Response to comments of Reviewer 1 (Henning Löwe) on manuscript tc-2021-358

We would like to thank the reviewer for the in-depth peer-review, and for constructive comments and suggestions how to improve the paper. Below we give a point-by-point reply to individual comments. The reviewer's comments are labeled as **RC#** and the corresponding author responses are labeled **A#**. Suggestions to change or add in the manuscript are written in blue color.

RC1: (l73): This sounds as if CBOE may occur in pure water ice. I would mention the disorder here (e.g. porosity) too.

A1: We agree and propose to change the beginning of the paragraph at line 73 as follows:"In many of these experiments, observation of a backscatter enhancement peak at radio-frequencies was interpreted as the CBOE. This interpretation was then used to infer the possible existence of water ice (presumably with a porous or disordered structure so as to elicit the effect) on the surface of the corresponding solar system bodies."

RC2: (l104): Its commonly termed traditional grain size.

A2: We agree and propose to change the in line 104 the word "classical" to "traditional".

RC3: (l115): missing spaces around the hat symbol.

A3: Agree. We propose to add the spaces around the hat symbol.

RC4: (l236): hat notation was already explained before.

A4 Agree. We propose to remove the sentence "The hat symbolˆindicates measured quantities."

RC5: (l298): Would be nice to state what's in fact the meaning of the porosity coefficient, besides giving its value.

A5: We agree. We propose to clarify the meaning of the porosity coefficient in section 2.3 as follows (see also author response **A13** for rationale and new proposed full text of section 2.3): "K is a correction factor, described in (Hapke, 2012, p.164–167) as "porosity coefficent", which increases the extinction coefficient $E = S + A$ due to inter-particle effects in densely packed media where particles are large relative to λ. As ice grains are much smaller than the wavelength, we assume $K = 1$."

RC6: (l.349): This information belongs rather into the method section.

A6: We agree that it fits better into the method:data-selection section than into method:model-fitting section. We will move the sentence "From these, we removed 14 acquisitions for which TanDEM-X instead of TerraSAR-X acted as transmitter, resulting in slightly different antenna pattern that could not be 350 compensated through the calibration, especially in the HH polarization." to l.180 (method section 2.2.1) which will then read: "For 104 acquisitions TerraSAR-X acted as transmitter, for 14 acquisitions TanDEM-X acted as transmitter. We removed the 14 TanDEM-X acquisitions because they showed slightly different antenna patterns that could not be compensated through the calibration, especially at HH polarization, because of a too small number of acquisitions. For the remaining 104 acquisitions, bistatic baselines ..."

RC7: (fig7): Maybe I missed it later in the discussion but what is the significance of the fact that Λ_T estimate in summer is roughly the same as Λ_T in winter? Since the backscattering enhancement is absent in summer, an interpretation of the summer data within this CBOE model should naively give an idea about the error of the parameters in winter. Why is the error on the length scale so drastically reduced?

A7: We interpret the fact that the best estimates of Λ_T are roughly the same for summer and winter ($\sim 0.4\,\mathrm{m}$) as a coincidence, that can not be assigned a strong physical interpretation for two reasons. Firstly, the estimate of Λ_T for summer has a much larger confidence interval which reduces the significance of the numerical match of the best estimate. Furthermore, due to the non-linearity of the model, the behaviour of the errors of one parameter is affected by the current value of the second parameter. As a specific example of the summer scenario, when the value of the estimate of the absorption mean free path Λ_A is low (0.4 m, i.e. comparable to or lower than the scattering mean free path Λ_T), the model becomes much less sensitive to variations of the value of Λ_T. Since Λ_T can be interpreted as a measure of the relative width of the intensity peak, its precise value becomes non-physical when no enhancement peak is present. This also makes drawing conclusions from direct comparison of the errors of Λ_T estimates between summer and winter difficult, because the Λ_A value is diametrally different in the two cases. To clarify this, we propose the following changes:

- Line 361-365: Reorder the paragraph to address the winter dataset first, and provide more information about the summer dataset model fit: "For the winter dataset a clear intensity peak is detected, with a HWHM of approx. 0.25° and amplitude $B_C(0) \approx 0.5$ (1.8 dB), corresponding to $\Lambda_T \approx (0.4 \pm 0.1)$ m for the HH and VV polarization. The derived absorption lengths Λ_A are much longer than the scattering lengths with $\Lambda_A \approx (11 \pm 7)$ m for the HH polarization and $\Lambda_A \approx (19 \pm 12)$ m for the VV polarization. For the summer dataset, the flat profile of the observed intensity curve indicates that very little or no backscatter enhancement is present – this is reflected in the model fit in the low value and large confidence interval (relative to the value) of the absorption length $\Lambda_A \approx (0.4 \pm 0.4)$ m. The estimates of the scattering length in the summer dataset ($\Lambda_T \approx (0.40 \pm 0.27)$ m and $\Lambda_T \approx (0.43 \pm 0.39)$ m for the VV and HH polarization respectively) have comparable value to the winter estimates, however the much larger confidence intervals indicate that the value of Λ_T could not be determined more precisely for the summer dataset due to the absence of a clear enhancement peak. The uncertainty of the value estimates corresponds to the 95% confidence interval."
- Fig. 7: After the first sentence, add the following sentence: "For the summer dataset (orange), the comparable values of the Λ_T and Λ_A estimates, as well as their relatively large confidence intervals, indicate that the CBOE peak was not detectable."
- In the Discussion section 4.2.1, modify the first paragraph by replacing the lines 434-437 (Starting at "The absence..." until the end of the paragraph) with the following text: "In the summer scenario (i.e. absence of a clear backscatter enhancement peak), the model, described in Sect. 2.3 and visualized in Fig. 6, predicts that the absorption length is shorter or equal to the scattering length ($\Lambda_A \leq \Lambda_T$). An interpretation of this scenario is that higher-order scattering paths are suppressed due to absorption, and thus the summer scenario is dominated by a single-scattering process. In the summer scenario the model becomes much less sensitive to the precise value of Λ_T (which is a measure of the width of the peak), and thus estimates of this value have much higher uncertainty as opposed to the case of a clearly detectable enhancement peak in winter."

RC8: (fig10): What does "supported by the horizontal gray line" mean in the caption? Is it a calculated line?

A8: In an earlier version of the processing, we used a manually chosen threshold on the backscatter intensity at −8 dB to remove data with wet snow. However, this threshold was replaced by the temporal constraint 01 Dec - 31 May. Therefore we propose to remove the gray line from Fig. 10 and to remove the statement "(supported by the horizontal gray line)" from the figure caption.

RC9: (sec 3.2.2): This is now a bit disappointing that no results are shown (in the main text) for the secondary observation site due to limited data. Why was the site chosen and introduced here at all? Maybe it should be dropped completely?

A9: The secondary site was chosen in hope to see a stronger effect because of possibly larger bistatic angles. However, the bistatic angles were very similar here. Nevertheless, the analysis confirmed that CBOE also occurs in the accumulation zone of Teram-Shehr/Rimo glacier. The observed enhancement was slightly stronger, but no additional information was gained from the secondary site. We propose, therefore, to move almost all information regarding the secondary test site from the main part of the manuscript to the supplements. As the secondary site still confirms our observations we will keep a reference at line 175 "As a best compromise, we selected the Jungfrau-Aletsch region in Switzerland but also analyzed the Teram-Shehr/Rimo glacier in the Karakorum (supplementary material) where a considerably lower number of acquisitions is available.". In addition, we will add in line 462 "These observations were confirmed by the data from the Teram-Shehr/Rimo glacier in the Karakorum (see supplements)." and remove "as well as for Teram-Shehr/Rimo glacier the Karakorum (Figs. S10 and S11)." above (l.460).

RC10: (l450): Was the corner reflector installed in summer?

A10: We suggest to change l.450 "a corner reflector at the bottom of a 1.55m deep snow pit" to "a corner reflector lowered to the bottom of a 1.55m deep snow pit with vertical walls" to clarify that the reflector was installed in winter.

RC11: (l445): "thickness of the snow layer" you mean snow depth?

