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Correlated Measurements of the Disturbances of Geomagnetic Field and Changes of Secondary Particle Fluxes at Aragats-Space Environmental Center (ASEC)

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14. ABSTRACT Our objective is the development of a geomagnetic storms forecast service. It will consist of a observed solar bursts data, particle detector data and current geomagnetic activity data. They originate in solar activity and variability of many different forms including solar flares, coronal mass ejections, solar wind sector boundaries and coronal hole streams. Variations of geomagnetic field can adversely affect any technical systems which rely on local magnetic field measurements to be taken in the absence of significant geomagnetic variations. Users who are unaware of and thus unprepared for the imminent occurrence of major magnetic field disturbances may conduct operations which later turn out to have been useless and eventually a waste of time and resources. Our project attempts to address geomagnetic storm forecasting by developing a service which gives advance notice of increasing geomagnetic activity and thus enables the affected users to plan and conduct their operations in a more cost-effective way.
Information on flux changes for different secondary particles helps to test Interplanetary Magnetic Fields (IMF) and magnetosphere for understanding of the level of disturbance and specific mechanisms leading to cutoff rigidity reduction. Our observations of the GMS occurred during 23rd Solar activity cycle demonstrate that Cosmic Ray increase during GMS occurs coherently (or ~ 1 hour in advance) with abrupt changes of the geomagnetic field, sized up by Dst index. To test geomagnetic disturbances models and provide a valuable user-oriented forecast, it is not sufficient to have only global geomagnetic indices. Several studies demonstrate that local geomagnetic indices are better correlated with consequences of severe GMS. Unfortunately in the radius of 1000 km. from mt. Aragats there are no permanently operating geomagnetic observatories or magneto-telluric stations. In the framework of the project we equip ASEC with modern facilities allowing precise measuring geomagnetic and electric fields at location of ASEC monitors.
Special low-noise magnetometric laboratory was setup at premises of the Nor Amberd research station of Yerevan Physics Institute at altitude of 2000 m. The LEMI-417 magnetometer was purchased from Lviv Space Research Center of Ukrainian Space agency. The device was installed and tuned with help of Ukrainian experts. After testing and comparison with world data and analogical device purchased later the data of geomagnetic field first time in Armenia is monitored and stored in ASEC data bases.
Conclusion - The new facilities for precise measuring of the geomagnetic field are installed and giving data, available on-line. Data will be used for the forecasting of the upcoming geomagnetic field along with data on Solar bursts and secondary cosmic ray data. The magnetometer operates stable, noise level is low.

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Final Report January 1, 2009 – December 31 2009

Summary

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They originate in solar activity and variability of many different forms including solar flares, coronal mass ejections, solar wind sector boundaries and coronal hole streams. Variations of geomagnetic field can adversely affect any technical systems which rely on local magnetic field measurements to be taken in the absence of significant geomagnetic variations. Users who are unaware of and thus unprepared for the imminent occurrence of major magnetic field disturbances may conduct operations which later turn out to have been useless and eventually a waste of time and resources.

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Introduction

The Earth's magnetic field varies both in space and time. Historically, magnetic observatories were established to monitor the secular change of the Earth's magnetic field, and this remains one of their most important functions. Over 70 countries operate more than 200 observatories worldwide. The magnetic observatory mean data are crucial to the studies of secular change, investigations into the Earth's interior, and to global modeling efforts.

Huge magnetized plasma clouds and shocks initiated by Coronal Mass Ejections (CME) traveling in the interplanetary space with velocities up to 2000 Km/sec (so called Interplanetary Coronal Mass Ejection (ICME), are known as major drivers of severe space weather conditions. On its way to Earth ICME disturb the IMF. These disturbances “modulate” flux of Galactic Cosmic Ray (GCR) introducing anisotropy and changing energy (rigidity) spectra of the previously isotropic population of protons and stripped nuclei accelerated in the numerous galactic sources. Changes of rather stable flux of GCR are detected by space-born spectrometers (rigidities up to ~1GV) and by world-wide networks of particle detectors (rigidities up to ~100GV) located at different latitudes, longitudes and altitudes. Therefore, changes of GCR fluxes (so called precursors) can be used for forewarning on upcoming ICME and, consequently on expected GMS.

Most geoeffective types of ICMEs, so called magnetic clouds (cylindrical flux rope structures with helical magnetic field lines, see for details (Mulligan and Russell, 2001) are directly connected to the flaring region of Sun where Solar Cosmic Rays (SCR) are accelerated. Recently “flux-rope” like structures were observed by the payload of the THEMIS satellite constellation (http://www.nasa.gov/mission_pages/themis/news/). This can explain the “collisionless” transport of SCR via “highways” inside the magnetic system connecting Sun with ICME. The cascade particles generated by these SCR with GV rigidities can be registered by surface detectors during so called Ground Level Enhancement (GLE). Fast arrival of the solar particles of highest energies can alert on upcoming abundant SCR flux (of much more higher MeV energies) dangerous for satellite electronics and some surface industries.

