MAGDAS PROJECT FOR MONITORING SPACE AND LITHOSPHERE WEATHER

ПРОЕКТ MAGDAS ДЛЯ МОНИТОРИНГА КОСМИЧЕСКОЙ И ЛИТОСФЕРНОЙ ПОГОДЫ

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С тех пор, как начались изучения и измерения магнитного поля, было собрано огромное количество информации о магнитном поле Земли. Центром исследования околоземного пространства (SERC) университета Кюшу (KU) в Японии собраны геомагнитные данные за период более 10 лет с помощью системы тихоокеанской сети магнитометров (Circum-pan Pacific Magnetometer Network, CPMN) (Yumoto и др., 2001). В настоящее время SERC устанавливает новую систему сбора магнитных данных в реальном времени (MAGDAS) в тихоокеанском регионе, а также сеть радаров FM-CW вдоль 210° магнитного меридиана для исследования космической погоды и (Yumoto и др., 2006). Этот проект подразумевает полное подключение сети MAGDAS, а затем использование данных для изучения космической и литосферной погоды. В данной работе мы предполагаем, что с помощью нового метода мы изучим какая из трех моделей СНЧ излучений, связанных с землетрясениями, не противоречит магнитным наблюдениям в Тихоокеанском регионе.

1. SCIENTIFIC OBJECTIVES

The MAGDAS project as shown in Figure 1 aims to establish a continuous monitoring electromagnetic network and utilize the observations for forecasting changes in space and lithosphere environments. This project is actively providing information about the space weather condition through the following: (1) Global 3-dimensional current system - to know electromagnetic coupling of regions 1 and 2 field-aligned currents, auroral electrojet current, Sq current, and equatorial electrojet current; (2) Plasma mass density along the 210° MM - to understand the plasma environment change during space storms; (3) Ionospheric electric field intensity with 10-sec sampling at L=1.26 - to understand how the external electric field penetrates into the equatorial ionosphere.

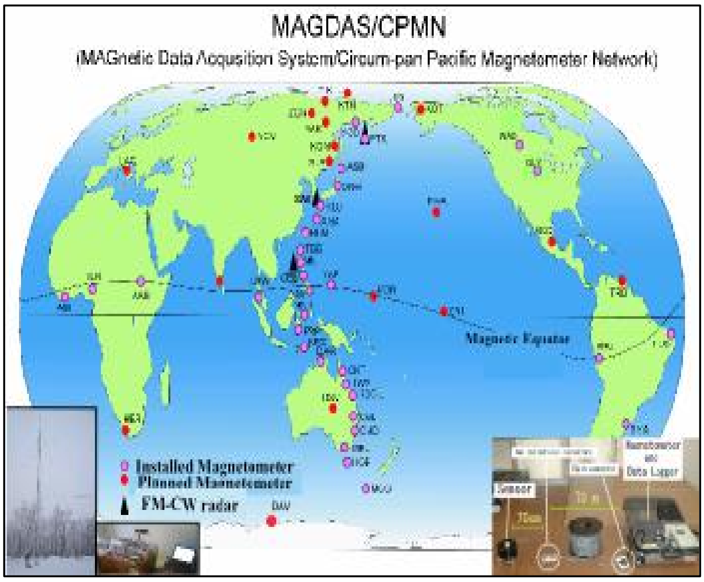

Fig.1. Location of MAGDAS stations.

To forecast changes in the lithospheric environment with electromagnetic (EM) techniques, it is necessary to understand the role of the space environment at the same time because ground-based magne-tometers are more affected by space events than by lithospheric events. Lithospheric signal changes are small in comparison to signal changes caused by the space environment.

Numerous studies have been published on electromagnetic precursors and its association with earthquakes and volcanic activity. This type of precursor has been studied with a wide frequency range such as ULF and electric pulsating emission (Hayakawa et al., 1996; Hayakawa et al., 2000; Hashimoto et al., 2002), VLF and VHF sounding of the atmosphere (Gokhberg et al., 1982;Oike and Yamada, 1994; Eftaxias et al., 2003) and satellite plasma wave observations (Molchanov et al., 2003). But the ground observations of EM waves in the ULF range ($f < 10$ Hz) are considered the most promising means for monitoring crustal activity because the skin depth of EM is comparable to the depth at which crustal activities take place, and fluctuations of electric conductivity in the Earth's interior can be detected directly (Park et al., 1993; Molchanov et al., 1992; Hayakawa et al., 2000;Hattori et al., 2002). Therefore, this project proposes only to look into the most promising range, which is the ULF range.

