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Geomagnetically Induced Currents in the Western Pacific Region during February 8-9, 1992 Magnetic Storm

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Abstract

In order to study geomagnetically induced currents in the sea and its effects on environmental changes in the geospace, we installed a volt-ammeter system in the AT & T station at the end of a cable (called TPC-1) between Guam and Ninomiya, and also fluxgate magnetometer systems at Moshiri in Japan, Guam and Hawaii in the USA. From comparisons of the observed voltage fluctuations on the cable with D-component magnetic variations at Guam, Moshiri and Adelaide in Australia along the 210° magnetic meridian, it is found that global magnetic variations at magnetic latitude of $\Phi < 40°$ during a geomagnetic storm can produce induction voltage and current fluctuations on the TPC-1 cable, but latitudinally localized magnetic variations at $\Phi > 45°$, e.g., caused by low-latitude aurorae, do not induce notable voltage on the cable located at magnetic low latitudes of $\Phi < 25°$.

1. Introduction

Magnetospheric storms and substorms driven by variations in the solar wind can produce large changes in the geophysical environment and have significant impacts on human technologies. For example, spacecrafts are damaged by charged particles striking solar cells and the lifetime of Earth-orbiting satellites is shortened by enhanced orbital drag. On the other hand, magnetic disturbances can produce large induced currents in long conductors used for electrical power distribution, telecommunications, and pipelines on the Earth's surface (see, MEDFORD et al., 1989; LANZEROTTI et al., 1992). The great magnetic storm on March 13, 1989 induced a current of very low frequency in the Hydro-Quebec transmission system, then sustained a load of 21,350 MW, and knocked out power in almost all of Quebec, Canada, for about 5 hours. During the storm, the cable power supply voltage at the North American end of the Fiber optic transatlantic telecommunications cable TAT-8 measured the large scale changes as large as 700 volts in the total Earth potential across the Atlantic, i.e. the potential gradient of as large as 0.12 volts/km.

In order to study geomagnetically induced currents in the sea and its effects on long-term environmental changes in the geospace (e.g., FRIIS-CHRISTENSEN and LASSEN, 1991), we installed in December 1991 a volt-ammeter in the Guam AT&T station at the end of a submarine international telecommunication cable, calledTPC-1, between Ninomiya in Japan and Guam in the USA. Fluxgate

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magnetometer network data from the 210° magnetic meridian (MM) chain stations at Moshiri in Japan, Guam and Honolulu in the USA (YUMOTO et al., 1992, 1996) are also used to compare the geomagnetically-induced voltage with current fluctuations on the undersea cables. In this paper, preliminary results on low-latitude aurorae events during a magnetic storm will be presented.

2. Observations

2.1 Magnetic observations in the western Pacific region.

Magnetic observations along the 210° and 250° magnetic meridians were conducted by the Solar-Terrestrial Environment Laboratory (STEL), Nagoya University, for the international STEP period (1990-1997) (YUMOTO et al., 1992, 1996), and are continued by the Department of Earth and Planetary Sciences, Kyushu University, in collaboration with kind supports from about 30 organizations in the circum-pan Pacific region. Figure 1 shows the Circum-pan-Pacific Magnetometer Network (CPMN) stations along the 210 ° MM and the magnetic dip equator near the undersea TPC-1 cables between Guam and Ninomiya in Japan.

