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The Cryosphere
Discussions

Interactive comment on "Multi-modal sensing drifters as a tool for repeatable glacial hydrology flow path measurements" *by* Andreas Alexander et al.

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First of all we would like to thank Samuel Doyle for reviewing our manuscript and provide helpful and constructive feedback, which will help to improve the paper. In the following we present our responses to the referee comments and how we will address these in the revision of the manuscript.

The referee comments are presented in ***bold and italic***, our replies follow immediately thereafter.

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Overall comments:

Alexander et al. present a statistical assessment of the performance of a new sensing system – a Lagrangian drifter – for glacier hydrological experiments. They report results from repeated tests in a supraglacial channel and suggest (though never that directly) that there may be future potential for deploying the drifter within the subglacial environment. The sensor system is novel and this manuscript makes an important contribution to the very limited literature on Lagrangian drifters in glaciology.

We thank the reviewer for his positive judgment.

Although it is verbose, the paper is generally well-written.

We agree, and will shorten the manuscript in the following revision, please see also the response to RC 1.

The figures and tables are clear, though the number of tables and figures within the manuscript could be reduced.

The total number of figures and tables will be reduced by either removing them, or adding them to the supplement. See also the response to RC 1.

Citations are appropriate, however, it is unclear why the introduction focuses (e.g. Table 1) on wireless in situ sensor systems, which are not really relevant, while previously published drifter studies from fluvial and oceanographic studies are not discussed in detail.

The idea was to give a general overview of different available technologies to measure in the **subglacial** environments and then present drifters as additional possibility. We will add additional clarification in the introduction.

Major comments:

1. With the exception of the "Moulin Explorer" and the eTracer, the introduction lacks a section describing what drifters are currently available (or have been used before). I believe that there are citations to drifters used in fluvial and oceanographic studies but no detail or discussion is present of their capabilities or performance. This is odd given the space afforded to wireless in situ sensors within glaciology, much of which isn't really relevant to this study. I would recommend that the introduction of Lagrangian drifters is expanded and that the removal of any strictly unnecessary sections is considered.

There are indeed a wealth of different drifter platforms available for fluvial and oceanographic studies. However, there are very few which are specially designed to withstand harsh physical environments, especially the conditions faced during subglacial deployments. Our focus is on drifters for glaciological studies, and a complete review including river and oceanographic drifter platforms would be a stand-alone contribution. Too maintain the focus and scope of this manuscript, we will shorten the current introduction to make it more clear and concise, and at the same time include additional references to general drifter capabilities in other fields.

2. Given that this paper introduces a new instrument, the methods section lacks a decent description of the drifter electronics or the sensor's physical construction. The drifter's sensors are described but there is no description of the microprocessor used or the method of data storage. No schematic is provided and the method of fabrication is not mentioned.

We will add additional information about the fabrication process, as well as the used microprocessor and the method of data storage. We will additionally also modify the current drifter illustration (see also comment to RC1).

Hence, many questions present themselves such as how is the microprocessor programmed and in what language?

We will add this information.

What is the sensor housing made from and how robust is it? Could it survive deployment in a subglacial channel?

The sensor housing is made of a polycarbonate tube and the endcaps are made from Polyoxymethylene plastic, and can withstand 3000 g of impact. They were originally designed and have been successfully deployed to measure conditions in large-scale hydropower turbines. Successful survival in a subglacial channel was meanwhile proven during new field tests in 2019. The latter tests will be incorporated as part of a future subglacial study using newer, smaller versions of the drifters . However, we will add a comment to our present manuscript to confirm robustness of the drifters from our new field tests.

What water depth can the housing withstand? It would not be easy to replicate the experiment without further information and it is currently difficult to assess the limitations of the existing system.

The pressure sensors are tested in a laboratory barochamber up to 55 m water depth, and the measurement limitation results from the measurement range of the pressure sensor, rather than the housing. We will give a more detailed description of the platform as stated in the answers above.

3. The description of the results is very verbose with many unnecessary explanations of standard statistical techniques and detailed descriptions of what is plotted in the figures. As such, the manuscript could be condensed with no loss of important detail. Please see specific comments below. Condensing the text may also highlight opportunities for minor restructuring (e.g. combining sections).

We will cut down the unnecessary explanations and condense the result section considerably. Additionally several of the figures and the tables will be removed from the main manuscript or moved to the supplement.

Minor comments:

P2L8 – "has also been" rather than "was also"

Will be changed.

P2L9 - delete "the" before "channel"

Will be changed.

P2L21 – given the intention to discuss new methods, SF6 tracing should be mentioned (e.g. Chandler et al. 2013).

Thanks. We will include it.

P2L25 - Andrews et al. (2014) also instrumented moulins and their results I would argue are more than encouraging. There are also a few other studies that are not cited so I suggest you use e.g. before the citations.

We are thankful to the reviewer for making us aware of this study. We will include it in our references and also include "e.g." as suggested.

P2L29 - while this is arguably true, it could also be argued that the majority of data still comes from wired sensors. There have also been recent developments in wired sensors. I'm not sure this needs mentioning and I would recommend focusing the introduction on drifters rather than borehole sensors.

We will still mention the borehole sensors in the introduction but condense it considerably and shift the focus towards drifters.

