Investigating the impact of cutting down nearby trees on measured values of the atmospheric electric potential gradient data

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Abstract

A group of trees located at the eastern side of the atmospheric electric potential gradient (PG) measurement site in the Széchenyi István Geophysical Observatory at Nagycenk (NCK) was cut down on the 24^{th} February in 2020. In order to assess the impact of this event on the PG measurements, an electrostatic numerical model was built to model the effect of the removal of trees. Moreover, the PG data recorded between 2017 and 2021 were analyzed. It was found that the PG increased by up to 52% after the trees in question were cut down. Based on the numerical model calculations this enhancement was expected to be larger, 78%. Further investigations concerning the seasonal variation of the PG recorded in 2017–2021 affirm that this increase is not part of the regular seasonal variation of the PG and it is an anomaly most likely caused by the diminished electrostatic shielding effect due to the fewer remaining trees.

Keywords: atmospheric electricity, atmospheric electric potential gradient, electrostatic shielding effect, trees, atmosphere–biosphere coupling, numerical modeling, electrostatics.

Introduction

The atmospheric electric potential gradient (PG) is the negative of the vertical component of the atmospheric electric field measured in Vm^{-1} units. It is a widely monitored parameter, usually measured near the ground (ca. at a height of 1–3 m) in geophysical and meteorological observatories all over the globe (Nicoll et al., 2019). The PG is one of the main parameters of the DC part of the so-called atmospheric

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Global Electric Circuit (GEC), which is a framework of electric currents connecting the Earth's surface and the lower ionosphere (Rycroft et al., 2012). The PG can be used as a versatile diagnostic tool as it can mirror variations in the GEC, global changes in Earth's climate system, or space weather processes (Rycroft et al., 2012).

PG measurements in the Széchenyi István Geophysical Observatory at Nagycenk, Hungary (NCK) began in 1961 under the supervision of geophysicists Pál Bencze and Ferenc Märcz with a locally developed potential equalizer instrument including radioactive ionizing source (Bencze & Märcz, 1981). Regular maintenance and weekly instrument calibration ensured high data quality over the course of decades up to the present date. In 1998, another locally developed radioactive instrument was installed to measure the PG simultaneously. Ultimately, in 2013, a more state-of-the-art apparatus, a Boltek EFM-100 field mill was deployed (Bór et al., 2020).

The shielding effect of trees

Nearby conducting objects, such as a metallic pole or living trees, bias the equipotential surfaces of the ambient atmospheric electric field, thus they can lower the PG measured in the vicinity (Lees, 1915). This phenomenon is called the electrostatic shielding effect and it contributed greatly to the reported long-term reduction in the PG time series recorded in NCK (Märcz & Harrison, 2003; Williams et al., 2005; Buzás et al., 2021). The site of the PG measurements in NCK is located on a clearing surrounded by groups of trees and a forest. In the course of time, as the trees grew taller, their shielding effect became more and more significant, further lowering the PG near the surface. In order to correct for this unwanted shielding effect, a numerical model based on the finite element method was built. The detailed description of the model can be found in the paper by Buzás et al. (2021).

On the 24^{th} February in 2020, the group of trees that bordered the measuring site at the eastern side was cut down. To quantify the impact of this event, the geometry of the numerical model was changed; the eastern group of trees was removed from the model (Fig. 1). By evaluating the model with the two configurations, the impact of the change in the local geometry on the recorded PG values can be inferred (Fig. 1).

