



The effect of the atmospheric electric field on trees

Guenter Buntebarth

5 Institute of Geotechnology and Mineral Resources, Technical University of Clausthal, D-38678 Clausthal-Zellerfeld, Germany

email: pggb@tu-clausthal.de

10 **Abstract.** Between the ionosphere and the Earth's surface, a continuous electric field exists that is influenced by solar activity and, particularly in the lower atmosphere, by meteorological processes. The positively charged ionosphere induces a negative charge on the Earth's surface, resulting in a continuous current flow from the surface into the atmosphere. Irregularities in the electrical properties of the surface, such as trees, cause local variations in the atmospheric electric field, which can be measured as electrical potential gradients along the tree stem. Owing to its higher electrical conductivity compared with the surrounding air, a tree acts as a conductive pathway in the lower atmosphere, allowing variations in the atmospheric electric field to be directly reflected in stem potential measurements. The temporal variability of the measured signals is dominated by periodic components associated with solar radiation, consistent with thermally driven atmospheric tides that influence both the atmospheric electric field and sap flow in the tree. As a result, the individual contributions of these two effects cannot be separated. Superimposed on these patterns are meteorologically induced variations, including pronounced perturbations associated with electrically charged thunderclouds. Furthermore, directional dependencies in the measurements suggest sensitivity to wind-driven changes in the local atmospheric environment. At larger scales, enhanced potential gradients coincide with periods of increased solar activity, such as X-ray fluxes, particle events, and coronal mass ejections, indicating a coupling between space weather and near-surface electrical conditions. In contrast, no evidence for an influence of tidal gravitational forcing was found in this study.

25 1 Introduction

Since the nineteenth century, it has been recognized that the Earth is surrounded by a layer of positively charged ions in the ionosphere, continuously generated by cosmic radiation, solar radiation, and radioactive decay at the Earth's surface (e.g. Elster and Geitel. 1899a,b,c; Kähler, 1921, 1929). Due to electrostatic induction, the Earth's surface carries a net negative charge, establishing a vertical electrostatic field in the atmosphere that drives a continuous current from the surface into the atmosphere (e.g. Israel, 1957, 1969; Mühleisen, 1957).

The atmosphere acts as a weak electrical conductor, while trees can be conceptualized as resistive elements within the electrical pathway between the Earth's surface and the atmosphere. In this framework, a tree represents part of a voltage



divider within the atmospheric column. Because the tree exhibits higher electrical conductivity than the surrounding air, an enhanced current flows from the roots through the stem and is released at the canopy via point discharge or through charge exchange with airborne particles (Gibert et al., 2006; Mühleisen, 1957).

Under fair-weather conditions, the atmospheric electric field typically exhibits a mean potential gradient of approximately 100-130 V m⁻¹ near the surface. This gradient varies across diurnal, seasonal, and annual timescales and is strongly modulated by meteorological conditions and anthropogenic influences (e.g. Burr, 1947; Elster and Geitel, 1899b; Kähler, 1921, 1929). In particular, combustion processes and industrial emissions introduce charged aerosol particles that can locally alter the atmospheric electrical state (e.g. Israel, 1969; Kähler, 1921, 1929; Mühleisen, 1957; Retzow, 1936).

The rotation of the Earth and its relative configuration with the Sun and the Moon give rise to daily, monthly, annual, and longer-period gravitational and thermal variations. However, the global electrostatic field is primarily generated by the Sun (e.g. Haurwitz, 1964; Laplace, 1799; Mühleisen, 1957; Siebert, 1961; Volland, 1997). Solar thermal radiation heats the atmosphere and drives thermally induced mass transport, such as atmospheric tides (Lindzen, and Chapman, 1969). These tides involve the motion of charged particles and lead to periodic variations in atmospheric electricity as well as in the electrical potential at the tree.

Through point discharge at its top, the tree loses charged particles, while the roots continuously supply water and minerals. The mobile charged particles are generated mainly by the decay of unstable isotopes, particularly potassium, as well as by decay products of uranium, thorium, and others (e.g. Israel, 1957; Kähler, 1921, 1929; Mühleisen, 1957; Retzow, 1936). Depending on the decay products, some particles are incorporated as nutrients (e.g. calcium), whereas others leave the tree in the form of argon. The potassium content of a tree contributes significantly to the electrical conductivity within the stem, not only through ionic conduction but also via beta decay, which continuously generates charged particles. If a tree contains 5% potassium, several thousand decay events occur per second per kilogram of wood.

The relationship between meteorological conditions and atmospheric electricity has been described in many studies (e.g. Burr, 1947; Elster and Geitel, 1899a,b; Haurwitz, 1964; Israel, 1957, 1969; Kertz, 1957; Mühleisen, 1957; Retzow, 1936; Siebert, 1961). All factors that influence the electrical conductivity of air also affect the electrostatic field; in particular, air humidity strongly determines its resistivity. Variations in pressure and temperature influence resistivity indirectly by modifying relative humidity. Strong perturbations occur during thunderstorms (e.g. Israel, 1957, 1969; Kähler, 1921, 1929; Retzow, 1936).

Most of the studies of the electrical potential at the tree stem consider the active contribution by demonstrating coherence between sap flow and electrochemical and electro-physical effects (e.g. Fensom, 1963; Hu et al., 2024; Fromm and Lautner,



2007, Ghildiyal et al., 2025), whereas the passive role within the atmospheric electric field is rarely discussed (e.g. Le Mouél et al., 2010).

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Numerous studies have investigated gravitational effects associated with the Sun and Moon and reported empirical relationships with both the electrical potential at the tree stem and stem diameter (e.g. Burr, 1947; Fisahn, 2018; Gibert et al., 2006; Hao et al., 2021; Holznecht and Zürcher, 2006; Koppán et al., 2000; Zürcher, 2006, 2019; Zürcher et al., 1998). Although empirical correlations can be identified within specific geographical regions and limited time intervals, a universal law has not been established, and a direct causal relationship has not been conclusively demonstrated. Very likely, the availability of water in the subsurface is modulated under specific conditions with the same periodicity as tides. The depth of the water level beneath the surface can relate to the tides (Buntebarth et al., 2020; Hsieh et al., 1988; Jahr et al., 2020; Jimsheladze et al., 2021; Kümpel, 1997; Melchior, 1960). Large trees require substantial water, and limited availability may trigger uptake variations driven by tidal permeability changes (Pinheiro et al., 2023).

This study aims to determine which external effects influence the electrical potential gradient at the tree stem and to what extent.

2 Methodology

A fruit tree (*Prunus cerasifera*) was selected for continuous measurements of the electrical potential gradient along its stem at the coordinates: 51.81, 10.34. The tree has a height of approximately 7 m and a stem diameter of about 0.12 m. Two platinum electrodes of 2 mm x 25 mm were installed on the stem at the main geographic orientations with a vertical separation of 0.6 m. The lower electrode was positioned ca. 0.5 m above ground level. The electrodes penetrated the xylem and phloem tissues.