In January, 1991, the fluxgate magnetometer system was installed at the Pacific Tsunami Warning Center (EWA: Φ =22.72°, Λ =269.05°, L=1.18) at Ewa Beach in Hawaii. The magnetometer sensor and the system including amplifier, data logger, and time signal generator were installed in the bush and the house, respectively. Dr. A.W. GREEN and D.C. HERZOG of the U.S. Geological Survey and Mike BLACKFORD of the Officer-In-Charge of PTWC, kindly accepted our project and have been

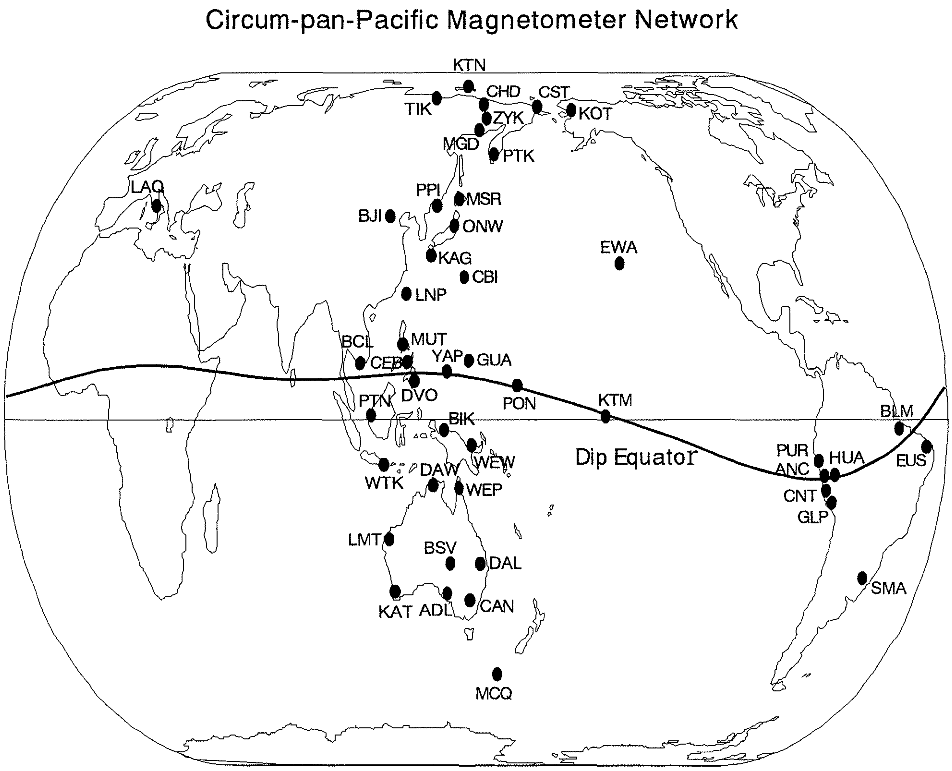


Fig. 1. The station distribution of the Circum-pan-Pacific Magnetometer Network (CPMN) along the 210 ° magnetic meridian and the magnetic dip equator.

supporting it. Frank TAKENOUTI and Richard K. NYGARD were friendly and cooperative in the routine-based magnetic observation in Hawaii. In February, 1993, a part of the magnetometer system was replaced to keep time accuracy and to do continuous routine-based observation.

In June,1991,the magnetometer system was also installed at Guam (GUA: 9.02°, 215.18°, 1.03) in the USA, by the courtesy of Paul M. HATTORI of the Guam Magnetic Observatory, the U.S. Geological Survey. The sensor and recording system were set in the building for optical magnetic recording. We visited Guam again to maintain the equipments in November, 1992. Magnetic variation data (Δ H, Δ D, Δ Z, dH/dt, dD/dt, dZ/dt) from all stations were obtained using ring-core fluxgate magnetometer with identical logging system and time signal generator. The resolutions of ordinary analogue outputs Vo(Δ H, Δ D, Δ Z) in the 0-2.5 Hz frequency range are ± 300 nT/± 10 volt for low-latitude stations. The time-derivative components (VTD; dH/dt, dD/dt, dZ/dt) were obtained by putting an analogue circuit at the output terminals of the ordinary components (Vo). The VTD outputs in the frequency range of 0.0-0.1 Hz exhibit essentially the same frequency response as an induction magnetometer. The noise level of the magnetometer system was lower than 0.1 nT rms equivalent. The six magnetometer signals and time pulses (1min, 1hr, 24hr) were registered on a digital cassette tape using the digital data logger with sampling rate of 1 sec and 16 bit resolution of 0.012 nT/LSB. Each cassette tape held 21 days of data. The time pulses from the time signal generator were also recorded on the digital cassette tape to check the crystal clock inside the data logger. The time pulses were maintained accurate to be within ± 25 ms by automatic comparison with standard radio transmissions from WWVH (Maui, Hawaii), JJY (Koganei, Japan), and WWV (Boulder, USA).