Data and methods

Only the fair-weather PG data of the Boltek EFM-100 field mill (measured at a height of 3 m) that were not corrected for the shielding effect of nearby trees are used in the present study. This study is based on fair-weather PG values which are PG values that were measured in the so-called fair-weather conditions, i.e., in time periods when the effect of local meteorological conditions and clouds is not significant on the PG measurements (Harrison & Nicoll, 2018; Nicoll et al., 2019). As we lack concurrent supplementary meteorological data suitable for identifying fair-weather conditions reliably, fair-weather selection of the PG data was made

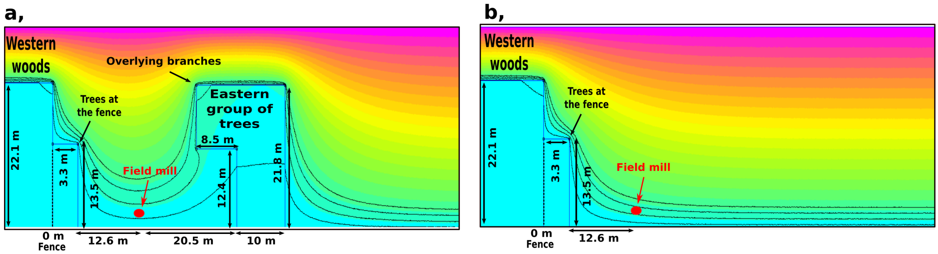

Fig. 1: Model geometry **(a)** before and **(b)** after the eastern trees were cut down on the 24^{th} February, 2020.

on the basis of statistical considerations solely based on the sign and magnitude of the measured PG values. Firstly, negative PG values can be omitted as they are characteristic to foul weather conditions (Harrison & Nicoll, 2018). Moreover, large positive PG values can also be associated with foul weather (e.g., low level charged clouds very near or over the measurement site). Altogether, the positive PG values that were below five times the median of all absolute deviations from the median of the full distribution were considered as fair-weather data (Lucas et al., 2017). Fair-weather correction was made on the original, high time resolution fair-weather PG data recorded at 2 Hz. Hourly averages were calculated from the high time resolution fair-weather data, and these hourly averages were used in all further analysis. In this work, only the fair-weather raw PG data measured at a height of 3 m by the Boltek EFM-100 field mill were used. Note that the data were not corrected either for the shielding effect of nearby trees in any way, or by the form factor of the instrumental setup.

The expected effect of cutting down the trees is estimated using the two numerical models for the site. The modeled PG values are calculated from the two models at the location and height of the EFM-100 measuring head (Fig. 1). The ratio of these two modeled PG values is supposed to mirror the ratio of the measured PG values before and after the change in the configuration of objects onsite.

Since the trees were cut down on a single day, the change in the data, if it appears, should be apparent immediately. Day-to-day variations in the PG, however, can mask smaller differences, so a statistical approach is preferred. Seasonal variation of the PG data (Chalmers, 1967, pp. 168–169), however, imposes a limit on the extension of the time periods of the investigation before and after the tree-cut. To make a compromise, fair weather data from 14 days before and after the tree-cut were considered and the corresponding statistics obtained from the selected measured data were compared.

To investigate how the tree-cut affects the PG measurements in NCK on a longer term, seasonal variation of fair weather data (i.e., monthly averages) were calculated from years of 2017–2021. This way, ratios of the PG data in the same periods of the years before and after the change could be studied.

Results

Derived from calculations based on the two different states of the numerical model before and after the eastern group of trees was cut down, the modeled enhancement of the PG at the location of the Boltek EFM-100 field mill is +78% after the removal of the trees (Fig. 1).

Figure 2 shows the histograms of the PG values recorded two weeks before and after the eastern group of trees was cut out in 2020. The mean, median, and the maximum of the Gaussian Kernel Density Estimation (KDE) function of the PG values taken from the 10–23 Feb 2020 period, two weeks prior to the eastern trees were cut down, are 60 Vm^{-1}, 58 Vm^{-1}, and 57 Vm^{-1}, respectively (Fig. 2a and Tab. I). However, the mean, median, and the maximum of the KDE of the PG values taken from the data recorded two weeks after the trees were cut down (25 Feb–09 Mar 2020) are 89 Vm^{-1}, 88 Vm^{-1}, and 88 Vm^{-1}, respectively (Fig. 2b and Tab. I). This means an enhancement of 29 Vm^{-1} (+48%), 30 Vm^{-1} (+52%), and 31 Vm^{-1} (+54%) when considering the mean, median, and the maximum of the KDE, respectively.