ULF emissions have been considered to directly reflect information on the microfracturing in the lithosphere. There are two known models for this mechanism as shown in Figure 2. One model based on relaxation of charges on the walls of opening cracks was considered by Molchanov and Hayakawa (1995, 2001). The second model was suggested by Fenoglio et al. (1994). They proposed a model of ruptured isolated reservoirs, resulting in the electro-kinetic (EK) generation of a transient magnetic field. This model considers electro-kinetic conversion in a course of water diffusion just after the crack opening in order to compensate changes in high pore pressure around the crack (Mizutani et al., 1976; Jouniaux and Pozzi, 1995; Fenoglio et al., 1995). Aside from the direct ULF radiation from the earthquake (EQ) origin zone connected with the earthquake preparation and reflected in ULF electromagnetic emissions, the third model is the changing of geo-electric conductivity inside and nearby the EQ focal zone which leads to the changing of amplitudes of reflected electromagnetic waves generated by non-lithospheric sources (Mogi, 1985; Kovtun, 1980). Using the three models, we will investigate which is best for space and lithosphere weather forecasting in the CPMN region.

Generally, magnetic polarization method is used to investigate ULF magnetic emissions. It was shown (Hayakawa et al., 1996; Kopytenko et al., 1999) that there is an increasing trend in the polarization (Z/H ratio) values before a strong earthquake takes place, and after the earthquake the ratio decreases. A new method SOFCUA (Separation method Of Factors Controlling ULF Amplitude) was proposed by Yumoto and Obana in order to study the third model. This new method enables the separation of the wave amplitude factors of the solar wind, magnetosphere, iono-sphere, and lithosphere from processed magnetic data. Upon extraction of the wave-amplitude factor of the lithosphere, we can monitor a long-term electric conductivity change in the lithosphere.

2. ULF EMISSION MODELS ASSOCIATED WITH EARTHQUAKES

2.1 Microfracturing

In this model, ULF emissions are believed to be definitely generated in the focal zone and propagate up to the subsurface ULF sensors as shown in Figure 2. The observed increase in ULF magnetic field results from induced electric currents flowing in a fault-zone where it is made temporarily much more electrically conductive by stress-induced reorganization of pore geometry. Let's consider a rock medium, which can be characterized by the macroscopic dielectric permittivity and conductivity. In principle, any fluctuation of charge or electromagnetic field in a source dimension should cease after some time if there are no changes in external fields like geomagnetic field, geo-electric potential or electro-kinetic potential on the water–solid contact. Since the time scale of these fields is in the order of macroscopic stress changes; ~10^5 –10^8 seconds , we cannot obtain the rather fast ULF variations. Therefore, it seems that the

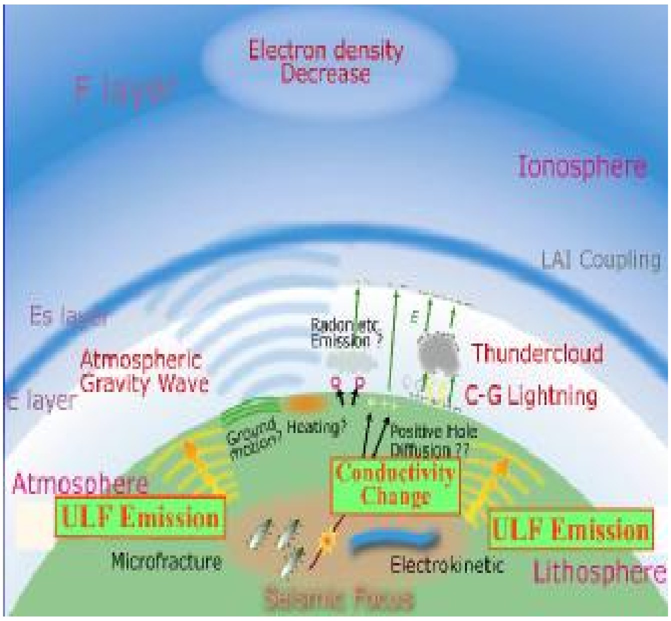

Fig.2. Three known models of ULF emissions associated with earthquakes. (Courtesy of Hattori, 2006)

