Comments from referee #2

This is an interesting paper that studies the effects of two possible 1-in-100 years geoelectric field events on the Swedish power grid using the most advanced tools available in Sweden. However, the approach to create the 1-in-100 years geoelectric fields is not convincing at present and needs some reconsideration. The topic is worthwhile, and with some more work this should make a valuable addition to the series of Swedish publications that characterize geomagnetic activity and the power grid response in Sweden.

We thank the reviewer for a critical review and helpful comments. We have done our best to reply to each concern. The original review is written in black and our replies in red. The line numbers refer to the original version of the manuscript.

Major comment:
You create two possible 1-in-100 years events, Case 1 and Case 2, based on magnetic field observations during the Halloween storm. In Case 1, you calculate the geoelectric field based on the magnetic field observations and then scale the resulting values upward in southern Sweden. In Case 2, you assume spatially uniform external magnetic field with an amplitude and time development based on one magnetometer station during storm. The resulting geoelectric field is again scaled similar to Case 1.

I find this approach problematic. Clearly, the reason for the characteristic latitude of the geoelectric field maximum, on which the scaling is based, is due to the external driver. In Case 2, you first create a spatially uniform external driver, but then change the latitude profile of the resulting geoelectric field such that it no longer corresponds to the driver. Nonetheless, you describe Case 2 to represent "an idealized scenario in which the magnetic field time series is spatially uniform" (lines 113-114). This is inconsistent. I suggest that either you drop the scaling or scale the external driver instead of the resulting geoelectric field. The latter also requires changing the way you describe the case.

We thank the referee for this important point. We agree that the original wording for Case 2 scenario is described in an inconsistent way. We have revised the text to make it clearer.

Line 5:
[...] In Case 2, we assume an idealized ionospheric current system in which all stations share the same temporal magnetic field pattern.[...]

Line 105:
[...]. Our motivation for scaling the geoelectric field was that it is the physical driver of GICs. Using real ground-magnetic perturbations as input preserves a realistic ionospheric forcing (rather than relying on a synthetic magnetic-field time series), while the scaling ensures that the resulting geoelectric field reaches the level associated with a 1-in-100-year event from the perspective of the physical driver of GICs. This allows us to generate as many worst-case scenarios as magnetic field inputs are available. However, because ground magnetic perturbations are driven by ionospheric current systems that activate during geomagnetic storms and substorms, we recommend using magnetic-field inputs from previously recorded events that produced the largest geoelectric field response.

To illustrate the range of possible worst-case conditions, we explore two complementary approaches. The first worst-case scenario (Case 1) is intended to remain as realistic as possible, with each geographic location experiencing a different magnetic field perturbation. This is achieved by using as many magnetometers as are available in Sweden, providing a well-resolved ionospheric driver. The second worst-case scenario (Case 2) is intended to represent an idealised case in which every location in Sweden experiences the same magnetic field perturbation (i.e., the frequency content remains identical). This is achieved by using data from a single magnetometer. Such an idealised situation could be produced by a large-scale westward electrojet (WEJ) extending across Fennoscandia. [...]

The text in Line 113, resulted in a revised version that involves Lines 111-114:

[...] As mentioned above, we explore two different scenarios. In Case 1, we use the actual observed magnetic field perturbations, interpolated across the Fennoscandian region using the SECS method. We remind the reader that this approach is intended to represent a realistic situation where signatures of meso- and small-scale magnetosphere–ionosphere currents are represented. In the second case (Case 2), we construct an idealised worst-scenario in which all magnetometer stations experience the same temporal pattern of magnetic field perturbations.

Furthermore, we analyzed your suggestions:

- Drop the scaling: We decided not to follow this suggestion because the unscaled idealized case (Case 2 without scaling) does not attain the 1-in-100-year geoelectric magnitude; it would only represent an idealized event at the Halloween storm's scale (see Figure 1, unscaled maximum geoelectric field for Case 2).

- Scale the external driver: We decided not to adopt the referee's suggestion to scale the external magnetic driver, due to several reasons:

    - Scaling the external driver implies rescaling ground B time series and deriving new return-period estimates for B (an extreme-value analysis analogous to Lanabere et al., 2024). That is a separate study on its own and cannot be completed within the present manuscript's scope and timeline.

