Impact of the extraordinary solar activity of October/ November 2003 on the upper boundary of the Earth-ionosphere cavity resonator.

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ABSTRACT:. A series of dramatic episodes of solar activity occurred in October and November of 2003 known as "Halloween storms". The hard solar X-ray flux increased by more than two orders of magnitude already between October 18 and 20 and lasted until November 5 while the 10.7 cm radio flux indicating 2-3-fold variations of EUV radiation maximized only on October 28. The time evolution of the disturbances of these two ionization sources was quite different. At the end of October and the beginning of November 2003 two active regions produced a series of extremely energetic solar eruptions. In connection with the flare on October 28, 2003, a coronal mass ejection was emitted at a high speed directly towards the Earth and caused a dramatic Forbush decrease of the galactic cosmic rays (GCR). The large solar storms also caused very large proton fluxes in the final days of October and early November. The fourth largest proton event in the last 40 years occurred in October 28. All these solar electromagnetic and particle radiations have important roles in the ionization of the D-region which forms the upper boundary of the Earth-ionosphere cavity resonator. The effects of these events have been studied by Schumann resonance (SR) parameters measured at Nagycenk, Hungary and in Mitzpe Ramon, Israel. The SR frequency increased simultaneously with the increase of the hard solar X-ray flux in October 18, 2003 and followed it in case of the 1st and 2nd E_Z modes both at Nagycenk and in Mitzpe Ramon until November 5, 2003. Neither the increased EUV radiation with maximum on October 28, 2003 nor the huge Forbush-decrease as well as the giant proton events between October 28 and November 4, 2003 left any signature on SR frequencies. SR intensities seem to be largely unaffected by these solar events. These observational results verify the conclusion by Sátori et. al. [2005] that the hard solar X-ray has an important role in modifying the Earth-ionosphere cavity in the range of heights from ~ 90km -100 km.

INTRODUCTION

The upper boundary of the Earth-ionosphere cavity is the ionospheric D-region. The upper part of this region (~70km-95 km) is ionized by the solar UV, EUV, Lyman-α (121,6 nm) and Lyman-β (102,6 nm) as well as the soft (1-10 nm) and hard (<1 nm) solar X-rays on the sunlit site of the cavity. The lower part of the D-region (~50km-70km) is formed by the ionization oft he galactic cosmic rays Strong solar activity is often accompanied by energetic solar particle events when high energy protons can deeply

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Penetrate into the atmosphere mainly at high/mid latitudes causing extra ionization in the D-region [Hargreaves 1992]. The solar radio flux at 10.7 cm wavelength measurable on the surface is used to indicate the variations of solar UV and EUV radiation [Elphic et al. 1984]. Hard X-ray and proton fluxes are measured by the GOES satellites [http://www.swpc.noaa.gov/Data/] and GCR is measured with neutron monitors. The flux of all these ionization sources exhibited dramatic changes during the extreme solar activity occurring in October/November 2003 as shown in Fig.1.

