MIPT
MOSCOW INSTITUTE OF PHYSICS AND TECHNOLOGY

ИКИ SPACE RESEARCH INSTITUTE RUSSIAN ACADEMY OF SCIENCES

V All-Russian Conference
Turbulence, atmospheric and climate dynamics

On the Electrical and Electromagnetic Properties of Windblown Sand Flows Under Moderate Wind Conditions

Об электрических и электромагнитных свойствах ветропесчаного потока в условиях умеренных ветров

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Scientific team:
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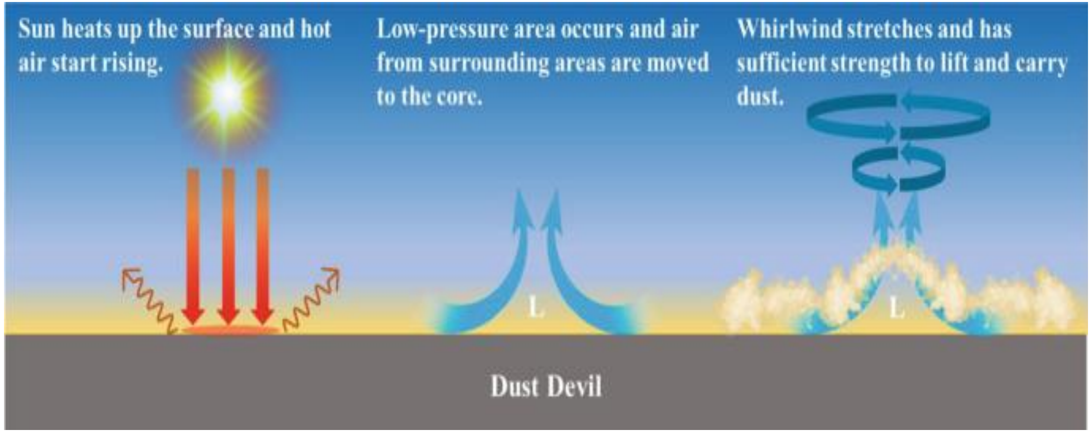
Research Objectives

- ➢ Investigate the electric and electromagnetic properties of windblown sand flows under moderate wind conditions.
- ➢ Examine the processes of dust particle electrification and the generation of electromagnetic bursts.
- ➢ Identify the correlations between meteorological parameters (e.g., wind speed, temperature, humidity) and the observed electromagnetic activity (EMA).

Significance:

- ➢ **Understanding Dust Electrification:** Provides insights into the mechanisms driving charge accumulation in arid environments, influencing local and global atmospheric dynamics.
- ➢ **Planetary Science Implications:** Enhances understanding of dust-related phenomena on Mars, such as dust devils and their role in electric field generation.
- ➢ **Environmental Applications**: Helps model dust storm behavior on Earth, contributing to climate studies and improving prediction of dust-related weather events.
- ➢ **Technological Relevance:** Advances methodologies for measuring and analyzing high-frequency electromagnetic signals in extreme environments.

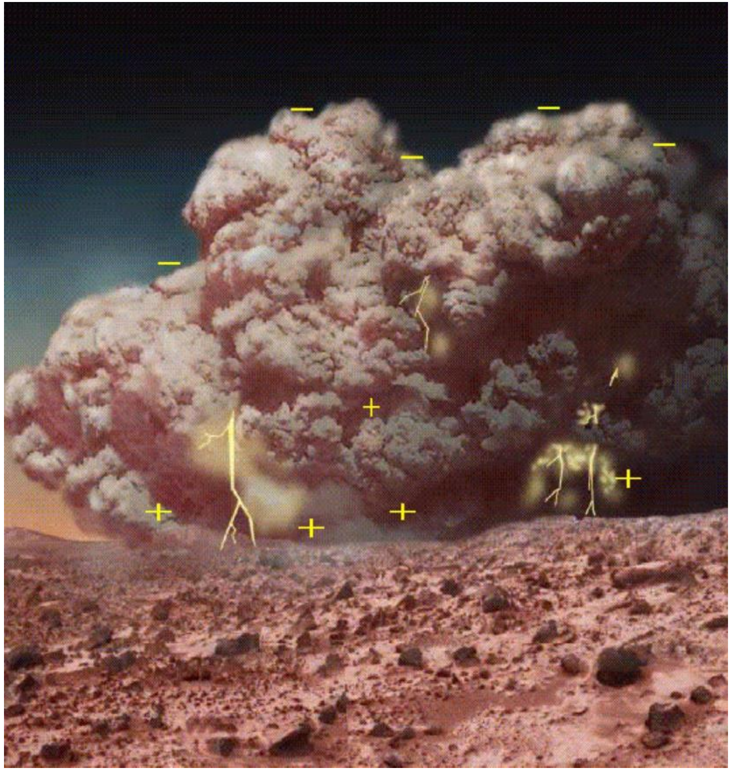
Dust particles levitation



Stretched color version of a movie of a huge “dust lifting” event taken by the Navigation Camera (Navcam) on sol 117. Images are 14 seconds apart.

Credit: NASA/Caltech-JPL/SS

Dust storms on Mars



An artist's impression of an electrified dust devil at Mars (from Farrell et al. 2004)

Mars without a dust storm in June 2001 (on left) and with a global dust storm in July 2001 (on right), as seen by Mars Global Surveyor
https://www.nasa.gov/feature/storm-chasers-on-mars-searching-for-dusty-secrets

MRO: https://mars.nasa.gov/resources/5307/the-serpent-dust-devil-of-mars/

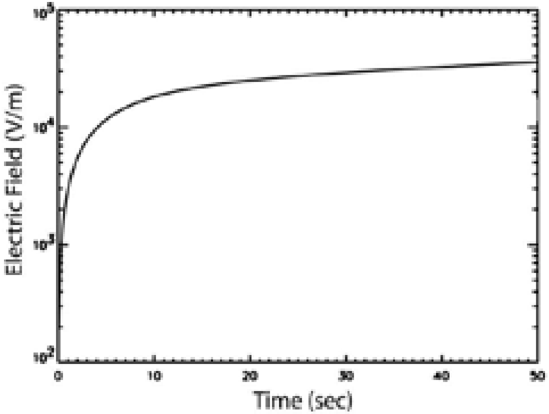


Fig. 1. The evolution of the electric field strength E in a dust storm at a wind speed of 7 m/s (Farrell et al., 2006).

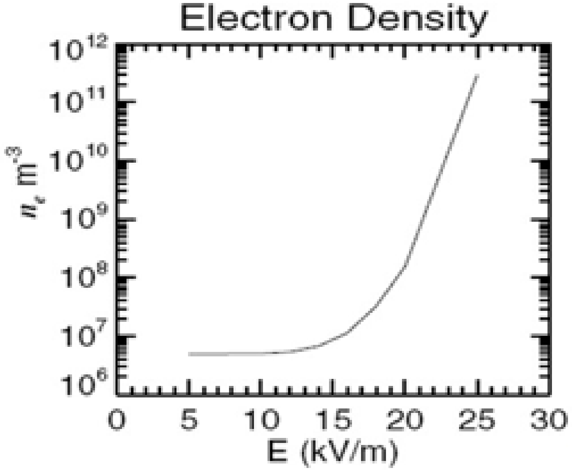


Fig.2. Electron concentration near the surface of Mars as a function of electric field magnitude during a dust storm (Delory et al., 2006)

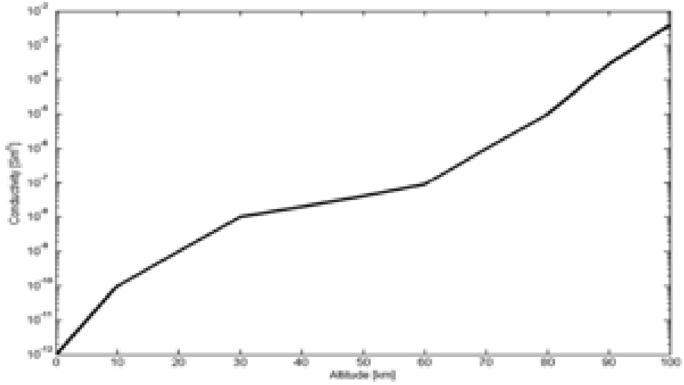


Fig .3. Conductivity profile of the martian atmosphere 10^{-12} and 10^{-7} S/ m. Credit: F. Simões et al. / Icarus 194 (2008) 30–41

Dust Particle Motion During Dust Storms

To determine whether electrostatic discharge takes place in the low Martian atmosphere during dust storms it is necessary to know the number of collisions between dust particles moving under wind action and then to calculate the electric field induced by the charge density to check if the breakdown voltage could be reached.

