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GPS phase scintillation and auroral electrojet currents during geomagnetic storms of March 17, 2013 and 2015

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Abstract

Interplanetary coronal mass ejections (ICMEs) compounded by high-speed plasma streams from coronal holes caused two intense geomagnetic storms on March 17-18, 2013 and 2015 during the current solar cycle. Ionospheric responses to the storms in the northern and southern hemispheres are compared in the context of solar wind coupling to the magnetosphere-ionosphere system. Phase scintillation is observed at high latitudes by arrays of high-rate GNSS Ionospheric Scintillation and TEC Monitors (GISTMs) and geodetic-quality GPS receivers sampling at 1 Hz. The high-rate GPS receivers are distributed in the northern and in the southern high latitudes with sparser coverage. In addition to GPS receivers, the high-latitude ionosphere dynamics is studied using arrays of ground-based instruments including HF radars, ionosondes, riometers, magnetometers, optical imagers as well as particle detectors and ultraviolet scanning imagers onboard the DMSP satellites.

1. Introduction

Electron density irregularities in the ionosphere causing variable group delay and phase advance of the radio wave result in rapid phase fluctuations, also called phase scintillation. At high latitudes, GPS phase scintillation is primarily enhanced in the cusp, tongue of ionization broken into patches drawn into the polar cap from the dayside storm-enhanced plasma density, and in the auroral oval during energetic particle precipitation events.

Interhemispheric comparisons of aurora and auroral currents reveal similarities and asymmetries [1,2,3]. Phase scintillation during geomagnetic storms have also been studied in the southern hemisphere [4,5,6,7], although such studies are limited by sparse data coverage in Antarctica.

In this paper, the occurrence of GPS scintillation during two storms is mapped as a function of geomagnetic latitude and time, either universal or magnetic local time, in both hemispheres. Inter-hemispheric comparison is attempted, subject to data availability. Focusing on the northern hemisphere, the GPS phase scintillation is studied in relation to auroral electrojet currents.

2. Instruments

Phase scintillation is observed at high latitudes by arrays of high-rate GISTMs and geodetic-quality GPS receivers sampling at 1 Hz. The high-rate GPS receivers are distributed in the northern and in the southern high latitudes with sparser coverage. In addition to GPS receivers, the high-latitude ionosphere dynamics is studied using arrays of ground-based instruments including HF radars, ionosondes, riometers, magnetometers, optical imagers as well as particle detectors and ultraviolet scanning imagers onboard the DMSP satellites.

In the Canadian Arctic, the GPS phase and amplitude scintillation is monitored by the Canadian High Arctic Ionospheric Network (CHAIN) consisting of about 25 GISTMs. At the Canadian Geodetic Survey of Natural Resources Canada about 150 globally distributed 1-Hz GPS stations (mostly those of the real-time-IGS network with additional stations over Canadian region) are used in near-real-time to derive L1-L2 inter-frequency phase rate variations by means of mapped-to-zenith standard deviation of delta phase rate (sDPR) over 30 sec [8].

In the European sector, the Norwegian Mapping Authority (NMA) operates 10 GISTMs and a dense nationwide network of about 185 1-Hz geodetic receivers. In the Svalbard region, the Birkeland Centre for Space Science operates four NovAtel GPStation-6 multi-GNSS receivers at Ny-Ålesund, Longyearbyen, Hopen, and Bjørnøya. Additional GISTMs are operated in Norway, Cyprus and in the UK by the Nottingham Geospatial Institute (NGI) of the University of Nottingham. The Technical University of Denmark, National Space Institute (DTU Space) contributed high-rate GPS receivers of the Greenland GPS Network (GNET). GNET consists of 62 GPS stations (11 of these sample at 1 Hz) that are distributed around the Greenland inland ice.

GISTMs have been operated in southern high latitudes, primarily in Antarctica, at Concordia and Mario Zucchelli by Istituto Nazionale di Geofisica e Vulcanologia and at South Pole and McMurdo GPS receiver in a collaborative effort of University of Bath and Siena College. The GISTMs of the South African National Antarctic Expedition in Antarctica are operated by the Space Science Directorate of the South African Space Science Directorate. Also, GISTMs are operated at Macquarie Island by the Australian Bureau of Meteorology and at Zhongshan station by the Chinese Academy of Sciences.

