First Observations at the Bulgarian Antarctic Astronomical Observatory

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(Submitted on 15.05.2026; Accepted on 30.05.2026)

Abstract. We present the objectives, implementation, and preliminary results of the first Bulgarian polar astronomy project, "Impact of Solar Activity on Ionospheric Dynamics and High-Energy Particle Fluxes over Antarctica" (2024–2025), conducted at the Bulgarian Antarctic Base on Livingston Island. The study aims to investigate solar-terrestrial interactions, focusing on solar flares, coronal mass ejections, and their effects on ionospheric disturbances, geomagnetic field variations, and radiation levels. Four synchronized experiments were deployed: (1) HF radio spectrography for direct solar burst observations (50-1000 MHz), (2) VLF monitoring of ionospheric D-layer disturbances via long-range ground-based transmitters, (3) magnetometric measurements of local geomagnetic field variations, and (4) radiation dosimetry using passive detectors. Data analysis is ongoing, with plans for long-term monitoring to improve space weather forecasting and mitigate impacts on satellite communications. This initiative establishes Bulgaria's capacity for cutting-edge polar astrophysical research, supported by collaborations between the Institute of Astronomy and NAO, Technical University-Sofia, the Nikola Vaptsarov Naval Academy, and international partners.

Key words: Polar astronomy project; Solar activity; Ionospheric dynamics; Antarctic research; Geomagnetic field.

Introduction

The study of solar activity and its effects on Earth is essential for understanding important interrelationships in solar-terrestrial physics. Solar activity has a direct impact on aspects of our daily lives, such as communication, navigation systems, and power grids, as well as many other indirect aspects of life on Earth, which have been studied by numerous scientists, researchers, and science writers. Due to the large amount of radio-frequency noise (power networks, office communication, mobile communications, FM radio, remote controls, etc.), it is extremely important that radio-frequency studies of solar activity be conducted in a radio-quiet location, where the obtained data cannot be compromised, and direct observations of solar activity require direct visibility of the Sun. This, in turn, creates the need for a location where the day is as long as possible. For these and other reasons (considered in detail in this article), the Bulgarian Antarctic Base "St. Kliment Ohridski" ("Ohridski base" hereafter), located on Livingston Island, part of the South Shetland Islands group, at coordinates 62°38'29" S and 60°21'53" W (Fig. 1), was chosen as the site for the experiments. The measurements described in this article were carried out during the 33rd Bulgarian Antarctic Expedition over 45 days in January and February 2025, recording solar activity in the radio-frequency spectrum and Earth's magnetic field. During the period in which the experiments were conducted, the Sun was near the maximum of its twenty-fifth 11-year solar cycle. This period was particularly suitable for carrying out the experiments, since it is when the most intense and frequent events related to solar activity occur, affecting the Earth directly and indirectly. From a scientific point of view, the solar-cycle maximum provides an opportunity for observations and for expanding our knowledge of so-called space weather. This article presents research on solar activity through three systems: direct observation of solar activity at VHF radio frequencies of 50-1000 MHz; observation of the effects of solar flares on the D-layer of the ionosphere through VLF observations of distant ground sources; and observations of changes in the Earth's magnetic field in the area of the Bulgarian polar station. In addition, dosimetric detectors were installed on the territory of Ohridski base to register cosmic-ray fluxes concentrated in the polar regions. The four experiments were intended to operate simultaneously, allowing us to study the connections between the observations directly. The unique location of Ohridski base allows continuous observation of solar activity in metric-decametric radio waves during the Antarctic summer for more than 20 hours per day. This enables unprecedented research on the effects of solar activity at far southern latitudes. The results presented in this article verify the reliability of the data measured by the system, and the first measured and analysed results are also presented.

