Study of Equatorial Spread F Region and Factors Affecting Spread F

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Abstract— ***This paper provides a brief overview of the enigmatic phenomenon Equatorial Spread F. Ionospheric disturbance is a major impediment to current communication systems with the signals propagating through the ionosphere. A signature of such disturbance when appearing in an ionogram, resulting from the ionosonde observation system, is known as spread-F. From low solar activity period to high solar activity period- Plasma scale length of spread F region comes closer to a range between 10 km to 45 km. This indicates solar activity depends on the plasma scale length L.***

Keywords- ***Equatorial Spread F(ESF), Rayleigh-Taylor instability (RT), Evening Enhancement (PRE), Plasma scale length (L), base height (h'F).***

I. INTRODUCTION

The upper part of atmosphere where charged particles are present which results the ionization appreciably is known as Ionosphere. The lower boundary of the ionosphere coincides with the region having the most penetrating radiation, produces free electrons and ion pairs sufficiently which affects the propagation of radio waves. The upper boundary of the ionosphere absorbs large quantities of radiant energy from the sun directly or indirectly interacts with the solar wind. The interaction region between the solar wind and the ionospheric plasma represents the termination of the ionosphere on the sunward side, may be called the ionopause. Ionosphere is formed by the photo-ionization of the neutral atoms or molecules by the solar X-rays and UV radiation and by the precipitation of the energetic particles at the higher latitudes where as in lower latitude it by cosmic rays. This ionization rate depends upon the intensity of the ionizing radiations, atmospheric density and composition. The idealized electron density profile called **Chapman profile**, produced solely by the absorption of solar radiation.[1]

II. IONOSPHERIC LAYERS

Due to the result of variety of physical, chemical and dynamical processes there is a redistribution of ionization causes the formation of distinct regions in ionosphere. These distinct regions are symbolised by the letters **D**, **E** and **F**. F layer is further divided into three sub- regions denoted by **F1**, **F2** and **F3**. The ionization rate at any altitude and time is a result of three main processes- production, loss and transport. Figure 1 shows the ionospheric regions in earth's atmosphere.

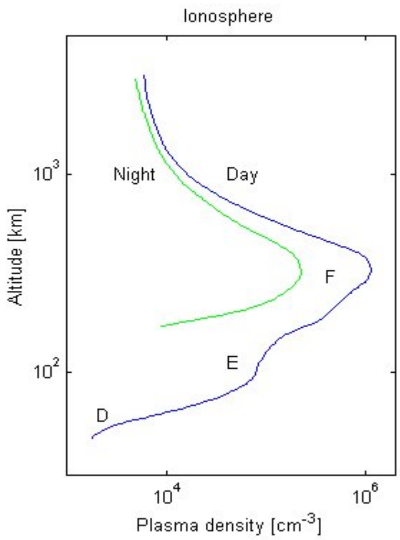

Fig.1. Earth's ionospheric regions

1. D-Region

The lower most region of the ionosphere where the level of ionization is too slow. This is due to the fact that the degree of ionization depends on the altitude of the sun. The ionization is primarily due to the hard X-rays, Lyman series-alpha absorption by nitric oxide. Because of the recombination rate is too high, this region is present only during the daytime and disappears at night.

2. E-Region

The E region (90-120 km) corresponds to a moderately dense layer composed of molecular ions, NO^+ and O_2^+ and the ionization is mainly due to the absorption of soft X-rays, far UV and the Schumann-Runge continuum radiation by molecular oxygen.

- Normal E-region

The region which lies just above the D region as narrow layer of ionization is known as normal E-region or Kennedy Heaviside region/layer. This layer occurs during day light and at night hours it remains as weakly ionized. The main function of E-layer is to reflect some of high frequency signals during day hours and it has appreciable effect on the direction of propagation of radio waves.

