First of all, we would like to thank Fabian Walter for his time and constructive, thorough and helpful suggestions, which are each addressed below. Our responses are organized in the following color code:

- the original text of the reviewer (black)
- response to the reviewer comments (blue)
- text removed from the main article (lila)
- text added to the main article (green)

This submission by Eckstaller et al. proposes technical solutions for deploying on-ice seismic broadband stations in Antarctica. The authors present a setup that solves some of the technical problems implied by the rough Antarctic environment and offer an outlook on future developments and additions to their system to tackle other challenges like limited sunlight during the Austral winter.

The manuscript is clearly written and easy to follow. As someone who has installed seismometers in icy conditions throughout his scientific career, I welcome such a communication. Written and publically available documentation on technical details of instrument deployments can be extremely important for future projects and may make the difference between research success and failure. At the same time, I would encourage the authors to make some major modifications on how this material is presented. I detail these points of criticism below.

Fabian Walter.

MAJOR COMMENTS

An easily implemented though to me essential change would be not to mislead the reader in thinking that a technical solution to year-round broadband station deployment has been successfully tested. This is suggested in the title and the last paragraph of the introduction. In the final paragraph of the Discussion, the authors back down from this claim stating that bridging the winter gap was not yet the goal of this technical solution but is left for future efforts. This will likely annoy the reader who truly looks for useful information for his/her future deployment and feels encouraged by the abstract and introduction. At all parts of the manuscript, the reader should be clear on what this study is for. To my mind there is nothing wrong with presenting an intermediate step to an ideal broadband setup, but this has to be communicated from the beginning.

We agree with the reviewer that this is misleading. We changed the title to "**Towards a** self-sufficient mobile broadband seismological recording system for year-round operation in Antarctica"

With respect to the last paragraph of the introduction, we changed our message in a way that we: "**present strategies** to get the system through the sunless polar winter".

My second point of major criticism is that the material tends to be presented as an experience report rather than a systematic evaluation of different options, which I would expect for a scientific paper. It would help to see more numbers, especially on power consumption, that were the basis for the hardware choices. See my specific comments below.

We fully agree with the reviewer. Throughout the text, we have added information on e.g., power drain of the instruments (see new Table 1), estimates on the total power consumption over a year for a single station as well as more numbers with respect to the performance of batteries (in the text and in the new Figure 5).

Concerning our hardware choices, we would like to emphasize that we still use instruments from our older equipment pool for various reasons (e.g., acquisition costs and continuity in data). Our basic goal (as emphasized in our manuscript) is to use a seismometer station that is as energy-efficient as possible. The new components for this (e.g. the more economical Metrozet MBB2 seismometers or the Quanterra data loggers) will be taken over piece by piece into our equipment pool. For many of our permanent stations, however, we also consider it more important to keep the existing instruments to ensure the continuity of the data and save costs by continuing to use existing equipment as long as it works reliably.

Finally, I suggest providing more information on the Antarctic setting: Like I said, I have deployed many instruments on glacial ice myself, however, the majority was on ablation zones, which are ice-free in the summer. This is a very difficult environment, as well, although completely different from the Antarctic setting. For example, if the station is visited infrequently and rarely, which is the final goal of the author's set up, how do you deal with snow accumulation? Do the instruments have to be unburied and moved close to the snow surface regularly? Or is snow accumulation negligible at the locations and over the time scales of interest?

We agree and gladly provide more information on the Antarctic setting of our seismic stations. In the following we respond to the questions of the reviewer:

How do you deal with snow accumulation?
Snow accumulation is present at all our sites that are located on ice and at none of them we are located in an ablation regime. Accumulation on the different sites (permanent and temporary sites) ranges from 15-20 cm per year on the plateau (e.g., at Kohnen station) to almost 3 meters at VNA3 (Sörasen). This factor is the most important one that determines the frequency of station visits (e.g., once a year at Sörasen but less frequently at other sites). If the corresponding time window is not maintained, the stations have to be dug up very deep or, in the worst case, are not found anymore.

Do the instruments have to be unburied and moved close to the snow surface regularly?
Most of our stations (permanent and mobile stations) need to be relocated to the surface and, as stated above, the intervals depend on the local snow accumulation. However, some stations are also located on nunataks, where the equipment is not buried by snow over time and, thus, does not need to be visited to relocate the instruments. Solid fixing of the instruments and stable enclosure for the seismometer is much more important at the rock (nunatak) stations. They provide a better connection to the ground but on the downside, we have more problems with noise. The ratio between snow and nunatak stations is approximately 80/20.