The installation of a magnetometer system at Muntinlupa (MUT: 3.58°, 191.57°, 1.00), Philippines, was also planned to examine relationships between H-component magnetic variations observed at MUT and GUA and voltage and current fluctuations induced by geomagnetic activity on the long telecommunication cable, called GP-1, between Guam and Philippines. We visited the Muntinlupa Magnetic Observatory, the Coast and Geodetic Survey, Philippines, to look for a magnetic observation site and co-investigators who will participate in the 210° MM magnetic observation project. After constructing a new sensor house, we visited Manila again to install the same magnetometer system at GUA in June-July, 1993.

2.2 Observations of voltage and current induced on TPC-1 cable.

Two volt-ammeter systems were installed by the Earthquake Research Institute (ERI), the Univ. of Tokyo, and the STE Lab., Nagoya Univ., in the Guam AT & T station during the interval of December, 1991-January, 1992, in order to measure voltage and current fluctuations induced on the TPC-1 cable between Guam in USA and Ninomiya in Japan. The system and preliminary results on the comparison of the induced-voltage and D-component magnetic variations were already reported by HAMANO et al. (1992). Figure 2 shows one example of voltage and current fluctuations induced on the TPC-1

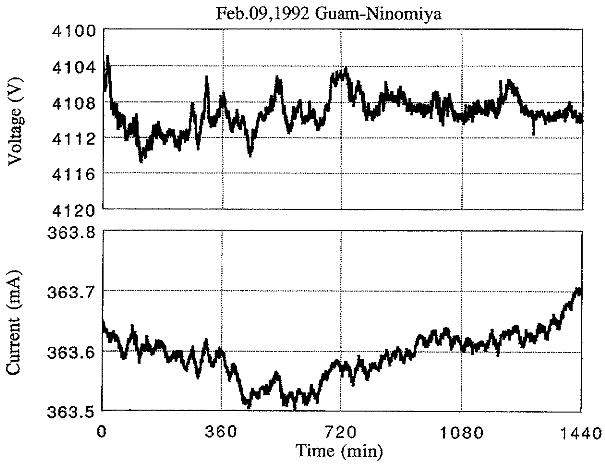


Fig. 2. One example of voltage and current fluctuations induced on the TPC-1 cablebetween Guam and Ninomiya, observed by the ERI system on February 9, 1992.

