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## **Constellation of Micro and mini satellite for earthquake prediction: Towards International Collaboration**

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### **Abstract**

Both ground based and satellite observations which we studied so far for the large earthquakes ( $M > 6.5$ ) show the ionosphere modification before they occurred. The special features also appear in the height profile of neutral temperature and vertical ground motion observed with the slant gauges. Although, we have now the firm evidences of the growth of ionosphere disturbance before an earthquake, we still need the further evidences to predict the large earthquakes. However, as the large earthquakes are very scarce though devastating, we surely need satellite constellation which makes it possible to go further deeper by using worldwide earthquakes. The manuscript is prepared to persuade people to work together among earthquake suffering countries.

According to our final target to launch the earthquake study-satellite, we introduce our findings related to the ionosphere disturbance before large earthquakes, which was studied by means of satellite as well as ground observation. We also describe other geophysical parameters to be studied by means of the satellite, in addition to the parameters to be observed on the ground.

*Keywords: Earthquake, Precursor, Ionosphere, Electric field, satellite*

### **1. Introduction**

Recently we [Oyama and Minakshi, 2020] summarized the precursor signals which have been reported by many observers so far. We are now trying to find the common behaviors about the modified ionosphere before large earthquakes ( $M > 6.5$ ). One of the common features of NmF2 observations is that the abnormal behavior of maximum F layer electron density (NmF2) starts appear about 10 days before the earthquakes. Depending on the geomagnetic latitude, NmF2 gradually increases(decreases),

shows the peak (the minimum), and then gradually reduces (increases). This phenomenon can be explained by the enhanced dynamo electric fields as we describe in chapter 3.

Other ionosphere precursor signals are :1) . 2 days period of NmF2 appears about 1 week before the earthquakes. 2). NmF2 starts reducing as well about one week before, and it continues after the earthquakes . The 2 days' period, in NmF2 behaviour that we describe above, should more clearly appear in the magnetic field caused by Dynamo current. This will be followed up in the near future, by adopting the frequency analysis technique.

Satellite data observed by DEMETER [Parrot et. al.,2006], and DMSPF15 [ Bankov et al.,2010] shows that before large earthquakes ( $M > 6.5$ ), the increase of plasma parameters ( $Ne, O^+$  density) starts to appear from about 10 days before the earthquakes over the geomagnetic equator. As the orbit height of both satellites is 700 Km (Ryu et al., 2019) and 800 km (Bankov et al.2010 ) respectively, no clear sign appears over the epicenter. GIM TEC also shows the enhancement of the TEC both day and night over the geomagnetic equator with 2 days period.

The behavior of the power spectrum density (PSD)calculated from the slant gage data (Hi-net) shows a good relationship with the NmF2.The PSD which have been calculated for 4 large earthquakes in Japan so far shows the unique feature starting from about 10 days before the earthquakes [ Chen et al., 2023]. The behavior seems to reflect process of the rock fracturing, and water flows into the fractures rocks [Oyama et.al, 2024]. We might be able to identify the exact location of the epicenter and the day of the earthquake occurrence.

We might be able to predict the occurrence of earthquakes and the epicenter in the time range of 10 days before the earthquake, if the satellite (s) survey(s) the height below 300 km, which is the essential factor. At higher height, to find the epicenter is absolutely difficult, but still we can inform the date of the occurrence with the accuracy of 2-4 days,because over the geomagnetic equator,NmF2 /TEC enhances day and night with the period of 2 days. Once satellite observation suggests the possible days of occurrence and the rough location,the ground based observation can be a powerful tool to identify the epicenter as well as the day of the occurrence, if the number of the instrument is distributed enough to identify the epicenter. Devi and Barbara (2012) and Devi et al., (2013) have identified the epecentre location by analyzing TEC behavior and apperance of abnormal numer of satellites (PRN) at the epecentre location by analyzing azimmuthal positions of satellites (PRN) .

In the past there are several satellite missions proposed [Jason et al., 2002; Korepanov et al.,2008;Oyama et al., 2010] 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.

