CONSTELLATION OF MICRO SATELLITES FOR EARTHQUAKE STUDY

- TOWARD INTERNATIONAL COLLABORATION-

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ABSTRACT

Past studies show that the effects of earthquake appears on the ionosphere prior to large earthquakes, and recently the number of the papers which report the precursor effect is drastically increasing and the quality of the paper is improving. However the result is still not fully convincing, because the number of the events, which are studied from ground based as well as satellite measurements, is not enough to get morphology of the effects, and the data presented is still not fully persuasive.

We discuss the problems, which we encountered in getting morphology associated with earthquake precursors. To establishment of the morphology is the first step to solve the mechanism for earthquake to influence on the ionosphere. Since the data which have been reported suggest the high probability for large earthquake to be foreseen, we propose to collaborate to launch micro / mini satellites, especially, among the countries who are suffering from earthquake disasters, and to share the cost for the mission. Key issues, which should be taken into account for the mission, are also discussed.

KEYWORDS: Earthquake, Precursor, Top side Ionosphere, Electron temperature

1. INTRODUCTION

The possible effects of the earthquake on the ionosphere have been reported by many scientists (Pulinets and Boyarchuk, 2004). Recently the number of the report is being drastically increasing in scientific journals. Reduction of total electron content (TEC) produced prior to earthquake occurrence has been reported by Liu et al. (2001). Devi et al. (2004) reported reduction of TEC as well as increase of TEC at the anomaly crest region. They also reported the bite out phenomena of NmF2, which they claim to appear prior to earthquake. In addition to the earthquake effects on low latitude ionosphere, there are several reports, which study the middle latitude ionospheric f_oF_2 and f $_bE_s$ (Silina et al., 2001; Ondoh, 2000). Zakharenkova et al. (2007) reported precursory phenomena observed in the TEC measurements before Hokkaido earthquake of September 25, 2003 (M=8.3).

Recently Pulinets et al. (2007) conducted an intensive analysis on Irpinia earthquake which occurred on 23 November 1980 by using seismic data, radon emanation, hydrological anomalies, ground based ionosonde network, thermal infrared irradiance, Intercosmos-19 satellite topside sounding. They concluded that air lionization by radon which was emanated during the earthquake preparation could explain all atmospheric and ionosphere parameters.

Oyama et al. (2008) reported reduction of electron temperature (Te) of afternoon overshoot at the height of 600km for three near equator earthquakes. Their result is convincing. However most of ionosphere researchers are still not fully convinced with the existence of precursor effects of earthquake (Rishbeth, 2007). This attitude of the scientists is quite understandable, because the number of the events, which we can study, is limited, and the quality and quantity of the data, which we can use, is limited, depending on the countries, and therefore quality of the most of the manuscript is far from convincing. Even we have sufficient information, we need a lot of energy and time to conclude on the existence of the effects of earthquake on the ionosphere, because this is a new field and established methods do not exist. Most of the scientists do not want to take risks by spending time this un-established field.

What is lacking now is data which can be studied systematically and globally. To get systematic data, we need constellation of mini/micro satellites, which should be organized internationally among the countries which are suffering from earthquake disasters.

In this paper, we discuss the ionosphere parameters, which should be measured in order to understand the physical mechanism on the effect of earthquake on the ionosphere. We propose launching of 6 micro-satellites for earthquake study as the first step. We discuss the size of the satellites to be launched, basic items to be included during the planning. We also stress that the mission cannot be useful without international collaboration.

2. NEED FOR CONSTELLATION OF SATELLITE

The examples we have studied (Oyama et al., 2008) are the cases where ionosphere is believed to be modified by the earthquake. To study earthquake effect, we need to survey the ionosphere globally to investigate whether abnormal feature you find is local or global. High latitude above 50 degrees might be difficult to be studied at this moment because high latitude is very often highly disturbed. However even for low/mid latitude cases, there are several cases, which we cannot see any precursor effects even if USGS list resisters the earthquake. There are also cases where no modification of Te is not found even we can see Earthquakes in the USGS list. We are trying to use as many data as possible form the past satellites as well as ionosonde data to explain these cases. However we find the difficulty to draw morphology and find the mechanism. Two reasons can be raised for this difficulty. First there are not so many satellites in the past, which provides reliable and routine data. So far we believe that only Langmuir probe on board DE-2 (Krebbiel et al., 1981) provides reliable values, because the effort to erase contamination effect was made by heating the electrode as well as by applying negative voltage to the electrode. We confirmed the accuracy and reliability of the DE-2 Langmuir probe data by comparing HINOTORI satellite. Secondly in order to make the model first, the number of the input parameter, such as height, longitude, latitude, solar activity, and season should be as small as possible. Constant altitude of the satellite makes the model construction much easier. However there is no satellite of circular orbit except HINOTORI in the past. As we mentioned above, to study the earthquake effect, we should study the global area, however the installation of ground based instruments in remote area is time and energy consuming and it is limited to land surface.