The dust particles are considered as spherical with a radius r_p, mass m_p, velocity V_p, and charge q_p. **Particle movement is given by Newton's equation:**

$$m_p \frac{dv_p}{dt} = F_F + F_G + F_d$$

Where $\mathbf{F_F}$ is the force due to the electromagnetic field, $\mathbf{F_G}$ is the force of gravity, and $\mathbf{F_d}$ is the drag force due to the viscosity:

Electrification Mechanism

The space time variation of the quasi-electrostatic field is given by:

$$\boldsymbol{E} = -\boldsymbol{\nabla\varphi}$$

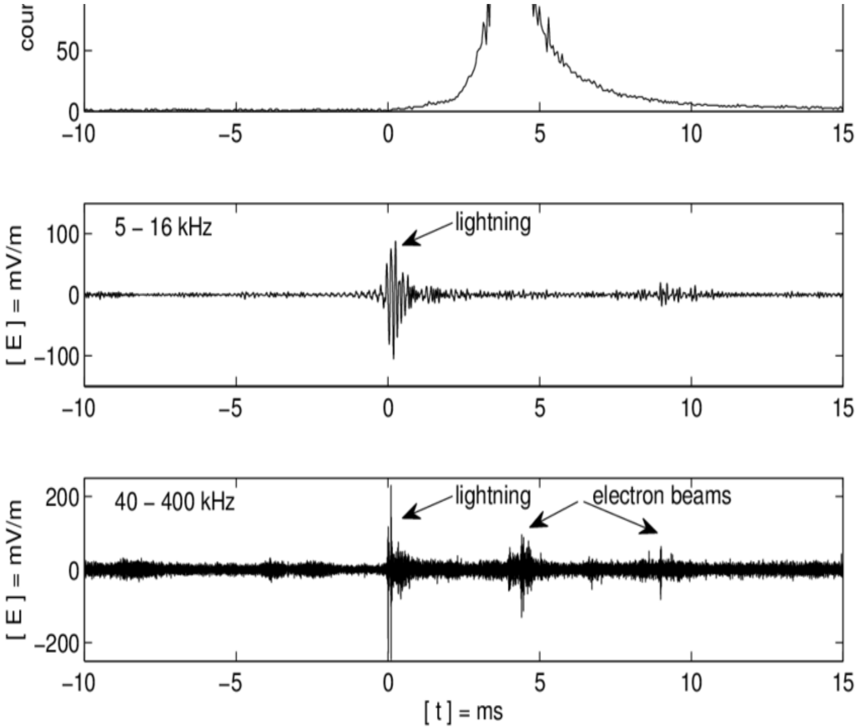
Where $\boldsymbol{\varphi}$ is the electrostatic potential. The potential $\boldsymbol{\varphi}$ and the charge density ρ are related by the continuity equation:

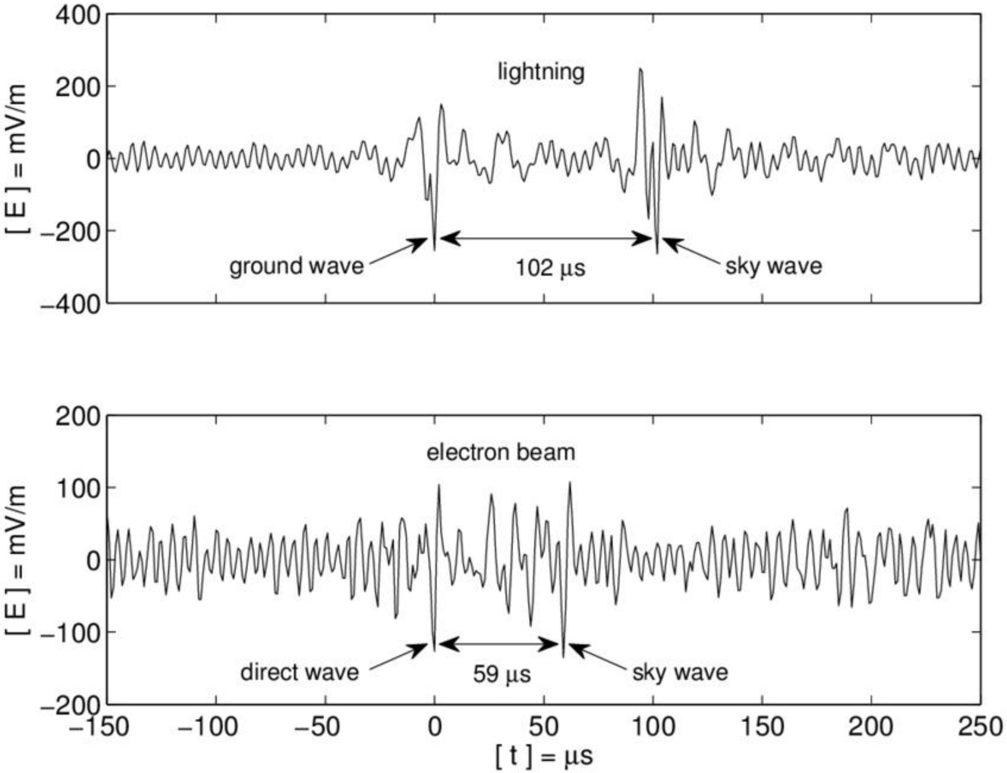
$$\frac{\partial\rho}{\partial t} - \nabla[\sigma\nabla\varphi] = 0$$

And Poisson's equation:

$$\nabla^2\varphi = -(\rho + \rho_s)/\varepsilon_0$$

Melnik et. al. 1998

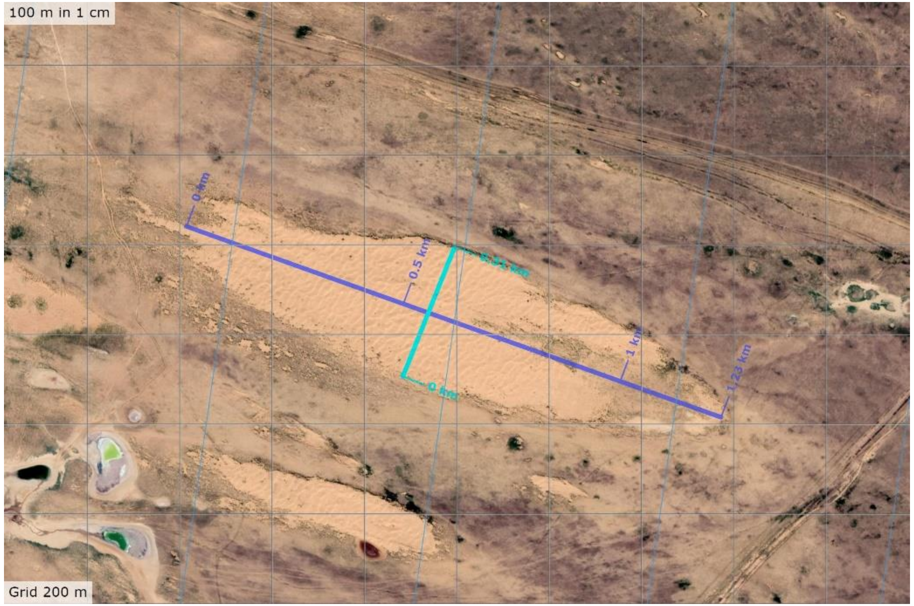




M. Fullekrug et al.: Relativistic electron beams above thunderclouds 2011

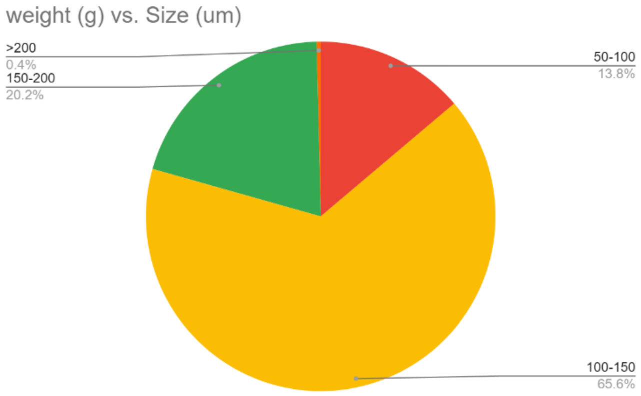
Location of study

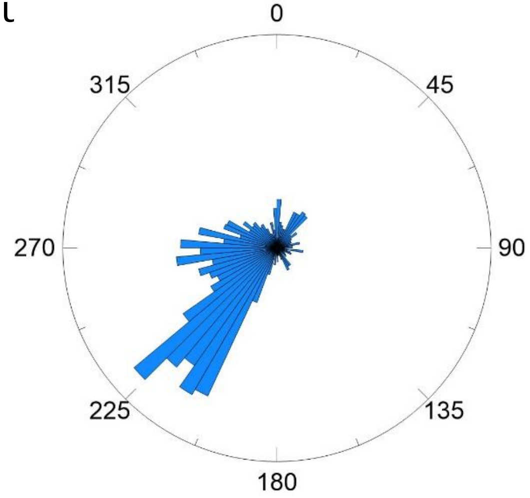
- Kalmykia, 2024
- Temperatures reached **35°C** during the day.



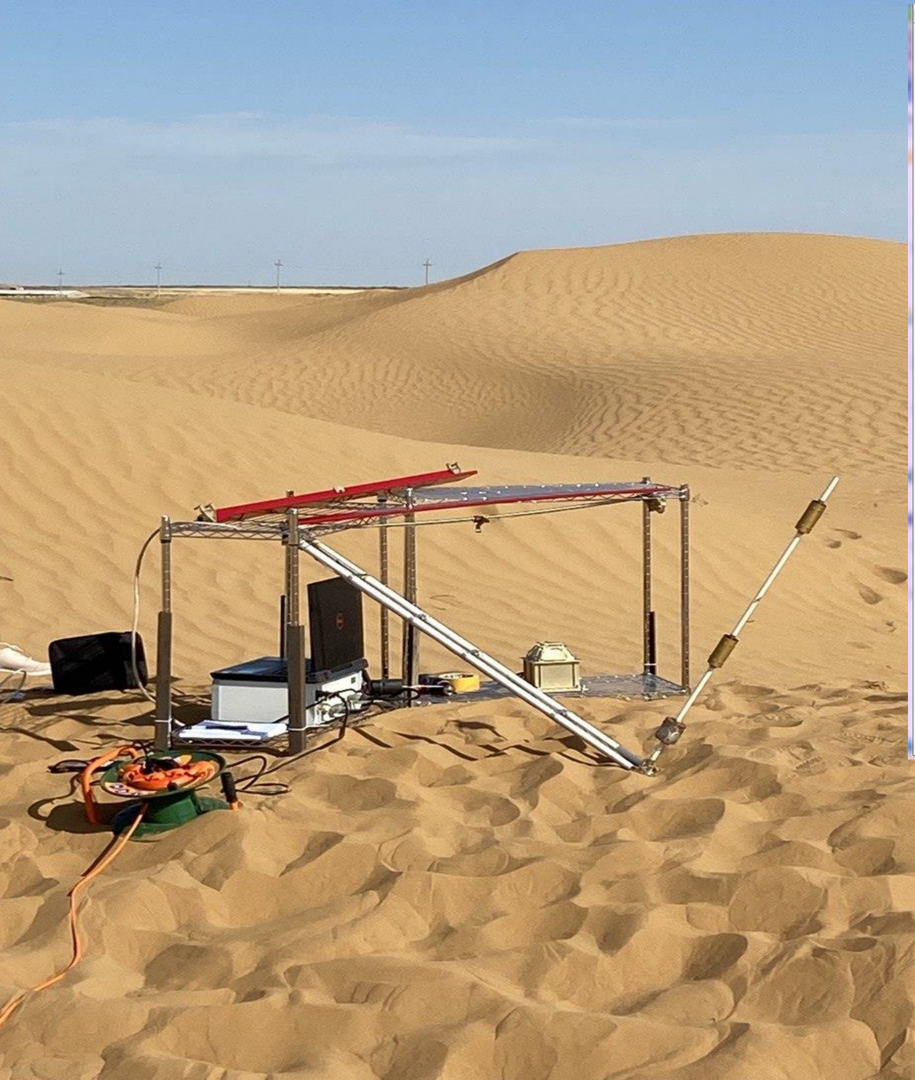
Dust Particle Size and Wind Charecterstics

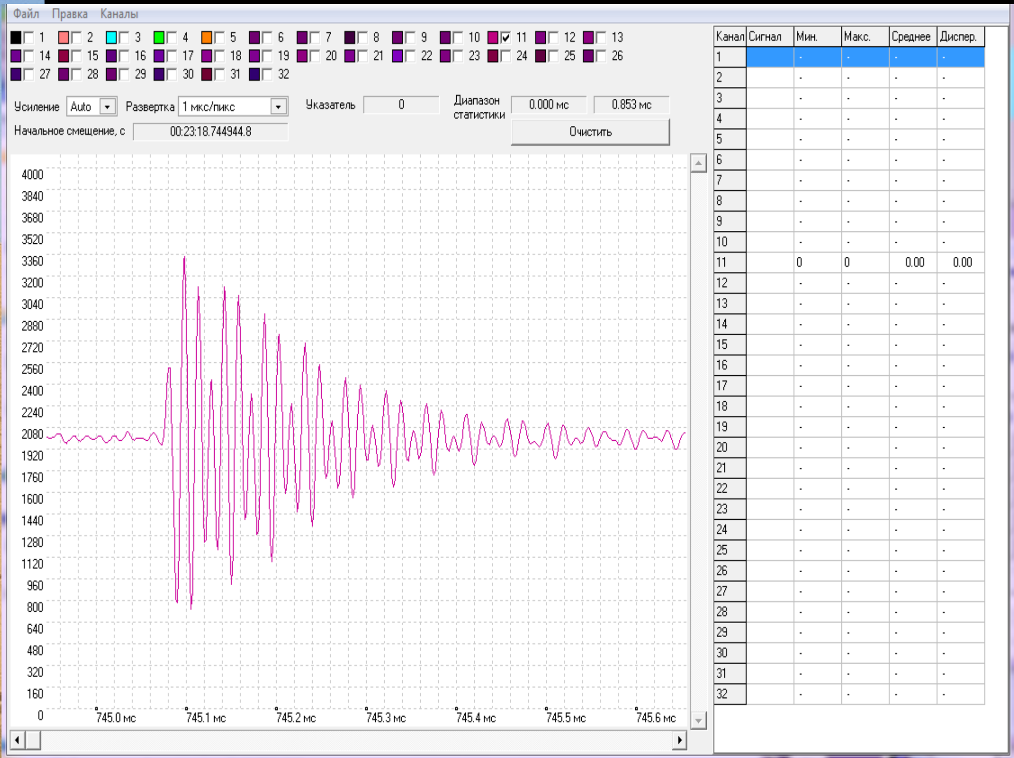
The collected dust particles in the Kalmykian desert were predominantly in the 100–150 μm size range, with some additional presence in the 50–100 μm and 150–200 μm ranges. Particles below 50 μm and above 200 μm were almost absent in the sample, indicating that the local atmospheric and environmental conditions favor the mobilization and suspension of mediu





Wind direction mainly was south-east.
Wind speeds: 2-4 m/s on average, peaking at 5–6 m/s during the evening.





