Analysis of the geomagnetic variations and GPS scintillations over the Canadian auroral zone.

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Abstract

A detailed analysis is performed between magnetic field data provided by geomagnetic observatories and ionosphere scintillation indices. The hourly ranges (HR) of the geomagnetic field from Canadian geomagnetic observatories in auroral zones: Churchill (58.759° N and 265.912° E), Sanikiluaq (56.5° N and 280.8° E), and Yellowknife (62.480° N and 245.518° E) are compared with the ionosphere scintillations from GPS receivers. For GPS stations co-located with the observatories, variation statistics are computed for mapped-to-zenith absolute mean of delta phase rate over 30 sec (mDPR). To compare with the hourly range of magnetic data, the maximum of mDPR in each hour (mDPRm) was used in evaluation. The analysis of the data includes a regression model of scintillation indices versus the three geomagnetic components. The correlation between scintillation and geomagnetic indices is about 0.7-0.8 between these two hourly indices. The essential results are that the correlation between scintillation and geomagnetic indices is greatest during night time hours; the regression model is strongest with the Z-component of HR; and to a first approximation, mDPRm index is proportional to the square root of HR. These results may be useful in developing a forecast of GPS scintillation in the auroral zone based on magnetic activity.

Introduction

Ionospheric scintillations can have a dramatic effect on GPS-GNSS performance (e.g. Pi et al., 1997; Beach and Kintner, 1999; Jakowski et al., 2012). The rate of change of the phase of GPS signals can be used to characterize the ionosophere conditions and ionospheric irregularities (Ghoddousi-Fard et al., 2013, Prikryl et al., 2013). Space weather activity can cause disturbances in the ionosphere in auroral region as well as geomagnetic activity. A study of correlation between the phase scintillation index and geomagnetic activity for some Canadian geomagnetic observatories (Ghoddousi-Fard et al., 2014) indicated that the ionosphere conditions could be related geomagnetic activity. As a follow-on paper, a detailed analysis between the ionosphere scintillation indices and magnetic indices is provided.

Ionosphere scintillations and magnetic activity indices

The magnetic field activity at the Canadian geomagnetic observatories can be characterized by the hourly ranges of the magnetic field (Hruska and Coles, 1987; Trichtchenko et al., 2005). The hourly range is the difference between the maximum and the minimum value of components of the geomagnetic field (HRX, HRY, HRZ) for each hour. The magnetic activity indices in the

Canadian auroral region are computed from data of the Canadian Magnetic Observatory System (CANMOS).

GPS phase rate index is a representative measure of ionosphere irregularities. 1-Hz GPS data are used to compute the phase rate variation statistics (Ghoddousi-Fard et al., 2013) by means of mapped-to-zenith absolute mean (mDPR) and standard deviation (sDPR) of delta phase rate over 30 sec as defined below:

$$mDPR = \frac{|\langle f(I_g, \varepsilon_g)\rangle|}{m(e)}, \quad 1)$$

$$sDPR = \frac{\sqrt{\langle f(I_g, \varepsilon_g)^2\rangle - \langle f(I_g, \varepsilon_g)\rangle^2}}{m(e)}, \quad 2)$$

where $f(I_g, \varepsilon_g)$ is the rate of change for the geometry-free GPS dual frequency phase, which contains contributions from GPS phase ionospheric effects variations (I_g) and the phase multipath and noise (ε_g); and $m(e)$ is an elevation angle (e) dependent mapping function.

This study contains one year of scintillation and geomagnetic data from 2013 for three Canadian observatories at Yellowknife, Churchill, and Sanikiluaq. Scintillation index was calculated based on data from GPS receivers co-located with the geomagnetic observatories. The codes and geographical coordinates for GPS stations and geomagnetic observatories are presented in Table 1.

In order to study how GPS indices vary with hourly ranges of magnetic field, hourly mean of mDPR over all satellites observed during each hour in 2013 were computed. The correlation coefficient is determined between hourly mean mDPR and sDPR indices with respect to magnetic hourly range and is summarized in Table 2. Correlation of magnetic hourly ranges with mean of sDPR is higher than those with mean of mDPR. Overall, the correlation coefficients of about 0.7 - 0.8 between hourly mean GPS phase rate indices and hourly range of magnetic field indicates that magnetic hourly range can be used to represent mean values of mDPR and sDPR in the region. The correlation with HRZ is higher than with the other two components for all stations.

