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# INSTRUMENTAL SUPPORT FOR IONOSPHERIC, MAGNETIC AND HELIOGEOPHYSICAL OBSERVATIONS

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**Abstract:** During the period of maximum solar activity, extreme space weather events increasingly affect technical means and systems. The article considers the ground-based heliogeophysical observation platform, as well as on-board heliogeophysical hardware complexes (GGAK), which conduct operational monitoring of space weather from space crafts.

**Keywords:** ionospheric, magnetic, heliogeophysical observations, space weather, instruments, metrology.

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RESEARCH ARTICLE

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## 1. Introduction

At the peak of the 25th cycle of solar activity instrumentation support, reliability and accuracy of ground-based ionospheric, magnetic, and heliogeophysical observations and space grouping are becoming increasingly relevant, due to the increasing dangerous phenomena of space weather [*Mayorova et al.*, 2024a] (Figure 1).

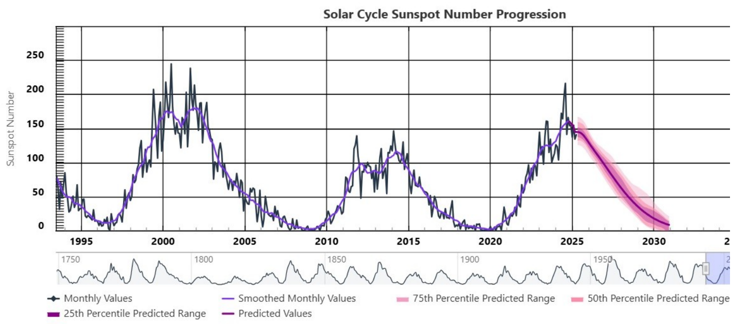



**Figure 1.** Graph of sunspots and solar cycles (https://www.swpc.noaa.gov/products/solar-cycle-progression).

In Russian Federation, Roshydromet is responsible for operational monitoring of the quality and reliability of ionospheric, magnetic and heliogeophysical observations in accordance with federal regulations. The leading scientific and methodological organizations are FGBI "IPG" (http://ipg.geospace.ru/?view=desktop) and FGBI "AANI" (https://www.aari.ru).

Ionospheric, magnetic and heliogeophysical observations are carried out to monitor space weather and identify dangerous heliogeophysical phenomena. Space weather and storms affect a wide range of human activities: they create a radiation hazard for astronauts, can destroy or damage power lines, cause corrosion of oil and gas pipelines, affect radio communications and navigation of terrestrial and satellite systems, absorb radio waves in the polar cap, causing failures in radio communications and radar. Irradiation of spacecraft with high-energy particles can cause anomalies in operation, destroy electronics, degradation of solar panels and "blindness" of optical systems of telescopes and stellar orientation sensors [*Minligareev et al.*, 2023b].

Taking into account the factors of space weather, forecasting their negative impact and operational information support are important elements of national security, including the Arctic zone of the Russian Federation [*Minligareev et al.*, 2023a]. The instrumental support of ionospheric, magnetic and heliogeophysical observations plays a key role in this process. The last modernization of the instrument bases for geophysical monitoring was carried out more than 12 years ago, therefore, a planned replacement of equipment is necessary, taking into account modern realities.

## 2. Instrumental observations of space weather

Russia has established a system for monitoring the geophysical situation (which dates back to 1973 with the ionospheric magnetic service), which is part of the observation network of Roshydromet. Geophysical information is received from ground-based (ionospheric stations, magnetic observatories, GNSS receivers, solar and radio telescopes) and space platforms (spacecraft of the Meteor-M, Electro-L, Arktika-M, Ionosphere-M series), as well as through international information exchange channels.

The main structure of the ground-based ionospheric and magnetic observation network includes: the Parus-A ionosonde (10), the CADI ionosonde (7), the LFM ionosonde (6), the riometer (8), the hardware and software complex of high-orbit radiotomography (120), magnetometers (14).

In addition, ground-based observation instruments of the Russian Academy of Sciences are used, including solar observatories (ISTF RAS (https://badary.iszf.irk.ru/ssrt.php), GAS GAO (https://observatories.ru/gas-gao/), Special Astrophysical Observatory (https://www.sao.ru/), etc. Measurement information is transmitted and processed in the analytical centers of Roshydromet, including the Heliogeophysical Service, the Federal Information and Analytical Center, the International Space Weather Center for Air Navigation CRC (https://space-weather.ru/) and the Polar Geophysical Center (https://geophys.aari.ru/main.php). Mailing and warnings about dangerous geophysical phenomena are carried out in 200 organizations of the Federal executive power, international organizations, including WMO, ISES and ICAO.