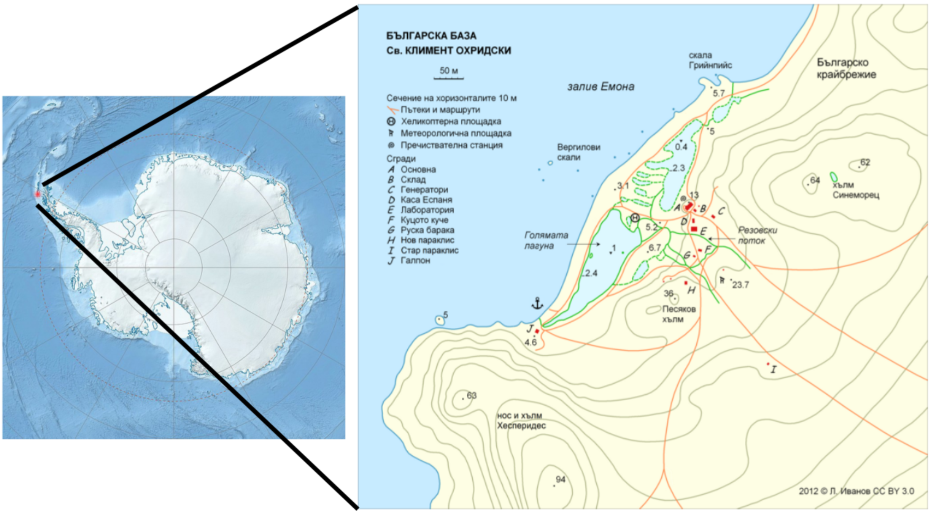


Fig. 1. Location of the Bulgarian Polar Base "St. Kliment Ohridski", site of the Bulgarian Polar Astronomical Observatory.

The paper is structured as follows: The methods Section 1 describes the experimental setup and the observations. It is followed by a description of the first results in Section 2. We discuss some aspects of the observations in Section 3. Finally, we summarize the work in Section 4.

1. Equipment and scientific experiments

To achieve the project's goals of carrying out the measurements and further analysing the results, it was necessary to design, assemble, and test the equipment and its reliability for operation in a location with adverse meteorological conditions such as Antarctica. Three experiments were planned, as described below.

0.1 VHF Observations of Solar Radio Bursts

Direct observation of solar activity at Very High Frequency (VHF) radio frequencies of 50-1000 MHz. Typically, this type of measurement is carried out with large radio telescopes (Altyntsev et al., 2020) because of the high level of radio noise caused by the many communication technologies operating in this frequency range (FM radio, mobile communications, remote controls, service communication channels, etc.) (Ala-Fossi, M., & Bonet, M. (2018); Wright, D. (2021)).

0.2 VLF Observations of Solar Flares

Due to their ability to penetrate seawater and diffract around large obstacles, Very Low Frequency (VLF, 10–100 kHz) radio waves are crucial for communication with submerged submarines. In addition, VLF signals can be used to characterise the propagation properties of the Earth–ionosphere waveguide formed between the Earth's surface and the ionospheric D-region. Variations in these properties (e.g., amplitude, phase, and group delay) enable the inference of solar-flare activity, D-region electron-density changes, and space-weather effects (Cummer, S. A. (2000); Indira Devi et al. (2008)). In order to estimate the amplitude perturbations of the received signal, a VLF precision receiver was designed, constructed, and tested at the Technical University of Sofia. The system consists of the following components (Fig. 2): 1 - magnetic loop antenna, 2 - capacitor bank, 3 - differential twin line, 4 - low-noise amplifier, 5 - coaxial transmission line, 6 - Software Defined Radio (SDR), 7 - USB line, 8 - PC with software used to separate signals and record the signal level. For this system to achieve high sensitivity, a large distance between the ground source and the receiving station is required.

The inductor (magnetic loop), which acts as a receiving antenna, consists of plastic tubing and 50 turns of copper wire with a diameter of 0.5 mm. The inductor wire is wound around a square plastic duct with a side length of 1150 mm, enclosing an area of 1.32 m^2. This provides an inductance of 7.2 mH and a series resistance of 10-15 Ω in the frequency range 10-25 kHz. The inductor is paired with a polypropylene capacitor bank with a total capacitance of approximately 8 nF. The resulting parallel resonant tank circuit has a resonant frequency of 22 kHz, an unloaded quality factor of approximately 65, and an equivalent parallel resistance of R_p=65 $k\Omega$. The matching and filtering network at the input stage of the low-noise amplifier provides additional filtering and loads the balanced line with approximately 12 $k\Omega$, resulting in a loaded quality factor of Q_L=10.7. The corresponding $\sim$3 dB bandwidth is approximately 2 kHz, which allows simultaneous coverage of the 24 kHz Cutler transmitter and the 21.4 kHz NPM Lualualei (Hawaii) transmitter.

