

Response to Referee #1

Authors: We would like to thank Referee #1 very much for his or her time and work devoted to carefully reviewing our manuscript and for the helpful comments.

The paper introduces newly recovered historical data contributing to the investigation of the 13-15 May 1921 extreme geomagnetic storm. Since both extreme geomagnetic events and their surviving recordings before the 1930s are rare, any new data are important. The unscaled recordings were carefully calibrated. The authors presented the Stara Dala data in the context of other observations of the same storms, as well as closely located aurora observations. The section detailing data processing is too lengthy.

Response:

The data calibration for the preserved magnetogram forms an important part of our manuscript because in this part of our study we tried to piece together the sketchy information in order to obtain the most reliable resulting data available. We have tried to make the manuscript more attractive by adding a piece of information about the content of the relevant parts of the text. Namely, in Lines 89–91 (line numbers in the manuscript with the changes marked) we clarified that the Section 2.2 describes in detail the procedure of the calibration, and the resulting calibrated data are presented later, in Section 2.3. By such improved navigation in the text, we will hopefully allow the reader who is less interested in the calibration procedure to avoid the uninteresting parts.

Global magnetic data used for this study re taken from WDC. However, it is not clear if this is a complete set of the available data. Figures 4 and 5 includes 10-12 data points, while Hapgood listed 21 observatories (excluding Stara Dala) with available data.

Response:

The data utilised here were all the hourly means of the geomagnetic field available for the period in question via the webpage of the World Data Center for Geomagnetism, Kyoto. The hourly means of Seddin were obtained from the Niemegek observatory, the successor of the Seddin observatory. (Lines 296-299.)

The authors seem to consider only Czech aurora observations. Hapgood mentions other sources (see also their references). Relatively little information is given on how other researchers interpreted the available data related to this event. Missing the summary of others findings it is difficult to judge what are the new findings of this paper.

Response:

In our work, we wanted to point out to the international scientific community a little-known piece of information about the aurora borealis observed during the storm of May 1921 from the territory of former Czechoslovakia. In the new version of the manuscript, we have also added that the aurora observations from former Czechoslovakia extend the information about observed auroras to a part of Europe not covered in Hapgood's review article. Also, we have mentioned how the observations from Czechoslovakia fit into the information published so far (Lines 251 – 256).

Minor comments:

18: curtailed > limited

Response: Corrected. (Line 18 in the manuscript with the changes marked)

29: size > magnitude

Response: Corrected. (Line 34)

38: extent > the extreme equatorward extension

Response: Corrected. (Line 43)

41: an extreme solar storm > the causative solar storm

Response: Corrected. (Line 46)

42: Mountwilson > Mount Wilson

Response: Corrected. (Line 47)

47: will be > could be

Response: Corrected. (Line 52)

52: in low magnetic latitudes > at low magnetic latitudes

Response: Corrected. (Line 57)

63: the descending phases > a declining phase

Response: Corrected. (Line 68)

Table 1: Throughout the paper CGM latitudes are used, geomagnetic coordinates could be removed from the table. They just confuse the reader. See also comment to line 277.

Response: CGM coordinates have been changed to QDP coordinates. (Lines 244-245, 248, 305-306-307, 329 Table 1, Table S1, caption of Figure 4)

Table 2 and throughout the text: The unit in this form is not correct as it includes a decimal dot. Use „arc minute/mm” or „’/mm” instead.

Response: All the units that had been improperly included a decimal dot have been corrected in the new version of the manuscript. (Lines 152, 156, 158, 170-172, 410-411 and 413, and Table 2)

162: centre > median (?) Please specify clearly!

Response: The word "centre" has been changed to "median" (Line 170).

175: Contemplating > Considering

Response: Corrected. (Line 183)

182: thoroughly selected: based on what selection criteria?

Response: We selected records in which the light trace on the magnetogram (photo paper) was clear and thin, to allow obtaining values with as little uncertainty as possible (Lines 191-192).