    - Scaling the external driver does not guarantee that the geoelectric field reaches a 1-in-100-year level, which is the central part of this study.

    - The paper's objective is to compare two constructions that produce the same target 1-in-100-year geoelectric level.

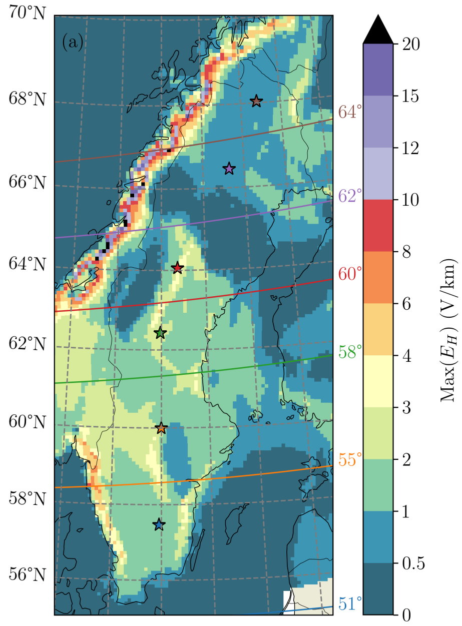

Figure 1: Map of Maximum geoelectric field magnitude during the interval 19:40 to 20:30 UT, for Case 2 without scaling.

In Case 1, you note that your analysis fails to explain the observed Malmö blackout. This you explain to be due to the missing magnetometer observations in the key area (lines 237-239). You also note that in northern Sweden the Halloween event is classified as a 1-in-100 years event whereas in southern Sweden it only reached 1-in-10 or 50 years (lines 108-110). Combining these, it rather sounds to me that the Halloween storm might well have been a 1-in-100 years event across Sweden, but the insufficient magnetometer coverage in southern Sweden did not allow full observation of its effects in this area. Thus, the role of the scaling in this case would not be to increase the classification of the storm but to rather correct for missing data. Such a correction should be applied to the driver rather than to the resulting geoelectric field. As this may not be straightforward, I suggest at least discussing the point in the text.

We thank the referee for this comment. We do not agree with the interpretation that the Halloween storm would have been a 1-in-100-year event across all of Sweden but was simply under-observed in the south. Although southern Sweden (~55° Glat) was not included in previous return-value analyses (Lanabere et al., 2024), the dataset did include stations spanning 58.26° Glat (34.5° Mlat) to 68.02° Glat (64.7° Mlat). Across this latitude range, the return-period characterization of the Halloween event shows a clear and robust latitudinal dependence:

- North of ~60° MLAT, the Halloween event corresponds to a 1-in-100-year level.
- South of ~60° MLAT, the same event corresponds to 1-in-10 to 1-in-50-year levels.

This latitudinal contrast is not an artefact of missing magnetometer coverage but reflects the different tail behaviours of the extreme-value distributions at different latitudes. As shown in Lanabere et al. (2024) and previously in Wintoft et al. (2016):

- Below ~60° Mlat, the shape parameter of the Generalized Pareto Distribution (GPD) is positive, indicating a heavy-tailed distribution with no upper bound. In these regions, the maximum observed values during the Halloween storm are not close to the statistical upper tail, and substantially larger events are expected in the future.

- Above ~60° Mlat, the shape parameter is often negative (or its confidence interval includes negative values), implying a bounded or weakly heavy-tailed distribution. In these regions, the maximum observed values are already close to the statistical upper limit.

Therefore, the lower return-period classification of the Halloween event in southern Sweden is a statistical property of the extreme-value behaviour, not a consequence of insufficient magnetometer coverage. Even with perfect spatial coverage, the EVT characteristics south of 60° Mlat would still classify the Halloween storm as a substantially less extreme event than in the north.

We have now added a short discussion of this point in Line 110

[...] This latitudinal contrast reflects systematic differences in the tail behaviour of the extreme-value distributions (heavy-tailed with positive shape parameters in the south of 60° MLAT and bounded or weakly heavy-tailed in north of 60° MLAT) as documented in both Lanabere et al. (2024) and Wintoft et al. (2016). These differences arise from the underlying statistics rather than from gaps in magnetometer coverage, and therefore the Halloween event is not expected to represent a 1-in-100-year level in southern Sweden even under complete observational coverage.