Two ecoV data acquisition systems (GeoTec) recorded measurements at 15-minute intervals. The monitored parameters included air pressure and device temperature inside a nearby building, as well as the electrical potential, the relative humidity and the temperature from 4 sensors mounted at the stem between the electrodes at the four geographical orientations. Each sensor was equipped with a 24-bit analog-to-digital converter with an extremely high input impedance to minimize electrical loading effects.

Particular emphasis was placed on identifying extraterrestrial as well as meteorological influences. The solar activity is published at SpaceWeatherLive and the general meteorological conditions of the environment are measured at the Weather Station of the TU Clausthal. Spectral analysis was applied to separate and characterize the different contributions. The predicted gravitational forces were computed using the software package ETERNA34 (Hartmann and Wenzel, 1995; Wenzel, 1996).



3 Results

The results are presented in several sections. One section analyzes the electrical potential gradient (grad E) as a function of temperature. A second section examines weather-related effects on the potential gradient measurements. Another section investigates the relationship between solar influences and the electrical potential gradient at the stem, while a final section explores the effect of gravitational forces on the electrical potential gradient.

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3.1 Relationship between the electrical potential gradient (grad E) and stem temperature

Temperature and potential gradient were measured at different orientations around the stem and during different seasons. A winter data series is shown in Fig. 1a. For clarity, the potential gradient axis is inverted. The potential gradient exhibits a pronounced diurnal variation, with maximum values occurring in the early morning and minima in the afternoon. Spectral analysis (Fig. 1b) reveals a dominant 24-h periodicity together with additional components at 12 and 8 h. Similar spectral characteristics are observed on both the northern (shaded) and southern (sunlit) sides of the stem, consistent with the temperature spectrum.

Measurements obtained during summer (8–16 August 2025) are presented in Fig. 1c. Again, the potential gradient axis is inverted for visual comparison. In contrast to the winter observations, the potential gradient maximum occurs in the late evening shortly before midnight (local time, UTC+2). Two daytime minima are observed, separated by a weak relative maximum; the first occurs before noon and the second during the afternoon. Spectral analysis (Fig. 1d) shows a dominant diurnal component (24 h, 1 cpd) with additional harmonics at 12 and 8 h (2 and 3 cpd) in both temperature and the shadowed northern potential gradient signal. On the sunlit southern side, multiple spectral contributions with peaks at periods of 11.28 and 6 h are identified.

A fair-weather period in May 2025 was analyzed to investigate the influence of solar thermal radiation (Fig. 2). Figure 2a shows the temperature and potential gradient measured on the southern side of the stem, with the potential gradient axis inverted for comparison. A clear relationship between both variables is apparent. When the direct influence of solar radiation is excluded by considering only nighttime data (evening to morning), a strong linear relationship between potential gradient (mV m^{-1}) and temperature T ($^{\circ}\text{C}$) is obtained (Fig. 2c):

$$\text{grad E (mV m}^{-1}\text{)} = -2.49 T + 25.2 \text{ during night.} \quad (1)$$

Including periods of maximum solar heating, which correspond to the highest stem temperatures, results in a temperature dependence:

$$\text{grad E (mV m}^{-1}\text{)} = -1.62 T + 41.7 \text{ during day.} \quad (2)$$

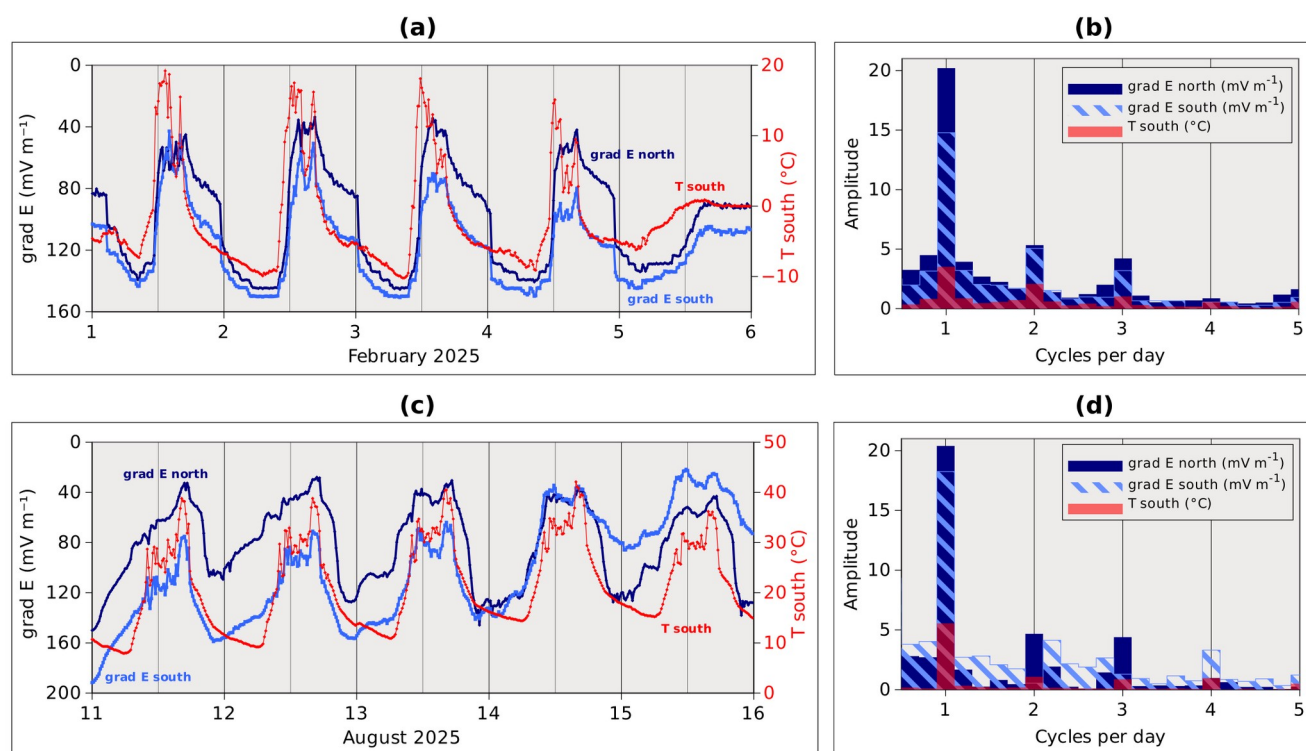


Figure 1: Measurements of temperature and potential gradients (a) during the first week of February 2025 with (b) spectral components of these measurements and (c) from 8–16 August 2025 with (d) spectral components of these measurements.

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The influence of solar heating during a single day and at different orientations around the stem is illustrated in Fig. 2b,d. As solar radiation reaches the eastern side of the stem around 10:00 local time (Fig. 2c), the potential gradient decreases, as seen in Fig. 2d (potential gradient axis inverted). A small relative maximum occurs between 13:00 and 14:00 but is not evident on the northern side. The strongest temperature increase occurs between 16:00 and 17:00, when the southern, western, and northern sides warm simultaneously, accompanied by corresponding variations in the potential gradient. The eastern side, being opposite the solar position in the afternoon, is no longer affected by direct thermal radiation. After sunset, temperature decreases while the potential gradient increases at all orientations.

