Final response to RC2- Anonymous Referee #2

Code:
Green = Reviewer comment accepted
Yellow = Reviewer comment discussed
Italics= Authors' response to the reviewer's comment

General comments

This manuscript describes the development and testing of a novel instrument for direct measurement of the scattering coefficient in the interior of sea ice. Sea ice is a strongly multiply forward-scattering domain so direct measurements of the inherent optical properties have been challenging. This instrument uses an active optical test to acquire reflectance data used to interpret the spatial distribution of scattered light in a relatively small volume. A forward radiative transfer model is run for a wide range of scattering coefficients to generate a look-up table to which the observed reflectance pattern is compared. Results indicate that inferred scattering coefficients fall into the range of expected values.

The probe itself appears to have significant promise for investigation of the optical properties of sea ice. The manuscript describing the probe is comprehensive and does a good job of outlining the theoretical basis for the probe, its design, validation, and an example data set. The figures are clear and appropriate (one minor comment on Fig. 1, below). I have no substantial concerns about this manuscript and recommend it for publication. I was a bit surprised that the field tests did not include more information about the IOPs of the ice near its upper surface. Seems this is where this instrument could really shine, but it sounds as though there may be some technical issues to work through before the instrument can be used to interpret scattering through the entire column.

The remainder of my comments are minor and address the clarity of the language. There are numerous instances where the language is a bit imprecise, so obscures the intended meaning. I've attempted to point these out below. Otherwise, the presentation does a good job of motivating and explaining the hardware, results, and issues associated with data interpretation.

We want to thank the reviewer for its precious contribution regarding the precision and clarity of the manuscript and for its corrections regarding some key elements of the cited litterature.

Specific comments

19 – 22: sentence beginning "Comparison to a Monte Carlo." This sentence implies that all three IOPs can be inferred, whereas in practice it appears that satisfactory inversions are accomplished by assuming a and gamma? Also, this sentence should be broken into two sentences.

We will add :"Comparison to a Monte Carlo simulated lookup table allows, in theory, to retrieve the absorption coefficient, the reduced scattering coefficient and a phase function similarity parameter γ,"

*And "*Fixing the absorption coefficient and γ, which proved difficult to measure, vertical profiles of the reduced scattering coefficient were obtained with decimeter resolution on first-year Arctic interior sea ice on Baffin Island in early spring 2019." (line 25)

22-23: Sentence beginning "Monte Carlo simulations..." needs to be rewritten for clarity 29: strongly dependent *on* gamma?

Will be rewritten as :"The depth reached into the medium by detected photons was estimated using Monte Carlo simulations: The maximum depth reached by 95% of the detected photons was between 40±2 mm and 270±20 mm depending on the source-detector distance and on the ice scattering properties."

30: "novel probe" delete "developed"; also "scattering in sea ice" not "into".
32: govern (not "are governing")

45: "the vertical distribution of IOPs"

48: "approximations"

51: instead of enlightenment, solar insolation or incident illumination

85: Does G also depend on the viewing direction of the receiving fibers (enclosed angle between direction of centers of source and detector fibers)?

The direction of the viewing fiber affects the depth of signal origin as demonstrated by one of our colleagues. By intuition, we could presume that the direction of the viewing fiber effect on R is strongly dependent on the angular profile of the backscattered light: under angularly homogeneous backscattered light, the direction of the viewing fibre would not affect R. Under strictly upward backscattered light, we believe the reflectance would diminish proportionally to the foreshortening of the effective detection area. That is if we don't consider the effects of refraction.

Regarding the refractive effects, the effect of the viewing direction on R would depend on whether the fibre is held in the uppermost media or tilted downward to dip in the bottommost media. The various refractive effects would be different in those 2 situations.

We did not include the direction of the viewing angle as part of G, because its effect is not well documented and because the correlation to geometry is not as obvious as for the other parameters. We assume the reader will understand that, in our case, the fibres are strictly perpendicular to the probed medium as it is illustrated on fig.1,3 and 4.

97-98: fewer moments required as number of scattering events in the optical path augments. Do you mean "optical path increases"? Rewrite for clarity.

122-125: I think it likely that Grenfell & Hedrick (1983) had difficulty isolating single scattering and were probably measuring a domain somewhere between single scattering and diffusion regime.

From Grenfell and Hedrick (1983):

"optical thickness through the ice for the most opaque samples was estimated using extinction data from Perovich(1979) to be less than 0.0025 - excluding ice below the eutectic point. This was assumed to be sufficiently optically thin to give a reasonable representation of single scattering"

But indeed their sample were 10 mm thick while scattering mean length of interior sea ice is roughly 10 mm at the lower extreme. Meaning their measurements are potentially biased by multiple scattering in the sample.

Because of the ambiguity, we decided to take off the sentence.

128: Please check this reference.

Corrected to Van de Hulst and Christoffel 1980

134 (paragraph beginning): Is "N" defined? Is it the same as "n"? It is not clear exactly what is being evaluated here. What is meant by "set free"?

n corresponds to the order of the Legendre polynomials moments g_n, while N represents the regime, meaning the number of free moments g_n needed to correctly characterize the phase function. For example, the Henyey-Greenstein phase function has infinite moments g_n described by $g_n = g_1^n$, but only one of them is a free moment (g_1). It therefore lies in the N=1 regime.

We will add the definition of N to the manuscript and precise what is meant by set free.

149: Please provide a reference for precipitated salt crystals that are smaller than the wavelength and thus serving as Rayleigh scatterers.

We realised that smallest known ice crystals are roughly 1 micron in size (according to Light 1995), which is roughly 1.5 times the wavelength. Therefore, Rayleigh scattering probably does not play an important role when it comes to salt crystals.

However, Rayleigh scattering, though not documented in sea ice litterature, could be caused by nanometric scale dislocations in the ice matrix, dissolved NaCl and insoluble dust particles (Price and Bergström, 1997). We will modify the text to correct the potential Rayleigh scatterers. At the same time, we will add the mathematical equation stating that for anisotropic scattering: $g_2 \leq g_1$ and for Rayleigh scattering $g_1=0$ and $g_2=0.1$ in order to be more precise.

P. B. Price & L. Bergström (1997) Enhanced Rayleigh scattering as a signature of nanoscale defects in highly transparent solids, Philosophical Magazine A, 75:5, 1383-1390, DOI: 10.1080/01418619708209861

158 optically dense?: "impenetrable"? *We meant solid.*

169: Light et al Monte Carlo model uses reciprocity to solve the RT equation, but is not truly an inverse model.

Figure 1: would it be helpful to show an arrow going from "Filter & photodiode" to "Computer" to show that the measured light is compared with MC simulations?

Indeed, the arrow were already included, but some element of the figure disappeared when converted to .pdf. We will make sure to correct this technical issue before submission.

221: bandpass filtering at 633 nm designed to reject sunlight, but there is plenty of sunlight in the ice at this wavelength? Maybe just say "reject sunlight at extraneous wavelengths"?

307, 311, 390: horizontally? Not clear what this means?

We will add this clarification" leaned horizontally (meaning the fibers are looking downward)"

329 – 331: this last sentence could be omitted
416: lowest (not coldest) temperature
544 inclusions "fusion"? Maybe merging inclusions?