The role of water vapor transport and sea ice leads on Arctic mixed-phase clouds during MOSAiC

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Abstract

Based on wintertime observations during the MOSAiC expedition in 2019-2020 (Shupe et al., 2022), it has been found that Arctic cloud properties show significant differences when clouds are coupled to the fluxes of water vapor transport (WVT) coming from upwind regions of sea ice leads (Saavedra Garfias et al., 2023; Saavedra Garfias, 2023). Mixed-phase clouds (MPC) were characterized by the Cloudnet algorithm using observations from the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) mobile facility and the Leibniz Institute for Tropospheric Research (TROPOS) OCEANet facility, both on board the RV Polarstern . A coupling mechanism to entangle the upwind sea ice leads via the water vapor transport entraintment to the cloud layer has been proposed to successfully identify differences of MPC properties under and without the influence of WVT. For MPC below 3 km liquid water path was found to be increasingly influenced by sea ice lead fraction whereas ice water path was not significantly different in the presence of sea ice leads. However, the ice water fraction, defined as the fraction of ice water path to the total water path, was exhibiting distinguishable asymmetries for cases of MPC coupled to WVT versus decoupled cases. Mainly, the ice water fractions of MPC coupled to WVT were monotonically increasing with decreasing cloud top temperature, while the decoupled cases show increases and decreases in ice water fraction at some specific temperature ranges. The dissimilar behavior of ice water fraction suggests that WVT could importantly influence the processes responsible for heterogeneous ice formation and solid precipitation, therefore coupled MPC and the ice water fraction was also analyzed as a function of snowfall rates at ground. These characteristics are presented based on case studies where WVT back trajectories are available to have a deeper understanding of the interaction processes with sea ice leads that drives the cloud coupled/decoupled differences. Moreover the statistics of our findings based on the whole MOSAiC wintertime period will be put into consideration.(von Albedyll et al., 2023)(Shupe et al., 2022)(Saavedra Garfias, 2022)

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1.- Research Objectives

Arctic mixed-phase clouds were found to present differences in properties when coupled to water vapor transport (WVT) under the presence of sea ice leads [1]. We extend the study by analysing snowfall to address the following questions:

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

The study ranges from November 2019 to April 2020, i.e. wintertime legs 1 to 3 of MOSAiC expedition [2], where sea ice leads are most active in the central Arctic. Instrumention & data provided by the Atmospheric Radiation Measurement's (ARM) Mobile Facility 1 (AMF-1) and OCEANET-Atmosphere container from Leibniz Institue for Tropospheric Research (TROPOS).

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.

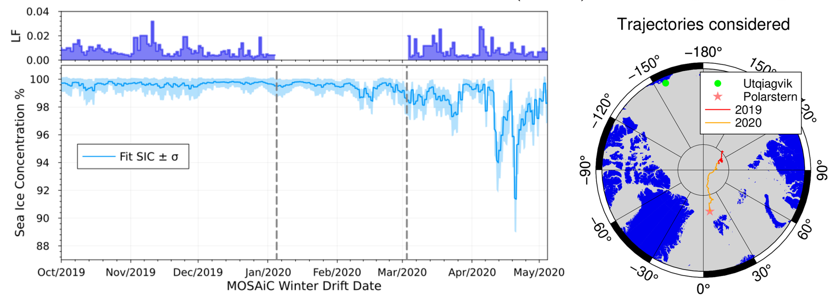

Figure 1: Left: LF and SIC for MOSAiC leg 1 to 3. Vertical dashed-grey lines indicates period without Sentinel-1 data. Right: RV Polarstern drift.

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

- LF is analyzed for a sector 50 km around the RV Polarstern (red star in Fig. 2, right) with its coordinates updated every minute.

