

## Response to Reviewer 1

We thank the Reviewer for reading and commenting on our manuscript. We provide our replies below each comment, which is shown in italics.

1. *I note that the air-conditioning system at the BOU observatory was not working during calibration. Since the authors are set up near that observatory, are there plans to revisit the BOU observatory and investigate system response over a wider range of temperatures?*

The specific site discussed in this manuscript is no longer operational. As we mention in Section 6 of the manuscript, the magnetometer remained deployed only until September 26, 2024.

Given the temperature stability achieved by means of the insulation measures we took and the fact that we are using the magnetometer as a variometer and not for absolute measurements, we do not anticipate the need for calibrating our magnetometer over a wider range of temperatures. Nevertheless, we will keep monitoring the temperature variations and if need be we will seek ways to calibrate it at the closest available facility.

2. *Are there plans to make the data available to the scientific community in the style of (say) Intermagnet or SuperMag? This is important. Other investigators will make use of the data, and, in the end, the project represented in this manuscript will find indirect support from the wider scientific community.*

Yes, all our data are meant to be publicly shared. We have already uploaded at Zenodo all the raw magnetic field and temperature data collected over the days discussed in the manuscript, and we are happy to share the rest of our data with anyone interested. Currently, due to limited resources, we cannot make all data directly available. By default, we process the data we consider interesting based on a variety of factors. For example, in the case of this manuscript, we considered interesting the data that were representative of the performance of the magnetometer. But we are happy to allocate resources to respond to specific data requests.

## Response to Reviewer 2

We thank the reviewer for the encouraging feedback and the detailed comments that help us improve the manuscript. We provide our responses below each comment, which is shown in italics.

- *Page 5: The discussion of the magnetometer / ADC interface is a bit short, e.g. it is nice to be told the noise floor of the magnetometer, but if it is poorly interfaced to a insufficient ADC, this noise floor is never reached. Please elaborate a bit here. How far is the experimental noise floor from the theoretical noise floor?*

We have added information about the specs of the ADC in the revised manuscript. More precisely, we addressed this comment by doing the following:

## Section 2

We now term NI-9239 the Data Acquisition Module (DAQ) and explain that it contains an ADC rather than being just an ADC.

We provide the following specifications for the DAQ and its ADC:

“The DAQ contains a 24-bit delta-sigma analog-to-digital converter and has an input range of  $\pm 10$  V. The DAQ allows for sampling rates,  $f_s$ , that range from 1.613 to 50 kHz, has an alias-free bandwidth of  $0.453 \times f_s$ , and an input-referred noise of  $70 \mu\text{V}_{\text{rms}}$  or equivalently 700 pT. Assuming that the input-referred noise corresponds to the highest possible sampling rate, the expected noise in our raw measurements, given that we sample at the lowest possible  $f_s$ , is approximately 120 pT. This makes the noise floor of the DAQ the main contributor to the expected noise of our setup.”

To allow the reader to follow the conversion from V to T, we now specify the sensitivity of the magnetometer: “The measurement range of the magnetometer is  $\pm 100 \mu\text{T}$ , its sensitivity is 1 V per  $10 \mu\text{T}$ ,....”

We also provide the noise floor of the PSU: “The PSU has a noise floor of  $< 5\text{pT}/\sqrt{\text{Hz}}$  at 1 Hz.”

## Section 6.1

We revised extensively this section. Now we present also our raw data, and we provide an estimate of the experimental noise level, both for the raw and the low-pass filtered data:

“Figure 9 shows the raw measurements (left column) and the 1-sec low-pass filtered data (right column) obtained during May 9th, 2024, a magnetically quiet day ( $K_p$  index  $< 3$ ). In the panels of the right column, the black solid line corresponds to our magnetic field measurements, while the red dashed line corresponds to the magnetic field data recorded at BOU. The baseline of our 1-sec data has been adjusted to that of BOU (hence the difference in the baseline between our raw and 1-sec data). The X, Y, and Z magnetic field components are shown, in the top, middle and bottom row, respectively. The RMS noise of our raw magnetic field measurements is  $\approx 20$  nT for the X and Y component, and  $\approx 50$  nT for the Z component. These values, which are typical for our raw measurements on any given day, are two orders of magnitude higher than the theoretical noise floor according to the specifications of the magnetometer and the DAQ, presented in section 2. The potential source of this noise is discussed in the Discussion section. Given the experimental noise of our raw measurements, the expected RMS noise of the 1-sec data is approximately 1-2 nT per magnetic field component, which is indeed what we observe. In addition to that, we observe that the Z component of our raw measurements (Figure

