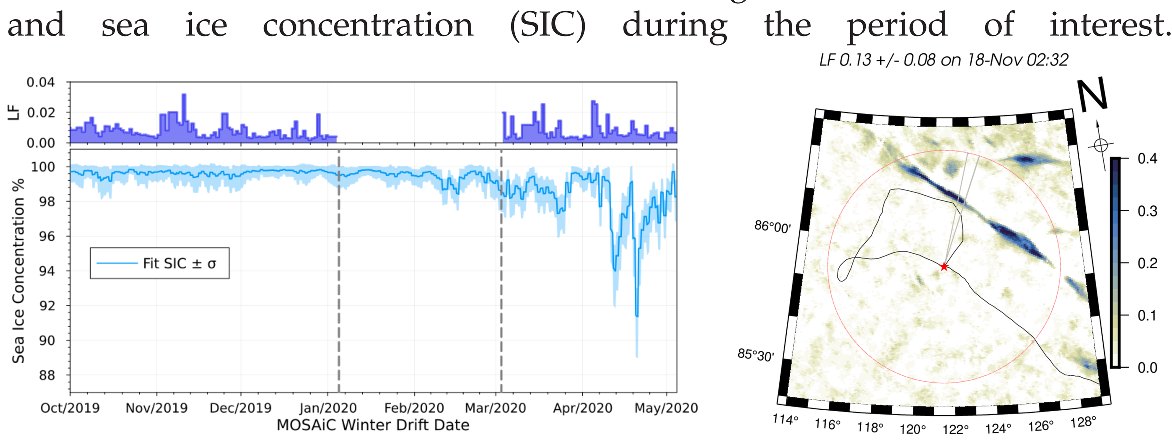


Figure 1: Left: LF and SIC for *MOSAiC* leg 1 to 3. Vertical dashed-grey lines indicates period without Sentinel-1 data. Right: case study 18 Nov 2019.

The following analysis is performed following [1] to relate sea ice lead fraction to cloud observations above RV *Polarstern*:

- LF is analyzed for a sector 50 km around the RV *Polarstern* (red star in Fig. 1, right) with its coordinates updated every minute.

- Sea ice - atmosphere coupling conceptual model

Vertical gradient of water vapour transport (∇WVT) is calculated from specific humidity q_v $[\mathrm{g\,g^{-1}}]$ and horizontal wind $\vec{v}_w$ $[\mathrm{m\,s^{-1}}]$ 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. 1) is used to relate LF with zenith observations at RV *Polarstern*.

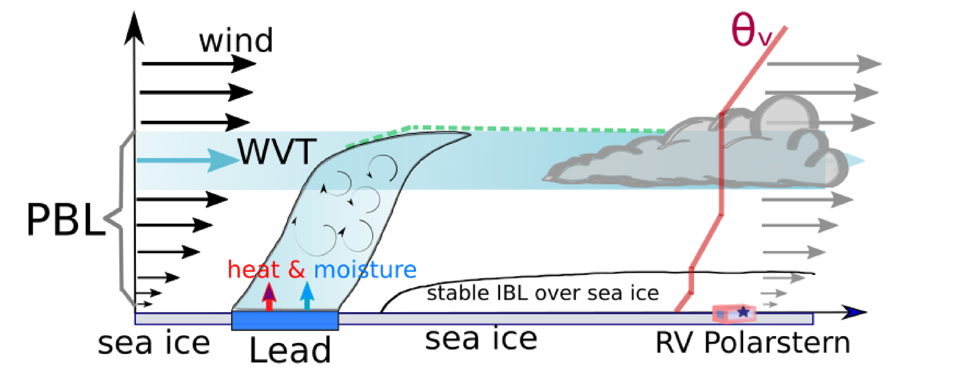


Figure 2: Sea ice interaction with observed clouds via water vapour transport.

- Cloud coupling classification: criteria based on the virtual potential temperature θ_v and location of maximum ∇WVT below PBLH. The θ_v is analyzed to determine cases where the cloud is coupled or decoupled to ∇WVT.