Файл
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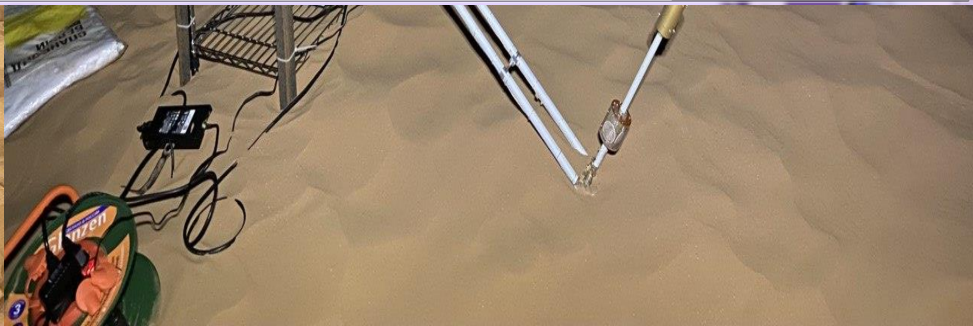


Influence of Humidity

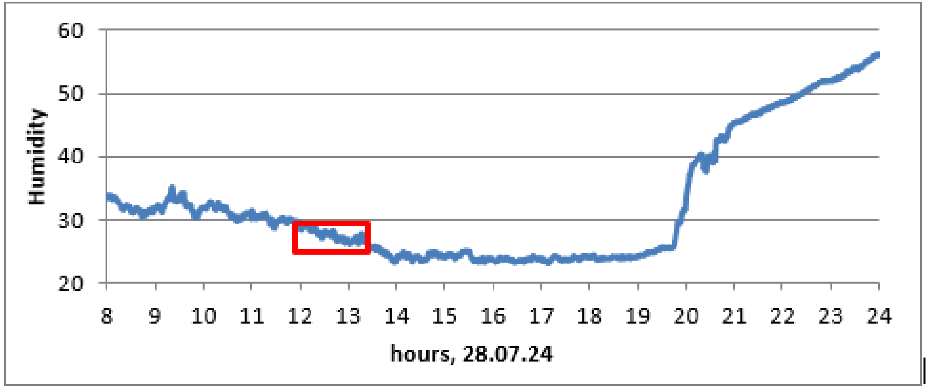
•**Key Findings**:

- Number of electromagnetic bursts increased as **humidity decreased** from **30% to 20%** during the day.
- Noticeable emission activity begins when humidity falls below **40–50%** [1].

•**Insights from Literature**:

- Aerosol electrification is enhanced in low-humidity conditions [2].
- Wet particles reduce charge accumulation [3].

[1] Golitsyn G. S. et al., 2003
[2] Смирнов В.В., 2010
[3] Petrova G.G. et al, 2021; Петрова Г.Г., 2023



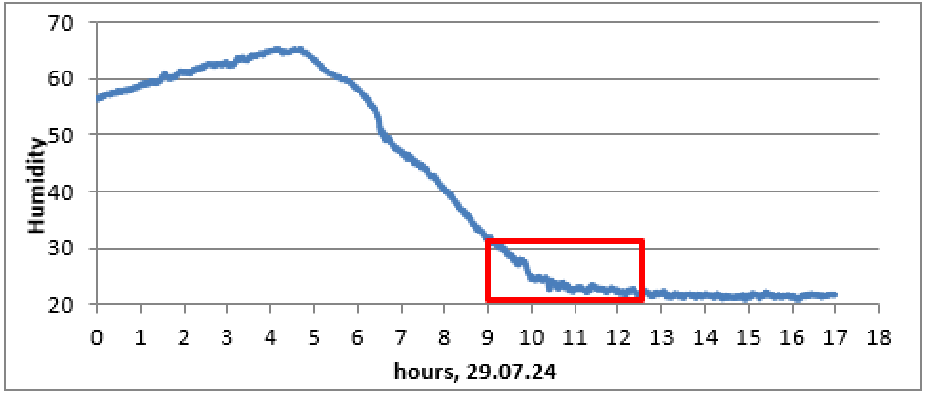


Fig 10. The relationship of the amplification of the number of electromagnetic bursts with the range of relative humidity values. The area with more than 12 electromagnetic bursts is highlighted in red.

Correlation with Meteorological Parameters

•Parameters Studied:

- Temperature (T).
- Wind speed (U).
- Vertical wind speed (Uz).
- Electric field strength (Ed).
- Difference in electric field (dE) between 5 m and 0.5 m.
- Piezo electric sensors (PZT).
- Electro-Magnetic Analyzer (EMA).

•Findings:

- Bursts align with **wind gusts** and **vertical wind changes**.
- Discharge events increase after **spikes in electric field strength**.

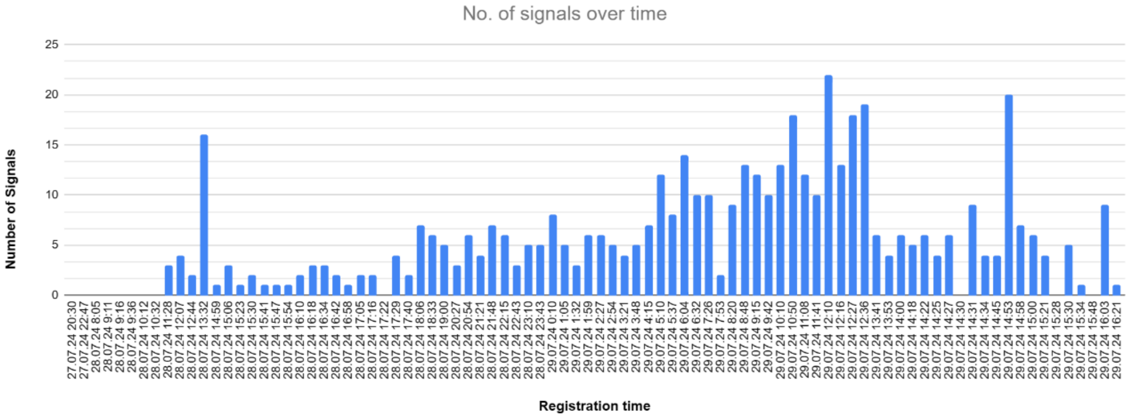


Fig. 11. Number of electormagnetic signals registered over 28 and 29 of Jul 2024.

Observations Over Time

- **Time Intervals Compared**:
    - **Morning (8:00–11:00)**: Moderate bursts, steady rise in wind speed and temperature.
    - **Afternoon (11:00–14:00)**: Stronger bursts correlated with higher winds and lower humidity.

- **Key Observation**:
    - Afternoon conditions (higher temperatures, stronger winds, and lower humidity) amplify discharge activity.

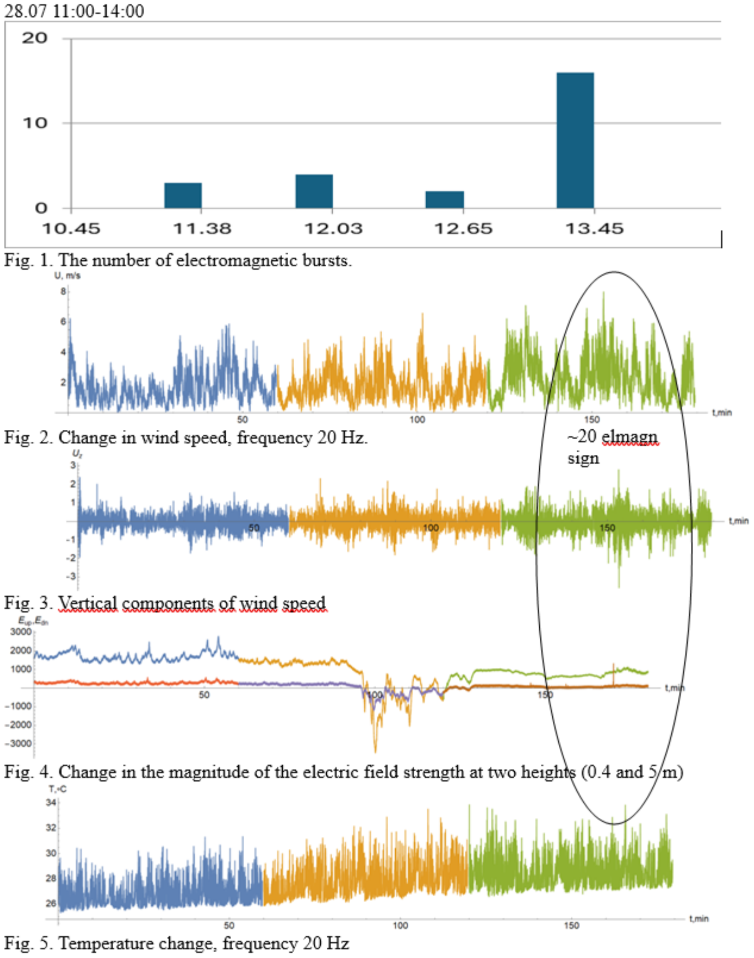


Fig. 1. The number of electromagnetic bursts.

