Answers to the Reviews of A Brisbourne and the Anonymous Referee #2
Seismic wave propagation in anisotropic ice: Part I. Elasticity tensor and derived quantities from ice-core properties

First, we thank both reviewers for their thoughtful comments, which helped us to clarify the manuscript in various aspects. A point-by-point account for the main issues follows below.

General points:

For both reviewers one of the major points was to clarify the different terminologies (glaciology, seismics) and the connection between the different quantities describing the anisotropic fabric.
- Instead of Figure 1 showing the enveloping of the c-axis distributions we included Table 1 (see end of this text). This Table shows the enveloping of the c-axis distribution, also including that of isotropic and VSM-fabric. Further, it includes the glaciological term and the corresponding seismic symmetry class, the eigenvalue range and derived opening angel range, as well as the stress regime in which these fabrics are most common. We think that this representation has clear advantages compared to the former Figure 1, to help the reader understand these interrelations and analogies.

Specific comments:

A Brisbourne
P4355-L3 onwards:
There are a number of issues with this paragraph which need clarification. Why three out of eight fabrics selected? Cone and cluster name interchanged but not clarified as the same. How do these fabrics relate to the stress regimes found in ice divides? Section 2.1 is written in the language of a glaciologist so needs context for the seismologists without this background.
- We included information on the common stress regimes in the first paragraph of Section 2. We use the fabrics that are mostly present in these stress regimes to explain why we choose exactly these three fabric types for our analysis. Further, we note that we will use the term cone fabric instead of cluster fabric, as it is the more common one in glaciology.

P4357-L1 onwards:
This paragraph is for me where the style of writing transforms from that of a glaciologist writing about anisotropy to that of a solid Earth /exploration seismologist, introducing terms such as LPO and VTI/HTI. It is also the key point where readers without a seismological background can have terms used in seismic anisotropy clarified. This is done in more detail in Section 2.1 but in the language of a glaciologist. A table comparing nomenclature would be helpful, as would further embellishment of Fig. 1.
- We changed Figure 1 to Table 1, including more information on the different fabrics and the relation of the different terminologies. Further, we moved the two paragraphs of Sect. 2, explaining the connection between the fabrics and the opening angels, to Sect. 3, paragraph 2 and 3. Thus, we first explain the concept of seismic anisotropy, VTI and HTI media, and introduce the elasticity tensor. We could then include information on these seismic terms in these two paragraphs as well. Table 1 should help here to understand the relation of common fabrics in the two scientific communities.

P4390 - Fig. 1:
This diagram could be enhanced with additional information such as VTI/HTI labels, eigenvalue range labels. Otherwise, put this in a table for reference. Maybe present the isotropic and extreme VTI cases? Is the geophone line label necessary or just confusing? As stated above, this diagram could be the bridge between readers with different backgrounds. It is also useful to get the concept of the envelope across, probably done most clearly by demonstrating how isotropic and VSM.

- We changed the representation of the different fabrics into a table (see end of this text). The geophone line was removed. The VSM and isotropic case were included in the Table as extreme cases of the cone fabric.

P4364 Limitations:
One of the major limitations of this method is the classification of eigenvalue distributions into discrete fabric categories. This has the potential to introduce discontinuities (as per Part 2). This is of course valid but inherent in the methodology applied here. This is discussed in the final paragraph of the conclusions but should be mentioned here as it becomes clear in Part 2 that this is critical.
- We included a paragraph explaining the problems that are introduce due to the classification into the different fabric groups. This paragraph deals also with the suggestion of Referee #2 to use the ODF to calculate the elasticity tensor.

<u>Referee #2</u>
Sec. 1. Improving the readability of the abstract and introduction would also aid accessibility. All the information is there but typographic errors and ambiguous statements sometimes detract from the content. Some detail on laboratory-based studies, which provide the most information on the anisotropic flow properties and seismic properties could be included here.
- We followed the detailed suggestions of A. Brisbourne to improve the abstract and introduction and included some changes in the structure of the sentences to improve readability.