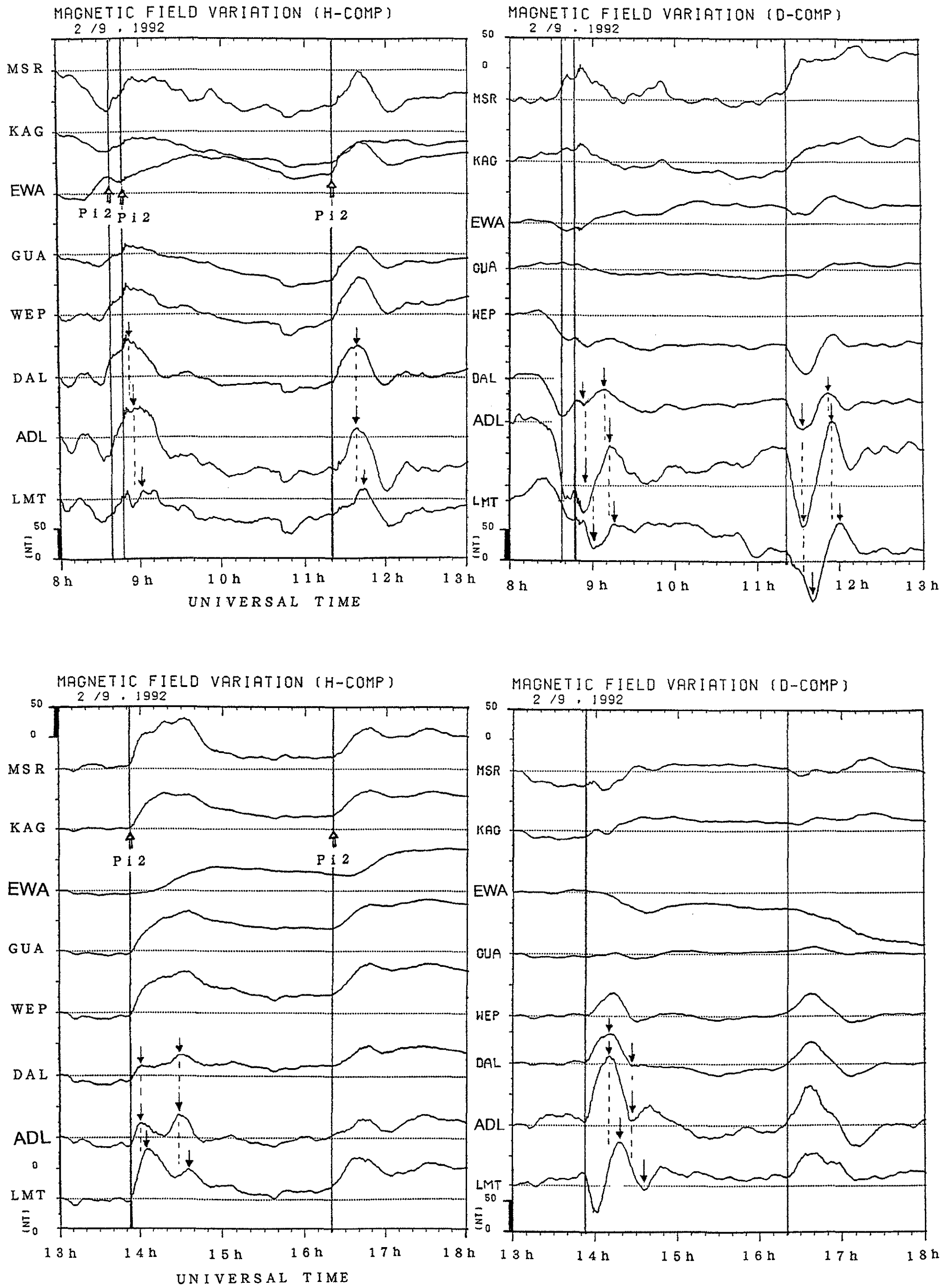


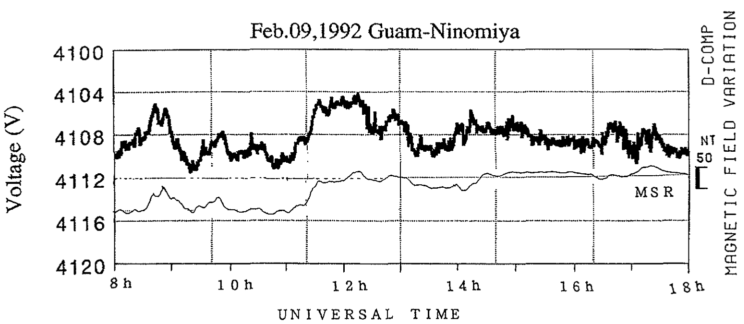
Fig. 3-1 and 3-2. The H- (left) and D-component (right) amplitude-time records of magnetic field variations observed along the 210 ° magnetic meridian during the magnetic storm intervals of 08-13 hr and 13-18 hr UT, respectively, on February 9, 1992. Solid lines indicate the times of Pi 2 onset, i.e., auroral expansion onset.

cable, observed by the ERI system on February 9, 1992. The voltage variations between Guam and Ninomiya were already confirmed to have a good correlation with the D-component magnetic variations at Kakioka and Guam (see HAMANO et al., 1992).

