

Ann. Geophys. Discuss., author comment AC2
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Reply on RC1

Mirjam Kellinsalmi et al.

Author comment on "The time derivative of the geomagnetic field has a short memory" by
Mirjam Kellinsalmi et al., Ann. Geophys. Discuss.,
<https://doi.org/10.5194/angeo-2022-4-AC2>, 2022

Thank you for the comments regarding our manuscript. We appreciate bringing the Weygand et al. (2021) article to our attention. We find it useful in providing explanations to some of our findings, and will add it to the references of our manuscript. Specific replies (in bold) to the referee comments:

"... The main new result claimed is the large and quickly reached (~ 2 min) asymptotic value of the standard deviation of the time-averaged angle of dH/dt "

The standard deviation is calculated of the change in the direction ($\Delta\theta$) of dH/dt , not of the angle of dH/dt .

"The "main new result" of this paper, that the direction of the geomagnetic field time derivative has a very short "reset time," was anticipated by Belakhovsky et al. (2018), as the authors note,"

These authors show examples illustrating how dB/dt varies clearly more rapidly in direction than B . However, no quantitative characteristic time scale is given in this paper.

"... but also in significant detail in a recent study of similar events in Arctic Canada by Weygand et al. (2021) ... "

The time scale that Weygand et al. discuss is different from ours. However, their study provides useful insight which is relevant also to our manuscript.

Specific Comments

▪

Line 150: The text incorrectly states that "Figures 10 and 11 show $\Delta\theta$ " but these figures and their captions make it clear that what is shown is the standard deviation of $\Delta\theta$, not $\Delta\theta$.

The figures show the standard deviation of $\Delta\theta$. The text will be corrected accordingly.

■

Lines 152-153: Given the above confusion between $\Delta\theta$ and the standard deviation of $\Delta\theta$, it is not clear to this reviewer whether or not “standard deviation” belongs in this sentence. It is also not clear what is meant by their “mean values” yielding similar results. Over what variable and range are these mean values ($\Delta\theta$ or $\text{std}(\Delta\theta)$) calculated?

Here, the mean is calculated as: $\text{mean}(|\Delta\theta|)$. This will be clarified in the text.

■

Lines 185-186: The westward electrojet also produces southward magnetic field perturbations before magnetic midnight. See, for example, Table 3 of the SECS analysis of large (>6 nT/s) pre- and post-midnight magnetic field perturbations reported by Weygand et al. (2021).

This is correct, and was also shown by Viljanen et al. (2001): Fig. 9. Text will be reformulated.

■

Lines 215-218: The time scale of 80 s to 100 s for the behavior of dH/dt is clear in the Pulkkinen et al. (2006) paper, but is asserted without any specific documentation or quantification as being a result of the analysis presented in this paper. This statement needs to either be adequately justified or removed.

Figures 11 and B2 show examples of this time scale. As stated in the text (line 152), this is seen at all studied stations. Also a lower threshold for the activity level of dH/dt does not change the result (line 170, and Appendix B). $\text{std}(\Delta\theta)$ reaches an asymptotic value after about 2 minutes, and this is of the same order as the time scale shown in Pulkkinen et al (2006) study. Attached (supplement) are also figures from eight other stations. The behavior of $\text{std}(\Delta\theta)$ is similar at all of them. We may add these figures in the Appendix, and also emphasize this more in the text.

■

Lines 217-218: The manuscript does not provide any explanation for this time scale, other than that “The size, motion, and lifetime of the dH/dt structures may contribute to the observed time scale.” The Weygand et al. (2021) paper provides detailed

information at higher time resolution than provided in this study that may be helpful in developing such an explanation.

Additional discussion will be added based on Weygand et al (2021).

Figure 2 of Weygand et al. shows a histogram of the duration of all dB/dt derivative amplitudes above 6 nT/s observed at two Canadian stations during 2015. The peak of the distribution of the durations of derivative amplitudes $|dB/dt| \geq 6$ nT/s, which are different from the duration of the magnetic perturbations (ΔB), was between 10 and 15 s, but the range was between a few seconds (most common for MPEs with peaks only slightly above 6 nT/s) up to 71 s.

