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New Research Project: Ground-Based Monitoring of Cosmic Particles and Space Weather

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1. Abstract.

During the various cosmic events, including supernova explosions, star formation processes, collisions or strong accretion processes in stars and black holes, etc., photons (light) covering the entire electromagnetic spectrum and high-energy particles (called cosmic rays) are released, with energies from tens of eV to thousands of GeV. Cosmic rays (CRs) consist of mainly protons (about 90%), atomic nuclei (primarily helium), as well as free electrons propagating in space with speed close to the speed of light. Of course, the diverse energy spectrum of CRs also includes high-energy particles that are product of solar activity processes. On the one hand, the answer to the nature and physics of these questions is directly related to the continuous monitoring of various manifestations of solar activity, such as sunspots, solar prominences, solar flares and coronal mass ejections. But on the other hand, the possibility of continuous observational series of data has opened up new fields of scientific debate with increasing attention being paid to small-scale structures and short-living manifestations of solar activity. They turn out to have a significant role in a global interconnection with all other members of the Solar system, including our planet Earth. Solar activity and the resulting solar radiation, together with the total cosmic radiation, appear to be the main cosmic factors influencing the Earth's global climate.

Keywords: space weather; energetic particles; neutrons.

2. Introduction

Throughout the long evolutionary change of our Solar system, in particular our planet Earth, climate changes have occurred and still occur under the complex combined influence of various factors, but among them the impact of cosmic factors is of primary importance, especially when we talk about time scales ranging from several decades to several centuries. Among the cosmic factors influencing the Earth's climate are the cosmic rays (CRs). Recently, an idea related to the climate change, called cosmoclimatology, was presented that suggests that variations in the intensity of CR flux influence [Svensmark, 2007], yet still under debate e.g. [Sloan and Wolfendale, 2008; Kulmala et al., 2010] and the recent CLOUD experiment results.

Solar radiation has a significant effect on the weather. "Weather" usually defines the short-term physical state of our atmosphere. However, it is determined by many complex and interacting phenomena that also affect local and global climates over long periods of time. The Sun and every other star have continuous radiation over a wide range of wavelengths with varying intensities. Electromagnetic solar radiation falling into the upper limit of the Earth's atmosphere is called extra-terrestrial radiation, which determines an average power of 1360.8 W/m^2 (solar constant). The radiation with the greatest importance and influence on Earth processes lies in the range 280-3000 nm (shortwave radiation) and 3 μm->40 μm (longwave radiation). The maximum intensity of the solar spectrum at the Earth's surface is between 400 and 500 nm (depending on sky conditions).

Solar radiation reaching the Earth is key to managing the food and water resources that determine the population's viability. But of course, it is even more important to note that solar energy is the main reason for the existence of life on our planet at all. The Sun, as an energy source, is increasingly used to provide clean and renewable energy with no carbon footprint or greenhouse gas emissions. Solar energy can be used to generate electricity and provide heat, but of course this is also highly dependent on climate and weather.

The climate system, whether local or global, is a complex and highly interconnected environment consisting of the atmosphere, the hydrosphere, the solid Earth's surface, the cryosphere, and the biosphere. Under the influence of solar radiation and the rotation of the Earth, air masses move from one region to another on a large scale. Improved numerical methods and analysis of observed meteorological data in recent years have provided outstanding meteorological models for real-time forecasting of the weather system. These models are used both to study the dynamics of the weather and the climate system and to provide increasingly accurate short-term (a few days to a few weeks) weather forecasts. However, the spatial and temporal uncertainty of climate models is large, and global models cannot resolve horizontal scales finer than about 50 km, and regional projections are even less certain. Therefore, the probability of extreme weather events is still an open question.

Traditional approaches to the multiscale climate modeling problem are unlikely to lead to breakthroughs when used separately. Meteorological data for temperature and humidity near the Earth's surface are crucial inputs to atmospheric models for short-term forecasting. In-situ measurements of temperature and moisture profiles by radiosondes have limited temporal resolutions (e.g., twice daily) and spatial coverage, especially in remote regions. We offer not only the construction of a station of modern sensors for measuring meteorological parameters with high resolution in time (seconds or minutes of the day), but also the possibility of CR observations, which are a promising new source of meteorological data to narrow data gaps by providing indirectly measured continuous records of temperature and moisture.