9e) exhibits a  $\approx 40$ s long spike with an amplitude of  $\approx 80$  nT. As will be discussed in section 6.4 and in the Discussion section, such spikes occur in our raw measurements usually a few times per week, at irregular intervals.”

This is now Figure 9, along with its revised caption:

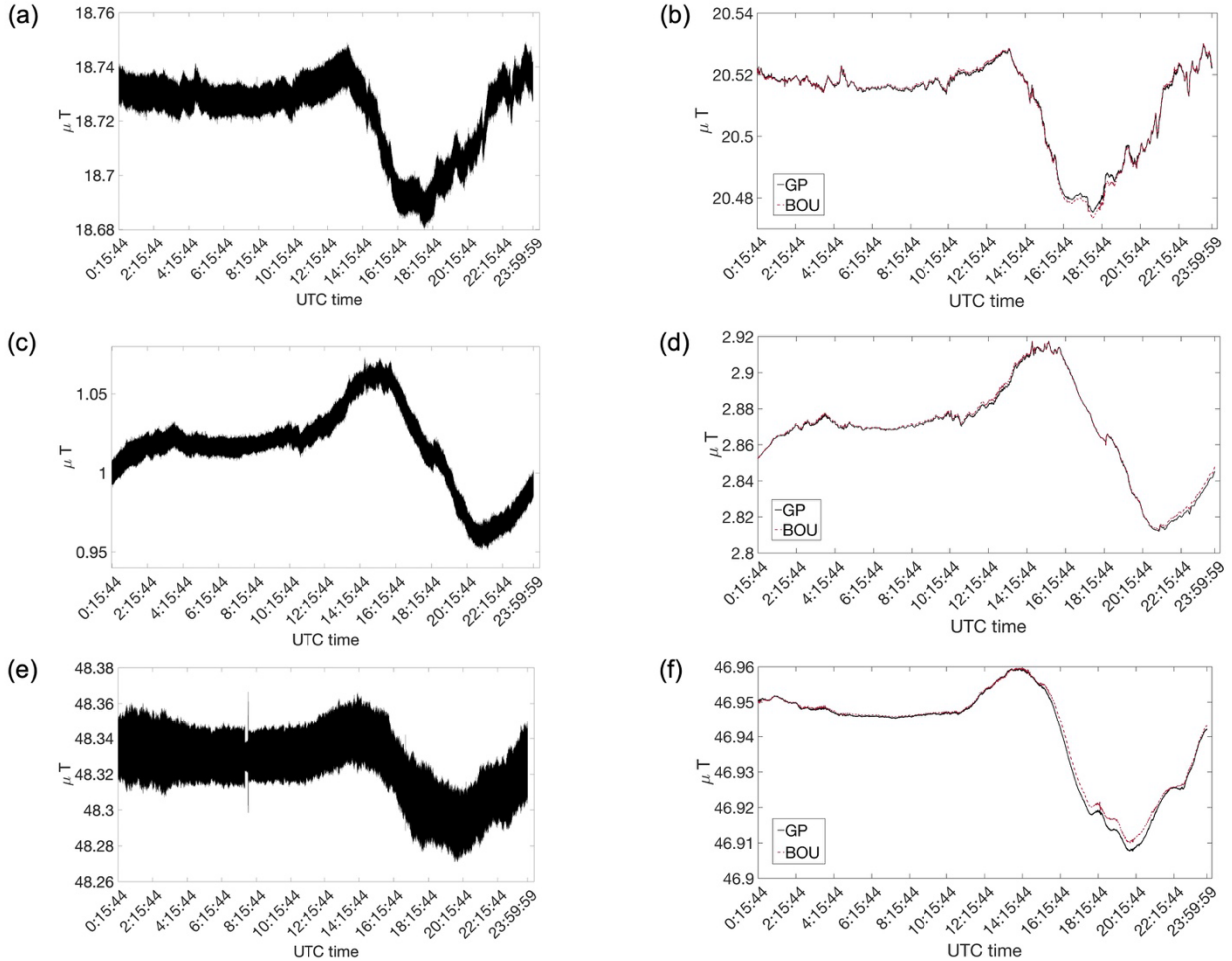


Figure 9 : Vector magnetic field data recorded on May 9, 2024, a magnetically quiet day ( $K_p < 3$ ). Left column: Our raw data. Right column: Our 1-sec magnetic field data (black solid line), after their baseline has been adjusted to the nearest USGS magnetic observatory, which is located in Boulder, Colorado (BOU), and 1-sec magnetic field data recorded at BOU (red dashed line). From top to bottom: The magnetic field components pointing toward geographic North (X), geographic East (E), and Down (Z), respectively.

The potential source of the experimental noise is discussed in the Discussion section, whose first paragraph now starts as follows:

“As noted in section 6.1, the experimental noise in our magnetic field recordings is two orders of magnitude larger than the theoretical noise floor, according to the specs of the magnetometer, the PSU1 and the DAQ. This theoretical noise floor, however, does not

account for the 10 meters cable that we use to connect our magnetometer to the PSU1. Given our experience with the external temperature and humidity sensor (see Appendix A), we consider this to be the most plausible explanation for this discrepancy. Nevertheless, this experimental noise, which for our 1-sec data corresponds to 1-2 nT per magnetic field component, is still largely within our performance requirements. These were laid out in the GP Science Traceability Matrix (Watters et al., 2023), which states that the magnetometer should have a "resolution of order  $\sim$ nT to resolve diurnal geomagnetic field variations". The diurnal variation, ..."

- *Figure 4: The data are sorted by temperature, but it might be beneficial to add a small inset to the figure with the raw data as a time series.*

Thanks to this comment we realized two things: we had plotted the data as a function of increasing temperature, while temperature decreased with time, and moreover that we were calling "raw vector data" the "uncalibrated, 1-sec vector data".

We corrected the term wherever it appears in the text and we added a panel in Figure 4 with the raw uncalibrated data as a function of time. Moreover, we now show the results of the calibration as a function of temperature in its actual order (i.e., descending), so that the two panels show the data in the same order. This is the revised Figure 4:

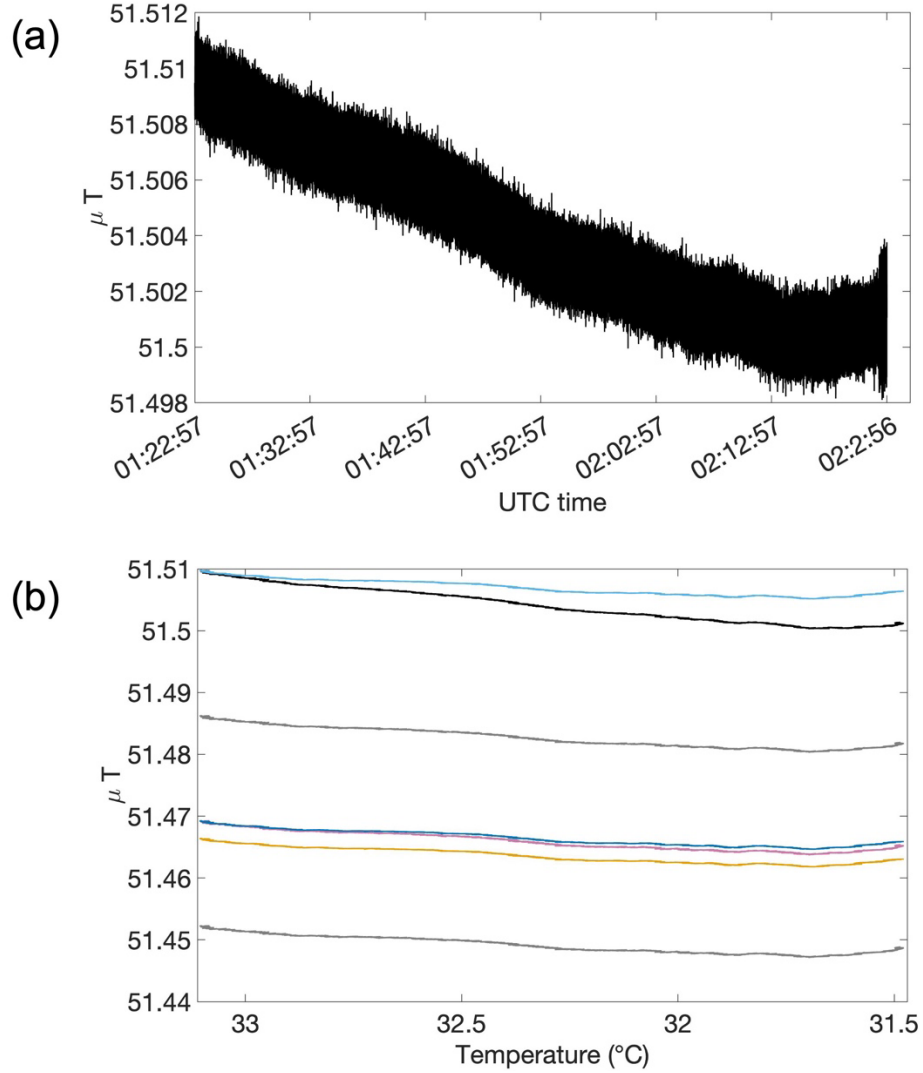
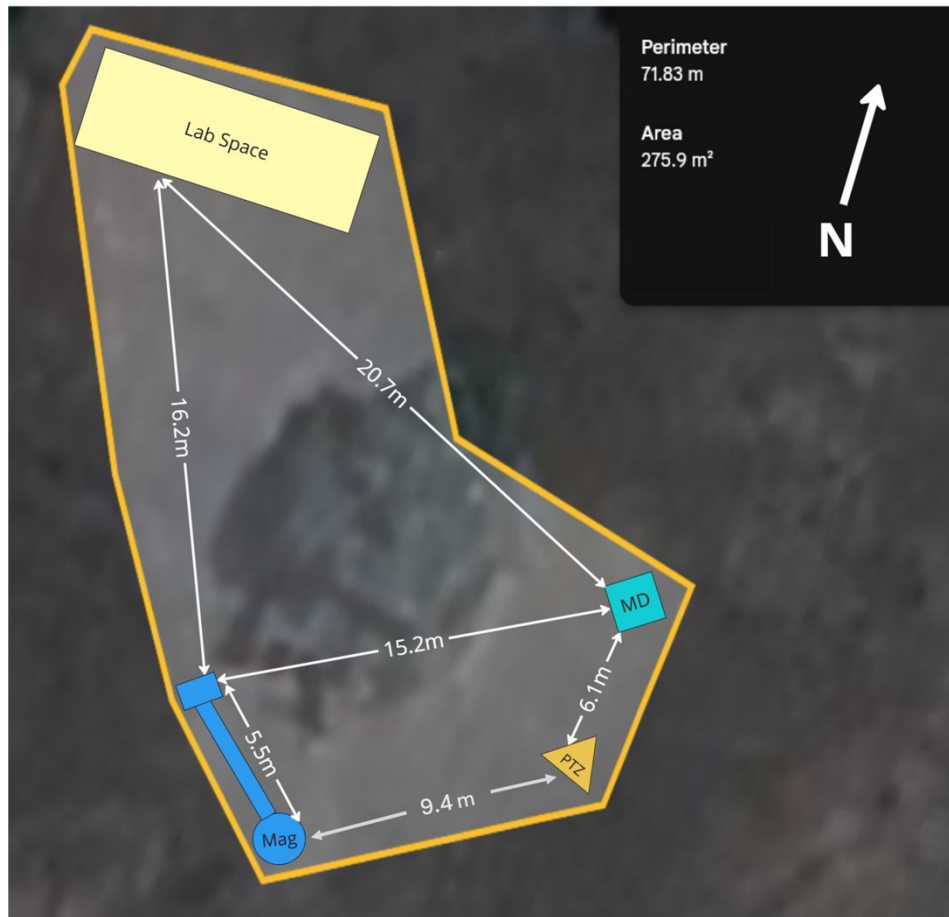


