3-4 Quasi-real time geomagnetic data transfer from near northern magnetic pole region

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It is well known that the magnetic field variations in the near geomagnetic-pole region can be used as an index of magnetospheric convection driven by solar wind-magnetosphere coupling (PC index). Northern PC index (PCN) is derived from Qaanaaq (formally, Thule). Unfortunately, PCN is not produced in near-real time. To monitor the current condition of magnetospheric convection, it is necessary to collect geomagnetic field data in the near-geomagnetic pole region and to produce PCN-like index from those data. We have developed the system for collecting magnetic field data from Eureka, which is located in the northern near-pole region and transferring the data from Eureka to CRL in near real-time. Our system was installed at Eureka and has been operated since summer of 1999.

Before producing PCN-like index from Eureka, we have compared geomagnetic field variations at Eureka and those at Qaanaaq. From the results of our data analysis, we have confirmed that PCN-like index can be derived from Eureka except for the period of low solar zenith angle (SZA < 70 deg.).

Keywords

Solar wind-magnetosphere-ionosphere coupling, Magnetospheric convection, Geomagnetic observation, PC index, Space weather forecast

1 Introduction

In the Earth's magnetosphere, solar wind-magnetosphere coupling drives plasma convection, creating a 3-D current system connecting the magnetosphere to the ionosphere. Variations in the geomagnetic field are affected by this current system, and by monitoring these variations, it becomes possible to predict the conditions of the magnetosphere. Thus, to realize space weather forecast, it is necessary to monitor the current conditions of the space environment near the Earth as a first step. Specifically, observing geomagnetic field component is important when monitoring the conditions of the electric current flowing in the magnetosphere and the ionosphere. Variation in the horizontal geomagnetic field component near the magnetic pole regions, for example, represents an important factor in determining the PC index, which is an indicator of the state of magnetospheric convection. Quasi-real-time calculations of the PC index will prove extremely useful in understanding the current state of solar wind-magnetosphere coupling. However, quasi-real-time calculations and publication of the PC index of the northern magnetic pole have yet to be realized.

The geomagnetic observatory nearest to the northern magnetic pole is in Eureka, Canada. We expect that monitoring of the magnetospheric convection will be realized through quasi-real-time acquisition of geomagnetic field data collected at Eureka and the calculation of an index roughly equivalent to the PC index. Furthermore, CRL currently receives real-time data from the ACE satellite, which conducts observations of the solar wind at the L1 point[1]. By comparing the results of these two observations, it should be possible to perform sequential analysis of cause (solar wind) and results (magnetospheric convection), which will contribute to the study of solar wind-magnetosphere coupling and to the improvement of daily space weather forecast.

This paper will provide an outline of the quasi-real-time data collection and transfer system installed at Eureka, and will also present the results of analysis performed on the correlation of the geomagnetic field data at Qaanaaq and at Eureka in the calculation of the approximate PC index from the data collected.

2 PC Index

Geomagnetic variations in the polar cap regions reflect the convective motions within the magnetosphere. If it is assumed that the ionospheric conductivity is uniform, the 3-D current system-composed of magnetospheric currents, field-aligned currents, and the ionospheric Pedersen current would have no apparent effects on the conditions on the ground.

Therefore, one may conclude that geomagnetic variations are caused solely by the ionospheric Hall currents. However, in the actual ionosphere, conductivity is not uniform, and the 3-D current system and the Hall current system are coupled, making it difficult to distinguish the effects of the two. In summertime, ionospheric conductivity is high and relatively uniform. Therefore, the observed conditions on the ground can roughly be considered to be effects of the Hall current system. In contrast, in wintertime, the conductivity in the polar cap regions decreases and the effects of the Hall current system are suppressed. Therefore, the geomagnetic variations in the polar cap regions in the winter can be considered to reflect the effects of the 3-D current system.