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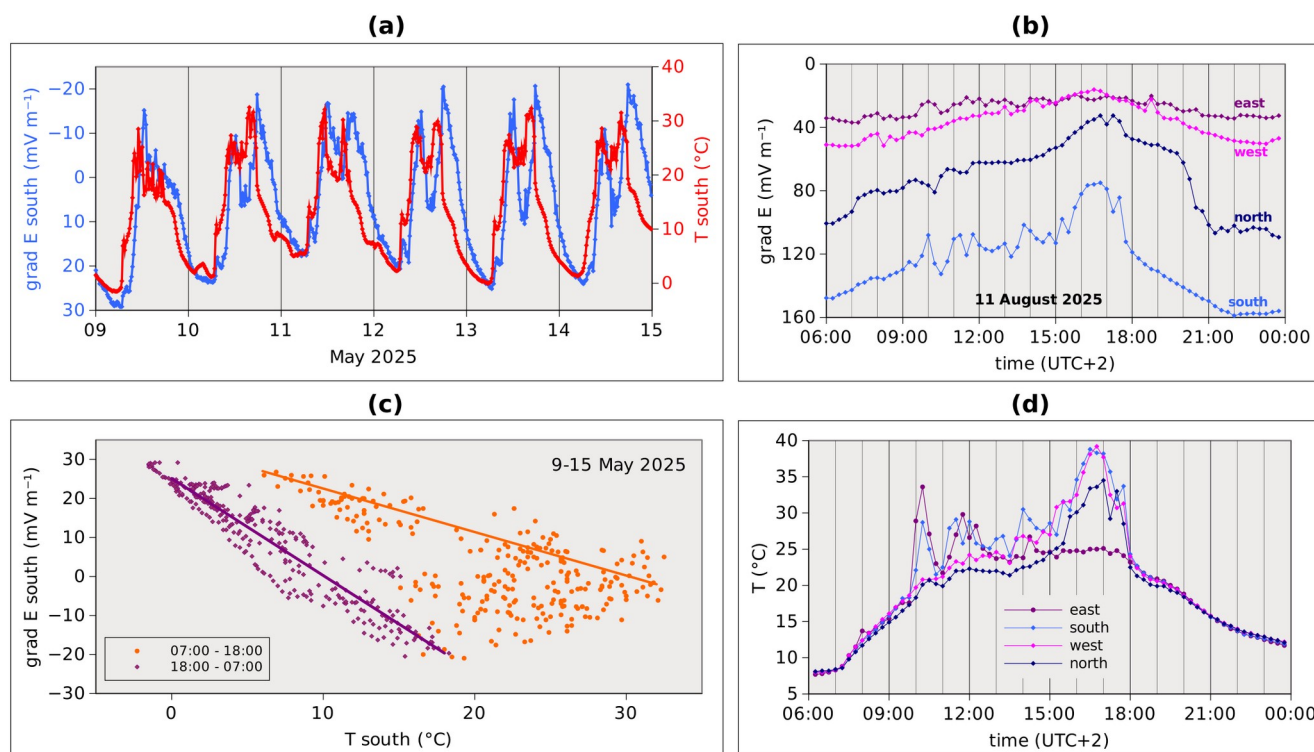


Figure 2: Measurements of temperature and potential gradients (a) on the southern side from 9–15 May 2025 with (c) temperature dependence of the potential gradient during day and night and (b) potential gradients measured at the main geographical directions with (d) stem temperature during a single day.

3.2 Relationship between the electric potential gradient (grad E) and weather conditions

The previous chapter demonstrated the influence of temperature under fair-weather conditions. Another relevant meteorological parameter is air pressure; however, pressure variations cannot be considered independently of other atmospheric properties. Changes in air pressure are typically accompanied by temperature variations, and both influence the relative humidity near the Earth's surface. Cloud cover in combination with wind is another decisive factor, as several related processes strongly affect the atmospheric electric field. Precipitation also produces pronounced changes in the potential gradient.

Measurements from all geographical directions are shown in Fig. 3d,e. A strong decrease occurred on 23 July at the southern side, whereas the other directions show much smaller anomalies at the same time (Fig. 3d,e). The bars along the time axis indicate the wind direction (Fig. 3b,c). Sudden changes in wind direction are immediately reflected in the potential gradient.

On 22 July, strong southwesterly winds brought heavy rainfall (Fig. 3a). During this event, the potential gradient on the southern side decreased from about 140 mV m^{-1} to -50 mV m^{-1} and by about 40 mV m^{-1} on the northern side, while only minor changes were observed on the western and eastern sides. After the rainfall, air pressure and temperature increased on 23 July, whereas the potential gradient decreased, consistent with typical fair-weather behavior.

The wind was not strong on 25 July, but it veered from different directions with thundery shower. During this event the grad E increased at all directions.

On 26–27 July, air pressure decreased while the wind veered from southwest to north. This period was associated with heavy precipitation and increasing potential gradient values on the eastern, northern, and western sides, but a pronounced decrease of about 200 mV m^{-1} on the southern, wind-shadowed side. Notably, the temperature–potential gradient relationship was not inverse on the morning of 22 July or on 25 July prior to precipitation. During such conditions, charged clouds dominated the electric field in the lower atmosphere and not the temperature.

