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Atmospheric Measurement Techniques Discussions

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Interactive comment on "A low-cost mobile multidisciplinary measurement platform for monitoring geophysical parameters" *by* Olivier F. C. den Ouden et al.

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This paper describes the design, calibration results, and initial testing of a small instrument that has the capability to measure multiple variables, with an emphasis on infrasound. Overall, the manuscript was well-written and easy to read, though there are a few typos throughout (some are pointed out below). The subject matter is generally appropriate for the AMT journal and the topic is practical and interesting. Since this work is being presented to an atmospheric-leaning audience, I have a few suggestions in the "General Comments" below which I think should be addressed prior to publication of this work. It seems like some of the measurements are not quite as high quality as one would like (especially the wind sensor, see comments below); however, I appreciate the honest assessment of the measurements by the authors.

We would like to thank the reviewer for its careful, positive, and constructive review of our paper, and have included our responses towards your comments in this response letter. Changes to the manuscript based on the comments have been made and highlighted in a marked-up version of the manuscript. The comments have really helped us to produce a much improved manuscript and we thank you for your diligence and attention to detail.

General Comments:

1. In the title, the words "geophysical parameters" are vague. Since the centerpiece of the instrument package is the infrasound portion, it seems like it would be appropriate to have "infrasound" included in the title. Something like: "A low-cost mobile multidisciplinary measurement platform for monitoring infrasound"

The logger has been designed as a multidisciplinary sensor platform. However, the KNMI mini-MB is not an 'off-the-shelf' MEMS sensor and can not be bought online as described within the paper. Therefore, an extra introduction and explanation have been added to the mini-MB. Reviewer 2 asked for a different name for the device, which has now been changed from 'infrasound-logger' to 'INFRA-EAR' (Infrasound and Environmental Atmospheric data Recorder). The title, therefore, has been modified to: 'The INFRA-EAR: a low-cost mobile multidisciplinary measurement platform for monitoring geophysical parameters.'

2. Since you have submitted this to a journal which emphasizes atmospheric measurements, it seems appropriate to have some discussion about the inlet port used to

obtain the (static) pressure. Though the wind/turbulence in this study is considered “wind-noise” (i.e., p.3, l.80; p.15, l.345-346; p.16, l.363-365), there has been quite a bit of work on static-pressure inlet ports which are not mentioned or considered. Perhaps this is a case where "one’s persons noise, is another persons signal"; however, I think that the so-called noise is primarily due to dynamic-pressure effects on the port where the pressure is sensed. In the atmospheric community this has typically been dealt with by using a port which reduces the effect of dynamic pressure on the sensed static pressure. such as the Nishiyama-Bedard quad-disk. For examples, see work by Nishayama, 1991; Wilczak, 2004; and Zhang 2011. There is also a paper in review by Burns 2021 (which may not yet be available), but has related information. For example, the inlet port would be an important consideration, when the sensor is deployed on a tower. I would appreciate some comment and/or insight into whether the inlet port is considered important (or not) for the infrasound-logger.

Air turbulence can generate dynamic pressure effects or stagnation pressure at the pressure dome [Raspet et al.,2019]. The stagnation pressure increases with altitude, which results in higher wind speeds. Atmospheric measurements at altitude might therefore be influenced by stagnation pressure [e.g., Bowman et al., 2015, Smink et al., 2020, Krishnamoorthy et al., 2020]. The influence of stagnation pressure on pressure measurements is theoretically elucidated by [Raspet and Webster 2008].
The application of a quad-disk might remove the stagnation pressure. Quad-disks are developed to cancel dynamic pressure effects, and helps detect slower static pressure changes or acoustic perturbations. Theoretical analysis of the quad-disk indicates that it should remove sufficient dynamic pressure to be useful for turbulence studies [Wyngaard et al., 1994]. However, recent studies have shown a minimum effect of quad-disks on infrasound recordings [Krishnamoorthy et al., 2020]. The casing of the INFRA-EAR is designed and developed for mobile and rapid deployments at remote places, adding a quad-disk to the design will expand the dimensions of the casing. Moreover, the pressure dome is positioned at the bottom of the casing, not orientated

towards the dominant wind direction, in order to minimise the stagnation pressure on the pressure sensors.
The comparison between the barometric pressure sensor and reference sensor (Figure 5) does not show a lack of resolution within the barometric pressure recording. The infrasound calibration has been done within a shelter, which lowers the possibility of stagnation pressure on the sensor. Atmospheric tower measurements are one of the use cases for the INFRA-EAR. The application of quad-disks as an inlet port for the INFRA-EAR pressure sensors is of interest for measurements around the atmospheric boundary layer and needs further review. This explanation has been added to the manuscript in section 2.2.