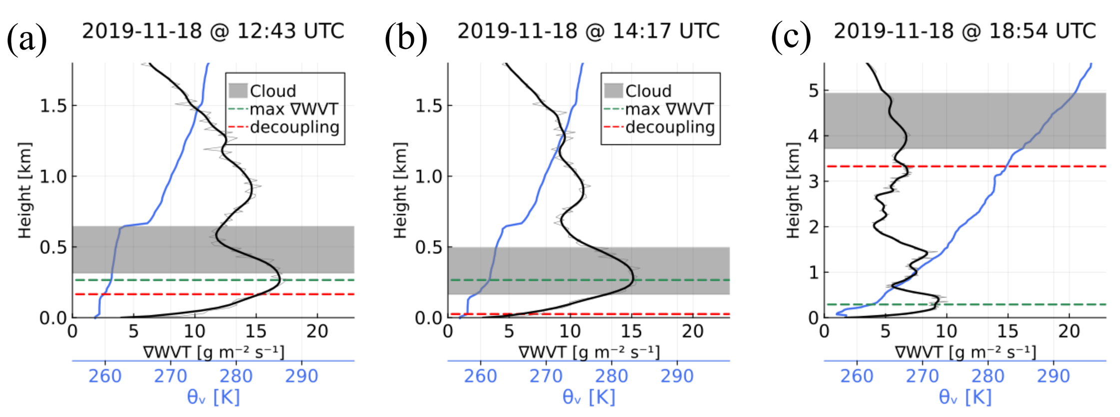


Figure 3: Examples of ∇WVT profiles for cloud coupling (a & b), and decoupling (c). Blue lines are profiles of virtual potential temperature.

Based in this methodology, cloud micro- and macro-physical properties have been analyzed for the *MOSAiC* wintertime. It has been found that clouds coupled to the WVT have larger liquid water path (LWP) as a function of upwind sea ice leads (LF) Fig. 5, while ice water path (IWP) the same is true only for depth precipitating clouds [1]. Next we study whether the increase of IWP is also related to snowfall rates at surface level.

3.- Results for cloud properties and snowfall coupled to sea ice via ∇WVT

Cloudnet target classification [4] is used to determine cloud macro- and microphysical properties. Radiosonde observations are exploited to obtain information on the thermodynamic states of the atmosphere, e.g. θ_v, ∇WVT, wind vectors, and Richardson number Ri_b.

- Snowfall rates (S_r) during *MOSAiC* are available from the M1 ARM mobil facility on beard of RV *Polarstern* (PARSIVEL[2]), the ice camp, and estmations from Ka-band radar [3] at 170 and 230 m above the RV *Polarstern* measurement deck. For this study, only PARSIVEL[2] and Ka-band at 170 m is considered.

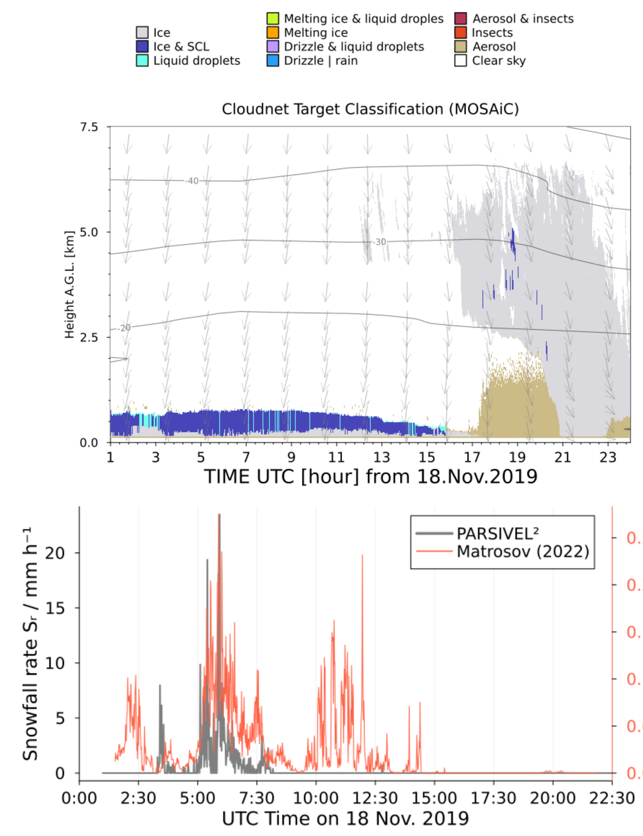


Figure 4: Top: Cloudnet classification. Bottom: Snowfall rate S_r from PARSIVEL[2] (gray line) and estimated from radar by [3] (orange line) at 170 m above RV *Polarstern* deck.