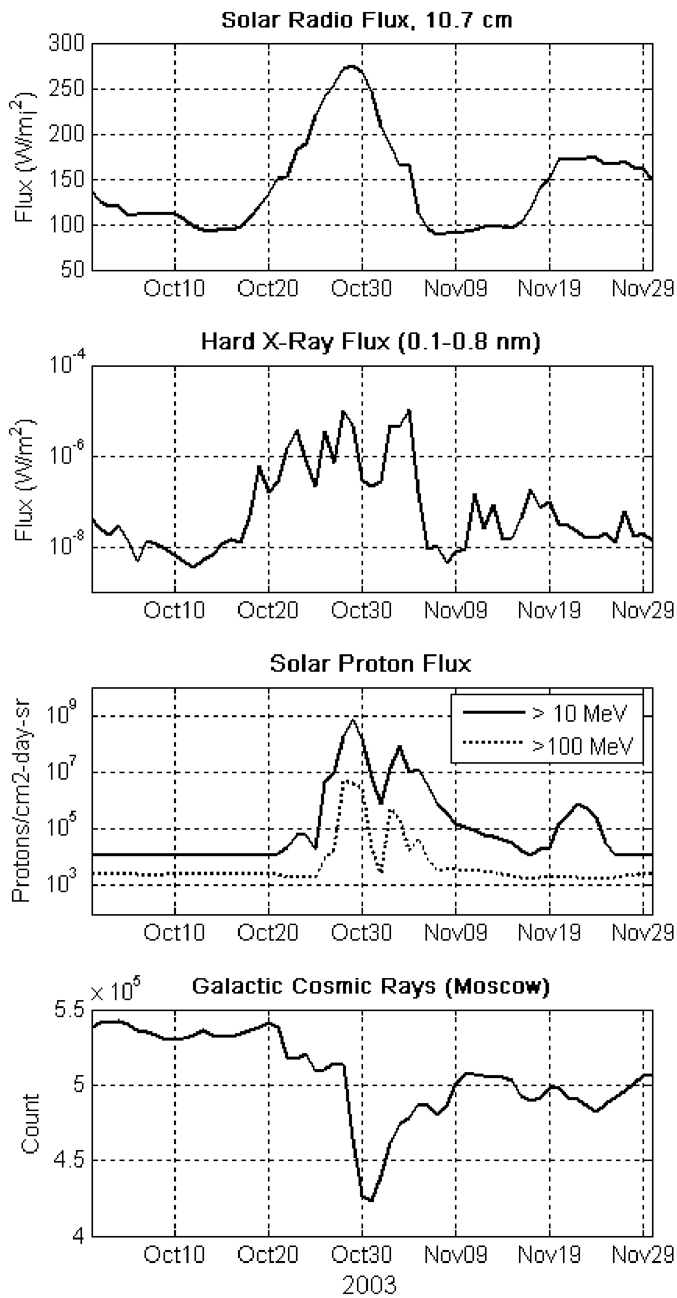

Figure 1. Time evolution of the different solar disturbances (upper three panels) and Forbush-decrease (bottom panel) candidates to induce variations in the ionization of the D-region during the extreme solar activity of October/November 2003.

DATA ANALYSIS

The hard solar X-ray flux increased by more than two orders of magnitude between October 18 and 20 and persisted until November 5 while the 10.7 cm radio flux indicating 2-3fold variations of EUV radiation maximized only in October 28 (Fig.1.). The time evolution of the disturbances of these two ionization sources was quite different. This rather exceptional case also provided observational evidence that the variation of hard solar X-ray flux with an increase of more than two orders of magnitude can be responsible for the SR frequency variations and not the 2-3-fold changes of UV/EUV radiation even if the latter has much higher flux than the X-ray and is the main ionization source of the upper D-region between 70 and 90 km. Sátori et al. [2005] had arrived at this result on the 11-year solar cycle based on theoretical considerations. Figure 2 shows that the flux variations of these two ionization sources during the extraordinary event of October/November 2003 have similar or even larger magnitudes as compared to the flux changes on the 11-year solar cycle.