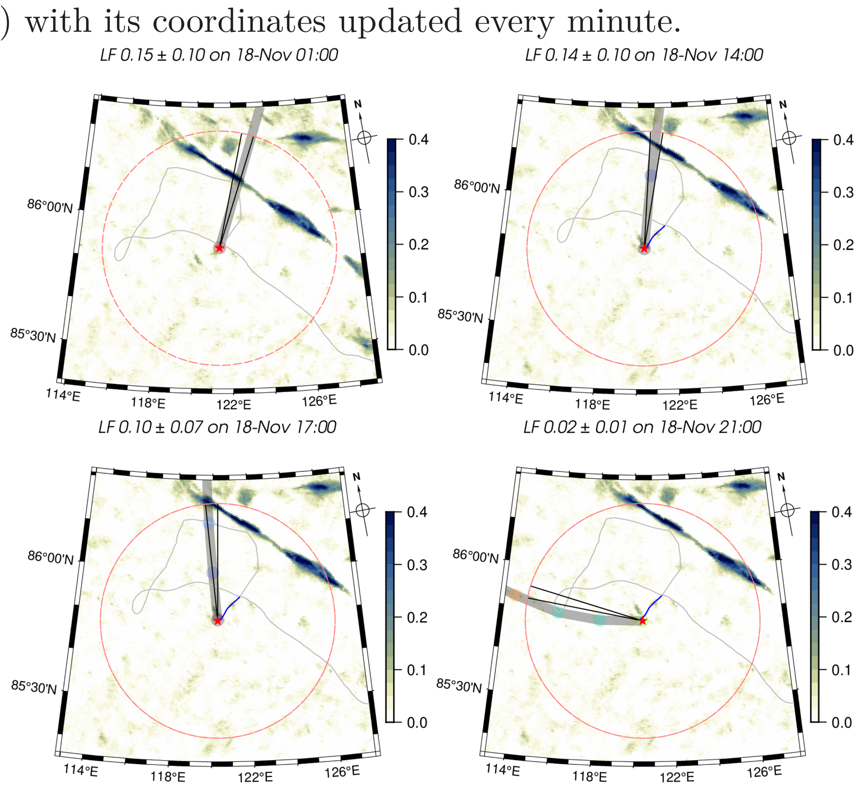

Figure 2: LF from 18 Nov 2019. Black conical lines indicates sector of interests. WVT back-trajectory is shown as thick gray line.

- 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:

$$\nabla \mathrm{WVT} = -\frac{10^2}{g} \left| q_v \cdot \vec{v}_w \right| \frac{dP}{dz} \tag{1}$$

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

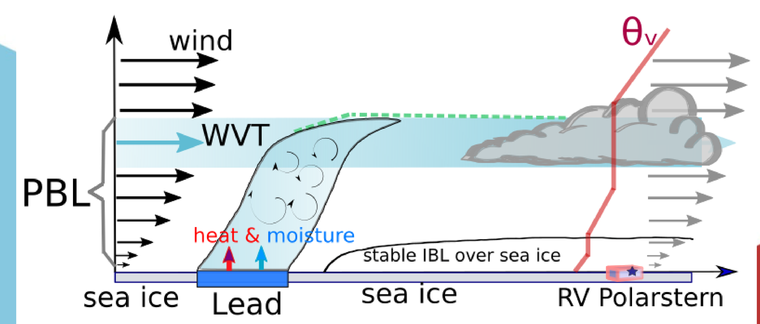

Figure 3: Sea ice interaction with observed clouds via water vapour transport.

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

3.- Results for cloud properties 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.