Table 1. GPS stations and geomagnetic observatories used in this study

GPS station	Latitude	Longitude	Magnetic observatory	Latitude	Longitude
yell	62.481	-114.481	Yellowknife YKC	62.480	-114.482
chur	58.759	-94.089	Churchill FCC	58.759	-94.082
kuuj	55.278	-77.745	Sanikiluaq SNK	56.5	-79.2

Table 2. Correlation coefficient between scintillations indices and geomagnetic indices

GPS stations/Geomagnetic observatory	Scintillation indices/geomagnetic indices	HRX	HRY	HRZ
kuuj	sDPR	0.75	0.78	0.81
	mDPR	0.68	0.7	0.74
chur	sDPR	0.736	0.74	0.78
	mDPR	0.69	0.71	0.74
yell	sDPR	0.73	0.77	0.8
	mDPR	0.71	0.76	0.79

For further study of relationship between the hourly ranges of geomagnetic activity and ionosphere scintillations indices, the maximum of mDPR per hour (mDPRm) was determined for the analysis. The hourly maximum value was chosen to highlight the maximum level of scintillations as an important characteristic for the description of ionosphere disturbances. The natural logarithms of mDPRm and geomagnetic hourly ranges are plotted for Churchill on Figure 2.

A linear trend is noted between the two parameters. The slope of ~ 0.54 for each component indicates that the mDPRm is approximately related to the square root of the magnetic HR. The correlation coefficients are ~ 0.7 with Z-component having a slightly higher value. For the Y and Z components of the magnetic data, a large subset of data do not seems to be correlated with the HR index and have a constant level close to log(mDPRm) of -0.2. In general, this data corresponds to periods during the daytime.

To check the hypothesis that the daytime periods are not related to magnetic activity, similar graphs were created for each hour from 16 to 22 UT. The correlation coefficients were less than 0.6 with typical slopes from 0.2-0.4. Clearly during daytime hours the mDPRm is not influenced by HR as strongly as during the nighttime. In figure 3, hours outside of 16 to 22 UT were considered. Clearly the correlation coefficient improves with highest value 0.8 for the Z component. The slope of the best fit line does not change appreciably, since the larger values during the nighttime periods are still retained in the analysis; whereas, a large number of lower values during the daytimes have been removed.

