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

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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.

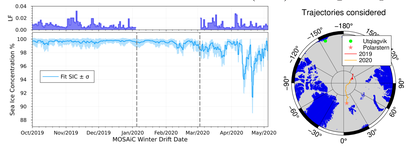

Figure 1: Left: LF and SIC for MOSAiC leg 1 to 3. Vertical dashed-grey lines indicates period without Sentinel-1 data. Right: RV Polarstern drift.

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.

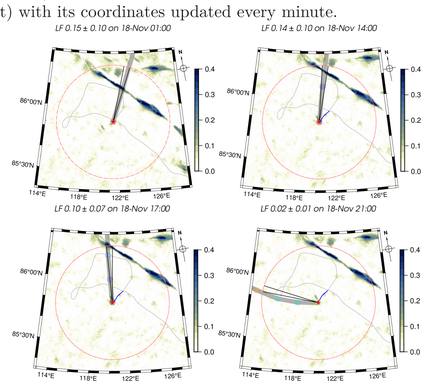

Figure 2: LF from 18 Nov 2019. Black conical lines indicates sector of interests. WVT back-trajectory is shown as thick gray line.

- 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.

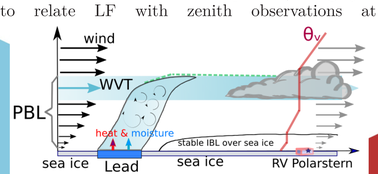

Figure 3: Sea ice interaction with observed clouds via water vapour transport.

- Cloud coupling: criteria based on the virtual potential temperature θ_v and location of maximum ∇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.

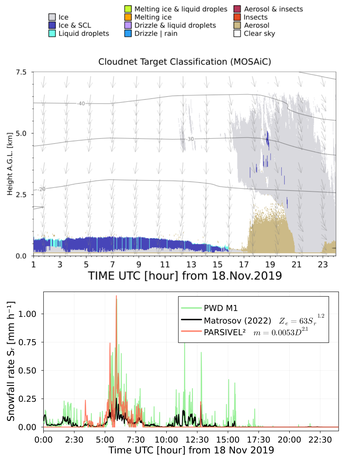

Figure 4: Top: Cloudnet classification. Bottom: Snowfall rate S_t from PWD (green), KAZR@170m (black), and PARSIVEL^2 (red) on RV Polarstern deck.

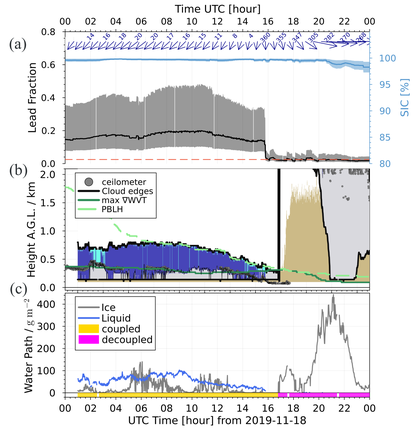

Figure 5: Time series of (a) wind direction at max ∇WVT (blue arrows), mean & IQR Lead fraction, (b) Cloud classification with cloud boundaries, PBLH, max ∇WVT. (c) Single layer cloud liquid and ice water path LWP & IWP. Bottom yellow/magenta band indicates coupled/decoupled cases [1].

- 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).

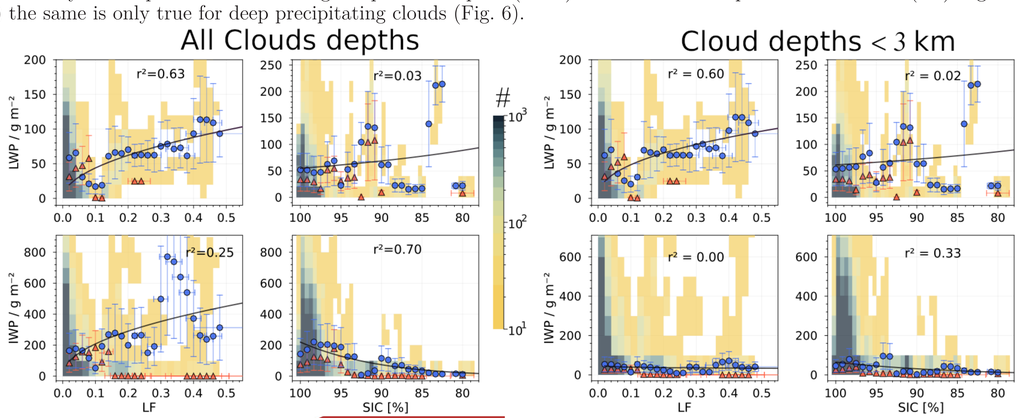

Figure 6: Single cloud layer LWP (top row) and IWP (bottom row) vs. lead fraction LF & sea ice concentration SIC, for coupled (•) and decoupled (▲) clouds. Left panel: Statistics for all cloud depths, Right panel: same but only cloud depths below 3 km.

- 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.

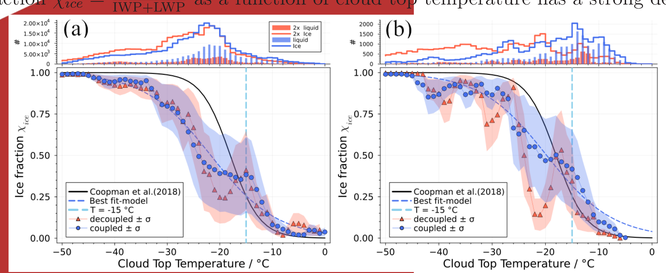

Figure 7: Ice water fraction χ_{ice} as a function of cloud top temperature (a) all LF cases, (b) only LF>0.02. Extracted from [1]

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?

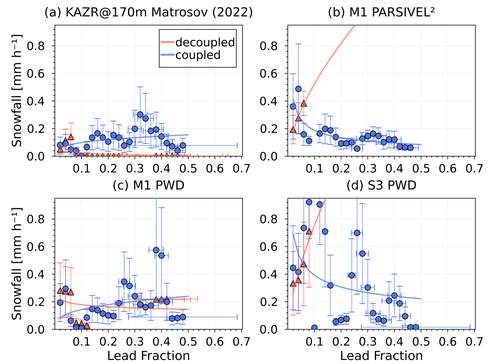

Figure 8: Snowfall rate as a function of Lead Fraction for coupled and decoupled cases: (a) KAZR as [3], (b) PARSIVEL^2, (c) Present Weather Detector (PWD) on RV Polarstern (M1), (d) PWD on ice floe (S3).

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.

7.- References

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Acknowledgements

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