3. Preliminary result of low-latitude aurora event

A moderate geomagnetic storm with a sudden commencement of 88 nT range at Moshiri (MSR: 37.76°, 212.96°, 1.60) began at 14:28 UT on February 8, 1992, developed rapidly over the next three hours, and with a slow intensification on the next day, reached an ordinary minimum value of the H-component variation around the noon of February 9 (see YUMOTO et al., 1994). Five magnetic positive excursions appeared quasi-periodically around the minimum of -166 nT on the H-component amplitude-time record in the midnight sector of the 210° magnetic meridian. The universal time of 15 hr corresponds to the local midnight of the 135°E geographic longitude. The observed positive bays with about 40-70 nT range accompanied large-amplitude Pi magnetic pulsations at 08:38, 08:49, 11:20, 13:53, 16:20 and 19:48 UT, of which onset times are indicated by vertical solid lines in Figs. 3-1 and 3-2. During the interval when the third positive H excursion took place at 13:53 UT, gradual intensity enhancements of the 630 nm emmision associated with low-latitude aurorae were observed by a highly sensitive video camera in the clouded sky at Rikubetsu in Hokkaido island in Japan, but the onset time of low-latitude aurorae event could not be identified (see SHIOKAWA et al., 1994, YUMOTO et al., 1994).

Figures 3-1 and 3-2 give sets of H- and D-component magnetograms during the intervals of 08h-13h and 13h-18h UT on February 9, 1992, respectively, from the 210° MM chain stations at MSR, Kagoshima (KAG: 25.23°, 201.99°, 1.22) in Japan, EWA in Hawaii, Weipa (WEP:-23.06°, 214.07°, 1.18),



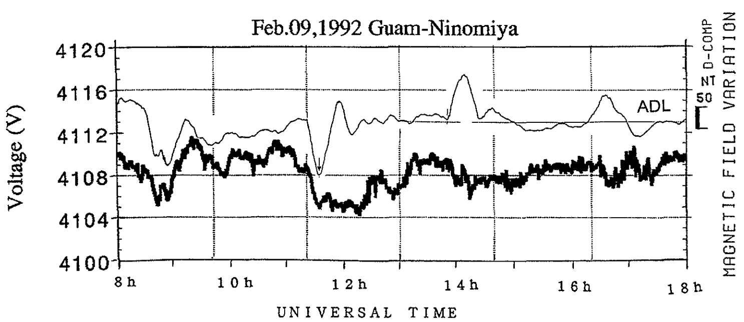


Fig. 4-1 and 4-2. Two examples of comparisons betweent induced voltage fluctuations in the cable between Guam and Ninomiya and the D-component magnetic variations observed at MSR and ADL, respectively, during 08-18 hr on February 8, 1992

Dalby (DAL: -37.30°, 226.53°, 1.58), Adelide (ADL: -46.72°, 213.34°, 2.13), and Learmonth (LMT: -34.36°, 184.64°, 1.47) in Australia. The very interesting feature in Fig. 3 is that there are northern and southern hemisphere asymmetries of H- and D-component magnetic field variations during low-latitude aurorae, which show an unipolar structure in the H component and a bipolar structure in the D component, i.e., negative-positive deflections of the Earth magnetic field at DAL, ADL, and LMT during 11:20-12:20 UT and at LMT during 13:53-15:00 UT. These magnetic variations during the low-latitude aurorae suggest that a localized ionospheric equivalent current vortex with upward field-aligned current should be formed at middle latitudes around the ADL station (Φ =-46.72°) in the southern hemisphere, while the localized current system would be formed at higher latitudes than MSR (37.76°) in the northern hemisphere (see YUMOTO et al., 1994).

