General comment

The paper reports measurements of particle fluxes using a gradient approach in Arctic to investigate emission and deposition over different surfaces. Measurements were done during the ARTofMEL expedition in an environment that is difficult to characterise in terms of particle fluxes being challenging for the measurement setup. I believe that the results are interesting and may be of interest for the scientific community. There are a few aspects that should be improved as detailed in my specific comments.

We sincerely thank the reviewer for his/her time, effort and thoughtful feedback. The constructive comments have been highly helpful in improving the manuscript. Below, we provide a point-by-point response to each of the reviewer's comments. Reviewer comments are presented in black, our response in blue, and changes in the manuscript in orange.

Specific comments

It is used to mention the normalised flux that is essentially what is indicated in other studies as deposition velocity. Why not using the more common deposition velocity?

We agree with the referee that the formulation deposition velocity is more common. Deposition velocity is usually used to refer to true concentration-dependent dry deposition. As stated in equation 11, V_D is defined as a normalized flux.

The relationship between the flux and mean concentration is different for a surface emission flux and a deposition flux. For deposition, the flux is dependent on the mean particle concentration and the strength of turbulence - losses to the surface occur via turbulent impaction and Brownian diffusion. For a given size and turbulent conditions, the flux scales linearly with the particle concentration. A source from the surface is controlled by some surface processes, for example, bubble bursting processes in open water. This is independent of the concentration in the atmosphere.

Given an existing particle concentration in the atmosphere, both emission and deposition processes can operate at the same time, and the net measured flux (emission and deposition) does depend on the ambient concentration, but only through the deposition term.

Due to these reasons, to emphasize that we do not refer only to deposition processes, we would like to keep the term "normalized flux".

Line 211: To emphasize that we do not only refer to deposition processes we use the term normalized flux for V_D.

It seems that when it is mentioned net deposition or net emission it is referred to a single 20-minute period, it may create confusion with long-term average of fluxes.

The cases where it is not entirely clear whether a single 20-minute period or a long-term average is meant have been adjusted accordingly:

Line 329: However, taking into account the estimated maximum uncertainty (grey shading in Fig. 5), fluxes may be positive or negative but with a tendency toward net particle emission 20-minute intervals.

Line 340: Rather, both net particle emission and deposition intervals may be observed in this mixed area of influence.

Line 381: Net particle emission intervals from a closed ice surface like on 1 June (Fig. 6 (b) has also been observed in other studies, e.g. in Nilsson et al. (2001). As particle fluxes and normalized fluxes are strongly dependent on particle size (Nilsson and Rannik, 2001), a changing size distribution (Fig. 6 (e), (f)) could explain a change from net particle deposition to net particle emission intervals.

Line 432: On several occasions, net particle emission intervals occurred under the influence of closed ice.

Figure 5 / 6 / A3 / A4: The brown color indicates net particle emission 20-minute intervals, and the blue color indicates net particle deposition 20-minute intervals.

In equations (1) to (5) it is used the capital U' for fluctuations while this was not done for other velocity components, why?

To avoid confusion with the longitudinal component of wind speed u, the capital U was used for the horizontal wind speed.

Line 45. I would say ideally 10 Hz because very often it is a lower resolution, also in the EC measurement here. I also suggest to mention that in EC measurements involving particles, or more in general closed path sensors, it is important the first order time response of the inlet rather than the sampling frequency, because this is often a more limiting factor for fast instruments see for example the discussion in Conte et al (2018, Science of the Total Environment 622, 1067-1078).

We changed that sentence and added the information about the closed path sensors.

Line 45: Difficulties arise particularly from the need for particle measurements with a high temporal resolution of ideally 10 Hz, which is essential for flux measurements to capture the fine-scale fluctuations of small variations, combined with the challenge of low particle concentrations. In addition to the first order time response of the device, fluctuation dampening of the inlet must also be taken into account, which is often the limiting factor (Conte et a. 2018).

Figure 2. It would be interesting to add the comparison among the two EC systems, ice mast and ship mast to discuss is the differences are due to the different location or to the different methods (EC and gradient). The same for Figure 3. Do you have an interpretation on why the comparison for H is significantly worse than that for u*?