- Sporadic E-region

Along with the more stable D, E and F regions in the ionosphere, there is a presence of an anomalous ionization layer termed as Sporadic E regions (E_s) because its presence is much irregular. The E_s layer usually occurs in the form of clouds. The occurrence of this layer is unpredictable and may be observed in the day and night hours

3. F-Region

The F-region corresponds to a dense layer in ionosphere consist mainly of O+ ions and the ionization is mainly due to extreme UV radiations which ionize atomic oxygen. During day time the F region sometimes gets split into distinct layers such as F_1, F_2 and F_3 layers. F-region is the upper most ionized region which remains ionized irrespective of hours of days and seasons of years. In 1925, Appleton showed that there was another layer which is densely ionized at greater than Kennedy Heaviside layer (D-region). He concluded this prediction by hearing echo effect after sending short duration HF signals projected vertically upwards. These reflected echo signals indicated that there was a higher layer called Appleton or F layer.

The F layer found its importance because its ionization persists throughout the dark hours. The existence of F layer during night hours is due to the following facts:

- Being the topmost layer, layer will be highly ionized and ionization remains after sunset.
- Although ionization density is high, its actual air density is not much so most of the molecules are remain ionized.

During the day time after the sunrise F region is found to be split into as F_1, F_2, and sometimes F_3 layers. F_1 layer is the region where it approximately follows Chapman's law of variations. It is situated at an average height of 220 km and its behavior is like normal E- region. F_1 layer is formed by the ionization of oxygen atoms. Although some of the HF waves are reflected from the F_1 layer but mostly penetrate it and are reflected from the F_2 layer. Hence the main purpose is of F_1 layer is to provide more absorption for HF waves. F_2 layer is the uppermost region situated at a height of about 250-400 km, being highest in height the air density is so low that the ionization disappears very slowly. F_2 layer is formed by the ionization of UV rays, X-rays etc... The ionization in F_2 layer is largely effected by Earth's magnetic field, ionosphere tides and winds, ionosphere storms and other geomagnetic disturbances. The ionization density of F_2 layer shows large change with solar activity and change from sunspot minimum to sunspot maximum is high for this layer. Unlike F_1 layer, F_2 layer does not follow Chapman's law and shows a number of irregularities. Splitting up of F_1 and F_2 layers is produced by tidal effects and increasing temperature with increasing height. F_2 layer is the most reflecting layer for HF radio waves.[1][2]

III. SPREAD F

Spread F is the term which denotes the presence of diffuse radio reflections from the F region of the ionosphere either superposed upon or replacing the specular reflection from the F layer. Spread F is a result of irregularities in the electron concentration in the F region. These irregularities will be aligned with the magnetic field as the conductivity of ions and electron parallel to the field is high and very much greater than that perpendicular to the field at F region heights(>200 km). This property allows the earth to be divided into 3 regions

1. An equatorial region where the geomagnetic field is nearly horizontal dip angle(0-25°)
2. A high latitude region where the field is nearly perpendicular to earth (60-90°)
3. A middle latitude region (between 25°-60°)

Spread F mainly of two basic types:

1. Frequency Spread F- applied to diffuse reflection from a height near to the maximum electron concentration hmF2
2. Range Spread F- diffuse reflection occurring at heights well away from hmF2

IV. EQUATORIAL SPREAD F

Equatorial spread F is a spectacular phenomenon in which equatorial F region ionosphere is reshaped after sunset. This was proved from the earliest observations using ionosondes, which showed that an occasion the reflected echo did not display a well-behaved pattern but was "spread" in range or frequency. This phenomenon was named as "Convective Equatorial Ionospheric Storms (CEIS).CEIS primarily occurs at night. Today, ESF refers to a wide spectrum of field aligned plasma irregularities that manifests themselves as bottom side spread in ionograms, bite outs in thermospheric air glow, plumes in UHF/VHF and HF radars and scintillations of UHF, VHF as well as GHz frequencies.