Or is snow accumulation negligible at the locations and over the time scales of interest?
Snow accumulation is a factor that concerns all permanent stations that are not located on nunataks, which is the majority in our station network. In regard of our mobile stations, snow accumulation has

not been a crucial issue as long the deployment times do not exceed several years (depending on the accumulation at the respective site).

We added the following paragraph to Section 2 (AWI's regional seismographic network):
"The permanent and mobile temporary seismological stations of the regional AWI seismographic network are located in different glaciological regimes and thus are affected by different snow accumulation rates. None of our stations is located in an ablation area. Snow accumulation on the plateau (e.g., KOHN at Kohnen station; Figure 1b) ranges between 15-20 cm per year. By contrast, we observe several meters per year of snow accumulation at the coastal stations (e.g., 3 m per year at VNA3). Depending on the local snow accumulation, the components of the seismological stations, as well as the solar panels or masts, must be relocated to the ice surface, otherwise they will be buried by the snow over a longer period. This action is mandatory once a year for VNA3 on Sörasen and every 3-5 years for the stations on the plateau. Some stations (e.g. UPST, SVEA, WEI; Figure 1b) are located on nunataks where we observe neither significant snow accumulation nor ablation."

SPECIFIC COMMENTS

The manuscript has a few typos and grammatical mistakes (in particular the use of past tenses) that should be corrected with a thorough proofread.

"Data" is plural.

Agreed and changed where we used "data" in the singular form.

Line 37: rewrite: "However, there is little on ...".

We agree that there is a mistake in that sentence. We changed it to:
"However, there is only little seismic activity originating from on the Antarctic plate itself due to a low level of tectonic activity (Sykes 1978)."

Line 53: "adequate capacity" should be defined.

We changed it to: "effective capacity".

Line 75: "ice lying over solid rock": as opposed to what? Lying over subglacial till?

Thank you for pointing this out. We are not much more precise:
"The data quality of VNA2 and VNA3 is substantially better than VNA1 data because the latter is stationed on the ice shelf and the former two are stationed on grounded ice."

Figure 2 and associated text: The wind battery box still seems an idea rather than an established solution. This should be made clear from the beginning of the manuscript. What is the difference between an equipment and an electronic box?

The wind battery box is not just an idea, we have implemented this system at several stations (VNA2, VNA3, UPST, SVEA and KOHN). However, the reviewer has a point because we are not clear throughout the text for which stations the battery box is implemented and for which stations it is not. Typically, the wind battery box is only implemented at stations that run for a longer time and not for our short-term mobile stations. This is actually mentioned in Section 4.2.1 and is also written in Figure 2 (below the wind battery box), however, we now added this information also to the figure caption in Figure 2:

“Note that the station design for our mobile stations does not include the wind battery box. The wind battery box is, however, part of our permanent stations (VNA2, VNA3, SVEA, KOHN and UPST; Figure 1b).”

Concerning the question about the difference between the equipment and electronic box, we assume that the reviewer is referring to the legend in Figure 2. The equipment boxes are those where for example the batteries and data loggers are stored (Peli Case; e.g., those in Figure 3d,e). They have a light gray background and a blue border color. The electronic boxes are stored inside the equipment boxes and have a darker gray background color and a black border color (e.g., those in Figure 4a,b).

Table 1: This table would strongly benefit from numbers, especially on power consumption or supply (which is given in the text for some elements). Such a concise presentation would be extremely useful for a reader interested in adopting the author's approach or parts of it.

This is a great idea and we agree that this information was missing. We added the power drain for all instruments now in Table 1.

Lines 103-106: Here some numbers about the power consumption for different configurations would be more helpful than just specifying the authors' favorite choice.

Agreed and numbers added as suggested.

Figure 3A: Is the battery box associated with solar or wind power? Later from the text it is clear that it's the former, but it should also be stated in the figure or its caption.

Agreed. We now write “solar battery box (e)” in panel (a) of Figure 3.

Line 152: As a non-expert I would expect a reference for this statement.