A more detailed discussion on why the comparison for H is worse than that for u* can be found in the comments of reviewer 2 (Thomas Foken) and our response to these comments. Briefly, when using the gradient method, H is calculated not only from the wind profile (as for u*) but also from the temperature profile. For near-surface profiles, the lowest height close to the ice surface will exhibit very low temperatures in all situations and “may ‘simulate’ stable stratification”, as pointed out by reviewer 2. Thus, the gradient can become very large and vertical decoupling may further affect the comparison, especially when the friction velocity is very low.

We followed the reviewer’s recommendation and added the comparison among the two Eddy Covariance Systems:

Line 256: The results demonstrate that the eddy covariance measurements on the ship mast and ice mast show the highest degree of agreement (Fig.2(a)). Nevertheless, as can be seen in Fig. 2 (c), many of the u∗ values determined at the ice mast and gradient system sites are in good accordance and close to the 1:1 line. In particular, when both systems are influenced by the same surface type (closed ice), there is good agreement of u*. The agreement of the u∗ values determined at the ship mast and gradient system sites (Fig. 2 (b) is slightly lower, but still consistent with expectations. The deviation of u∗ between the gradient system and ship mast measurements was less than 50 % in 63 % of the cases. The deviation of u* between the gradient system and ice mast measurements was less than 50 % in 77 % of the cases, and between the ship mast and ice mast in 89 % of the cases.

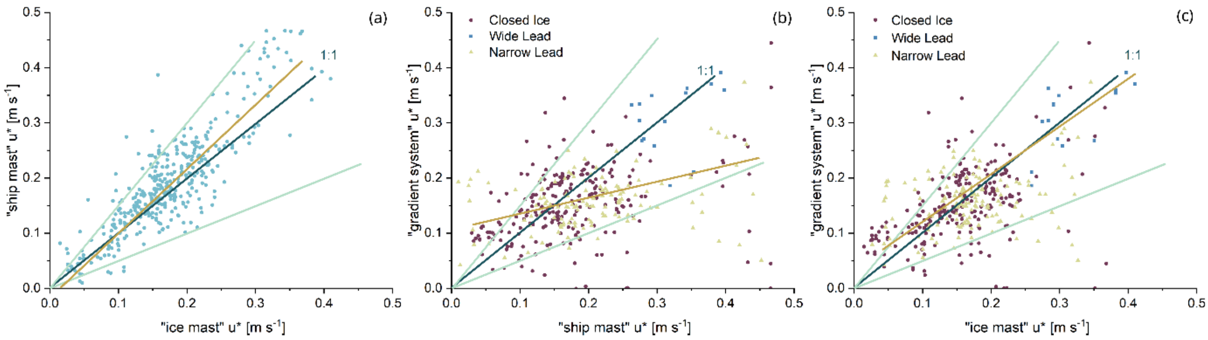


Figure 2. (a) Scatter plot between friction velocities [u*, m s^{-1}] measured by the ship mast (y-axis) and the ice mast (x-axis). (b) Scatter plot between friction velocities measured by the gradient system (y-axis) and the ice mast (x-axis). (c) Scatter plot between friction velocities measured by the gradient system (y-axis) and the ship mast (x-axis). The dark blue lines symbolize the 1:1 line, the turquoise lines the 50 % deviations. The beige line shows the linear regression fit. The three different symbol colors in (b) and (c) divide the measurements according to the surface type, which influenced the gradient system.

Line 264: The comparison of the sensible heat fluxes between the three systems shows the dependence of the sensible heat flux on the type of surface surrounding the system (Fig. 3 (b), (c). As for the friction velocity, the sites ship mast and ice mast (Fig. 3 (c)), both evaluated with the eddy covariance method, show the highest degree of agreement. The comparison between the ice mast and gradient system shows that for the narrow lead surface type, the fluxes differ in sign and thus in direction. Also, when the gradient system is influenced by wide leads, clear differences can be seen, which is to be expected due to the different surface types influencing the two systems. However, when influenced by the same surface type (closed ice) the values are of the same magnitude (Fig. 3 (c)). When comparing the gradient system with the ship mast (Fig. 3 (b)), the opposite sign is also evident for the narrow lead. For the wide lead, high positive sensible heat fluxes are observed with both systems. This is consistent with the ship mast being surrounded by wide leads at the same time as the gradient system.