We have now one possibility to detect the precursor from space and therefore we should pursue the satellite mission, and to try to confirm its possibility. That satellite can be micro satellite (10-100kg) and minisatellite (100-500kg).

2.1 Instruments candidates

It is essential that each satellite should accommodate the same two well- established fundamental instruments to measure Te and Ne (Electron density). These two probes are a resonance rectification probe for Te and an impedance probe for Ne (Yamamoto et al., 1998). It is noted again that it needs special attention to get accurate electron temperature. Langmuir probe data, that are obtained from recently launched satellite shows electrode contamination clearly.

Data from another satellite seems to give higher temperature due to insufficient amplifier gain. Apart from two instruments, to find the mechanism of phenomena associated with earthquake, the following instruments might be needed. Those are;

a. Electric field probe (DC to AC)

There is a big possibility that anomalous feature is triggered by the electric field associated with earthquake. Especially it is important to know the electric field. The measurement accuracy should be more than 0.2 mV/m in order to discuss the deviation of 1 mV/m.

b. Plasma drift meter, (University of Texas type)

By measuring plasma drift Vd= ExB/B^2 , one can get the electric field which is perpendicular to the magnetic field and the information from the drift meter can be a backup of the electric field probe.

c. Ion mass spectrometer

Recently one paper has been published (Bankov et al., 2008), which used DMSP and DEMETER satellite data. Several hours before the Sumatra earthquake, a ratio H^+/ O^+ increased at about 800km height. The results seem to be acceptable. However amount of data is still not enough to be convinced. We need to confirm their results. Ion mass to be measured is H^+, and O^+.

d. Neutral mass spectrometer

Regarding the ration of H^+/O^+, a possibility cannot be deleted that modifications of neutral particle generate modification of the ratio.

e. Topside sounder

Pulinets (1998) reports the results from topside sounder onboard intercosmos-19, and ISS-b. Both foF2 and height profile of electron density in the topside ionosphere change right before and after earthquake. There is a possibility that height profile is modified by electric field associated with earthquake. Therefore result from topside sounder can be discussed together with electric filed measurements. Topsisde sounder is surely one of the strong candidates to be accommodated. However the topside sounder emits intense RF power, and disturbs ambient plasma as well as potential of satellite itself. It is highly recommended to launch one micro satellite, which only accommodates a topside sounder.

f. Energetic particle analyser

There are also several papers, which report precipitation of energetic particles triggered by VLF waves associated with earthquake (Gal'Perin et al., 1992).

g. Photometers

A report also exist that intensity of the airglow intensified. This report is reasonable, because if the plasma density increases, airglow emission in the ionosphere increases. To mount a photometer can support measurement of Ne made by impedance probe. The narrow band photometer of narrow FOV might be able to give us 3D picture of ionosphere electron density as Formosat-3 (Taiwan satellite) conducted. The instrument can provide the change of equatorial ionisation trough and cleft (Hsu, 2008). Through one orbit scan, we might be able to get height profile of O^+ density. 2D photometer at several wave lengths (135.6nm, 630nm, and 555.7nm) might provide 2D map at night on the atmospheric glow at night at several heights. Emission from atomic oxygen is a function of oxygen ion. Measurement of 557.7nm (emission from OH) gives us the structure at the height of about 97 km, whilst 630 nm gives the structure at 200-300km.

2D structure might indicate the wave structure of neutral wind at around 100km. There is a possibility that electric field associated with earthquake is produced as a modulation of neutral wind in the Dynamo region as we mentioned before (England et al., 2006).

h. VLF wave receiver (magnetic field)

Considering the data obtained from DEMETER (Parrot et al., 2006), and our data analysis of VLF measured by DE-2 satellite, it is very difficult to identify the earthquake related noise because many VLF noise exist in the ionosphere. One is in the high latitude; the second one is very often detected over geomagnetic latitude. The third one seems to be related with Equator Temperature and wind anomaly (Raghavarao et al., 1999). It seems to be difficult task to identify the epicenter. We might need to find the direction. Even in this case we might encounter the difficulty to identify the source. However the direction finding might be able to give useful information on ray tracing VLF into ionosphere, after the epicentre is identified.

