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Atmospheric Measurement Techniques
Discussions

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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The authors describe a new geophysical sensor package that focuses on infrasound. The unit is remarkably small, lightweight, low power, and ideal for temporary or remote deployments. The authors suggest it could be used in mobile platforms as well - balloons and perhaps oceangoing vessels are implied. The work describes a set of detailed tests on each sensor in the package, as well as theoretical calculations describing the expected response. The authors conclude with a discussion of the strengths and weaknesses of the package compared to other extant solutions. This is good work and worthy of publication after some further background work and

motivation. The technical content appears sound, and the device is well characterized. It joins a bevy of low cost infrasound sensor/logger combinations, such as the Gem (cited, but not specifically mentioned), the Raspberry Boom (not mentioned), and the one discussed in Grangeon Lesage (DOI: 10.1016/j.jvolgeores.2019.106668, not mentioned). Some discussion on how this particular device differs from them is warranted; see comments below.

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.

MAJOR COMMENTS

1. This paper is similar in scope and intent to Anderson et al, 2018: "The Gem infrasound logger and custom-built instrumentation" and Grangeon and Lesage, 2019: "A robust, low-cost and well-calibrated infrasound sensor for volcano monitoring". The present work includes several other sensors, including accelerometers and anemometers, that the above units lack. This should be highlighted. The authors should also read both of the above papers carefully and specifically address how their unit is different. The Raspberry Boom (Raspberry Pi based infrasound monitor) should also be mentioned.

Agree, an extra paragraph is added to the introduction, which highlights earlier work. This has been added around line 78.

2. The use cases of the device are not well defined. The Gem unit and the one Grangeon and Lesage developed were originally meant for volcanoes. Is that (one

of) the use case(s) envisioned here? The connection between ground motion and infrasound sensor interference is important, but will only be a problem when ground shaking is especially strong. That is, for infrasound studies involving local earthquakes or other strong motion sources (see Johnson et al (2020) "Mapping the sources of proximal infrasound" or Bowman, 2019 "Yield and emplacement depth effects on acoustic signals from buried explosions in hard rock".). Maritime environments are mentioned and might make a very good fit, I suggest the authors look up the chapter by Grimmett et al. in the second volume of Infrasound Monitoring for Atmospheric Studies. Balloons are also mentioned – the recent article by Poler and others is cited. The sensor noise level of 0.05 Pa is generally too high for ambient infrasound studies on stratospheric balloons, although focused efforts against loud targets (ground explosions, the microbarom) might be possible. The inclusion of the accelerometer reminds me of the recent paper "An active source seismo-acoustic experiment using tethered balloons to validate instrument concepts and modelling tools for atmospheric seismology", which might suggest a better use case.

The manuscript explains the design, development, and calibration of the INFRA-EAR. Initially, the INFRA-EAR has been designed as a biologger for the monitoring of atmospheric parameters. In total 25 INFRA-EAR loggers are produced and used during the 2020 field campaign at Crozet Island in the Southern Ocean. The loggers are fitted to Wandering Albatrosses as biologgers. The Southern Hemisphere has very little in situ measurements, due to limited shore areas. The use of INFRA-EAR in such areas is ideal.ÂăThe first study of this dataset has been completed and will be submitted soon.
However, thanks to multiple geophysical sensors on the platform, various more applications are possible. The KNMI mini-MB has been designed for infrasonic measurements. Volcanic, earthquake and nuclear monitoring are possible thanks to the mini-MB. Moreover, figure 4 has shown that the mini-MB resolves the microbaroms source peak, which hints that the platform can monitor the infrasonic ambient noise

field.
The accelerometer on the platform allows us to monitor strong distant motions, or nearby motions (e.g., earthquake and volcanic monitoring). Furthermore, monitoring of seismo-acoustic events becomes possible thanks to the combination of both the accelerometer and mini-MB.
This extra information about the use cases has been added around line 575.

3. I am very skeptical about the utility of the anemometer. The tests were performed under constant temperature and humidity conditions, but it seems to me that different ambient temperatures would really affect its performance. While knowing the wind speed is indeed useful for assessing the source of infrasound background noise, it is generally very clear when interference is due to wind or other sources. Finally, I am not clear why the wind direction is relevant.

