REVIEWER No. 2

This manuscript presents the investigation of the relationship between sea ice lead fractions and cloud micro- and macro-physics during the MOSAiC field campaign. The study is constructed with an introductory case study followed by statistical analysis. The statistical analyses show that the coupled cases are under the influence of enhanced water vapor transport from the leads area, hence the enhanced moisture supplies contribute to the cloud properties. I found the manuscript to be well constructed and logical in the narrative. Nevertheless, I do have a few comments and suggestions listed below, which should be considered and addressed before potential publication.

General Comment.

The statistical results seem to be based on the available cloudy samples regardless of the cloud types. At least, the cloud type criteria are not clearly stated in the manuscript (i.e., in Fig. 1 and D1, there are already two types of cloud systems: stratiform and convective). I am concerned that the intrinsic differences in the microphysical processes of those different cloud systems would impair or blur the robustness of the results, especially in the interpretation of the comparisons between coupled/decoupled cases and different LF circumstances (i.e., the discussions regarding Fig. 9 to Fig. 11). For instance, the differences in the LWP and IWP between coupling and LF categories could potentially be more influenced by the cloud thicknesses.

Reply: We understand the concern. For our analysis, in case of observations with multiple cloud layers, we always consider the single cloud layer which is closest to the maximum of WVT. It happens, however, that for coupled cases that layer is commonly the lowest layer and for decoupled clouds can be located higher up, that is the reason why we do not specifically consider only stratiform low level clouds. By doing so, some decoupled clouds could have been dismissed and we would have only analyzed coupled low level clouds but the idea of the methodology is to have a reference to compare the coupled clouds, i.e. using the decoupled clouds as a reference of cases without interaction with the sea ice leads. It is correct that cases as shown in D1 includes convective systems even though they are still considered one cloud layer, but we found that by constraining the cloud thickness below 2.5km, the relationship between LWP vs LF and SIC practically is preserved, whereas the relationship between IWP vs LF and SIC is considerable reduced. This is an indication that the presence of sea ice leads mainly have an effect on the liquid fraction of the mixed-phase clouds e.g. liquid water content, liquid cloud base height.