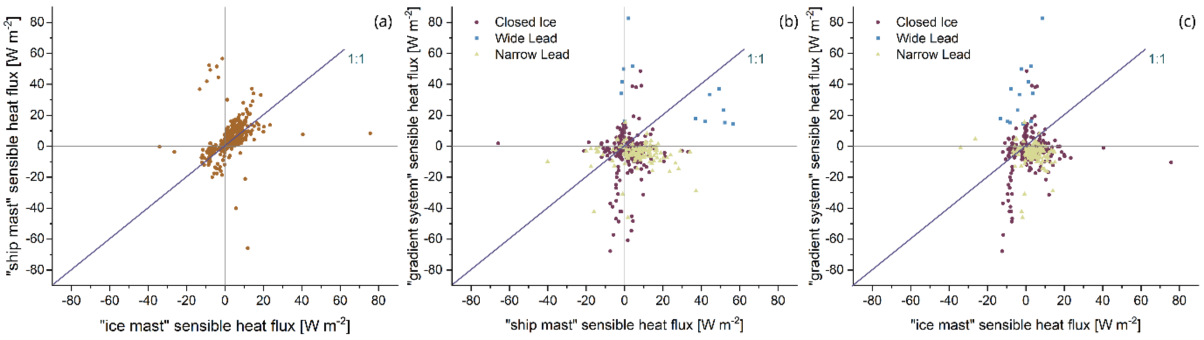


Figure 3. (a) Scatter plot between sensible heat fluxes [H, W m^{-2}] measured by the ship mast (y-axis) and the ice mast (x-axis). (b) Scatter plot between sensible heat fluxes measured by the gradient system (y-axis) and ship mast (x-axis). (c) Scatter plot between sensible heat fluxes measured by the gradient system (y-axis) and ice mast (x-axis). The dark blue lines symbolize the 1:1 line. The three different colors divide the measurements according to the surface type, which influenced the gradient system.

Line 244. The uncertainties of fluxes are quite high, it would be useful a comment if this is enough to have a robust measurement.

We agree with the referee that the low particle concentrations combined with a long sample inlet and the resulting losses lead to large uncertainties. The uncertainties calculated by the Monte Carlo simulation are the maximum uncertainties, which may significantly exceed the true uncertainty. In lines 321-324 we have commented that exact quantification is subject to large uncertainties and that the focus should therefore be on tendencies towards net emission or net deposition, depending on the surface type.