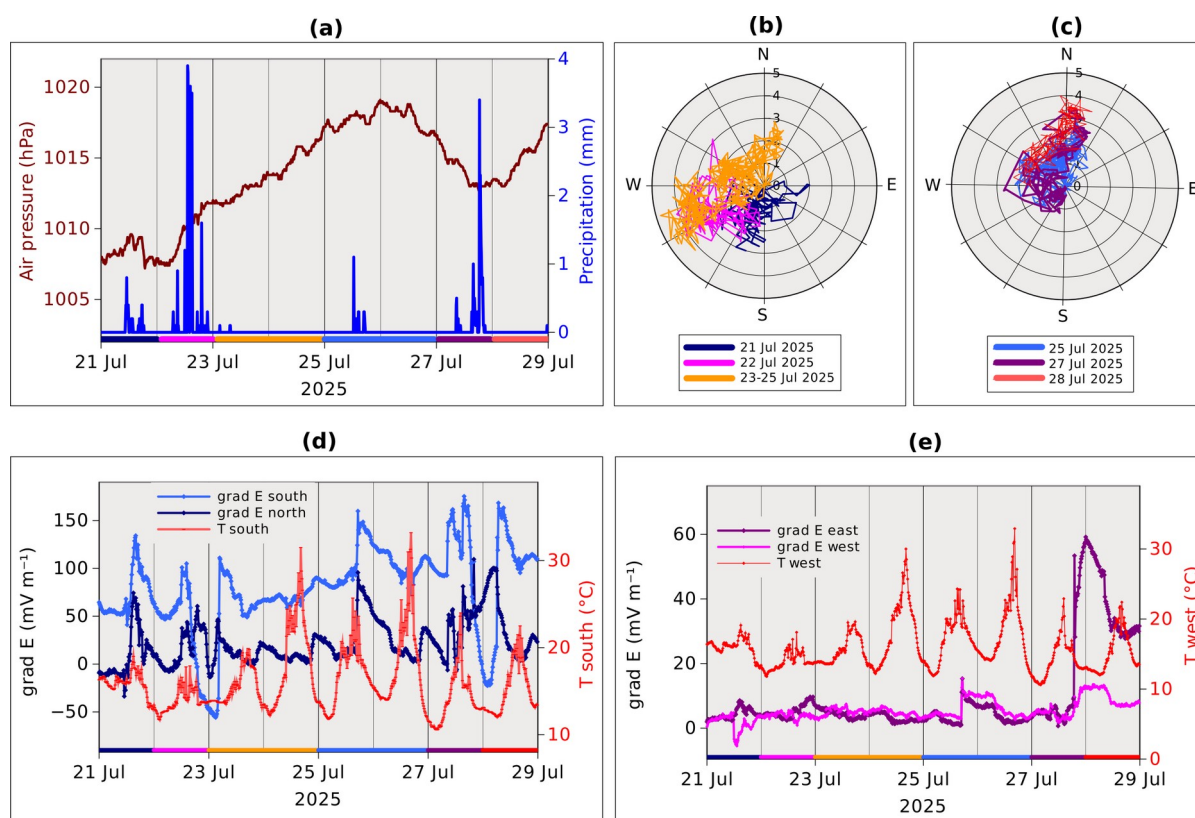
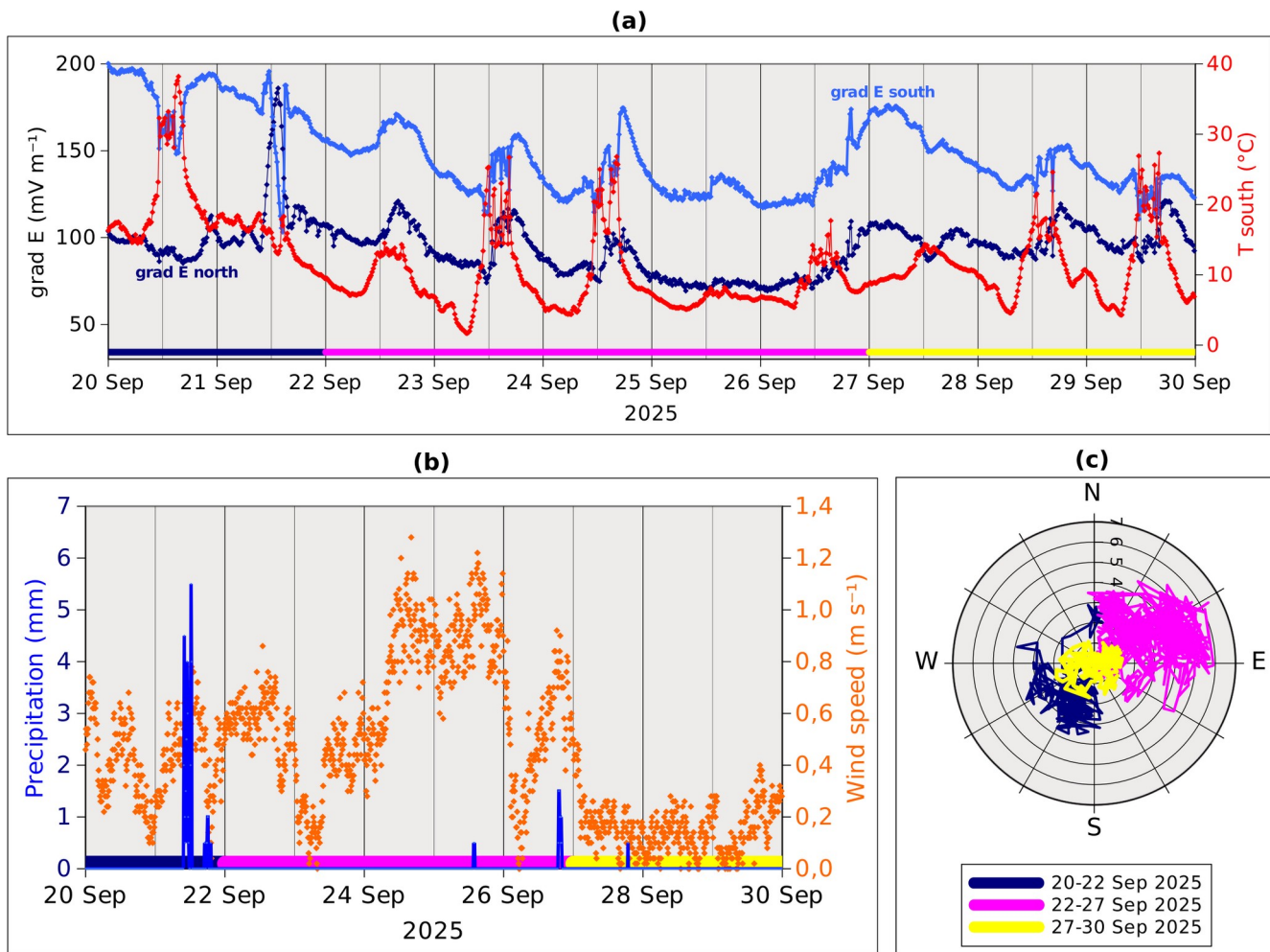


Figure 3: Temperature and potential gradient (a) at the southern and northern sides during 21–29 July 2025 and (b) measurements at the western and eastern sides during the same period; (c) air pressure and precipitation during 20–29 July 2025; (d) wind direction and strength during 20–24 July 2025; (e) wind direction and strength during 27–29 July 2025.



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A further case study is presented in Fig. 4. Under normal conditions, the temperature–potential gradient relationship is inverse as shown on 20 September; however, heavy rainfall can temporarily reverse this behavior. On 21 September 2025, precipitation produced a negative potential gradient anomaly of about 80 mV m^{-1} on the southern side and a positive anomaly on the northern side. At the same time, the wind direction shifted from southwest to northeast according to Fig. 4c with the bars along the time axis of Fig. 4a. Subsequently, potential gradient increased with rising temperature during the following days. After the wind weakened, the typical inverse temperature–potential gradient relationship was restored on 29 Sep 2025.



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Figure 4: (a) Temperature and potential gradient at the southern and northern sides during 20–30 September 2025; (b) precipitation and wind speed and (c) wind direction and its strength during the same period.

Thunderstorms constitute highly dynamic atmospheric phenomena. Cumulonimbus clouds are capable of inducing rapid variations in the atmospheric potential gradient, reaching magnitudes of several hundred mV m^{-1} . In August 2024, a sudden shift in wind direction from southeast to north as Fig. 5c and the bars along the time axis indicate, triggered a precipitation event (Fig. 5b) with a total rainfall of up to 5 mm accompanied with a step of both the southern and northern potential gradient of more than 100 mV m^{-1} . Subsequently, cumulonimbus clouds advected from the west, resulting again in an increase in the potential gradient exceeding 100 mV m^{-1} on both the northern and southern sides of the stem (Fig. 5a).