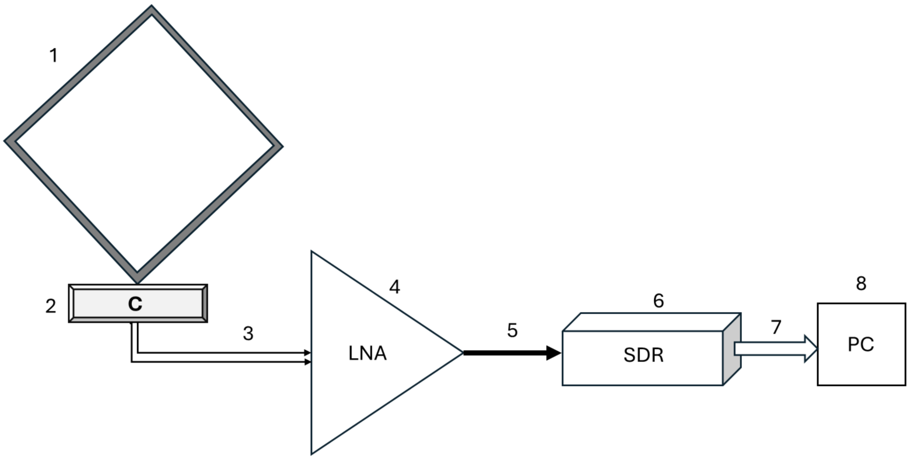


Fig. 2. Diagram of the VLF receiver system. 1 - Magnetic loop antenna, 2- Capacitor battery, 3 - Differential twin line, 4 - Low noise amplifier, 5 - Coaxial transmission line, 6 - Software Defined Radio (SDR), 7 - USB line, 8 - Computer.

The amplifier consists of three stages. The first stage employs an AD8421 instrumentation amplifier configured for balanced input operation, followed by two gain stages based on NE5532 operational amplifiers. The overall voltage gain is manually adjustable and set to 200. The amplified signal is envelope-detected, digitized using an RSPdx software-defined radio receiver, and recorded on a PC.

0.3 Magnetic Field Measurements

The Earth's magnetic field is mainly influenced by the Earth's inner core, but external factors have also been observed to cause variations in it. The dynamics of the solar wind and geomagnetic storms also contribute to short-term fluctuations in the Earth's magnetic field (Regi, M. et al., 2021). The installation and verification of a magnetometer in the current system contribute to the identification of relationships between events related to solar activity and specific changes in the Earth's magnetic field.

One can see that the three experiments are extremely complex to implement, and the hardware synchronization and unification used by the three experiments further complicate the implementation for smoothing the overall system. Figure 3 presents a block diagram of the overall system. The system can be divided into an internal and an external block. The internal block contains the measuring devices for the VLF and VHF systems, a computer configuration for storing the recorded data, and the components required to synchronise the individual blocks. Due to the large distance between the two modules, additional communication modules are used to support communication and synchronisation between the internal and external equipment. The main module for the external equipment is the Synchronisation and Communication block, which provides synchronisation between the external components