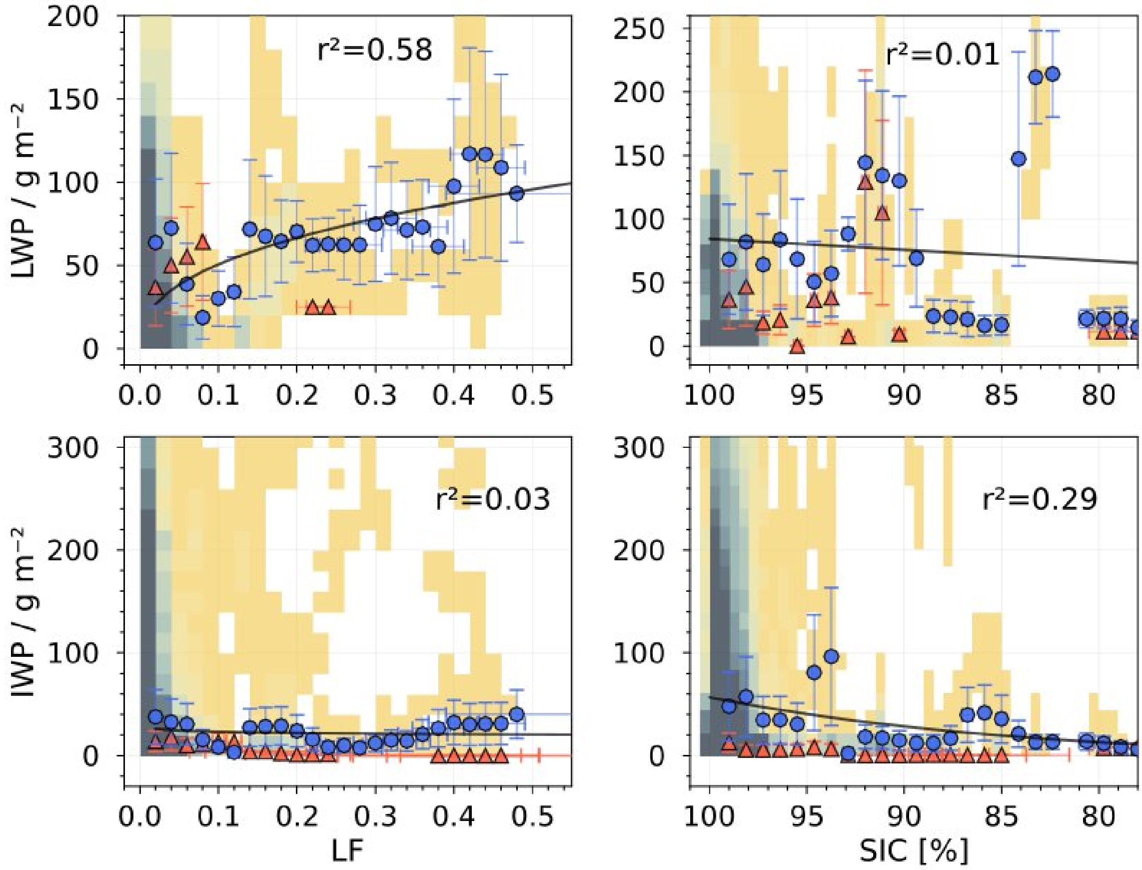

Figure 1 Same as in the manuscript Figure 11 but the symbols are the result of constraining the cloud top height to cases below 2.5km to represent low level clouds.

I wonder if you have considered enhancing the robustness of the analysis in a more controlled environment, e.g., confining the cloud selection to stratiform or convective clouds only. Please give it some thought.

Reply: Thanks for the comment. This has been considered by carefully selecting the case study from November 18th, 2019, to explain the methodology. In this case study two cloud systems were present, first, a low stratiform cloud and later a convective deep precipitating cloud (Figure 1 and 5 in manuscript). To highlight the effect introduced to our statistical analysis, we reproduced the manuscripts's Figure 11 by only considering cloud top heights below 2.5km (Figure 1 in this document). The Figure 1 *reveals the robust positive relationship between LWP and LF (r^2 =0.58, versus r^2=0.63 for all cloud heights in manuscript Figure 11) is originated mainly from the low level clouds. Regarding IWP, it can be seen that when cloud top height is constrained to 2.5km clouds have values for IWP below 100 g m^{-2} , with the coupled cases (blue circles) having systematically larger IWC than the decoupled cases (orange triangles). Therefore, we can conclude that the main source of higher ice water content are deep precipitating systems rather than stratiform low level clouds.*

Minor Comment.

L86. Please define HATPRO.

Reply: HATPRO stands for Humidity And Temperature PROfiler and it has been defined in Line 86.

L109. 'Advanced Microwave Scanning Radiometer 2 (AMSR2)'

Reply: Thank you. It has been corrected.

L184. Can you provide the precisions or the estimated errors for the Cloudnet retrievals, referably, compared with the aircraft in-situ measurements?

Reply: Cloudnet retrieves ice water content (IWC) based on a relationship to reflectivity and temperature (Hogan et al., 2006). Comparison with in-situ aircraft measurements shown a root mean square error in retrieving IWC of around +50% to -33% for the temperature ranges from -20°C to -10°C. Whereas for temperatures below -40°C the error rises to +100% to -50%. As stressed by (Hogan et al., 2006) these uncertainties are, however, large due to the small sample volume of the aircraft probes. The main source of uncertainty comes from the radar reflectivity factor Ze. To have an insight into the effect of Ze uncertainty into the total ice water path (IWP), we performed an estimation of the relative error for the IWP when the reflectivity is changed by ±3, ±10 and ±20% of the original measured value. This results in changes on retrieved IWP as shown in Figure 2 for the manuscript's case study from November 18th 2019. It can be seen that by modifying the reflectivity by Ze +20% the relative error obtained in IWP has a practically constant value of -12%, while for Ze -20%, IWP is slightly lower than 13% of the original retrieved value. For the cases of ±10% and ±3% the retrieved IWP lays within a constant margins of ±6.5% and ±1.9%, respectively, regardless of the absolute value for IWP. Even though Figure 2 confirms the sensitivity of IWP on the reflectivity factor, it is realistic to assume that the uncertainty of radar reflectivity is within the ±3% of measured value, which gives a solid ±2% of IWP uncertainty.

