FM-CW / MAGDAS OBSERVATIONS DURING SC

НАБЛЮДЕНИЯ С ПОМОЩЬЮ FM-CW / MAGDAS ВО ВРЕМЯ ВНЕЗАПНОГО НАЧАЛА

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Внезапное увеличение динамического давления (Psw) солнечного ветра приводит к внезапному увеличению геомагнитного поля, особенно на низких широтах. Такое явление называется внезапное геомагнитное начало (ВН). Магнитное возмущенное поле ВН изучалось многими исследователями. Тем не менее, электрические поля, связанные с ВН, в ионосфере на низких широтах еще не достаточно изучены.

Для того, чтобы измерять электрические поля, в Сасагури, Фукуока (магнитная широта=23.2 градусов, магнитная долгота=199.6 градусов), нами разработан радар FM-CW (ВС радар). Наблюдения радара FM-CW были начаты в ноябре 2002 г. С помощью доплеровского режима наблюдения можно определять скорость вертикального смещения (v) ионосферы и ее высоту с 10-сек выборкой. Ионосферное электрическое поле E расчитывается с помощью выражения отношения $\mathbf{E} = -\mathbf{v} \times \mathbf{B}$. Для расчета магнитного поля (B) в Сасагури используется модель IGRF. С помощью вышеупомянутого отношения мы можем измерить ионосферное электрическое поле в восточно-западном направлении, а также можем наблюдать короткопериодные явления электрических полей, проникающих (или распространяющихся) из магнитопаузы в низкоширотную ионосферу.

Нами выбраны 40 событий с ВН, которые были определены магнитометром в KUJ (широта =23.6градусов, долгота =203.2 градусов) и FM-CW радаром за период с 2002 по 2005 гг. Магнитная станция является частью тихоокеанской цепи CPMN [Юмото и группа CPMN, 2001]. Сначала мы анализировали изменения ступенчато-подобной функции ионосферных электрических полей во время ВН и обнаружили, что ионосферные электрические поля направлены на восток в дневное время (06-20 LT) и на запад в ночное время (17-07 LT). Средний диапазон амплитуды электрических полей составляет 0,5 мВ/м в дневное время и 1,0 мВ/м в ночное время. Мы сравнили изменения ступенчато-подобной функции электрических полей с изменениями ступенчато-подобной функции магнитных полей во время ВН и обнаружили положительную корреляцию (коэффициент корреляции =0.70) между изменениями электрических и магнитных полей. Мы также сравнили ионосферные электрические поля с изменениями в Psw во время межпланетного ударного события. Между ними наблюдается слабая корреляция (коэффициент корреляции =0.65), в то время как между электрическими полями солнечного ветра (Esw) и ионосферными электрическими полями не было найдено никакой корреляции. Оказывается, что ионосферные электрические поля зависят в основном от Psw.

Эти наблюдения предполагают, что ионосферные электрические поля на низких широтах во время ВН состоят из электрических полей утро-вечер со средней амплитудой 0,75 м/Вм, которые проникают из полярной ионосферы в экваториальную ионосферу и направленных на запад электрических полей волн сжатия со средней амплитудой 0,25 мВ/м, которые распространяются поперек магнитосферы.

The ionospheric electric field at low latitude during the main impulse (MI) phase of geomagnetic sudden commencement (SC) was investigated by Doppler observation of an FM-CW ionospheric radar with 10 seconds sampling. From the statistical analysis of the ionospheric electric field intensity for 40 SC events, we found that there is a positive correlation between the ionospheric electric field and the change in the geomagnetic H-component at the time of SC in low latitude. Therefore it seems that the source of the low-latitude ionospheric electric field at the time of MI is the dynamic pressure of the solar wind.

1. Introduction

The sudden increase of the dynamic pressure of the solar wind causes a sudden increase of the geomagnetic field especially in low-latitude region. This phenomenon is called geomagnetic sudden commencement (SC). The disturbance field of SC is divided into two components [e.g. Araki, 1977].