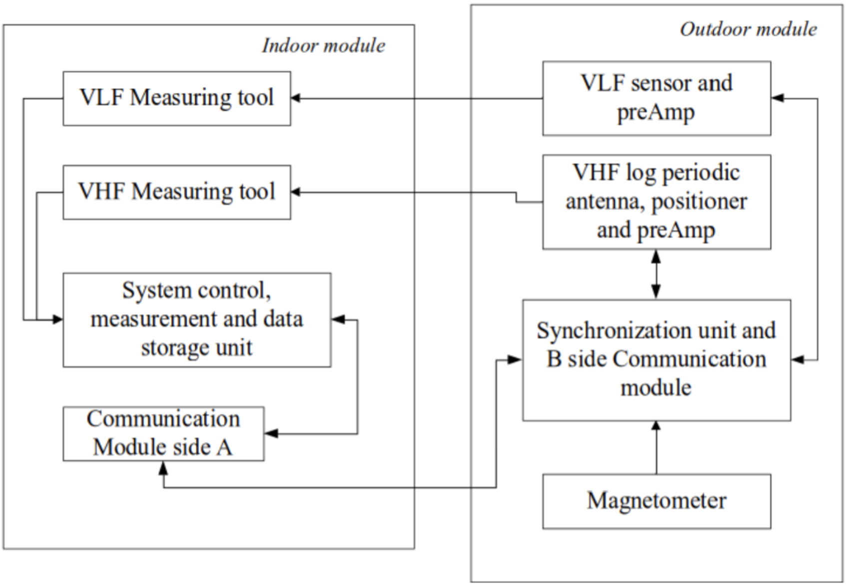


Fig. 3. Block diagram of the implemented system for studying solar activity

of the systems. Figure 4 shows the deployment of the VLF and VHF systems on site.

The VLF sensor and preamplifier block consists of the VLF sensor and amplifier themselves (Fig. 2); therefore, this segment of the system has very high sensitivity. The VHF log-periodic antenna, positioner, and preamplifier block is composed of a log-periodic antenna operating in the studied range and mounted on a positioner, which keeps the antenna continuously directed towards the Sun and enables it to receive radio signals associated with solar activity with high sensitivity. Finally, there is the magnetometer block, which is located at a distance from the other blocks in order to minimise the possibility of detecting interference from the systems' power supply.

A separate energy-independent experiment is the study of the flux of cosmic particles using dosimetric sensors made of polyallyl diglycol carbonate, which is extremely sensitive to energetic protons, alpha particles, and heavier nuclei. This experiment is intended to complement the data from the three system elements described above; however, as of the date of publication of this article, the results and analyses are not yet complete and are therefore not considered in this paper.

2. First Results

Here we present some of the initial results obtained during the first observation campaign:

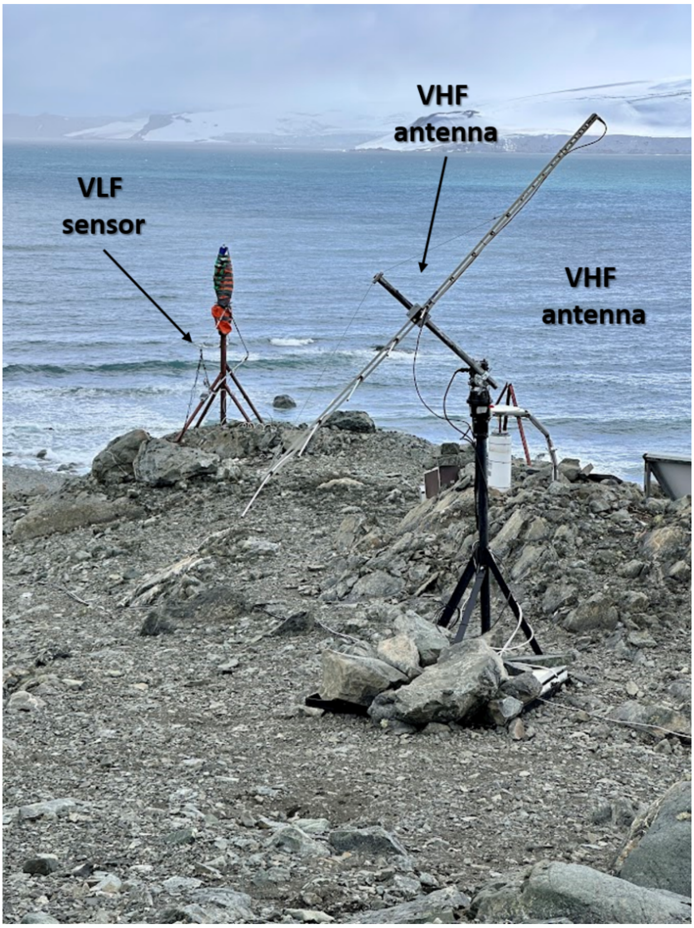
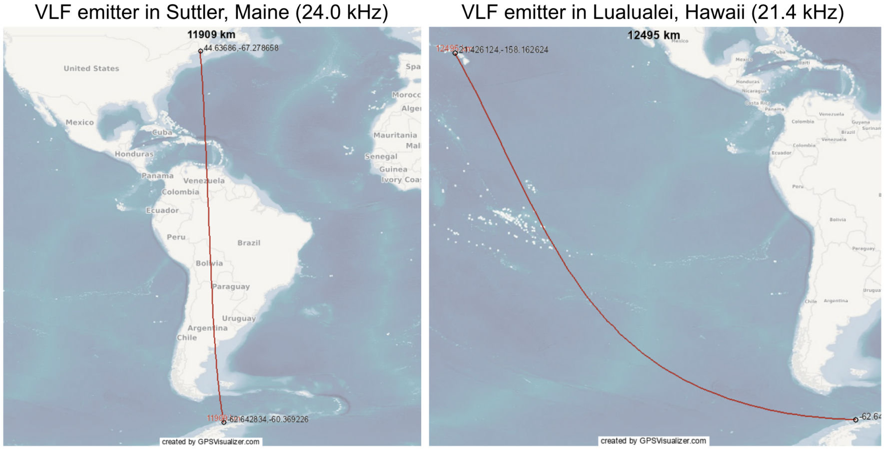


