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Study of Generation Mechanism and Propagation Characteristics of VLF/ELF Emission at Sub Auroral Zone MAITRI, Antarctica

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ABSTRACT

Observation of VLF/ELF emissions at high latitude is attributed to the lightning, thunderstorm activities and power line radiations solar flares, at high latitudes. Contribution due to solar particle fluxes becomes important for VLF/ELF discrete emissions. The discrete auroral structures which may be generated by wave particle interactions between up and down-going energetic electrons and magnetospheric electric current generally observed at high latitudes. Discrete inverted-V shaped emissions shows a close association with auroral precipitation and these emissions are observed at ground station with a multiple structure and fading characteristic resulting from an ionospheric and/or magnetospheric mechanism of stratification. Variations in the magnetospheric potentials are related with the gradients in the gradient mechanism of the field-aligned current generation whereas pressure gradient contributes to the generation of field aligned current at the onset of substorm or in the magnetically disturbed condition. The radiation from lightning discharge in low frequency range, -0.3 to 30 kHz is the source of whistler. These impulse are propagated along the magnetic field lines through the plasmasphere and the magnetosphere to the opposite hemisphere in whistler mode. This mode of propagation is possible in magnetized plasma and at frequencies below both the electron plasma- and gyrofrquency. In the XXII Indian Scientific Expedition to Antarctica we have carried out VLF/ELF recording with Direction finding technique (Triangular Loop Array Antenna), to deduce the magnetospheric density from the dispersion values and to determine the emerging region of whistlers from the ionosphere is important.

INTRODUCTION

Very low frequency (VLF) (ionospheric noise) and Extremely low frequency (ELF) emissions, a class of naturally emitting radio phenomena very important diagnostic tool for probing the plasmasphere and beyond. VLF emissions are appear in wide variety of spectral forms and it may appears in short burst to several minutes or hours. These emissions acquires importance because of its ability to allow to understand the electron density variation derived from the dispersion characteristics at simultaneously observation at different suitable stations as well as the effect of solar wind - magnetospheric interaction on the propagation along the field aligned irregularities [Helliwell R.A., 1965]. VLF/ELF emissions are localized geographically at the locations that are geomagnetically conjugate to one another [Helliwell, 1965 and Bespalov et al. 1980]. VLF electromagnetic waves generated by lightning discharges which propagates along the magnetic field lines of the earth, get dispersed due to field aligned irregularities [Pathak et al., 1982; Prasad and Singh, 1982].

The importance of VLF (0.3-30 kHz) radio waves in the magnetosphere has long been recognized in understanding plasma physics aspects of wave-generation, amplification, and damping through linear and non-linear interactions with particles. The wave and wave particle interactions occurring in the magnetosphere generate wide variety of emissions in the VLF range. The VLF emissions are characterized by their trigger source. The VLF discrete emissions are often with periodic and quasi-periodic nature. Observation of VLF/ELF emissions at high latitude is attributed to the lightning, thunderstorm activities and power line radiations solar flares. In addition, the role of waves in the exchange of energy between different regions of geo-space is also important. Hook emissions are discrete emission which can be seen as the decrease then increase or increase then (inverted) or show some more complicated combinations. Periodic and quasi-periodic emissions, chorus and various other transient discrete emissions such as VLF risers, fallers and hooks have been reported at Antarctica .The hook emissions are known to be caused by wave particle interactions between up-and down-going energetic electrons and whistler mode waves along the field lines near the magnetic equator at higher L shells (L > 2) hence are generally observed at high latitudes [Sazhin et al„ 1993; Morrison et al., 1994; Smith and Noon, 1998]. Smith et al. (1998) have reported periodic and quasi- periodic VLF emissions observed at Halley and South Pole stations, which are approximately in the same meridian and geomagnetic latitude of 61 ° and 74° respectively. Although discrete emissions appear to be restricted in geographical coverage, it has been observed that the intensity of emissions integrated over a minute or more correlates well at stations spaced up to several thousand kilometers apart [Pope, 1959; Ellis, 1959; Dowden, 1961].