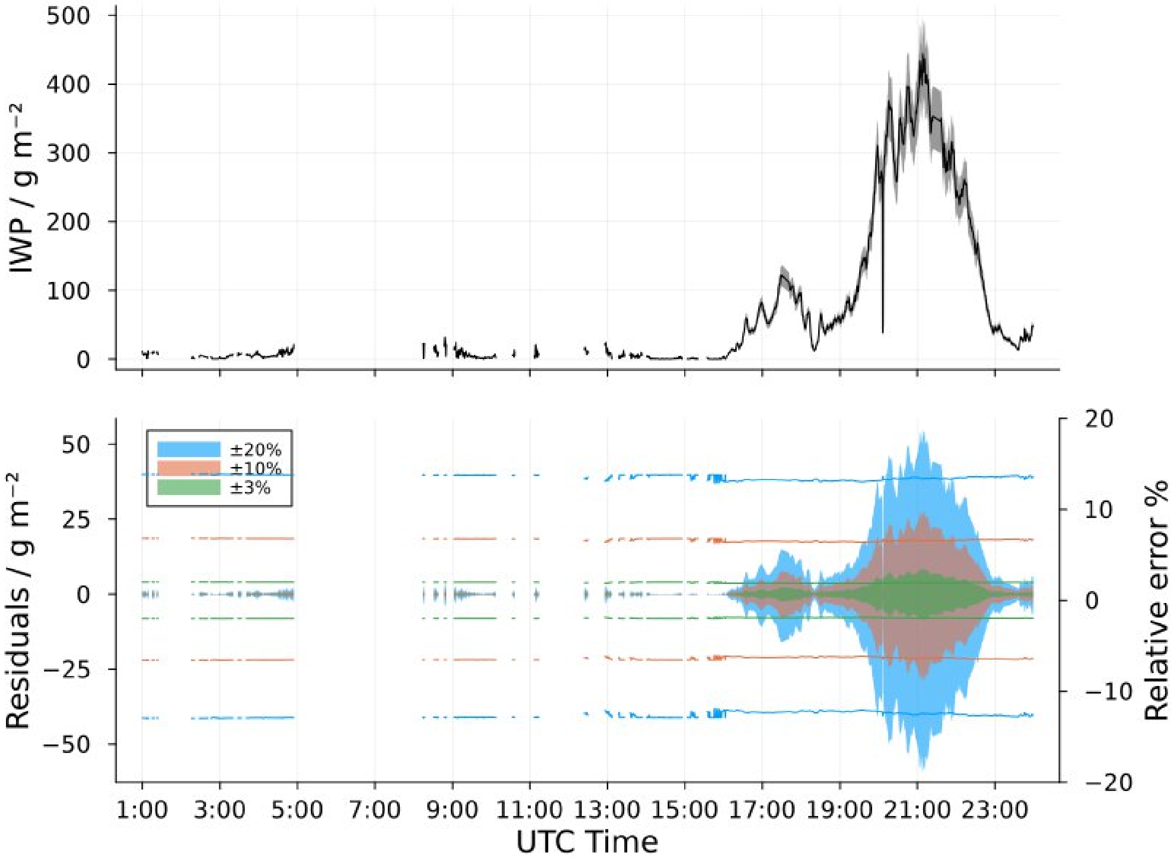

Figure 2 Top panel: November 18th, 2019 Cloudnet IWP retrieved from measured reflectivity with grey shadow area indicating the range of IWP retrieved when the reflectivity is modified within ±20%. Bottom panel, left y-axis: the IWP residuals (original - modified) for cases when Ze is modified by ±3 (green shading), ±10 (orange shading), and ±20% (blue shading). Bottom panel, right y-axis: relative IWP error.