Fig. 4. Photo of the solar activity monitoring equipment installed on site.

2.1 VLF sensor for monitoring the effects of solar flares on the D-layer of the ionosphere through VLF observations of distant ground sources.

The VLF experiment involves observing individual frequencies (time series of amplitude and phase) of changes in the ionospheric-earth waveguide propagation characteristics. This is done through 24/7 monitoring of signals in the Very Low Frequency (VLF) range from stationary sources located in the Northern Hemisphere. The experiment lasted 2 months, or throughout the entire duration of the 2024-2025 Antarctic expedition, operating continuously 24 hours a day without interruption. We observed very long ionospheric paths between Livingston Island and two VLF transmitters in the northern hemisphere. This is several times longer than the observations currently being conducted, which most commonly cover Europe-America, Europe-Europe, and Europe-Asia paths. The antenna was stationary, manually aligned once. The path has


VLF emitter in Suttler, Maine (24.0 kHz)

VLF emitter in Lualualei, Hawaii (21.4 kHz)

Fig. 5. The radio paths used for the studied Ionosphere-Earth waveguide

been selected along the meridian to ensure simultaneous terminator crossing and identical day/night conditions at both ends of the path (i.e., both stations experiencing either day or night simultaneously). The 21.4 kHz signal is emitted from the United States Navy transmitter (call sign NPM) at Lualualei, Hawaii, USA, with a shortest path length to the Ohridski base of 12 495 km. The 24.0 kHz signal is emitted from the United States Navy transmitter (call sign NAA) at Cutler, Maine, USA, with a shortest path length of 11 909 km. (Fig. 5). The initially obtained and processed data from these studies have a form similar to that presented in Fig. 5 - data for the period 24.01.2025 and 08.02.2025 are presented. To verify the reliability of the data, a comparison was made with satellite data from the GOES (NOAA Space Weather Prediction Center, 2025) satellite network - Fig. 6 (right).

2.2 Direct observation of solar activity at VHF radio frequencies 50-1000 MHz.

By observing changes in radio emission during solar bursts, we can gather information about the speed and strength of the coronal shock wave, how effectively it accelerates ions and electrons, and the local density of the solar wind and corona. Specifically, we observe with high temporal resolution the dynamic spectra of Type II and Type III radio bursts, indicative of a coronal shock wave and a solar flare, respectively.

Since solar activity is directly connected to short-term and long-term changes in Earth's magnetosphere, ionosphere, atmosphere, as well as in the radiation environment between Earth and geostationary satellite orbits, our radio observations provide additional information for space-weather forecasting. Collecting long-term radio observations also allows the study of long-term changes in the Sun's emission and, consequently, changes in Earth's climate.

For the current experiment, we used an existing design of a CALLISTO-type radio telescope-spectrograph (Compound Astronomical Low-cost Low-