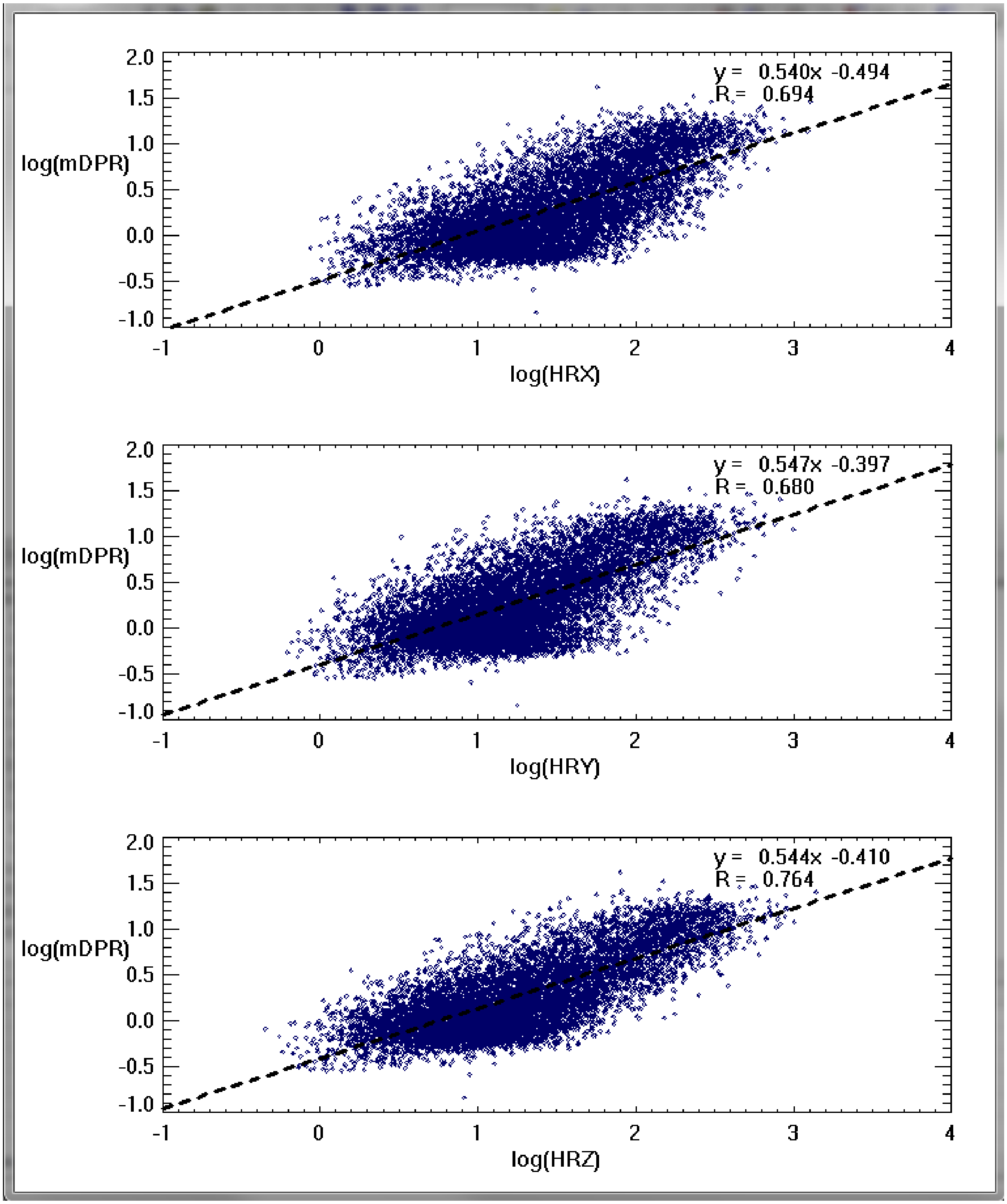

Figure 2. Logarithms of hourly maxima of mDPR and hourly range of magnetic variations at Churchill. The dashed line is the best fit to the data with the fitting parameter shown in the upper right. The correlation coefficient is denoted by R.