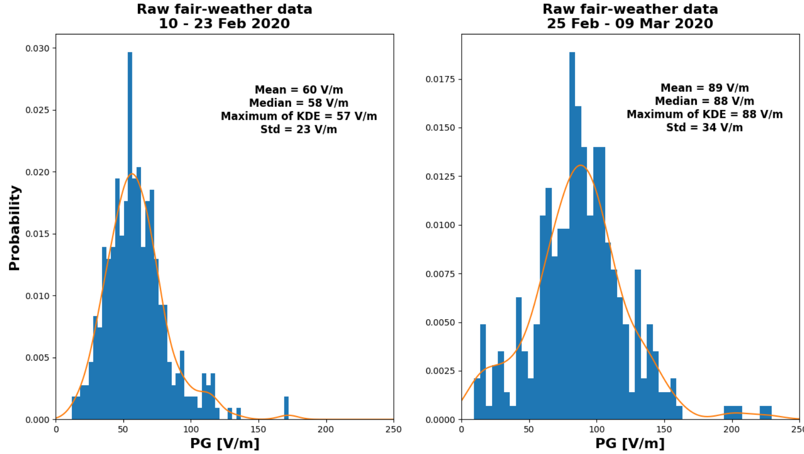

Fig. 2: Histograms of the raw PG data measured two weeks before and after the eastern group of trees was cut down in 2020. Orange solid lines denote the Gaussian Kernel Density estimation functions, an estimation of the probability density function of the raw PG data.

In order to affirm that the enhancement was not caused by the regular seasonal variation of the PG, the mean PG values were calculated for the past three years (2017, 2018, and 2019) and for 2021 in the same time periods (Tab. I). The PG decreased in 2017, 2019, and 2021, or stagnated in 2018 between the time periods

10–23 Feb and 25 Feb–09 Mar, i.e., two weeks before and after the day of the year when the change happened in 2020. Compared to these trends, the PG increased dramatically in the same time period in 2020. This supports the conclusion that the PG increased in 2020 due to the cutting down of the eastern trees, which reduced the shielding effect (Tab. I).

Table I: Mean values of PG data measured 14 days before and after the day of the year (24^{th} February) of cutting the trees. Averages from the years 2017–2021 are given.

	Mean values in years				
	2017	**2018**	**2019**	**2020**	**2021**
PG in 10–23 Feb [V/m]	99	95	79	60	158
PG in 25 Feb–09 Mar [V/m]	73	99	67	89	92
Percental change	-26%	+4%	-15%	**+48%**	-71%

The PG measured at continental stations on the northern hemisphere has a minimum in the summer and reaches its annual maximum during the winter (Chalmers, 1967, pp. 168–169). The PG in the years of 2017, 2018, 2019, and 2021 follows this regular seasonal variation (Fig. 3). However, that is not the case in 2020. In 2020, the PG began to decrease in February, yet it does not continue to diminish in March. In March 2020, there is a significant increase in the PG which is not a regular phenomenon (Fig. 3). This increase was likely caused by the cutting down of the eastern trees on 24^{th} February. Moreover, after February 2020, the PG is higher than the average PG taken from the years 2017–2019 and this continues in 2021 as well (Fig. 3). In 2020 until February, the PG followed the average of the previous years while from March on, the values are clearly closer to the values recorded in the next year. Note that fairly large PG values were measured by the field mill especially in the winter of 2017–2018 in NCK compared to the values recorded in the following years. It is not currently known why those PG values were so large.