VLF/ELF noise burst of varying amplitudes and durations, are observed which are usually attributed to local and global source such as lightning and thunderstorm activities, spherics, power line radiations, wave particle interaction and solar flares etc. Sudden ionospheric disturbance (SID) are caused by solar flares, which have been identified [Hayakawa and Sato, 1994]. Van Bise and Rausher (1994) observed ELF solar flares in addition to other environmental signals and [Hato et. al., 1994] observed ELF sudden enhancement of atmospheric (SEA) triggered by solar flares using magnetic antenna. Simultaneous observation of SEA at multiple stations confirmed their origin in Solar Flares. Emission activity generally decreases with magnetic activity at high latitude and increases at low latitudes and a close association exist between auroral phenomena [Hattori et. al., 1989]. The relation between VLF emissions and aurora were explored by [Morozumi, 1962], a close association between auroral arcs and band were found. The VLF intensity decreases because of the absorption of VLF energy in D region of the ionosphere [Helliwell, 1965]. The two proposed models of the emissions at high latitudes, could explains the nature of VLF emissions [Sazhin and Hayakawa, 1994]. In the first model the emission period was related to the bounce period of the charged particles bouncing between conjugate hemispheres. In the second model, the emission period was related to the two-hop whistler-transit time [Dowden and Helliwell, 1962].

PROPAGATION CHARACTERISTICS OF WHISTLERS

Whistlers are a very low frequency (VLF) electromagnetic wave originated in the lightning stroke, which emits VLF impulse. Lightning discharge radiates electromagnetic waves over a wide frequency range extending from 10"^{3}to 10^{6} Hz, covering wide varity of natural electromagnetic phenomenon associated with space plasma. The radiation from lightning discharge in relatively low frequency range, -0.3 to 30 kHz is the source of whistler. This impulse is propagated along the magnetic field lines through the plasmasphere and the magnetosphere to the opposite hemisphere in whistler mode. This mode of propagation is possible in magnetized plasma and at frequencies below both the electron plasma- and gyrofrquency. Propagation in this mode is strongly affected by the static magnetic field and is characterized by low propagation speeds that vary with frequency. Because of the highly dispersive nature of the medium different frequencies have different delays and as a result the impulse is smeared out into a gliding tone such that the wave frequency decreases with time; i.e. T = D f ""^{2} where T = time, f: frequency and D is constant called " dispersion" determined by the plasma parameters along the propagation path [Helliwell, 1965]. The solution of the dispersion equation for whistler mode propagation in hot anisotropic plasma has been obtained by many workers [Sahzin 1986, 1987, 1987b, 1988, a, b, c; 1989]. Electromagnetic waves traveling in whistler mode have widely been used for measuring plasma density and drifts in the magnetosphere.

The part of signal emitted by the lightning, which penetrated the ionosphere, travels with the group velocity, which depends strongly on frequency. Different frequencies have different speed so that the signal is highly dispersed. In many cases ducts guide the signal along the magnetic field lines so that the wave normal is approximately field aligned. Because the wave normal is parallel to the magnetic field the group velocity is in the same direction as the phase velocity.

The time interval

$$dt' = ds/V_G = \frac{1}{C} n' ds \qquad \dots 1$$

Thus the time delay over the whole part is

$$t' = \frac{1}{C} \int_{path} n' ds \qquad \dots 2$$

At higher latitudes near the plasmapause the magnetic field near the equatorial plane is small enough so that the gyrofrequency is comparable with the wavelength. Here X >> Y2 ~1 (X is square of normalized plasma frequency ω_p^2 / ω^2 and Y is normalized gyrofrequency Ω / ω) and we get

$$t' = \frac{1}{2\omega^{1/2}} \int_{path} \frac{\Omega \omega_p}{(\Omega - \omega)^{3/2}} ds \qquad \dots 3$$

In a uniform medium it is easy to see that the group velocity is maximum at $\omega = 1/4\,\Omega$ because Ω varies substantially along the path the frequency component having maximum speed varies along the path. The net effect, when integrated along the path, shows that there is a particular frequency, which arrives first. It has been since recognized that these waves play an important role in the loss of electrons from the radiation belts in the earth's and other planets magnetosphere [Kennel and Petschek, 1966; Coroniti et.al., 1987; Gurnett et al.,1990]. Wave energy can pentrate through the ionosphere and magnetosphere and propagate almost along the geomagnetic field lines to the opposite hemisphere. Whistlers can be short or long depending upon whether they are observed in the opposite of same hemisphere in which they are originated from the lightning discharges.