3. GPS phase scintillation in relation to auroral currents

In the northern hemisphere, we focus on the relation between te GPS scintillation and auroral electrojet currents observed by arrays of ground-based magnetometers. Equivalent ionospheric currents (EICs) are obtained from ground magnetometer data using the spherical elementary currents systems technique [9] that has been applied over the North American [10] and European ground magnetometer networks. The results for the March 2015 storm has been previously published [11,12]. Furthermore, a comparison of phase scintillation occurrence during the March 2013 and another storm in November 2011 has been made [13].

For both storms, preliminary results indicate that the GPS phase scintillation is mapped to strong westward electrojet and to the poleward edge of the eastward electrojet, while it is mostly absent or low in the auroral zone when the electrojets are weak. Fig. 1 shows the results for the longitude sector between 260° and 300°E in North America.

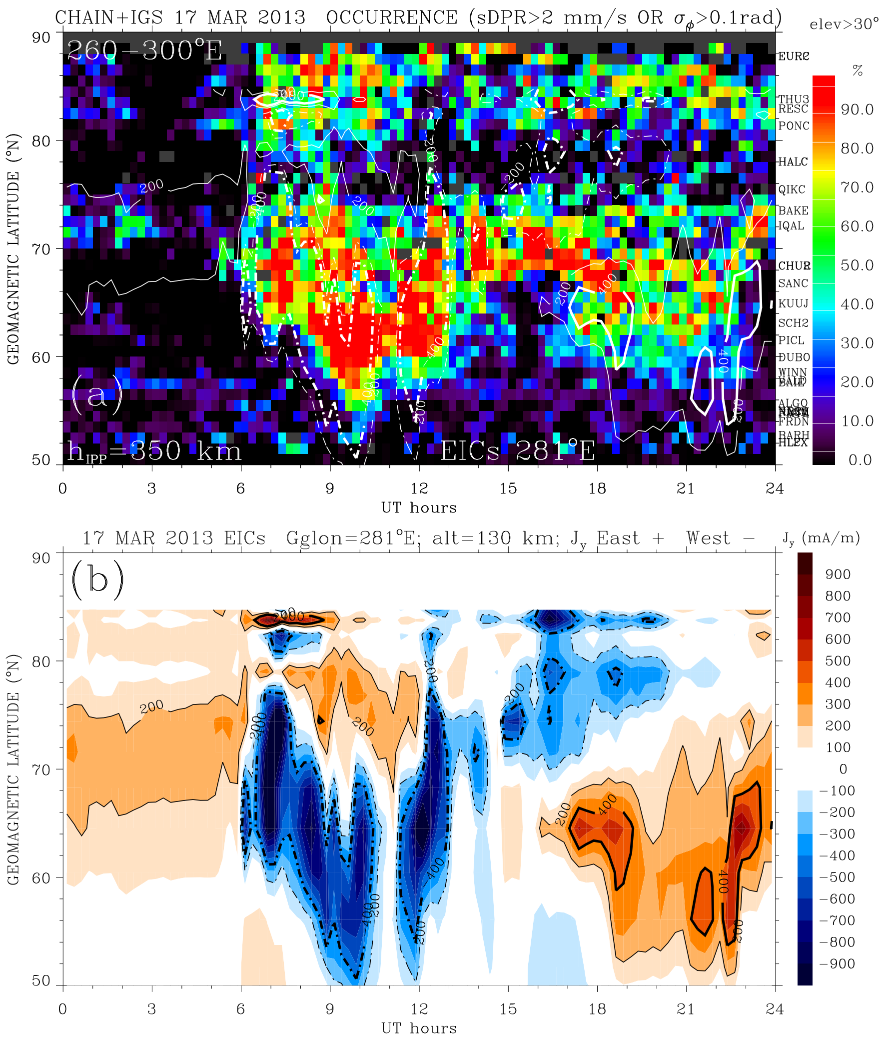

Figure 1. (a) The phase scintillation occurrence of $\sigma_\Phi > 0.1$ rad or sDPR > 2 mm/s as a function of geomagnetic latitude and UT for CHAIN combined with 1-Hz GPS receivers. Contour plots of the westward and eastward equivalent ionospheric currents are shown in white broken and solid lines, respectively. (b) Westward and eastward equivalent ionospheric currents are highlighted in blue and brown shades, respectively. The data displayed are limited to the longitude sector between 260° and 300°E.