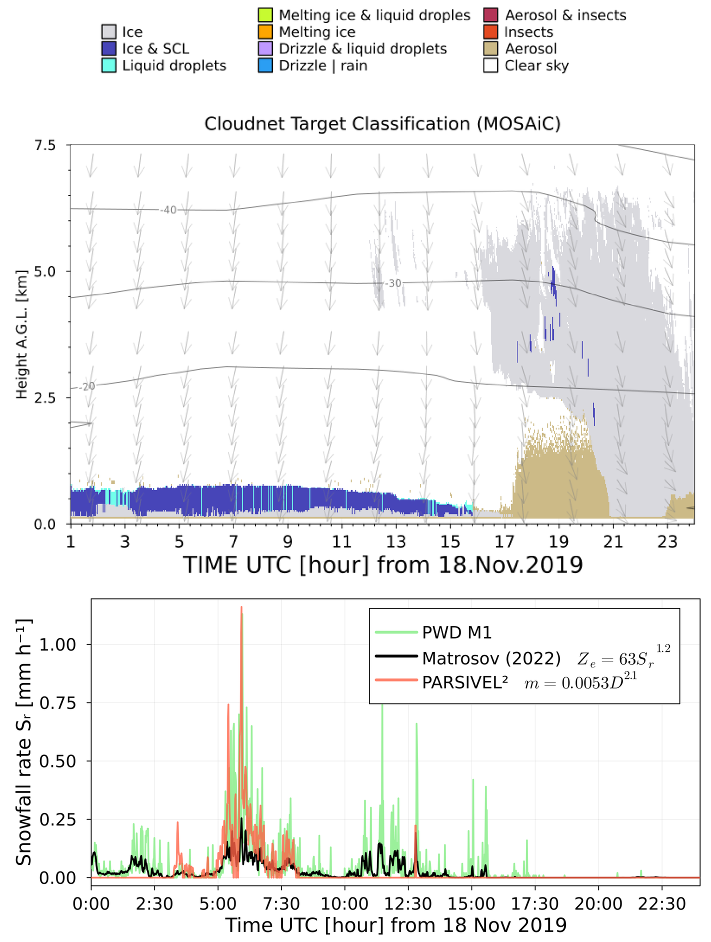

Figure 4: Top: Cloudnet classification. Bottom: Snowfall rate S_t from PWD (green), KAZR@170m (black), and PARSIVEL^2 (red) on RV Polarstern deck.

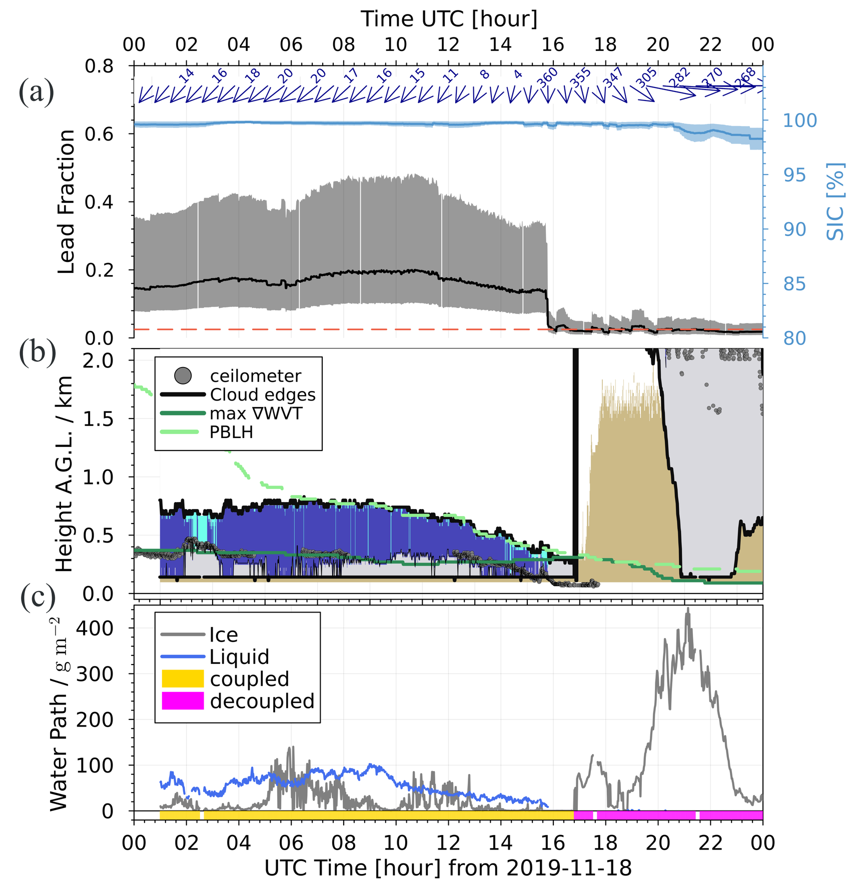

Figure 5: Time series of (a) wind direction at max ∇WVT (blue arrows), mean & IQR Lead fraction, (b) Cloud classification with cloud boundaries, PBLH, max ∇WVT. (c) Single layer cloud liquid and ice water path LWP & IWP. Bottom yellow/magenta band indicates coupled/decoupled cases [1].