Regarding the liquid water content (LWC), Cloudnet first classify the grids containing liquid droplets and estimates the LWC profile based on the theoretical adiabatic LWC gradient from cloud base. The adiabatic LWC is then scaled so that its integral matches the microwave radiometer measurement of liquid water path (LWP). Therefore the main source of uncertainty is due to the LWP retrieved from the microwave radiometer. A multi-frequency radiometer as HATPRO using a quadratic regression to retrieve LWP can have a root mean square error of about 15.4 g m^{-2} (Hogan et al., 2006; Löhnert & Crewell, 2003). Based on a similar sensitivity exercise as for IWP, in we found that the retrieval error is covered by a variation of less than 20% on the total LWP to be scaled by the adiabatic LWC approach. That gives us a confidence that the LWP used in this work is within a 20% uncertainty.

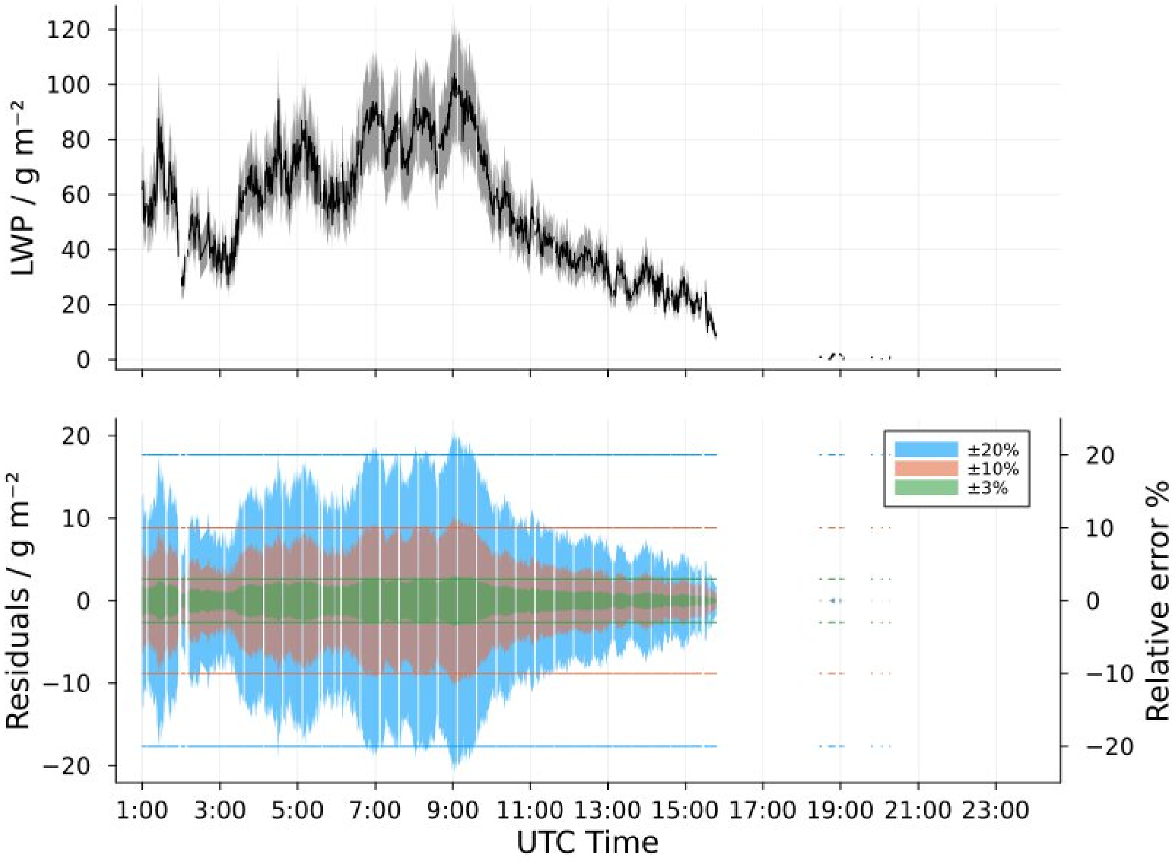

Figure 3 Same as Figure 2 but for the LWP.

