

DERIVING SEISMIC VELOCITIES ON THE MICRO-SCALE FROM C-AXIS ORIENTATIONS IN ICE CORES. KERCH ET AL.

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Kerch et al make a useful contribution to the literature with this study of crystal orientation fabric distributions and their resulting seismic velocities. The manuscript mainly focuses on presenting a framework by which c-axis observations can be converted to representative elastic properties, which are then used to estimate seismic phase velocities. The manuscript also spends considerable time comparing the new technique, which requires detailed knowledge of the c-axis distribution, to an already established framework that uses the more readily available eigenvalue representation of the c-axis distribution. The paper is well considered and includes findings that are useful to researchers working at both the micro and macro scales. Some clarification of the text is needed. Most of my comments below are intended to improve the presentation of the study and highlight some of the implicit and explicit findings.

To improve accessibility a flowchart type figure showing both the *ev* and *cx* framework would be a useful addition. The topic is necessarily dense, and the distinctions, while clear in the text, would be more instantly apparent in a figure. This would make it clear to the casual reader what is required as inputs, and what are the key steps that influence the result. Furthermore, to improve accessibility, Figure 1 could be thoroughly described in the introduction. This description could include details on the seismic acquisition reference plane currently described in section 3.2. Doing this would link the scales considered in the introduction.

The abstract needs some work. Mainly, it should include the key findings of the study. At present it details what will be presented but does not provide summary information of the main findings regarding the impact of azimuth, the degree of shear wave splitting, etc. Quantifying key findings in the abstract would be appropriate.

Minor Changes

Title

The title could benefit from rewording. One of the aims of this work is bridging the gap between the micro and macro scales in various ways. Your results inform both the micro scale and, through RMS velocities, the macro scale. To reflect this and to increase the audience consider something like: “Deriving micro to macro-scale seismic velocities from ice core c-axis orientations”

Introduction

P1 L1–2. To avoid hyperbole, I would also change the ‘greatest’ to ‘great’ and the ‘urgently needed’ to ‘needed’. This first sentence also suffers from two objects, consider changing to ‘One of the great challenges in glaciology is presented by the lack of an efficient method for estimating the bulk...’ or similar.

P1. L3. ‘in a glacier’ to ‘in ice’.

P1. L3. ‘We revisit..’ to ‘We establish a new method of estimating seismic velocities from c-axis distributions and compare it to an already established method that uses fabric eigenvalues.’

P1. L6 ‘Alpine’ to ‘alpine’ (here and elsewhere).

P1. L8 ‘seismic velocity as a function of horizontal azimuth’ How much variation?

P1. L9 ‘strong azimuth-dependent shear wave splitting’ How much?

P1. L10 How much change observed over what scale?

Introduction

P1 L15–16. ‘...of the ice...’ to ‘of ice dynamics, in which internal deformation...’

P1 L16 ‘...evident and described on the macro-scale..’ Elaborating on this point would be useful.

P2 L7–9 ‘...obtain information...’ to ‘...obtain spatially distributed information on the COF structure at various depths in the ice column, the acquisition of which would be unfeasible using direct sampling via ice-coring.’

P2 L14 ‘...commonly used...’ to ‘...commonly reported...’

P2 L16 ‘(ev framework)’ to ‘. (We refer to the method of Diez and Eisen (2015) as the *ev* framework.)’

P2 L17. Define EDML and EPICA on first usage.

P2 L17 ‘The main objective....’ to ‘Our main objective is to present an improved method for the estimation of the bulk elasticity tensor, and to use this to evaluate the use of the *ev* framework.’

P2 L21 ‘on the submetre’ to ‘at the submetre’

P2 L22 ‘effect’ to ‘affect’

P2 L22 ‘asymmetrical fabric distributions...’ on what... seismic velocity.

P2 L26 ‘KCC’ define on first usage.