Done. We have added as a standard reference for all our statements about batteries the technical manual for batteries of Lifeline:

https://lifelinebatteries.com/wp-content/uploads/2015/12/6-0101F-Lifeline-Technical-Manual-Final-5-06-19.pdf

---

Section 3.1.3: This paragraph is held rather general and superficial. Many readers would be interested at which temperature range or minimum temperature battery heating is worth it and when it costs more than it provides gains in terms of power supply. Ideally, this information should be given here and backed up with numbers, e.g., from test measurements.

We agree that this would be helpful. However, our battery heating system only use excess energy from the solar panels (therefore it doesn't "cost" anything). Until now, we have made no tests to evaluate how battery heating in winter (with energy from the batteries themselves) would increase the performance of the available capacity. This type of system would be desirable but is not implemented for our battery heating. From our point of view this is clearly stated in the text:
"Therefore we realized the option for battery heating if sufficient power is available."
Hence, unfortunately, we are not able to provide the information requested by the reviewer.

Nonetheless, we added a few more sentences to this section to make clear what we mean. We also added an extra figure (Figure 5) where we display a curve on battery capacity vs. temperature and electrolyte freezing point vs. temperature. The data from these plots were taken from the Lifeline Technical Manual for Batteries.

Line 157: Not sure what is meant by "which can switch 6 amperes of heating current".

We agree with the reviewer that this statement is confusing.

It means that the switch permits a heating current of up to 6A. This implies that we have to make sure with the heating plates that not more than 6A can flow, which corresponds to a maximum heating power of 72 W. Our heating plate set includes 2 times 15 W, which is well below that.

This information has now been added to the corresponding part in the text.

Line 167: What is meant by "switched opposite to each other"?

We mean that they function in a way that power only comes from the battery box with the higher voltage.

We changed the sentence accordingly: "For two connected solar battery boxes the BBat-controller acts as two ideal Schottky diodes which function in a way that power comes only from the battery box with the higher voltage."

Lines 174-175: What is meant by "cascading batteries"?

We mean that the amount of total battery capacity in the system can be extended through additional battery boxes. We modified the text accordingly.

Lines 184-185: This sentence reads more like an instruction manual than a scientific piece of text.

Agreed. We changed the sentence accordingly:

“If using a Quanterra Q330, the cable from the rear sensor connectors needs to be configured appropriately for this recorder.”

Lines 194-195: Is this based on test measurements? Or is there a reference for this statement?

Thank you for pointing this out. We agree that the sentence is not fully clear (and the initial statement was not correct) and we added more information from the technical manual for Lifeline batteries. We added a reference with respect to the usable effective capacity of our AGM batteries (new Figure 5) when fully charged at 25°C, which is ~ 30% at -40°C. The statement that the remaining power after polar winter onset (if solar panels are the only power source) lasts for approximately 14 days for one battery is based on our experience. Therefore, we now state:

“Based on our experience, when considering a usable effective capacity of 30% at -40°C (Figure 5), one 125 Ah AGM battery can provide power for approximately 14 days at polar winter onset (if solar panels are the only power source).”

Source:
Lifeline Technical Manual: For Lifeline Batteries (2019). Concorde Battery Corporation, https://lifelinebatteries.com/wp-content/uploads/2015/12/6-0101F-Lifeline-Technical-Manual-Final-5-06-19.pdf

---

Line 196: delete "additionally"

Done.

Line 201: use of "huge" is awkward.

Agreed. We changed “huge” to “large”.

Lines 210-211: Why can Li batteries not be recharged? Because of low temperatures?

True, in principle, it is possible to use rechargeable lithium batteries but we are also aware that charging lithium batteries at very low temperatures can be complicated. In addition, next to the increased costs, this would make the overall system more complex and larger, which we want to avoid.

Regarding our Li-battery concept, we are talking about additional (fully charged) batteries installed during assembly or maintenance only for the polar night. Whether these are chargeable or not makes no difference and is only a question of cost and sustainability. They are replaced with full batteries at the next maintenance (or, in the case of mobile stations, the station is removed and reassembled at another location after one or two years). If they were left to charge in the field throughout the year, additional charging resources would be needed. Then they would resemble the same system that is already existing: solar cells and rechargeable batteries.

Lines 217: Which remaining energy?

We are referring to the remaining energy (or better excess energy) from the wind generator.
We adapted the sentence accordingly.