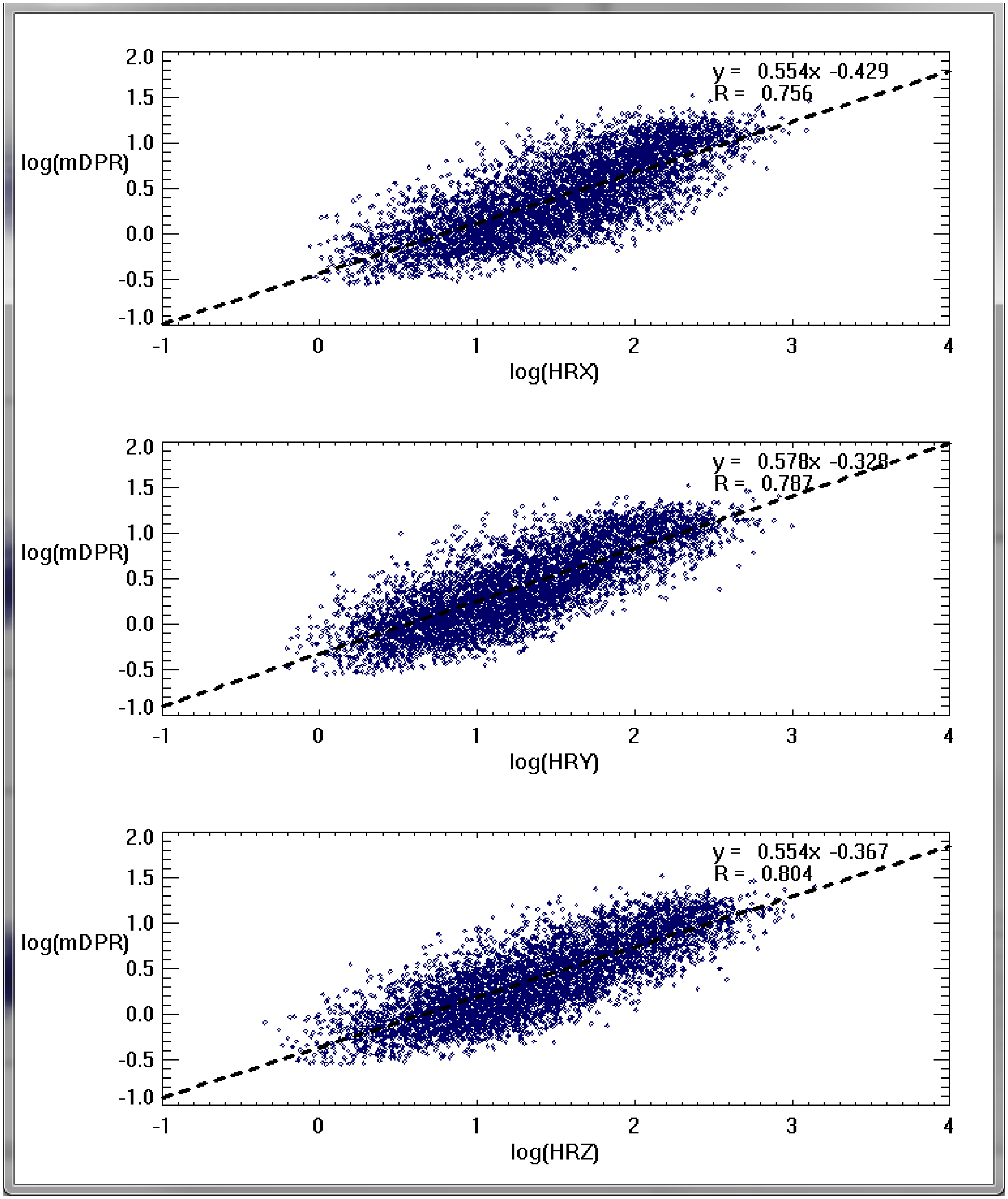

Figure 3. Logarithms of hourly maxima of mDPR and hourly range of magnetic variations at Churchill for periods outside of 16 – 22 UT. The dashed line is the best fit to the data with the fitting parameter shown in the upper right. The correlation coefficient is denoted by R.

Summary and conclusions

Hourly ranges of magnetic field are being used in the Canadian space weather forecast center for geomagnetic forecasts. In this study GPS phase rate indices are used as a representative measure of irregularities over the region at the same hourly intervals. A correlation analysis was done between the mean of mDPR and mean of sDPR with geomagnetic HR. Overall, GPS dual frequency phase rate indices and magnetic indices over the Canadian auroral zone have a correlation coefficient of 0.7-0.8. The highest correlation is found between sDPR and HRZ at three auroral zone observatories. This can be explained by the dynamics of auroral substorms with the Z-component being most sensitive to motion of the auroral electrojet. During the expansive phase of substorms, the most intense ionospheric currents and brightest auroras are caused by particle precipitation. Thus strongest scintillation is expected at such times due to the patchiness of precipitation.

The maximum of mDPR index was analyzed as another scintillation index. Good correlation between logarithmic values of mDPRm and geomagnetic indices demonstrate that to a first approximation, mDPR hourly maximum is proportional to the square root of geomagnetic hourly range. During night time, the correlation between scintillation and geomagnetic indices is larger than the daytime. This shows that hourly indices of geomagnetic field variations can be a representative measure for the maximum GPS scintillation proxy index (mDPRm) over the auroral zone, a region that experience frequent effects of geomagnetic and, as observed in this paper, ionospheric disturbances.

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