The major mechanism that plays the important well known generalized Rayleigh-Taylor instability, which is mainly caused by pre-reversal electric field enhancement indicating the uplift of F-layer bottom side.[3][4]

V. EVENING ENCHANCEMENT

During daytime the motion of the equatorial ionosphere due to the EXB drift is generally upward and during nighttime it is in downward direction. This electric field is produced by the dynamo effect of the E-region neutral winds. At dusk, the upward drift velocity increases for 1-2 hours prior to the drift reversal. This is termed as evening enhancement of the equatorial ionospheric electrical field. This characteristic is known to be the result of the dynamo effect of rapid changes in the E region conductivity at sunset. The simplified explanation is illustrated in the figure. The thermospheric neutral wind at equatorial F region blow eastward and this eastward motion of the neutral particles cause only ions to drift upward by collision. The electric field produced by the charge separation is projected onto the E region through magnetic field lines with high electric conductivity. As the F-region dynamo is a constant source with high internal resistance, it is easily short circuited by the E region with high Pedersen conductivity before sunset. During night, conductivity is reduced by the decrease in E region electron density creates a downward electric field in the F region. The EXB drift induced by this electrical field has the same direction as thermospheric winds. The electrical field created by the F region dynamo effect results a non-uniform E-W distribution of electric conductivity in the E region results a charge separation. Thus the eastward electric field is intensified immediately before the reversal of the electrical field drift. [4][5]

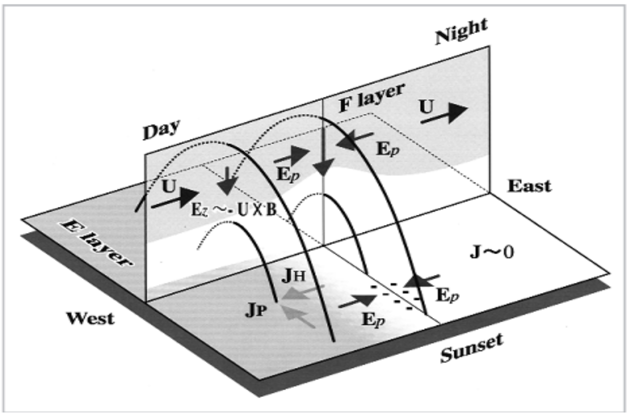

Fig: 2 Evening enhancement of equatorial ionospheric electrical field by the F-region dynamo

VI. THE GENERALISED RAYLEIGH-TAYLOR INSTABILITY

The primary mechanism for the generation of plasma irregularities is the Generalised Rayleigh Taylor Instability GRTI. This primary instability mechanism generates horizontal gradients on which secondary instabilities can operate giving rise to a spectrum of irregularities.

The plasma analogy of the classical GRTI occurs only when acceleration due to gravity 'g' is anti parallel to the electron density gradient ∇n with both of them are perpendicular to the magnetic field B. Such situation always exists in the equatorial bottom side of F-region.

The Growth rate of instability can be written as

$$\gamma_g = [-v_{in} + (v_{in} + 4g/L)^{½}]/2 - \beta \qquad (1)$$

where, v_{in} is the ion-neutral collision frequency, L is the gradient plasma scale length and is $L = N(\partial N/\partial h) - 1$, Nis the electron density and h is the altitude, β is the attachment coefficient in the F region. (1) reduces to :

$$\gamma_g = g/\, v_{in} L - \beta \quad \text{for} \quad v_{in}^2 > 4g/L \qquad (2)\ \&$$

$$\gamma_g = (g/L)^{1/2} - \beta \quad \text{for} \quad v_{in}^2 < 4g/L \qquad (3)$$

(2) and (3) represents the Collisional and Collisionless Rayleigh Taylor regimes respectively.

This mechanism can operate only in the bottom side F-region where the electron density gradient is upward where as ESF has been observed also in the top side F-region well above F-region peak. The RT instability mechanism in its generalised form includes both E×B instability mechanism and neutral wind effects. When E×B is parallel to ∇n the electric field is destabilizing and the linear growth rate due to electric field is given by,

$$\gamma_E = E/BL \qquad (4)$$

For altitudes above 300kms, γ_E is in general less than γ_g. Thus during the post sunset period, a westward electric filed electric field can make the bottom side of the F region unstable if downward density gradient is present.