Line 218: "easily integrated" sounds a bit fuzzy. The reader is left wondering why then it hasn't been integrated (see following sentences).

Agreed, we removed “easily”.

Lines 224-225: Why is the wind turbine installation so involved?

We highlight the wind generator installation procedure because with respect to the mobile station it consumes a considerable amount of time, which is proportionally large considering the fast deployment of the solar panels, seismometer and connecting the boxes. We added this now to the corresponding sentence.

Line 232: The use of adjectives like "careful" and "proper" weakens this part of the paper. More specifics would help.

We agree and removed “careful” and “proper” from the sentence. However, we believe that more specifics on the solar controller that we decided not to use anymore, would be also confusing for the reader. Hence, the sentence reads now more neutral:

“The SB 3000i offers a variety of features and needs comprehensive programming for the setup.”

Line 241: Quantify "very low temperatures".

Agreed. We added: “-20 to -40°C”.

Line 244: Is "mass" the right word here? Better "ground"?

Agreed. Changed: “mass” to “ground”.

Section 4.3: A general remark: we also had big problems with static charge on Alpine glaciers. In the end we found it beneficial to make sure all station elements (sensor, digitizer, metal frames, ...) were connected and at the same potential. This solved most problems although no ground was available on the ice.

Thank you for the remark. With regard to connecting all instruments at the same potential (minus), we had initially the problem that this was not possible with the BlueSky solar controller because it messed up the charge controller. This problem does not exist with the Morningstar controller and we have been doing it this way since. We also experienced that the system failure after connecting all elements to the same potential was less frequent, however, the discharge problem remained in general.

Although this is just a general remark from the reviewer, we added the information stated above to the text because we find it to be useful for the reader.

“Additionally, by connecting all instruments and equipment to the same potential (minus), the damage or failure rate of the system due to electrical discharge was reduced. It should be noted that this is not possible with all solar charge controllers (for example, it was not possible with the Blue Sky solar charge controller but possible with the Morningstar solar charge controller).”

Line 253: rewrite "partly very different"

We changed the sentence accordingly:
“The component design and the available resources of various temporary or long-term year-round seismic measurements in Greenland (e.g., Dahl-Jensen et al., 2010) and Antarctica (e.g., Hansen et al., 2015) differ between surveys.”

Line 255: "fast to deploy" with respect to what?

With respect to using the limited time in the field efficiently. We changed the sentence accordingly:

“Our concept of a fast to deploy, compact, modular self-sufficient mobile seismic station aims to use the limited time in the field efficiently and is based on many of the experiences described in the literature, which we discuss in the following.”

Lines 274-278: Here the original goals are redefined. This has to be changed.

We agree and removed the paragraph due to its redundancy.

Line 291: In this sentence the term "polar" or "on-ice" or something equivalent should appear.

Done. We added “polar regions”.

Lines 294-295: This statement is trivial.

We agree and removed this statement.

Lines 296-298: Perhaps it's worth considering that seismic records have high sampling rates and thus the setup could easily afford power supply for GPS, temperature gauges, and other environmental monitoring logging at lower sampling rates.

We appreciate the idea of the reviewer and modified the sentence accordingly:

“Our system concept is not specifically limited to the application to seismology stations (except for noise suppression) and can also be extended by additional instruments with low power consumption (e.g., to monitor environmental parameters).”

General question: Would it be possible to stream data with this setup or is this more than an incremental step in power consumption?

Yes. At VNA2 and VNA3 data is streamed in real-time over terrestrial data radio to Neumayer Station. However, this is only possible because these two stations are located relatively close to Neumayer Station (< 100 km; Figure 1b) and the transmission path is free of obstacles. In principle, the data transmission over iridium, other satellite systems, or via repeater stations would be possible for our other stations. However, this requires new equipment, additional power, is more expensive, and is thus not planned at the moment.

As this comment is labeled as a “general question” we performed no modifications in the text.

There are two sections 3.1.1. In general, I find this manucript contains many sub and sub-sub sections given its limited length.

We agree and changed the section number accordingly. The comment about too many subsections in the text is justified. However, one can also argue that it is a matter of taste to list more or fewer subsections. If this is not a major issue for the reviewer, we would like to keep the number of subsections. We argue that this provides a better structure in the manuscript and also makes it easier for the reader to find his way through the text.