A STUDY OF SUB-IONOSPHERIC EARLY VLF PERTURBATIONS OBSERVED AT AGRA (L=1.15), INDIA

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Abstract

In this paper, we present the results of sub-ionospheric VLF perturbations observed on NWC (19.8 kHz) ransmitter signal propagating in the Earth-ionosphere waveguide, monitored at Agra (Geomag. Lat 27˚E, long. 78˚N) using SoftPAL receiver. During the period of observation (June, 2011 to December, 2011), we found 75 cases of abrupt amplitude/phase perturbations showing early character. Most of the early events observed show an amplitude change lying between 0.16-4.5 dB, only few cases having >4.5 dB and phase change lying between 01-17 degree respectively. The onset duration of these early perturbations is up to ~ 5 sec, showing early slow character. The World Wide Lightning Location Network (WWLLN) data and the broadband VLF data is analysed to find the location of causative lightning associated with these early VLF perturbations. During the period of our study majority of the events are observed at nighttimes and only few cases are observed at daytimes most likely due to the occurrence of red sprite or elves in the daytime. The lightning discharge and associated processes that leads to the changes in the waveguide characteristics and hence VLF transmission have been discussed.
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1. Introduction

Variations in the ionospheric D-region due to the different geophysical phenomena lead to changes in the propagation conditions for very low frequency (VLF) waves propagating subionospherically, and hence changes in the observed amplitude and/or phase of VLF transmissions [1]. The phase and amplitude of the fixed frequency VLF transmitter signals propagating between the Earth-ionosphere waveguide (EIWG) is influenced by lightning and associated processes such as sprites, elves. Sprites appear directly above an active thunderstorm system and coincident with cloud-to-ground or intra-cloud lightning strokes. Lightning discharge generate huge amount of e.m. radiations, most of the energy propagates along the EIWG, a part of the energy lying in the range of VLF(3-30 kHz) waves generated during lightning discharge propagate along magnetic field lines into the magnetosphere, where these waves undergo cyclotron resonance with trapped energetic particles. These VLF signals propagating along the EIWG and geomagnetic field lines are used for the D-region probing of the lower ionosphere [2]. Lightning can cause ionospheric perturbations in the D-region in two ways. The first is through VLF radiofrequency waves launched into the magnetosphere also called "whistler" waves which can interact with radiation belt electrons and cause them to precipitate into the ionosphere. These disturbances are known as Lightning-induced Electron Precipitation (LEP) events. Additional ionization can also occur from direct heating/ionization as a result of huge motions of charge in lightning strikes.

The First observation of amplitude and phase perturbation on short time scale (~ 100s) was given by M.L. Trimpi from the VLF data recorded in Antarctica and it has been also discussed by Helliwell et al [3]. After that Armstrong [4] observed the events having the small time delay <50 ms between the onset of perturbation and lightning, the category of this type of events are known as the early VLF perturbations [5]. Haldoupis et al. [6] reported a new category of Early VLF namely "Early/slow" event having the longer onset duration with similar signatures of recovery. The study of early VLF events has been carried out in last two decades, mostly at Stanford University [7-8] and recently at Crete University [5, 9]. Haldoupis et al.,[5] from Euro-Sprite 2003 campaign data shows that there occur one-to-one correlation between sprite and early/fast events. Mika [10], have done the detailed work on these events.

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It is accepted that the sprites have a certain relationship with the optical emissions occurred in magnetosphere and in lower ionosphere.

2. Observational Results

Monitoring of phase and amplitude of VLF transmitter signals are in progress at our low latitude station Agra(Bichpuri campus of R.B.S. College Agra) since August 01, 2002. Bichpuri is located in rural area about 12 km west of Agra city where local electric and electromagnetic disturbances are low. We have analysed the six month phase and amplitude of VLF signal data recorded during 01 June to 31 December, 2011for the purpose of examining the possibility of early VLF events and the characteristics associated with them at our low latitude. VLF events showing early characteristics are found in both, the amplitude as well as phase of the signal. In total out of 74 events, we observed most of events in nighttime and only few cases are observed in day time. Fig.1 shows the NWC transmitter

