Reply to Referee #1

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Dear Referee #1,

thank you for very useful and constructive comments. Please, see below for our point-by-point replies. The original review is written in *black* and our replies in blue.

Review comments on the manuscript egusphere-2024-2831, entitled: Estimation of the 3-D geoelectric field at the Earth's

5 *surface using Spherical Elementary Current Systems*

by Liisa Juusola et al.

The authors tried to derive the geoelectric field at the Earth's surface from magnetic field variations measured in the vicinity. The various components of the E-field are estimated with the help of the SECS approach and by using the 3-D induction model PGIEM2G. This approach is applied to IMAGE Magnetometer Network area. Convincing results are obtained in this

10 *way, which compare quite favorably with GIC measurements in gas pipelines. The computational design of the framework is suitable for running it in near-real time for estimating space weather hazards, resulting from GICs in the Fenno-Scandian region.*

In spite of these generally positive ratings, the study would gain, when improvements were made in a number of cases.

Open issues

15   1. *One thing, the authors obviously have not taken into account is the effect of prompt penetrating electric fields on the geoelectric field. As shown by Brändlein et al. (2012) doi:10.1029/2012JA018008, the ionospheric Hall current, driven by the prompt penetration field, causes ground-based magnetic signatures, but it does not cause geoelectric fields on the ground. At mid-latitudes significant effects of this process can be observed. I am not aware that anyone has studied this effect at auroral latitudes. This point should be discussed.*

20   Thank you for bringing this to our attention. We suggest to add at line 132:

"This follows from neglecting the displacement current, as is usual in geoelectromagnetism. However, it should be noted that the displacement current may play a role in producing ground-based magnetic field signatures that do not cause a geoelectric field on the ground (Brändlein et al., 2012)."

and at line 151:

25 "Brändlein et al. (2012) discussed a waveguide transmission, where the wave mode on the ground has a non-zero horizontal magnetic field component but a zero horizontal electric field. In the vertical direction such a wave mode is expected to have a zero magnetic and non-zero electric field components. The SECS reconstruction is able to reproduce such a magnetic field as a superposition of the magnetic fields of ionospheric and telluric equivalent currents. Because the vertical magnetic field is zero, $\boldsymbol{E}_{DF}$ would also be zero."

2. *Table 3: Larges ground E-fields are predicted at the end of 7 Sep. 2017 for a location close to the transformer of Namsos. It should be checked if measurements of ground currents are available at that station. In case there are, they should be compared with the predictions. This would make the study much more convincing and relevant for application.*

   Unfortunately, the Namsos GIC measurement did not start until 2020. Furthermore, in order to predict the GIC, the network geometry and resistances would be needed. This information is generally classified.

3. *In the Introduction it is mentioned that a second layer is introduces below the Earth's surface. From the following sections it is not clear what this extra layer physically represents. How does it account for lateral conductivity variations?*

   This is a good point. We suggest to modify the text at line 78. The original text is

   "... a second layer just below the Earth's surface. This..."

   and the modified text would be

   "... a second layer just below the Earth's surface, to represent the magnetic field of the telluric currents. A ground conductivity model is not needed for the DF electric field calculation, because the conductivity distribution affects the telluric current distribution, and this is reflected in the magnetic field it produces. Using two layers instead of one..."

4. *Another statement is that the radial component of EDF is not required to be zero. What is the effect of that assumption? What does it physically imply? These two latter assumptions are pointed out as important assets of the presented approach. Therefore, they should be better explained to the readers.*

   We do not make any requirements about the radial direction of EDF, but show that, because of the geometry of the DF SECS, EDF only has a horizontal component between the ground surface and the ionospheric sheet current. In order to try to make this more clear, we suggest to modify the text at line 132. The original text is

   "Consequently, the induced electric field only has a ϕ' component,"

   and the modified text would be

   "Due to the geometry of the DF SECS magnetic field, the corresponding induced electric field only has a ϕ' component (see also the vector potential derivation in Amm and Viljanen (1999)),"

   Furthermore, we suggest to add at line 151, after the addition suggested in our reply to point 1:

   "Although the combination of ionospheric and telluric DF current densities always produces a DF electric field that has a zero vertical component between the ionspheric and telluric equivalent current sheets, this does not necessarily mean that E_{DF} cannot have a vertical component in this region. This issue was investigated in detail by Pirjola and Viljanen (1998). In addition to the parts described by the DF current densities, the 3D current distributions in the ionosphere and in the ground include a part that has a zero magnetic field between the ionosphere and ground surface. However, the corresponding vector potential A may not be zero, although $\nabla \times A$ must be zero. The corresponding DF electric field is a Laplace field that has its sources above the ionosphere and inside the ground. A similar Laplace electric field could also be produced with electric charges in these regions. According to the results by Pirjola and Viljanen (1998), valid up to neglecting the displacement current, any horizontal part of this DF field is cancelled by charges accumulated on the ground surface, leaving only an insignificant vertical component. Thus this part of the induction process does not drive any GIC."

In addition, we will remove some extra ϵ_0 from Eq. 22 and Eq. 24. This is just a typo and does not affect the results.

References

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