## 2. Our Findings

### 2.1 Satellite observations .

#### 2.1.1 Electron temperature measurement

Japanese Sun Observation satellite 'Hinotori' was put into equatorial orbit (the inclination;  $30^\circ$ ) at the height of 600 km in February 1981 (<http://isas.ac.jp/enterp/mission/hinotori.shtml>). Although the satellite was dedicated to study the solar physics, two unique plasma probes that were developed in Japan were accommodated. The two probes are a resonance rectification probe for electron temperature,  $T_e$  [Hirao and Oyama, 1970] and an impedance probe for electron density,  $N_e$  [Oyama and Obayashi, 1966; Oyama et al., 1986]. As these probes, especially,  $T_e$  probe, have been flown in number of sounding rockets and satellites, their performance is well established [Oyama et al., 2004; Kakinami et al., 2008]. Data were accumulated for 16 months, until the satellite operation was terminated in June 1982 due to the battery problem. The instruments gave accurate and reliable data under the ambient of plasma density of  $10^4$  electrons /cc, and of  $T_e$  to 3000, with the accuracy of more than 10%. A model of  $T_e$  was constructed by using data acquired by Hinotori.

For all three seasons (northern summer, northern winter, and equinox),  $T_e$  takes the minimum value at  $\sim 4$  LT, rises steeply and shows a peak at  $\sim 9$  LT (named as "morning overshoot"). After the morning overshoot,  $T_e$  reduces toward noon, starts increasing at  $\sim 15$  LT, and shows the second peak at  $\sim 17$  LT (named as "afternoon overshoot"). Finally, the peak disappears at around 20 LT. The first peak is not so sensitive to geomagnetic latitude, comparing to the second peak. The second peak shows a clear latitudinal variation; the peak is not remarkable over equator, but becomes clearer in higher latitudes.

By using the data acquired by Hinotori, we studied three earthquakes which occurred in the north of Philippine [Oyama et al., 2008]. These are the earthquakes of (1) 22 November 1981, with magnitude of  $M_s=6.7$ , depth 37km, the epicenter 15.05 N and 120.84 E, (2) January 11 1982  $M_s=7.4$ , 13.75 N, 124.36 E, depth 45km and (3) January 24, 1982  $M=6.6$ , 14.09 N 124.35 E, depth 37km.

Our findings show the total or partial disappearance of the afternoon overshoot before these earthquakes. **2.1.2 DE-2 data-Behavior of  $O^+$  and  $N_e$**

DE-2 satellite was in Orbit from June 1981 and 1982. DE-2 is highly eccentric in orbit mainly to study high latitude region. We show one example of the ionosphere modification, for an earthquake, which

occurred on the 15 October, 1981 (Lat; -33.13; Lon, 073.07. Ms; 7.5). It is noted that the data was studied when the satellite was located near the perigee height of about 300 km [Oyama et al., 2011]. The Figure. 1 shows the  $O^+$  along the DE-2 satellite orbit, starting from 5 days before the earthquake and 5 days after the earthquake. As the observation approaches earthquake days,  $O^+$  density shows the minimum over epicenter as if the equatorial ionization trough shifted from geomagnetic equator to the epicenter. This tendency is more remarkable as the observation longitude is closer to the epicenter as the figure 2 shows. The longitude where disturbance is found extends wider than 40-50 degrees. Sometimes (not always) fluctuation of  $O^+$  density of about 1 % is found, being superposed on the background  $O^+$ .