Minor comments:

Lines 11-12: "East–west-oriented power lines are especially vulnerable, as they align with the dominant orientation of the induced electric field." Do you mean this statement applies generally? Is the geoelectric field in Sweden typically oriented in the east-west direction? If not, please modify the statement.

We thank the referee for this observation. It is true that, in general, the geoelectric field in Sweden is typically oriented in the east-west direction (Lanabere et al., 2023 Figure 2c). However, we wanted this sentence to emphasize the results found in this study. We have rewritten sentence in line 11-12 to:

[...] East–west-oriented power lines are especially vulnerable, as they are mainly located south of 60° MLAT, where the largest geoelectric fields are calculated.[...]

Line 29: "most commonly" On what is this claim based? Kp is also very widely used.

Thank you for this comment. We changed the statement to “*commonly*”

Line 43: "(NERC, 2016)" What is NERC?

NERC stands for “North American Electric Reliability Corporation”. We have added this clarification after the citation.

Line 63: "the paper of this paper" Delete "the paper of"?

Done

Lines 67-68: "a once in 100 year event" Shouldn't "year" be "years"? Please check throughout the manuscript.

We thank the referee for noting this. After consulting with native English speakers, we confirm that the correct forms are:

- a 1-in-100-year event
- once in 100 years.

We checked and corrected throughout the manuscript.

Lines 71-80: This section does not describe either data or methods. It could be moved to section 3.

Thank you for the comment. We agree that this paragraph does not describe either data or models, so we have moved it to Section 3 (Line 108) as the first step of the Method. This step now indicates that a previously observed event should be selected as a reference. We have also included it as the first step in the workflow presented in Table 1.

Lines 75-76: What about differences due to 1D and 3D modelling? 3D modelling is expected to give higher geoelectric field amplitudes than 1D due to the effect of lateral conductivity gradients.

Thank you for this comment. We agree that the differences between 1D and 3D are significant mainly in areas with strong lateral conductivity gradients. We have modified the text from lines 75-76 to:

> *The significantly higher value in Rosenqvist et al. (2025) is attributed to the fact that the maximum was observed near Sweden’s west coast, an area not covered in the analysis by (Lanabere et al., 2023), and to the expected higher geoelectric field amplitudes from 3D modelling compared with 1D modelling, due to the effect of lateral conductivity gradients.*

Line 86: "external (Bext) produced by", "internal (Bint) produced by" Something is missing here. Do you mean external component and internal component?

Thank you for the observation, we meant “external component” and “internal component”. The text has been updated accordingly.

Line 90: More detailed descriptions of GIC-SMAP and RAISE should be included. For example: What are the inputs and outputs of each model? What are the key principles and assumptions of these models? What are the key sources of uncertainty?

Thank you for pointing this out. We agree that more detailed descriptions of the GIC-SMAP and RAISE models should be included, as this is important for improving the reader's understanding of the models. We have restructured Section 2 and added in line 90 two new subsections: GIC-SMAP model and RAISE model with the following text:

2.2 The GIC-SMAP model

The GIC-SMAP model calculates the horizontal geoelectric field $E_H(\omega)= Z(\omega)\mu_0^{-1}B_H(\omega)$ *in the frequency domain by relating the ground impedance tensor* $Z(\omega)$ *to local magnetic field perturbations* $B_H(\omega)$*. An inverse Fourier transform is applied then in order to transform into the time domain. In a new version of the model, where the* E_H *is computed at every point of the grid in Sweden, the magnetic field data is first interpolated using the Spherical Elementary Current System (SECS) method (Amm & Viljanen, 1999) using all available IMAGE stations.*

The ground impedance tensor is previously obtained by computing the geoelectric field using a uniform magnetic field variation with unit amplitude, by solving the equations describing the current distribution in the ground in the frequency domain using the commercial software COMSOL Multiphysics for a unit-amplitude (H_0 *= 1 A/m), uniform magnetic source field applied at 100 km altitude for a fixed set of frequencies (1–100 mHz). See the supporting information (S2) in Dimmock et al., (2019) for a further description of the technical setup (i.e., equations, parameters, domain, etc) and Rosenqvist and Hall (2019) for additional details about the model.*

