Response of the 3rd Nov 2021 storm over Cyprus and Russia

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Abstract

On 1-2 November several Earth-directed CMEs (coronal mass ejections) erupted from the Sun. Subsequently a CME from November 2 overtook the CME from November 1, and the combined event was first detected as a shock wave at 19:57 UTC by the DSCOVR solar wind monitor. Subsequently a strong compression of Earth's magnetosphere due to this shock was detected at 21:29 UTC causing a G1 geomagnetic storm which later developed into a G2 geomagnetic storm and eventually to a G3 (strong storm level). In this study we investigate the ionospheric response over a narrow longitude range over the European sector during 3-4 November 2021.

1 Introduction

As a first step in our investigation we examined the temporal variation of ionospheric characteristics over the three Digisonde stations by exploiting ionospheric observations from the Digital Ionogram DataBase (DIDBase) of the Global Ionospheric Radio Observatory (GIRO) portal (http://giro.uml.edu). We manually scaled ionograms and extracted h'F2, hmF2 and h'F values during the storm period. Vertical TEC variations at GNSS stations collocated to these Digisonde stations were also analyzed for the same interval. TEC data were retrieved from the International GNSS Service (IGS) (http://igs.org/) and the EUREF Permanent Network (http://www.epncb.oma.be/). To compute vertical TEC we processed RINEX files from the International GNSS Service (IGS) (http://igs.org/) with a calibration algorithm [1]. The existence of a strong electric field and currents over the high latitude ionosphere during geomagnetically disturbed conditions has been reported by several authors on several occasions in the past. The prompt penetration of electric fields (PPE) over high to mid-latitudes occurs due to sudden changes in cross-polar cap potential drop developed by the interaction between magnetosphere-solar wind dynamo under IMF Bz southward condition for the northern hemisphere. To analyze the nature of cross-polar cap potential, the Polar Cap (PC) index can be used as a factor. The PC index is a fifteen-minute index for magnetic activity over the polar cap based on data from a single near pole station. The data is available at https://www.ngdc.noaa.gov/stp/SOLAR/pcindex.html.
The PC index is based on an idea by Troshichev et al. [2]. The station Thule, Greenland at 86.5° geomagnetic invariant latitude, fulfils the requirement of being close to the magnetic pole of the northern hemisphere and provides the PC index for the northern hemisphere (PCN). Similarly, Vostok (83.3°) provides the PC index for the southern hemisphere (PCS).

2 Results and Discussion

Figure 1 presents the variation of the PC index for November 3-5, 2021 where PCN and PCS are represented by the blue and red lines. As the present study deals with the ionospheric effects of Russia and Cyprus during the geomagnetically disturbed period so we will focus on the northern hemisphere thus PCN. A prominent peak is noted during 22:00UT of November 3, 2021 and also during most of the November 4, 2021, over the PCN curve followed by some small scale undulations around 16:00 to 22:00UT of November 5, 2021. The storm-induced PCN fluctuation indicates the transport of ionization from the polar to the mid-latitude region.

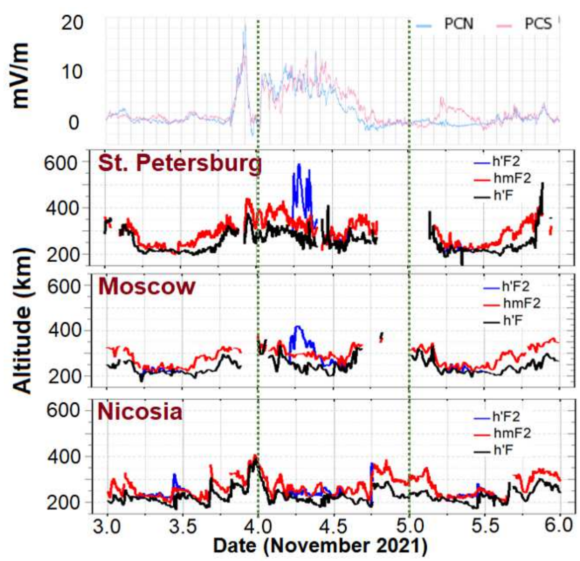

Figure 1. Variations of h'F2, hmF2 and h'F during 3-5 November 2021with respect to variations of the Polar Cap (PC).