Infrasound array recordings often show the interference of wind, as evidenced by shape of the pressure spectra, revealing the characteristics of turbulence spectra. Therefore, an anemometer is useful to obtain the wind direction and speed, which relate to the local atmospheric infrasound array/station conditions.
In line with Reviewer 1, future platforms should include as well a temperature/humidity sensor. The anemometer on the platform is inspired by a 2D hot-wire anemometer, a passive anemometer. The anemometer analysis has been improved and explained in line 416, which shows how to convert thermistor measurements into a numerical temperature gradient. The gradient is used to determine wind speed and direction. This approach improves the analyses. Furthermore, it enables us to add a statistical error analysis to the measurements. Future 2D hot-wire anemometers should be considered with a minimum of 8 thermistors to exclude geometric uncertainties (Line 442).

4. My general complaint with this type of paper is that the sensor availability is not described. How can the scientific audience get their hands on one of these devices? Will they be ever available for sale, or perhaps part of an equipment pool? This is very important information for groups that may be weighing the option of developing their own units vs. purchasing those already made by others.Âă This paper describes the design, development, and calibration processes of our multidisciplinary sensor platform. Those aspects are of relevant use for various scientific communities. The paper can either function as a guide for calibration of MEMS sensors, design guideline for future sensor-platforms, or as reference for specific MEMS use.

The INFRA-EAR has been used in a scientific field-campaign as biologger. The KNMI mini-MB has been used to resolve infrasonic sources in the Southern Ocean and will be integrated into the sensor network of the KNMI. Furthermore, whoever is interested in this sensor platform can either produce it themself, follow the paper, or contact Dominique Filippi (co-author) of Sextant Technology Inc. Some of the used components can be bought 'off the shelf', and thus the platform could be easily reproduced. In that sense, this paper is also guideline. This has been emphasised in the acknowledgement.

MINOR COMMENTS:
Âă Line 13: I suggest a less generic name. Infrasound loggers already exist. Something clever and memorable would be nice here.
The sensor-platform's name has been changed from 'infrasound-logger' to 'INFRA-EAR', which is an acronym for Infrasound and Environmental Atmospheric data Recorder.
Lines 59-60: Be specific here – e. g. on buoys in the open ocean (cite Grimmett) and on stratospheric balloons (cite Poler).
Corrected

75: its, not it's
Corrected
76-77: Here is where a paragraph comparing the unit with others such as the Gem, Raspberry Boom, etc., would be very useful
Added
91: Integrating with existing sensor infrastructures is repeated throughout the paper but no examples of how this would be done are given
The sensor platform is embedded with digital MEMS, which generate digital outputs. Therefore the outputs can easily be integrated within existing monitoring software. This has been extra emphasis within the introduction.
94: It is not "novel", there are similar sensor packages already available (e. g. the Gem).
It is correct that similar infrasound packages, barometric pressure sensors, anemometers are available. However, the combination of all on one PCB is novel.
105: How many days can it run on one battery charge?
This depends on how many sensors concurrently switch on, how long each sensor measures, and their sample frequency. For example; every hour 5min recording of all sensors, with each measurement a GPS timestamp and a GPS position every 15min, will last approximately 20 days.
115: mb or gb?
mb. The data is stored in bits.
133: List horizontal and vertical accuracy, and whether it can function above 60,000 ft. This is important if the unit is deployed on a balloon.
The GPS's horizontal accuracy is +- 2.5m; for an altitude varying between 0 and 60000ft, this has been added to the text (Line 150). Above 60,000ft (20km) no information about the sensor has been presented by the datasheet/manufacturer, mainly because of the ITAR limits. If the sensor platform can be used on 60,000 ft we have listed the atmosphere's parameters at surface level and 60,000 ft. and compared these values with the operation ranges of the MEMS sensor on the PCB.