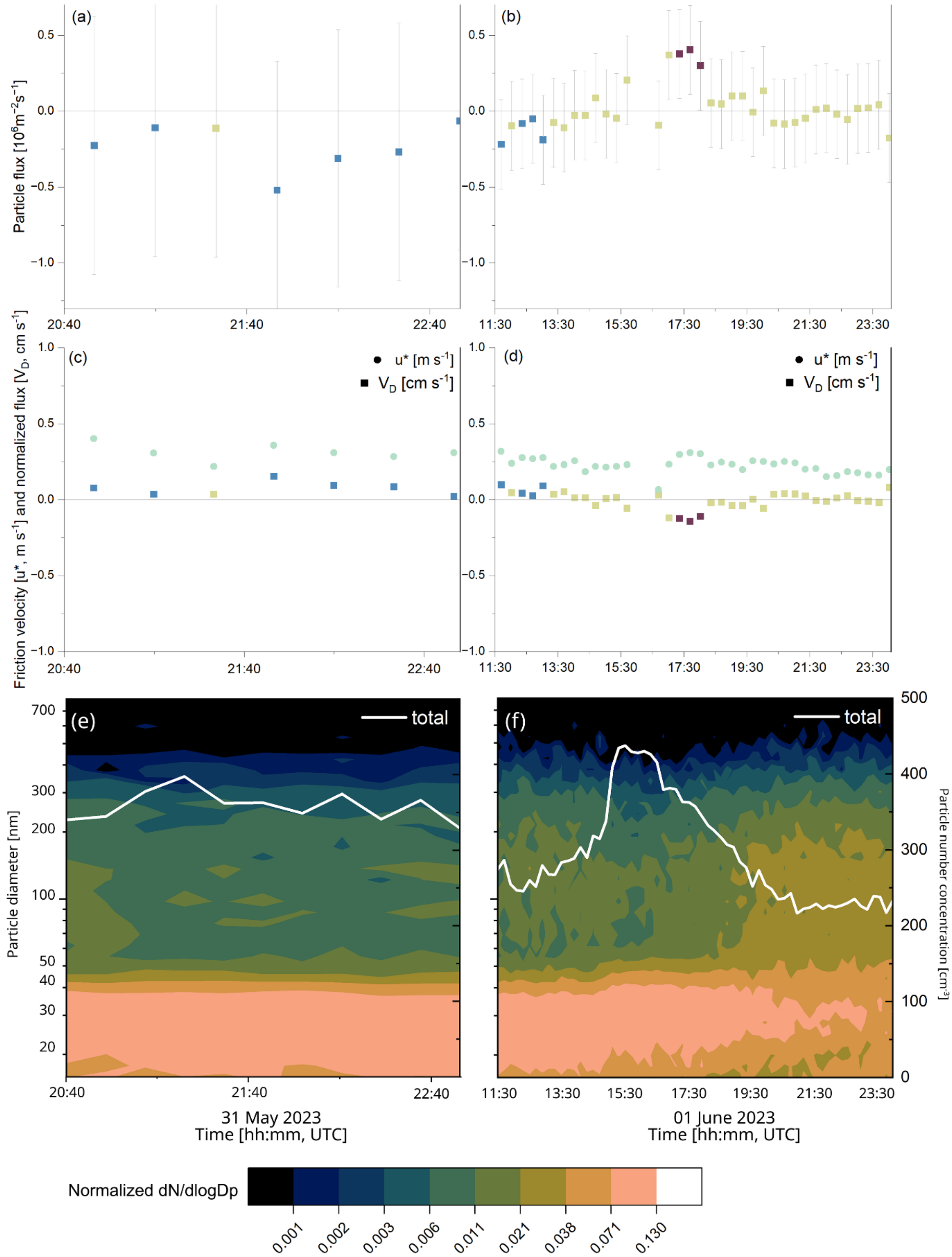
Table 2. Better to write 0.03-0.04 in the first raw and 0.005 in the second because the inerval 0.05-0.05 is not clear.

We agree with the referee and have changed the values.

Figure 6. What do you mean with normalised concentrations? Why not showing the size distribution with the typical normalisation using dLog?

We agree that the term normalized concentrations might be confusing here. The size distribution data are expressed in the conventional way using dN/dlogDp, and in addition, normalized by dividing by the total integrated concentration for each scan. In this way, the relative contribution of different size classes to the overall size distribution in Figure 6 e) and f) can be compared independent of the total particle concentration. The term “Normalized dN/dlogDp” better reflects the presented data and the term has been changed accordingly in Figure 6 and the caption of Figure 6.

Figure 6. […] (f) Normalized dN/dlogDp [%] particle size distribution from 15 to 790 nm (left y-axis) with total particle number concentration, measured with a DMPS on the 4th deck of Oden (white line; right y-axis).



(a)
(b)
Particle flux [10^{6}m^{-2}s^{-1}]
0.5
0.0
−0.5
−1.0
20:40
21:40
22:40
11:30
13:30
15:30
17:30
19:30
21:30
23:30
(c)
(d)
u* [m s^{-1}]
V$_D$ [cm s^{-1}]
Friction velocity [u*, m s^{-1}] and normalized flux [V$_D$, cm s^{-1}]
1.0
(e)
(f)
total
Particle diameter [nm]
700
300
200
100
50
40
30
20
Particle number concentration [cm^{-3}]
500
400
300
200
100
0
31 May 2023
Time [hh:mm, UTC]
01 June 2023
Time [hh:mm, UTC]
Normalized dN/dlogDp
0.001
0.002
0.003
0.006
0.011
0.021
0.038
0.071
0.130