Previous studies have revealed that there are two major types of polar geomagnetic variations: the DP-1 electric current system, which develops in association with the development of the phenomenon known as a substorm, and the DP-2 current system, which is associated with the development of magnetospheric convection. Variations in the horizontal geomagnetic field component in the polar cap regions caused by the DP-2 current system are known to display a good positive correlation with the southward component of the interplanetary magnetic field (IMF)[2]. According to statistical analysis by Troshichev et al., the variations in the horizontal geomagnetic field component in the polar cap regions feature the highest correlation with the solar wind parameter referred to as the merging electric field ($E_m = VB_T\sin^2(\theta/2)$)[4] proposed by Kan and Lee[3]. The PC index is defined based on this correlation and is used as an indicator for magnetospheric convection[5]. However, it should be noted that since the correlation between the solar wind parameters and geomagnetic variations is dependent on changes in ionospheric conductivity, the PC index is normalized for statistically determined local-time (LT) and seasonal dependencies.

Correlations have been reported between the PC index and various physical quantities of the magnetosphere. Troshichev found a linear correlation between the PC index and the polar-cap potential[6]. The PC index is also known to display a positive correlation with Joule heating in the polar ionosphere[7]. Furthermore, the results of statistical analysis of solar wind parameters and the PC index have shown that, when the magnetosphere is affected by strong solar wind-magnetosphere-ionosphere coupling, the intensity of magnetospheric convection levels off[8][9].

3 Eureka

Eureka (ERK) is a meteorological observatory on Ellsmere Island, Canada (80.0°N lat., 274.1°E long.). As shown in Fig.1, Eureka's location (88.5°N CGM (Corrected Geomagnetic (2000)) lat., 328.2°E CGM long.) is nearer to the magnetic pole than that of Qaanaaq (THL).

As part of efforts to construct a geomagnetic observation network in the polar regions by the University of Tokyo's group under the Solar-Terrestrial Energy Project (STEP), a magnetometer was installed at Eureka in 1991, and since then, continuous observation of the geomagnetic variations has been performed at the site. Eureka is set in an isolated location with no available commercial air routes. It is also set outside of all wired networks and the conditions for satellite communication are severe, due to the extremely low elevation angle relative to communication geostationary satellites near the horizon. However, the Meteorological Service of Canada maintains a satellite connection with Eureka using a large parabolic antenna, and Internet access is secured. Therefore, it is possible to construct a system to collect on-site magnetometer data and transfer it to CRL through the Internet, permitting the use of quasi-real-time geomagnetic field data at Eureka for space weather forecast.

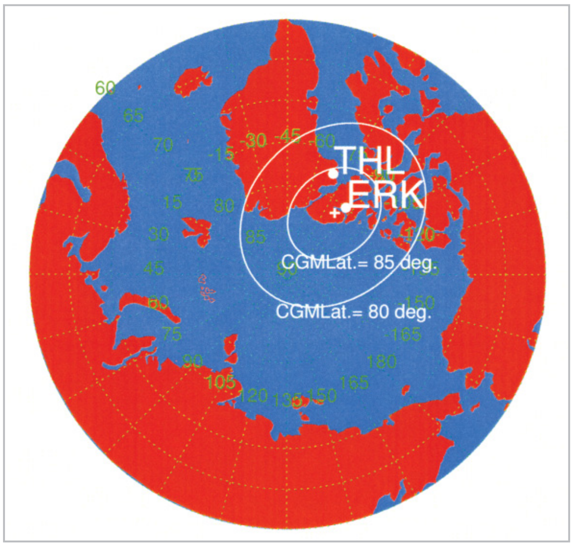


Fig.1 Locations of Eureka (ERK) and Qaanaaq (THL)

When the PC index is used as an indicator for magnetospheric convection, it should be noted that in the summer, when the effect of the ionospheric Hall current dominates as a result of increased ionospheric conductivity, the PC index may take a negative value during northward IMF due to the effects of reversed convection generated in the polar cap region[5].

Therefore, when using the PC index to monitor magnetospheric convection, geomagnetic variations near both the northern and southern magnetic pole regions should be monitored simultaneously to enable continuous data acquisition in the winter hemisphere.