### 2.1. Ground observation network

The ground segment is represented by ionospheric stations, magnetic observatories, GNSS receivers, solar and radio telescopes. The main part consists of Roshydromet's own observation points, some of them are instruments and observation points of the Russian Academy of Sciences and the Ministry of Education and Science.

Ionospheric observations are the most demand part. The ionospheric network is represented by ionosondes of vertical and inclined sensing, software and hardware complexes of high-orbit radiotomography. Ionosondes measure the delay time of a 1–20 MHz radio pulse, which is recorded and presented in the form of ionograms. The network ionosonde and its characteristics are shown in Figure 2 and in Table 1.

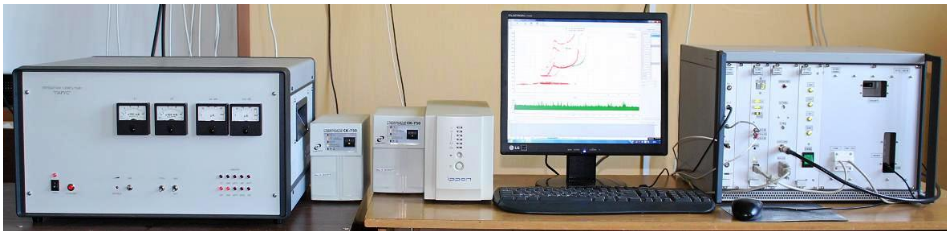


**Figure 2.** General view of the ionosonde "Parus-A".

**Table 1.** Technical and metrological characteristics of the ionosonde "Parus-A".

| Characteristics | Value |
|---|---|
| The measurement range of the delay time of the radio pulse | 0.5–10 ms |
| The limits of the permissible absolute error in measuring the delay time of the radio pulse | ±12 µs |
| The range of reproducible radio pulse filling frequencies | 1–20 MHz |
| The limits of the permissible absolute error in measuring the frequency of filling the radio pulse | ±5 kHz |
| Limits of permissible error of setting GPS second pulses | ±1 µs |
| The number in the State Register of Measuring Instruments | 51425-12 |

### 2.2. Space grouping

The space segment of the heliogeophysical observation network is represented by a grouping of hydrometeorological and heliogeophysical spacecraft of the Meteor-M, Electro-L and Arktika-M series with GGAK hardware heliogeophysical complexes (Figure 3).


**Figure 3.** International grouping of hydrometeorological and heliogeophysical satellites with Russian satellites (https://www.nesdis.noaa.gov/news/what-satellite?page=5).

GGAK heliogeophysical hardware complexes (modifications E, VE, M) are designed for global monitoring of heliogeophysical parameters in order to [*Avdyushin et al.*, 2014]:

- monitoring and forecasting of solar flare activity;
- monitoring of the radiation situation in the OKP;
- diagnostics and monitoring of the state of the geomagnetic field.

The integrated target heliogeophysical equipment (CCA) on the Electro-L spacecraft is shown in Figure 4.

Typical composition of GGAK-VE on the Electro-L spacecraft:

- SKIF-VE spectrometer for measuring the flux density of protons (up to 160 MeV) and electrons (up to 10 MeV);
- GALS-VE spectrometer for measuring galactic cosmic rays (proton flux densities of more than 600 MeV and electrons);
- ISP-2M solar constant meter (1360–1365 W/m$^2$);
- VUSS-E solar extreme ultraviolet radiation flux meter in the HLa range (121.6 nm);
- DIR-E Solar X-ray flux density meter in the range of 3–8 keV;

**Figure 4.** KCA GGAK-VE on the Electro-L spacecraft.

- FM-E magnetometer for measuring the components of the Earth's magnetic field in the range of +65,000 NT.

## 3. Promising developments

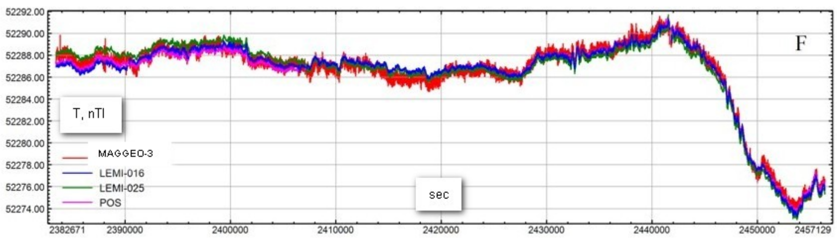
As noted, the ground equipment on the observation network has been in operation for more than 12 years and needs to be replaced. FSBI IPG is developing a program for the replacement of devices and equipment, which includes several key positions.