$D_{SC} = DL + DP$

where DL represents a step-function like increase of the H-component dominant at low latitudes. It is caused by the current circuit flowing on the magnetopause and the propagating compressional hydromagnetic (HM) wave [Araki, 1994]. DP shows the two pulse structure dominant at high latitudes due to the polar ionospheric electric field.

$DP = DP_{PI} + DP_{MI}$

PI (preliminary impulse) and following MI (main impulse) are caused by the dusk-to-dawn and dawn-to-dusk electric fields respectively. These electric fields are believed to penetrate into the polar ionosphere from the magnetosphere [Tamao, 1964; Araki, 1994], and transmit instantaneously to the low-latitude ionosphere by a TM mode [e.g. Kikuchi and Araki, 1979].

Kikuchi et al. [1985, 1986] analyzed low-latitude ionospheric electric field at the time of SC by a High Frequency (HF) Doppler measurement. Then they found that the preliminary frequency deviation (PFD) caused by the dusk-to-dawn electric field occurs simultaneously with high-latitude PRI. Moreover he showed the subsequent main frequency deviation (MFD) caused by the dawn-to-dusk electric field occurs simultaneously with MI.

However, the intensity of the SC-associated electric fields in the low-latitude ionosphere is not yet clarified sufficiently.

In order to measure ionospheric electric fields that penetrate the low-latitude ionosphere, we have constructed an FM-CW radar (HF radar) at a low-latitude station Sasaguri, Fukuoka, Japan [Yumoto et al., 2006]. An FM-CW (Frequency Modulated Continuous Wave) radar is one kind of HF (High Frequency) radar and using it for Doppler observation was first put to practical use by Poole [1985] and Poole and Evans [1985]. Nozaki and Kikuchi [1987, 1988] made improvements to the design.

Our Doppler observation started in November, 2002. By using the Doppler mode of the FM-CW radar, we can measure vertical drift velocity and virtual height of ionospheric plasmas with high time resolution. Therefore, we can estimate the intensity of the ionospheric electric fields by the method explained in section 2 of this paper. Furthermore, altitude information enables us to confirm whether or not the observed ionosphere is F-region.

2. Data Set

This present study is based on the data from our FM-CW radar located at Sasaguri, Fukuoka, Japan (Magnetic Latitude 23.2°, Magnetic Longitude 199.6°). The FM-CW radar is a type of HF radar and can measure the range of target as well as its Doppler related information. This application of the FM-CW radar is a variation of a technique developed by Barrick [1973] to measure sea scatter. With our radar system, we are able to measure the vertical drift velocity of the F-region of the ionosphere and its virtual height. Generally sampling time of our radar is 10 seconds.

When the eastward electric field penetrates into the low-latitude ionosphere, it drifts upward owing to the frozen-in effects ($\mathbf{E} \times \mathbf{B}$ effects) of the F-region. On the other hand, the ionosphere drifts downward when the westward electric field penetrates.

Our radar provides us the Doppler frequency Δf which is the difference of transmitting frequency (f_0) and receiving frequency ($\Delta f + f_0$) because of the Doppler effect responsible for the vertical movement of the ionosphere. The relational expression of Δf and f_0 is represented by $\Delta f = f_0 \times 2v/c$, where v is vertical drift velocity, and c is the velocity of light. Generally we use 8.0 MHz in daytime and 2.5 MHz in nighttime for the transmitting frequency f_0, because of the day and night variations of the ionospheric plasma density. From the above relational expression, the vertical drift velocity v of the ionosphere is given. The accuracy of the vertical drift velocity is 1.5 m/s by 8.0 MHz and 4.7 m/s by 2.5 MHz.

In addition, to estimate the intensity of the ionospheric electric fields, we are trying to calculate E of $\mathbf{E} = \mathbf{v} \times \mathbf{B}$, where E is east-west electric field of the F-region, v is vertical drift speed, and B is the magnetic H-component at Sasaguri. This B is derived using the IGRF model provided from World Data Center for Geomagnetism, Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp/index.html), which requires two inputs: (1) the altitude of the F-region (in this case, given by our radar), and (2) the geographical coordinates of Sasaguri given by GPS system.