Sec. 3. From my understanding, crystallography typically uses the Orientation Distribution Function (ODF) to quantify the CFO distribution. (The ODF can be calculated from a pole figure.) I believe the ODF can then be used to calculate the elasticity tensor. Would this simplify the process and eliminate the need for the threshold classification? If not, then it would be useful if the authors detailed the advantages and disadvantages of their methodology over one that employs ODFs such as that presented by Mainprice et al., 2014 (Geological Society, London, Special Publications, August 1, 2014; doi 10.1144/SP409.8) and available for determining elasticity tensors through the MTEX package.
- Using the ODF to calculate the elasticity tensor is also a possibility. Within the MTEX package, this calculation is as well based on the concept of Voigt-Reuss bounds. So the averaging technique is based on the same theory. However, the information available are much larger than those given by the eigenvalues. The representation of the anisotropic ice fabric, based on eigenvalues, is a very compressed form, and a lot of information about the crystal orientation gets lost. Hence, using the information of the orientation of the single crystals and calculating the ODF has the advantage of including more information into the calculation of the elasticity tensor. However, in glaciology the standard representation of crystal anisotropy is still in the form of eigenvalues. With the framework presented here it is still possible to calculate the elasticity tensor based on these information. Nevertheless, we hope that the theory can be extended to a more general form in the future, along with more general descriptions of fabric in glaciology.

<u>Line Specific Comments:</u>

<u>A. Brisbourne</u>
- Most of the comments in the tech document were included. A lot of these comments were on grammar or spelling issues. These were included in the text. We don't list all the comments that were included in the text, only the major ones or where we have a different opinion.

P 4350, L16: *Awkward sentence*

- We changed this sentence to: Hence, it is possible to remotely determine the bulk ice anisotropy.

P 4351, L16: *Awkward sentence*
- We changed the sentence to: At ice divides features like double bumps and synclines are observed (Drews et al., 2013), next to single bumps.

P 4352, L28: *Awkward sentence*
- We changed the sentence to: Further, the anisotropic fabric has an influence on the wave propagation of seismic waves. Hence, by analysing COF-induced reflections and traveltimes the anisotropic fabric on the macroscale can be determined.

P 4353, L 27: *develop possibilities?*
- Changed to 'develop ways'

P 4356, Paragraph 'The two opening angles ...' + Comment to P 4359, L4:
- We moved this paragraph to Sect. 3 and included information on the symmetry class as used in seismics, as well as on the prevailing stress regime.

P 4360, L 20:
- We changed from Figure 1 in the submitted paper to Table 1, including the information about eigenvalue ranges.

P 4361, L 23: *Structure of sentences*
- We restructured the sentences regarding Voigt and Reuss calculation of the elasticity tensor.

P 4365, L15: *Order of magnitude with and without grin boundary sliding.*
- Elvin et al. (1996) modeled Poisson ratio and Young's modulus with and without grain boundary sliding and derived difference up to 25%. We included this information in the text.

P 4367, L22: *Triplication, mention significant result*
- We included a sentence, that this triplication is not of importance at the moment with the accuracy of the data available at the moment.

P 4368, L5: *Expressing seismic velocity in terms of percentage*
- Normally given in percentage is the difference between the zero-offset velocity and the horizontal velocity. However, this is only a good representation in case of elliptical anisotropy. For the P-wave velocity we have a minima at 51°, so that the percentage for the difference of 0° and 90°-velocity does not represent the actual anisotropy very well. But I included the percentage for the SH-wave and for the P-wave.

P 4370, L 10: *Awkward sentence*
- We changed the sentence to: To calculate the P-wave reflection coefficient for the bed reflector with an overlaying cone fabric, i.e. VTI media, we use the equations given by Thomsen (1993), that were further developed by Rüger (1997).

P 4370, L16: *Modeling reflection coefficients for step changes not transitions*
- We changed the paragraph referring to interfaces between layers instead of transitions.

P 4373, L13: *Rewrite paragraph, We could...*
- We changed the paragraph to: Velocities we derived for different cone fabrics agree well with velocities derived for cone fabric using the already established method of Bennett (1968). However, with our method it is now also possible to calculate velocities for girdle fabrics. Further, we can use the derived elasticity tensors to investigate the reflections coefficients in anisotropic ice.