The main source of uncertainty in the GIC-SMAP model arises from the sparse distribution of active IMAGE magnetometers in Sweden used in the SECS method to interpolate the magnetic field onto the model grid. Additional sources of uncertainty arise from the conductivity model (Marshalko et al., 2023). First, the underlying crustal conductivity map for the Fennoscandian Shield (SMAP) (Engels et al., 2002; Korja et al., 2002) is well constrained by extensive magnetotelluric surveys in northern Sweden, whereas large parts of southern Sweden remain sparsely surveyed and rely more heavily on extrapolated conductivity estimates. Second, the calculation of the surface impedance assumes a uniform magnetic field, whereas in reality, the magnetic field exhibits spatial variability. Third, frequencies below 1 mHz may contribute to the amplitude of the geoelectric field when superimposed on the higher frequencies (Wallner et al., 2026).

The model has been validated against GIC measurements in both northern and southern Sweden (Rosenqvist and Hall, 2019; Rosenqvist et al., 2022), indicating that the uniform-source-field assumption performs well during geomagnetically quiet periods, while further validation during geomagnetically active intervals remains pending.

2.3 The RAISE model

The recently developed RAISE model (Rymdvädersmodell för Analys av Inducerade Strömmar och Elektriska fält, Swedish for ``Space Weather Model for the Analysis of

Induced Currents and Electric Fields"), introduced by Rosenqvist et al. (2025), was employed to analyze the voltages in the Swedish power grid lines. The simplified Swedish power grid representation consists of 194 nodes and 335 transmission lines, of which 49% are 400 kV lines and 51% are 220 kV lines. This model has previously been applied to investigate GIC activity during the April 2023 and May 2024 geomagnetic storms (Dimmock et al., 2024; Rosenqvist et al., 2025). RAISE integrates the GIC-SMAP model (Rosenqvist and Hall., 2019) with a simplified representation of the Swedish high-voltage power grid, assuming constant earthing resistance and fixed line resistances for both 200 kV and 400 kV transmission lines. Due to this simplification in line resistances, the results presented here focus on calculated voltages without explicitly computing the corresponding GICs.

The RAISE model relies on the following assumptions and simplifications:

- Only transmission lines and power stations operated by Svenska kraftnät (SvK) are included. Substations and lines owned by regional or private operators are not part of the dataset.

- Power Stations without verifiable connections are removed. Thus, power stations located more than 650 m from any mapped transmission line are excluded to ensure a topologically consistent network.

- International interconnections are omitted. This implies that all AC and DC links to neighboring countries (Norway, Finland, Denmark, Poland, Lithuania) are removed, and Sweden is treated as an electrically isolated system.

- The curvature of Earth is neglected, assuming that the distance between the nodes of the transmission line is of the order of hundreds of kilometers, much less than the Earth radius.

-The earthing resistance is considered constant, and the transmission lines are assumed to have a constant resistance per unit length depending on the transmission voltage level.

Line 102: Please check the style of references throughout the text.

The reference style has been checked and corrected.

Lines 104-105: "amplitude of the EH reaches an amplitude" Maybe write "amplitude of EH reaches a level" to avoid repetition?

Revised as suggested.

Table 1: Should you add Lanabere et al. (2023, 2024) and Rosenqvist et al. (2025) as references to step 1 (cf. lines 71-80 and 108-110)?

Thank you for the suggestion. We included the references in the new Step 1 related to the identification of the event with the largest E_H.

Lines 118-120: Please explain this in more detail. Does GIC-SMAP expect Btot or Bext as input? I would have expected a first-principles model to take Bext as input and return Btot as output, but apparently this is not the case?

We have now included more information about the GIC-SMAP model in section 2. (see comment before). There we say that:

The GIC-SMAP model calculates the horizontal geoelectric field $E_H(\omega)= Z(\omega)\mu_0^{-1}B_H(\omega)$ in the frequency domain by relating the ground impedance tensor $Z(\omega)$ to local magnetic field perturbations $B_H(\omega)$. [...]