Currently, the PC index is calculated using data at Qaanaaq (formerly Thule), Denmark for the northern magnetic pole region and at Vostok, Russia for the southern magnetic pole region, based on the recommendations of the International Association of Geomagnetism and Aeronomy (IAGA), Division V. To reflect the differences in the calculation algorithm between the two sites, the PC index obtained at Qaanaaq is referred to as PCN, while that at Vostok is referred to as PCS. Quasi-real-time collection of geomagnetic field data is conducted at Vostok via the Geostationary Meteorological Satellite (GMS), with the cooperation of Russia's Arctic and Antarctic Research Institute (AARI), the University of Michigan, Kyoto University, and CRL, and the PCS index is calculated and made available to the public in quasi-real-time at AARI (http://www.aari.nw.ru/clgmi/geophys/pc_main.htm). The Qaanaaq data, on the other hand, is publicized one day after data acquisition, preventing quasi-real-time utilization of the PCN index. Therefore, CRL plans to conduct quasi-real-time calculation of an approximate PCN index using the geomagnetic observation data collected and transferred in quasi-real-time from Eureka, which, like Qaanaaq, conducts geomagnetic observations in the northern magnetic pole region; this Eureka data will be used for current assessment of the state of magnetospheric convection.

4 Outline of the System

Fig.2 shows a schematic view of the developed system. This system consists of a data collection PC, which digitizes the data output from the magnetometer, and a data transfer PC, which performs quasi-real-time transfer of the collected data to the geomagnetic data server within CRL.

The data collection PC converts the analog output of the three orthogonal components of the fluxgate magnetometer into digital data using a 16-bit A/D board. The output voltage of the magnetometer is ±10 V, which is equivalent to a magnetic flux density of ±2,000 nT. Thus, the quantization unit for the 16-bit A/D conversion is 0.305176 mV (6.10352×10^{-2} nT). A one-second value is calculated by averaging 10 samples of data at a sampling rate of 10 Hz. Clock adjustment and synchronization is performed using time code signals from the GPS time and frequency processor module (DATUM BC627AT). Data is filed for each minute and is transferred to the data-transfer PC by socket communication, as well as being stored on hard disk (HDD) and Jaz drive. Files stored on hard disk are automatically deleted after one year due to restrictions in disk volume. Windows 95 and LabVIEW are used for system control.

Files transferred from the data collection PC by socket communication are converted into one-second value files for each hour and one-minute value files for every 12 minutes. The one-minute values are created by averaging data over 60 seconds. The OS for the data transfer PC is Linux, and the converted files are transferred to the geomagnetic data server at CRL by the Cron process every 12 minutes for one-minute values and every hour for one-second values. Initially, files were transferred via ftp to a relay server set outside CRL, and a CRL server periodically accessed the relay server to retrieve the files. However, at present, the SSH port forwarding function is used for increased security and simplification in transfer; this has allowed direct transfer of data from the data transfer PC to a geomagnetic data server connected to the CRL LAN, via a CRL proxy server. Clock synchronization of