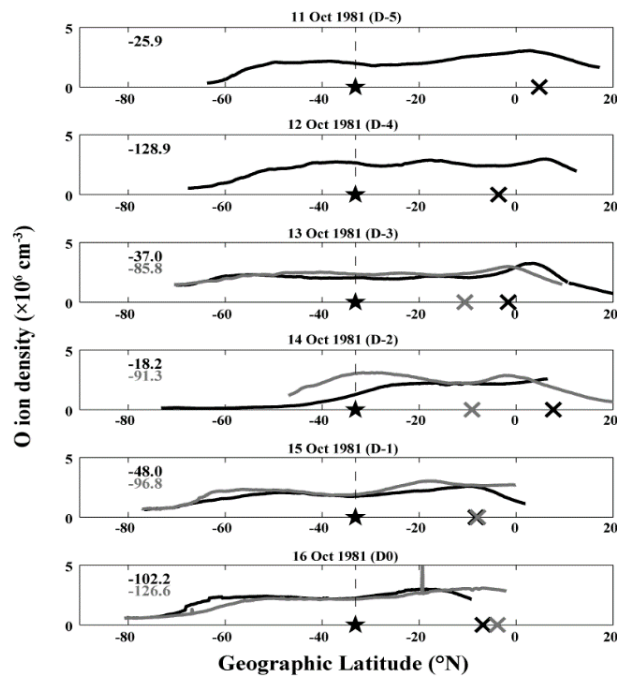


Figure .1 Behavior of  $O^+$  density along DE-2 Orbits for the earthquake ,16 October 1981. The letter, -D5, -D4, -D3, -D2, -D1, D0 mark from 5 days before the earthquake and to the earthquake day/. Black star, gray and black crosses in each plot is the epicenter and geomagnetic equator.

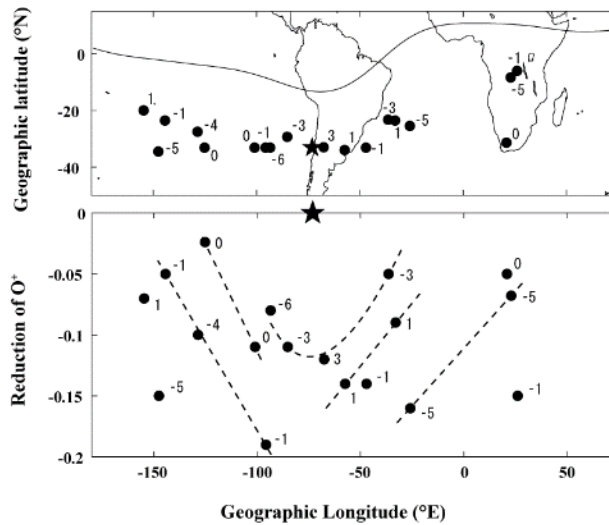


Figure.2 Upper panel: The shift of the trough at geomagnetic equator to the epicenter. A minima of  $O^+$  density due to Equatorial Ionization Anomaly approached to the minimum caused by the earthquake toward the earthquake day, and after the minimum of equator ionization anomaly departs. Lower panel: The ratio of  $O^+$  density at the minimum versus  $O^+$  density and measured at the both side of the minimum. Near the epicenter region,  $O^+$  density shows the maximum reduction (lower panel).