The concurrent onset of increasing atmospheric pressure and a northerly wind shift with increasing wind speed was associated with a decrease in air temperature and an abrupt rise in the potential gradient of approximately 60 mV m^{-1} . Within 24 hours, the potential gradient gradually returned to baseline values ranging between 0 and 50 mV m^{-1} .

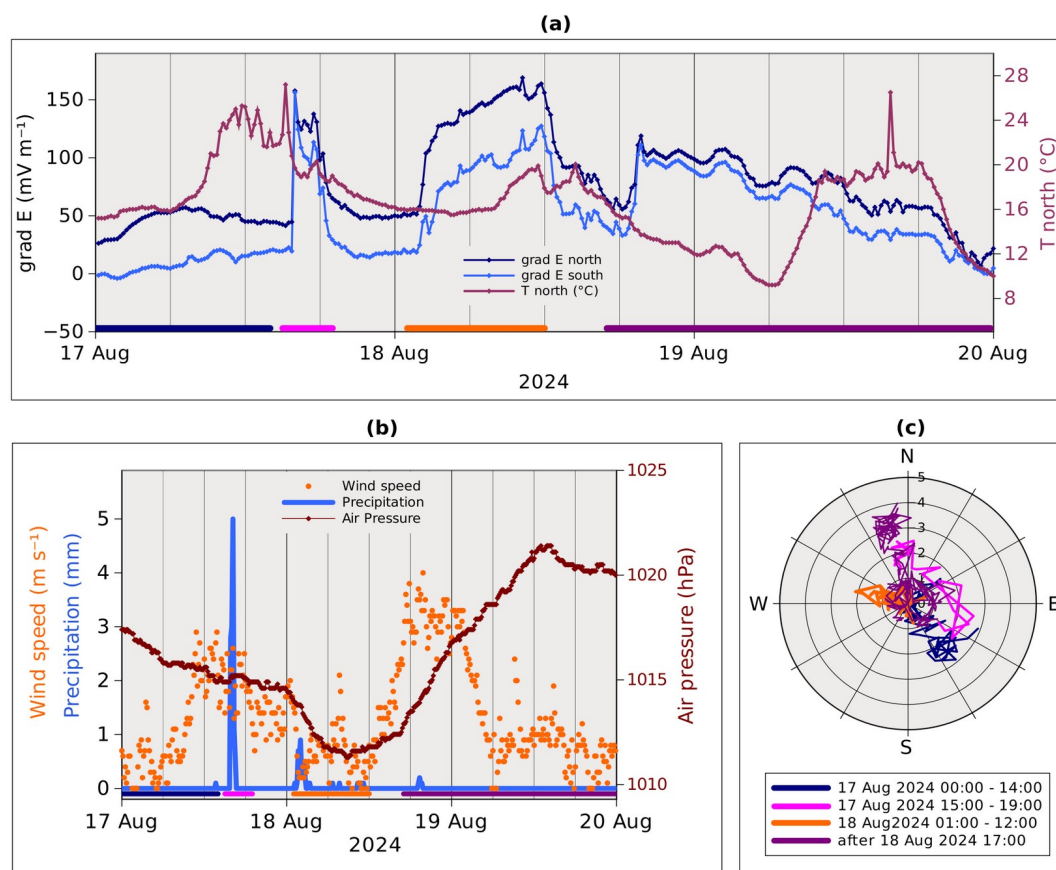


Figure 5: (a) Potential gradients and temperature during a thunderstorm period; (b) the weather conditions and (c) wind direction and its strength during the same period.

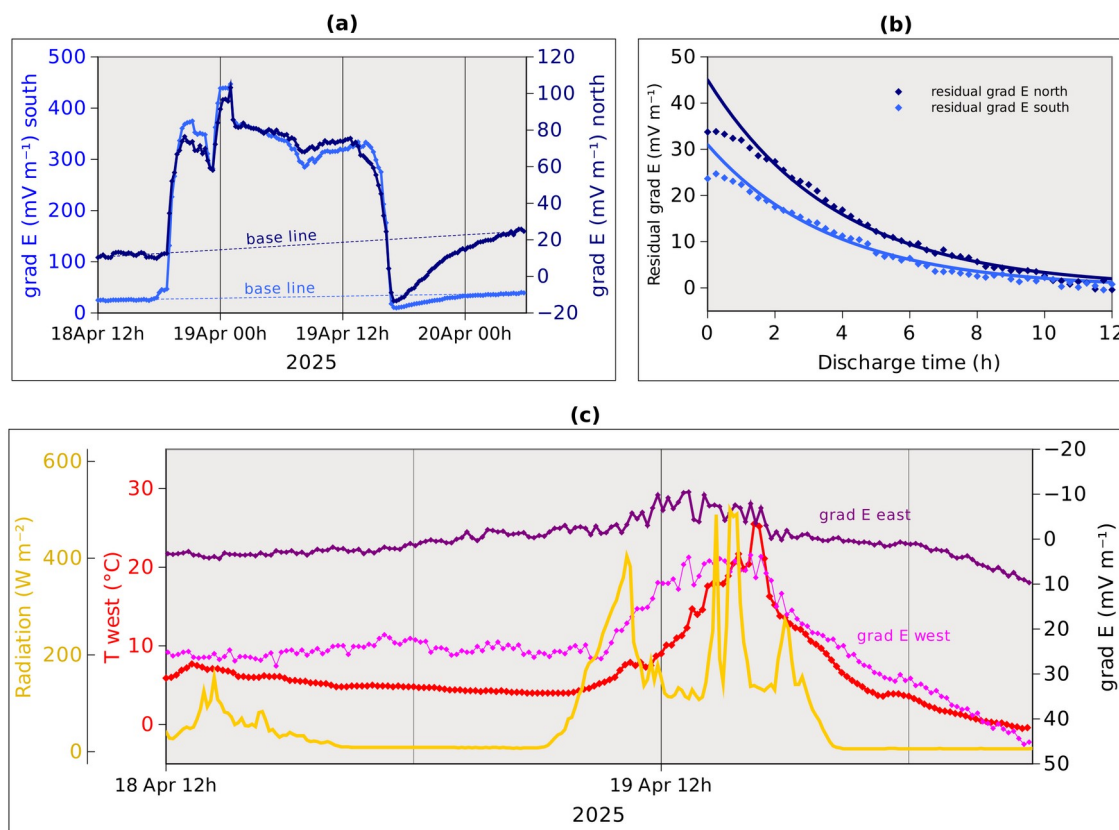


Figure 6: (a) Southern and northern potential gradients during a flare passing the Earth; (b) the eastern and western residual potential gradient after the flare has passed the Earth as well as (c) southern temperature, radiation, the eastern and western potential gradients.