Whistlers radiated from a lightning discharge travel large distances in the earth ionosphere waveguide, being reflected back and forth between the conducting ionosphere and the ground to several Earth radii out into space. It becomes clear that they contained useful information about the medium through which they had propagated and thus they plays a vital role in advance understanding of the ionosphere and magnetosphere. Whistler show wide variety of frequency time signatures, depending on the electron density distribution and ion composition of the medium. The whistler technique has been used to measure the L motion of thermal plasma in the plasmasphere [Carpenter and Stone, 1967; Park and Carpenter, 1970] and coupling fluxes of ionization between the protonosphere and the ionosphere [Park ,1970]. A new subprotonic whistler characteristic and certain aspects of the plasmapause probing by whistlers such as the whistler method of measuring the magnetospheric density were presented by Carpenter (1983). A theoretical model for the study of the observed correlations between whistler mode waves and the energetic electron precipitation event in magnetosphere was given by Chang and Inan (1983).

DIRECTION FINDING TECHNIQUE

In order to study the propagation mechanism of whistlers and also to deduce the magnetospheric density from the dispersion values; it is of great importance to determine experimentally the region where whistlers emerge from the ionosphere [Sazhin and Hayakawa, 1992; Hayakawa and Sazhin 1992; Sahzin et al., 1993]. This is called the "Direction Finding".

Field analysis direction finding method is based on the simultaneous measurement of two horizontal magnetic field components and one vertical electric field component, which is made at a specific point frequency, where it is expected maximum energy in the whistler spectrum lies. The problem is to know whether the results of direction of arrival and polarization measured at the particular frequency. Ohta et al., (1986) seen that the amplitude ratio and phase difference of whistler signal on the crossed loop show no particular frequency dependence and thus the whistler characteristics (direction of arrival) do not depend on frequency. But when the polarization characteristics of the whistler vary with frequency the direction of arrival will be different at different at different frequencies for the relevant whistler. An elliptically polarized whistler is assumed to be incident angle i (measured from the zenith) and an azimuth angle (measured eastward from north) and polarization is defined by:

$$p = u - jv = {H_{\parallel}}/{H_{\perp}} \qquad \dots 4$$

(where $H_{\parallel}$ and $H_{\perp}$ are the magnetic field components parallel and perpendicular to the incident plane). Then, the voltage induced by horizontal magnetic fields of the whistler signal on loop aerials in the E-W and N-S directions are expressed by

$$V_x = Y(\omega)\{-(\sin\theta + u\cos i\cos\theta)\cos\omega t - v\cos i\cos\theta\sin\omega t\} \quad \dots \ 5(a)$$

$$V_y = Y(\omega)\{-(\cos\theta - u\cos i\cos\theta)\cos\omega t - v\cos i\sin\theta\sin\omega t\} \quad \dots \ 5(b)$$

where $Y(\omega)$ is transfer function of the antenna system. The amplitude ratio and phase difference provide useful information on the whistler ionospheric transmission mechanism.

THEORETICAL FORMULATION OF INVERTED-V EMISSIONS

Inverted-V shaped emissions are generally observed on the same auroral zone extend over a latitudinal width of 50-200 km at ionospheric altitudes [Stepanova et.al. , 2001] and these emissions are also observed in the dusk and pre-midnight sectors accompanied by quasi-periodic electric fluctuations [Johnson et.al.,1998]. This resulting electric field at ionospheric altitudes should reflect the distribution of the equatorial magnetospheric potential, but modified by the field –aligned potential drops accompanying by inverted-V and this is also explained by the Lyons (1980) model of discrete precipitating structures, which necessary appear in the presence of large variations in the gradient of the magnetospheric potential. Experimental results [Luizar et.al.,2000] demonstrate that the number of structures observed within a given event is well described by a 'scaling' parameter provided by the hot plasma stratification theory and expressed in terms of the field aligned current density, the total width of the current band, the plasma sheet ion temperature, and the height–integrated Pederson conductivity of the ionosphere. Oscillations of the magnetospheric potential (or the pressure gradients) arise in the Tverskoy model and may naturally result when the initial pressure gradients needed to generate a large scale field-aligned current have a sufficiently wide equatorial scale, of about 1 R_E or more.