- Based in the methodology by [1], mixed-phase cloud micro- & macro-physical properties (as shown in Fig. 4) with coupling status to the sea ice via WVT (Fig. 5) are analyzed for MOSAiC wintertime
- Statistics analysis: coupled clouds have larger liquid water path (LWP) as a function of upwind sea ice leads (LF) Fig. 5. For ice water path (IWP) the same is only true for deep precipitating clouds (Fig. 6).

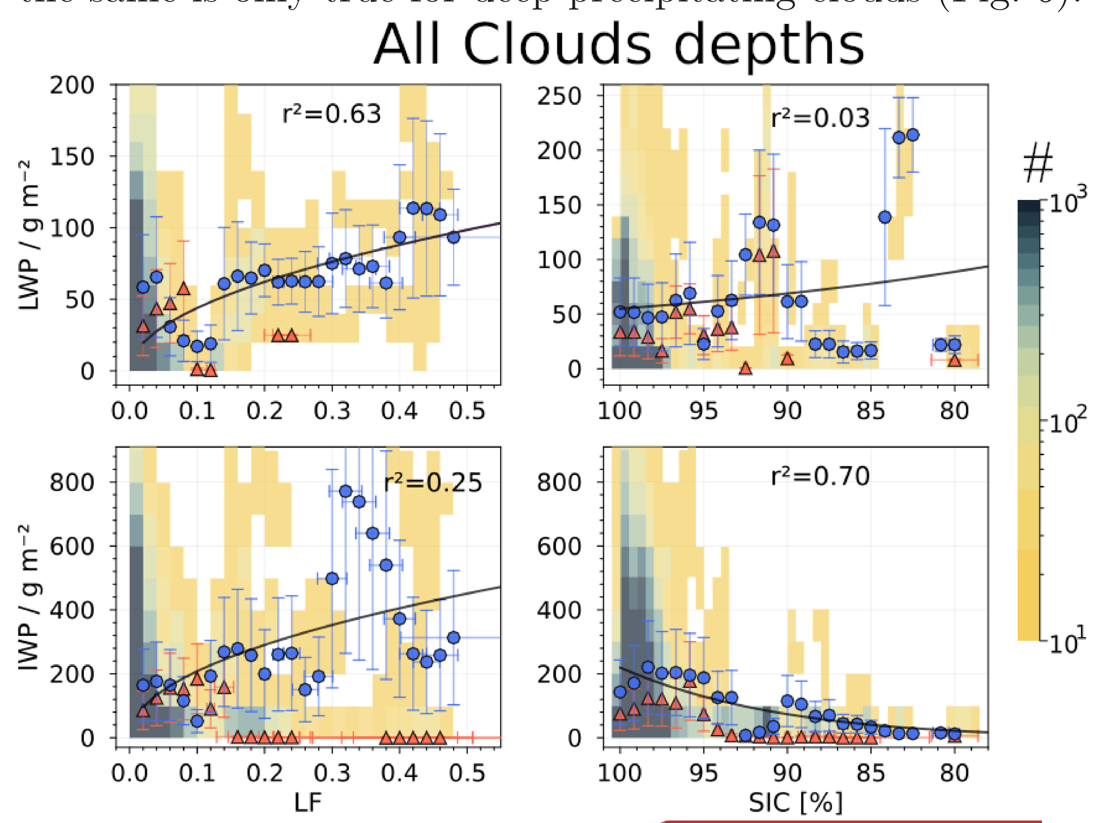

Figure 6: Single cloud layer LWP (top row) and IWP (bottom row) vs. lead fraction LF & sea ice concentration SIC, for coupled (•) and decoupled (▲) clouds. Left panel: Statistics for all cloud depths. Right panel: same but only cloud depths below 3 km.

- The ice water fraction $\chi_{ice} = \frac{\mathrm{IWP}}{\mathrm{IWP+LWP}}$ as a function of cloud top temperature has a strong dependency on the coupling status (Fig. 7.