A11: We propose to change the wording in following lines:

- Line 445: "thickness of the snow layer" → "snow depth"
- Line 446: "the snow layer thickness" → "snow depth"
- Line 448: "ground layer" → "ground"

RC12: (l448): "snowpacks thickness" → snow depth

A12: We agree and propose to simplify the sentence to: "Nevertheless, the snow depth of only 3–4 scattering mean free paths could limit higher order scattering."

RC13: (l494): Here, or before in sec 2.3, it would be helpful to discuss the relation of the effective transport parameters with the microstructure of the medium. What I grasp e.g. from Tsang, Ishimaru J. Opt. Soc. Am. A 1, 836 1984 is that the peak can be fully characterized by the effective (complex) wave propagation constant of the medium which can be computed from the two-point correlation function using common scattering approximations for snow. Is this sufficient or would a prediction of the profile (or prior estimates of the effective parameters) from in-situ measurements require more advanced structural information that is not yet measured in snow?

A13: Yes, we agree and will describe the relation between the effective transport parameters Λ_A, Λ_T and the microstructure of snow using references to empirical data (Wiesmann et al., 1998; Wiesmann and Mätzler, 1999) and also to the modelling work. To keep the model-section concise, we add a brief reference to the SMRT model (Picard et al., 2018) and will add a new discussion section (4.4) to provide further details. Providing this relation requires putting the model from (Hapke, 2012; Akkermans et al., 1986) into context with earlier models (e.g. (Tsang and Ishimaru, 1984, 1985)) and outlining assumptions of current models for CBOE. Based on the current state-of-the art of microwave backscatter models for snow (e.g. (Picard et al., 2018)) we can then provide a link of the transport parameters to the snow microstructure.

Regarding prediction of the peak profile from in-situ measurements: We would like to point out that current CBOE models assume mostly a half-space filled with a medium with homogeneous scattering/absorption properties which is not the case for a natural, layered snow pack where scattering can also occur at the interfaces between different snow layers and also at density-fluctuations in the horizontal direction (Proksch et al., 2015). Even for homogeneous snow slabs, results from the characterization of the microstructure with different methods, as well as the application of different microwave scattering models, can differ significantly (Vargel et al., 2020). To avoid overcomplication of the model we consider the multi-layer snow pack as a homogeneous semi-infinite scattering medium but would like to point out, that the derived parameters Λ_T, Λ_A might require additional correction factors when a scattering model for CBOE in snow at microwave frequencies becomes available or when the limited thickness of the snow pack becomes relevant, i.e. when its optical thickness becomes relevant (see comment from Reviewer 2).

In order to provide the above discussed information in the manuscript, we suggest to rework the model-section (2.3), to add to the discussion a subsection "4.4 Link to the microstructure of snow", and to add a new discussion subsection "4.5 Limitations of the model". The complete proposed new text of these sections is shown in the itemized list below:

- **2.3 Backscatter model of the CBOE**
  Coherent backscatter enhancement was first explained through time-reverse propagation in double and multiple scattering paths between scatterers with a low volume fraction in free space using second order multiple-scattering theory and expansion in Feynman diagrams (Tsang and Ishimaru, 1984, 1985; Van Der Mark et al., 1988); Wolf et al. (1988) added particle-independent absorption through the background medium. For a review see (Akkermans et al., 1988) and the book from Hapke (2012). To our knowledge, no complete theory for CBOE in densely-packed media of particles small compared to the wavelength exists. Furthermore, in snow, scattering can occur at various length scales (i.e. ice grains, density fluctuations, inter-layer boundaries, and ice layers (Picard et al., 2018)) and no CBOE model for multi-layer structures is currently available. In order to describe the complex snow structure in the context of existing models, we consider snow as an effective scattering medium occupying a semi-infinite space with homogeneous scattering and absorption properties and follow the description from Hapke (2012) for interpretation and modeling of our results: in Chapter 9, Eqs. 9.40 and 9.44 (Hapke, 2012), as well in (Akkermans et al., 1986, 1988; Akkermans and Montambaux, 2004), the peak shape of the coherent backscatter enhancement is described for non-absorbing and absorbing media by the equation:

  $$B_C(\beta) = \frac{1}{[1 + 1.42K]\,[1 + \xi(\beta)]^2} \left[1 + \frac{1 - e^{-1.42K\xi(\beta)}}{\xi(\beta)}\right] \tag{6}$$

  where $B_C(\beta)$ is the magnitude of the coherent backscatter intensity enhancement relative to the incoherent background I_0 at small bistatic angles $\beta \approx \sin\beta$. For notational simplicity, and in accordance with (Hapke, 2012, Eq. 9.44) and (Wolf et al., 1988), we defined

  $$\xi(\beta) = \sqrt{\left(\frac{2\pi\Lambda_T\beta}{\lambda}\right)^2 + \frac{3\Lambda_T}{\Lambda_A}}. \tag{7}$$

  In this equation λ is the free space wavelength, $\Lambda_T \propto S^{-1}$ is the transport mean free path which is proportional to the inverse of the scattering coefficient S of the medium, and $\Lambda_A = A^{-1}$ is the absorption mean free path in the medium with absorption coefficient A. Assuming that the snow depth is much larger than Λ_T, i.e. that snow can be considered as an optically thick medium, the scattering and absorption coefficient that parameterize Eq. 7, can be linked to snow properties derived from density and the microstructure (Picard et al., 2018) as discussed in Sect. 4.4. The factor K is a correction factor, described in (Hapke, 2012, p.164–167) as "porosity coefficent". The factor K increases the extinction coefficient $E = S + A$ in densely packed media where inter-particle effects of particles large relative to λ occur. As ice grains are much smaller than the wavelength, we assume $K = 1$.

The incoherent background intensity I_0 is determined by the single- and multiply scattered background intensity from the medium for which no time-reverse counterparts exist (i.e. no coherent enhancement), so that

$$I(\beta) = I_0[1 + B_C(\beta)] \tag{8}$$

describes the total backscatter intensity $I(\beta)$ in the proximity of several degrees from the direct backscatter direction.

The peak shape, as drawn in Figure 9, is determined by the ratio of scattering mean free path Λ_T to the wavelength λ, as already indicated by Tsang and Ishimaru (1984), and by the probability distribution of scattering path lengths in the medium. A (monostatic) scattering path begins at the first scattering event in the medium, travels along multiple scatter events with mean distance Λ_T, and ends when the radiation is scattered back out of the medium in the direct return direction (Hapke, 2012, Chapter 9.3). In the monostatic configuration, radiation traveling along such a path interferes constructively with radiation propagating along the time-reversed counterpart, thus causing the backscatter intensity enhancement. Long scattering paths, consisting of multiple scattering events, have a longer distance between the path's start and end point and cause a narrow peak, while short scattering paths cause a broad peak. The final peak shape is determined by the sum of all occurring peak shapes of different widths (Tsang and Ishimaru, 1985), weighted according to their occurrence probabilities. The more absorption occurs, the shorter are the scattering paths that can contribute to the coherent peak, and the lower is the probability for the occurrence of higher order scattering, hence the peak becomes rounder and wider (Akkermans et al., 1988; Wolf et al., 1988, Fig. 7). Long scattering paths can also be limited by a finite sample (snowpack) thickness, which also causes a rounding of the peak and an increase of its width (Van Der Mark et al., 1988; Van Albada et al., 1988, Fig. 20).

Figure 9 shows the shape of the CBOE peak for a range of values of Λ_T, Λ_A given in multiples of λ. For non-absorbing media ($\Lambda_A = \infty$, black curves), longer scattering lengths Λ_T cause a narrower peak with a HWHM of $0.36\lambda/(2\pi\Lambda_T)$ (Van Der Mark et al., 1988; van Albada et al., 1987). This peak width holds for sparsely packed media; for densely packed media of hard spheres, (Mishchenko, 1992a) suggests a significantly reduced HWHM.