This figure, based on 10x higher sampling rate data than was used in this manuscript, provides a corrective to the statement in lines 232-233 that "the amplitude of the derivative tends to decrease immediately after reaching the threshold value." The amplitude of course must increase immediately after reaching whatever threshold is used, whether 1 nT/s or 6 nT/s, if it is ever to reach a much higher value (which is often observed) but this figure quantifies the distribution of durations; it is short (not immediate) only relative to durations quantized by 10-s sampling.

We will add clarification of the fact that amplitude tends to decrease soon, not immediately, relative to the 10s data that is used in this study, and the standard deviation is large (Fig. 14). There are great amounts of larger, as well as smaller, values of dH/dt after reaching the threshold.

The statement that "The amplitude of course must increase immediately after reaching whatever threshold is used " does not always hold true for our data set. Attached (supplement) is a figure of dH/dt tot (Sodankylä, SOD, 20170219) with values above the threshold marked with red dots. This shows that values after reaching threshold can fall below the threshold.

This rapid falloff of durations above 20 s provides a ready explanation (with a correction) for the statements in lines 230-233 and agrees with the statement on in lines 234-235 that it is rare for the derivative amplitude to remain at high values for long periods.

Weygand et al. (2021) also examined the dB/dt durations above 6 nT/s as a function of three categories of time delay Δt_{so} after the most recent prior substorm. For $\Delta t_{so} \leq 30$ min category the mean duration was 19.0 ± 0.9 s, for $30 < \Delta t_{so} < 60$ min the duration was 17.7 ± 2.1 s, and for $\Delta t_{so} \geq 60$ min the mean duration was 12.8 ± 1.8 s where the uncertainty given is the error of the mean.

In addition, Weygand et al. (2021) presented several example events, combining multistation magnetometer observations with SECS analyses and in some cases auroral images, that showed that short-lived and highly localized vertical currents and associated localized ionospheric currents were associated with large perturbations and dB/dt values at individual stations.

We agree. This shows that predicting dH/dt is a big challenge. There is a still a general question of which characteristics of the near-space ultimately determine the observed features of H and dH/dt.

The location of these currents relative to the measuring stations determined details of the orientation of the observed magnetic perturbations and their vector derivatives as well as the extent of their duration. No issue of memory needs to be invoked.

The “issue of memory” is merely a lighthearted and easily accessible way of describing one of our results. We find it important to emphasise the difference between H and dH/dt . H has a longer “memory”, i.e. its direction changes clearly more slowly than of dH/dt . As is visually obvious (as illustrated by Weygand et al.), the magnitude of H also changes slowly. So, if we know the present value of H , its (near-)future values (the next few minutes or later) will not be very different from the present. On the contrary, the next value of dH/dt (<1 min from the present) can be completely different, both by magnitude and direction.

This difference is clear also if we consider attempts to forecast different magnetic activity measures. Just as a single example of an empirical approach, the lower auroral electrojet index (AL), related to the north component of the field, can be reasonably well predicted as a time-series based on solar wind observations (Amariutei and Ganushkina, 2012).

A similar way does not work for dB/dt as shown, for example, by Wintoft et al. (2015). Instead of time series, they considered the 30-min maximum of $|dH/dt|$.

First-principle physics methods (simulations) also still have a major work to become really accurate (Kwagala et al.,2020).

Technical Corrections

Line 209: This line contains two minor errors. First, as in line 150, the words “standard deviation of” need to be added before “ $\Delta\theta$.” Second, the values “104 to 110” do not agree with the values of “105 to 109” stated in line 155 in reference to Figure 13.

Will be corrected in the new version.

References

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Please also note the supplement to this comment:

<https://angeo.copernicus.org/preprints/angeo-2022-4/angeo-2022-4-AC2-supplement.pdf>