ICME is a major modulating agent, forming depletion and enhancement regions of GCR, manifested themselves as peaks and deeps in time series of surface particle detectors. Both GCR and SCR can be used for “probing” ICME, providing highly cost-effective information on the key characteristics of the interplanetary disturbances. Because cosmic rays are fast and have large scattering mean free paths in the solar wind, this information travels rapidly and may provide useful for space weather forecasting (Leerungnavarat et al., 2003).

Size and strength of the “frozen” magnetic field in an ICME are correlated with the modulation effects ICME poses during its propagation up to 1 AU on the energy spectra and direction of the GCR. In the same time the presence of strong and long duration southward magnetic field is the primary requirement of ICME geoeffectiveness (Valtonen, 2007). Thus, strong magnet field “frozen” in ICME is both modulation agent of GCR and driver of GMS.

The magnetic field found in the magnetic cloud of ICME usually has a well-formed flux-rope structure (see Koskinen and Huttunen, 2006, also see cross-section of the magnetic "rope" - a twisted bundle of magnetic fields) connecting Earth's upper atmosphere directly to the Sun, observed by the THEMIS satellites on May 20, 2007 (NASA science, 20.03.08). At November 20, 2003 the magnetic cloud was directly connected with solar eruptive region and southward magnetic field was enhanced by an order of magnitude (up to ~ -50 nT).

It is not possible to assert that there is one-to-one correspondence between variations of the GCR and strength of GMS, furthermore, besides IMCEs, there are other drivers of storms and modulation agents of GCR. However, large B_z value associated with approaching ICME is best known diagnostics of GMS strength. Therefore, as was mentioned in the statistical study (Kudela & Storini, 2006) appropriate observations of the variations of the primary and secondary cosmic rays can be a proxy of B_z value available long before IMCE reach libration point at 1.5 mln. km from Earth where B_z can be measured directly.

Direct detection of the Energetic Storm Particles (ESP) by the Electron, Proton, and Alpha Monitor (EPAM) instrument on board the Advanced Composition Explorer (ACE) space station (Gold, 1998) can alerts hours prior to the approaching interplanetary shock and plasma cloud (ACE news, 2003). Another space station located in libration point 1.5 mln kilometers from Earth - Solar and Heliospheric Observatory (SOHO) - detected relativistic electrons by its Comprehensive Suprathermal and Energetic Particle Analyzer (COSTEP) instrument. Enhancements in the electron flux also can point on approaching ICME. The modulation effects posed by ICME on the particles of higher energies, not measurable by space-born facilities due to very weak fluxes, are detected by the world-wide networks of Neutron Monitors (NM, responding to GCR energies $\geq$ 10 GeV) and Muon Telescopes (MT, responding to GCR energies $\geq$ 15 GeV) well before the onset of a major geomagnetic storm (Belov et al., 2003, Munakata et al., 2000).

To conclude, ICMEs dominate intense storm occurrences and simultaneously they are correlated with variations of spectra of particles and nuclei in the interplanetary space, ranging from isothermal solar wind ions till GeV energy galactic cosmic rays. Therefore, for developing timely and reliable forecasting service it is necessary to get more insight in the correlations of IMCE parameters with geospace parameters, including changing intensities of the particle fluxes measured at the Earth surface.

Instrumentation

To study the Earth's magnetic field the best instrument is the magnetotelluric station LEMI-417 which was specially developed for the long-term monitoring of geomagnetic field. Construction of device ensure thermal and temporal stability and low noise level for magnetic measurements. The high-sensitive magnetic sensor of flux-gate type, which mainly determines these parameters, was manufactured using well-proved technology on the base of marble and quartz combination implementing recent findings in the excitation circuit construction. The waterproof sensor has the support with bubble level to provide its proper leveling at the selected place (see Fig.1).