It is now known that inverted-V structures corresponds to the regions of the intense field aligned currents, carried by hot magnetospheric electrons which accelerated at relatively low altitude by field aligned potential drops and which present shell-type distribution functions [Evans, 1974; Antonova and Tverskoy, 1975; Chiu and Schultz, 1978; Chiu et.al., 1983; McFadden et.al., 1999].The latitudinal width is relatively independent of the current density, and is determined not only by the existence of a potential difference above the inverted-V, but also by basic oscillations of the ionosphere-magnetosphere coupling system predicted by Tverskoy (1982). Satellite observation infers that the structures observed can be related directly to oscillation of the magnetospheric potential (or pressure gradient) on scale of ~1000-200 km in the near -Earth plasma sheet. According to Lyons (1980), ionospheric electric fields under inverted-V structures must have a negative divergence. When the top of the acceleration region is located far from the Earth, the upward field aligned current is linearly related to the field aligned potential drop [Antonova and Tverskoy, 1975; Carpenter,1978].

Variations in the magnetospheric potentials are related with the gradients in the gradient mechanism of the field-aligned current generation. The contribution of pressure gradient to field aligned current generation during quiet time or at the onset of substorms has been quantitively analyzed by [Galperin et.al.,1992; Galpherin and Bosquel,1999; Wing and Newell, 1998; Wing and Newell, 2000] by using the principal equation of perfect magnetosphere- ionosphere coupling for the most general case, corresponding to space scales comparable with the ion Lamor radius[Harel et al.,1981].

In this approach the pressure gradient is balanced by Ampere's force, and at the same time inertial and viscous forces may be neglected when the large-scale bulk plasma velocity is lower than the Alfven and sound velocities:

$$\vec{\nabla} p = \left[\mathbf{j} \times \mathbf{B}\right] \qquad \ldots 6$$

where j is the current density, B is the magnetic field.

In the presence of the conducting ionosphere, in the stationary case the ionospheric part of field-aligned current (left side) is equal to the magnetospheric part right side and the fundamental equation of the magnetosphere-ionosphere interaction is [Heinemann.,1990; Kamide and Baumjohann, 1993].

$$div\left(\Sigma \vec{\nabla} U_i\right) = \mathbf{n}\left[\vec{\nabla} W \times \vec{\nabla} p\right] \qquad \ldots 7$$

where Σ is the height -integrated conducting tensor, U_i is the ionospheric potential, $W = \int dl/\mathbf{B}$ is the magnetic flux tube volume per unit flux, integrated from the equatorial plane to the ionosphere, l is the length along the field line, **n** is the unit vector (along the field line) pointing towards the ionosphere, and p is the scalar pressure.

EXPERIMENTAL SETUP

To have more acquaintance of the propagation characteristics of high latitude VLF/ELF emissions, recordings were carried out at Indian Antarctica Base Station Maitri, (70°46'S, 11°44'E, L ~ 4.6) with Orthogonal Crossed (Triangular) Loop Antenna (TLA). In which one loop in North-South Direction and other one in East-West Direction. Area of each loop is 144m^2. This TLA is Thin Wire Loop antenna designed to receive from the VLF range (30 kHz). Output impedance of both loops is matched and frequency above 30 kHz was filtered out remaining signal were suitably amplified by transistorized pre and main-amplifiers. Signal recording is carried out in digital format at the sampling rate 48 kHz by Digital Recorder and online on computer system. Data is stored in amplitude versus time file format and these file are converted in visible gray scale plot by Spectrum analyzer.