Figure 4: *Include color bar with percentage of anisotropy.*
- Instead of a color bar with percentage we included contour lines with the velocity differences in percentage.

Figure 4: *Change order of labels*
- The order of the labels is that way, due to the orientation within the coordinate system. This is more significant for Figure 5. However, we would find it strange to label Figure 4 different than Figure 5. That is why we would like to keep the order of the labels the way they are right now.

Complete text: Comma after e.g. and i.e.
- When I looked it up it said that no comma should be put after e.g. and i.e. for British English. We would leave this to the final typesetting of the manuscript.

Referee #2
Throughout manuscript the reference to Bennett 1988 should instead be 1968.
- Sorry, that got mixed up in the typesetting process, we changed it back to Bennett 1968.

The specification of 'ice-core properties' in the title is perhaps unnecessary as the observables required are the crystal orientations regardless of the sample origin and no analysis of ice core properties is undertaken.
- We would like to keep the title as it is. Together with Part II the goal of the companion papers is to use the ice-core properties for the derivation of the seismic properties.

A couple of repeated statements could be removed (Sec.3 L17 & Sec. 3.3 L20. Sec 4.4 L19 & Sec 4.5 L25)
- We changed this.

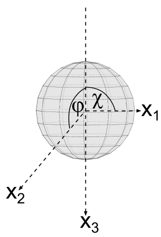
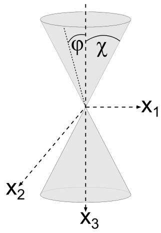
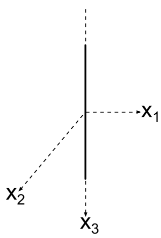
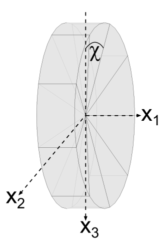
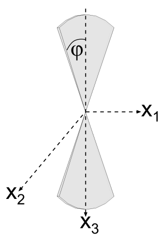
Figure 1. The geophone line is redundant, increase line weights.
- Figure 1 was changed to Table 1, the geophone Line was removed (see below).

Figure 2. Fully words in legend
- We changed the wording in the legend to isotropic and anisotropic.

Fig 3. Last sentence in caption not needed.
- We removed the last sentence, but added the information, that the triplication is between 43° and 46° to the sentence before that.

Fig 4 & 5. Add some contour to help see differences between subplots.
- We included contour lines for Figure 4 and witness lines in 30° steps for Figure 5.

Table 1. The different ice crystal distributions as used for the calculation of seismic velocities and reflection coefficients. Given are the sketches for the enveloping of the c-axis distribution, the glaciological terms, the common stress regime and the corresponding eigenvalue range. In the second part the seismic term for the anisotropic regime is given together with the opening angles derived from the COF eigenvalues to calculate the elasticity tensor.

fabrics	**glaciological context**			**seismic context**	
envelope	term	stress regime	eigenvalues	term	opening angle
	isotropic	uniform	$\lambda_1 = \lambda_2 =$ $\lambda_3 = 1/3$	isotropic	$\varphi = \chi = 90°$
	cone (cluster in Mineralogy)	simple shear	$\lambda_1 = \lambda_2$ $\lambda_3 \geq \lambda_1, \lambda_2$	vertical transversely isotropic (VTI)	$\varphi = \chi$ $0° \leq \varphi \leq 90°$
	vertical single maximum (VSM)	simple shear	$\lambda_1 = \lambda_2 = 0$ $\lambda_3 = 1$	vertical transversely isotropic (VTI)	$\varphi = \chi = 0°$
	thick girdle	uniaxial compression, extension	$\lambda_2 = \lambda_3$ $\lambda_1 = 1 - 2\lambda_2$	horizontal transversely isotropic (HTI)	$\varphi = 90°$ $0° \leq \chi \leq 90°$
	partial girdle	axial compression, extension	$\lambda_1 = 0$ $0 \leq \lambda_2 \leq 0.5$ $\lambda_3 = 1 - \lambda_2$	orthorhombic	$\chi = 0°$ $0° \leq \varphi \leq 90°$