3. In the atmospheric flux community, 3D wind is usually measured with sonic anemometers. Some of these have become quite small, e.g., the TriSonica: https://www.apptech.com/products/ultrasonic-anemometers/trisonica-mini/ Was this type of technology ever considered for measuring wind with the infrasound logger? This could eliminate the need to generate heat to measure the wind. Also, to deploy the wind sensor on the infrasound-logger means the entire instrument/enclosure needs to be mounted outside at the location where the wind is measuredâĂŤis that correct? If so, does the box itself present an issue due to distortion of the wind? The ability to displace the wind sensing element away from the infrasound logger box has some practical advantages (and it’s unclear if this is possible with the current setup). To convince me that the wind sensor is actually useful, I think a data comparison between the infrasound logger wind speed and direction with a standard wind sensor (in the real atmosphere, outside of a wind tunnel) should be included in the manuscript.

The sensor-platform as described in the paper is one unit, that is to say all the sensors are physically connected to the PCB. The anemometer, therefore, can not be unmounted from the PCB and be used separately. This indeed means that the entire

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Discussion paper

enclosure needs to be mounted outside. The casing has been designed to provide laminar wind flow around the anemometer, avoiding turbulence around the sensing elements.

Furthermore, the casing and sensor-platform has been designed to be firm and robust, so the sensor can function under harsh environmental conditions.

In total 25 INFRA-EAR loggers have been produced and deployed during a 2020 field campaign at Crozet Island in the Southern Ocean. These loggers have been fitted to Wandering Albatrosses as bio-loggers. As this was foreseen, the loggers had been designed to be able to withstand extreme conditions (e.g., extreme weather, damage by hits/beaks, and diving). A mechanical anemometer, therefore, was discarded as such devices would easily damage underwater. A sonic anemometer requires a relatively high power supply (see remark 4). Instead, it was opted to design an anemometer that is inspired by a 2D hot-wire anemometer, i.e. a passive anemometer. Within the paper we show how the anemometer functions within a controlled calibration area (i.e., a wind tunnel). In the revised manuscript, we have added and modified the analyses of the calibration and have expressed the shortcomings in more detail. The analysis of the anemometer has been expressed at line 416, which shows how to convert thermistor measurements into a numerical temperature gradient. The gradient is used to determine the wind speed and direction. This approach improves the analyses. Furthermore, it enables to add a statistical error analysis to the measurements. Future studies will focus on the analysis of the 2020 field season data and will discuss how the anemometer compares to model data.

The remarks about the anemometer have been considered within the paper at line 416. Future 2D hot-wire anemometers should be considered with a minimum of 8 thermistors, in order to exclude geometric uncertainties (Line 442).

4. The infrasound logger has 64 mb flash memory for data storage (p.5, l.115). What is the typical sample rate used to collect data (based on Fig. 4, looks to be around 100 samples/sec)?....how long can it run unattended without filling up the 64 mb flash

memory? Are there communication capabilities (e.g., WIFI, network port, etc)? How do you get data off of it? Is there any custom software (which language) used to make everything work? Can some of these details be described?

The PCB sensors are controlled by an MSP430 microcontroller, which is integrated on the PCB and is powered by an 1800 mAh lithium battery. The microcontroller runs on self-made software. The microcontroller defines the sample time, sample frequency, and data storage. For Fig.4, a sampling frequency of 100 Hz has been used. The limitation of the platform is not the flash memory but its battery life. The platform, concurrently measuring various geophysical parameters, requires a specific power supply, emptying the battery before running out of memory.
Moreover, no data processing is performed by the microcontroller. The data is stored digitally. The casing functions as protection and as a backing volume for the differential pressure sensor. The battery has therefore been included inside the casing. To extract data from the platform, the platform needs to be connected to a computer. There are (yet) no wireless communication possibilities.
The remarks about the memory and data storage has been taken into account at line 123