The GIC-SMAP should use the total magnetic field. However, the GIC-SMAP model can be used with either Btot or Bext, and the output is the geoelectric field associated with the total magnetic field (including the internal source produced by the induced telluric currents in the ground and the external part produced by currents in the ionosphere and magnetosphere) or external magnetic field (produced by currents in the ionosphere and magnetosphere) respectively.

Figure 1: What are the arrows in panel (a)?

More information is added in the label of Figure 1, panel (a).

Interpolated magnitude (shaded) and direction (arrows) of the horizontal magnetic field (B_H) at 20:04 UT, the time when most stations recorded their maximum B_H.

The following text is included for clarification:

The colored stars in panel (a) mark the sites where time series data were extracted.

Figure 2: "specific sites" Are these the same locations as the stars in Fig. 1a?

We changed the relevant sentence to:

Colored stars mark the same sites as in Figure 1a, where the temporal dB_H/dt and E_H profiles were extracted and shown in the panels (b) and (c) respectively.

Figure 3: "Magnetic field perturbations (dBH,ext /dt) at the magnetic stations along 25.42oE (solid line) and in Sweden (dashed line)." Please clarify this sentence. The stations in Finland and Estonia do not have a constant longitude. What are the arrows in panel (a)?

We include in the description of Figure 3 panel (a) the following clarification:

(a) Ionospheric equivalent current (J_{eq}) magnitude (shaded) and direction (arrows) [...]

And we clarified the sentence related with panel (c)

(c) Magnetic field perturbations ($dB_{H,ext}/dt$) at the magnetic stations along Finland and Estonia (solid line) and in Sweden (dashed line).

Line 193: "the induced electric field response is greater at HAN." Do you really mean that the induced electric field was calculated at HAN? (I understand this to mean the true location of

HAN.) Or do you mean that the induced electric fields calculated using Bext from HAN at the locations marked with stars in Fig. 3a were greater than those calculated using Bext from OUJ?

Thank you for pointing this out. The correct statement is “the induced geoelectric fields calculated using Bext from HAN at the locations marked with stars in Fig. 3a were greater than those calculated using Bext from OUJ”. We changed the old statement to:

[...]; however, the induced geoelectric fields calculated using $B_{H,ext}$ from HAN at the locations marked with stars in Figure 1a were greater than those calculated using $B_{H,ext}$ from OUJ.

Lines 194-197: I do not understand this reference. Dimmock et al. (2024, Figure 4) concerns a different event (23 Apr 2023) and they do not show the geoelectric field.

Thank you for checking this. The correct reference was to Figure 9 in Dimmock et al. (2024). In this example, dB/dt and E are shown for the 23 April 2023 event, and we aim to highlight that the largest peak in dB/dt does not necessarily correspond to the largest peak in E.

Line 211: "and the similarly response at the OUJ station" Please explain what this means.

We improved the description in 210 with the following text:

Between 58° and 62° MLAT, the differences are minimal because the magnetic field input in Case 1 at these latitudes is mainly dominated by the observations in HAN and OUJ, which are very similar to the input used in Case 2.

Figure 5: What are the arrows?

We have updated the caption of Figure 5 to clarify what the arrows represent.

Line 223: "3 V/km"
Line 225: "1 V/km" Why were these threshold values selected?

Thank you for making this important observation. The thresholds of 1 V/km and 3 V/km were selected to represent low and high maximum voltage per km during the substorm event. To better define these limits, we used the 20th and 80th percentiles (P(20) and P(80) respectively) of the maximum voltage per km in each case:

Case 1: P(20) = 1.17 V/km; P(80) = 3.34 V/km
Case 2: P(20) = 0.75 V/km; P(80) = 2.76 V/km

Panels (b, c, d and e) in Figure 6 and Figure 7 have been updated together with the caption.