Methodology

P2 L26 ‘Alpine’

P2 L26 ‘...European...’ should be defined on first usage.

P2 L26 ‘until 2006’ provide actual years.

P2 L29–30 ‘..in about 100 m distance to’ ‘100 m from the ice core KCI’ (define KCI).

P2 L31 ‘bed rock’ ‘bedrock’.

P2 L32 ‘minimum’ ‘a minimum of’.

P3 L1 ‘by means of’ ‘using’

P3 L11 ‘done with’ ‘performed with’.

P3 L12 ‘and covers’ ‘covering’.

P3 L26 ‘are not subject’ ‘Here we focus on phase velocities and group velocities are not considered.’

P4 L3 ‘In case’ ‘In the case’ This sentence should state how and by whom. Currently the sentence implies that this study did this, but I don’t think this is intended.

P4 L14 “effective medium” to ‘the “effective medium”’

P5 L2 ‘...is often used’ ‘...is often used (cite), and we use this approach here.’

P5 L2 ‘They provide’ Ambiguous ‘Voigt-Reuss bounds provide...’.

P5 L12 ‘with the density’ ‘where ρ denotes density, U denotes...’

P5 L28 ‘will generally not be applied’ I don’t think a temperature correction is ever applied here ‘is not applied.’

P6 L10 ‘a monocrystal’ ‘the monocrystals’.

P6 L21, L25 ‘By restraining’ ‘By assuming’.

P6 ‘In fabric...’ wording makes this unclear, I think you mean ‘Fabric data from ice cores indicates that transitions between fabric classes usually occur gradually, and sudden change are only expected to occur due to changes in impurity content or deformation regime’.

P7 L11 ‘number N_g of grains’ ‘number of grains (N_g)’.

p7 L11 ‘hundred to a thousand’ is this accurate for the lowest parts of the cores.

p8 L1 ‘For the aim of con...’ ‘To determine the...’

p8 ‘Sm, i.e....’ clarify with a new sentence ‘To accomplish this, the mono...’.

P8 L4 ‘to C_p^R ...’ ‘inverted to provide C_p^R , where R denotes Reuss’.

P8 L17 “by -1.5 to 0.5%” clarify what this range refers to. It’s velocity differences, but state which framework is faster and what the range represents.

From ice core fabric to seismic velocities – case studies

P8 L22 ‘complemented by additional’ ‘complemented by XX additional...’.

P8 L22 ‘threshold values’ ‘threshold eigenvalues’.

p8 L27 ‘in all samples’ ‘in all KCC samples’.

p8 L27–28 ‘...girdle can be made out...’ ‘...girdle is observed...’

p8 L29 ‘with the cx .’ ‘from the cx ’.

p9 L4 ‘We assess’ ‘We now assess...’

p9 L5 ‘i.e. $\psi = 0^\circ$ ’ ‘(Figure 1; $\psi = 0^\circ$)’

p9 L5 ‘with focus’ ‘with a focus’

p9 L5 ‘effect of fabric classification’ ‘affect of the cx framework fabric classification’

p9 L8 ‘for the assessment’ ‘in our assessment of...’

p9 L11 ‘apparent from’ ‘apparent when’

p10 L7 ‘velocity is due to’ ‘velocity below 1785 m is due to’

p10 L8 ‘is clearly enhanced by this.’ ‘is an example of this.’ Consider indicating this with an annotation on the figure.

p10 L9 ‘is reflected in’ ‘is evident in’

p10 L10 ‘by switching from’ ‘due to a switch from...’

p11 L3 ‘as a result of the compensation..’ ‘as a serendipitous result of the systematic...’ As currently worded it reads like compensation is deliberate. I don’t think this is the case and the results could have easily not converged.

p11 L5 ‘(SWS)’ I don’t think the acronym is used and if it is it probably is not necessary.

p11 L7 ‘..shows more recent high resolution measurements...’ ‘shows high resolution measurements completed since Diez (2015)...’

p11 L9–10 ‘project fabric measurements have started to cover...’ ‘...projects have fabric measurements covered continuous intervals, providing...(cite)’ Include example studies.

p11 L13 ‘This is the first time...’ Not really the place for this kind of statement, which is more suited to the introduction or the discussion.