TRIANGULAR LOOP ANTENNA

The triangular loop antenna work as a voltage generator. From the wave normal direction u_k of VLF/ELF Signal signals and Maxwell's equation, the relation

$$u_k x E = c \, {}^{B}\!/_{n} \, . \qquad \ldots 8$$

where n is the refractive index. n can be calculated by Appleton-Hartree equation using the observed u_k. The L is the intrinsic inductance of the loop; the R is the resistance of the loop's wire. Open circuit voltage of a multi-turn loop is

$$V = 2\pi\mu_0 NAH_0 f \cos\theta \qquad \ldots 9$$

$2\pi\mu_0$ is constant, $\mu_0 = 4\pi 10^{-7}$, $\cos\theta$ cosine of angle between loop axis and field vector, assumed equal to 1. N = number of turns, A = loop area in m^2, H_0 applied magnetic field in ampere/meter. *f* Frequency, in Hz, the output voltage, is function of *f*. Loop is closed or short-circuited. The current flowing through it is,

$$I = \frac{V}{\sqrt{(R^2 + X_L^2)}} \qquad \ldots 10$$

where V is the open circuit voltage, R is the conductor resistance and X_L is the loop reactance,

$$I = \frac{2\pi\mu_0 NAH_0 f \cos\theta}{\sqrt{(R^2 + X_L^2)}} \qquad \ldots 11$$

It shows that for small values of f the output current is limited only by R and increases with f; when X_L becomes bigger than R the output current

Fig. 1: Triangular Loop Antenna installed at "MAITRI"

is limited mainly by X and is no more dependent from f. So if we want to have a flat frequency response from a loop antenna the best way is to close it in short circuit, and use the output current instead of voltage. This will be the best way to extract the signal from the antenna.

For the present study, we have chosen VLF signals recorded at high latitude Indian base station at Maitri, Antarctica during day and night time during last week of January 2003 to February 2003. A large number of VLF emissions were observed in the daytime during both magnetically quiet and disturbed periods.

RESULTS AND DISCUSSION

The VLF/ELF emissions are widely used for investigating the magnetospheric processes of wave generation and propagation, wave-particle interactions, wave-induced particle precipitation and for probing of magnetospheric plasma structures and motions [Carpenter, 1978]. The inverted-V shaped VLF/ELF emissions are observed in an average frequency range of the below 1000 Hz to 8 kHz. From the spectrogram it is clear that this inverted - V structure appears with higher density in ELF region and disappears in VLFband. Inverted-V [Frank and Ackerson, 1971] or Lambda [Heikila, 1970] structure have an association with auroral precipitation and these emissions are apparently results from an ionospheric and/or magnetospheric mechanism of stratification [Luizar, etal.,12] follows the framework of the ionosphere-magnetosphere coupling model proposed by Tverskoy (1982). We have observed this type of emission in moderately disturbed days and disturbed condition, as auroral oval expansion does not take place in quite days.

At high latitudes the large scale convection of the magnetic field lines due to solar wind interaction and the precipitating particles, which comes from the collision retardation of magnetospheric energetic particles results in disturbance of polar caps. Some of the energy entering the dayside magnetosphere is directly transferred to high latitude ionosphere via field-aligned currents. The electron flux, energy flux and the number density is greater inside the inverted - V structure. At the energy of the peak flux the electrons are field aligned whereas those with higher energies are isotropic over the down coming hemisphere. This distribution is consistent with the electrons having been accelerated through a field aligned potential drop at an altitude above the point of observation [Evan, 1974]. Electrons with energies less than that of the peak show highly complex pitch angle distributions. Some of the low-energy electrons are highly field-aligned suggesting that they are accelerated electrons of ionospheric origin. The complexity of their distribution suggests that the field-aligned potential drop is varying temporally and/or spatially. The fading/damping observed in VLF portion because of the absorption in D region (between 70 and 12 km) of the ionosphere [Helliwell, 1965]. Because of collisions between electrons and other particles, these types of emissions lose some energy as it propagates through ionosphere. Some loss appears in the form of heat and some as disordered electromagnetic radiation. Same fading phenomena are observed here in this case where we see harmonics in the VLF range. The energy coupling processes at the magnetopause is magnetic reconnection or field aligned merging which imply interaction between the solar wind magnetic field, i.e. interplanetary magnetic field (IMF) and the terrestrial magnetic field at the dayside magnetopause. As the magnetopause may originate