With increasing absorption, the peak height decreases, its width increases and the peak becomes rounder. To characterize the peak height and width for absorbing media, we found, that Eq. (6), with $K = 1$ can be well approximated by

$$B_C(\beta) \approx \frac{1}{[1 + 1.3\,\xi(\beta)]^2} \tag{9}$$

where the factor 1.3 corrects deviation resulting from neglecting 1st and 2nd order terms of $\xi(\beta)$ in the numerator. Eq. (9) provides an analytical form to link the ratio Λ_T/Λ_A to the peak height

$$B_C(0) = \frac{1}{\left(1 + 1.3\sqrt{3\frac{\Lambda_T}{\Lambda_A}}\right)^2}. \tag{10}$$

A slightly more complicated equation can be obtained for the peak width for finite Λ_A. Hence, when characterizing the full peak shape, or at least its height and width, the parameters Λ_T and Λ_A can be determined.

Most CBOE models are based on scalar waves which do not consider the vector character of electromagnetic waves which describes their polarization. However, experimental and theoretical works show that CBOE occurs predominantly for co-polarized transmitted and received waves (VV and HH) where the model matches well experimental observation. They also show that CBOE for cross-polarized (VH) observations is significantly weaker and decreases with increasing sample thickness (van Albada et al., 1987; Mishchenko, 1992b,c; Wolf and Maret, 1985).

- **4.4 Link to the microstructure of snow**
  In the model outlined in Sect. 2.3 and which assumes an optically thick medium, the two parameters Λ_T and Λ_A, defining the peak shape, can be linked to the snow microstructure and to the density of snow. The transport mean free path $\Lambda_T \geq \Lambda_S$ is a measure of the medium's scattering properties, and corresponds to the scattering mean free path $\Lambda_S = S^{-1}$ for particles that scatter EM radiation symmetrically in the forward and backward direction (Hapke, 2012, Eq. 7.24b and Sect.5.2.7), see also (Van Der Mark et al., 1988, Sect. IV-A). For negligible absorption, Λ_T describes the one-way penetration depth where the incident radiation is reduced to $1/e$ by side-way scattering. While in the context of CBOE modelling, the (volume-averaged) scattering coefficient S is derived from the scattering cross section of individual particles in sparse media (Hapke, 2012, Ch. 5), (Ishimaru, 1978, Ch. 2) and (Van Der Mark et al., 1988), for snow the scattering coefficient needs to be estimated with dense-media radiative transfer theories like DMRT (e.g. (Tsang et al., 2007)) or IBA (Mätzler, 1998) as shown in [Sect. 3.1](Picard et al., 2018) and as already indicated by (Mishchenko, 1992a). The description of the SMRT model (Picard et al., 2018) provides a direct relation between the scattering coefficient S and the phase function and links these to the autocorrelation function of the mediums indicator function that represents the spatial 3D microstructure of the snow/ice matrix (Löwe and Picard, 2015). Still, both theories, DMRT and IBA, are not yet sufficiently parametrized by field-measurable quantities (Picard et al., 2018). An empirical relation to link the microstructure to S is given in (Wiesmann and Mätzler, 1999).

  The absorption mean free path $\Lambda_A = A^{-1}$ is a measure of the medium's absorbing properties given by the volume-averaged absorption coefficient A (Hapke, 2012, Eq. 7.18a). For negligible scattering, Λ_A describes the absorption length where the incident radiation intensity is reduced to $1/e$; For continuous media (without scatterers) A would be equivalent to the absorption coefficient $\alpha = 4\pi/\lambda n_i$ with n_i the imaginary part of the refractive index. For snow, Picard et al. (2018) recommends computation of n_i from the Polder-van Santen formular, e.g. in (Sihvola, 2000; Mätzler, 1998; Wiesmann and Mätzler, 1999); the refractive index of pure ice is given by Warren and Brandt (2008).

  The absorption and Scattering coefficient sum up to the extinction coefficient $E = S + A$ which corresponds in the sparse-media models from Tsang and Ishimaru (1984, 1985) and Van Der Mark et al. (1988, below Eq.(26b)) by $E = 2K''$ to the effective propagation constant K'' that is related to particles absorption and scattering properties described by the scattering amplitude f.