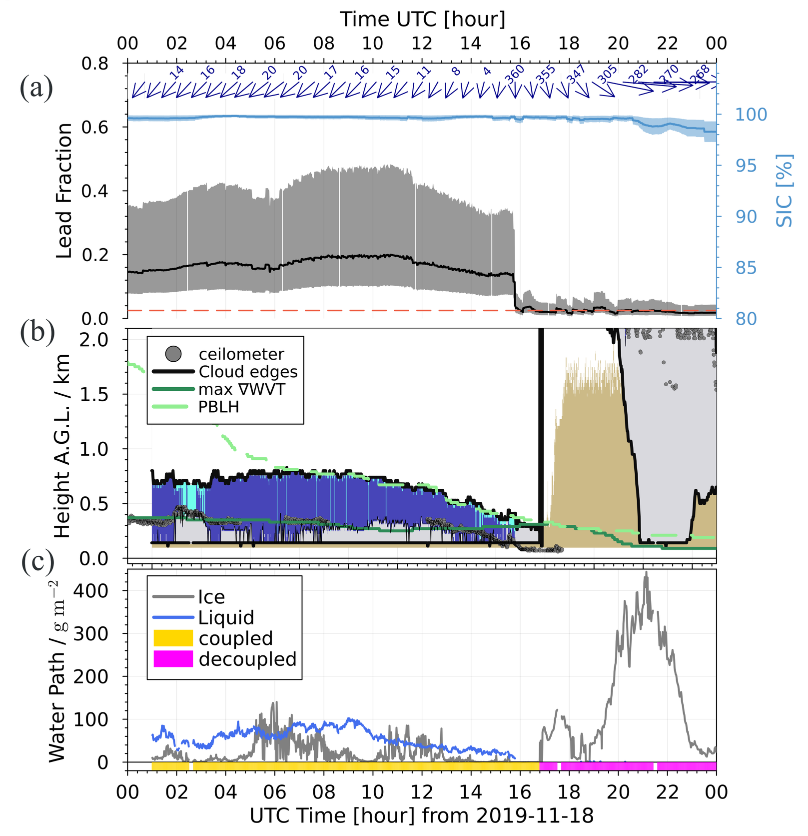


Figure 5: Time series of wind direction at max ∇WVT (blue arrows), mean and IQR Lead fraction LF (a), Cloudnet classification indicating cloud boundaries, PBLH, and max ∇WVT (b). Single layer cloud liquid and ice water path LWP & IWP. Bottom yellow band indicates coupled and magenta decoupled cases. Extracted from [1].

- Mixed-phase cloud classification as shown in Fig. 4 and coupling status to the sea ice lead fraction (LF) (Fig. 5) have been performed for the entire *MOSAiC* wintertime expedition. The results of the statistical analysis for liquid water path (LWP), ice water path (IWP), and snowfall rate (S_r) are shown below in Fig. 6.