only stress-induced process that can explain the observations is the opening of microcracks of dimensions $c = t\, V_c = 10^{-4} - 10^{-1}$ m. Where t is a time scale of $10^{-4} - 10^{-7}$ s, and V_c is the velocity of the opening of cracks, i.e. the order of seismic velocity (~10^3 m/s). If the rate of production of microcracks is rather high, then the process of opening microcracks will lead to production of wideband electromagnetic noise. This noise dissipates outside the source region and produces ULF emissions on the earth's surface with an upper cutoff frequency ~1 Hz due to the skin depth attenuation.

2.2 Electro-kinetic

This model proposes that during the failure of faults containing sealed compartments with pore pressures ranging from hydrostatic to lithostatic levels, electric and magnetic fields are generated. The rupture of seals between compartments produces rapid pore pressure changes and fluid flow and may create fractures that propagate away from the high-pressure compartment along the fault face. Then, a nonuniform fluid flow results from pressure decrease in the fracture from crack-generated dilatancy, partial blockage by silica deposition, and clearing as the pressure increases. The direct consequence of this unsteady fluid flow is the associated transient magnetic signals. The electro-kinetic signals produced by this unsteady flow are comparable in magnitude and frequency to the magnetic signals observed during large earthquakes.

2.3 Changing geo-electric conductivity

The external electromagnetic waves incident on the earth's surface is the normal magnetic-noise background. These waves are reflected and transmitted at the earth's surface due to the earth's conductivity. The reflected magnetic field is practically equal to the incident field and, as a result, the measured background-level amplitude is twice that of the incident magnetic field. The implication of this result is that no model of horizontal conductive layers could create the observed anomalous high magnetic fields. However, theoretically, this mechanism is possible if an electromagnetic wave impinges on a thin infinitely long wire with incident electric field parallel to the wire. The field induces a current within the wire, which acts as an antenna and in turn creates a circumferential magnetic field. Then if a highly-conductive long thin region was created under or nearly under the magnetometer towards the time of the earthquake, then the incident electromagnetic waves would have induced a high current in this region, which in turn created the anomalous high magnetic fields. Therefore, in a quasi-static model, the conductive fault zone acts as an antenna to couple with the external electromagnetic field to generate the observed magnetic anomalies.

3. METHODOLOGY

A new study is designed to examine which of the three models of ULF emissions associated with earthquakes is consistent with the magnetic observations in the CPMN region. However, prior to that, we need to establish a complete electromagnetic network.

The research design is organized into the following sections: (1) Electromagnetic observation network set up, (2) Implementation and comparison of the three models.

3.1 Electromagnetic observation network set up

Figure 3 shows that in order to detect ULF anomaly for earthquakes with a magnitude greater than 7.0, the magnetic station should at least be located within the distance of 100km from the epicenter.

3.2 Implementation and comparison of the ULF emission models associated with earthquakes

The following methods will be implemented in order to find out which of the three models agrees with the magnetic observations for lithosphere weather forecasting in the CPMN region.

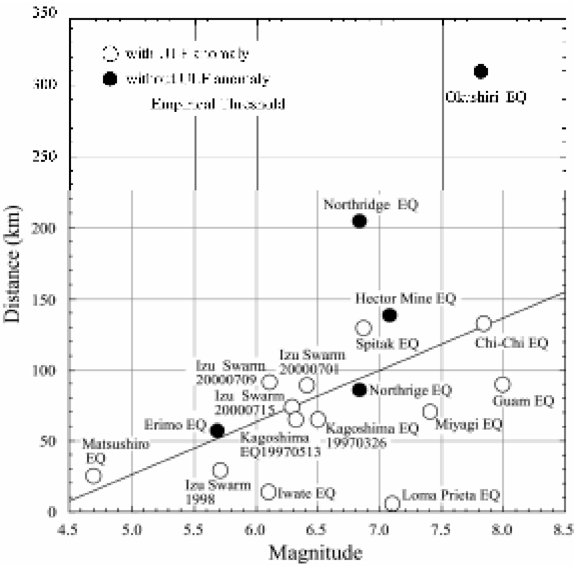

Fig.3. The relationship between the magnetic station distance from epicenter and the magnitude of the earthquake. (Courtesy of Hattori, 2006)

Polarization Analysis Method

Magnetic field polarization method refers to the ratio of the vertical component (Z) of the magnetic field variations to the horizontal (H) component. This method is used under the microfracturing model. Polarization values are calculated from magnetic data measured on the Earth's surface by 3-component magnetometers. Then, the raw data is checked for completeness, impulsive noise,etc. In order to remove man-made noise and geomagnetic activity of solar origin from the data, FFT (Fast Fourier transform) is applied. From the processed data, calculate the Polarization values and check its trend whether it is increasing or decreasing.

