Available online at www.sciencedirect.com
SCIENCE DIRECT
Physics and Chemistry of the Earth 31 (2006) 416–421
PHYSICS and CHEMISTRY of the EARTH
www.elsevier.com/locate/pce

Day–night, seismic, and solar flare effect on the propagation of 24 kHz sub-ionospheric VLF transmitter signals

Manoj Kumar [a], Vikram Singh [a], Birbal Singh [b,*], P. Steinbach [b], J. Lichtenberger [b], D. Hamar [b]

[a] Department of Physics, R.B.S. College, Bichpuri, Agra, India
[b] Space Research Group, Department of Geophysics, Eotvos University, Pf32H-1518, Budapest, Hungary

Accepted 6 February 2006

Abstract

The preliminary results of a collaborative study on the amplitude variation of 24 kHz sub-ionospheric NAA VLF transmitter signals transmitted from Cutler, Maine (Lat. 44.6°N, Long. 67.2°W) and monitored simultaneously at Budapest (Lat. 47.5°N, Long. 19.17°E), Hungary and Agra (Lat. 27.2°N, Long. 78°E), India are presented. The time segments of the propagation paths are so chosen that they lie in the post-midnight hours over Budapest and sunrise hours over Agra. The results show that the amplitude at Budapest decreases after midnight hours by about 3 dB whereas the same at Agra increases by 5 dB during sunrise normally. The anomalous enhancements and reductions in the amplitude variation during the three month period of July–September 2002 along Cutler–Agra great circle path (GCP) are examined in the light of seismic, solar flares, and magnetic storm effects. It is found that the occasional amplitude reductions are caused by earthquakes ($M > 5$) which occurred along the GCP, and the enhancements are caused by solar flares. The magnetic storms do not seem to influence the data except in the case when associated with large solar flares.

Keywords: VLF transmitter signal; Amplitude; Earthquake; Solar flare

1. Introduction

The lower ionosphere undergoes significant localized structural changes as a result of some naturally occurring geophysical phenomena such as precipitation of energetic particles due to wave particle interaction in the upper atmosphere, earthquakes, and solar flares. The lightning-induced particle precipitation, popularly known as Trimpi effect, was detected as early as in 1973 (Helliwell et al., 1973) as short period localized enhancement of ionization in the D region of the ionosphere. The enhancement in ionization has also been found during the periods of earthquakes (Hayakawa and Sato, 1994) and solar flares (Deshpande and Mitra, 1972). An effective technique to study the ionospheric modification caused by these events is to monitor the phase and amplitude of fixed frequency VLF transmitter signals which are propagated to long distances through earth–ionosphere waveguide. Studies have shown that the ionospheric reflection height is reduced by 0.1–1 km during Trimpi effect (Inan et al., 1985), 0.7–2 km during the period of large earthquakes (Hayakawa et al., 1996; Molchanov and Hayakawa, 1998) and 4–11 km during large solar flares (Deshpande and Mitra, 1972; Rodger et al., 1999). This technique has also been found to be very useful in studying the variations in lower ionosphere during changes in solar zenith angle (Thomson, 1993) and red sprites (Hardman et al., 1998). Recently, Clilverd et al. (1999) and Thomson and Clilverd (2000) have studied the sunrise effect and solar cycle changes in daytime VLF attenuation, respectively.

* Corresponding author. Present address: Department of Electronics and Communication Engineering, Faculty of Engineering and Technology, R.B.S. College, Bichpuri, Agra 283105. Tel.: +91 941237079; fax: +91 562 215 1288.
E-mail address: birbal@sancharnet.in (B. Singh).

1474-7065/$ - see front matter © 2006 Published by Elsevier Ltd.
doi:10.1016/j.pce.2006.02.044