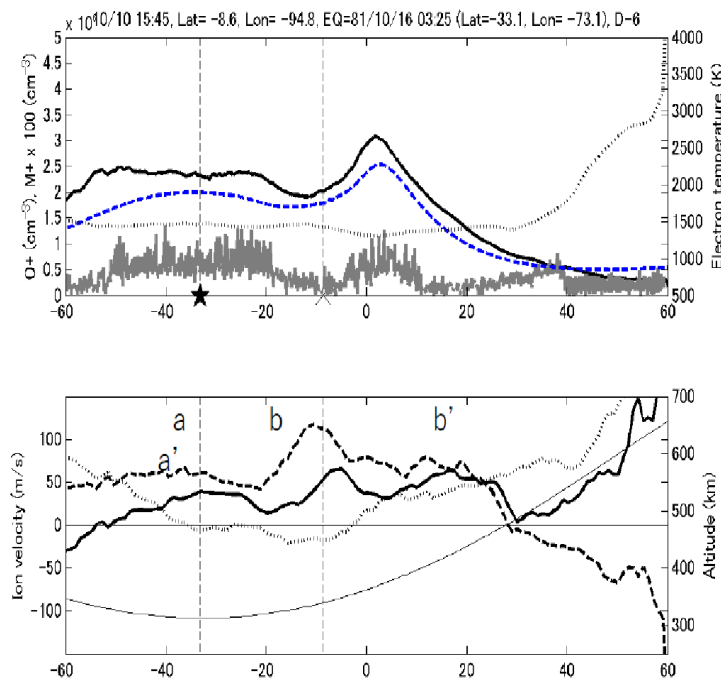


Figure .3 DE-2 plasma measurements 6 days before the earthquake on 15 October, 1981: Upper: Black line shows the observed  $O^+$  density, blue dotted line is  $O^+$  density calculated from IRI, grey line is for molecular ions. Te observed is shown by a thin dotted line. A star indicates the epicenter. Lower: Plasma drift of 3 components; Black, thin, and dashed lines are for vertical drift, east-west drift, and north-south component respectively. Positive values are away from the earth for the vertical drift, for the east ward and for the NS direction respectively.

Figure 3 shows all plasma parameters in one of the orbits for the earthquake above. The vertical drift meter in the disturbed region (marked by a and b) by the earthquake shows the plasma drift which is larger than the background. The letter b shows the conjugate point of the point a. The change of the ionosphere at this geomagnetically conjugate point was not clear for this earthquake.

### 2.1.3 DEMETER and DMSP F15

Ne observed by DEMETER (French satellite "DEMETER", Sun synchronous circular orbit at 715 km, 130kg, 3 axis control, ([http://smc.cnes.fr/DEMETER/GP\\_satellite.htm](http://smc.cnes.fr/DEMETER/GP_satellite.htm)) shows the increase of Ne over the geomagnetic equator [Ryu, et al., 2016]. The increase of plasma density over the geomagnetic equator is also found in TEC.

The only DMSP F15 satellite was in orbit of 800 km with high inclination  $81^\circ$  during March 11, 2011 earthquake. Although we did not expect much of the fruits due to the high altitude of DMSP, our unexpected findings are following for Tohoku-oki earthquake (M=9) which occurred 11, March 2011 in Japan. Mid latitude trough becomes deeper as earthquake day approaches, and back to the higher latitude after the earthquake. Two day' periodic change of  $O^+$  density (One day, increase and the second day; decrease) repeating 3 times is found in the geomagnetic equator region [Oyama et al., 2019].

### 3.0 Ground observations of the ionosphere

NmF2, maximum plasma density observed by the ionosonde for Tohoku-oki earthquakes occurred on 11 March 2011 shows the following. three features: 1). NmF2 increases at Jeju (Korea) shows the minimum on the 6 March, while higher latitude, Yakutsuk station, it shows the maximum. 2). Two days' periodic change of NmF2 (one-day increase of NmF2, starting from one week before the earthquake and the next day the reduction). This repeats 3 times before 11 March. NmF2 reduces from the same time before the earthquake, and continues even after the earthquake.

The similar features are also found in another 4 earthquakes [Oyama et al., 2024].

### 3.1 Possible mechanism to disturb ionosphere

The most probable candidate is electric field. Many papers that the behavior of Ne, NmF2 or TEC which appears in related scientific journals are explained by the electric field [Ruzhin et al., 1998, Decvi et al., 2001, Devi et al., 2004, Devi et al., 2018 ], because the effect also appears in the conjugate point and the effect appears about 5 days before the earthquake.

We suggested before that the driving force to modify the ionosphere is the intensified dynamo electric field which is mainly generated around 100-200 km. During the preparation period of the earthquake, the eastward daytime electric field is intensified, and it pushes the ambient plasma upward, trying to fill the magnetic tube of flux. The part of the plasma flows down along the magnetic field line. Night time westward electric field pulls back the plasma lifted during the daytime. At higher latitude, more plasma flows down and the clear increase of NmF2 was found for Tohoku-Oki earthquake occurred in 2011. The disturbed Electric field area is intensified over the epicenter, and extends to a wide range (about 60 degrees in east-west direction, and about 40 degrees in north-south direction).