Table 5 and text: Use nT/mm as scale unit!

Response: All the units that had been improperly included a decimal dot have been corrected in the new version of the manuscript. (Lines 202, 208 and 415, and Table 5)

201: we read the five-minute data (i.e., five-minute means): this needs to be clarified. Means are typically calculated and not just read.

Response: We added an explanation, "For this purpose, we imitated the method commonly used in determination the hourly averages by means of a glass scale. The mean value was determined using an imaginary horizontal straight line, which was put on the magnetogram so that we were making equal the areas between the trace being scaled and the horizontal line (McComb, 1952, pp. 177–178)" [see Lines 211-214]. In the Reference, we added one new item, namely (McComb, 1952) [Line 509].

202: not at our disposal > missing OR Where the magnetograms were incomplete

Response: We have used "Where the magnetograms were incomplete..." Thank you for the suggested wording. (Line 215)

Table 6 caption in ... days > on ... days

Response: Corrected.

Figure 1: Use wider line, connect sporadic red points with a thin or dotted line to guide the reader eye (line in Fig 2). Now it is difficult to follow the development of the storm in the presented plots. Consider if you could make this figure smaller.

Response: We have made the figure smaller, widened the line and connected the sporadic red points.

Figure 2: This figure could be made smaller. Note in the caption that the lines connecting the observations is added only to guide the reader's eyes.

Response: The note has been added to the caption of Fig. 2. The figure has been made smaller. The questionable values composing the second maximum are marked with question marks.

226: limpid > clear

Response: In the new manuscript, we have used the word "transparent". (We like the word "clear" as well, but it had already been used in the same sentence.) [Line 241]

226: sank > set

Response: Corrected. (Line 241)

227: the light was whitish even white: This is not very clear. maybe 'whitish or even white'

Response: We have added "or". (Line 242)

243: positive: does it have any relevance? The baseline is instrumental and does not have any physical meaning.

Response: We have erased "positive" and only written "eastern". (Line 267)

Fig 3: Thicker lines, smaller figure with properly adjusted caption size.

Response: A completely new Figure 3 has been included in the manuscript, in which we show original analogue magnetograms recorded by the Seddin observatory.

273: reference point > origin or pole

Response: Corrected we have used "origin". (Line 305)

277: Use QDP coordinates everywhere rather than a mixture of coordinates (it is unlikely that you need to redraw any plots because of this technical correction, since as you mentioned QDP and CGM are indistinguishable at high latitudes. Modify Table 1 accordingly.

Response:

Table 1 has been modified (quasi-dipole coordinates have been listed).

The QDP coordinates have been used everywhere in the new version of the manuscript.

283: the orientation of the arrows is adjusted as the respective variations would appear in the northern hemisphere if they were the result of currents in auroral ovals or FACs belonging to the northern hemisphere: This is not very clear to me.

Response: An explanation is provided in Lines 315-316 and 319-322.

288: parallels > circles of latitude

Response: Corrected. (Line 325)

290: increase: of what? Help the reader!

Response: Increase in the vertical intensity. Added to the text. (Line 327)

294: outer: ok, but equatorward is more specific.
Response: Changed to "equatorward". (Line 331)

318: locality > region
Response: Corrected. (Line 362)

320: close to the equatorward boundary of the oval, in this part of which the westward electrojet flowed > close to the section of the equatorward boundary of the oval associated with the westward electrojet [or sg similar]
Response: We have used the offered wording. Thank you for it. (Lines 364-365)

329: A possibly interesting ... : Rephrase this sentence, make it shorter and simpler.
Response: Rephrased (Lines 380-381).

332: each to other > in relation to each other
Response: Corrected. (Line 384)

333 With a great deal of... : Rephrase this sentence [themselves, northernmost]. This is a statement, the reasoning is missing.
Response: We have rephrased this sentence. In the current manuscript, the new piece of text is in Lines 386–391.