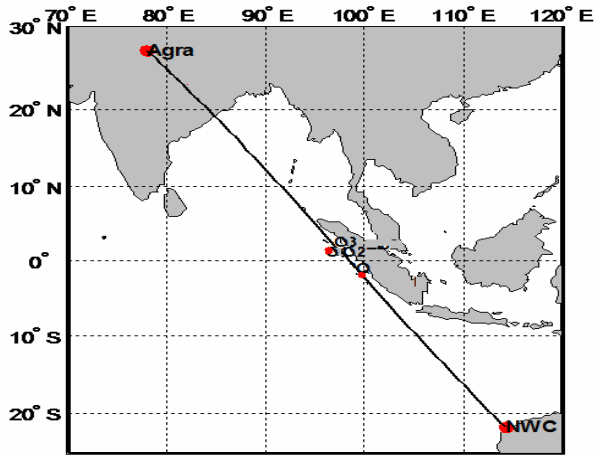

Figure 1: The location of NWC transmitter, receiver and great circle path to Agra. WWLLN-determined locations of the lightning discharge associated with the early VLF events.

(located at North West Cape, Australia), our low latitude receiving station Bichpuri, (located in Agra, India) and corresponding transmitter-receiver great circle path (TRGCP) plotted by using an azimuthally equidistant projection Centre at Agra. After analyzing the bulk of amplitude and phase data, a new type of the VLF event has been observed, which occurred <100 ms, a very short time-scale perturbation in the VLF transmitter signal after the associated lightning discharge known as "early" event [11].

Typical examples of early VLF perturbations are shown in figure 2 having the different onset time, which is related to the associated lightning discharges detected by the WWLLN. Location of these lightning (indicated by the vertical dashed lines) associated with the events is shown in Figure 1. The date and time of occurrences of these events are as follows; Figure 2a show the early VLF event recorded on 23 October, 2011 at 19:14:18.0 UT. WWLLN detect

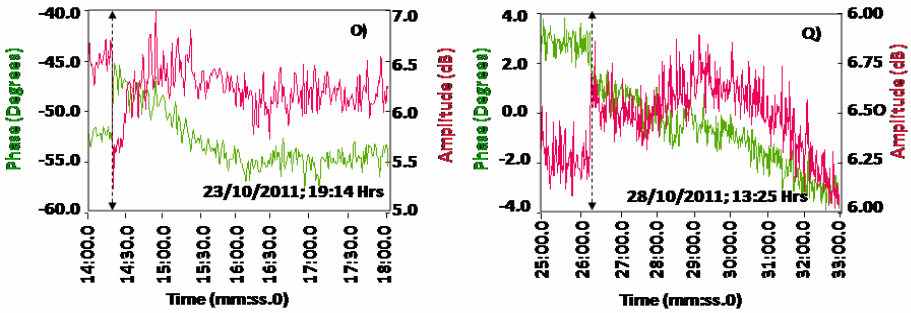

Figure 2: Typical example of observed amplitude (solid-traces: green color) and phase (dotted-traces: purple color) perturbations on (a) 6 January, 2010 at 21:39:07.82 h UT and (b) 28 October 2011 at 13:26:11.0 h UT.

three lightning event in the vicinity of TRGCP one at 19:14:17.79465 h UT (geog. lat. 1.4715, geog.long. 96.321) other at 19:14:17.71 (geog. lat. 1.4803, geog.long. 96.2696) and another at 19:14:17.71003 (geog. lat.1.4631 , geog.long. 96.3422) indicated by 'O1', 'O2' and 'O3' respectively in figure. Another example of early event recorded on 28 October 2011 at 13:26:11.0 during daytime is shown in figure 2b. Corresponding to this event WWLLN detect lightning at 13:26: 10.76931(geog. lat. -1.8829, geog.long. 99.5681) marked as Q in the vicinity of TRGCP. We have found that phase perturbations are as high as 27 degree and in case of amplitude perturbations it is as high as ~5 dB respectively.