Fig. 2. Change in wind speed, frequency 20 Hz.

Fig. 3. Vertical components of wind speed

Fig. 4. Change in the magnitude of the electric field strength at two heights (0.4 and 5 m)

Fig. 5. Temperature change, frequency 20 Hz

29.07 08:00-11:00

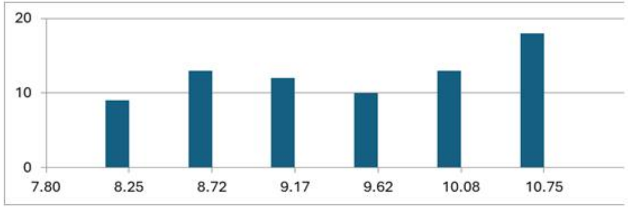


Fig. 1. The number of electromagnetic bursts

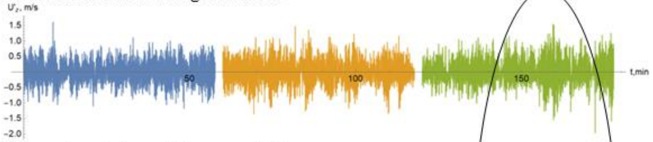


Fig. 2. Change in wind speed, frequency 20 Hz

~20 elmagn sign

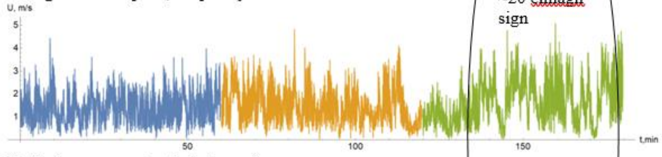


Fig. 3. Vertical components of wind speed

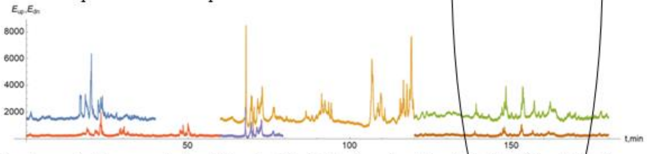


Fig. 4. The change in the magnitude of the electric field strength at two heights (0.4 and 5 m)

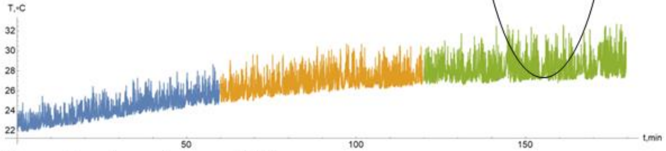


Fig. 5. Temperature change, frequency 20 Hz

29.07 11:00-14:00

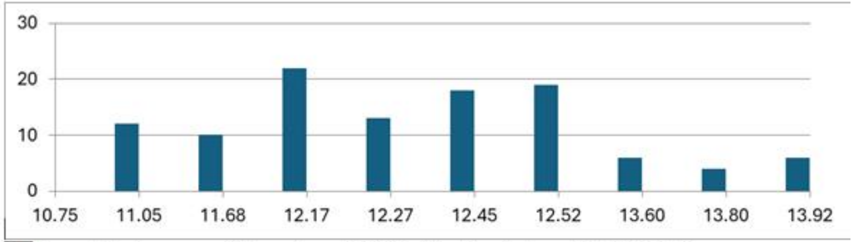


Fig.1. Number of electromagnetic bursts on 29.07 in the time interval 11:00-14:00

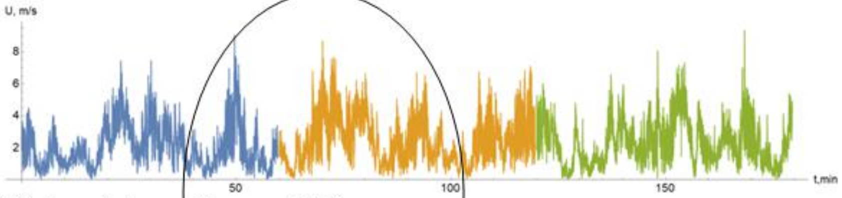


Fig. 2. Wind speed change, frequency 20 Hz

~20 elmagn. sign

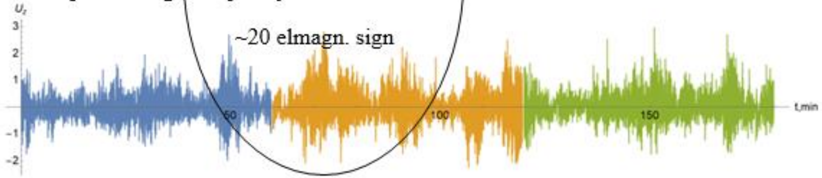


Fig. 3. Vertical components of wind speed

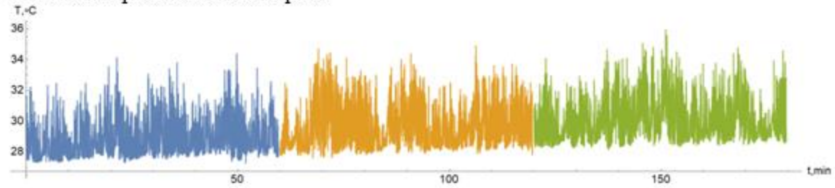


Fig4. Temperature change, frequency 20 Hz

Electromagnetic Signal Characteristics

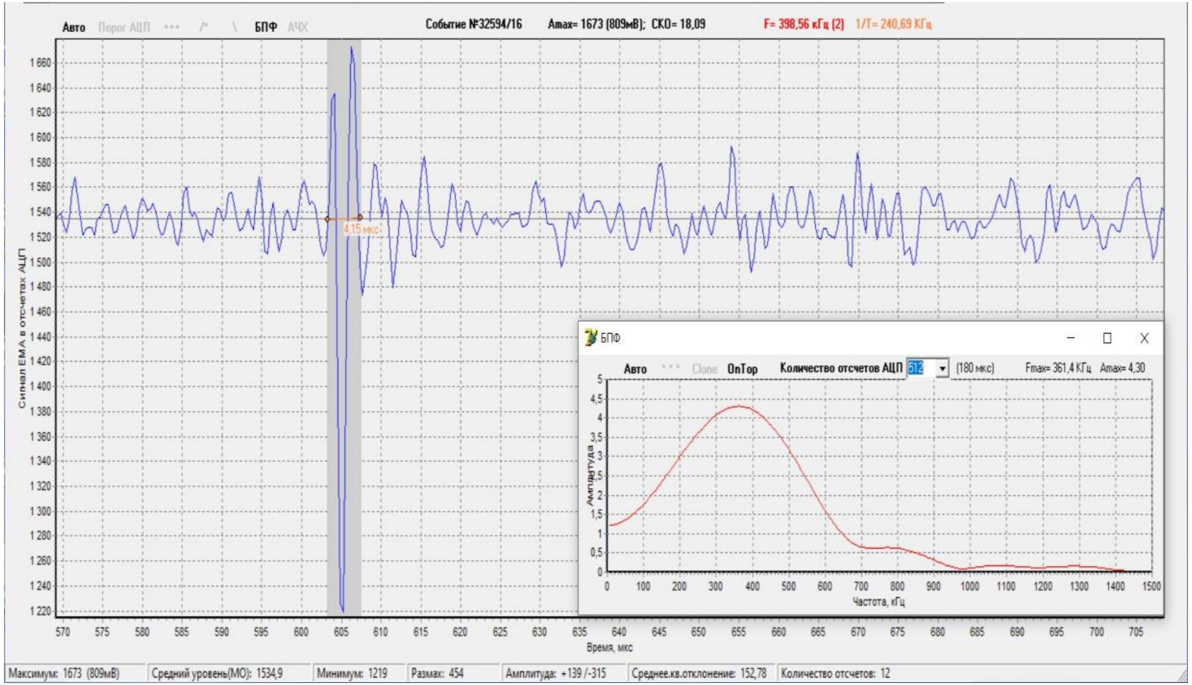
Frequency Range: 330–430 kHz.
Amplitude range Vpp: 255 and 300 mV.
Time period: of 3.3-4 μs

An Example of a Primary Signal:

Duration: 3.27 μs
Amplitude: 293.4 mV
Standard deviation: 221.14 mV
Indicates moderate signal variability.