3.3 The effect of solar flares and mass ejections

Solar eruptions and particle ejections produce radiation streams that may graze or directly impact the Earth, thereby affecting the atmospheric electric field. X-ray bursts are short-lived, whereas solar flares vary in duration and magnitude. These processes maintain the positively charged ionosphere and the continuously varying current flow through the atmosphere. A few examples illustrate the strong impact of solar flares and mass ejections on the atmospheric electric field, with consequences observable at the Earth's surface. The arrival of a solar flare with a sufficiently long duration and a high density of charged particles can significantly increase the charge of the upper atmosphere and, through electrostatic induction, the negative charge on the Earth's surface. Once the flare has passed the Earth, the accumulated negative charge equalizes across the surface, and the resulting capacitor discharges exponentially according to the resistance of the



subsurface and the atmospheric conductivity. Figure 6a shows measurements taken on the southern and northern sides during the passage of a flare from 18 April, 15:00 UTC, to 19 April, 14:30 UTC which could be launched on 14 April 21:00 (SpaceWeatherLive). By applying assumed baselines, the effect of the flare can be isolated. After the flare has passed, the difference between the measurements and the baseline is calculated as a residual electrical gradient, as shown in Fig. 6c. Approximately 10 hours are required for the charge to equalize.

The trend lines are described by:

$$\text{residual grad E south (mV m}^{-1}\text{)} = 31 \exp(-0.27 t) \quad (3)$$

$$\text{residual grad E north (mV m}^{-1}\text{)} = 45 \exp(-0.26 t) \quad (4)$$

with the time t (h) after the flare has passed the Earth.

Figure 6c provides information on the impact of the flare on the western and eastern sides of the stem, as well as on the meteorological conditions. The arrival of the flare causes a slight increase of only a few mV m^{-1} on the western side, while the eastern side is not affected. The variations observed on 19 April can be explained by temperature changes and increased sunshine. The grad E axis is inverted for better visual comparison.

Figure 7a demonstrates the influence of solar flares on the electrical potential gradient at the tree stem during beginning of February 2025. The spatial extent of the flares was so large that the Earth passed through them over four rotations. The jump in the electric field gradient (grad E) occurred within a single measurement interval, i.e. within 15 minutes. This is highlighted by a colored line in the measurements. The impact started between nine o'clock in the evening and midnight and it was active during 11 hours. The amplitudes varied between 15 and 17 mV m^{-1} at the southern side and between 21 and 30 mV m^{-1} at the northern side. A detailed analysis is provided in Table 1, showing the temporal evolution of potential gradient during the impact event.

On 14 February 20:45 UTC, a M-class eruption was observed (SpaceWeatherLive), which grazed the Earth on 17 February 2025 19:00 UTC. The resulting speed of the flare is approximately 590 km/s. Its impact is shown in Fig. 7b, together with the daily temperature at the southern side of the stem (Fig. 7c) and wind direction and strength (Fig. 7d). It is evident that neither temperature nor wind influenced these anomalies in potential gradient. After two Earth rotations, the effects of the flares subsided.

A partial-halo coronal mass ejection (CME), observed in LASCO-C2 data (a camera aboard the SOHO spacecraft) on 28 December at 23:00 UTC, was expected to reach Earth from 1 January onward (SpaceWeatherLive). This CME produced a pronounced impact at the end of December 2025, with potential-gradient anomalies reaching several hundred mV m^{-1} , as illustrated in Fig. 8. The impact peaked on 31 December at 21:00 UTC, and the estimated speed of the coronal mass was 595

km s⁻¹. The anomaly reappeared 24 hours later with a smaller maximum; however, by the following day (Fig. 8a), the CME had already propagated beyond Earth. This impact differed significantly between the northern and southern potential gradient, suggesting that the electrical conductivity at the site varied between the two directions during this period. Increasing temperature resulted in a decreasing potential gradient during this interval (Fig. 8a), as measured under fair-
 255 weather conditions. This excludes a meteorological influence from charged clouds during the first week of January 2026.

A C6.4 flare peaked on 29 December at 20:40 UTC (SpaceWeatherLive). Sharp peaks were observed, with a maximum variation of approximately 300 mV m⁻¹ (Fig. 8a,b). These short-duration peaks are attributed to X-ray bursts and did not reappear on the following day.

Table 1: Time scale of solar flares during February 2025

Arrival time (UTC)	Amplitude of impact grad E south (mV m ⁻¹)	Amplitude of impact grad E north (mV m ⁻¹)	Duration of impact (h)	Period (h)
1/2/2025 0:48	15,2	20,8	9	-
1/2/2025 21:18	16,3	22,1	12	21
2/2/2025 22:33	16,3	28,4	11	25
3/2/2025 22:45	17,4	28,1	11	24
4/2/2025 21:15	16,9	30,2	12	23
17/2/2025 19:00	17.3	35.6	14	-
18/2/2025 19:15	14.2	29.8	14	24
19/2/2025 23:15	15.2	20.6	9	28