### 3.1. Development of a three-component ferrosonde magnetometer

Figure 5 shows the magnetometer MAG GEO-3 and its tests with leading domestic and foreign analogues. The main characteristics are given in the Table 2. The device is used for retrofitting networks, placement on spacecraft and small spacecraft of the CubSate type.

(**a**)

(**b**)




(**c**)

**Figure 5.** External view of the magnetic sensor, control unit and test results (comparison of the full magnetic field vector).

**Table 2.** The main characteristics of the magnetometer MAGGEO-3.

| Characteristics | Value |
|---|---|
| Limits of relative measurement error, not more than | ±0.5% |
| The standard deviation according to second measurements in one minute | ±0.3 nT |
| The absolute error | ±1 nT |
| Operating temperature range of the control unit, ranging | from −40 °C to 80 °C |
| The supply voltage from a DC source, within | 12 V |
| Power consumption, no more than | 5.0 W |
| Sensor weight | 300 g |

### 3.2. Development of an ionosonde for vertical sensing of the ionosphere

To replace the network ionosonde “Parus-A”, a new generation of complex with automatic ionogram processing, remote access for maintenance via telemetry, a new compact antenna-feeder complex (AFC) 60×60 m, domestic software and ECB is being developed (Figure 6).

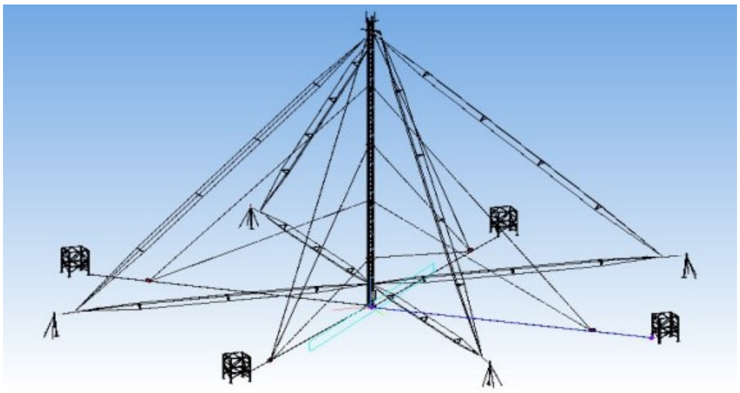


**Figure 6.** Antenna-feeder complex of the new ionosonde.

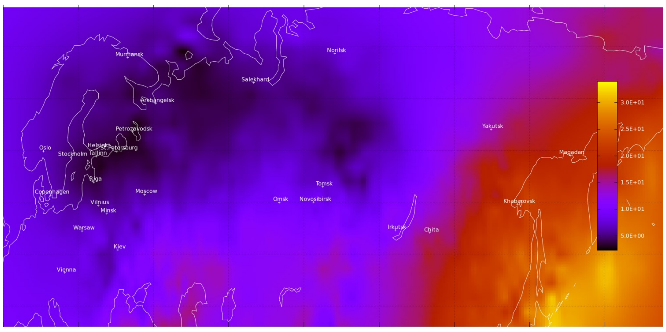
Ionosondes are designed to determine the heights of reflection of radio waves of various frequencies from the ionosphere, the critical frequencies of the ionosphere and the altitude distribution of electron concentrations for consumers and research.

### 3.3. Development of hardware and software complex of high-orbit radiotomography

Ionospheric radiotomography methods are used to determine radiotomographic sections of the ionosphere and three-dimensional distributions of the ionospheric electron concentration (TEC). This method is implemented in the of hardware and software complex of high-orbit radiotomography. The technical and metrological characteristics of the “Venus” package being developed (Figure 7) are shown in Table 3. The hardware and software complex of high-orbit radiotomography allows you to build electronic maps of the critical frequency f0F2; PES, flicker indices (scintillation) RoTi and other characteristics of the ionosphere in real time.