L264. According to Appendix A, do you mean 0.05 K2 here for estimating the sub-cloud mixing layer right?

Reply: The text is correct, we used 0.01 K^2 for the estimation of the sub-cloud mixing layer.

L377. It seems that the liquid and ice effective radii shown here range from non-precipitating to heavy-precipitating clouds, have you considered the aerosols (e.g., sea salts) advected along the WVT pathway that served as CCN or INP and affect the cloud microphysics, and in turn, bias the results?

Reply: We agree with the reviewer that this is certainty the case. Nevertheless there is neither direct nor remote sensing measurements of advected aerosols along the WVT path. During MOSAiC expedition aerosols and INP have been sampled at the RV Polarstern location (Creamean et al., 2022), showing that INP concentration are found to be persistent among the months from October to April mainly between the range of temperatures from -25°C to -15°C

(Creamean et al., 2022) , with large INP sampling during periods with high lead occurrence and wind speeds above 5 m s^{-1}. Therefore , as highlighted by (Creamean et al., 2022) the high fractional occurrence of ice in clouds below 3km (low-level clouds) in winter implies that observed small INPs could serve as important role in cloud ice formation. However due to the fact that the surface is predominantly frozen the local source of INPs is locally limited. Thus, it is plausible to support the hypothesis that leads play an important role as sources of sea spray by windy conditions during the wintertime. We consider that the sea ice leads as sources of INP like sea-spray can be advected along the WVT, and therefore included in our analysis as part of the coupled/decoupled classification. However, since no continues INP sampling has been performed we cannot separate our dataset based on INP concentration, but we agree that such type of analysis is an important source of information to narrow down the leads effects on cloud properties.

L424. If, in the case of LF > 0.02, presumably implied in the aforementioned discussion, it indicates more moisture supply to the cloud layer. How do you interpret the difference in the χice dips (~ -20°C) of the decoupled cases, i.e., any ascribable relations between the increased moisture supply and the heterogeneous freezing process? Similar questions can be asked for the dips in ~ -30°C and -40°C.

Reply: This is an important concern about the finding presented in the manuscript. The reviewer is right by interpreting that for LF>0.02 more moisture supply should be present, however for the decoupled case it means that the cloud layer is not interacting with the moisture supply. Our finding on the χ_{ice} asymmetry between coupled and decoupled, e.g. dips at -20°C, -30°C and -38°C, is certainly surprising. The dips on χ_{ice} for decoupled cases can be interpreted as a consequence of the cloud layer not being supplied by any moisture or nucleating particles which can be originated from leads. On the contrary the χ_{ice} coupled cases (blue symbols) indicates a continuous source of moisture and INPs from leads, therefore the mixed-phase clouds are likely unstable the Wegener-Bergeron-Findeisen process favors the ice growth at the expense of vapour deposition, the heterogeneous freezing process. (Danker et al., 2022) using CloudSat-Calipso DARDAR product for clouds below 2.5km, have also reported the increase on occurrence of mixed-phase and decrease of super cooled liquid clouds at temperatures around -15°C, although they only consider cloud top temperatures up to -20°C. For similar *dips on χ_{ice}* at lower temperatures no other references have been found.

L442. Since it is mentioned here that the SIC and LF are not equivalent, it would be interesting to show if there is any relationship between SIC and LF, i.e., a scatter plot of conical SIC vs. LF.

Reply: We mentioned that SIC and LF are not equivalent with the intention to stress that those are independent sea ice states estimates, with LF being more suitable to resolve small divergent leads (between two consecutive satellite overpasses) with a nominal resolution of 700 m. Whereas SIC is a merged product from MODIS (thermal, 1km resolution) and AMSR2 (microwave, 3.124 km resolution) more suitable to detect larger leads or partially frozen leads. In other words, a simple conversion of variable like SIC = 100(1 – LF) is not applicable for our case. In Figure 4 is the scatter plot of the conical sector within 6° around the wind direction and centered at the location of the RV Polarstern.*