Figure 5. There is no need to repeat almost the whole caption of Fig 4. You could say simply: Same as Fig. 4 but for the vertical component.
Response: This figure has been removed from the manuscript.

340: good to mention > worth mentioning
Response: Corrected. (Line 397)

346: To achieve this goal, we dealt with several partial tasks > We achieved this goal through several steps.
Response: Thank you for the improved wording. We have used it in the new text (Lines 403-404).

355: can be compared > is comparable
Response: Corrected. (Line 413)

Units!
Response: Corrected.

365 and 377: You already mentioned in line 15 the changes of the name of the location throughout its history. It is ok to remind the reader once but it is absolutely unnecessary to do it twice
Response: We have removed this unnecessary information from here (Lines 423-424 and 434-435).

378: 56.5 nT: Not clear why this arbitrarily chosen temporal variation is relevant for the storm studied.
Response: This part of the text has been removed (Line 436).

Response to Referee #2

Review comments on the manuscript 10.5194/angeo-2023-12

" The record of the magnetic storm on 15 May 1921 in Stará Dala (present day Hurbanovo) and its compliance with the global picture of this extreme event"

E. Koci and F. Valach

Authors: We would like to thank Referee #2 for his or her time and work devoted to reviewing our manuscript and for the helpful comments.

The authors have tried to reconstruct the historical magnetic field recordings of the former Stará Dala observatory for the period of the major magnetic storm in the middle of May 1921. This can be considered a valuable contribution to better characterize space weather conditions during extreme magnetic storms. By applying different approaches for recalibrating the recordings and by comparison with neighboring observatories they obtain reasonably convincing data series for the time period of interest.

Besides these generally positive results the study contains also weaknesses, in particular when it comes to the storm-related magnetic variations. More details of the expected improvements are listed below. Overall, the work is regarded worth being made public, but substantial revisions are expected before it should appear in *Annales Geophysicae*.

General comments

1) The interpretation of the storm features based on the observed magnetic variations is not convincing. Generally, it is a pity that the northward, H component is missing at Stará Dala. This is most important for the characterization of magnetic activity. Deflections of the vertical, Z component are strongly influenced by the subsurface conductivity distribution. This fact should be clearly stated in the paper. For example, the observatories Wingst and Niemegek exhibit commonly opposite deflections during times of magnetic activity. This is caused by the effect of the so-called northern German anomaly. After having said that, it is worth to continue with the available data from Stará Dala.

Response: In Lines 374-378 (line numbers in the manuscript with changes marked) we added the following explanation: "In addition to the change in the vertical intensity due to the proximity of the west-flowing currents in the electrojet, the magnetic fields generated by the induced currents in the conductive ground play an essential role in the variations of the vertical intensity. They are thus strongly dependent on the subsurface conductivity distribution. Without an appropriate deeper analysis of the subsurface conductivity, which would be beyond the scope of this study, more detailed interpretations of vertical intensity variations cannot be correctly performed."

In the paper the shown variations recorded at Niemegek give the most complete picture of the storm evolution. However, they are taken about 5° north of Stará Dala. This can make significant differences during a magnetic storm. It would have been very instructive to add complete field recordings from similar latitudes. In my view Munich-Bogenhausen could provide valuable recordings for comparison, complementing very well the Niemegek data. The H variations from Munich could help to better quantify the southward extend of the electrojet.

Response: We have added the following explanation in the new manuscript: "Unfortunately, the relevant hourly means in Munich are not available as recording the temporal variations of the

geomagnetic field were discontinued during the years when the storm we are interested in occurred (Soffel, 2015)." (Lines 24-25) Also, a new reference has been added: H. C. Soffel, History of the Munich–Maisach–Fürstfeldbruck Geomagnetic Observatory, Hist Geo Space Sci, 6, 65–86, 2015.

