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Interactive comment on "Sea ice melt pond fraction estimation from dual-polarisation C-band SAR – Part 1: In situ observations" *by* R. K. Scharien et al.

Anonymous Referee #1

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I've been asked to provide a review of the LiDAR and field observations portion of this paper. I feel obliged to disclose that I also provided review of the author's other paper cited 'in press' regarding the methods used for LiDAR data collection in this work. In that review I express reservations about the use of a terrestrial scanner to derive surface roughness at scales as small as 2mm, which I largely reproduce here. This paper is not primarily focused on the LiDAR work, instead centering on presenting results that could lead to useful differentiation of ponds and bare ice in SAR data. It seems the paper communicates good progress toward advancing the use of C band SAR in sensing sea ice surface processes to the community, and I believe this paper should be published subject to review of the content by radar experts.

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Still, the authors have some issues to address, acknowledge or more artfully dodge related to errors in the surface roughness measurement techniques. Specifically, the authors seem to overlook the limitations in the use of several pieces of equipment. Deriving mm scale roughness from LiDAR and from the ultrasonic sensor is really beyond the capabilities of these instruments. The authors revise to acknowledge that mm scale roughness derived from these LiDAR and ultrasonic techniques is stretching the abilities of the sensor techniques and the limitations this imposes on conclusions here, conduct careful analysis of the errors in surface sensing at the sub mm scale to produce convincing calibrations, or approach the radar focus of this paper in a manner that avoids the complications of the LiDAR and ultrasonic sensor data.

Specifically: 1. I do not believe it is possible to retrieve accurate mm scale snow and ice surface information from a pulse-type LiDAR scanner without incorporating detailed information on beam divergence and beam incidence geometry, waveform processing, and (possibly) corrections for atmospheric refraction (and the methods paper did not convince me otherwise). The C10 Leica scanner used for this work is a pulse –based time of flight LiDAR unit. The unit fires a pulse of light and times the duration until a return is received. The first return stronger than the internal thresholding is interpreted along with the azimuth and zenith angle the pulse was fired at to yield an xyz point. The scanners are amazing new tools, but several aspects of this technique limit its accuracy for a given pulse, typically to around 1cm, but down to a few mm with particularly good error control. Either way, single point returns from a snow or ice surface cannot be expected to have accuracy on the order of 1mm – as appears to be required for some of the the results of this study. These errors, which were not discussed, include: a. The beam from the laser does not produce a true point measurement on the surface because it has finite diameter (2.5mm at 1.5m) and finite divergence (0.25 mrad if I recall correctly). This means that sampling a 2mm grid (as carried out in this study) with the scanner results in overlapping laser footprints and does not generate unique samples. This is extremely important to this study. Correlation lengths and surface roughness are likely strongly impacted by the fact that adjacent samples are non-unique. Setting the scanner to exceptionally high angular sampling (as this study did) results in overlapping point samples at closer ranges. b. The incidence angle of the laser on the surface further enlarges the laser spot sample into an ellipsoid. This is very important to this study because low scanner incidence angle will create anisotropy in correlation (greater re-sampling of the same point along the long axis of the laser footprint ellipsoid.) Assuming the scanner was mounted on a tripod and scanned a surface some distance away, low incident angles likely are important to this study. c. The absolute time of flight accuracy of the scanner, as determined by the scanner's internal microchip, is approximately 4mm (1sigma) at modest distances ($\sim$20m). Noise in ranging estimates of at least a few mm is to be expected. d. The snow and ice surfaces of interest do not have a unique surface location within the footprint of the laser. Snow and decaying ice grain sizes are often smaller than the footprint of this laser and the laser pulse return will not be a neat square pulse, but rather a time-spread version of the original pulse that incorporates light returns from a variety of surfaces within the laser footpring. The ultimately determined surface location will fall within the range of surface roughness sampled by the laser footprint but within those bounds is highly dependent on the methodology used to interpret the return pulse from the laser. This prevents the use of single return pulsed LiDAR to derive information about surface roughness at the scale occurring within a single laser footprint. e. The snow and ice surfaces are not opaque to green (532nm) light used by the scanner, but rather reflect by backscattering from a transparent media. A 532 nm (green) laser will penetrate into the snow and ice several mm, and multi-path returns from within the upper backscattering portion of the snow result pulse returns that have mm-scale ambiguities introduced.

2. The use of the TPSC30S1 sensor for observing pond surface roughness suffers from similar issues as the LiDAR data. The author estimates a footprint of 0.04m, but lobes of the sound footprint likely extend beyond this and within this footprint the water is likely not flat. Without an analysis of how the sensor selects the 'true surface' from a messy pulse return, it is hard to understand whether the sensor's variability is reflecting the true amplitude of the surface roughness. Additionally, the sampling technique likely

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has significant artificial noise as well because the sensor's accuracy and repeatibility is only within a mm or two considering all sources (e.g. 0.2% of range repeatibility error, surface roughness in footprint errors, resolution of 0.86mm). The authors observation that the MEAN error is very small is insufficient to understand how well the sensor is capturing surface roughness variability. Because surface roughness variability is so important to the study this is a notable issue.

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