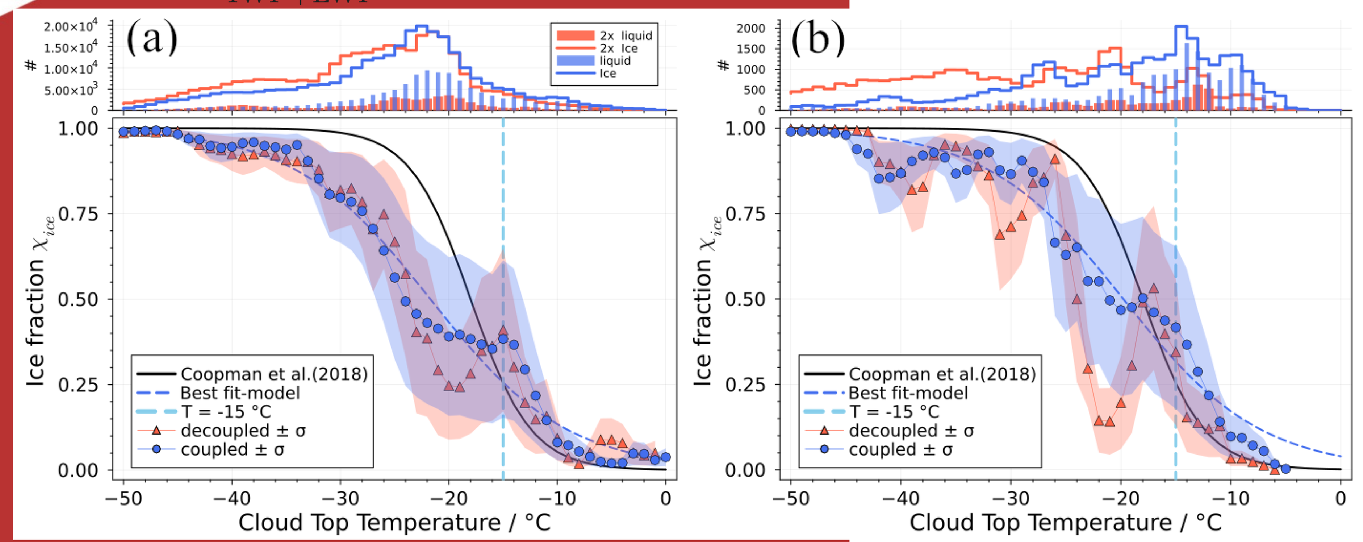

Figure 7: Ice water fraction χ_{ice} as a function of cloud top temperature (a) all LF cases, (b) only LF>0.02. Extracted from [1]

4.- Results for Snowfall

MOSAiC snowfall rates are available from ARM onboard RV Polarstern (M1) and ice camp (S3). Estimations by [3] from PARSIVEL^2 and KAZR radar at 170 & 230 m above the RV Polarstern deck (Fig. 4 bottom).

- Is the increase of IWP with sea ice (Fig. 6, left bottom) also related to snowfall rates at surface level?