2) Another topic of concern is the frequent quoting of field-aligned currents (FAC) in connection with observed eastward, D component variations. It is known since Fukushima's famous publication that field-aligned currents cause virtually not magnetic signature on ground. For that reason, all the parts where FACs are mentions should be revised in this respect. If FACs are quoted, the related Hall currents, that give rise to ground deflections, have to be introduced and made consistent with the observations. In some parts the major storm of October 2003 is taken as reference. For that, detailed observations from ground and satellite are available. For example, Wang et al. (Annales Geophysicae, 24, 311–324, 2006) describes well the relation of FAC to the intensity of solar wind input and ring current activity. This is different for day and nightside. Considering their results may help to support the offered interpretation.

Response: We have removed some interpretations related to this comment from Section 3.2.2 and from Discussion. Instead, we focus on the declination variations that were observed in the mid-latitudes in the morning sector between 03:00 UT and 07:00 UT. However, we do not quite agree with the referee regarding the application of Fukushima's Theorem to middle geomagnetic latitudes. Because the geometry of the geomagnetic field in mid-latitudes does not strictly meet the assumptions of Fukushima's Theorem (field lines in mid-latitudes cannot be considered perpendicular to the earth's surface; moreover, in disturbed geomagnetic conditions, the assumption of uniform conductivity might not be well fulfilled), even ground-based geomagnetic observations can capture at least some manifestations of FACs. In our opinion, this may also be the case for the mentioned mid-latitude declination variations in the morning sector between 03:00 UT and 07:00 UT. We added a paragraph that explains it in Lines 345–350. Side note (not included in the manuscript): Fukushima in another of his works "Field aligned currents in the magnetosphere" (in Geofísica Internacional, 1991, 30/4, pp. 241-248) dealt with field-aligned currents at middle and low latitudes. He wrote, for instance, that "The seasonal variation of the Sq field (in particular for magnetic declination or Y-component) will be attributable to some field-aligned currents [...]". However, these are not the FACs related to the auroral oval, of course.

Detailed comments

Line 117: The sentence "We also know that the then device worked in ..." is not clear.

Response: The recording in the variation device was made on photographic paper, which was moved at a speed of 1 cm per hour using a clockwork machine. The explanation has been added in Lines 125-126 (line numbers in the manuscript with the changes marked).

Sect. 2.2.3: The variations of the vertical component depend strongly on the subsurface conductivity; opposite deflections are observed between Wingst and Niemegek. The dependence on conductivity has to be mentioned.

Response: Done in Lines 374–378.

Fig. 1 It would have been instructive to mark the times of SCs here, possibly also in Fig. 3.

Response: We have marked the times of SCs in Figs. 1 and 3.

Fig. 2 The second peak in declination from Clementinum is rather questionable, while the first corresponds reasonably well with the related variations in Niemegek. However, around 18 UT the storm activity has died out. It is thus practically impossible that such a large D deflection could have happened. Here again the Munich data could be decisive. When presenting historical data, it is important to check critically their reliability. This critical assessment of the Clementinum data has to be spelled out clearer, e.g. in the paragraph following line 240.

Response: We also admit the two unexpectedly extreme data forming the second maximum might be erroneous; the cause of the error, however, has remained unrevealed for us. We added such an idea in Lines 270-271. In Fig. 2, we also marked graphically (using question marks) the two data in question.

Line 245ff: “Possibly it might be a manifestation of a field aligned current”, All these statements concerning FACs in relation to declination variations are misleading. They should be removed here and elsewhere.

Response: See our answer to the general comment no. 2.

Lines 320ff: The relations between H und Z variation at Niemegek and possibly Munich, could be used to estimate the latitudinal position of the westward electrojet. Actually, Z goes through zero under the electrojet. A simple model for quantifying the H to Z relation is to assume a line current in the ionosphere.

Response: Yes, we agree. However, this should also involve analysing subsurface conductivity, dealing with spectral analysis of the geomagnetic variations etc, which would be beyond the scope of our study.

Fig. 5: I am not sure what to learn from this figure. The sign of Z deflection varies from place to place, and not conclusions are drawn in this work from it. It well could be dropped or put into the Supplements.