**Table 3.** The main characteristics of the of hardware and software complex of high-orbit radiotomography "Venus".

| Characteristics | Value |
|---|---|
| Operating frequency range | 1–20 MHz |
| Average radiation power, no more than | 60 W |
| Pulse duration | 100–200 µs |
| The error in measuring the amplitudes of reflected signals | 1 dB |
| The error of linking time to the time scale | 1 µs |

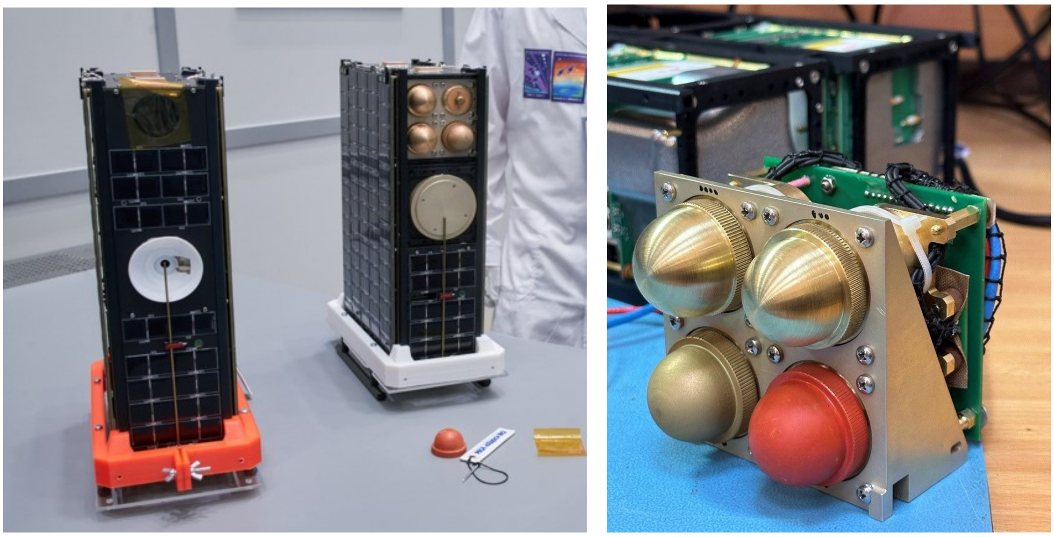




**(a)** **(b)**

**Figure 7.** PAK VORT "Venus" and TEC map.

### 3.4. Development of target equipment for small spacecraft of the CubSate type

The development of small spacecraft is rapidly gaining momentum [*Bragina et al.*, 2023; *Melnikova et al.*, 2021]. Targeted equipment for small spacecraft of the CubSate heliogeophysical type is being developed. The FSBI IPG has developed the GAMVEKI-GM charged particle detectors, which have passed flight qualification on the Khors No. 1 and No. 2 spacecraft (launched and successfully operating in a 550 km circular polar orbit since June 2023) [*Mayorova et al.*, 2024b]. These devices monitor space weather by measuring the density of electron and proton fluxes in the Earth's radiation belts using Geiger-Muller counters. (Figure 8). In the future, small spacecraft with magnetometric systems are being prepared for development [*Bragina et al.*, 2022].



(**a**) (**b**)

**Figure 8.** 6U-XL CubSate "Khors" MCA No. 1, 2 with GAMVEKI detectors.

All the above developments are technologically innovative and are performed mainly on domestic ECBs and software. An important direction in ensuring the accuracy and reliability of measurements is the metrological support of geophysical observations. FSBI IPG, as the basic organization of Roshydromet for metrology in its field, ensures the unity of measurements on the ionospheric, magnetic and heliogeophysical observation network [*Minligareev et al.*, 2016; 2021].

## 4. Conclusion

Thus, the instrumental provision of ionospheric, magnetic and heliogeophysical observations on the state observation network is important for monitoring the geophysical situation in Russia. This is especially true during periods of peak solar activity. The above-ground part needs to be upgraded with outdated equipment.

FSBI "IPG" has developed and is preparing for production fluxgate magnetometers for magnetic observatories (with an error of ±0.5%), which are not mass-produced in Russia, as well as vertical sounding ionosondes in the range of 1–20 MHz, the production and scientific development of which are currently absent in our country. Together with the leading universities of the country (Bauman Moscow State Technical University, Lomonosov Moscow State University), a new unique direction has been mastered — the development of devices for heliogeophysical spacecraft of the CubeSat format, which have both a scientific basis and new technological solutions (based on the results of measurements, it is possible to install a sensor inside the device instead of an external rod) [*Bragina et al.*, 2025].

Based on previous and current developments shown in the publication in the Federal State Budgetary Institution "IPG", by decision of ICAO and the International Commission on Space Weather, one of the four global world centers of space weather for ensuring the safety of air navigation CRC has been operating since 2021. The CRC center carries out duty around the planet once every 2–2.5 months, based on high international standards for dangerous space weather phenomena (solar flares, magnetic storms affecting communications and positioning, the danger of radiation load during air travel) and issues warnings on dangerous heliogeophysical phenomena to automated air traffic control centers in real time.

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