Reviewer #1 Comments from Nathan Kurtz

This is a very interesting and useful study on the impacts of wind-driven changes to Ku and Ka radar returns from ground-based observations during MOSAiC. The study is quite thorough and rigorous, I just had a few minor comments and suggestions for the text as noted below. I would suggest publication subject to some minor revisions.

The authors thank Dr. Kurtz for their valuable time to review our manuscript and suggest publication subject to minor revisions.

Overall, I find the results to be quite interesting to ponder as they show a very detailed look at wind and roughness induced changes in Ku and Ka radar returns. The authors make clear this is a step towards interpreting what factors influence the often-times complex radar returns found in airborne and satellite radar altimeter data, there is not necessarily definitive conclusions to be determined for going from these results to altimeter data but the results are certainly intriguing and worthwhile to publish. I do wonder what this might mean for next steps in terms of future experiments with radar systems on field sites such as this, perhaps this could be added to the end discussion to further highlight what the significance of the data and results may be.

Thanks for your comment. We have added additional concluding statements related to future experiments using the KuKa radar on Arctic and Antarctic sea ice, as follows:

"In future field-based experiments, we will aim to combine coincident KuKa radar data and terrestrial laser scanner measurements of snow surface roughness to better characterize snow depth retrievals from radar altimetry. Forthcoming KuKa radar deployment campaigns on Antarctic sea ice can further shed valuable insights into complex snow geophysical processes (e.g. slush, presence of melt/refreeze layers, snow-ice formation etc) that may affect snow depth and sea ice thickness retrievals from satellite radar altimetry. With frequent occurrence of winter storms in the Arctic and the Antarctic, our findings will facilitate deeper insights and improvements towards better quantifying the impact of snow redistribution to produce accurate retrievals of critical snow/sea ice parameters from presently operational and new high frequency radar altimeter and microwave scatterometer missions such as SARAL/AltiKa, CryoSat2, Sentinel-3A, Sentinel-6, SWOT, CRISTAL, and ScatSat-1."

Minor comments

L38: "snow redistribution events increased the dominance of the air/snow interface at nadir as the dominant radar scattering surface" Is the use of the term "dominant" here redundant, or purposeful?

We have changed the sentence to *'At both frequencies, snow redistribution events increased <u>scattering at</u> the air/snow interface at nadir and its prevalence as the dominant radar scattering surface, due to wind densifying the snow surface and uppermost layers.'*

L73-74: I'm not sure the term "originate" is applicable here, perhaps stating they are assumed to be the dominant scattering surface is more appropriate.

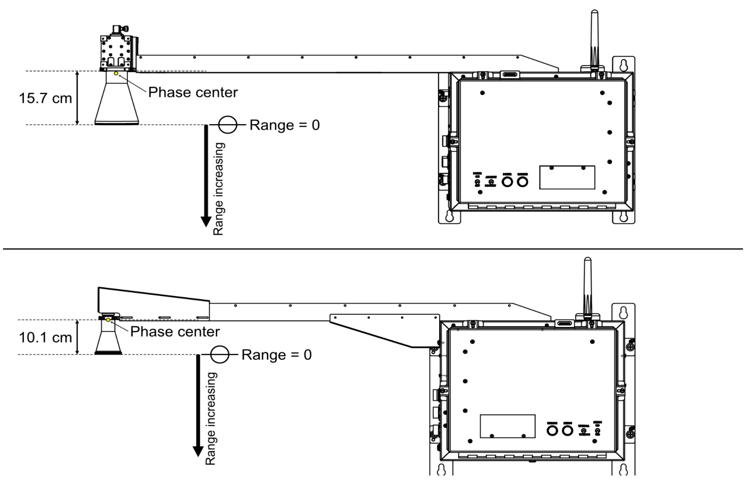
Sentence corrected as suggested: *'Under cold and calm snow conditions, a common assumption in radar altimetry is that, <u>the dominant scattering surface of co-polarized Ka- and Ku-band radar signals are assumed to be at the air/snow and snow/sea ice interfaces, respectively</u> (e.g. Lawrence et al., 2018; Tilling et al., 2018), due to dominant surface scattering from these interfaces (Fung & Eom, 1982)'*

Figure 1(a) and (b): What is "foot" in the figures? I think the caption may be describing this, but it would be good if consistent terminology is used.

'Foot' refers to the foot of the radar pedestal that mounts the radar antennas and the positioner system. We have changed the legends to 'distance from pedestal foot' for consistency.

Also L130-131: Is the pedestal here just the platform the radar sits on? Not the phase center of the radar or some determined zero range point?