The mean surface pressure for 2020 at the KNMI test field (5 E, 52 N) according to ECMWF ERA5 is 1000 hPa, whereas the absolute pressure at 60,000 ft has been specified as 70 hPa. Corresponding to these altitudes, the mean surface temperature and 60,000 ft temperature are 12 and -50, respectively. The relative humidity depends on temperature and pressure, which is 75% and 5% at the surface and 60,000 ft.
The MEMS on the PCB operate according to the specifications listed in the paper, and datasheet. For altitude measurements at 60,000 ft, all MEMS will act/record at the limits according to the datasheets' behaviour. Before a measurement campaign can be executed at 60,000ft, we recommend obtaining knowledge of the sensor behaviour in these circumstances, done by calibration within climate chambers.
149 A comma missing here?
Corrected
161-166 Particle velocity sensors are pretty rare and probably not worth mentioning, especially since the present unit doesn't use them.
They are indeed very rare. However, differential pressure sensors only provide scalar information about the dynamic pressure field, whereas a particle velocity sensor gives insight in the amplitude and directionality. Such a device could be of interest whenever only one sensor is available (e.g., on a scientific balloon, a biologger). Bringing it up will place it in perspective, therefore we like to keep it within the text.
167-169: But this is not true on balloons, see spectra in Bowman and Albert (2018) "Acoustic Event Location and Background Noise Characterization on a Free Flying Infrasound Sensor Network in the Stratosphere"
The reference of the global noise curves within the text is towards the sensor responses of IMS certificated infrasound sensors, not actual ambient noise recordings. The IMS specifications state that the sensor self-noise should be at least 18 dB below the low noise curves at 1Hz [Brown et al., 2014; Marty, 2019]. This has been added to the text.
188: Isn't this the same sensor, or at least very similar, to the one used by Gems, InfraBSUs, and the Raspberry Boom?
The KNMI mini-MB does not vary extensively from earlier developed differential pres-

sure sensors for infrasound monitoring. However, this is the first miniature differential pressure sensor with an integrated ADC. All the devices listed in the question are analogue MEMS. Moreover, the ability to measure various geophysical parameters concurrently improves the fundamental analyses of infrasound.
This paper has shown how to design and use new sensor techniques to develop miniature sensor-platforms. Integrate various geophysical sensors on one PCB, control the power supply, and divide the measurements in various bursts, which allows concurrently measuring various geophysical parameters on one platform, something the devices within the question cannot do. The PCB is created with the latest technology, including a 3D printed casing.
Furthermore, an extensive analysis regarding the sensors' theoretical responses has been presented, as well as calibration protocols.
282: How were these resistivity values determined? From the manufacturer?
Correct. The citation towards the manufacturer has been added.
373-375: In general wind noise is pretty obvious from the infrasound time series itself, and the added effort of an anemometer may not be strictly necessary in many cases. Also, how will the anemometer work in extreme environments, such as maritime or high altitude applications?
Agree. Those things are interesting to discover and will follow soon after. The anemometers' calibration shows how the anemometer functions and how future measurement should be interpreted (by knowing its behaviour in the controlled area). Having independent measurements of wind is useful for the interpretation of turbulence spectra. Within the INFRA-EAR design as biologger, the anemometer was part of the application requirements. For a different set of design requirements, the anemometer could be omitted.
397: What is ANSYS?
Corrected in the text.
402-406: Can wind speed and direction be accurately determined across the whole range of temperature and humidity conditions the sensor is expected to encounter?

This is a very specific and relatively benign set of conditions for the test!
Correct. Ideally, the calibration conditions are valid for the entire range of temperature and humidity. However, the wind tunnel of the KNMI is not placed inside a climate chamber, so such a calibration test is not possible, and this information has to be obtained during field measurements. Future work will have to address this. Furthermore, future sensor platforms should include a temperature/humidity sensor to measure those atmospheric parameters concurrently. This has been added to the discussion.
431-434: Has the acceleration response of the MEMS microbarometer been investigated? Some MEMS-based infrasound sensors, like the InfraBSU, are remarkably insensitive to acceleration.
Âă No acceleration response has been obtained for the mini-MB. However, the mini-MB is the digital version of the InfraBSU; a similar response is expected.
489: I would not characterize the anemometer as "robust" since I am not convinced it has been sufficiently tested under the variety of environments it may encounter in the field.
Agree, correct
528: A "weather balloon" is a specific term for a continuously ascending latex balloon carrying a radiosonde. If a long duration drifting balloon like the one described by Poler is intended, please use the term "scientific balloon".
Corrected
Figure 4: If the IMS curves are being used for reference, please make that clear and cite Brown et. al (2014)
Corrected
Figure 7: Please also cite the source of these noise models.
Corrected