We need to note that the black and blue curves overlap during most of the time but divert during the early hours of the 4th of November. This increase appears to be more pronounced at the higher latitude station of St Petersburg which is also indicated clearly by the ionogram examples around the same time interval as shown in Figure 2. We also observe clear fluctuations in h’F2, hmF2 and h’F over all three stations signifying TID activity.

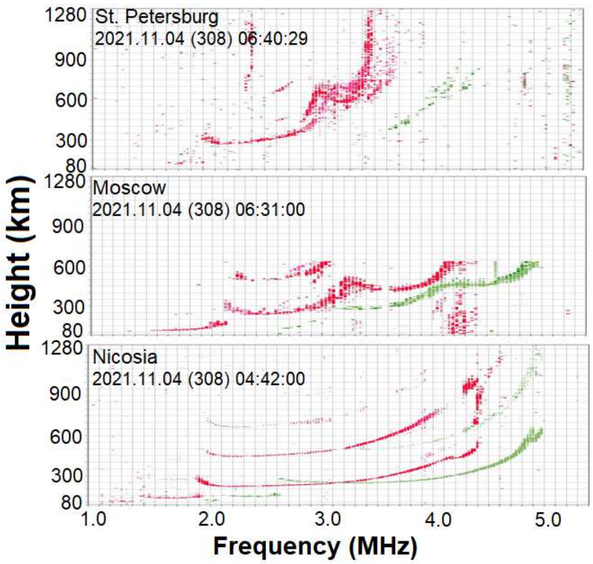

Figure 2. Ionograms over Nicosia, Moscow and St Petersburg indicating an increase in F2 region altitude.

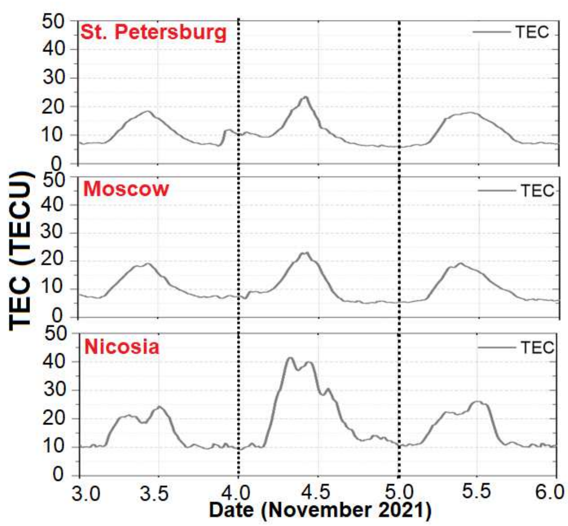

Figure 3. TEC variations during 3-5 November 2021.

Unlike F2 layer altitude increases that are most evident over Moscow and especially over St Petersburg an electron density increase is apparent over Nicosia on the 4th of November based on TEC values. Although quiet time TEC increases have been reported over Nicosia during low solar activity years we attribute this increase as a consequence of the storm [3]. We can also identify clear TEC fluctuations on TEC over Nicosia which suggest the presence of TID activity over Nicosia latitudes.

To identify these TID variations and their corresponding periodicity and strength over Nicosia we have used the daily output of a special implementation of the Height-Time-Intensity (HTI) technique which is operational in the frames of the TechTIDE (http://techtide.space.noa.gr/) project, funded by the European Commission Horizon 2020. This technique operates on ionogram virtual height variations in accordance to an optimal frequency bin within which the F-region trace of the ionograms is processed at each instant during a 24 hour interval [4]. For each ionogram at the appropriate frequency bin a virtual height profile of signal strength is obtained. By estimating the virtual height of the points of maximum intensity within each profile and by superimposing those resulting from each ionogram a wave periodicity and virtual height amplitude may be extracted that classifies the strength of the TID as weak, moderate, strong and very strong as shown in Figure 4. By exploiting both ordinary and extraordinary traces in the ionograms we can extract the TID signatures on a series of ionograms with confidence.

The output of this technique as applied on the 4th of November over Nicosia is shown in Figure 4. It clearly indicates the detection of LSTID (based on the dominant period of 150 min) with strong amplitude variations during 4:00-6:00 UT.