Two mechanisms are possible for the intensified dynamo electric field. One idea is that small scale dynamo region might be formed by the neutral wind. Another, but most plausible mechanism is the reduced conductivity of E region ionosphere. The reduced conductivity is caused by the plasma irregularity which is generated as a breaking of the neutral wind. As the electric field which appears between dawn and dusk is divided by the Ohm's law, the potential drop at the both end of the reduced conductivity region enhances. Immel et al.[2006]. showed that a newly discovered 1000-km scale longitudinal variation in ionospheric density might be explained by consideration of the dynamo interaction of the tides with the lower ionosphere (E -layer) in daytime.

#### **4. Toward satellite mission [Oyama et al., 2010]**

We find the difficulty to draw the morphology ionosphere modification due to the earthquakes in the whole globe and find the mechanism by the satellites which have been launched so far by two reasons. 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 positive 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.

Another reason comes from the height of the satellite. The height, 600- 800 km of the two satellites is too high to find the effect of the earthquake. As the satellite goes higher, the signal of ionosphere disturbance generated by the earthquake smears, because neutral wind might erase the foot print of the earthquake effect. In order to identify the epicenter, the satellite should go down below 300km as the DE-2 data shows. Data acquired by DE-2 satellite suggest the possibility to

detect the precursor phenomena from space, even to identify the epicenter as well as the day of the earthquake at the latest about one week before the earthquakes. We should pursue the satellite mission for the possible large earthquake prediction, and to try to confirm its possibility. The satellite mission might be a combination of constellation of CubeSat ( $\sim 10\text{kg}$ ) and at least one small satellite, mother satellite for which we describe in detail below.

#### 4.1 Instruments candidates

##### (a) *Electron density and Temperature*

The fundamental parameters are the instrument to measure electron density ( $N_e$ ) and electron temperature ( $T_e$ ). The parameters are basic one to be measured both by Cube sat. and small satellite. It is essential that each satellite should accommodate the same two fundamental instruments (electron temperature probe and impedance probe). It is noted that it needs special attention to get accurate electron temperature. Electron temperature, which has been measured with DC probe recently, is not accurate. Langmuir probe data from recently launched satellite shows an electrode contamination problem (see DEMETER). As  $N_e$  is calculated by using  $T_e$ ,  $N_e$  is also incorrect. The contamination of the electrode for DC Langmuir probe is serious. DC probe bias need to be swept over 5 Hz to remove contamination effect of the probe. Or the probe can be used as pulse mode.

Electron temperature probe ETP provide accurate  $T_e$ . The probe has been accommodated in more than 50 rockets more than 40 years in Japan including the sounding rocket is Showa Antarctic Japanese station [Schlegel et al., 1983]. The probe was used in India, Brazil, USA, West Germany under the international rocket collaboration. The probe data shows a good agreement with that measured simultaneously by EISCAT radar. The probe data also shows a good agreement with the data measured with a resonance cone instrument, which was conducted in Japan under German-Japan collaboration [Rohde et al., 1993]. The probe was also installed in Korean satellite KOMPSAT-1 [<http://eportal.org/satellietmission>], Brazil [Muralikrishna et al., 2004] and Russian satellite, Universitetsky Tatyana-2 [Liu et al., 2014]

The ETP probe has been further upgraded to measure  $N_e$  simultaneously as well, for which we named "TeNeP". While  $T_e$  mode, the frequency of sine wave is fixed at 200kHz. Right after the  $T_e$  mode starts; the frequency is swept from 200 KHz to 10 MHz [Oyama et al., 2015]. To get one set of  $N_e$  and  $T_e$  needs about 2 seconds, which corresponds to the horizontal resolution of 14 km for the satellite of the altitude of  $\sim 500$  km. We strongly recommend the ETP with an impedance probe, or

TeNeP only. Especially TeNeP is good to be installed in Cube sat, because it is not effected by the area of conductive surface, in addition to the contamination effect free from the electrode contamination.

As ETP and TeNeP described above might be enough to study the morphology of ionosphere modification by earthquake. According to our experience while we acquired during the University course, Cube sat which only accommodates TeNeP might be able to be supplied from the University, and even ETP and TeNeP can be manufactured by master course students or technical college students.

To find the mechanism of phenomena associated with earthquake, the following instruments might be needed and these instruments can be accommodated in rather larger satellite. Those are listed in priority order below.