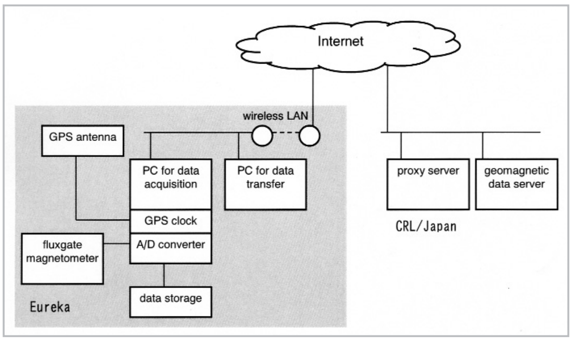


Fig.2 Schematic view of the system

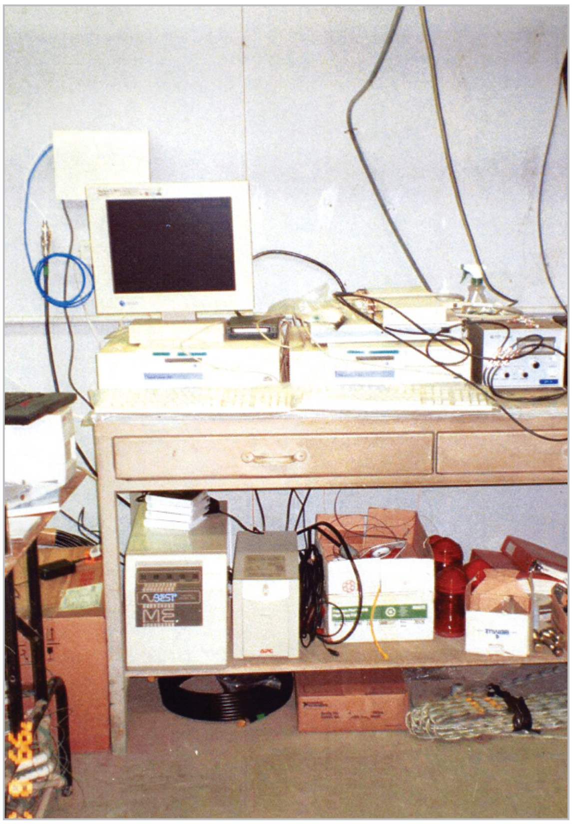
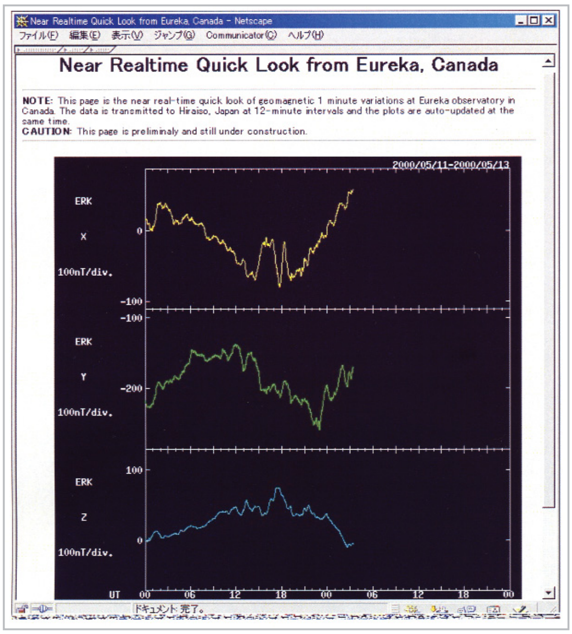


Fig.3 Conditions of installation at the site



Near Realtime Quick Look from Eureka, Canada

NOTE: This page is the near real-time quick look of geomagnetic 1 minute variations at Eureka observatory in Canada. The data is transmitted to Hiraiso, Japan at 12-minute intervals and the plots are auto-updated at the same time.
CAUTION: This page is preliminaly and still under construction.

Fig.4 Example of a Web page displayed for monitoring Eureka data on quick look monitor the data transfer PC is performed using NTP. Furthermore, since the building in which the magnetometer is installed is located approximately 1.5 km from the building featuring the Internet access environment, an independent wireless LAN network (Lucent Technologies) was constructed between the two buildings.

The geomagnetic data server not only stores data from Eureka, but it also stores geomagnetic data from INTERMAGNET and from an independent CRL observation network. The server then converts one-minute data from Eureka into what is referred to as the 210° data format[10]. Furthermore, the data is transferred from the geomagnetic data server to a Web server for database service, and data and QL plots are made available to the public in the form of a geomagnetic online database.

This quasi-real-time data collection and transfer system for Eureka observatory was developed and tested in Japan from 1998-1999, and was transported to Eureka in the summer of 1999 for implementation (Fig.3), with operations beginning in January 2000. There have been some cases of missing data due to on-site troubles (such as power failures and network interruptions), but overall, the system has operated successfully. The QL plots are still in the pilot phase, but preliminary plots are available at the website http://crlgin.crl.go.jp/sedoss/eureka/quick_look. An example of a QL plot is given in Fig.4. In the future, CRL plans to publicize data within a quasi-real-time on-line geomagnetic database system[11].