Galactic and solar CR particles entering the Earth's atmosphere with energies above 0.5 GeV undergo nuclear interactions with molecules from the Earth's atmosphere and produce a secondary stream of particles that reaches sea level. The development of the neutron monitors by J. A. Simpson provided a method for detecting and recording low-energy secondary neutrons [Simpson, 2000]. These secondary CRs fall in the energy range from several hundred MeV to about 1 GeV. Neutron detectors are most sensitive to the low energy (1-20 GeV) part of the spectrum. With their reliability and basic simplicity, they are a means of studying long-term weather variations, but their sensitivity and high counting (measurement) rates make it possible to observe short-term weather changes as well.

In the 1960s, a new neutron monitoring method was developed with a statistical accuracy of 0.1% for hourly data. This monitor, called a "super" monitor or NM-64, uses more advanced data collection techniques. Data from this type of monitoring observations have proven to be extremely stable and are particularly valuable for long-term cosmic radiation studies. Today, there are about 59 neutron monitor stations in operation worldwide with a wide range of geomagnetic boundaries, altitudes, and viewing directions.

The energy of cosmic ray particles that can penetrate the Earth's upper atmosphere is a function of the geomagnetic field. The Earth's magnetic field can be used as a spectrometer that allows measurements of the cosmic ray spectrum down to low primary energies. The magnetic width of a particular neutron monitoring station determines the lowest magnetic rigidity of the primary flux that can reach the detectors, the so-called "cut off rigidity". Accordingly, the altitude of the station also determines the amount of absorbing atmosphere above it. As a result, the amount of secondary CRs absorbed decreases with height because of the lower absorption number. By using a combination of lead (to create local interactions), paraffin or polyethylene (to soften or slow down the neutron component), and multiple slow neutron detectors, the particle counting rate can be greatly increased.

Nowadays, the measurement of solar radiation is extremely important in many different fields of application, such as climatology, meteorology, hydrology, pollution forecasting, solar energy, agriculture, and material testing [Dhasmana et al., 2023; Waldman et al., 2020]. Measuring solar radiation for climatology and weather forecasting is an important part of many of our daily activities that we can no longer do without. For example, the data obtained is essential for shipping and aviation. To understand and predict climate changes, high-precision and reliable measurements over long periods of time are needed to quantify small and slow, but significant trends. Weather observation and prediction are absolutely vital to our modern civilization and its technical progress. Transport and trade by land, sea and air cannot be sustained without continuous measurement and collection of weather data. Protecting human lives by predicting avalanches, torrential rains, hurricane-force winds and other hazards would not be possible without continuous monitoring of solar radiation.

In recent years, the measurement of solar radiation has also become increasingly important in the field of material testing, where, for example, the resistance to UV radiation of products and coatings comes to the fore. Accurate solar radiation data is critical to the solar energy industry. In research and development, selection of optimal locations and types of systems, performance monitoring and maintenance planning.

3. Project Implementation

3.1. Methodology

The new research project will investigate climate changes both in our country and on a global scale, using CR flux measurement combined with modern standardized sensors for various meteorological parameters. A ground-based continuous monitoring of CRs will allow our country to be included in a common global network, covering different parts of the globe.

To implement part of the tasks and objectives of the project, we envisage using data on solar activity from observations of already existing infrastructures – the new 30-cm chromospheric telescope at the NAO Rozhen [Tsvetkov and Petrov, 2021], as well as observations from ground-based observatories outside the country. For a better continuous observational sample data from space-based solar observatories (e.g., SDO, STEREO, SOHO, etc.) will also be used.

The work on observational databases of solar activity is the connecting element to the achievement and implementation of the main work packages of our project (Table 1). Suggested work packages will lead to the construction of a modern monitoring system for measurement and analysis of CR flux parameters and Earth's low atmosphere parameters.

Table 1. *Work organization on work packages (WP) and the tasks included in each of them.*

	Tasks
WP1	Creating a small network of mini-NMs at different altitudes in Bulgaria and becoming part of global neutron detectors network.
WP2	Building meteorological stations next to NMs in order to collect accurate and continuous data of basic meteorological parameters.
WP3	Creating a secure database open for teams with purely scientific and scientific-applied activities.