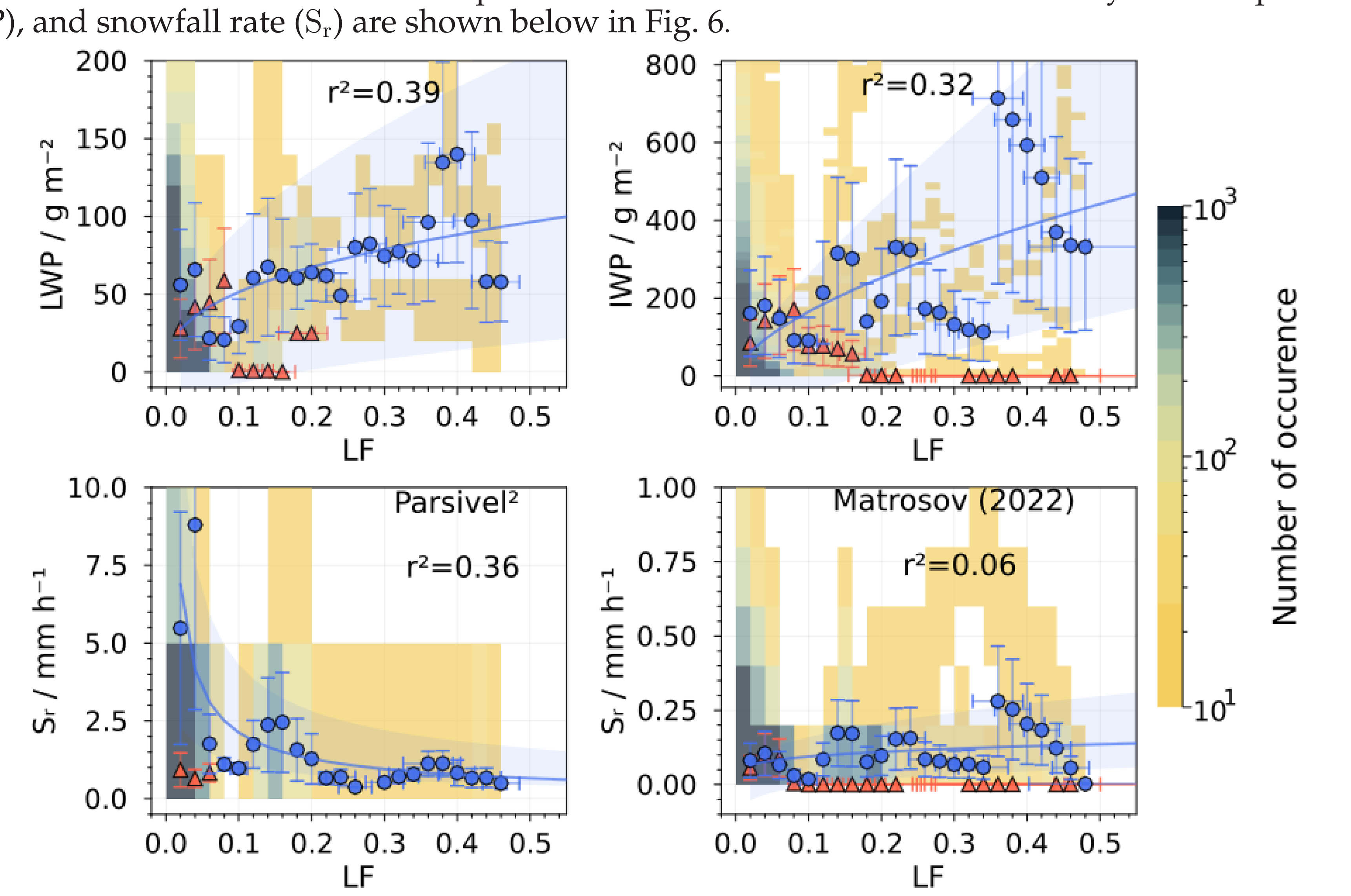


Figure 6: Statistics for the whole *MOSAiC* wintertime. Top row: single cloud layer LWP and IWP versus lead fraction LF for coupled (blue circles) and decoupled (orange triangles). Bottom row: snowfall rate S_r from PARSIVEL[2] and radar estimate [3] at 170 m. Colored scale indicates the number of occurrence for all observations, symbols indicate circle for coupled and triangles for decoupled.

- The ice water fraction $\chi_{ice} = \frac{\mathrm{IWP}}{\mathrm{IWP+LWP}}$ has been found to have a strong dependency to the coupling status when analyzed as a function of cloud top temperature (Fig. 7 (a) extracted from [1]). By analyzing χ_{ice} as a function of snowfall rate S_r has been found that large precipitation rates are associated to clouds coupled to WVT when sea ice is opened (LF>0.02) as shown inf Fig. 7 (b). On the other hand, decoupled cases are associated with low to moderate S_r.