5 Comparison of the Geomagnetic Variations at Eureka and Qaanaaq

Since the Eureka observatory is located near the northern magnetic pole, it should be possible to use the geomagnetic variations data collected to determine an indicator for magnetospheric convection, as is done at Qaanaaq. In calculating such an indicator, the uniformity of the geomagnetic variations in the polar cap regions must be guaranteed. Based on data collected by a geomagnetic observation network aligned along a single meridian in Greenland, Papitashvili and Rasumussen have concluded that it is possible to produce an approximate PC index following a method similar to that of Qaanaaq within a radius of 15° from the magnetic poles[12]. However, the area examined in their study was located at lower latitudes relative to Qaanaaq, and so their results do not prove conclusively whether or not the method used at Qaanaaq is applicable to Eureka, which is located at a higher latitude than Qaanaaq. Therefore, geomagnetic variations at Qaanaaq and Eureka were compared to determine whether or not variations were uniform at latitudes above Qaanaaq.

The correlation between variations in the horizontal geomagnetic field components at Eureka and Qaanaaq is low in the summer and high in the winter, and preliminary analysis by Nagatsuma et al.[13] has shown that the variations display solar zenith angle dependencies.

Here, we have analyzed the seasonal and UT dependencies of geomagnetic variations. The five-minute averages of the horizontal geomagnetic field components at Eureka and Qaanaaq were used for comparison, with variations on geomagnetically quiet days removed from the calculations. Fig.5 shows a contour map of the coefficients of correlation between

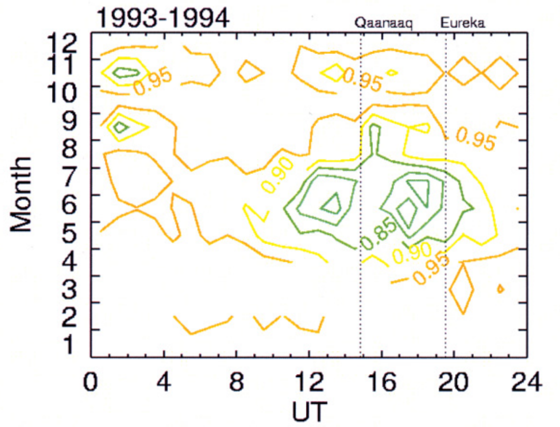


Fig.5 Contour map of the coefficients of correlation of variations in the horizontal geomagnetic field component at Qaanaaq and Eureka

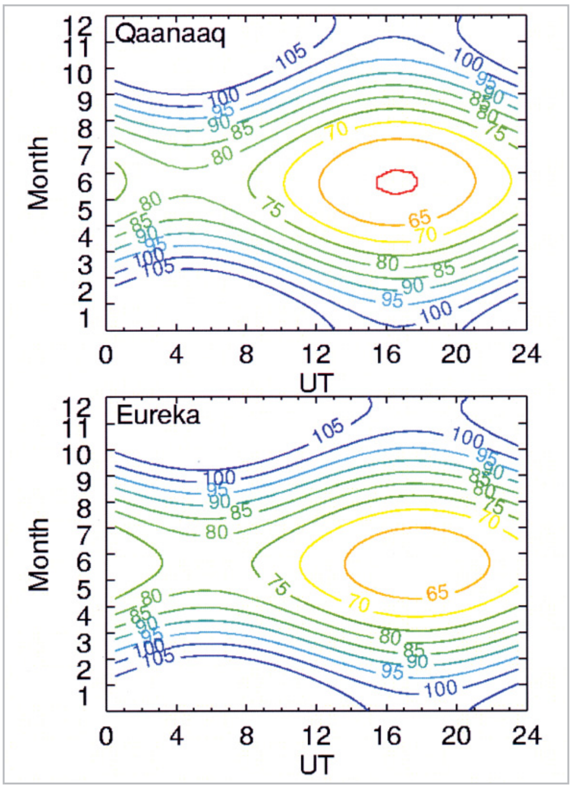


Fig.6 Contour map of the solar zenith angles at Qaanaaq (top) and Eureka (bottom)

the variations in the horizontal geomagnetic field components at Eureka and Qaanaaq in 1993 and 1994. Note that the coefficient of correlation could not be calculated for March, which featured long periods of missing data. The dashed lines show noon in magnetic local time (MLT) for Eureka and Qaanaaq. The coefficients of correlation remained high throughout the day in wintertime, while in the summertime, the coefficient of correlation tended to decrease near noon and increase near midnight in MLT.