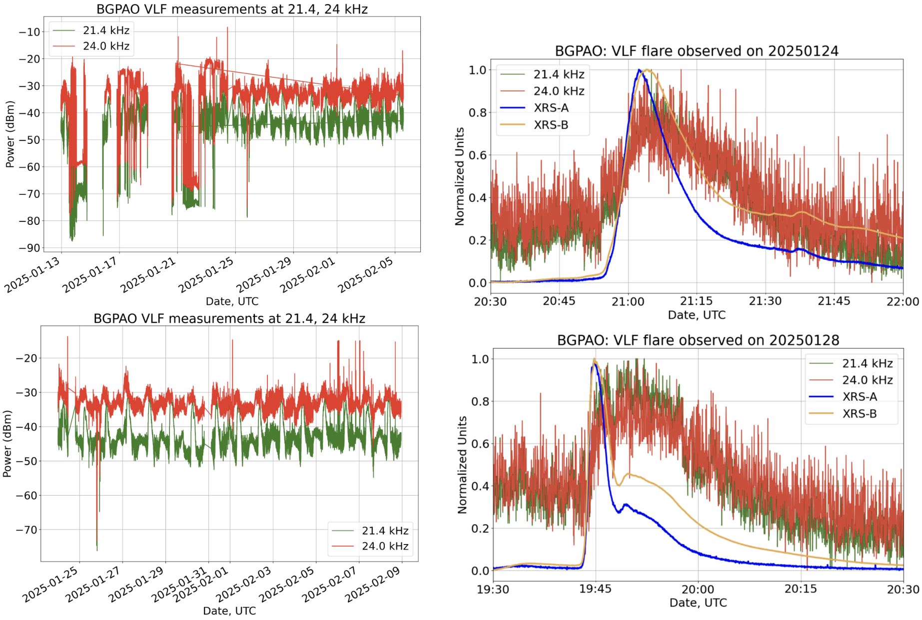


Fig. 6. (left) Full time series of VLF observations (top). Sample of observations between 24.01 and 08.02 (bottom). (right) Captured solar flares observed by the VLF system on Livingston Island on January 24 (top) and January 28 (bottom). The yellow and blue lines are X-ray observations from the GOES-18 space satellite.

frequency Instrument for Spectroscopy in Transportable Observatory) with a range of 50-1000 MHz, a typical frequency resolution of 120 Hz per frequency bin, and a temporal resolution of 0.5 seconds for the entire frequency range. The radio telescope was implemented using an existing antenna manufactured by TU-Sofia. The telescope consists of a log-periodic antenna, a CALLISTO-type digital receiver with a low-noise preamplifier and a real-time digitiser, a mast and rotator for solar tracking, an electronic autonomous rotator controller, and a computer for signal control and recording. It was prepared for operation under Antarctic conditions during the first phase of the project. The HF spectrograph was installed at Ohridski base on Livingston Island and operated every day between sunrise and sunset, automatically pointed at and tracking the Sun.

Figure 7 presents two panels showing dynamic spectra with a time resolution of 8 seconds and a duration of 13 minutes each, scanning the frequency range between 200 and 1000 MHz on 06.01.2025 and 15.01.2025. Many individual Type III radio bursts are visible, corresponding to mini-bursts at the base of the solar corona, seen as vertical spectral lines. The exceptionally radio-quiet environment of Livingston Island allows us to make these unique observations. The next steps include calibration of the frequency band and automated characterisation of individual bursts, including starting and ending frequency, duration, intensity, and time coincidence with other observations.

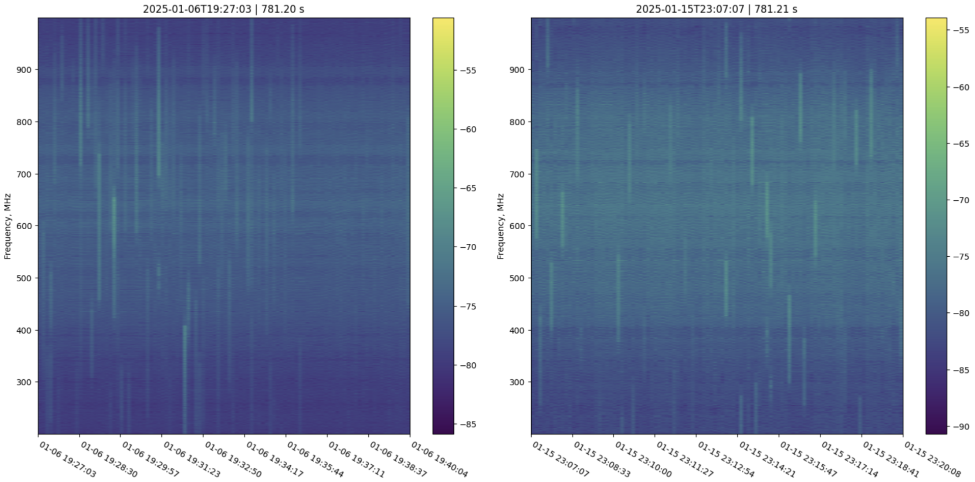


Fig. 7. Observations of metric wavelength bursts in 13-minute dynamic spectra observed from Livingston Island.