Just to be clear, the COF observations at depth are based on 100’s–1000’s of grains?

P12 L1 ‘The fabric data...’ This sentence is not useful. Perhaps a pers comm reference is what is needed here.

P12 L7 ‘in average’ ‘on average’

p12 L9 ‘, which is due to...maximum that is inclined’ ‘due to... maximum inclined... ’

p12 L15 ‘The S-wave...’ ‘The *cx* framework S-wave’

p12 L15–16 ‘...which is occurring and increasing with depth when applying the *cx* framework and which’ ‘...Which is increasing with depth and amounts to 45...’

P12 L19 ‘The velocities will be changing...’ ‘the velocities will vary depending on the incidence angle...’

P14 L5 ‘phase angle’ replace with ‘incidence angle’ (or change the incidence angles to phase angle).

p15 L1 ‘The slower S-waves...’ Worth pointing out something like ‘Although S-waves are not routinely acquired during seismic imaging in polar environments...’

p15 L3 ‘In case of’ ‘In the case of’

p15 L4 ‘observe a shear-wave...’ ‘observe S-wave...’

p15 L8 ‘but for the’ ‘except for the’

p15 L10 ‘around 10..’ ‘of 10–30...’

p15 L13 ‘No information...’ ‘For the EDML core, no information...’

p15 L15 ‘This needs to be...’ ‘Prior to the application of the *cx* framework any misorientation needs to be corrected...’

p16 L5 ‘We only...’ ‘We therefore only...’

p16 L9 ‘upper part’ Define this depth range.

Discussion

P16 L14. ‘The velocity...’ This stand alone sentence is awkward and not a good way to begin the discussion.

P17 L1–2 ‘By omitting the eigenvalue.... ’ ‘By including all the *c*-axis observations, instead of using eigenvalue representation, we keep...’

P17 L12 ‘as well as the’ ‘and’

P17 L13 'temperature corrections.' 'temperature corrections are required'

P17 L17 'seems to reflect' 'propagates this systematic variability more than the *ev* framework...'

P17 L21 'which is...' 'at a level which is...'

P18 L5 'In case' 'In the case'

P18 L9 'A main advantage... is the dispensation with...' 'An advantage of the...is the lack of a need for...'

P18 L12 'allowing to' 'allowing us to'

P18 L22 'S-wave' 'S-waves'

P18 L26 'To this date' 'To date...' This is an obvious application for borehole televising (optical and/or acoustic.)

P18 L27 'uncertainty for the' 'uncertainty in the'

P19 L19 'non-coherent' 'incoherent'

P19 L15 'over longer horizontal' specify distance scale (e.g. 10s of km)

P19 L18 'as has' 'as have'

P19 L25 'Following the perceptions of the present study...' 'Following the findings of our study...'
It would be worthwhile to include some recommendations for field acquisition seismics. For example S-waves are not routinely acquired, should they be. Are single line orientations sufficient, or single crossings adequate?

P20 L6 'Alpine'

P20 L21 'these short-scale variabilities' 'this short-scale variability'

Figures

Figure 1. Describe source and receiver annotations in caption. In general it would help the reader if this figure was more comprehensively described in the text.

Figure 5. It would make sense if panel a was the same as Figure 3a.

Figure 6. Phase angle and incidence angle are used interchangeably. Better to pick one.

Tables

Caption: 'Reading example (*):' Not sure what this refers to, clarify.

References

P 25 L10. This reference no longer has a clear path to publication. I suggest it is referred to as a pers comm if needed.

In closing, I thank the authors for their interesting study.

Sincerely, Huw Horgan