3. Diurnal variation of early VLF perturbations:

In this figure 3 we shows the statistical study of early VLF perturbations. We observed most of the events during the nighttime between 19 to 03 h (IST). During the last decades many researcher reported the early VLF perturbations and trimpi/TLEs during the nighttime. During the period of our study we have observed 12.5% of early VLF perturbations at the daytime when complete the TRGCP is in the daylight which is shown in the figure 4. This is because of the high tropical lightning by increasing the unfavourable gyro-frequency.

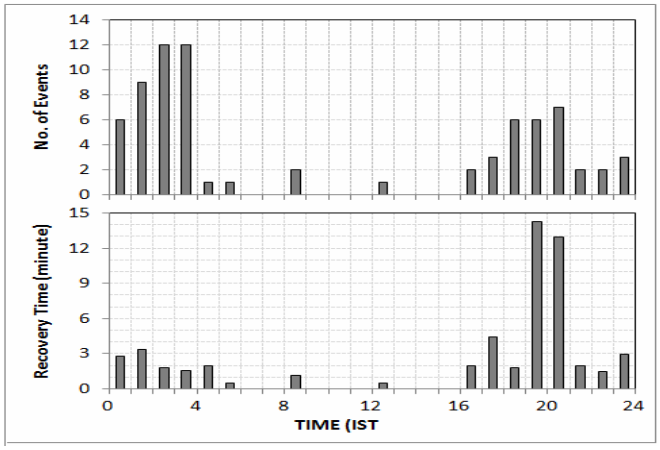

Figure 3: Diurnal variation of early VLF events during June to December 2011.

The diurnal variation of occurrence of early VLF events on NWC during January to June 2010 is presented in Figure 3(upper panel). Figure 3(lower panel) shows the variation of recovery time/relaxation time of different events observed during the different hours of the day. For this we have chosen the events having largest recovery and grouped them as event having recovery between 0.0-0.5 as 0.5, 0.5-1.0 as 1.0 and so on. Also we grouped the event only if three or more event has recovery in that interval. We observe that daytime event have lesser recovery time compared to nighttime, but no correlation during night hours itself.

4. Discussion & Conclusion

We observed different types of the early VLF events at our Agra station. In all total 75 events, the majority of the events are associated with lightning discharges and/or the causative sferics. Most of the early VLF perturbations are recorded at nighttime when the entire TRGCP or a part of it is in dark. Many researchers made an attempt to explain the early VLF phenomena. Dowden et at [12] gave the mechanism of scattering of VLF energy from sprite. Inan et al. [7] presented the first convincing result between the early VLF events and sprites occurring to the TRGCP but from the large distances from the receiver (>2000 km) and attributed these events to directional forward scattering from enhanced ionization associated with the lightning which is located to the TRGCP with the lateral extents of ~ 100-500 km. The occurrence of the early VLF events can be explained by two different phenomena: first is the heating of lower ionosphere by strong quasi-electrostatic field generated by the lightning discharges, this is because of the changes in conductivity [13,14,15], and the second is ionization which is produced by the transient luminous events (TLEs) like sprites halos, elves

[9,16] which appears at the VLF reflection height to the lower altitudes (between 90-75 km) . VLF perturbations could not affected by the mechanism of the sustained heating which is produced by the strong quasi-electrostatic field. The examples of the early VLF perturbations shown in the figure 3 with their lightning location within 100 km (marked by O1,O2,O3 and Q in figure. 1) indicating, such perturbations were produced by the narrow angle forward scattering most likely by enhanced ionization from sprite. Haldoupis et al. [6] presented the early/slow VLF events having the onset duration between 0.5 to 1.5 s associated with the sprites.

Occurrence rate of early VLF perturbation in the daytime is found to be less as compared to nighttime and have faster recovery time which may be due to faster electron relaxation time of ionization produced by daytime TLEs. Daytime early VLF perturbations received the greater attention of researchers because of the less optical observation of this category events during the sunlit hours. Number of the evidences are available to explain that early VLF perturbations have one-to-one correlation associated with sprites/elves and possibly a sprite halo [4,9].The category of the presented early events can be used to detect red sprites during the day time when optical measurements for sprites are not possible.

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