Review:

Development of a diffuse reflectance probe for in situ measurement of inherent optical properties in sea ice

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General comments

This is a well written paper that is based on a very substantial and impressive body of work by the authors. The authors developed and extensively tested a new diffuse reflectance for sea-ice. They carried out a detailed ice scattering model analysis using a complete Monte-Carlo code and experimentally validated its functioning and calibration using micro-spheres suspensions and a Mie code scattering phase function model. Their probe was then used in-situ to analyze the inherent properties of sea-ice as a function of depth from the surface. The results of this work and the resulting measurement techniques are extremely relevant and could be used as a starting point to ultimately obtain functional models of sea-ice generation and loss in natural environments. The probe and the signal analysis techniques give a glimpse of the possible performance and environment monitoring accuracy improvements obtainable from their use. This information will be extremely useful to other researchers in the field. For the reasons above I recommend publication of this paper. There are however several developments in the paper which, at the author's discretion, could, in my opinion, be improved before publication. I have noted those more serious problems and along with minor deficiencies/improvements in my comments below.

Specific comments

Suggestions for improvements

Line 95 and following:
I have had a problem in following the original theoretical introduction because of missing terms in the discussion. I would add the definition of the moments immediately after equation 2.
Where g_n

$$g_n = 2\pi \int_0^{\pi} P_n(\cos\theta)\, p(\theta) \sin\theta \, d\theta$$

$P_n(\cos\theta)$ are the Legendre polynomials and θ denotes the angle between incident photon direction and photon direction after scattering. The first three Legendre polynomials which we will use are:

$$P_0(\cos\theta) = 1$$

$$P_1(\cos\theta) = \cos\theta$$

$$P_2(\cos\theta) = \frac{1}{2}(3\cos^2\theta - 1)$$

Equation 3 then becomes

$$g_1 = 2\pi \int_0^{\pi} p(\theta)\cos\theta \sin\theta \, d\theta$$

Note that the solid angle element of integration $\sin\theta \, d\theta$ has been shifted to the end of the integral to separate it from the function being integrated over the solid angle to keep the physics underlying the equation clearer.

Line 145:
All the subsequent higher moments after the second moment of the modified phase function are simply

$$g_n = \beta g_{HG}^n \ \text{ for } n > 2$$

Since the integral of $(1-\beta)\cos^2\theta \, P_n(\cos\theta)$ term is identically zero due to the orthogonality of the Legendre functions for any $n \neq 2$. This fact should be mentioned since at the end of the paper there is some discussion of the importance of the higher moments. The conclusion above implies that those higher moments and any of their ratios are basically controlled by the g_{HG} parameter which considerably limits any flexibility to model more complex situations as the behavior of the solution as a function of g_{HG} is already fully accounted for in the current model.

Line 232:
The fact that the laser emitter cone does not have the same angular range as the NA of the fiber in ice is an indication that the fiber does not completely scramble the laser input and significant traces of the fiber input conditions remain at the fiber exit. This is not surprising for such a short fiber with a single bend. It’s a known problem in diode pumped lasers. This however implies that care must be taken not to disturb the fiber by moving it after the measurement of the output beam is done. Ultimately this problem can be corrected by using a longer fiber and winding it on a mandrill or around the cavity of the probe. However, given the minimum bend radius of the fiber, you may not have enough room in the probe in which case I would recommend making sure the fiber is fixed in place by a holder or support.

Line 395
The effect of the container wall of the theoretical values of reflectivity for the polystyrene sphere suspensions should be expanded as they could be a substantial portion of the errors which seem to occur predominantly at the low values of absorption and scattering. The authors mention this in the discussion and conclusions but it should be further addressed at this point to at least indicate clearly what results are significantly subject to the wall influence.

Line 610

As a suggestion for future work and to start bridging the gap between structural and optical knowledge the researchers could use the vast and valuable simulation data base to reevaluate the behavior of the absolute and relative reflectivity as a function of different non-dimensional parameterizations to identify the significant correlations. Two parameters come to mind immediately, the backscatter coefficient and the absorption over b' .

$$\frac{b_b(\beta,g)}{b} = 2\pi\int_{\pi/2}^{\pi} p(\beta,g,\theta)\sin\theta\, d\theta = \frac{\beta}{2\,g}\left[\frac{(1-g^2)}{\sqrt{(1+g^2)}} - (1-g)\right] + \frac{(1-\beta)}{2}$$

The second parameters of interest could be the asymptotic value of the mean cosine (first moment). Piskozub and McKee (see attached reference) have shown that the limit of the first moment of the radiation distribution after many collisions is given by:

$$g_\infty = \frac{g(1-\omega)}{(1-g\,\omega)}$$

g is the first moment of the scattering function for the first collision and g_∞ is the resulting radiation distribution after a large number of scattering collisions. ω is the albedo

$$\omega = \frac{1}{\left(\frac{a}{b}\right)+1} = \frac{1}{\left(\frac{a}{b'}\right)(1-g)+1}$$

$$g_\infty = \frac{g\left(\frac{a}{b'}\right)}{\left[1+\left(\frac{a}{b'}\right)\right]}$$

This indicates that the parameter $\frac{a}{b'}$ is also a candidate for which the correlations should be looked at

Finally the simple scaling against $b'z$ could be used to analyze the correspondence of the computed reflectivity at the different detectors. Detectors with identical $b'L$ where L is the distance between the source and the detector should have the same response if $\frac{a}{b'}$ and $\frac{b_b}{b}$ are the same.

Reference [1]
"Effective scattering phase functions for the multiple scattering regime"
Jacek Piskozub and David McKee Optics ExpressVol. 19,Issue 5,pp. 4786-4794
https://doi.org/10.1364/OE.19.004786

Technical comments

1) Line 18 "by optical fiber" should be replaced by: "by an optical fiber"
2) Line 19 "receiving fibres" should be replaced by: "receiving fibers"
3) Line 21 "allowing to analyze" should be replaced by: "allowing the analysis of"
4) Line 29 "dependent of" should be replaced by: "dependent on"
5) Line 30"this novel developed probe" should be replaced by: "this newly developed probe"
6) Line 185 "assuring them" should be replaced by: "which assured them"
7) Line 191"of optical properties" should be replaced by:"of the optical properties"

8) Line 206”concise volume” should be replaced by:”compact volume”
9) Line 227”splitted” should be replaced by”split”
10) Line 268 “thereof” should be replaced by “therefore”
11) Line 274”inverse” should be replaced by “the inverse”
12) Line 298’’detecting fibres” should be replaced by “the detecting fibers”
13) Line 331 “uncalibrated” should be replaced by “the uncalibrated”
14) Line 390”in function” should be replaced by “as a function”
15) Line 475”induced variation” should be replaced by ”induced variations”
16) Line 536”Using Grenfell” should be replaced by “Using the Grenfell”
17) Line 543”refractive index” should be replaced by “the refractive index”
18) Line 586” Then” should be replaced by “Also”
19) Line 592”adapted” should probably be replaced by “developed and validated”
20) Line 610 “ice core” should be replaced by ”ice cores”
21) Line 616”a more widespread study” could be replaced by ”more widespread and wide ranging studies”