- **4.5 Limitations of the model**
  The CBOE model used in this work can accurately predict the peak shapes observed in various volume-fractions of colloidal suspensions where the particle sizes are within the order of magnitude of the wavelength (Van Der Mark et al., 1988; Akkermans et al., 1988). The parameters of the model, in particular the scattering coefficient $S \propto \Lambda_T^{-1}$ and absorption coefficient $A = \Lambda_A^{-1}$ that determine the shape of the CBOE peak, can, in theory, be estimated from the microstructure and density of the snow pack when considering dense-media scattering theories (Picard et al., 2018), see also (Mishchenko, 1992a) who addresses already a snow-like structure. However, the often complex (multi-layer) snow structure (e.g., Proksch et al. (2015)) together with current limitations in accurately predicting the scattering coefficients from the snow microstructure (Vargel et al., 2020) might prevent a precise estimate of the peak shape even though a rough estimate of the peak width is feasible. An additional limitation for a accurate estimation of Λ_A, possibly also Λ_T, results from the assumption that the scattering medium fills a semi-infinite space whereas the snow pack has a limited optical thickness τ_d. Hence, Λ_A might be underestimated due to limited layer thickness (Van Der Mark et al., 1988; Van Albada et al., 1988).

Our observations of the CBOE peak shape originate from a natural (non-homogeneous) snow cover and currently no laboratory experiments of the CBOE at microwave frequencies, including a precise characterization of the microstructure, are available. Such experiments could validate the used model and might indicate whether adaption of the model or introduction of additional correction factors could be required in order to precisely link the microstructure to the CBOE peak shape. Nevertheless, we clearly observed the CBOE peak in natural snow, which can lead to development of new methods for snow and ice monitoring.

We also propose the following changes to further address this reviewer comment:

- Based on the model limitations, we like to adjust the sentence in line 494 to: "When prior estimates (...) are available, (...) to roughly estimate (...) where the CBOE might affect the measurements (see also Sect. 4.4)."
- To provide a more extensive historical context, we also propose to add (Tsang and Ishimaru, 1984) into the reference list at line 32.
- We propose to add sentences pointing out the good match between our observations and observations by Wiesmann et al. (1998) into appropriate places in sections 4.2.1 and 4.2.2

References

Akkermans, E. and Montambaux, G.: Mesoscopic physics of photons, J. Opt. Soc. Am. B, 21, 101–112, https://doi.org/10.1364/JOSAB.21.000101, 2004.

Akkermans, E., Wolf, P. E., and Maynard, R.: Coherent backscattering of light by disordered media: Analysis of the peak line shape, Physical review letters, 56, 1471, https://doi.org/10.1103/PhysRevLett.56.1471, 1986.

Akkermans, E., Wolf, P., Maynard, R., and Maret, G.: Theoretical study of the coherent backscattering of light by disordered media, Journal de Physique, 49, 77–98, https://doi.org/10.1051/jphys:0198800490107700, 1988.

Hapke, B.: Theory of Reflectance and Emittance Spectroscopy, Cambridge University Press, 2 edn., https://doi.org/10.1017/CBO9781139025683, 2012.

Ishimaru, A.: Wave propagation and scattering in random media, vol. 1-2, Academic press New York, 1978.

Löwe, H. and Picard, G.: Microwave scattering coefficient of snow in MEMLS and DMRT-ML revisited: the relevance of sticky hard spheres and tomography-based estimates of stickiness, The Cryosphere, 9, 2101–2117, https://doi.org/10.5194/tc-9-2101-2015, 2015.

Mishchenko, M.: The angular width of the coherent back-scatter opposition effect: an application to icy outer planet satellites, Astrophysics and space science, 194, 327–333, 1992a.

Mishchenko, M. I.: Polarization characteristics of the coherent backscatter opposition effect, Earth, Moon and Planets, 58, 127–144, https://doi.org/10.1007/BF00054650, 1992b.

Mishchenko, M. I.: Enhanced backscattering of polarized light from discrete random media: calculations in exactly the backscattering direction, J. Opt. Soc. Am. A, 9, 978–982, https://doi.org/10.1364/JOSAA.9.000978, 1992c.