Fig.6 shows a contour map for the solar zenith angles at Eureka and Qaanaaq during the period shown in Fig.5. By comparing Fig.5 to Fig.6, it can be seen that when the solar zenith angle is larger than 70˚, the coefficients of correlation are higher than 0.9. In contrast, when the angle is smaller than 70˚, the coefficients of correlation are low. This indicates that the development of the localized Hall current induced by increased ionospheric conductivity due to solar radiation is a factor reducing correlation. Based on these results, it can be concluded that the geomagnetic variations are generally uniform in the polar cap region, except in summertime, when the solar zenith angle is larger than 70˚, and thus it is possible to produce a proxy for the PCN index by substituting the data at Eureka for that of Qaanaaq.

6 Conclusions

A system has been developed, installed, and is currently operating to perform quasi-real-time collection of geomagnetic observation data at Eureka, a station near the northern magnetic pole; the system also provides for quasi-real-time transfer of the collected data to CRL.

Periods of missing data have occurred due to problems encountered on-site, but otherwise, we have succeeded in ensuring quasi-real-time acquisition of data. Results of comparison of the geomagnetic field data at Eureka and Qaanaaq have shown a good correlation between the two during the summertime period when the solar zenith angle is smaller than 70˚, indicating that it is possible to create an approximate PCN index from geomagnetic field data collected at Eureka. Plans for the future include the development of an algorithm to determine the approximate PCN index immediately after the data is acquired, thus contributing to the analysis of the current state of solar wind-magnetosphere coupling.

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Appendix: Format of the Eureka Geomagnetic Field Data

1 Format for the Data Collection PC

One-second values are filed for each minute. This file is stored on the data collection PC and is also transferred to the data-transfer PC.

1.1 File Name Conventions

File name: /raw_data/yyyy/mmdd/yyyymmddhhmm.erk

(yyyy: dominical year; mmdd: month-day;

hh: hour; mm: minute; erk: observatory code for Eureka (fixed))

1.2 Data Format

erk1secYYYYMMDDHHMMSS (header: 21 bytes) + (X (2 bytes)+Y (2 bytes)+Z (2 bytes)) × 60 = 381 bytes

(YYYYMMDD: year-month-day; HHMM SS: hour-minute-second of first data)(Missing value is FF)

2 Format for Data-Transfer PC

One-second values are filed for each hour. One-minute values are filed for every 12 minutes.

2.1 File Name Conventions

One-second value file name: /trans_data/yyyy/mmdd/Syyyymmddhh.erk

(S: label for one-second value (fixed); yyyy: dominical year; mmdd: month-day; hh: hour; erk: observatory code for Eureka (fixed))

One-minute value file name: /trans_data/yyyy/mmdd/Myyyymmddhhn.erk

(M: label for one-minute value (fixed); yyyy: dominical year; mmdd: month-day; hh: hour; n: counter for 12-minute periods in one hour (0-4); erk: observatory code for Eureka (fixed))

2.2 Data Format

One-second values: erk1secYYYYMMDDHHMMSS (header: 21 bytes) + (X (2 bytes)+Y (2 bytes)+Z (2 bytes)) × 3600 = 21621 bytes

(YYYYMMDD: year-month-day; HHMM SS: hour-minute-second of first data) (Missing value data is FF in hexadecimal.)

One-minute values: erk1minYYYYMMDDHHMM (header: 19 bytes) + (X (2 bytes)+Y (2 bytes)+Z (2 bytes)) × 12 = 91 bytes

(YYYYMMDD: year-month-day; HHMM SS: hour-minute-second of first data) (Missing data is FF in hexadecimal.)

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