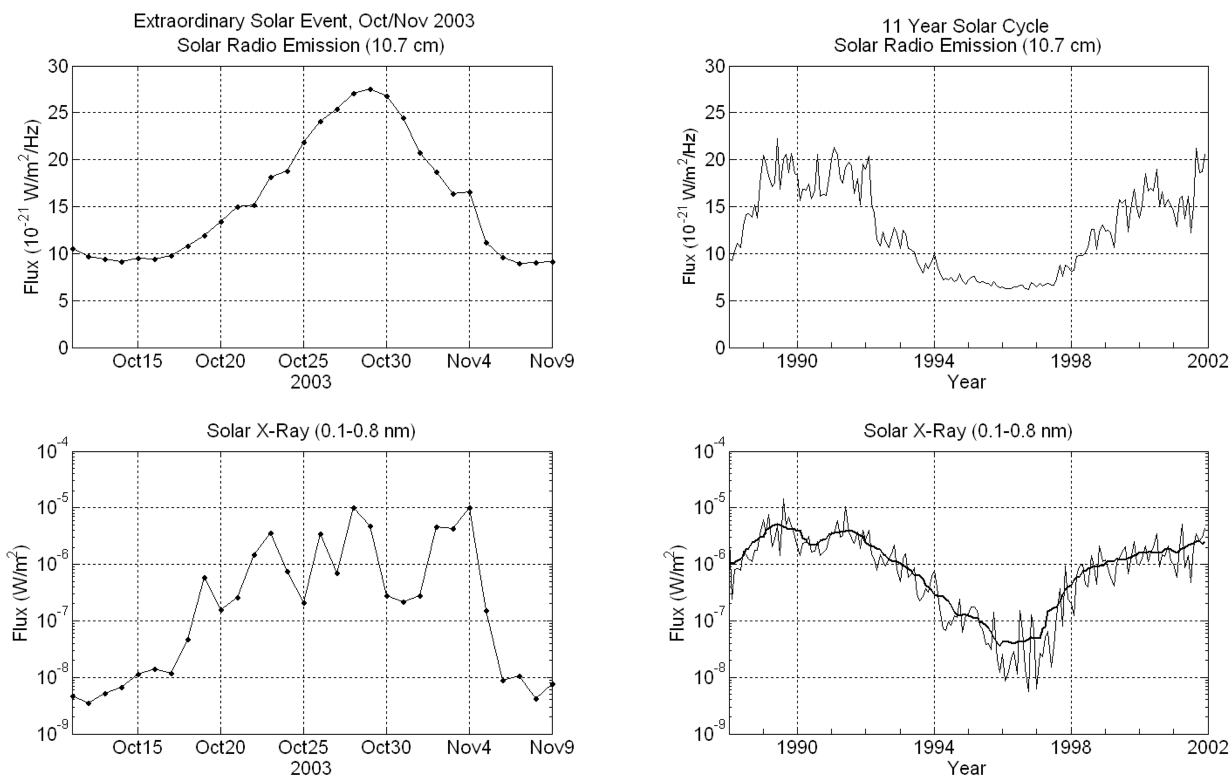

Figure 2. Variations of the 10.7 cm solar radio and hard X-ray flux during the event of October/November, 2003 (left panels) as well as on the time scale of the 11-year solar cycle (right panels).

Figure 3 shows that the SR frequency variations for the 1st and 2nd E_Z modes at Nagycenk (NCK), Hungary and for the first three E_Z modes in Mitzpe Ramon (MR), Israel. The frequency variations in all presented SR modes and at each station run almost parallel with the sudden increase of hard X-ray flux in October 18 as well as its abrupt decrease in November 4. Even the common day-to-day variability can be identified in some cases during the disturbed interval. However there is no indication of the influence of the enhanced UV/EUV radiation as well as that of the particle events: solar proton events and Forbush decrease, shown in Fig.1, on the frequency variations.