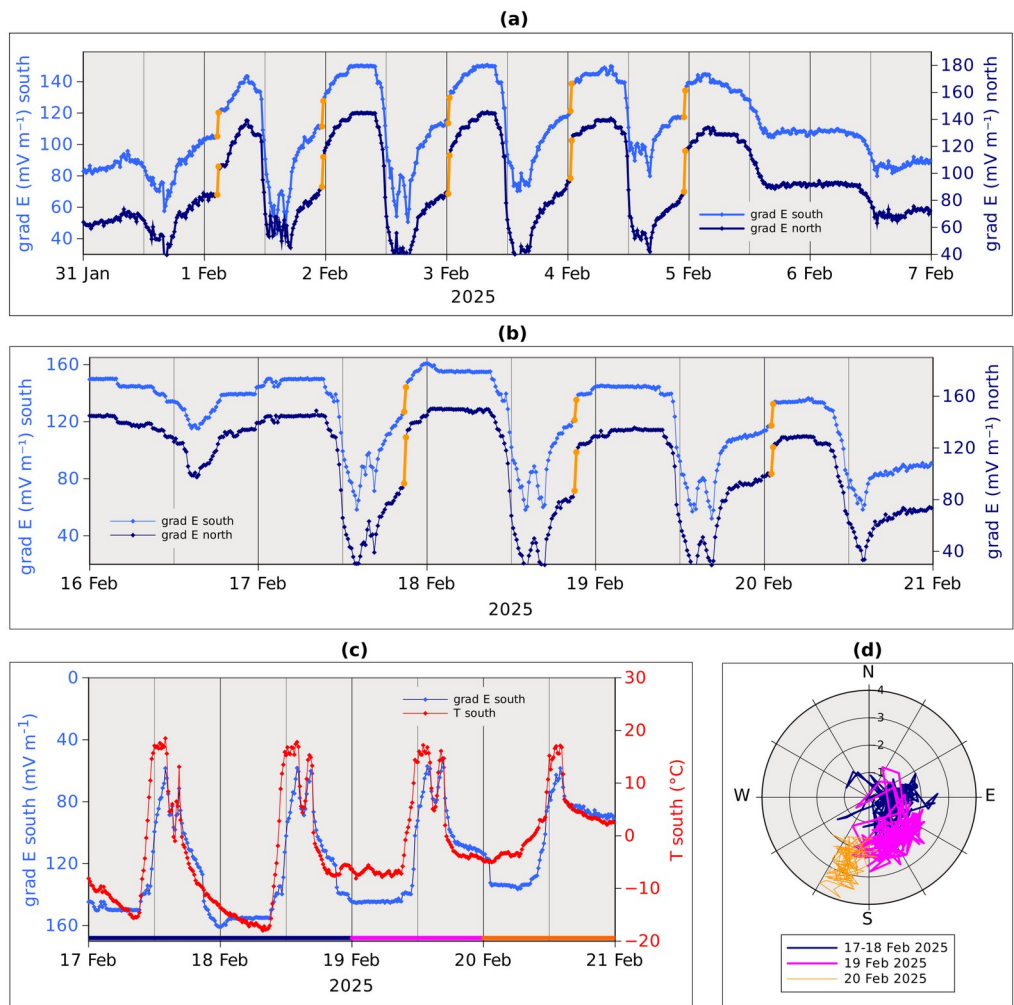
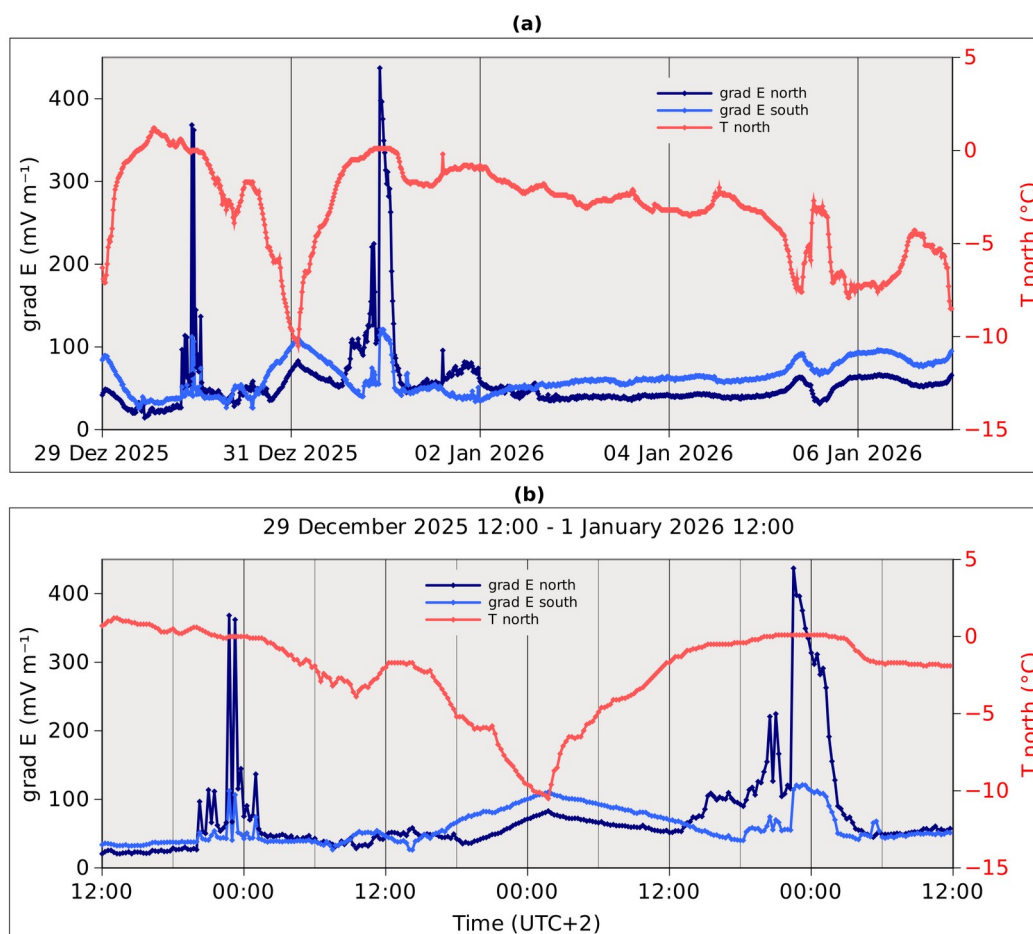


Figure 7: (a), (b) Effect of solar flares on the potential gradient at the stem after eruptions during February 2025; (c) potential gradient and temperature at the southern side on 17-20 February and (d) wind direction and velocity on 17-20 February.



295 **Figure 8: Effect of X-ray bursts and a coronal mass flow on the potential gradient at the stem after eruption (a) during end of December 2025 and 7 January 2026 with the southern stem temperature; (b) during end of December 2025 and 1 January 2026 at higher time resolution.**

300 3.4 The effect of gravitational tides on the electrical potential gradient

Gravitational tides are primarily generated by the motion of the Moon around the Earth. They constitute the principal lunar semidiurnal component (M2) of the tidal frequency spectrum, with a period of 12.4 hours (i.e., 1.94 cycles per day), as well as the lunar diurnal component (K1), which has a period of 23.93 hours and is therefore close to the diurnal cycle of solar radiation.

305 Figure 9 presents measurements obtained in April 2025 together with their corresponding frequency spectra. Solar radiation induces thermally driven tides, with components at 1, 2, 3, and 4 cycles per day. The electrical potential gradient (grad E)



exhibits these same components on the southern side of the tree (Fig. 9c). However, no contribution from the dominant gravitational component (M2) is observed.

The predicted gravitational tides are shown in Fig. 9a alongside the measured southern potential gradient, while Fig. 9b compares the predicted gravitational tides with the temperature at the southern stem. A qualitative similarity can be identified between volume strain (measured in nanostrain) and the potential gradient.

For spectral analysis, the data series has been extended to 25 days in order to achieve higher frequency resolution, compared to the 6-day interval shown in Fig. 9a and 9b. However, the frequency spectrum does not support a direct relationship (Fig. 9c), as the principal gravitational component (M2) is absent.

The frequency component at 1 cycle per day is symmetric in the potential gradient but asymmetric in the gravitational tides, which include the semidiurnal lunar K1 component. Furthermore, the amplitude ratios at 1 and 2 cycles per day differ significantly. Gravitational tides do not exhibit components at 3 or 4 cycles per day, whereas these are clearly present in both the daily temperature and the potential gradient, with comparable amplitude ratios.

These observations indicate that the potential gradient is thermally controlled, similar to temperature.