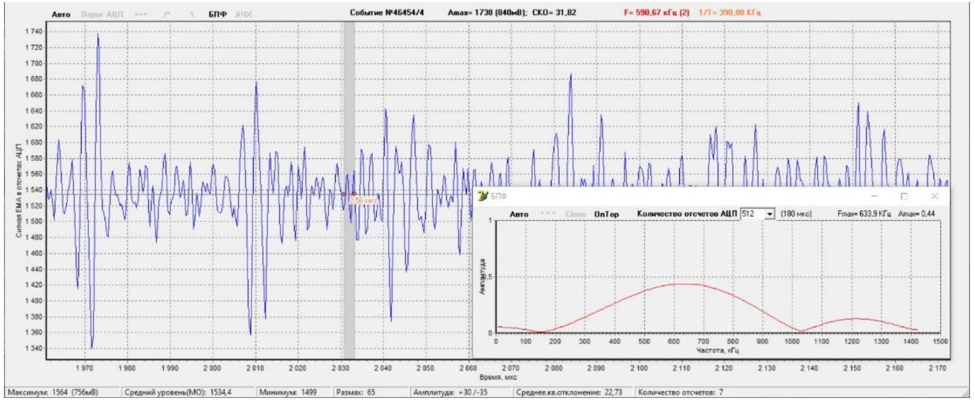
Correlation Observations:
Electromagnetic bursts align with:

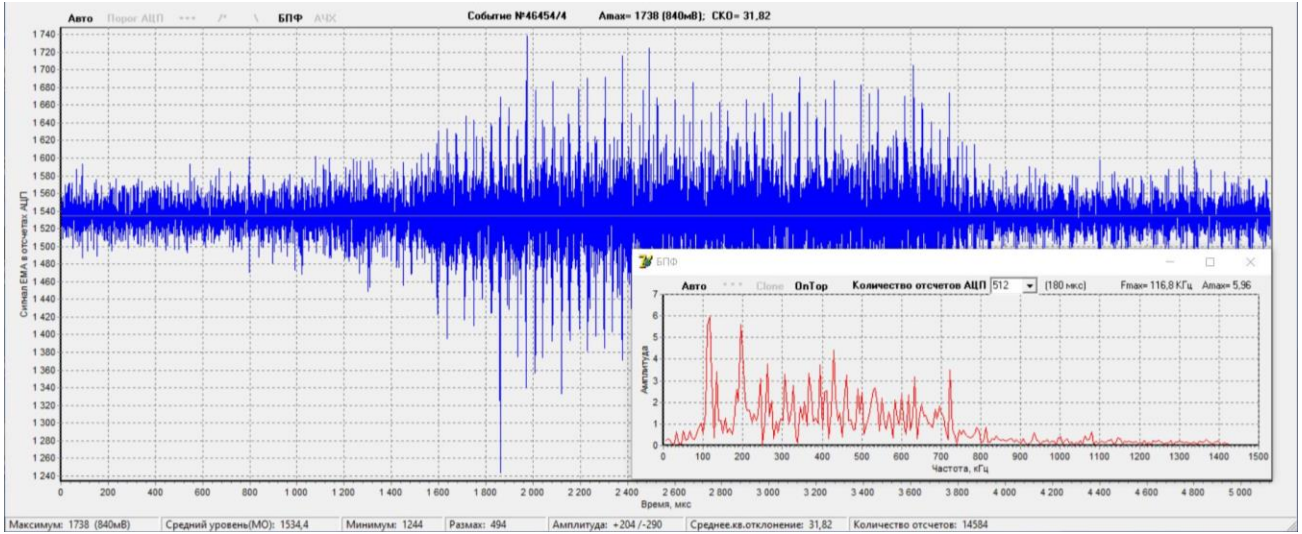
- Solar radiation intensity.
- Wind speed increases.
- Electric field strength fluctuations.



An Example of a complex Signal:

- **Frequency Range**: 300–600 kHz
- **Amplitude (Vpp)**: 60–150 mV





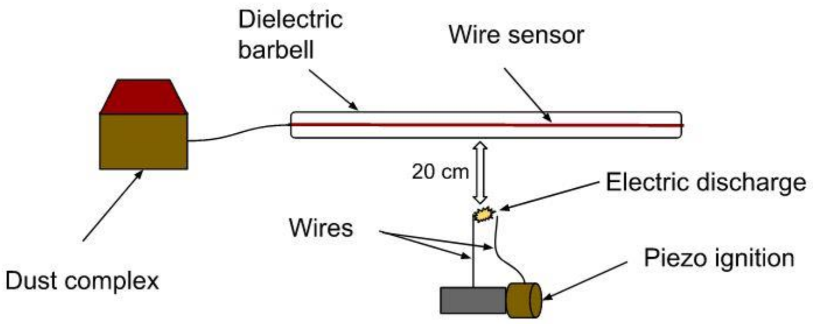
Comparison between the signals

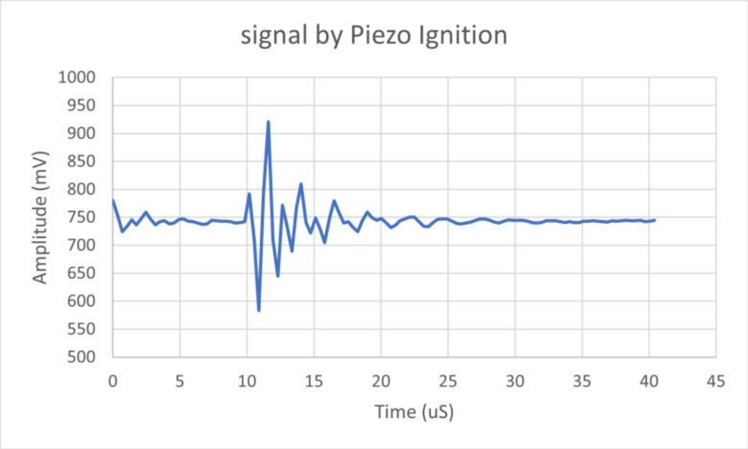
1. **Frequency Range**
   - **Main Signals**: Exhibit a narrower frequency range (330–430 kHz), with an average period of 3.3-4 µs suggesting a more irregular or transient source with varying discharge intensities.
   - **Complex Signals**: Have a broader frequency range (300–600 kHz), indicating a highly regular, consistent discharge process.

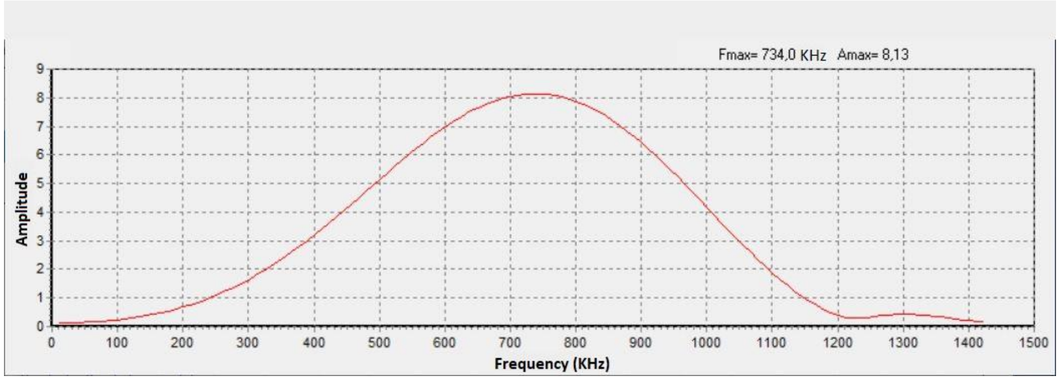
2. **Amplitude and RMS Values**
   - **Main Signals**: With a peak-to-peak amplitude of 250–300 mV and an RMS of 180–200 mV, these signals show high energy levels and effective discharge power, suggesting a more variable discharge intensity.
   - **Complex Signals**: Display lower peak-to-peak amplitudes (60–150 mV) with an RMS range closer to 60–100 mV, reflecting an irregular or transient source.