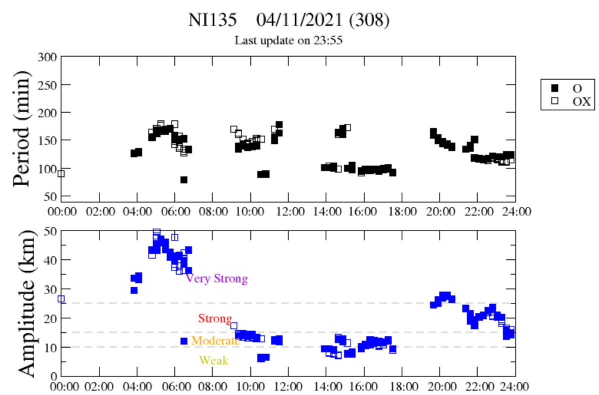

Figure 4. HTI detection of LSTID over Nicosia for 4 November 2021.

Therefore as we can identify in Figures 1-4, during this event we have detected a strong increase in the altitude of the F2 layer over St Petersburg and to lower extent over Moscow and during the same interval a strong electron density increase over Nicosia.

In this study, we have tried to use topside electron density data around the area of interest to examine the topside ionospheric response. Considering the fact that radio occultation (RO) profiles under specific criteria can provide accurate topside electron density information [5]. However no RO profiles were available over the area of interest at the time of the storm development. Therefore we exploited a in-situ Swarm B topside electron density data from the pass over the longitude range around the three stations to investigate the spatial features of electron density in an effort to detect TID signatures at an altitude of 505 km. As shown in Figure 5, the latitudinal electron density variation within 70°N to 50°N at around 4:15 UT on the 4th of November clearly captures a LSTID signature over an adjacent area as the electron density oscillates spatially on the N-S direction. In the same figure, the maximum electron density minimum which is noted around 53°N corresponds to the mid-latitude ionospheric trough latitude.

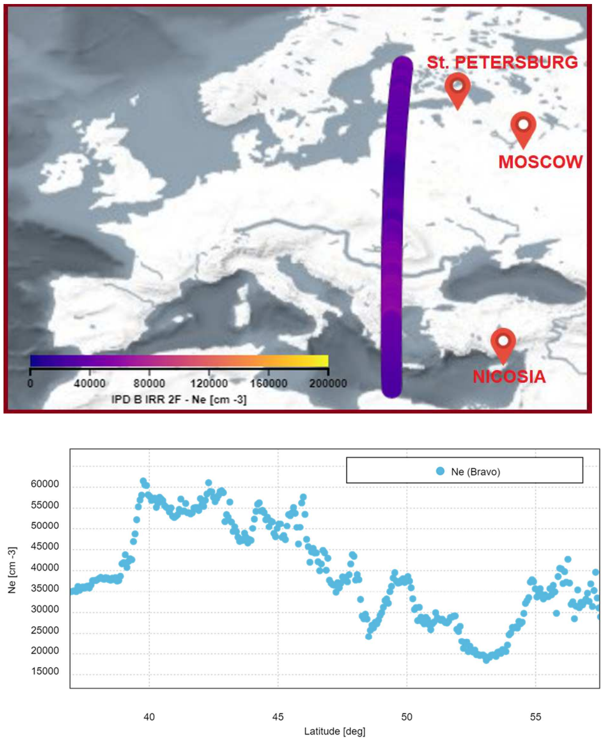

Figure 5. Swarm B projection and corresponding Ne variation vs latitude on the west of St Petersburg, Nicosia and Moscow.

3 Conclusions

In this study we investigate the ionospheric response over a narrow longitude range over the European sector during a storm that took place on 3-4 November 2021, primarily, by exploiting observations over three European locations around the longitude sector of 37 °E. The temporal variations of vertical TEC and F-region altitude ionospheric characteristics over the Digisondes at three locations (Nicosia, Moscow and St Petersburg) are used with the aim to examine phenomenological aspects of this event. We detected very sharp altitude increases during the main phase of the storm in addition to strong periodicities indicating large-scale traveling ionospheric disturbances (LSTIDs). These LSTIDs were also detected on in-situ Langmuir probe data on board European Space Agency (ESA) Swarm B satellite.

4 Acknowledgements

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