The radar antennas are mounted on the sides of the positioner, which is mounted on top of the pedestal. The positioner controls the azimuth and incidence angle ranges of the radar system. The radar phase centres are located ~ 16 cm from bottom of Ku antenna (top) and ~ 10 cm from the bottom of the Ka antenna (bottom) as sketched (courtesy: ProSensing Inc) below (not used in the paper).



L128: Isn't the center frequency a bit off from the CryoSat-2 frequency? Or do you mean the frequency ranges overlap?

The frequency ranges are 'close to'. We have modified the sentence as follows:

'The centre frequency was set to be close to the Ka-band of AltiKa (35 GHz) and the Ku-band of CryoSat-2 (13.575 GHz)'

L137-138: Given the small range of incidence angles of radar altimeters like CryoSat-2 and AltiKa (mentioned previously in the text), I'm curious what motivated the reasoning for the 5 degree incidence angle steps? Do you not expect there to be much variation at smaller incidence angles or was this an instrument limitation?

Good question. Having a 5 degree increment to the incidence angle step was not an instrument limitation. The radar was permanently stationed at the remote sensing site along with other radar scatterometers operating at multiple frequencies (C-, X-, L-band etc), acquiring data at the same incidence angle steps and increments similar to the KuKa radar. This was done to acquire consistent measurements of radar scatterometers to collect coincident multi-frequency radar signatures.

Yes, even within incidence angle ranges at shorter angles (e.g. nadir to 5 degrees), we do expect variation in radar backscatter and waveform shapes, however, strongly dependent on the geophysical state of the snowpack, polarization and frequency. In forthcoming campaigns on Arctic and Antarctic sea ice, we are planning to acquire KuKa radar measurements at small incidence angle ranges (e.g. nadir to 5 degrees) at high resolution increments (e.g, 0.5 degrees), to understand the effect of small scale surface roughness changes on radar signatures.

L189-191: What approximate time interval did this integration over the amplitude thresholds typically occur? I think including that could give further evidence to support the fact that you expect the returns to capture the entire snow interval.

The power integration to calculate the NRCS depends on the range of azimuth angles (90 degrees in our case), relative to the beamwidth. The azimuth velocity of the KuKa radar is 5.7 degrees per second. Therefore, for a 90 degree azimuth scan, the time interval for one azimuthal scan across an incidence angle (e.g. nadir) is 15.78 seconds (~ 16 seconds for both frequencies). We have added this information in the revised manuscript as follows:

The KuKa radar takes ~ 16 seconds (i.e. 5.7° per second) over a 90° θ_{az} *width to acquire data across an incidence angle scan line (e.g. nadir) and ~ 2.5 minutes for one complete scan between* θ_{inc} *= nadir to 50°*

L193: A similar statement about the time interval could apply here too. So long as there weren't sea ice ridges or very high surface features in the footprint I think a smaller interval as stated here is appropriate.

The KuKa radar footprint was relatively homogenous and did not contain any ridges or high surface features across the footprint, as observed from the TLS data (see Figure 6) and CCTV imagery (see Figure 5). Line 193 has been modified as follows:

'The NRCS value is calculated based on the power contained within this peak <u>over an incidence angle scan line</u>, by integrating over the range bins where the power falls below a threshold, are set to -50 dB on either side of the peak for Ka-band data, and -20 dB (-40 dB) on the on the smaller-range (larger-range) sides for Ku-band data.'

Figure 8: Are these plots from data averaged between -5 to 45 degrees? It seems so from the caption. Is there much difference in plots showing only data from the nadir

direction? I think to some degree this is shown in Figure 9, but I do like the waveform plots in the bottom panel of Figure 8 as a way to show the waveform structure in similar manner to altimetry data.

No. Figures 8 and 9 data are averaged between -25° and +25°, which is the commonly sampled region for Ku- and Ka-band frequencies. We had to correct the KuKa geometry based on the radar system setup. Although the KuKa azimuth scanning range was between -45 and +45 degrees (i.e. 90 degree azimuth range), there is ~ 20 degree offset between the individual antennas and the radar positioner axis origin (see below). The Ku-band antenna therefore scans between ~ -65 degrees to +25 degree azimuth range (region between purple lines) and from -25 degrees to +65 degrees for Ka-band (region between green lines). The region (yellow region between green and purple lines) between -25 degrees and +25 degrees is the overlapping Ku- and Ka-band footprint. We have incorporated these changes in the revised manuscript and in the reviewer #2's rebuttal response.

Yes, the echograms in Figure 9 show data from non-nadir incidence angles. We focused on nadir echograms in Figure 8 to focus more on the altimetry part.