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Discussions

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Comment on gi-2021-19

Geoffrey Phelps (Referee)

Referee comment on "A towed magnetic gradiometer array for rapid, detailed imaging of utility, geological, and archaeological targets" by M. Andy Kass et al., Geosci. Instrum. Method. Data Syst. Discuss., https://doi.org/10.5194/gi-2021-19-RC2, 2021

Review of

“A towed magnetic gradiometer array for rapid, detailed imaging of utility,

geological, and archeological targets”

by M. Andy Kass, Esben Auken, Jakob Juul Larsen, Anders Vest Christiansen

G. Phelps, 8/20/21

Thank you for the opportunity to review this interesting paper. Below is a summary of my comments, followed by specific comments and recommendations. I have also provided additional comments in the pdf copy of the manuscript.

Overall I found the paper interesting and useful. High-resolution magnetic data has a wide array of applications for shallow subsurface exploration, and the system put together by the authors will address some of those applications. The ability to collect dense sampling is definitely a benefit. It is also good that they are thinking towards full tensor gradiometry in the future; this is the ultimate goal and would provide for very powerful data analysis. I applaud the authors for pushing the technology forward. I recommend the paper for publication pending the appropriate resolution of my comments, listed below and in the pdf manuscript.

- I think the paper would be strengthened at the outset by better describing and linking the application to the tool: why the minimum resolution specifications of 6 nT and 8 nT/m? These are rather high values, and without context it’s difficult to imagine why they were chosen. The anomaly magnitudes are mentioned in section 4.1, but they should be briefly introduced earlier.
- The paper does suffer somewhat from a lack of clear application of the technology. The point of the paper is to describe the system, so it is understandable that a full description of applications (through processing and interpretation of anomalies) is not a major focus. None-the-less, there are important points that need to be clarified.
  - First, what is the range of usefulness of the system? Is 6 nT a reasonable standard

    for archaeological sites in general, or only some sites? Are there other applications for which this system is designed (e.g. infrastructure projects, geological applications)? Are there physical limitations (where it can collect data)? Etc. A short paragraph could address these questions.
  - Second, the extent of the downstream analytics consists of the total field anomaly and the total vertical gradient. One could get essentially the same results with a total field gradient magnetometer setup, and the precision would be much higher and with less issues of bias, temperature sensitivity, etc. (one could use an array of QuSpins or MFAMs, for example), so why use vector magnetometers if the results aren't being used? If it is because of the steady march towards full tensor gradiometry, that's fine, and you do state this several times throughout the paper, but perhaps emphasize it when discussing the case studies.
- The GPS antennas seem to be place too close to the fluxgates; I would expect noise from them. If you've tested the noise envelope for the antennas (changing orientation at all four compass points, pullaway tests, etc.) briefly include this information (or cite a previous white paper etc.). If you haven't tested this, I would strongly advise it.
- It was not immediately clear that the gradient system used by the authors is a commercial system. This is significant and should be made clear, because a commercial system is plug and play and has published specs. This lowers the bar for others who might be interested in building a system, knowing they don't have to build their own gradient system in addition to everything else. As written, the interpretation could be (and is what I initially assumed) that the individual sensors were purchased and a custom gradient system created in-house. Maybe add a picture of the Barington system, showing where the sensors are located?
- Fluxgates can be quite temperature sensitive. Did you test the temperature sensitivity? I didn't see any discussion of this in the Barington grad-13 manual. It's worth mentioning whether you or Barington has tested this – provide an opinion on the instrument's temperature stability.
- Section 2.4
  - Please do cite Reid's 1980 Geophysics short note paper, which can be found here Aeromagnetic survey design: SHORT NOTE (reid-geophys.co.uk)
- Section 3
  - The authors seem to have developed an allergy to Fourier-domain modeling – I don't think it's the problem that they do, and it is a tried and true way of processing signals. True, you need to buffer your area of interest because there are edge effects, but one can plan for that. While you don't need to work in the fourier domain, one benefit is less noisy derivatives, which might be significant if gradients are important. Noise management for calculating the derivatives (e.g. total gradient) should be briefly explained if Fourier methods are not being used.
  - The suggested workflow needs to be modified with caution – upward continuation (which is suggested) should not be used on a line by line basis, because in 1D upward continuation assumes no out of plane changes, which is not the case for the archaeology surveys. The data would need to be interpolated to 2D before applying Fourier filters.
- Section 3.1
  - Fluxgates can be very sensitive to temperature. They can also drift throughout the day, like a gravimeter does (this could be related to temperature fluctuations). Add a paragraph noting how you have addressed any hourly drift that may be associated with the fluxgate system (or that you have measured it and it doesn't appear to be a significant problem).
  - Note that at 20 ms data stream integration, at 20 kph and 230 Hz collection rate, that's 5 samples per distinguishable location, so that effectively limits the sampling rate of the mag. Still should not be a problem in the spatial domain, 20 kph is 5 m/s, so even if there are only effectively 60 samples per second, that's ample samples for 5 m along a line/
- Section 3.3 Bias Correction – two points here