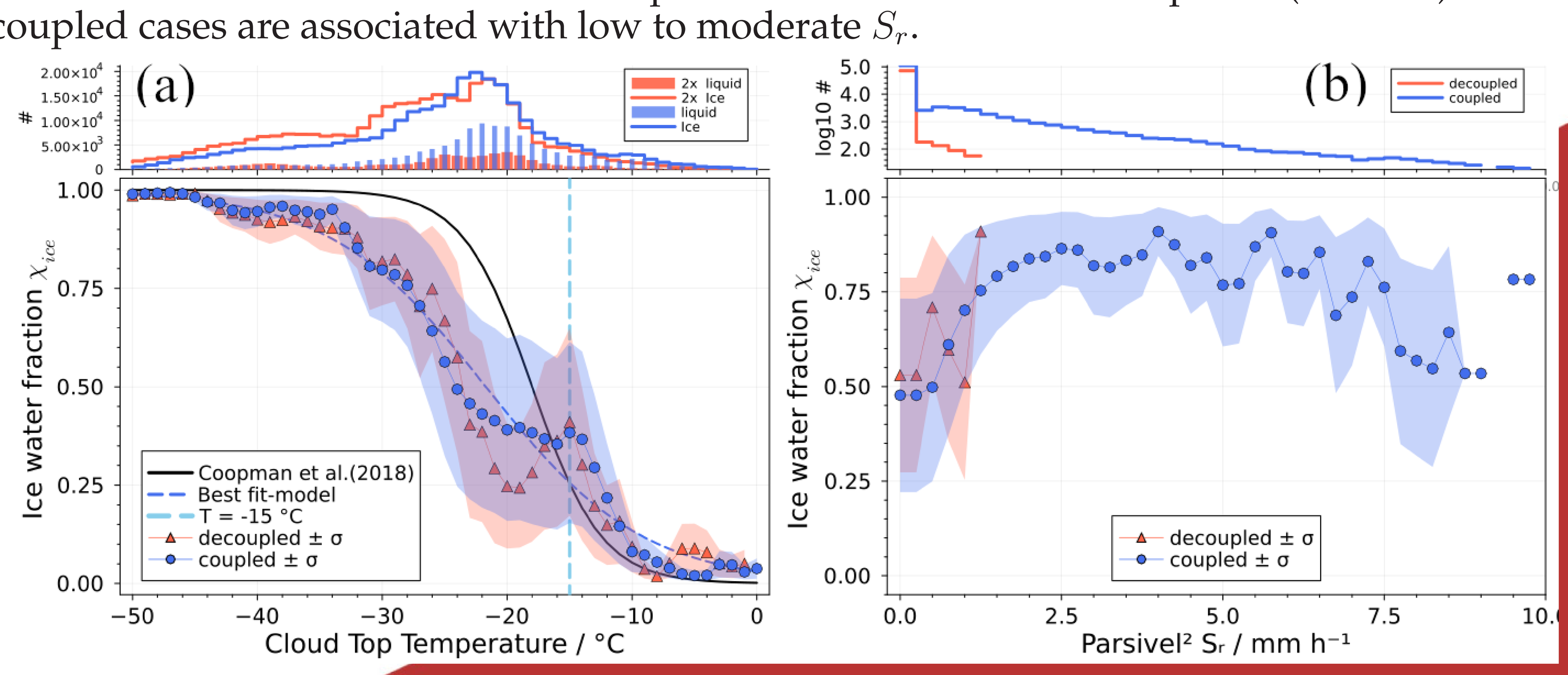


Figure 7: Ice water fraction χ_{ice} as a function of cloud top temperature (a) and snowfall rate (b), separated for coupled and decoupled cases.

4.- Conclusions

- Cloud observations coupled to upwind LF by water vapour transport as conveying mechanism uncovers differences on cloud properties but not so on surface precipitation,
- Sea ice leads tend to diminish the intensity of snowfall, this is evident for PARSIVEL[2] and less so for S_r derived from Ka-band radar,
- Moderate to low precipitation rates are found to correlate with high LF or when sea ice presents opening upwind RV *Polarstern*.

5.- References

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Acknowledgements

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