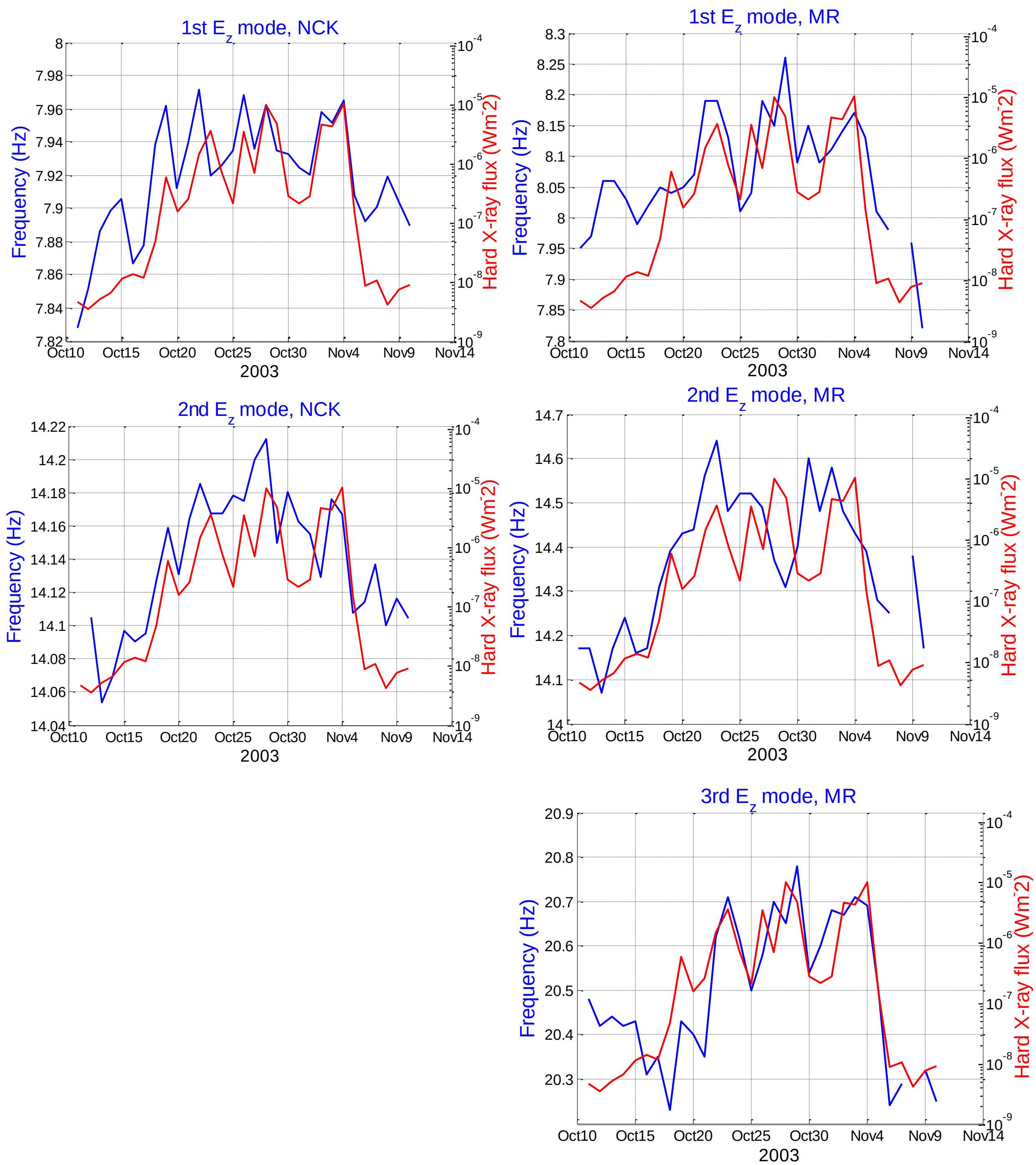

Figure 3. SR modal frequency variations at NCK (left panels) and in MR (right panels) during the days of strongly enhanced hard-X-ray flux (red curves).

Cumulative SR intensity values of the first three E_Z modes were only available at NCK station and show an increasing trend in October/November 2003 (see Fig.4.) but they don't exhibit changes which might be related to the hard X-ray flux anomaly and the other extraordinary solar events shown Fig.1.

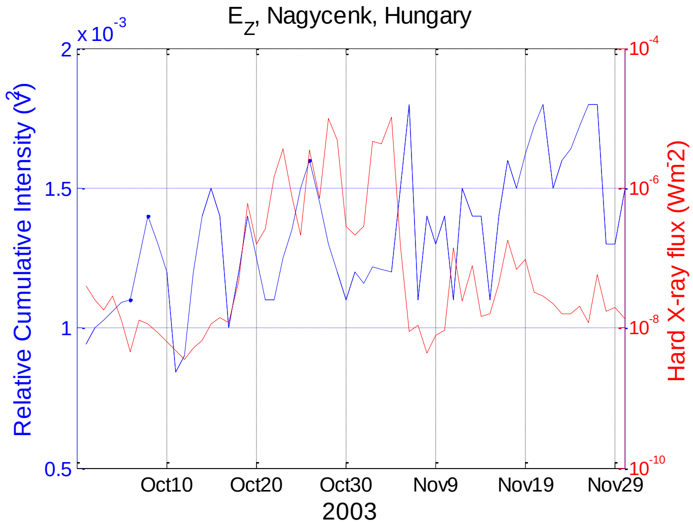

Figure 4. Cumulative SR intensity variation of the first three modes at NCK and changes of the hard X-ray flux in the months of October/November, 2003.

DISCUSSION

The observed frequency variations can be interpreted on the basis of the uniform ELF (Extremely Low Frequency) mode theory and the presence of two characteristic ionospheric layers responsible for ELF propagation (Greifinger and Greifinger 1978; Mushtak and Williams, 2002; Sátori et al. 2005). More than hundredfold changes in the background solar X-ray flux dominate the variations in the conductivity profile within the upper characteristic ELF layer (the 90 to 100 km portion of the E-region) during the extraordinary solar event in October/November 2003, similar to variations documented earlier (Sátori et al., 2005). Füllekrug et al. [2002] attributed the variations of ionospheric D-layer height to the variation of EUV flux on the 11-year solar cycle and 27-day solar rotational periods. The sudden increase/decrease of this conductivity by up to one order of magnitude is responsible for changes in the phase velocity of the wave and, consequently, in the observed SR frequencies by several tenths of Hz both at NCK and MR. A negligible effect on the lower characteristic layer (the 50 to 60 km portion of the D-region) was considered on the 11-year solar cycle [Sátori et al. 2005]. One would also expect a response in modal frequency for the huge proton events initiated in the final days of October, 2003, as with the solar proton event of July 14, 2000 reported by Roldugin et al. [2003]. The opposite ionization effects of the huge proton events (increasing ionization) and the giant Forbush-decrease (decreasing ionization) might be cancelling each other in the lower part of the D-region.

CONCLUSION

The sudden increase of the hard X-ray flux preceded by some days (almost one week) the other extreme solar events in October/November 2003. The prompt response of SR frequencies can be considered as the earliest signature of the series of dramatic effects on the Earth' magnetosphere, ionosphere, atmosphere system. However, the cavity proved immune to the other important solar influences also expected in the D-region in daily time resolution, too. The insensitivity of height change to radiation input had shown by Williams and Sátori (2007). The stable state of the cavity increases the value of SR parameters which can be used for monitoring of the source of SR phenomenon, namely the global lightning activity.

ACKNOWLEDGMENTS

. Vadim Mushtak's skillful merging of theory with observations that contributed so much to our collective understanding of Schumann resonances will be missed for a long time to come.

Veronika Barta's contribution was supported by the TAMOP-4.2.2.C–11/1/KONV-2012-0015 (Earth-system) project sponsored by the EU and European Social Foundation.

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