P2L34 – The sentence beginning "Drifters : : :" needs fragmenting, e.g. with commas. (Other sentences may benefit from this as well).

Will be done.

P3L16 - please state what you mean by "multimodal".

Will be done.

P3L29 – avoid the colloquial phrase 'already coming up'

We will remove it.

F1 caption – change "pressure holes" to "holes for pressure transducers"

Will be done.

P7L3 - define POM

Will be done.

P7L7 - by total pressure do you mean what is normally referred to as gauge pressure, which is the pressure indicated by the gauge and not corrected for e.g. atmospheric pressure variability? What digital communications protocol do these sensors use? What resolution? Accuracy? More detail is required here.

We will add more detail.

P7L9 – 'linear calibration' rather than 'linearly rated'

We will change this.

P7L12 - please explain what is meant by a second order corrective algorithm. Is this a second order polynomial? I realise this is described below but it could be clearer. If I follow right the zeroing is one-off so it's not right to say sub-diurnal variability is calibrated out as any post-zeroing variability in atmospheric pressure would not be corrected for.

We will clarify this.

P8L10 - more discussion of the BNO055 calibration would be worthwhile. My understanding is that this sensor self-calibrates continuously, which I expect has advantages and disadvantages with implications for the data collected. Is changing this sensor one of the future technical improvements you allude to below?

This is a very good question. There are major trade-offs between using the BNO055 and other IMUs which do not have on-chip sensor fusion. The major benefit of the BNO055 is indeed that the absolute orientation is calculated in real-time. The major downside is that the calibration and sensor fusion used in this procedure are “black box” in the sense that Bosch has not released the algorithms used. The next generation of smaller, less expensive drifters will incorporate newer IMUs which have lower energy consumption, as well as allow for absolute orientation in post-processing.

In addition, we will provide references to the accuracy of the BNO055 sensors, which are reported in several peer-reviewed journals, (mostly related to human kinematic studies).

P5L2 - write out month in full

Will be done.

P12L8 – typos: extra “an” and on L13 an extra “in”.

Thanks for pointing this out. Will be changed.

P12L21 - filtered how?

We will add the additional information on the filtering.

P13L14 – This section could be condensed by assuming the reader understands basic statistics and with the use of symbols and terminology. See below.

We will shorten this section.

P13L24 – ‘assess’ should be ‘assesses’, though ‘identifies’ or similar may be a better word here. That said skewness and kurtosis should not need defining, as they are standard statistical techniques.

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We will change the wording and remove the definitions.

P13L25 – the terms 'magnetometer in the y-direction' and 'gyroscope in the y-direction' are somewhat awkward which makes it difficult to read. Perhaps use symbols instead? E.g. My, Gy. Euler angles are often referred to as yaw, pitch and roll and have standard symbols.

Agreed. We will change it accordingly.

P13L26 – "are slightly skewed towards values above the mean" can be written in less words as "are positively skewed".

We will use this short form.

P13L30 – high kurtosis is referred to as 'leptokurtic'. A kurtosis which is nearly Gaussian can be referred to as no kurtosis (or almost no kurtosis). This section can be condensed significantly if these terms are used.

We will use those terms instead to shorten this section. Thanks.

P15L3 – delete 'data set' as its not necessary. The manuscript would be easier to read if unnecessary words were removed.

We will go through the manuscript carefully and remove this and other unnecessary words.

P16L4 – you don't need to explain Pearson's correlation coefficient. Scientific papers would become impractically long if every standard technique was introduced. If a nonstandard technique is used by all means describe it in the meth-

ods (not the results). It's also not necessary to list the classifications of Cohen et al. (1992) in full. Just say that you use their classifications in a single sentence and give the citation. If the reader is interested they can look it up. I would also recommend avoiding the style of describing what the figures show, as you do on L9-10. Instead I would recommend the style of making a statement or argument followed by the figure reference. This paragraph could be condensed to a few sentences without any loss of important detail. As it stands there are seven sentences before a result is described.

We will shorten this and other paragraphs accordingly. Thanks.

P18L5 and P23L3 and other occurrences – Phrases such as "the next plot in Figure 8" and "as shown in Figure 9" can be shortened by just giving the figure reference in brackets.

Will be done.

P23L2 and other occurrences – the first sentence here is methods and should not need repeating here.

We will remove it.

P25L5 – Referring to sample sizes on P14L9 you state that "These high numbers are however not necessarily an indicator of sensor accuracy, but rather an indicator of spatial and temporal flow variability", which obviously casts doubt on whether the calculations of a required sample size are useful at all. However, here you refer to the required sample size calculations again to conclude that such experiments will require "a significant number of deployments". Which of these is your preferred interpretation of your analysis on sample sizes?

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We will clarify the interpretation here as well.

P25L8 – Do you mean ($p > 0.05$) rather than less than?

Yes, it should indeed be $p>0.05$. Thanks for catching this mistake.

P25L8/9 – how will technical improvements to the drifter reduce the number of deployments required? Please be specific. What are the specific issues with the drifter presented here? What needs to be improved?

Technical improvements of the drifters will reduce the signal to noise ratio of the drifters. In addition, the number of deployments can be decreased with improved field deployment and recovery methods. We will briefly address these additional topics in the improved version of our manuscript.

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