All these instruments can not be accommodated in microsatellite ispecially when the instruments need accurate control of space craft, such as a mass spectrometer, and a drift meter. The instruments, which are listed above, are the instruments, which are needed for ionosphere study, and we need satellite(s),which is larger than microsatellite, in order to understand physics. It is noted here that satellite for the earthquake study is not special. The big difference between conventional science mission and this earthquake satellite mission is that scientists should examine the data with the eyes that earthquake effects should exist. The scientists, first, should conduct science to understand non-earthquake natural phenomena, and after that they should study the peculiar features associated with earthquake.

2.2 Constellation of Microsatellites

To find precursor effect, the measurement of two plasma parameters might work. Therefore we propose to put two probes in microsatellite. The total weigh of the satellite might be about 50kg. A spinning satellite, which has solar cells at the wall, might be the simplest one. Two probes can be mounted at the end of boom, as we indicate in Figure 1. Another type of satellite might be gravity gradient, with no or very slow satellite spin so that the gravity gradient is not disturbed. However there is a concern that either electron temperature probe or impedance probe is in the satellite wake for a long time during one satellite orbit if the satellite does not spin. If this is the case, we need 4 electron temperature

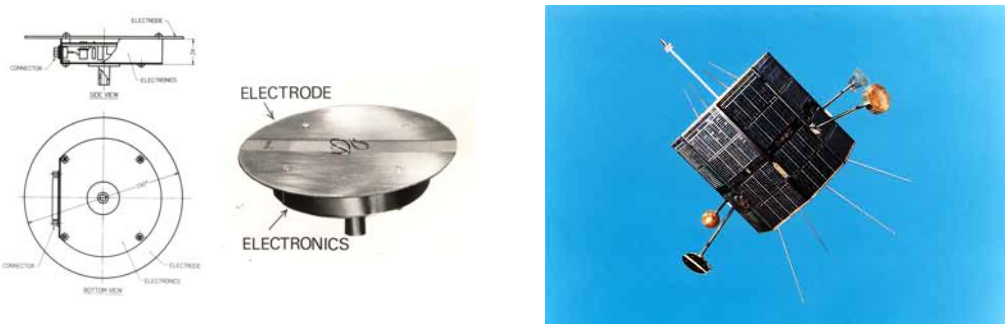

Fig. 1 Resonance rectification probe (Left) and its mounting on the satellite (Right).

instruments, and two impedance probes to get accurate data outside the satellite wake during a whole orbit. Even this set of instrumentation; the weight might be less than 10 kg. Apart from science instrumentations, we need instruments to provide attitude information, especially the ram direction. A sun sensor and magnetometer might be good candidates during daytime, mainly perpendicular to gravity gradient direction. The moving direction during nighttime can be guessed from daytime in formation suppose the satellite has slow spin.

2.3 Key issues to be in mind for

mission design

There are several key issues, which we should discuss during mission planning and should be executed in order to have cost/time effective mission.

1. All receiving facility is desired to be the same, if the country newly constructs a receiving station and tracking station. If the country has already by receiving station, it is still ok.

2. 2. Electronics parts of the satellite should be commercially available part in order to reduce the cost of the satellite. Trouble, which might be caused as a result of using commercially available parts, can be reduced by careful environment test and thermal vacuum test.

3. Two common instruments, resonance rectification probe and impedance probe, should be accommodated in all satellites and the instruments should be tested on ground and verified so that the instruments give the same result. Institute of Space and Astronautically Sciences, JAXA has a space plasma chamber of diameter 2m and the length of 5 m. The chamber, which is specially designed for ionosphere instruments, can produce of Ne of 10^4-10^6 els/cc, and Te of 500-3000 K.

4. Formant for information of the satellite orbit as well as format of science data should be in the same format so that data can be easily handled among the countries, which participates.

5. The software program for data reduction of Te and Ne should be provided from Japan.

6. Orbit information of each satellites and science data should be archived in each country, and should be easily accessed from member countries.

Since this mission is different from conventional science mission, strong data analysis group, which can work with scientists, is very important factor for the successful mission. Especially in the first year after the launch, to construct the Te/Ne model is a main task and the model should be revised as the increase of the data.

In the upper ionosphere, we have already listed up the instruments. It is essential to study the ionosphere from various aspects. The research on the effects of earthquake on the ionosphere should not be limited among ionospheric society. We need coordination among different fields.