Moreover, in order to detect the onset time of SC, we use 3 seconds averaged data from magnetometer at Kujyu (KUJ; M. Lat. 23.6°, M. Lon. 203.2°) or Kagoshima (KAG; M. Lat. 21.9°, M. Lon. 202.3°). For the data gaps at KUJ, the data from a similar instrument at KAG were used. KUJ is about 100 km southeastward from Sasaguri and KAG is about 230 km southward from Sasaguri. These magnetometer stations are a part of the Circum-pan Pacific Magnetometer Network [Yumoto and the CPMN Group, 2001].

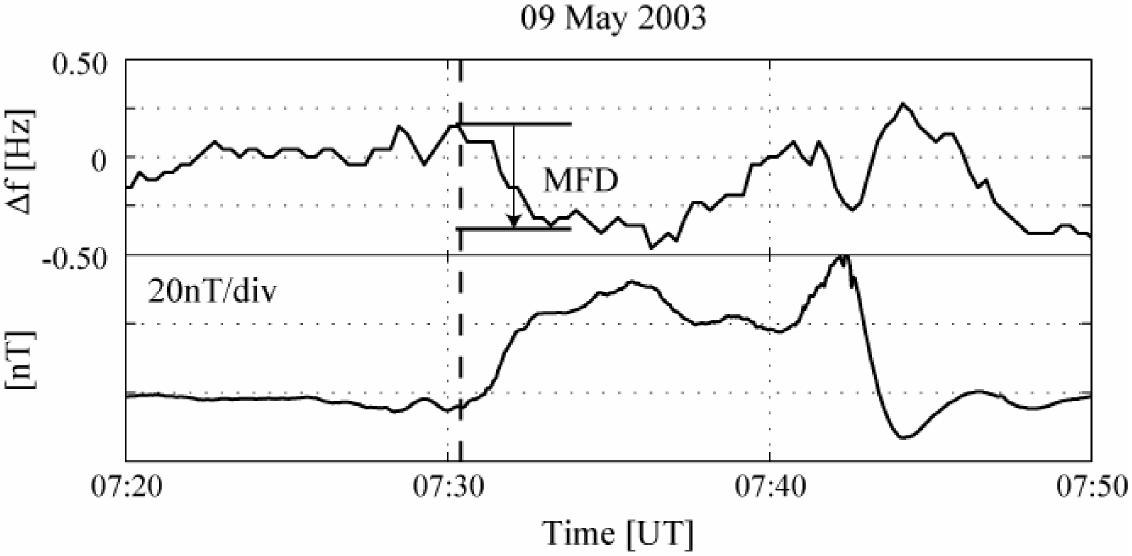

Fig.1. SC at daytime on May 9, 2003. The upper panel shows the Doppler frequency Δf observed at Sasaguri and the bottom panel shows the geomagnetic H-component at KAG.

3. Data Analysis

3.1. SC on May 9, 2003

Figure 1 shows a geomagnetic field variation of the H-component at KUJ and Doppler frequency measured at Sasaguri on May 9, 2003. When the westward electric field penetrates into the low-latitude ionosphere, the ionospheric plasma drifts downward and the Doppler frequency deviates positively. While, when the eastward electric field penetrates, the Doppler frequency deviates negatively. The SC onset at 07:30 UT (16:30 LT) is indicated by the vertical dashed line in Figure 1 and the amplitude of SC is about 38 nT (initial peak-to-peak change of H-component at KAG). After the SC onset, an abrupt decrease of the Doppler frequency occurs with correspondence to an increase of the H-component. Therefore, this negative deviation is an MFD. The initial peak-to-peak change of the MFD is -0.51 Hz, and from this value we estimate the electric field intensity (Hereafter, we call this electric field the MI-electric field) as 0.27 mV/m (eastward). During this SC event, the radar transmitting frequency was 8.0 MHz and the observed ionospheric altitude was about 300 km (virtual height).