***(b) 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 measure the electric field to get the clues for the ionosphere modification mechanism. The measurement accuracy should be more than 0.1 mV/m in order to discuss the deviation of 1 mV/m, because the natural dynamo electric field is about 2-3 mV/m.

One instrument to get the DC electric field might be a pair of two spheres (double probe) mounted at the end of long boom, which measures EW and NS components of the E field if the probe is rotated to know the unknown biased DC signals. As the noise level of the commercially available amplifiers is small enough and the AD converter has more than 12 bits, one meter boom might be enough. The double probe measurement of DC components, provides even AC components which provides us the information on the origin of electric field.

***(c) Plasma drift meter***

Another instrument to measure indirectly the electric field is Drift meter. The plasma drift measured by DE-2, is one of the good example. A plasma drift meter provides us the plasma drift (Hanson et al.,) of EW, NS. and vertical component. By measuring plasma drift  $V_d = E \times B / B^2$ , one can get the electric field of EW component from the drift component vertical to the earth surface. However, we need to stress even now (2024) that the measurement should be

contamination free in order to get the accurate value [ Oyama and Hirao, 1975; Fang et al., 2014]. To avoid the effect of contamination, all voltage applied to several grids should be operated in pulse mode.

***(d) Measurement of wind velocity and neutral temperature***

One paper reports 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 ionization trough and cleft [Hsu, 2008]. Through one orbit scan, we might be able to get height profile of O<sup>+</sup> 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.

It is highly recommended to measure the neutral wind and temperature around the height of 100-120 km. These are important parameters to confirm the role of the wind and temperature or find the new mechanism [ Sun et al., 2011]. The instrument, TIDI and SABAR on board TIMED satellite might be one of the candidate. One disadvantage of these instruments require large satellite.

***(e) Topside sounder***

There is a possibility that the height profile of the electron density is modified by electric field associated with earthquake. When the eastward electric field during daytime is intensified, the plasma is lifted to the higher altitude, and therefore the plasma density increase at the higher altitude, while plasma density reduces at lower altitude. Therefore, the result from topside sounder can be discussed together with electric field measurements. Topside sounder is surely one of the strong candidates to be accommodated [Pulinets et al., 1998; Uemoto et al., 2007]. However, the topside sounder emits intense RF power, and disturbs ambient plasma as well as potential of satellite itself. It is highly recommended to use one micro satellite dedicated for the topside sounder. Another way to avoid the disturbance from the topside sounder is to share the observation time with other instrument.

**(f) Ion mass spectrometer, and Neutral mass spectrometer**

One paper has been published [Bankovetal.,2008], which used DMSP and DEMETER satellite data. Several hours before the Sumatra earthquake, a ratio  $H^+/O^+$  increased at about 800km height both day and night.  $O^+$  decrease, while  $H^+$  increases. They explained this feature by chemical reaction  $H + O^{++} \rightarrow H^+ + O$ , which occurs at the height of transition height. Further physical detail might be that  $O^+$  is lifted by the eastward electric field during day, and pushed down during night time. During day time the lifted  $O^+$  experiences the charge transfer with Hydrogen, while at night helium ions are brought from the higher altitude. However, amount of data is still not enough to be convinced the feature by E field model. We need to confirm their results. Ion mass to be measured is  $H^+$ , and  $O^+$ . According to our data analysis obtained by DE-2,  $NO^+$  changes together with  $O^+$ .

Another possibility of the ionosphere modification that the change of the composition of the neutral particle modifies the ratio cannot be deleted [Pulinets et al., 2006]. Although to put the topside sounder might be able to provide the exact height profile of the plasma density, the priority to measure the neutral particles is low. GPS receiver can be used to construct the height profile. One disadvantage of GPS method is that we need set the upper boundary condition such as at the height of 1000 km.

**(g) Energetic particle analyzer**

Several papers report precipitation of energetic particles triggered by VLF waves associated with earthquake [Gal'Perin et al., 1992]. The priority to install the instruments in the satellite might be low.

**(h) VLF wave receiver**

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 epicenter is identified.