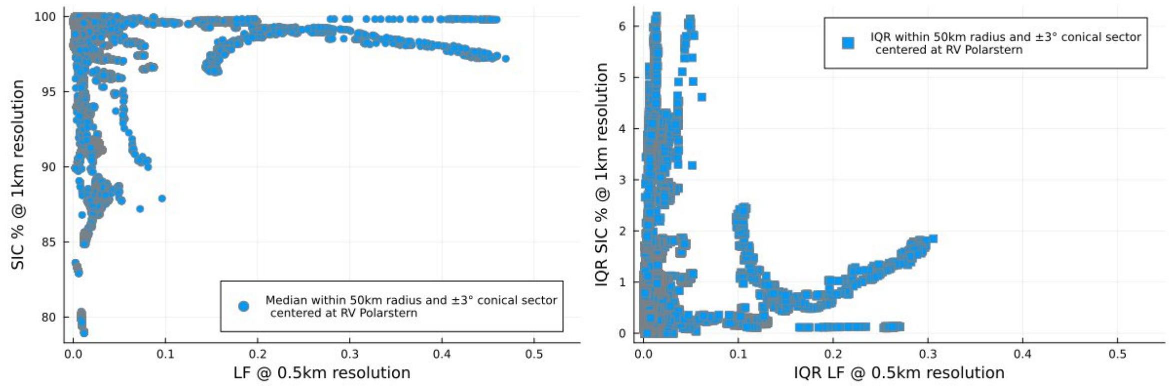

Figure 4 Sea ice concentration (SIC) vs lead fraction (LF) from November 2019 to April 2020 as scatter plot for the median (left panel) and the inter quantile region (IRQ) of the SIC vs. LF distribution within the conical sector centered at the RV Polarstern (right panel).

L447. '...for IWP vs. LF'

Reply: Thank you for the correction.

L448. Do you mean 'with only a fairly increase of IWP when SIC change from 100 to 97%'?

Reply: Yes, that is what we meant. Thank you for the observation, it has been corrected.

L559. 'WVT'

Reply: Thanks, it has been corrected to WVT.

L614. In Table 3 the ratio of coupled to decoupled is ~6:4, while here states that the coupled cases are 10 times more frequent than the decoupled cases when binned by water path. Can you clarify?

Reply: Table 3 indicated the total cases. Figure D3 (a), separated the number of cases within intervals of total water path, most of the points with total water path higher than 100 g m^{-2} (dark green symbols) lay along the 10:1 red dashed-line, i.e. coupled cases occur about 10 times more often than decouple cases.

Figure 11. The first sentence of the caption conflicts with the subfigures. LWP plots should be (a) and (b), while IWP plots should be (c) and (d). And can you clarify why the bars are sometimes discrete within the same LF bin?

Reply: Thank you for pointing out the mistake. It is corrected to: "Top row, distribution of LWP as a function of observed LF (a) and SIC (b); bottom row, distribution of IWP as a functions of LF (c) and SIC (d)".

Bibliography

Creamean, J. M., Barry, K., Hill, T. C. J., Hume, C., DeMott, P. J., Shupe, M. D., et al. (2022). Annual cycle observations of aerosols capable of ice formation in central Arctic clouds. Nature Communications, 13(1), 3537. https://doi.org/10.1038/s41467-022-31182-x

Danker, J., Sourdeval, O., McCoy, I. L., Wood, R., & Possner, A. (2022). Exploring relations between cloud morphology, cloud phase, and cloud radiative properties in Southern Ocean's stratocumulus clouds. Atmospheric Chemistry and Physics, 22(15), 10247–10265. https://doi.org/10.5194/acp-22-10247-2022

Hogan, R. J., Mittermaier, M. P., & Illingworth, A. J. (2006). The Retrieval of Ice Water Content from Radar Reflectivity Factor and Temperature and Its Use in Evaluating a Mesoscale Model. Journal of Applied Meteorology and Climatology, 45(2), 301–317. https://doi.org/10.1175/JAM2340.1

Löhnert, U., & Crewell, S. (2003). Accuracy of cloud liquid water path from ground-based microwave radiometry 1. Dependency on cloud model statistics. Radio Science, 38(3). https://doi.org/10.1029/2002RS002654