WP4	Sharing the results with colleagues, students and general public.

3.2. Goals and issues

One of the main reasons for the rapid rise of average global temperature (Fig. 1) is the increase of atmospheric carbon dioxide from the burning of fossil fuels. Scientific research shows that extreme weather events such as floods (due to sea level rise), strong storms and heat waves are likely to become more frequent and more intense. Such extreme weather conditions and unusual climate patterns are already evident today. Such events have a diverse impact on the living conditions of our planet, which obliges a transition to a low-carbon economy worldwide in order to be prepared and resist catastrophic climate changes.

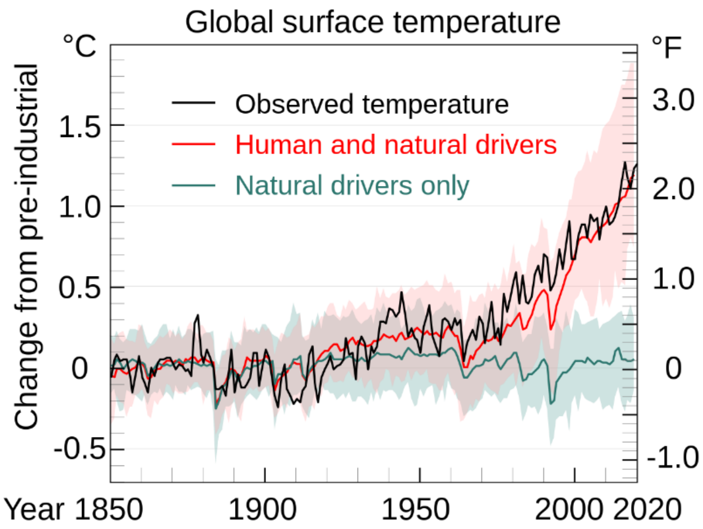

Figure 1. *Changes in mean surface air temperature since the industrial revolution according to data from the Intergovernmental Panel on Climate Change (IPCC).*

It is impossible to study the Earth's climate without studying the activity of the Sun since it modulates the Earth's climate over tens and hundreds of years. The relationship between solar activity and the Earth's environment (also known as "space weather") is not trivial and involve many interacting processes.

Satellite data show that the strength of solar radiation may correlate with the 11-year cycle of solar activity. That is why scientists continue to look for the connection between solar activity and climate changes on Earth. It has not yet been established exactly how closely the climate cycles coincide with the 11-year cycle of solar activity. Despite individual cases of coincidence are found, there are still no reliable statistical data to define a certain regularity. Solar events such as coronal mass ejections (CMEs) and solar energetic particle events (SEPs) can also influence changes in Earth's climate. This shows that there is disagreement among scientists about the direct effect of solar luminosity on climate. Therefore, understanding, analyzing and predicting space weather becomes important for the proposed approach to climate research.

The main goal of our research project is to build a modern monitoring system of CR fluxes and meteorological data. Accomplishing this primary goal aims to enable new models to more accurately predict short- and long-term climate changes on Earth related to cosmic factors that determine the space weather. The tasks and goals set in the project are of fundamental importance for the study of climate change in our country, but it is also an important step towards the opportunity for us to join the world networks for monitoring and analysis of global climate change on Earth.

3.3. Expected results and conclusions

- Continuous monitoring of CRs.
- Continuous monitoring of basic meteorological parameters.
- Exploring the relationship between solar activity, CRs and local meteorological parameters.
- Obtaining a new knowledge about the physics of interaction between CRs and local meteorological phenomena.
- Creating catalogs describing the manifestations of solar activity and unobserved anomalies of meteorological data.
- Acquiring deeper knowledge of the processes and phenomena considered as precursors of meteorological anomalies and/or extreme meteorological events.
- Obtaining more complete picture of the close relationship between solar flares, eruptive prominences and CMEs with measurements of the density of CRs that reach the ground.
- Determining statistical dependences in the cyclic behavior of the number and spatial distribution of eruptive prominences, solar flares and CMEs with the observed fluxes of CRs and meteorological parameters.

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