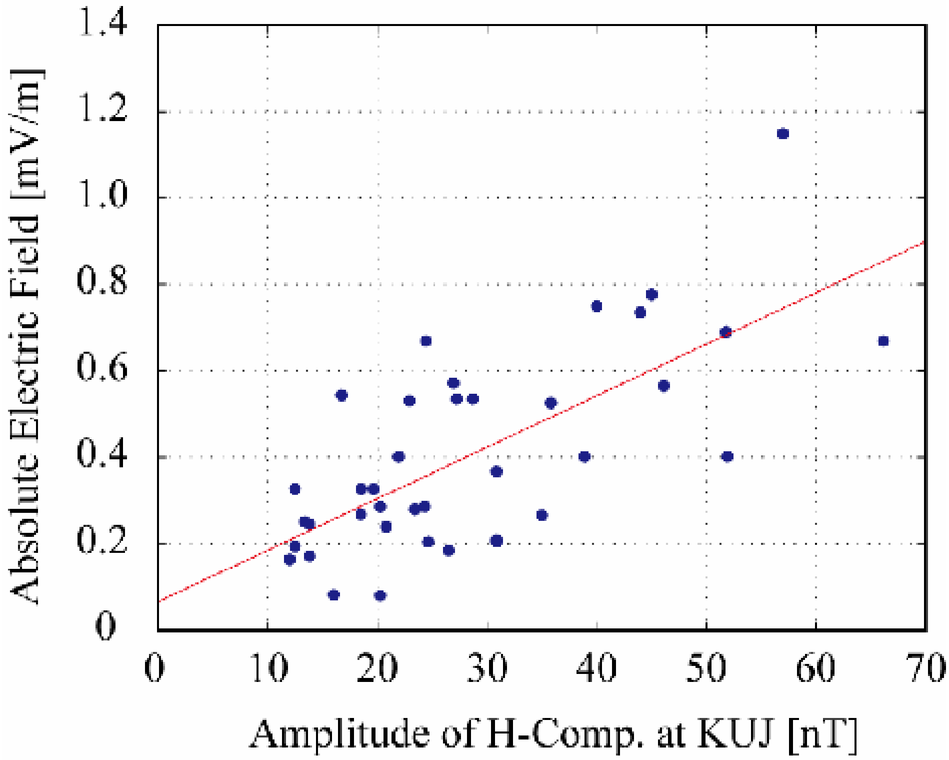

Fig.2. Scatter plot of the MI-electric field intensity versus the amplitude of the geomagnetic H-component. We note that the direction of MI-electric field is eastward in daytime and westward in nighttime, therefore the MI-electric field intensity of Figure 2 is absolute value.

3.2. Relation between ionospheric electric field and geomagnetic field

In order to verify the relation between ionospheric electric field and geomagnetic field, we analyzed 40 SC events that were recorded by a magnetometer at KUJ or KAG within a period from 2002 to 2005. The criteria of the analyzed SC events are that a geomagnetic field variation of the H-component rapidly increases more than 10 nT at KUJ or KAG. In these SC events, the amplitude of analyzed SC was in a range from 12 nT to 66 nT at KUJ or KAG, and the observed altitude of the ionosphere was in a range from 210 km to 460 km.

We compared MI-electric field intensity with change in the H-component of the magnetic fields at the time of SC (MI), and found a positive correlation between the electric and magnetic field changes (Figure 2). The correlation coefficient is 0.70. We note that the direction of MI-electric field is eastward in daytime and westward in nighttime, therefore the MI-electric field intensity of Figure 2 is absolute value.

4. Discussion and Conclusion

There is a positive correlation between the SC amplitude of geomagnetic H-component in low-latitude region and sudden changes in the dynamic pressure of the solar wind (e.g., Siscoe et al., 1968). This fact means that the source of the variation of the geomagnetic field at the time of SC is the dynamic pressure of the solar wind. From our observational fact (see Fig.2), it seems that the source of the ionospheric electric field at the time of MI is also the dynamic pressure of the solar wind.

However, the response of the geomagnetic field to dynamic pressure of the solar wind shows the dependence on local time [e.g. Russell et al., 1994]. Furthermore it depends on the direction of the interplanetary magnetic field (IMF). Therefore it seems that the MI-electric field also depends on local time and the direction of the IMF. We need to analyze the dependence of MI-electric field on local time and IMF in future study.

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