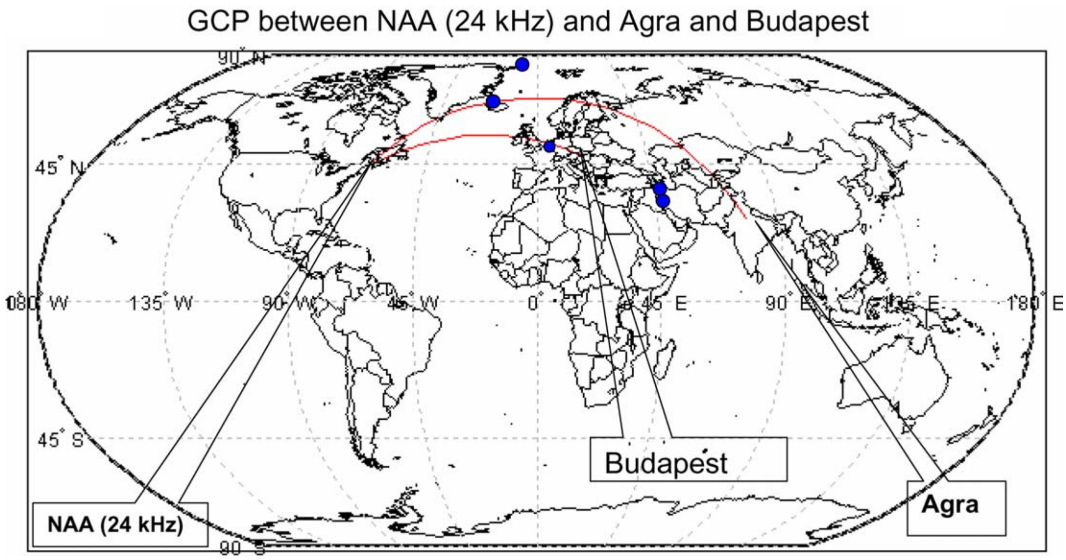

Fig. 1. Great circle path (GCP) between NAA transmitter (Cutler, Maine) and Budapest and Agra. Solid circles indicate the locations of earthquakes which influenced the amplitude of the signal.

The phase and amplitude perturbation of VLF transmitter signals as a result of earthquake-induced structural changes in the lower ionosphere have been studied in rather great detail by a number of research workers (Gokhberg et al., 1989; Gufeld et al., 1994; Hayakawa and Sato, 1994) even though there were negative reports of such perturbations also (Michael, 1996). Hayakawa and Sato (1994) have observed the ionospheric perturbations associated with a number of earthquakes. They have found that the daily mean amplitude of Omega VLF transmitter signal crossed 2δ limit (δ is the standard deviation in amplitude) before the occurrence of these earthquakes. Morgounov et al. (1994) have found anomalous variation of VLF signals associated with large magnitude earthquakes. Recently, a new concept of "Termination times" has been proposed by Hayakawa et al. (1996) to study the seismic effect on lower ionosphere. The termination times are defined as the times of sunrise and sunset when the phase (or amplitude) of received signal exhibits a characteristic minimum. Hayakawa et al. (1996) applied this approach to Hyogo-ken Nanbu earthquake and found abnormal behavior around sunrise and sunset a few days before the occurrence of main shock. Soloviev et al. (2004) have suggested that this technique is effective for shorter propagation paths only.

The VLF research group at Budapest (Lat 47.5°N, Long. 19.17°E), Hungary has been monitoring the phase and amplitude of NAA signals ($f = 24$ kHz) transmitted from Cutler, Maine for almost a decade. Recently, the VLF group at Agra (Lat. 27.2°N, Long. 78.0°E), India has also started monitoring the same frequency since October 2001. On account of geographical locations of the two stations which may lie in night and day hours simultaneously, it is worthwhile to compare the amplitude variation of the NAA signal over the two stations. In the present paper, we report the results of a preliminary collaborative study in which we have compared the amplitudes of the signal monitored simultaneously during post-midnight hours at Budapest and sunrise hours at Agra. We also identify the seismic and solar flare effects on the amplitude of the signal along the Cutler–Agra propagation path where we find that the average amplitude is reduced as a result of moderate earthquakes ($M > 5$) along the propagation path and enhanced substantially as a result of solar flare.

2. Experimental setup

We have employed AbsPAL (Absolute phase and amplitude data logger) receiver to monitor the phase and amplitude of sub-ionospheric VLF signals at three frequencies i.e. 19.8 kHz (NWC, Australia), 21.4 kHz (NPM, Hawaii), and 24 kHz (NAA, Cutler, Maine). The system consists of VLF antenna, amplifier, service unit, DSP card, and necessary software. This system is superior over Omnipal receiver because of the facility of phase locking with GPS which increases the stability and accuracy in phase and amplitude measurement. An Omnipal based measuring network has been set up in Hungary which can log six different transmitter frequencies and monitor the phase and amplitude variation caused by natural events mentioned in the previous section. This system has been set up and operated in collaboration with ELGI geophysical Institute Budapest. The details of Omnipal receiver may be seen in Dowden et al. (1994) and Dowden and Adams (1988). The great circle paths (GCP) between the transmitting and receiving stations are shown in the map of Fig. 1. The GCP lengths are 11280 km and 6311 km for Agra and Budapest, respectively.

3. Results and discussion

We have been carrying out phase and amplitude measurements at the three frequencies mentioned above since 9 October 2001. Initially, as a test case, the observations