Mätzler, C.: Improved Born approximation for scattering of radiation in a granular medium, J. Appl. Phys., 83, 6111–6117, https://doi.org/http://dx.doi.org/10.1063/1.367496, 1998.

Picard, G., Sandells, M., and Löwe, H.: SMRT: an active–passive microwave radiative transfer model for snow with multiple microstructure and scattering formulations (v1.0), Geoscientific Model Development, 11, 2763–2788, https://doi.org/10.5194/gmd-11-2763-2018, 2018.

Proksch, M., Löwe, H., and Schneebeli, M.: Density, specific surface area, and correlation length of snow measured by high-resolution penetrometry, Journal of Geophysical Research: Earth Surface, 120, 346–362, https://doi.org/https://doi.org/10.1002/2014JF003266, 2015.

Sihvola, A.: Mixing rules with complex dielectric coefficients, Subsurface Sensing Technologies and Applications, 1, 393–415, https://doi.org/10.1023/A:1026511515005, 2000.

Tsang, L. and Ishimaru, A.: Backscattering enhancement of random discrete scatterers, Journal of the Optical Society of America A, 1, 836, https://doi.org/10.1364/josaa.1.000836, 1984.

Tsang, L. and Ishimaru, A.: Theory of backscattering enhancement of random discrete isotropic scatterers based on the summation of all ladder and cyclical terms, Journal of the Optical Society of America A, 2, 1331, https://doi.org/10.1364/JOSAA.2.001331, 1985.

Tsang, L., Pan, J., Liang, D., Li, Z., Cline, D. W., and Tan, Y.: Modeling Active Microwave Remote Sensing of Snow Using Dense Media Radiative Transfer (DMRT) Theory With Multiple-Scattering Effects, IEEE Trans. Geosci. Remote Sens., 45, 990–1004, https://doi.org/10.1109/TGRS.2006.888854, 2007.

van Albada, M. P., van der Mark, M. B., and Lagendijk, A.: Observation of weak localization of light in a finite slab: Anisotropy effects and light path classification, Phys. Rev. Lett., 58, 361–364, https://doi.org/10.1103/PhysRevLett.58.361, 1987.

Van Albada, M. P., Van Der Mark, M. B., and Lagendijk, A.: Polarisation effects in weak localisation of light, Journal of Physics D: Applied Physics, 21, S28–S31, https://doi.org/10.1088/0022-3727/21/10S/009, 1988.

Van Der Mark, M. B., van Albada, M. P., and Lagendijk, A.: Light scattering in strongly scattering media: multiple scattering and weak localization, Physical Review B, 37, 3575, https://doi.org/10.1103/PhysRevB.37.3575, 1988.

Vargel, C., Royer, A., St-Jean-Rondeau, O., Picard, G., Roy, A., Sasseville, V., and Langlois, A.: Arctic and subarctic snow microstructure analysis for microwave brightness temperature simulations, Remote Sensing of Environment, 242, 111 754, https://doi.org/https://doi.org/10.1016/j.rse.2020.111754, 2020.

Warren, S. G. and Brandt, R. E.: Optical constants of ice from the ultraviolet to the microwave: A revised compilation, Journal of Geophysical Research: Atmospheres, 113, 1–10, https://doi.org/10.1029/2007JD009744, 2008.

Wiesmann, A. and Mätzler, C.: Microwave Emission Model of Layered Snowpacks, Remote Sens. Environ., 70, 307–316, https://doi.org/http://dx.doi.org/10.1016/S0034-4257(99)00046-2, 1999.

Wiesmann, A., Mätzler, C., and Weise, T.: Radiometric and structural measurements of snow samples, Radio Sci., 33, 273–289, https://doi.org/10.1029/97RS02746, 1998.

Wolf, P., Maret, G., Akkermans, E., and Maynard, R.: Optical coherent backscattering by random media : an experimental study, Journal de Physique, 49, 63–75, https://doi.org/10.1051/jphys:0198800490106300, 1988.

Wolf, P. E. and Maret, G.: Weak localization and coherent backscattering of photons in disordered media, Physical Review Letters, 55, 2696–2699, https://doi.org/10.1103/PhysRevLett.55.2696, 1985.