3. **Waveform Stability and Standard Deviation**
   - **Main Signals**: The standard deviation of 180–206 mV, close to the RMS, indicate higher variability in discharge strength, suggesting a more chaotic source like random environmental discharges.
   - **Complex Signals**: The standard deviations for these signals (93.25 mV and 22.73 mV) indicates a stable waveform with regular oscillations, characteristic of a consistent discharge

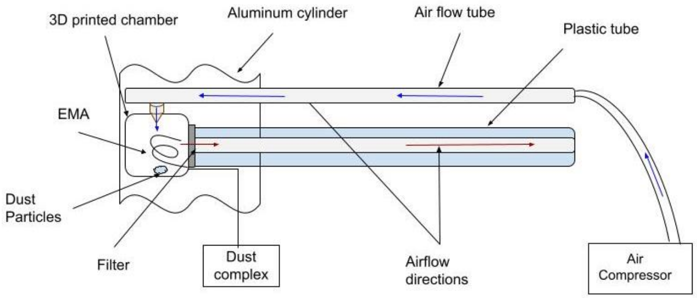
Experimental discharges







Fourier transformation spectrum of the Piezo Ignition signal


3D printed chamber
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Plastic tube
EMA
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Particles
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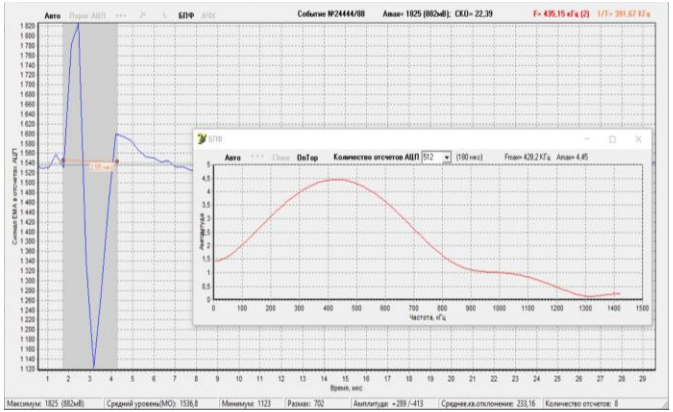
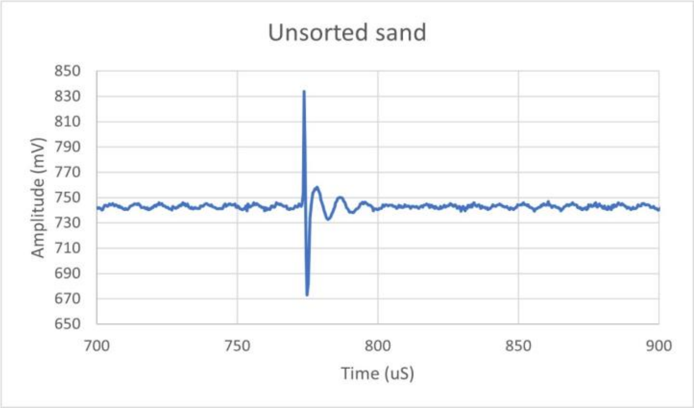
Air
Compressor


Авто
БПФ
Событие №24444/08
Amax= 1825 (882мВ); СКО= 22,39
Авто
OnTop
Количество отсчетов АЦП 512
Частота, кГц
Время, мкс
Максимум: 1825 (882мВ)
Средний уровень(МО): 1536,8
Минимум: 1123
Размах: 702
Амплитуда: +289 /-413
Среднее.кв.отклонение: 233,16
Количество отсчетов: 8


Unsorted sand
Amplitude (mV)
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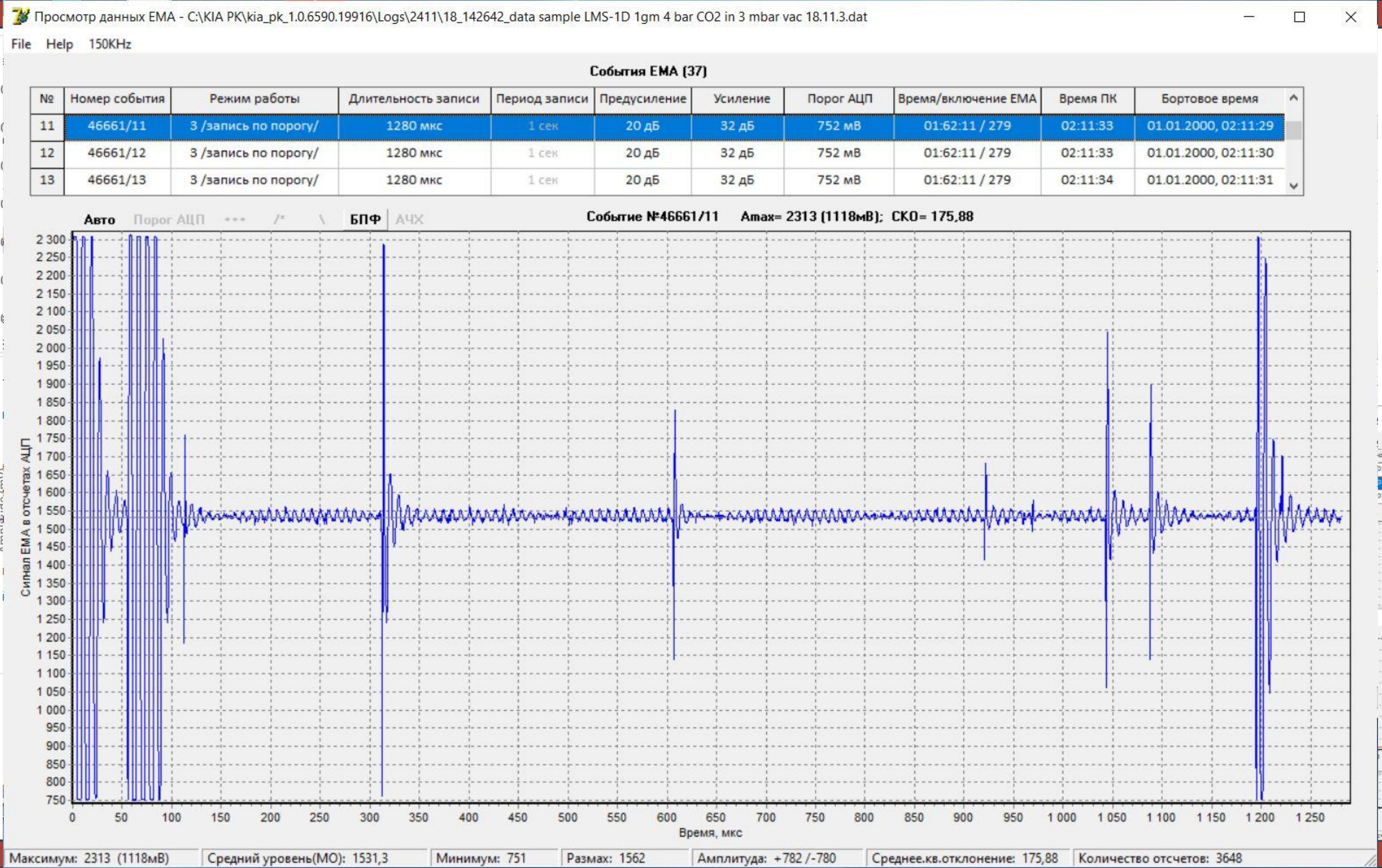
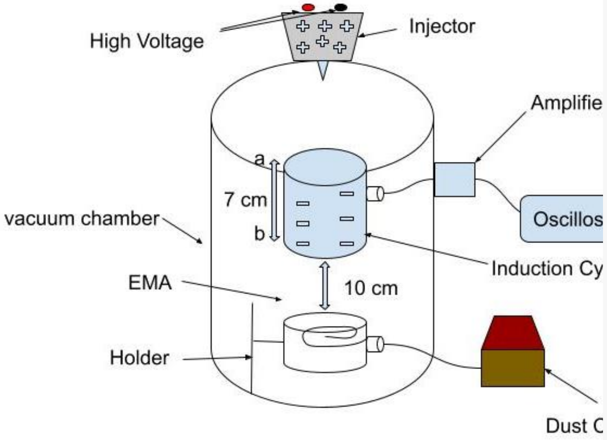
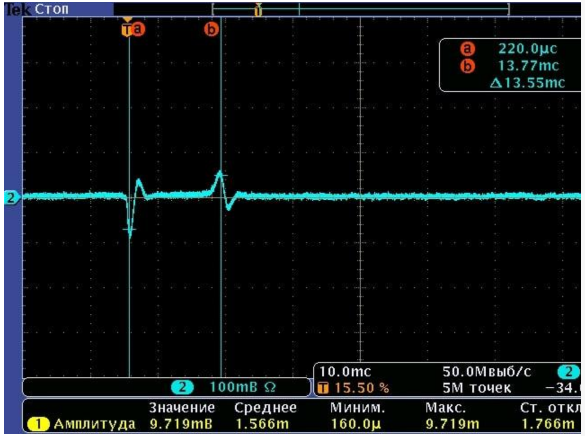
Time (uS)