The instruments which are listed above, for ionosphere study, are not special. In

In addition to the instrument above, a magnetometer and sun sensor to provide the information of satellite altitude, are fundamental needed. Cube sat maybe supported by magnetic torquer, or gyro-scope. Larger satellite even can have a magnetic torquer.

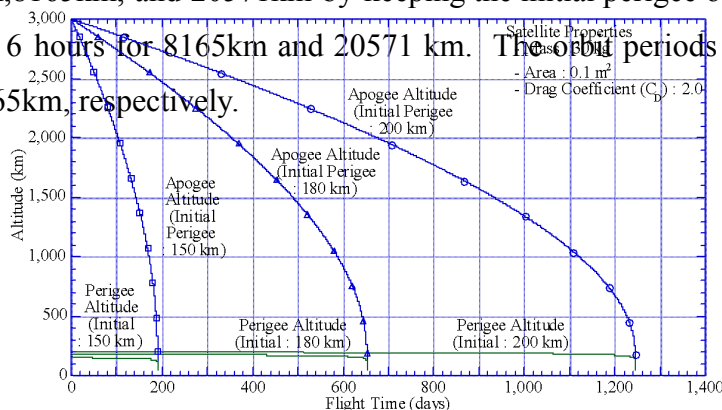
#### 4.2 Altitude, and period of the satellites

Basically two points need to be discussed for the satellite orbit for the earthquake study; one is the height, and another one is the orbit period (the duration which takes the one orbit). Ideally for both CubeSat and the small satellite (mother satellite) the height should cover the lower than 300 km in order to find the epicenter. As the satellite goes higher, the epicenter cannot be identified as the DE-2 data shows. Accordingly, the orbit might require the eccentric orbit, for the satellite is in space as long as it can from the economical point of view.

There is another option. The mother satellites flies at the height of -500 km (the period is about 90 minutes), which means the satellite shifts in longitude 22.5 degrees every 90 minutes; this means after the satellite measures one place, the next time it measures the place which is 22.5 degrees away from the previous place.

For small satellites which try to identify the epicenter, the orbit becomes eccentric to keep the long life from the economy point of view. The orbits are calculated by keeping the apogee altitude at 3000 km by changing the initial perigee altitude as 150 km, 180 km and 200 km. In Fig.4, upper panel shows the effect of the air drag on the mission life. The satellite mass, and the area are assumed 30 kg and 0.1 m<sup>2</sup>. The drag coefficient (C<sub>D</sub>) is 2.0.

Lower panel in Fig.4 shows the mission life when the apogee altitude is changed from 3000 km, 8165 km, and 20571 km by keeping the initial perigee of 200 km. The orbit period is 3 hours and 6 hours for 8165 km and 20571 km. The orbit periods are 3 hours and 6 hours for 3000 km, 8165 km, respectively.



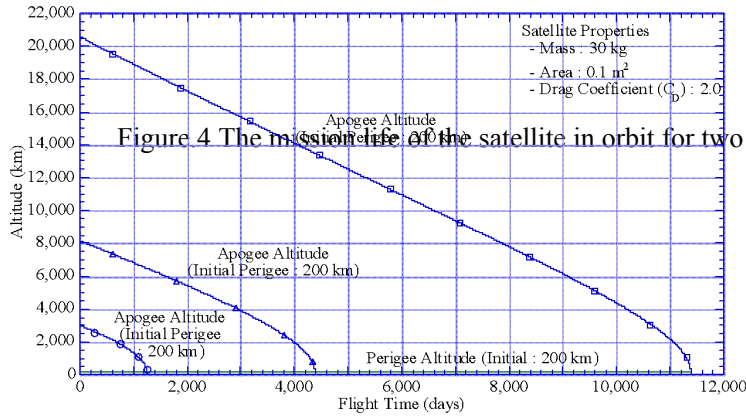


Figure 4 The mission life of the satellite in orbit for two different conditions

Figure.5 The mission life of the satellite in orbit for two different conditions. Upper: perigee altitude is changed from 150 km, 180 km, with the apogee height is fixed at 3000 km.; Lower: the apogees at the beginning of the mission are changed from 3000 km, 8000 km, and 20571 km respectively with the fixed perigee height of 200 km.

