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Synchronized whistlers recorded at Varanasi

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Abstract. Some interesting events of synchronized whistlers recorded at low latitude station Varanasi during magnetic storm period of the year 1977 are presented. The dynamic spectrum analysis shows that the component whistlers are Eckersley whistlers having dispersion 10 $s^{1/2}$ and 30 $s^{1/2}$. An attempt has been made to explain the dynamic spectra using lightning discharge generated from magnetospheric sources.

Keywords. Whistler-mode wave propagation; dispersion; synchronized whistler.

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It is well-known that electromagnetic waves in wide frequency range are associated with return stroke of lightning discharge. These waves propagate in all directions. Since the conductivity of Earth's surface and lower ionosphere is very high at low frequency, these surfaces behave like a perfect conductor. The VLF waves incident on these surfaces are reflected back and propagates in the space between the Earth and the ionosphere, as in a free space waveguide. These waves recorded by VLF receiver exhibit a series of impulses and are called as spherics or atmospherics [1]. Part of the VLF energy may penetrate the ionosphere and propagate along the dipolar geomagnetic field lines either in ducted- or pro-longitudinal-mode without much attenuation. The presence of magnetic fields facilitates the propagation of VLF waves. The wave is dispersed due to the interaction of plasma particles with the VLF waves in the presence of geomagnetic field. These waves have their frequency in the audible range and produce whistling tone and hence are called as whistlers. These are transverse electromagnetic waves having right hand circular polarization different from the acoustic wave propagating in the form of longitudinal waves [2].

The whistler mode involves frequencies much smaller than the electron gyrofrequencies $(f_{\rm B})$ and the plasma frequency $(f_{\rm P})$. The group velocity-vector for this mode lies within a cone having half-angle of 20° measured from the geomagnetic field direction [1]. This is known as magnetoionic guiding. The recorded dynamic spectrum of whistler wave shows that higher frequencies travel faster than the lower frequencies in the same pulse. For the frequency range $f \ll f_{\rm B}, f_{\rm P}$, the time of propagation for whistler mode wave is [1,3]

$$\tau = f^{-1/2}\left[\frac{1}{2C}\int_s \frac{f_{\rm P}{\rm d}s}{(f_{\rm B}\cos\theta)^{1/2}}\right],$$

where ds is path-element and integral is to be evaluated along the geomagnetic field line. The above equation shows that signals emitted simultaneously during the lightning discharge will be received at the magnetic conjugate point at different time. This means that the monochromatic pulse generated at the source, after propagating through a plasma medium embedded in the magnetic field is received in the form of dispersed pulse. The dispersion produced in the pulse depends upon plasma density, strength of magnetic field, wave frequency, wave normal angle and path length. If the wave has propagated once along the field line, we call it one-hop whistler. On the other hand, if the wave propagates n-times along the field line before being received, then such waves are called as n-hop whistlers. The dispersion of one-hop and n-hop whistlers is $1 : n$, where n is integer numbers 1, 2, 3, 4,.... The waves propagate along the geomagnetic field lines either in ducted- or pro-longitudinal-mode without appreciable attenuation and spreading in wave energy and hence n can have large values [4].

In this brief report, we present some examples of synchronized whistlers which were recorded at low latitude Indian station at Varanasi (geomag. lat. $= 14^\circ 55'$N, $L = 1.07$) during magnetically disturbed days – 9th, 19th and 22nd March 1977. A large number of whistlers were recorded [5]. The data were analyzed and the lifetime of whistler duct and the east–west component of plasmaspheric electric field was determined [6]. While analyzing the data we found completely new type of unexpected whistlers named as 'synchronized' whistlers during the magnetic storm period ($\Sigma K_{\rm p} = 10$) of March 19, 1977. Two selected examples from about twenty such events are shown in figure 1. Whistler occurrence started around 0000 hrs IST and lasted up to 0302 hrs IST on March 19, 1977. During this period more than hundred whistlers were recorded and $K_{\rm p}$ index varied between 2 and 5. The occurrence rate of whistlers is shown in figure 2. Figure 1 shows that the synchronized whistler consists of two whistler components separated by a frequency dependent time delay. In figure 1a, the first three whistler traces namely A, B and C are multiflash whistlers having dispersion of about 10 s$^{1/2}$. The other two traces E and L are three-hop and one-hop whistlers having dispersion of about 30 s$^{1/2}$ and 10 s$^{1/2}$ respectively. The difference in time delay between the two components E and L typically decreases to zero at a frequency of about 4 kHz giving an impression that the two components have merged at this frequency. The dispersion analysis of the E and L traces shows that each component has separate causative spherics as indicated by an arrow in the figure. This implies that the two electron whistlers originate from separate lightning impulses. In the second case (figure 1b), at least, the E trace appears beyond the crossing point. The fact that the two signals forming a synchronized whistler starting from two different lightning sources in the same region speaks of its rare appearance.