    - First, the bias correction; the concern here is that different lines have different signals, even though they may be close in space, e.g. one sensor passes over a very local source (a bolt that dropped out of a tractor 20 years ago, say). You want to keep the true signal (bolt) and eliminate the instrument bias (eventually you want to get rid of the bolt, of course, but not at this stage because it's part of the "true" signal). In this case longer line segments would be better than moving windows, because it allows greater opportunity for these sorts of local sources to "even out". The effect of these local sources is greater the smaller the window, and you want to minimize their effect. And if outliers are a problem, I would first try removing the median – it will be robust to outliers. I would try an experiment at some point – compare your method with simply removing the global median from each line, and see how the results differ. I think of the problem this way: for a given line measurement, M, there is signal S and bias B, M=B+S. The signal can further be broken down into its median and signal, Sm+S0. For two lines, M1=B1+Sm1+S01 and M2=B2+Sm2+S02, the true comparison is Sm1+S01 to Sm2+S02. If the difference in the signal medians is small (Sm1 - Sm2 ~= 0), as might be expected from lines that are not very far apart (I think you'd need some strong regional gradients for this not to be true), then subtracting a robust measure of central tendency (median is a pretty good one) should get you close to comparing the signals you want to compare, without the need for iteration or removal of the longer wavelengths.
    - Second, the long-wavelength removal; this is not necessary, and not desirable, if you can remove the bias without removing the longer wavelengths. Keeping the longer wavelengths preserves more of the "true" signal (from subsurface sources), and allows subsequent analysts the option of keeping it or removing it. Why filter out signal if it is unnecessary? Let the analyst do that (or not) as they see fit.
- Section 4.1
    - Nice to have the intro paragraph giving some background on the archaeology. Figure 6 would benefit from identifying some of the anomalies seen on the map e.g. suspected iron forge, suspected building, etc.
- Section 4.2
    - It would be helpful to list the magnitude and perhaps shape of the anticipated anomalies. Presumably they are > 6 nT and produce a gradient > 8 nT/m…?
    - Would also be helpful to estimate how long this would have taken to perform a total field walking survey, for comparison. I imagine the time improvements, as well as data density, would be significant, and would make your point about efficiency abundantly clear.
    - Would be helpful to know if you found anything archaeologically worthy. Also, why is there a magnetic contrast in the sediments such that the permafrost is outlined? This seems strange. I realize this is not the point of the paper, but the examples stands out as odd without further explanation. Could the permafrost be creating rough terrain, such that the instrument changes elevation or bumps, and this is propagated into the data?

Please also note the supplement to this comment:
https://gi.copernicus.org/preprints/gi-2021-19/gi-2021-19-RC2-supplement.pdf