Magneto-telluric Method

This is an electromagnetic method, which maps the spatial variation of the Earth's resistivity by measuring naturally occurring electric and magnetic fields at the Earth's surface. This method is used under the electro-kinetic model. With continuous data analysis of this method, it is possible to reveal a systematic trend in magneto-telluric field behavior before, during and after strong earthquakes. Some studies observed abrupt variations in electromagnetic field component intensity prior to earthquakes. And also, maximum values of MT-fields components had been recorded at the moment of events. Therefore, an abnormal variation in MT-field components, intensity and vector trend observed, may probably forecast an up coming EQ event.

SOFCUA Method

As for the third model we use this new technique, SOFCUA (Separation method Of Factors Controlling ULF Amplitude) which analyzes Pc 3-5 magnetic pulsations (ULF waves) observed at magnetic conjugate and longitudinally separated stations in order to monitor long-term electromagnetic change of the lithosphere. This method allows the extraction of the wave amplitude factors of the solar wind, magnetosphere, ionosphere, and lithosphere from Pc 3-5 pulsations. Pc 3 pulsations are ultra-low frequency hydro-magnetic wave with a continuous waveform of 10<45-second period observed at lower latitudes in the dayside magnetosphere. These pulsations are excited as standing field-line oscillation of magnetic line of force by an external source wave in the solar wind region. Therefore, Pc 3 pulsations have the information of its excitation and propagation regions. Also, it must be controlled by parameters in the solar wind, magnetosphere, ionosphere and lithosphere.

4. LOCAL EDUCATIONS, GLOBAL OUTREACH AND DATABASE SERVICE

The SERC of Kyushu University (KU) conducts space weather "now casting" everyday. There are two main goals in this effort: (1) To train and educate KU students about the complexities of the Sun-Earth system so that they will be equipped as space weather scientists in the near future. (2) To disseminate space weather information globally through SERC in service to the scientific community and the general public.

In order to understand the complexities of the Sun-Earth system, KU students analyze the data from four regions: solar surface, solar wind, geospace, and the Earth's surface. Using real-time public data from SOHO Real Time Movies, Solar Monitor, NASA/GSFC/SDAC, SEC's Anonymous FTP Server, they check daily the sun spot number, locations of active regions and coronal holes, and identify events of flare: GOES X-Ray Flux, CME: SOHO/LASCO-C2, 3, and proton event: GOES Proton Flux. Analyzing ACE Real Time Data, KU students read solar wind (speed, density, temperature) and interplanetary magnetic field (IMF: Bt, Bz, Phi), and identify events of sector boundary, CIR, CME, and shock/discontinuity. For understanding magnetic activities in geospace and on the Earth's surface, storms and substorms are also analyzed by using Dst index (Kyoto Univ.), Kp index (NOAA), EE Index (Equatorial Electrojet: SERC) and Magnetic Pulsation Index (Pc 3, 4, and 5: SERC). Every morning KU students create a Space Weather report and then discuss it with the staff at SERC for local training and education. The report and its details are published at home page of SERC (http://www.serc.kyushu-u.ac.jp) for global outreach through dissemination of space weather information by SERC.

MAGDAS magnetometers were installed in 19 locations along the 210° MM and in 15 locations at the magnetic dip equator in 2006, including East Asia, Pacific Ocean and Micronesian Islands, and South America and Africa as shown in Figure 1. After performing data quality check of the obtained MAGDAS data at SERC, MAGDAS project collaborators may access through a SERC server (in which the corrected data are stored) and may acquire a 1-sec <1-min. digital data. Moreover, MAGDAS data will be made available online for scientific purposes. SERC will offer its MAGDAS database to the scientific community for collaborative works.

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