Figure.5 shows for the satellite weight of 50 kg. The apogee altitude is changed from 3000 km, 8165 km, and 20571 km. All these figures show that the perigee height does not change, but the apogee height reduces as the day proceeds.

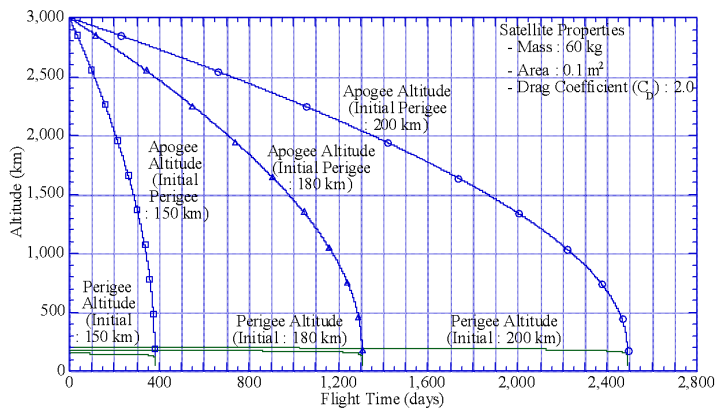


Figure.6 The change of the satellite altitude versus time (day) for the satellite mass of 60 kg.

More detail satellite orbits will be discussed in the near future.

### 4.3 Other points to be included in the mission

There are several key issues, which we should discuss during mission planning and should be executed in order to have cost/time effective mission. The followings are especially true for the CubeSats.

(a). All receiving ground facilities are advised to be the same for the different countries who join the mission, if the country newly constructs a receiving station and tracking station. If the country has already by receiving station, it is still ok.

(b). Electronics parts of the satellite should be commercially available parts in order to reduce the cost of the satellite. According to the long-time experience for space experiments, possible troubles, which might be caused as a result of using commercially available parts, can be avoided by the aging, including the careful environment test and thermal vacuum test on the ground. The key issue for the successful measurement is “we should be friend with your instrument”. TeNeP or ETP is good to manufacture in different countries for future mission, as well as training of the students according to the experience of one of the authors. Those might be available from Japan.

(c) Common instruments such as telemeter Transmitter /command receiver, are advised to be the same in addition to the magnetometer, and sun sensor, and gyroscope.

(d) Software for the orbit calculation, as well as science data analysis should be in the same format so that data can be easily handled among the countries, which participates. 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.

### 5. Coordination of various fields on the ground as well as from satellites

(a) As we discussed before, we would like to confirm the role of atmospheric waves. Accordingly, we need vertical profile of neutral gas temperature, at least up to 60km. This might be possible by radio occultation satellite. Currently a constellation of 6 Taiwan satellites is producing atmospheric temperature profile up to 60 km. To take the cloud picture at different heights might tell us the wave activity if we study the detail of the cloud. The cloud pattern might be modified by the atmospheric waves triggered by the ground motion before earthquakes. In addition, 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). In the upper ionosphere study, we have listed up the instruments on board satellite. The

signal of the earthquakes can be found in many fields. The research on the effects of earthquake on the ionosphere should not be limited among ionospheric society. We need coordination among different fields.

(b) Outreach and Education

To especially trigger the curiosity of young generation and to nourish the global eyesight, 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, starting from high school, technical school, university students, or even the graduate students. 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, a transmitter for amateur band should be accommodated in the satellite. Part of the signal is transmitted from satellite through low power transmitter. The project can be cooperated with government agency forum such as APRSAF (Asia Pacific Space Agency Forum).

### 5. Concluding remarks

We described our findings obtained from satellite as well as from ground. At least the earthquakes of larger than  $M=6.5$  produces clear signal before it occurs. Whether we can find smaller earthquake or high latitude earthquake in the future depends on the accuracy of the observation, 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 stronger from about 5 days before earthquake.

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 90 years since the discovery of the ionosphere.

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