Specific Comments:
Was the EGU journal, "Geoscientific Instrumentation, Methods and Data Systems" considered as a publication option?
No, only Atmospheric Measurement Technique has been considered as a publication option.
p.2, l.54, "...short-term and now-casting weather forecasts." include a reference?
Added
p.5, l.108, "...either be done..." fix typo.
Corrected

p.5, l.113, "build-in" should be built-in. "bite" should be either "byte" or "bit"?
Corrected
p.15, l.329, what is a "high-frequency shroud"? Is there a reason you need an acronym (HF?) for it? Is it only on the Hyperion sensor inlet and not the mini-MB inlet?
No need for acronyms, has been removed. Yes the shroud only applies the Hyperion sensor, since this is part of the sensor design.
p.15, l.337-338, why does a bias +/- deviations in dB convert to something that has only +/- deviations in Pa?
Correct. The conversion of the recordings in Pascal to decibels is a logarithmic conversion (i.e., $SPL = 10 * log10(P/(P_{ref}^2))$. The confidence interval in dB indicates the spectra's error, whereas the confidence interval in Pa shows the measurement error of the recordings. It is correct that an error in dB can not be transformed into a negative error in Pa. The sentences are not informative and have been changed.
p.16, l.366, the -5/3 slope is not really "noise", it is related the cascade of turbulent energy (see George, 1984; Zhang, 2011 for details).
Agree, correct.
p.14, l.321, p.15, l.341; I don't quite follow what the 12-bit dynamic range effects on the high-freq spectra are....comparing Fig 4a and 4b, the peaks in the Hyperion spectra for f >10 Hz) are due to the limits of the 14-bit ADC on the mini-MB? If a 24-bit ADC was used with the mini-MB would it fix this issue? What is the cause of the high-freq peaks in the Hyperion spectra? Are these real infrasound phenomena that the mini-MB is missing?
Yes, when a 24bit ADC has been used, the KNMI mini-MB's self-noise level would be lower. Sleeman, et al. 2007 show how the self-noise of an ADC depends on sample frequency and the number of ADC bits. Following this method, the self-noise of the 14-bit ADC of the KNMI mini-MB has been determined. Fig 4a shows the theoretical self-noise level of the ADC (dotted lines indicate 12, 13, and 14 bit ADCs theoretical self-noise levels), the recorded self-noise (solid black lines), and shows that the PDF follows from f>1Hz the theoretical self-noise levels.

We expect that the spectral peaks above 10 Hz correspond to resonances that exist inside the measurement shelter. It is expected that the Hyperion sensor records these pressure fluctuations correctly as the sensor has been calibrated by the vendor. The high-frequency peaks are below the KNMI mini-MB ADC's self-noise levels, and therefore not resolved by the KNMI mini-MB.

p.16, l.348, it was mentioned a few times that (air) temperature is important, but the sensor does not measure this (or humidity). These seem like important atmospheric variables that are missing from the sensor package...

Correct, both temperature and humidity are interesting parameters to add to the sensor platform. The barometers do measure temperature. However, we doubt the accuracy since those sensors are primarily built to measure the barometric pressure. Future platforms should include such sensors.

p.18, l.297, define ANSYS? *

Corrected. ANSYS is a numerical modelling software.

p.18, l.400, The atmosphere is turbulent. It sounds like this is an issue.

The anemometer elements are placed within a couple of millimetres from each other. To make sure the flow passing the anemometer is the atmospheric wind flow, and not changed by the anemometer design or the casing, the casing has been designed to not change the 'initial' wind flow.

p.18, l.417, "..different angles with respect to the air flow." Does this mean the yaw angle was varied? What about the pitch angle?

The calibration measurements have been performed within the horizontal plane. Thus the pitch angle has been zero. This has been added to the text.

p.21, l.480, "..phase (Figure 4." missing closing parenthesis.

Corrected

p.22, l.516, "adjust" should be "adjusted".

Corrected

Fig. 4, the caption states, "dotted lines", but do you mean dashed lines? Also, in panel (a), the horizontal gray dashed lines should be explained.

Corrected. The horizontal dashed line indicates the theoretical sensor self-noise (section 3.1.6)
* Many words in the references need capital letters (needs to be fixed)
Corrected