The modeled enhancement of the PG values due to the removal of the eastern trees (+78%) overestimates the enhancement that was measured (+48–52%) (Tab. I). In order to examine this difference on a longer time scale, percental differences between the measured monthly PG means in 2017–2021 were calculated (Tab. II). For each month from September to February, the average of the monthly means in the time period 2017–2020 (the first solid red curve in Fig. 3)

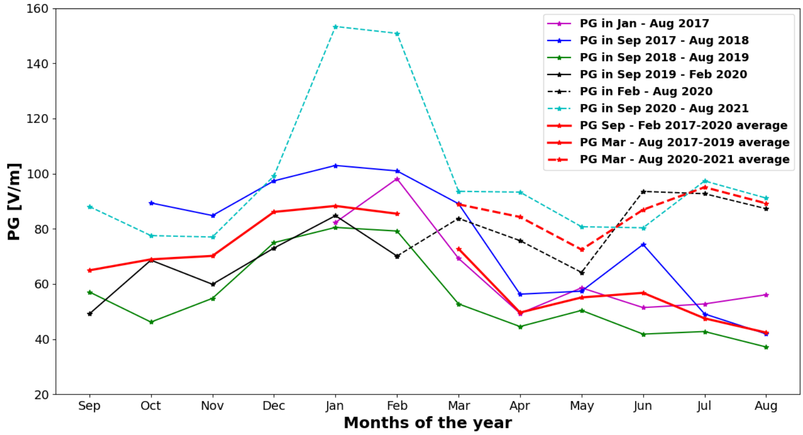

Fig. 3: The seasonal variation of the PG in NCK in years between 2017 and 2021. Note that the years are plotted from September to August to aid comparing measurements before and after the trees were cut down at the end of February, which is now in the middle of the time axis.

Table II: Percental change in averaged monthly PG means after the cutting down of the trees. Data from the years 2017–2021 are considered. See the text for details.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul
Percental difference	+75%	+73%	+26%	+69%	+31%	+56%	+97%
Months	Aug	Sep	Oct	Nov	Dec	**Mean**	
Percental difference	+98%	+66%	+14%	+16%	+21%	**+53%**	

was compared to the monthly mean in 2020–2021 (dashed cyan curve in Fig. 3). For each month from March to August, the average of the monthly means in the time period 2017–2019 (the second solid red curve in Fig. 3) was compared to the average of the monthly means in the time period 2020–2021 (dashed red curve in Fig. 3) (Tab. II). This percental difference is quite variable over the course of months, having higher values during the summer and in January and February, whereas having lower values near the end of the year (Tab. II). The mean of the monthly percental differences is +53% which is in good accordance with the +48–52% enhancement derived from the PG data two weeks before and after the eastern trees were cut down (Fig. 2; Tab. I and II). Exceptionally high PG values in the January 2017–August 2018 time period enhanced the average taken from 2017–2019 diminish the percental difference between the monthly averages (Fig. 3; Tab. II).

Summary and Conclusions

The group of trees at the eastern side of the PG measurement site in NCK was cut down on 24^{th} February in 2020. This event caused a significant increase in the PG by 48–52% compared to its former value based on the mean PG values taken from the PG data two weeks before and after the cutting down of trees (Fig. 2; Tab. I).

The increase in the PG after the trees were cut out is not a regular enhancement caused by the normal seasonal variation of the PG as the PG decreased in the same periods in 2017, 2019, and 2021 as well (Fig. 3; Tab. I).

The annual variation of the PG in 2020 does not follow the regular annual variation (Fig. 3). The PG in 2020 does not begin to diminish after February. On the contrary, it shows a significant increase from February to March. This phenomenon is most likely caused by the fact that the eastern trees were cut down on the 24^{th} February in 2020.

The numerically modeled increase in the PG is +78% which is higher than the measured one (48–52%). Considering that the PG drops significantly in that period of the year and the generally large variance of the PG values, the agreement between the measured and the modeled change in the PG values is fair. Note that the percental differences between the monthly PG means in 2020–2021 and in 2017–2019 also show a large variability, ranging from +14% (in October) to +98% (in August) (Tab. II). High PG values in January 2017–August 2018 tend to reduce the deduced average percental enhancement causing a larger difference between the modeled and measured enhancements (Fig. 3).

Acknowledgements

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