Figure 4: The results of an empirical evaluation of our temperature calibration, during a 1-hour recording under natural temperature variation. (a) The intensity of the raw uncalibrated data, plotted over time. (b) The results of the calibration. Black line: the intensity of the 1-sec uncalibrated vector data. Magenta line: the intensity of the calibrated vector data. Grey lines: the maximum and minimum values of the intensity of the calibrated vector data, accounting for the  $1\text{-}\sigma$  least-squares uncertainties of the calibration coefficients shown in Figure 3. Orange line: the scalar data. Light blue line: the scalar data, with their baseline adjusted to that of the intensity of the uncalibrated vector data. Blue line: the scalar data, with the baseline adjusted to that of the intensity of the calibrated vector data.

- *Figure 5: What is MD? I suggest to also add the distance between the magnetometer and the camera as this is not directly clear from the picture.*

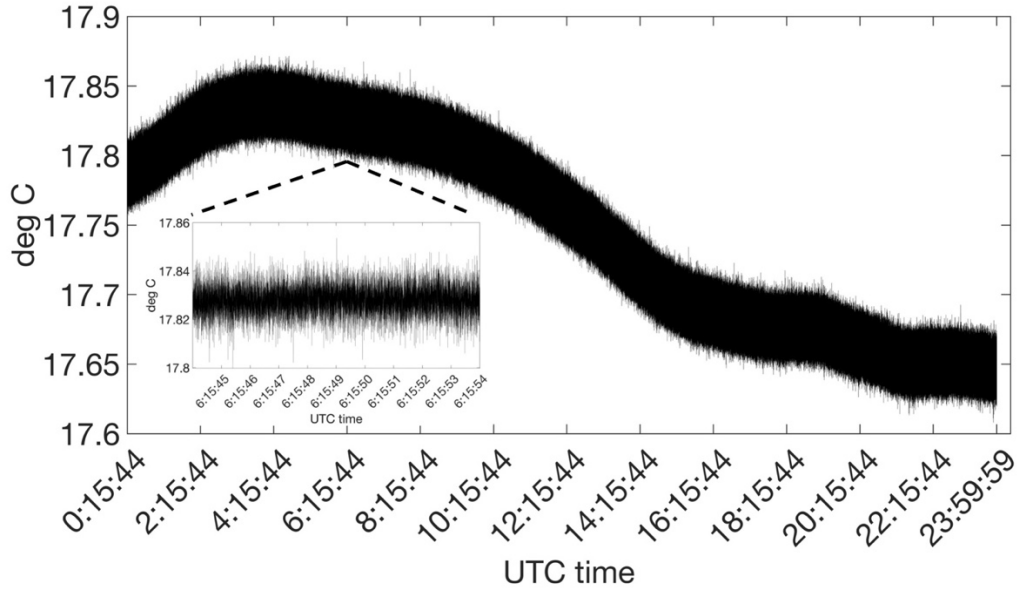
We have included the information about the distance in the figure (9.4 m), and we have included the initials PTZ and MD in the caption. In particular, MD corresponds to the all-sky camera arrays.

This is the revised Figure 5:



- *Figure 10 could be discussed in slightly more detail. Clearly, the instrument is very well insulated as seen by the small overall change in temperature, but the plotted data curve is very “thick”. I suggest adding an inset with a zoom on a few seconds of data to make the data quality and any structure in it more visible. Please also add a comment about the “thickness” of the plot. Is it explained by the electronic properties of the sensor or are external noise sources in play?*

We implemented the suggestion of the reviewer to add to Figure 10 an inset with a 10 sec zoom:



However, we consider that this inset still does not allow to discern any structure in the data. The raw data have been obtained at a sampling rate of 1612.9 Hz, and we need to go down to a resolution of a few hundred data points to start discerning any structure in the data. For this reason, we updated Figure 10 to include an inset of a 300 data points zoom-in. This is the revised Figure 10, along with the revised caption:

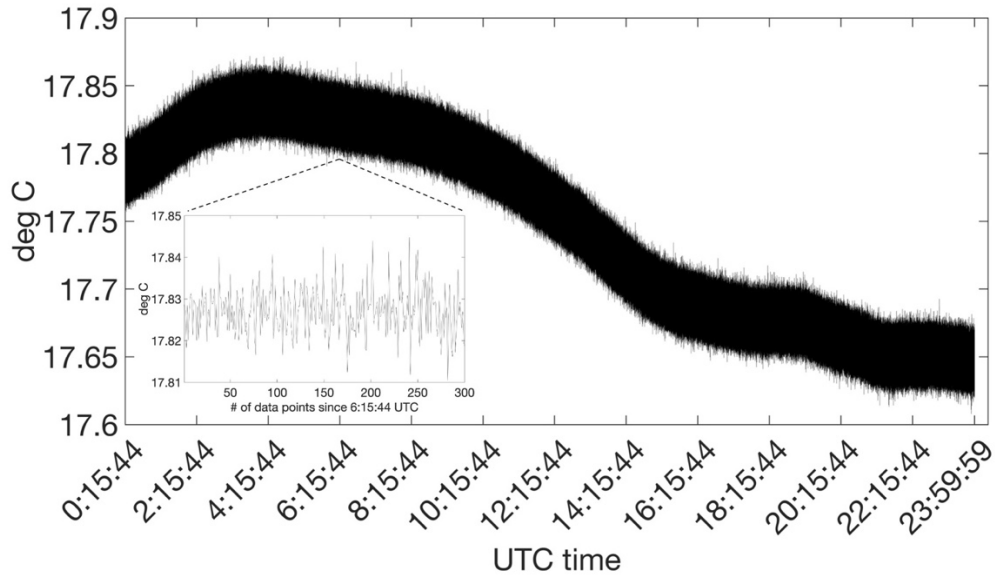


Figure 10: Raw temperature data, recorded with the integrated temperature sensor on May 9, 2024, with a sampling rate of 1612.9 Hz. The inset shows a 300 data points zoom-in. Temperature readings vary by less than 0.3 °C, as a result of the thermal insulation measures we took during deployment. Similar diurnal temperature variations characterize all our data up until July 1st, which is when the temperature readings became erratic (see text for details).

Moreover, we added a comment about the thickness of the plot:

“We note that the RMS noise in the raw temperature data shown in Figure 10 is approximately 0.07 °C. Although we do not have information about the noise specifications of the integrated temperature sensor, the observed noise level is consistent with typical industrial temperature sensors.”

And we also clarify at the beginning of the respective paragraph that these are raw data obtained with a sampling rate of 1612.9 Hz:

“Figure 10 shows the raw temperature measurements, obtained with a sampling rate of 1612.9 Hz by the integrated temperature sensor of our magnetometer, during the day of May 9th, 2024. The inset shows a 300 data points zoom-in.”

- *Figure 14: I suggest adding insets with zooms on the spikes, so the shape of the spikes can be seen.*

We implemented the recommendation. This is the revised Figure 14:

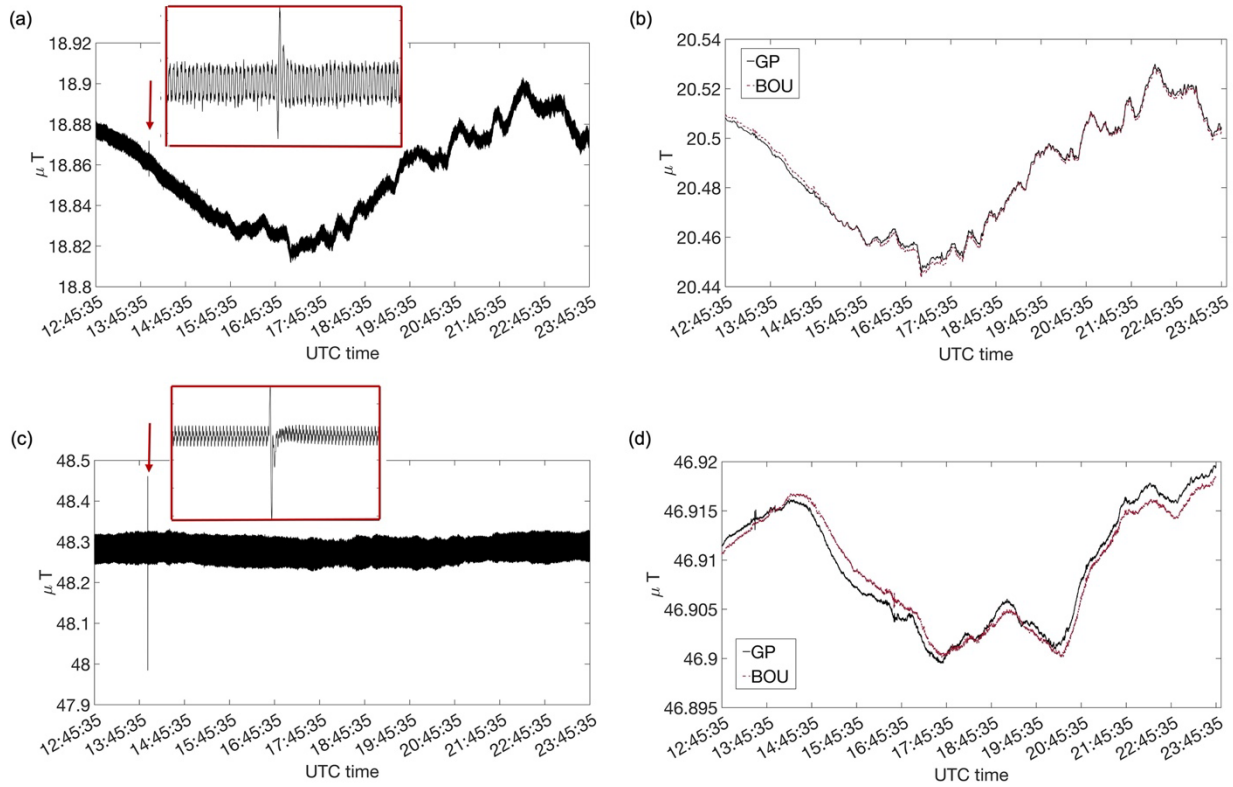


Figure 14: Our magnetic field measurements showing noise in the form of spikes (see text for details). (a) Raw (i.e., unprocessed) measurements of the magnetic field component pointing North (X) on September 9, 2024. Note the spike at 13:56:39 UTC (marked by the arrow). The inset shows a 1 second long extract centered on the spike. (b) The magnetic field component pointing North (X) of 1-sec data. Black solid line shows

our magnetic field data, after their baseline has been adjusted to that of BOU. The moving average filtering eliminated the spike. Red dashed line shows 1-sec magnetic field data recorded at BOU. (c-d) Same as (a-b) for the magnetic field component pointing Down (Z). Note that the moving average filtering did not eliminate the spike but only reduced its amplitude.

- *Page 21: The discussion of the origins of spikes is a bit short. Are there other potential sources of spikes in magnetometer data, e.g., could cosmic rays be the culprit? Is spikes like this a common feature for magnetic observatories? On page 6 a 160 m distant road is mentioned. Is there any correlation to traffic on this road or can any other noise be attributed to traffic?*

To address this comment by the reviewer, we have added this paragraph in the Discussion section:

“There are many different sources that can give rise to spikes in magnetometer data, and it is possible that not all of the spikes in our data have a common source. The spikes that have a duration of less than a second are most probably not of natural origin, but longer spikes can also be of artificial origin, like digital errors. For example, we see in Figure 9e that the spike occurs just after a change in the gain. Some spikes could be due to electromagnetic interferences, which themselves have a large variety of causes. The road at 160 m distance from our site could be the source of some interference, especially whenever large vehicles like trucks were passing by. While we are not able to interpret all spikes in our raw data, we expect that some will be eliminated after we install the ferrites recommended by NI for electromagnetic compatibility compliance when using NI-9239 (i.e., our DAQ), as opposed to the generic, cost-effective ferrites we used in this deployment.”

INTERNAGNET observatories typically do not publish data at a higher resolution than 1-sec data, and these data are typically cleaned before being published.