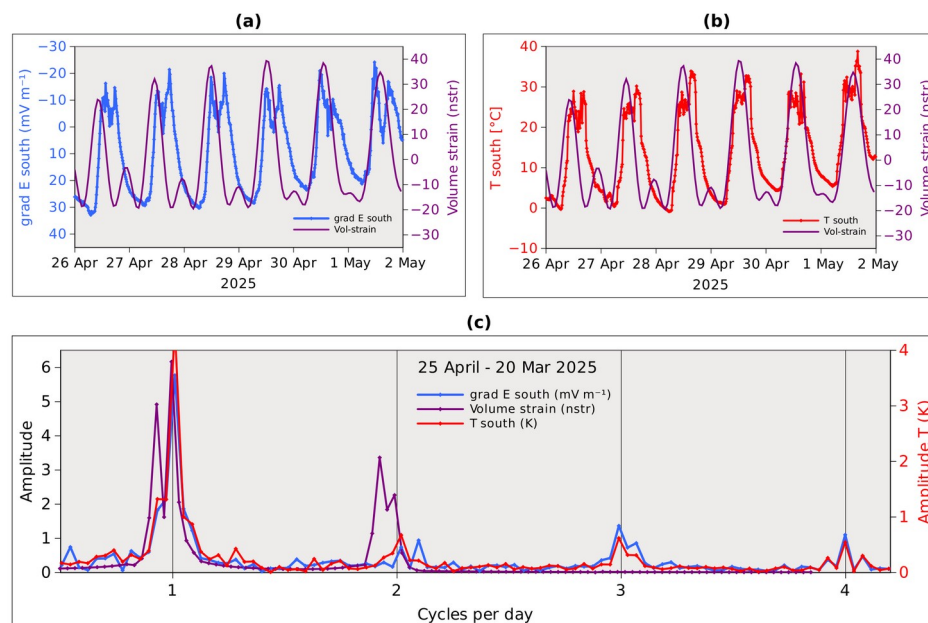


Figure 9: (a) Measurements of the southern potential gradient compared with the predicted tides; (b) measurements of the southern temperature at the stem compared with the predicted tides; (c) frequency analysis of the measured and predicted data.



4. Discussion

340 The measured pattern coincides with the annual variation of the atmospheric electric field. A characteristic geographical feature of inland Central Europe is that the atmospheric electric field exhibits two daily maxima during the summer season, namely before noon and again in the afternoon (Kähler, 1929). This feature is also observed at the tree stem. In addition to the tree's active contribution, the potential gradient at the stem reflects even subtle and rapid variations in the atmospheric electric field at high temporal resolution, which cannot be understood with a varying sap flow.

345 The phenomenon of a strongly varying azimuthal dependence cannot be explained solely by atmospheric electricity. It is likely caused by additional spatial variations in electrical conductivity within the cambium and the root system. During certain periods, potential gradient becomes negative (Fig. 2a), which may indicate a high nutrient demand during growth or a downward transport of charged particles toward the roots as suggested at Fig. 6a. In such cases, the atmospheric electric field is effectively overcompensated. Not only ambient temperature influences potential gradient; solar thermal radiation also
 350 increases electrical conductivity on the sunlit side of the stem, as demonstrated in Figs. 2 b, 2d.

The results cannot be clearly separated into an active contribution of the tree—arising from the uptake of water and ions from the soil—and a passive contribution acting as a resistance within the atmospheric electric field. The supply of charged particles increases the electrical conductivity of the stem, thereby reducing the potential gradient, and vice versa. Conversely, changes in the atmospheric electric field directly affect the potential gradient at the stem and may interfere with nutrient
 355 uptake.

The potential gradient ($\text{grad } E$) is highly sensitive to temperature variations. This sensitivity is evident not only on a diurnal scale - where potential gradient decreases after sunrise and increases during the night - but also on a seasonal scale. However, the potential gradient is strongly influenced by prolonged weather conditions, which may dominate regional weather patterns (Kähler, 1929). As a result, the potential gradient can be low during wet and warm periods in winter
 360 dormancy, while it can be high during dry and cold periods in the growing season. The regional climate conditions result an electric field in the lower atmosphere that is measured here and may differ considerably from that in other regions.

During heavy rainfall (Figs. 4 and 5), the tree absorbs significant amounts of water along with nutrients, leading to a marked reduction in potential gradient due to increased electrical conductivity. Additionally, the atmospheric electric field is reduced because of the higher conductivity of saturated air. In the presence of highly charged clouds, the tree may respond
 365 asymmetrically: nutrient uptake may increase in one direction, where potential gradient decreases, while potential gradient increases in another direction, influenced by the movement of charged clouds. Active and passive processes thus occur simultaneously at different sides of the stem, and this spatial distribution is not fixed but varies with environmental



conditions. Figure 5a shows that the northern potential gradient is higher than the southern gradient whereas Fig. 6a shows the relation vice versa. The tree appears to respond dynamically to the direction of moving charged clouds. Additionally, the clouds can be charged negatively and/or positively.

The pronounced and simultaneous changes in potential gradient in response to solar events - such as X-rays, flares, or coronal mass ejections - are remarkable. Not only the extent but also the duration and propagation speed of charged particle clouds following solar eruptions can be inferred. These observations support the findings of Douglass (1927), suggesting that trees are sensitive to solar activity. The effect of space weather to the potential gradient at a tree stem is not considered in general. A few examples are discussed. Its sudden and irregular appearance needs long-term measurements.

The influence of gravitational tides on the electrical potential of trees has been reported by several authors (Douglass, 1927; Fisahn, 2018; Holzknecht and Zürcher, 2006; Koppán et al., 2000; Zhou et al., 2023; Zürcher and Schlaepfer, 2014; Zürcher et al., 1998), primarily through visual comparison. A relationship has recently been reported (Pinheiro, 2023; Pinheiro et al., 2023) linking the potential gradient of a tree to volumetric strain in the subsurface induced by predicted Earth tides; however, this does not imply causality. Instead, variations in subsurface permeability likely modulate water uptake with the same periodicity (Jahr et al., 2020; Kümpel, 1997). Large trees require substantial water, and limited availability may trigger uptake variations driven by tidal permeability changes (Pinheiro et al., 2023). This effect was not observed in the present study, likely because the investigated tree is small, has a low water demand, and is located near a large pond. Spectral analyses of the measurements (Figures 1, 2, and 9) show no components indicative of gravitational tidal influence.

5 Conclusion

The measurements provide valuable insight into the effects of external events on trees, which are rarely taken into account. The results suggest that the electrical potential at the tree stem consists of two components: an active component generated by the tree itself and a passive external component that influences the measured electrical potential at the stem. Both components are governed by the Sun, albeit in different ways.

A relationship between sap flow and individual elements of the potential gradient may contribute to a better understanding of their influence on tree growth and may ultimately support the findings of Douglass (1927), who proposed that trees are sensitive to solar activity.

The basic atmospheric electric field between the ionosphere and the Earth's surface, generated by solar radiation, is influenced by meteorological events in the lower atmosphere as well as by space weather affecting the ionosphere. An analysis of both factors is necessary to understand the potential gradient at the tree stem.



Long-term observations are necessary to detect and assess the effects of major solar eruptions, including X-ray bursts. In this context, trees may serve as simple natural proxies for forecasting potentially harmful coronal mass ejections one or two days in advance.

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Declaration of competing interests

The author declares no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data availability

All data used in this study are available on request.

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