Caption of Figure 6: *[...] (e) Power lines exceeding the 80th percentile of the maximum voltage per km during the whole period (3.34 V/km, in red), and power lines that remained below the 20th percentile (1.17~V/km, in black).*

Caption of Figure 7: *[...] (e) Power lines exceeding the 80th percentile of the maximum voltage per km during the whole period (2.76 V/km, in red), and power lines that remained below the 20th percentile (0.75~V/km, in black).*

We adapted also the text in line 223:

[...] Around these areas, the maximum power line voltage per km exceeded 3.34~V/km (red lines in Figure 6b), which corresponds to the 80th percentile of the maximum voltage per km across all lines. Power lines that exceeded 3.34~V/km are typically short east–west oriented, [...]

We adapted also the text in line 225:

[...] In contrast, power lines with voltages per km below the 20th-percentile maximum voltage per km (1.17 V/km) throughout the storm (black lines) are mainly [...]

We adapted also the text in line 230-231:

[...]Consequently, power lines exceeding the 80th percentile of the maximum voltage per km across all lines for Case 2 (2.76~V/km) appear even at lower latitudes in Figure 7e.

In both cases, the lines that did not exceed the 20th percentile maximum voltage per km (0.75~V/km) [..]

We adopted the text in lines 358-361

- Voltage per km larger than the 80th percentile of maximum voltage per km across all lines (3.34~V/km for Case 1 and 2.76 V/km for Case 2) are concentrated near [...]

- In western Sweden, several power lines exhibit voltage per km larger than 3.34~V/km for Case 1 and 2.76 V/km for Case 2 even when oriented northwest–southeast, primarily due to localized conductivity structures. In eastern Sweden, for Case 1, the power lines exceeding the 80th percentile of maximum voltage between Vittersjö [...]

Section 4: Due to the limitations of the power grid model you use, the analysis is limited to estimating voltages in separate transmission lines. Such an approach does not consider the power grid as an entity as proper GIC estimation would do, and hence does not provide a full picture of the response. The limitations of the chosen approach in this respect should be discussed. For example, the most intense GIC are typically observed at substations located at the edges of the power grid (https://doi.org/10.1051/swsc/2012017). According to your power grid map, both Malmö and Karlshamn appear to be located at the southern edge of the Swedish power grid. Even without exact values for the resistances, more useful results would probably be gained by estimating the GIC instead of analyzing the separate line voltages. Of course, in order to explain actual impacts, such as the Malmö blackout, you would also need to know the true grid geometry at the time of the event.

Thank you for this important point. We agree that we should include a discussion of the limitations of our approach. We included the following paragraph in Line 219

The impact on the Swedish power grid is limited to the analysis of the induced voltages in the transmission lines, calculated by integrating the geoelectric field along the power lines under two 1-in-100-year event scenarios. To complement the total induced voltage, we also compute the voltage per kilometre, which corresponds to the line-averaged geoelectric field projected along the transmission line direction. This provides a measure of the effective *geoelectric driving experienced by each line, independent of its length. We acknowledge that this does not represent the full behaviour of the Swedish power grid as a connected network. However, large induced voltages (Voltages > 100 V) have been related to several issues during the March 1989 geomagnetic storm (Lucas et al., 2018).*

A proper GIC assessment would require detailed and time-accurate information on grid topology, transformer resistances, grounding configurations, and relay-protection settings. These engineering parameters are not publicly available at the level of detail required for reliable modelling the power grid. For this reason, it is not currently feasible to determine what would constitute a true worst-case scenario for the power grid itself, nor to model specific impacts such as transformer saturation or protection-system behaviour. Our study therefore focuses deliberately on the geoelectric field forcing, consistent with how Svenska kraftnät defines extreme events (based on the physical NOAA G-scale rather than grid-hardware responses). Moreover, large global geomagnetic disturbances, typically associated with locally enhanced geoelectric fields, are known to increase the likelihood of power-grid disturbances (Rosenqvist et al., 2025).

Lines 263-265: Is the number of power lines with the 100 V threshold exceeded really a relevant problem? It does not mean that there would be large GIC at the ends of all these power lines. Large GIC would be expected at the substations located at the edges of the power grid (see the point above).

Thank you for this comment. We agree that the number of power lines with the 100 V threshold is not always a relevant problem. However, large induced voltages (> 100 V) have been related to several issues during the March 1989 geomagnetic storm (Lucas et al., 2018).