2.4 Needs of Minisatellite

In order to understand the physics on the interaction between lithosphere, atmosphere-and ionosphere, two parameters are not enough. We need at least DEMETER (see Fig.8) class satellite to accommodate the instruments described above, except a topside sounder. We expect that some of the countries can launch one mini satellite. Good example of the mini satellite is Japanese satellite “TAIYO”, “HINOTORI” (circular orbit of 600 km at 31 degrees inclination, 188kg, controlled by using geomagnetic field, http://www.isas.ac.jp/e/enterp/mission/hinotori.shtml), and French satellite "DEMETER" (Sun synchronous circular orbit at 715 km, 130kg, 3 axis control, http://smsc.cnes.fr/DEMETER/GP_satellite.htm))

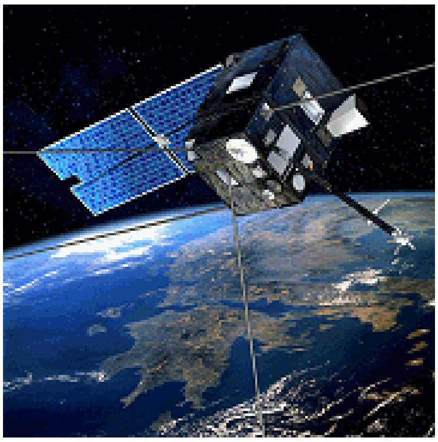

Fig.2 Good example of mini satellite, DEMETER

3. OUTREACH AND EDUCATION

To especially trigger the curiosity of high school students on science, the earthquake subject might be good target and at the same time the student can learn the importance of using space as a daily life. Therefore the mission might be able to provide a good tool for education. Toward this goal distribution of the data to high school students should be considered. Data distribution can be easily done through Internet. Or they can construct a set of RF receiver, which provides intensive course for all system for high school students. Therefore one small transmitter should be accommodated in the satellite for educational purpose. Part of the signal is transmitted from satellite through low power transmitter.

4. COORDINATION OF VARIOUS FIELD

As we discussed before, if we try to verify that the electric field is generated in the troposphere, we need vertical profile of neutral gas temperature, at least up to 60km. This might be possible by radio occultation satellite. A constellation of 6 Taiwan satellites is producing atmospheric temperature profile up to 60 km.

We also need cloud picture at different heights. This is available from meteorological satellite. Measurement of ground temperature by infrared camera reports the change of temperature along fault (Ouzounov and Freund, 2004; Pulinets et al., 2006; Ouzounov et al., 2006).

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5. SITUATION OF EARTHQUAKE SATELLITE PLANNING IN SEVERAL COUNTRIES

There are several satellites being discussed in several countries. The countries which are discussing earthquake study satellites are; Russia (Kompass-3, and Kanopus- Vulkan), Mexico (UNAMSAT-3), Ukaraine (Poperedjiennia, Ionosat), USA (Quakefinder), Italy (Esparia), and China (CSES). China officially announced the launching of earthquake satellite on the occasion of DEMETER workshop, which was held in Toulouse in 2007. Recently Australian group proposed Lightning –1/2.Other satellite missions are still not materialized. Exchange of information among the countries is urgently needed and international satellite group for earthquake study should be formed to accelerate the materialization of the mission.

6. CONCLUDING REMARKS

Electron temperature probe that was developed for pure science has now new application. Based on our firm confidence of the reliable measurements, we have studied three EQ events, which occurred around equator ionization anomaly. Both 3 events show common features. Continuous systematic reduction of Te in the afternoon overshoot can be found prior to the big earthquakes. O^+ density shows also clear features (similar feature can be seen in Ne as well).

Whether we can find smaller earthquake or high latitude earthquake in the future depends on the accuracy of the model, which can be made with repeated satellite observations. The features which have been described here strongly suggests the effect of electric field associated with earthquake, is playing a fundamental role in the region. The electric field is the order of 1 mV/m or less and it should have very slow time variation of the order of 10 days starting from about 5 days before earthquake. 5 days before earthquake. Although the generation of the electric field is puzzling, it might be atmospheric origin, which might be first triggered such as radon emission.

Our result suggests that even a small satellite, which carries two simple reliable plasma probes, can play unexpectedly significant role for the study of precursor phenomena associated with earthquake. Orbits of the satellites are very important. International collaboration among countries that are suffering from earthquake disasters should be established urgently to launch micro- or mini satellites from these countries.

Finally our findings might also encourage the ionosphere scientists to study lithosphere-atmosphere-ionosphere coupling, and even open new perspective in the ionosphere research, which has a long history of more than 80 years.

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