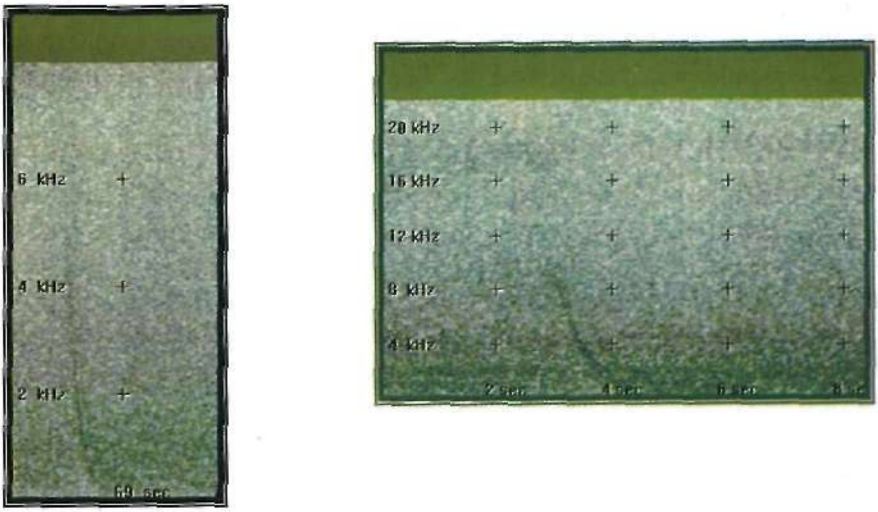

Fig. 2: Whistlers Traces observed at MAITRI

Fig. 3: Inverted V structures

minimum magnetic field strength that occurs off the magnetic equator as a result of solar wind compression of the dayside magnetosphere and subsequently propagate in the Polar Regions.

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REFERENCES

1. Antonova, E.E. and Tverskoy ,B.A., Geomagn. Aeronomy (English Translation) 15,105-111, (1975).
2. Bespalov, P.A. and Chukanov ,A.A., Geomagn. and Aeronomy , Vol. 20 No. 1, 1980
3. Carpenter, D.L, J. Geophys. Res., 83, 1558, (1978).
4. Carpetner, D.L. and Stone, Planet. Space Sci.,. 15, 395, 1967.
5. Chang, H.C. and Inan, U.S., J.Geophys. Res., 88, 10053, 1983.
6. Chiu, Y.T. and Schultz, M.,J. Geophys. Res., 83,629-642, (1978)
7. Chiu, Y.T., Cornwall, J.M., Fennell, F.J., Gorney, D.J,.and Mizera ,P.E, Space Sci. Rev., 35,211-257, (1983).
8. Dowden, R.L., J.Geophys. Res., 66, 1587,1961. Kennel, C.F. and Petschek, H. E., J. Geophys. Res., 71, 1, 1966.
9. Dowden, R.L. and Helliwell, R.A., Nature, 64, 1962.
10. DungeyJ.W, Phys. Rev. Lett., 6, 47-48, 1961.
11. Ellis, G.R.A., Planet. Space Sci., 1, 253, 1959
12. Evans,D.S., J.Geophys. Res., 79, 2853-2863, (1974).
13. Frank, L.A., and Ackerson ,K.L., J.Geophys. Res., 76, 3612- 3643 ,1971.
14. Fridman, M. and Lemaire ,J., J. Geophys. Res., 85,664-670, (1980).
15. Galperin, Y. I.,.Volosevich, A.V, and Zelenyi, L.M., Geophys. Res. Lett., 19,2163-2166, (1992)
16. Galperin, Y I. and Bosqued, J.M., Ann. Geophysicae, 17,358-374, (1999).
17. Gurnett, D.A., Kurth, W.S., Cairs, I.H.I, and Granroth, L. J., J.Geophys. Res., 95, 967, 1990.
18. Hard, M., Wolf ,R.A., Reiff, P.N., Spiro, R.W., Burke, W.J., Rich, F.J. and Smiddy, M., J. Geo phys. Res., 86, 2217, (1981).