The occurrence rate (figure 2) shows a feeble but discernible periodicity, which may be an indication of ducted propagation and periodicity could represent the duct lifetime [6,7]. The dispersion analysis shows that the one-hop and three-hop whistlers having dispersion of about 10 s$^{1/2}$ and 30 s$^{1/2}$ respectively may have propagated along the L value corresponding to Varanasi in ducted mode or pro-longitudinal mode because during magnetic storm period trapping conditions are not well-understood and non-ducted whistlers suffer heavy absorption by the ionospheric plasma. For example, three-hop whistler must suffer an additional four times absorption in the lower ionosphere and due to high attenuation it is impossible to receive three-hop whistlers by ground-based equipment. Waves propagating

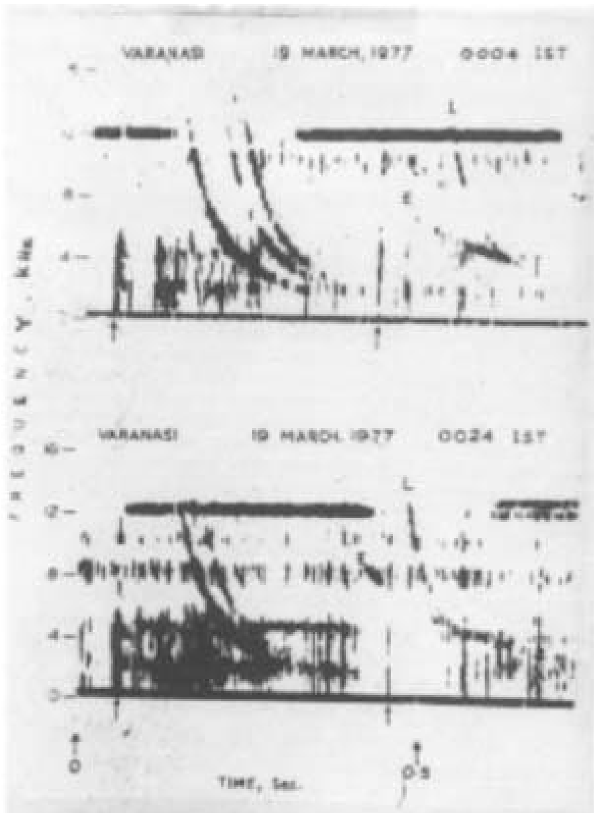

Figure 1. Examples of synchronized whistler recorded on March 19, 1977.

in ducted- and pro-longitudinal-mode suffer very little attenuation. However, based on the ground observations we can only say that the waves have propagated along the field lines. The mode of propagation cannot be deciphered. Ohta *et al* [8] using three-dimensional ray tracing for realistic ionosphere/magnetosphere model (the electron density profile with latitudinal and longitudinal gradients and international geomagnetic reference field) showed the possibility of detection of three-hop whistlers at low latitude stations in the northern hemisphere when the VLF waves are launched at small wave normal angle ($< 4^\circ$) in the southern hemisphere. Thus, echo train whistlers recorded at low latitudes can be explained by considering pro-longitudinal non-ducted mode propagation along the geomagnetic field lines.

The dynamic spectrum of synchronized whistlers can be explained by considering field aligned propagation of E and L components. Suppose, a lightning discharge in the southern hemisphere feeds energy in whistler mode which propagates along geomagnetic field lines ($L = 1.07$) gets reflected from the ionosphere in the northern hemisphere and reaches the southern hemisphere. In the southern hemisphere, wave energy causes excitation of lightning discharge which generates L-components [9]. The original wave energy again gets reflected in the southern hemisphere leading to E-components. Both the E and L

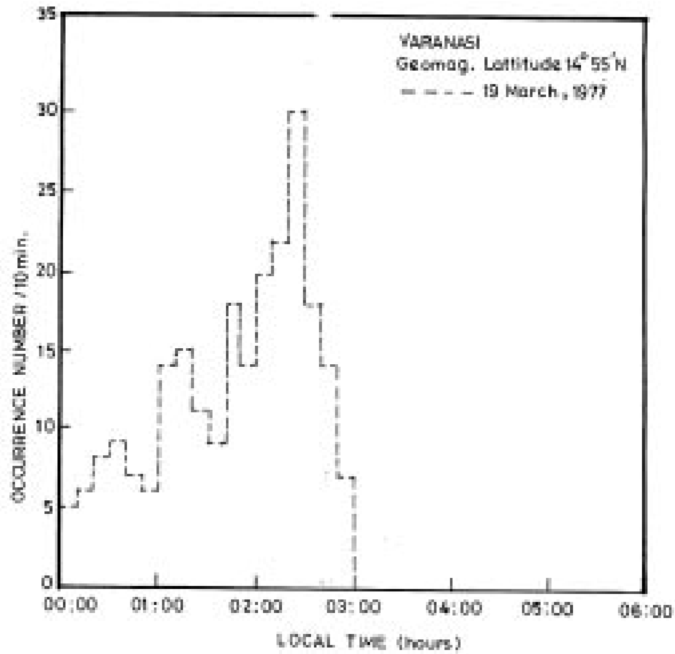

Figure 2. The occurrence rate of whistlers summed over ten minute intervals recorded on March 19, 1977.

components propagate along the field line to be received in the northern hemisphere as synchronized whistlers. The initial whistler wave energy propagating from the southern hemisphere may have interacted with counter streaming energetic electrons leading to their precipitation into the atmosphere of the southern hemisphere [10,11]. These energetic electrons precipitated into the atmosphere could easily excite lightning discharge [12,13]. In fact there are various observations whose interpretation independently suggested the existence of discharges triggered by the sources lying in the magnetosphere [14–16]. This is to be noted that Khosa *et al* [17] have mistakenly identified these whistlers as hook whistlers. In hook whistlers, both the traces are generated by the same causative lightning impulse [18] whereas in synchronized whistlers two traces are initiated by different discharges.

In this brief report, we have presented the dynamic spectra of synchronized whistlers recorded at Varanasi, which may be explained by considering both the constituent whistler signals to have propagated along the *L*-value corresponding to the recording station at Varanasi and one of the constituent (one-hop whistler) to be generated by a lightning discharge excited by the electrons that were precipitated in the southern hemisphere due to their interaction with the initial whistler wave traveling towards the northern hemisphere.

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