Figure 1 Magnetotelluric station LEMI-417 set (left) and its front panel (right)

Its main technical parameters are given in the Table 2 below:

Measured range of total magnetic field	± 65000 nT
Resolution along each component both at the display and registered into the internal FLASH-memory	0.01 nT
Temperature drift	<0.2 nT/°C
Frequency band	DC-0.3 Hz
Magnetometer output noise in frequency band (0.03 – 1)Hz	< 10 pT rms
Magnetic sensor components orthogonality error	<30 min of arc
Automated offset compensation band along each magnetic component	±65000 nT
Noise of electric meter in the frequency band 0.03 - 1 Hz	<0.5 μV rms
Sample rate	4 per s
Volume of the internal FLASH-memory	2 GB
Digital output	RS-232
GPS timing and coordinates determination	
Operating temperature range	Minus 10 to +50°C
Temperature sensors (both in magnetic sensor and electronic units) resolution	0.1 °C
Power supply	$+12^{+6}_{-3}$ V
Power consumption	<0.9 W
Weight:	1.1 kg

Device installation and testing

Magnetometric station LEMI-417, commissioned by Lviv center of Space Research Institute of Ukrainian Academy of Science, was installed in Nor Amberd, 2000 m above sea level (the same type of station with added electrical field sensors will be installed at Aragats, 3200 above sea level). One-minute time series of the 3-dimensional measurements of the geomagnetic field enter the data base of the Aragats Space Environmental Center (ASEC) and will highly improve research of correlations of the geomagnetic parameters and changes of the fluxes of cosmic rays now underway at Aragats. ASEC measures neutral and charged fluxes of secondary cosmic rays (Chilingarian et.al., 2005); correlations of changes of these fluxes with geomagnetic parameters and IMF parameters measured by facilities of the ACE space station located 1.5 mln. km from Earth will assist to understand Solar influence on the Earth environments (see, for instance Bostanjyan & Chilingarian, 2009, Chilingarian & Bostanjyan, 2009). Measurements of geomagnetic field from Nor Amberd will support forewarning of the upcoming major geomagnetic storm. Alert service planned to be provided by CRD in late 2010.

Figure 2 CRD PhD student Tigran Karapetyan examining geomagnetic field disturbances

Figure 3 CRD Postdoc Artur Reymers establishing Internet connection of the geomagnetic laboratory to CRD headquarters. Each minute measurement of the 3 components of geomagnetic field will be send to CRD servers for multivariate analysis and alert services.

Operation of magnetometric station started in July 2009. In Figure 4 we post the pattern of the first Geomagnetic Storm detected in Nor Amberd in compoarison with DST index (geomagnetic field disturbances averaged other several magnetomerters located in middle-low latitudes). Geomagnetic activity increased to major storm levels from 0300 - 1200 UTC on 22 July. Activity decreased to quiet levels at all latitudes on 26 July. ACE solar wind measurements indicated the storm conditions on 22 July were associated with the onset of a coronal hole high-speed wind stream. Solar wind velocities began to gradually increase early on 22 July and eventually reached a maximum of 601 km/sec at 24/0158 UTC. Interplanetary magnetic field (IMF) changes associated with the onset of the high-speed stream included an increase in IMF Bt (peak 18 nT at 22/0533 UTC) and a sustained period of southward IMF Bz (minimum -18 nT at 22/0703 UTC).

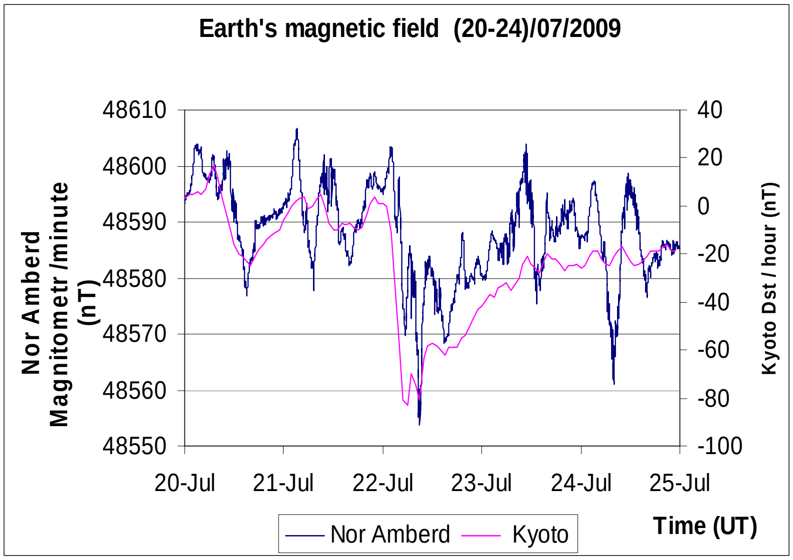
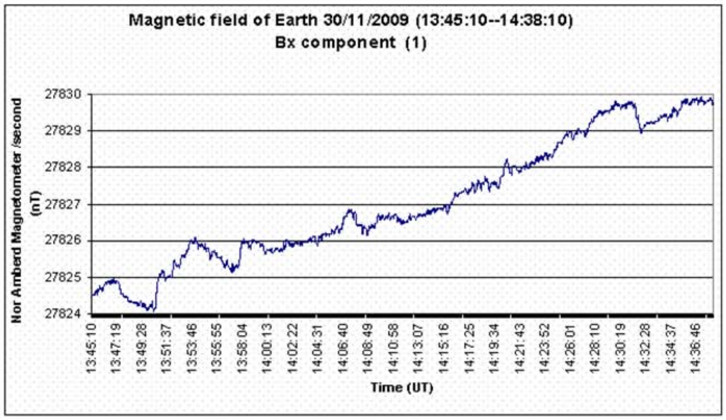