19. Hata, M. and Yabashi, S. ,Terra Sci. Co. Tokyo, (1994)
20. Hattori, K., Hayakawa ,M., Shimakura, S., Parrot M.and Lefeurvre L..Proc. of NIPR Symp. On Upper Atmospheric Physics 2, p .84,(1989)
21. Hayakawa , M. and Sato, H., Terra Sci. Co. Tokyo, (1994)
22. Hayakawa , M. and Sazhin S.S., Planet Space Sci. 40,1325, (1992)
23. Heikkila, W.I., Nature, 225, 369 - 370 , (1970).
24. Helliwell ,R.A. Whistlers and Related Ionospheric Phenomena; Stanford University Press, Stanford (1965)
25. Heinemann M.,J. Geophys. Res., 95, 7789-7797, (1990).
26. Heinemann M.and Pontius ,D.H., J.Geophys. Res., 96, 17 605-17 626,(1991).
27. Home, R.R., Planet. Space Sci., 38, 311, (1990).
28. Johnson,M.L., Murphree, J.S., Marklund, G.T.and Karlson. T, J.Geophys. Res., 103, 4271-4284, (1998).
29. Kamide Y. and Baumjohann, W.; Magnetosphere-Ionosphere Coupling Springer-Verlag Berlin (1993)
30. Luizar,0., Stepanova, M.V., Bosqued, J.M., Antonova, E.E.,and Kovrazhkin, R.A.; Ann. Geophys. 18, 1399-1411 (2000).
31. Lyons, L.R., J. Geophys. Res., 85, 17-24, (1980).
32. Lyons, L.R., J. Geophys. Res., 86, 1-16, (1981).
33. McFadden, J.P., Carlson, C. W. and Ergun, R.E..Geophys. Res., 104,14,453-14 480, (1999).
34. Morrison, K., Engebretson, M., Beak, R., Johson, E., Arnold, R.L., Cahili, Jr. L., Carpenter, D.L., Ann. Geophys., 12, 139, (1994).
35. Pathak, P.P. Ann. Geophys. 31,765 (1982)
36. Park, C.G. and Carpenter, D.L., J. Geophys. Res., 75, 3825, (1970).
37. Park, C.G., J. Geophys. Res., 75, 4249, (1970).
38. Pope, J. H., Sci. Rep. No. 4, Univ. of Alaska College, Alaska, (1959).
39. Prasad, R. and Singh, R.N., Nuova Cimento, 65, 462-76, (1982).
40. Russell, C.T., McPherron, R.L. and Burton, R.K., J. Geophys. Res., 79(7), 1105-1109,(1974).
41. Salvati,M.A., Inan,U. S., Rosenberg T Land Weatherwax, A.T., Geophy.Res.Let., (2000)
42. Sazhin, S.S., Bognar, P., Smith, A.J. and Tarcsai, G, Ann. Geophys., 11,619, (1993)
43. Sazhin, S.S., Bullough, K., and Hayakawa, M., Planet Space Sci. 41,153(1993)
44. Sazhin, S.S. and Hayakawa, M., Planet Space Sci. 40, 681, (1992).
45. Sazhin, S.S. and Hayakawa, M., J. Atmos. Terr. Phys.56, 735, (1994).
46. Sazhin, S.S., Ann. Geophys., 4, 155, (1986).
47. Sazhin, S.S., J. Plasma Phys., 37, 209, (1987b).

48. Sazhin, S.S., Planet. Space Sci., 36, 663, (1988a).

49. Sazhin, S.S., Astrophys. Space Sci., 145,163, (1988b).

50. Sazhin, S.S., Planet Space Sci., 36,1111,(1988c).

51. Sazhin, S.S., Planet Space Sci., 37, 311, (1989).

52. Sckopke, N. J. Geophys. Res., 71, 3125, (1966).

53. Smith, A.J., J. Atoms. Terr. Phys., 57,507, (1995).

54. Smith, A.J. and Jenkins, P.J., J. Atoms. Terr. Phys., 60, 263, (1998)

55. Smith, A. J. and Nunn, D., J. Geophys. Res., 103, 6771, (1998).

56. Stepanova,M., Luizar,0., Bosquel ,J.M., Antonova E.E.and Kovarzhkin, R.A., Adv. Space Res.28, 11, 1581-1586, (2001).

57. Syun-Ichi Akasofu; Polar Springer-Verlag New York (1993)

58. Van Bise W.L. and Rauscher, E.A.,Terra Sci. Co. Tokyo (1994)

59. Wing S.,and Newell ,P.T., J. Geophys. Res.,103, 6785-6800, (1998)

60. Wing S.,and Newell ,P.T., J. Geophys. Res., 105, 7793-7802, (2000).