2.3 Observations on changes in the Earth's magnetic field in the area of the Bulgarian polar station.

Fig. 8. Location of the Kliment Ohridski Base (BGPAO) and the Vernadsky (AIA) and Orcadas (ORC) magnetic measurement stations.

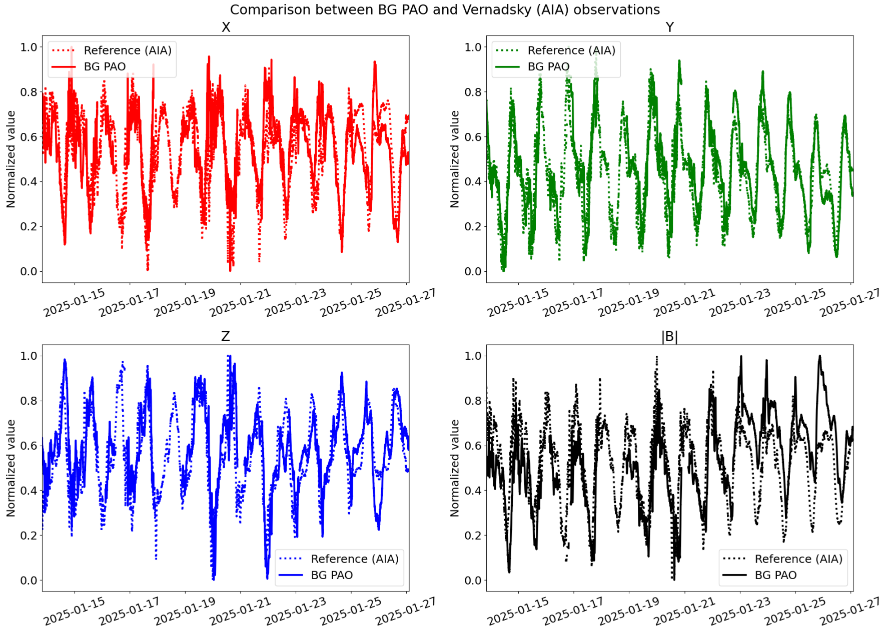


Fig. 9. Comparison of magnetic field measurements from BGPAO and AIA stations.

Magnetic observations from Ohridski base were carried out during the period 25.01-27.01.2025. To verify the data, they were compared with freely available observations from the two closest magnetic stations in the INTERMAGNET network: the Ukrainian Vernadsky station (code AIA) and the Argentine Orcadas station (code ORC). Fig. 8 shows a map with the locations of the three stations. We compare the components of the magnetic field in two different coordinate systems, according to the available comparison data, as well as its absolute value. For verification of the measurements obtained at Ohridski base, the presented values are normalised, since the absolute values differ between locations. In Fig. 9 we show a comparison with the observations from Vernadsky Station (AIA). Similarly, Fig. 10 shows a comparison with measurements from Orcadas Station (ORC). Overall, excellent agreement between the observations is found.

3. Discussion

The initial results obtained during the 33rd Bulgarian Antarctic Expedition (January–February 2025) demonstrate the high effectiveness and reliability of the deployed multi-instrument system. The unique electromagnetic environment of Livingston Island, combined with the period of solar maximum (Solar Cycle 25), has yielded significant scientific data.