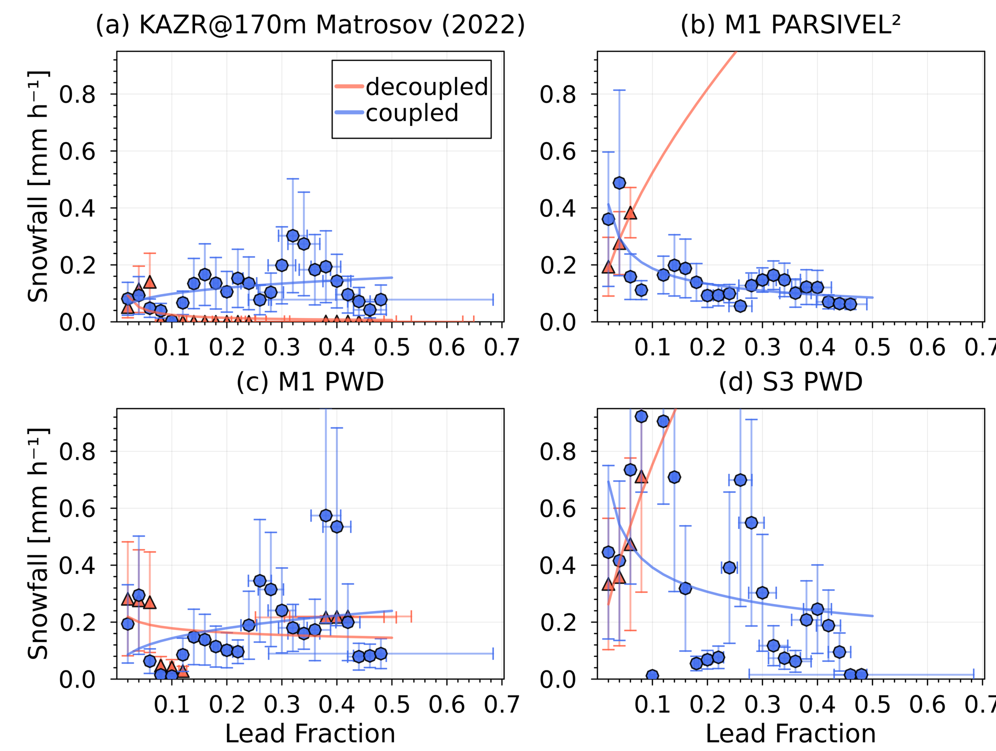

Figure 8: Snowfall rate as a function of Lead Fraction for coupled and decoupled cases: (a) KAZR as [3], (b) PARSIVEL^2, (c) Present Weather Detector (PWD) on RV Polarstern (M1), (d) PWD on ice floe (S3).

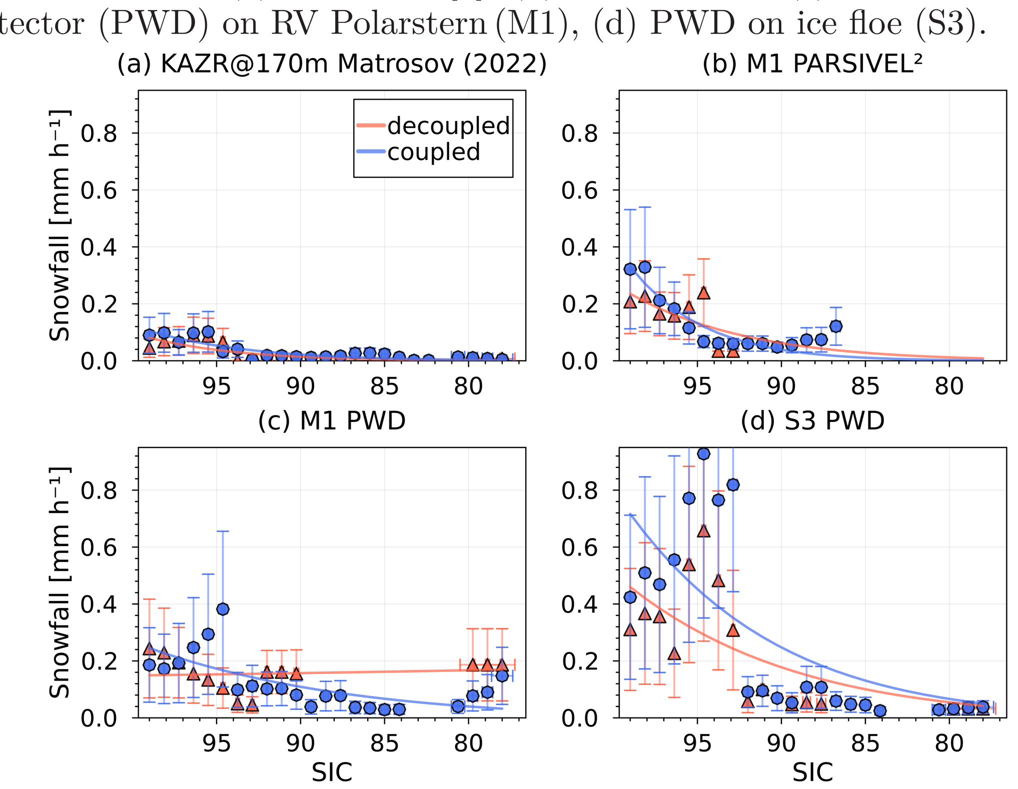

Figure 9: Same as Fig. 8 but considering sea ice concentration SIC.

6.- Conclusions

- Clouds coupled to upwind sea ice, via water vapour transport as conveying mechanism, have differents properties,
- Sea ice leads tend to diminish the intensity of snowfall, this is evident for PARSIVEL^2 and PWD S3, expect for snowfall derived from KAZR and PWD M1,
- Moderate to low snowfall rates correlate with high LF and low SIC i.e. when sea ice present openings upwind.

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