Response: We have discarded Figure 5, which had shown the variations in the vertical intensity, from the new manuscript. The series of the images are only kept in the supplement.

Lines 341ff: In comparison with the 29 Oct. 2003, storm the Wang et al. paper should be used to help quantifying the expansion of the auroral oval. Useful information can be obtained in this regard from a reconstruction of the ring current intensity from low-latitude stations.

Response: We have compared the results of Wang et al. (2006) for the day side close to the noon meridian with the QDP latitude at which we expected the most equatorward extent of the auroral oval in the morning sector on the morning on 15 May. Our results seem to agree with what they found for the October 2003 events (Lines 456-462).

Lines 388ff: The conclusions listed here are presently pure speculation. After revision of the manuscript, they have to be improved.

Response: The conclusions have been revised (Lines 450-462).

Response to Referee #3

Referee on Eduard Koci and Fridrich Valach: The record of the magnetic storm on 15 May 1921 in Stará Dala (present day Hurbanovo) and its compliance with the global picture of this extreme event

The authors contribute with this article a data set of the strong magnetic storm of 13-15 May 1921, which was up to now not yet considered. The publication extends with this important data set the possibilities of researching an interesting geomagnetic event. The authors found a suitable method to recalibrate the data. For my opinion the authors succeeded in this comprehensive challenge. I recommend this article for the publication in *Anales Geophysicae*. Only minor changes are necessary.

Response: We would like to thank Dr. Linthe very much for his time and work devoted to our manuscript and for the comments. We are especially grateful for the offered magnetograms from Potsdam and Seddin as well as for the hourly means of Seddin.

I have the following detailed comments:

Caption and last line of table 1, line 238 and further lines: At the time of the magnetic storm the observatories Potsdam and Seddin existed, but not Niemegek. Niemegek was started to be established only in 1929 and opened in 1932. Therefore, Niemegek should be skipped or only mentioned as the successor station of Potsdam and Seddin.

Response: In the new manuscript, the magnetograms and hourly means of Seddin have been used. (Lines 27-30, 79, 227, 258, 264, 268, 274, 372, 383, 395-396, 442 and Table 1)

Line 107: Supplement (S1) – There is no supplement and no Fig. S1

Line 281: Supplement (S2... – There is no supplement and no Fig. S2

Line 205 and further lines: supplement – There is no supplement

Response: The supplement, which is containing Figs. S1 and S2, is now available on the following address: <<https://angeo.copernicus.org/preprints/angeo-2023-12/angeo-2023-12-supplement.zip>>

Line 207 and further lines: The word “registration” should be changed into “recording”

Response: We have changed the word “registration” to “recording” or “record” throughout the manuscript. (Lines 124, 210, 221, 266)

Caption of Fig. 3: A better word for “one-hour means” is “hourly means” or “hourly averages”.

Response: Throughout the manuscript, we have changed words “one-hour means” to better words, as recommended. (Lines 276, 286, 297, 300, 302, 351)

The data of Potsdam and Seddin distinguish by several nT, especially during geomagnetic storms. Therefore, it is not common to present a plot of “Potsdam/Seddin”. You need to plot the data of Potsdam or [Seddin.] Or, if you averaged the data of both observatories to mention about this.

[Fig.] 3: A plot of hourly mean values is not very valuable due to the ramps every hour. I could offer you analogue copies of the original magnetograms of both observatories Potsdam and Seddin, which are available in the Niemegek data archive. It is up to you to decide, what is better to be used. You may get an image of such copies in:

Linthe, H.-J.: History of the Potsdam, Seddin and Niemegek Geomagnetic Observatories – First Part: Potsdam, History of Geo- and Space Sciences, submitted 2022

Response: We have changed the plot of “Potsdam/Seddin” hourly means to the analogue copy of the original magnetogram recorded by the observatory Seddin. We are grateful to Dr. Linthe for providing the analogue copy for our manuscript.