A portion of the TPC-1 time-amplitude records is shown in Figs. 4-1 and 4-2, principally to illustrate the fine example of the voltages induced by the geomagnetic field variations during the February 8-9 1992 storm. The voltage fluctuations in the cable between Guam and Ninomiya (Φ = 25.67°, L=1.23) nearly along the 210° magnetic meridian have a good correlation with the D-component magnetic variations at MSR (37.76°) located about 12° north of Ninomiya, i.e., the end of the cable as shown in Fig. 4-1, whereas a little correlation with the small-amplitude D-component variations at Guam in Fig. 3. In the simplest form, the voltage induced in the meridional cable can be expressed as

$$\text{volts} = d\Phi/dt = -\, d\,[\,D \cdot A\,]/dt,$$

where Φ is the magnetic flux through a cross section with area A in the sea, which is perpendicular to the D (east-west) direction. From the observed induced voltage of ~ 4 volts, i.e., ~ 1.5 mvolts/km for time change ($\Delta t \sim$ 6 min) of magnetic variation ($\Delta D \sim$ 50 nT) around 11:20 UT in Fig. 4-1, an effective area where magnetic flux crosses is found to be order of 3×10^{10} m^2 . This implies that the averaged effective depth of the sea between Guam and Ninomiya is 11 km for the length (2700 km) of TPC-1 cable.

It is also found that during low-latitude aurorae events starting at 11:20, 13:53 and 16:20 UT as shown in Fig. 4-2, the induced voltage fluctuations on the TPC-1 cable show little correlation with the D-component magnetic variations at ADL (-46.72°). This implies that the geomagnetic variations caused by the localized three-dimensional current system during low-latitude aurorae around Φ = -46.72° in the southern hemisphere are difficult to produce the induced voltage on the TPC-1 undersea cable between Guam (9.02°) and Ninomiya (25.67°) in the northern hemisphere. It is concluded that global magnetic variations at $\Phi < 40°$ during geomagnetic storm can produce induction voltage and current fluctuations on the TPC-1 cable, but the latitudinally localized magnetic variations at $\Phi > 45°$, caused by low-latitude aurorae in the southern hemisphere, are hard to induce voltage on the cable at magnetic low latitudes of $\Phi < 25°$.

4. Summary

From the observations in the previous section, we can summarize as follows:

(1) The voltage fluctuations in the cable between Ninomiya (Φ = 25.67°, L=1.23) and Guam (9.02°, 1.03) along the 210° magnetic meridian have a good correlation with the D-component magnetic variations at MSR (37.76°, 1.60) located about 12° north of Ninomiya, i.e., the end of the cable as shown in Fig. 4-1, whereas a little correlation with those at Guam in Fig. 3.

(2) During low-latitude aurorae events starting at 11:20, 13:53 and 16:20 UT on February 9, 1992, as shown in Fig. 4-2 the induced voltage fluctuations on the TPC-1 cable show little correlation

with the D-component magnetic variations at ADL (-46.72°, 2.13).

(3) Global magnetic variations at $\Phi < 40°$ during geomagnetic storm are concluded to produce induction voltage and current fluctuations on the TPC-1 cable, but the latitudinally localized magnetic variations at $\Phi > 45°$, e.g., caused by low-latitude aurorae, are hard to induce voltage on the cable at magnetic low latitudes of $\Phi < 25°$.

In the near future, using the undersea cables TPC-1 and GP-1 and magnetometer network, we can study two dimensional responses of induction currents in the sea to various geomagnetic disturbances. The undersea cables at higher latitudes are also needed to examine the induction effect of auroral substorms which occur frequently and have one-order larger magnetic variations.

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