We have removed the text in Lines 263-265 and incorporated a discussion of this observation into Subsection 5.2 Power grid implications, within the conclusion section. Line 318 now reads:

[...] We have shown that during intervals of very active ionospheric current variations, particularly during substorm activity, large dB/dt and E_H values were estimated at latitudes below 60° MLAT. As a consequence, several power lines exceeded high voltage thresholds (e.g., approximately 100 power lines experienced induced voltages exceeding 50 V at several times during the substorm period). For comparison, Lucas et al. (2018) reported that 62 transmission lines exceeded 100 V during the March 1989 geomagnetic storm, which triggered a major blackout in the Hydro-Québec power system. Although power-grid disturbances do not always coincide with the time of peak voltage or geoelectric field (Dimmock et. al, 2024, Wallner et al, 2025), or with peak GICs (Pulkkinen et al., 2005), intervals of high induced voltages still imply larger voltage variations.

Lines 345-346: "How do small-scale ionospheric currents during extreme storms influence the spatial variability of geoelectric fields and GICs?" What do you mean by small-scale? Due to the ~100 km distance between the ground and the ionosphere, magnetic field perturbations due to ionospheric current structures smaller than about 100 km in scale size are significantly attenuated before reaching the ground.

We thank the referee for this clarification. Our intention with the term small-scale was not to imply ionospheric current structures below ~100 km, which indeed become strongly attenuated before reaching the ground. In the GIC literature, small-scale typically refers to rapid, localized current systems with spatial scales up to several hundred kilometres, which can still produce localized strong dB/dt signatures. Such structures are often associated with vortex-like structures embedded within the large-scale auroral electrojet (Viljanen et al., 2001; Belakhovsky et al., 2019). Although the term is not sharply defined, in this context it refers to current features with scales < ~1000 km.

We improved Lines 345-346 by specifying our intended scale and now write:

[...] How do small-scale ionospheric currents (< 1000 km) during major geomagnetic storms influence the spatial variability of geoelectric fields and GICs?

Lines 354-355: "The largest scaled EH are found within the 55◦ –58◦ MLAT band" This is a circular conclusion since you have artificially scaled the geoelectric field amplitude up particularly in this latitude band.

We agree that the original wording could be interpreted as a circular conclusion. We have therefore rewritten this bullet point as:

The largest scaled EH values are found in localized areas with pronounced lateral conductivity gradients, reaching up to 12 V/km, and in the western part of the 55°–58° MLAT band where conductance is particularly low.

Line 356-357: "due to the prevailing orientation of the horizontal electric field" This conclusion sounds far more general than is probably intended or can be drawn based on you results. Please modify. (See also the similar comment on the abstract.)

Thank you for this comment. We have therefore rewritten this bullet point as:

North-South-oriented power lines experience larger total induced voltages because their overall length is greater than that of East-West lines. However, East-West lines show larger voltages per kilometre, mainly because they are located south of 60° MLAT, where the largest geoelectric fields are calculated.

Lines 365-366: "limited magnetometer coverage in southern Sweden" How accurate is the conductivity model in this area? Inaccuracies in the conductivity model can be a significant source of error for the modeled geoelectric field (https://doi.org/10.1029/2022SW003370).

We completely agree with this comment. The modeled geoelectric field in Southern Sweden has two main sources of inaccuracies. First, the limited coverage of magnetic field observations. Second, the number of magnetotelluric surveys used to build the conductivity maps.

We have therefore rewritten this bullet point as:

[...] is likely due to limited magnetometer coverage in southern Sweden (MLAT<55°) and to the inaccuracies in the regional conductivity model, [...]

Lines 368-370: This sentence is very long and difficult to follow. Please divide it into two or more shorter sentences. What is "sudden weakening of worst-case scenarios"?

We agree that the original sentence was long and difficult to follow, and that the phrase “sudden weakening of worst-case scenarios” was unclear.

We have therefore rewritten it as:

“During the WEJ peaks and sudden weakening in the worst-case scenarios, around 100 power lines exceeded 50 V multiple times during the substorm. At the moment of the WEJ weakening, close to the time of maximum dBH/dt , about 100 lines exceeded 100 V.”