№	Номер события	Режим работы	Длительность записи	Период записи	Предусиление	Усиление	Порог АЦП	Время/включение ЕМА	Время ПК	Бортовое время
11	46661/11	3 /запись по порогу/	1280 мкс	1 сек	20 дБ	32 дБ	752 мВ	01:62:11 / 279	02:11:33	01.01.2000, 02:11:29
12	46661/12	3 /запись по порогу/	1280 мкс	1 сек	20 дБ	32 дБ	752 мВ	01:62:11 / 279	02:11:33	01.01.2000, 02:11:30
13	46661/13	3 /запись по порогу/	1280 мкс	1 сек	20 дБ	32 дБ	752 мВ	01:62:11 / 279	02:11:34	01.01.2000, 02:11:31





Registered signals of charged particles on oscilloscope at different velocities - **(A)** 5,2

ORIGINAL RESEARCH article

Front. Astron. Space Sci., 06 May 2024

Sec. Space Physics

Volume 11 - 2024 |
https://doi.org/10.3389/fspas.2024.1347048

This article is part of the Research Topic

Advances In Mesosphere And Thermosphere Dynamics

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Experimental modeling of atmospheric discharge phenomena and charged dust particle interactions

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Stanislav I. Klimov[2‡] Genady G. Dolnikov[2‡] Alexander V. Zakharov[2†]

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Conclusion

Key Findings:

- Dust particle electrification and electromagnetic activity are significantly influenced by wind speed, temperature, and humidity levels.
- Lower humidity (< 30%) enhances discharge intensity, correlating with increased electromagnetic bursts.
- Electromagnetic signals (300–350 kHz) align with fluctuations in the electric field strength, particularly during wind gusts and vertical air movements.

Implications:

- Provides valuable insights into the mechanisms of dust electrification and discharge, essential for understanding atmospheric processes in arid regions.
- Advances our understanding of dust dynamics on Mars, with applications in planetary science and exploration.
- Supports the development of predictive models for dust storm behavior and their environmental impacts on Earth.

Future Work:

- Expand research to explore the effects of additional meteorological parameters.
- Conduct controlled experiments to validate field observations and refine theoretical models of dust electrification and electromagnetic discharge.

Thanks for attention!

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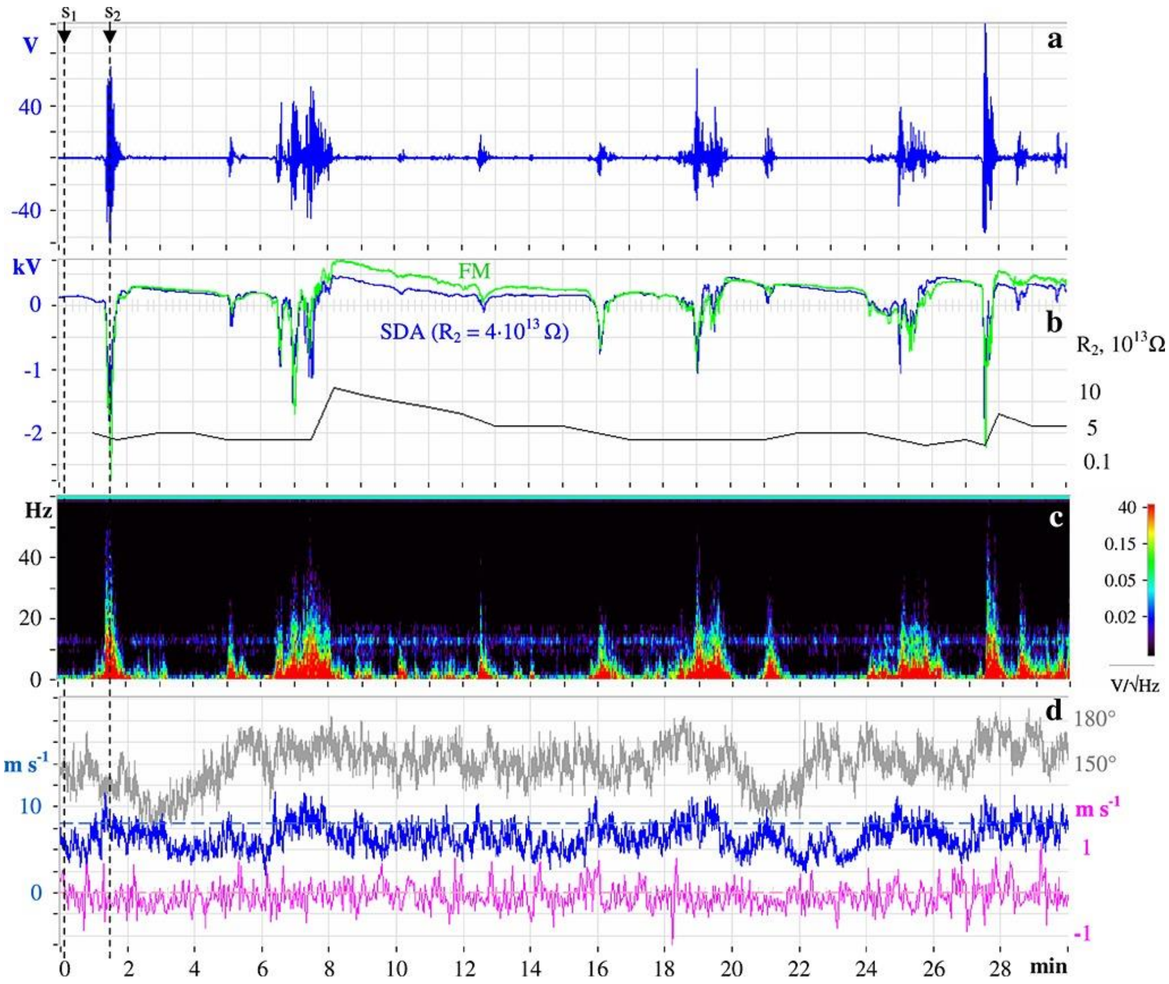

(a) Electric potential measured by the Short Dipole Antenna (SDA) electrode.

(b) Electric potential deduced from the electric field observed by the FM sensors at 6 and 55 cm (green line) and from the SDA measurements under the assumption that $R_2 = 4 \cdot 10^{13}\ \Omega$ (blue line). The coupling resistance deduced from the best fit of the FM and SDA, is shown by the black line.

(c) Spectrogram of low frequency emissions measured by the SDA electrode.

(d) Wind direction (grey), total horizontal wind velocity (blue), and 2 s averaged vertical wind velocity (magenta). Upward/downward wind corresponds to the positive/negative values.

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