The VLF experiment successfully monitored ionospheric D-layer disturbances by tracking signals from distant transmitters in the Northern Hemisphere (Cutler, Maine, USA and Lualualei, Hawaii, USA). The system mon-

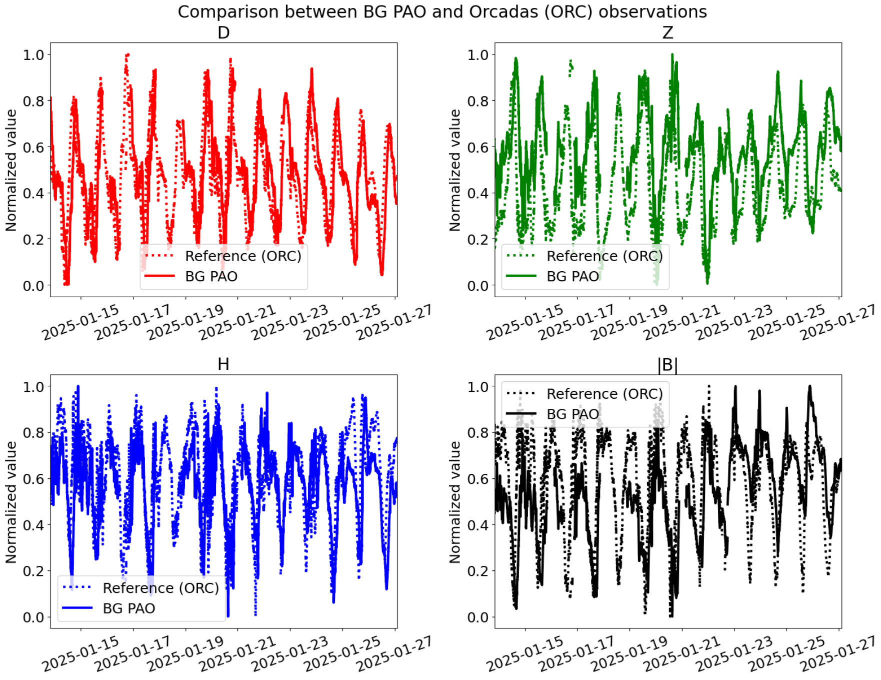


Fig. 10. Comparison of magnetic field measurements from BGPAO and AIA stations.

itored an exceptionally long ionospheric path of approximately 12,000 km, which is significantly longer than standard observation paths. The captured VLF data for solar flares (e.g., 24 and 28 January, 2025) showed a high degree of correlation with X-ray flux data from the GOES-18 satellite. This confirms the system's ability to accurately detect the impact of solar activity on the Earth-ionosphere waveguide.

The CALLISTO-type spectrograph successfully identified multiple Type III radio bursts in January 2025. These bursts are critical indicators of electron acceleration at the base of the solar corona. The system operated continuously between sunrise and sunset, with an automated solar tracking mechanism that maintained high sensitivity throughout the observations.

The magnetometric measurements conducted between 25 and 27 January, 2025, focused on local variations in the Earth's magnetic field. To verify the accuracy of the Bulgarian station (BGPAO), measurements were compared with data from two nearby INTERMAGNET network stations: the Ukrainian Vernadsky (AIA) and the Argentine Orcadas (ORC). The comparative analysis revealed excellent agreement between the observations from the Bulgarian Ohridski base and the established international stations. This validates the magnetometer's calibration and its placement, which effectively isolated it from power supply interference.

4. Conclusions

From the presented initial results of measurements of solar activity and magnetic changes, it can be seen that the obtained data are not only verifiable but also capture events caused by solar activity with high accuracy. This confirms the effectiveness of the proposed system. The reliability of the measurements demonstrates the effectiveness of the implemented system. Its observations are of essential importance for enriching databases for space weather and geomagnetic models, and for understanding direct and indirect dependencies in processes related to solar-terrestrial physics. At the same time, the data are unique for the studied period, as they provide observations of the twenty-fifth 11-year solar cycle from the location where the studies were carried out, namely the Bulgarian Antarctic Ohridski Base.

Acknowledgments

This study was funded by the Bulgarian Ministry of Education and Science through the National Centre for Polar Studies, and Sofia University “St. Kliment Ohridski” in the framework of the National Program for Polar Studies 2022–2025, grant number D70-25-44/12.04.2024. We acknowledge funding from the LOFAR-BG project of the National Roadmap for Research Infrastructure of Bulgaria, under contracts D01-362/14.12.2023 and D01-110/30.06.2025 with the Ministry of Education and Science. Part of the instrumentation was developed with financial support from NextGenerationEU, under the National Recovery and Resilience Plan of the Republic of Bulgaria (Project No. BG-RRP-2.004-0005).

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INTERMAGNET: International Real-time Magnetic Observatory Network. INTERMAGNET, https://intermagnet.org/.