Figure 4 Comparison of the geomagnetic storm detected by new facility in Nor Amberd and DST index calculated by Kyoto magnetic observatory (DST is measured in relative units; Nor Amberd magnetometer – in absolute)

The device provide possibility to measure the intensity of the magnetic field each second, usually we integrate the intensity above 1 minute interval to be compatible with particle detecters. However, the short variations of the geomagnetic field also can be studied. After purchasing another magnetometer of the same type we provide comparison studies of both detectors. Second magnetometer was located in the main building of the Nor Amberd station and was affected by the noise posed by movement of personnel and cars. It is why the pattern is not identical (see Figure 5) and shifted. However the overall closeness of both time series is apparent.



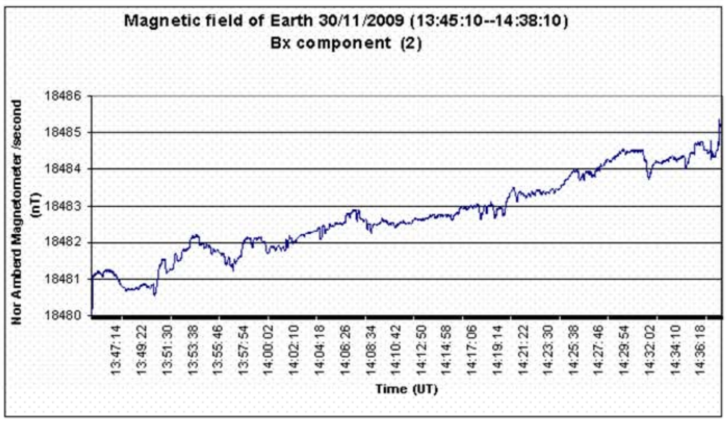


Figure 5 Comparison of the B_z measurements taken by 2 same type magnetometers located at magnetometric lab and Nor Amberd main building

Conclusion

The new facilities for precise measuring of the geomagnetic field are installed and giving data, available on-line. Data will be used for the forecasting of the upcoming geomagnetic field along with data on Solar bursts and secondary cosmic ray data. The magnetometer operates stable, noise level is low.

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ACRONIMS

CE Advanced Composition Explorer
ADAS Advanced Data Analysis System
ADC Amplitude-Digital-Converters
AMMM Aragats Multidirectional Muon Monitor
ANM Aragats Neutron Monitor
ASCII American Standard Code for Information Interchange
ASEC Aragats Space Environmental Center
ASNT Aragats Solar Neutron Telescope
AU Astronomical unit (distance Sun-Earth, $1{,}5\text{x}10^{11}$ m)
CME Coronal Mass Ejection
CMOS Complementary Metal–Oxide–Semiconductor
CPLD Complex Programmable Logic Device
CR Cosmic Rays
CRD Cosmic Ray Division, Yerevan Physics Institute
DAQ Data Acquisition
DVIN Data Visualization Interactive Network EAS Extensive Air Showers
ESA European Space Agency
Fd Forbush decrease
GCR Galactic Cosmic Rays
GLE Ground level Enhancement (Excess, Event)
GMS – Geomagnetic Storm;
GOES Geostationary Operational Environmental Satellite
GPS Global Positioning System
ICME – Interplanetary Coronal Mass Ejection;
IHY International Heliophysical Year
IMF Interplanetary Magnetic Field IP Interplanetary
LADC Logarithmic ADC
LAN Local Area Network
NAMMM Nor Amberd Multidirectional Muon Monitor
NANM Nor-Amberd Neutron Monitor NM Neutron Monitor
PMT Photo Multiplier Tube
SCR Solar Cosmic Ray
SEP Solar Energetic Particles
SEVAN Space Environmental Viewing and Analysis Network
SF Solar Flare
SNT Solar Neutron Telescopes
SVG Scalable Vector Graphics
TTL Transistor-Transistor Logic
URCS Unified Readout and Control Server
XML eXtensible Markup Language