4. References

1. Laundal, K. M. and N., Østgaard, "Asymmetric auroral intensities in the Earth's Northern and Southern hemispheres," *Nature* **460**, 491-493, doi:10.1038/nature08154, 2009.

2. Østgaard, N. and K. M., Laundal, "Auroral Asymmetries in the Conjugate Hemispheres and Interhemispheric Currents," *Auroral Phenomenology and Magnetospheric Processes: Earth and Other Planets, Geophysical Monograph Series*, **197**, American Geophysical Union, 2012, 10.1029/2011GM001190.

3. Sato, N., S., A. Kadokura, T. Motoba, K. Hosokawa, G. Björnsson, and T. Saemundsson, "Interhemispheric symmetries and asymmetries of aurora from ground-based conjugate observations," *Auroral dynamics and space weather, Geophysical Monograph Series Vol. 215*, Zhang, Y. and Paxton, L.J. (Editors), American Geophysical Union and John Wiley & Sons, Inc., IBSN 978-1-118-97870-2, 2016.

4. Prikryl, P., et al., "Interhemispheric comparison of GPS phase scintillation at high latitudes during the magnetic-cloud-induced geomagnetic storm of 5–7 April 2010," *Ann. Geophys*., **29**, 2287-2304, doi:10.5194/ angeo-29-2287-2011, 2011.

5. Kinrade, J., C. N. Mitchell, P. Yin, N. mith, M. J. Jarvis, D. J. Maxfield, M. C. Rose, G. S. Bust, and A. T. Weatherwax, "Ionospheric scintillation over Antarctica during the storm of 5–6 April 2010," *J. Geophys. Res.*, **117**, A05304, 2012, doi:10.1029/2011JA017073.

6. Prikryl, P., et al., "GPS phase scintillation at high latitudes during geomagnetic storms of 7–17 March 2012 – Part 2: Inter-hemispheric comparison," *Ann. Geophys*., **33**, 657-670, doi:10.5194/angeo-33-657-2015, 2015.

7. Cherniak, Iu. and I. Zakharenkova, "High-latitude ionospheric irregularities: differences between ground- and space-based GPS measurements during the 2015 St. Patrick's Day storm," *Earth, Planets and Space*, 68:136, DOI 10.1186/s40623-016-0506-1, 2016.

8. Ghoddousi-Fard R., P. Prikryl, and F. Lahaye, "GPS phase difference variation statistics: A comparison between phase scintillation index and proxy indices," *Adv. Space Res*., **52**, 1397-1405, doi: 10.1016/j.asr.2013.06.035, 2013.

9. Amm, O., and A. Viljanen, "Ionospheric disturbance magnetic field continuation from the ground to the ionosphere using spherical elementary currents systems," *Earth Planets Space*, **51**, 431–440, 1999.

10. Weygand, J. M., O. Amm, A. Viljanen, V. Angelopoulos, D. Murr, M. J. Engebretson, H. Gleisner, and I. Mann, "Application and validation of the spherical elementary currents systems technique for deriving ionospheric equivalent currents with the North American and Greenland ground magnetometer arrays," *J. Geophys. Res.*, **116**, 2011, A03305, doi: 10.1029/ 2010JA016177.

11. Jacobsen, K. S., and Y. L. Andalsvik, "Overview of the 2015 St. Patrick's day storm and its consequences for RTK and PPP positioning in Norway," *J. Space Weather Space Clim*., **6**, A9, 2016.

12. Prikryl, P., et al., "GPS phase scintillation at high latitudes during the geomagnetic storm of 17–18 March 2015," *J. Geophys. Res. Space Physics*, **121**, 3, 2016. doi:10.1002/2016JA023171.

13. Prikryl, P., R., Ghoddousi-Fard, J. M., Ruohoniemi, E. G.,Thomas, "GPS phase scintillation at high latitudes during two geomagnetic storms," *Auroral dynamics and space weather, Geophysical Monograph Series Vol. 215*, Zhang, Y. and Paxton, L.J. (Editors), American Geophysical Union and John Wiley & Sons, Inc., IBSN 978-1-118-97870-2, 2016.