The instability mechanism in the region from 100 km to the F peak. They found that the well below the bottom side F region the RT mode could be driven by a eastward neutral wind in the presence of vertical electron density gradient. The growth rate due to this mechanism is given by,

$$\gamma_{EW} = U/L(\, v_{in}/\Omega_i\,) \qquad (5)$$

Ω_i is the ion gyro frequency.

At about 140 km the ratio v_{in}/Ω_i less than unity and it decrease rapidly with altitude. This mechanism would become important for the ESF in the valley region between E and F region also later in the night when F region decreases to lower altitudes. The role of vertical winds on growth of the Collisional RT instability in the linear region and growth rate as:

$$\gamma_{VW} = -W/L \qquad (6)$$

Where, W is the upward wind. They found that the effect of vertically downward wind can be more effective than the gravitational term in triggering the instability in the altitude region 200-300 km.

A zonal neutral wind (U) eastward can be destabilizing in the presence of horizontal gradient of electron density. The cross field instability occurs when E×B has a component parallel to the density gradient where E' is equal to [E+(U×B)]. The growth rate due to the action of zonal neutral wind is given by:

$$\gamma_{ZW} = U/L \qquad (7)$$

Where, L= N $(\partial N/\partial y) - 1$ and y is the elemental length along eastward direction.

Considering the various growth rate mentioned above, the effective linear growth rate of the irregularities generated through GRTI can be written as:

$$\gamma = \frac{g}{Vin\ L} + \frac{E}{BL} + \frac{U\ vin}{L\Omega i} - \frac{W}{L} + \frac{U}{L} - \beta \qquad (8)$$

The first four terms depends upon the vertical gradient of electron density whereas the fifth term depends upon the horizontal gradient. [4][5] [6][7].

VII. EXPERIMENTAL SETUP AND METHOD OF ANALYSIS

The ionosonde data obtained from Trivandrum (8.5 ° N, 76.9 ° E, and dip latitude 5.5 ° N) is used for this study. In this present study we use digital portable sounder ionosonde .Data corresponding to the ESF occurrence during the year 2009, 2010, 2011, 2012, 2013, 2014(solar minimum to solar maximum) in equinoctial month (march) are used here.

VIII. RESULTS AND DISCUSSION

Here we analyzed datas from the year 2009-2014 considering both low solar activity and high solar activities in solar cycle. The month of March is taken here for study since it is an equinoctial month (means of equal time of day and night).

From R-T instability theory we understood the importance of plasma scale length L in determining linear growth rate determination. From ionogram, base height h'F and plasma scale length L are obtained. The h'F value and L value for quiet days of the years 2009 to 2014 obtained from ionograms are plotted by taking h'F as X-axis and L as Y-axis. The figures given below shows the graph.

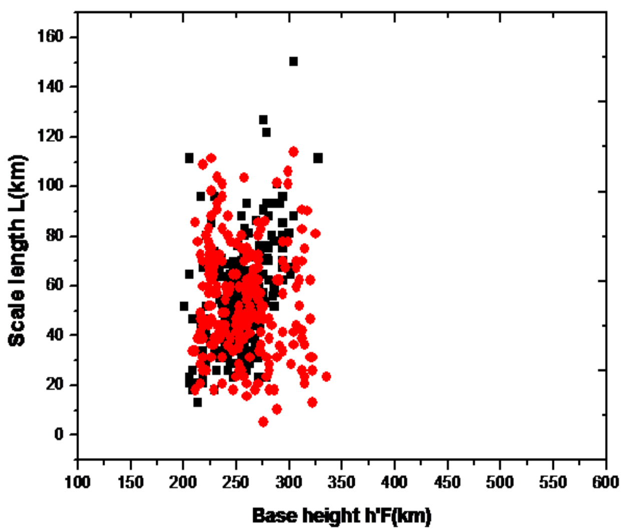

Fig: 1.a

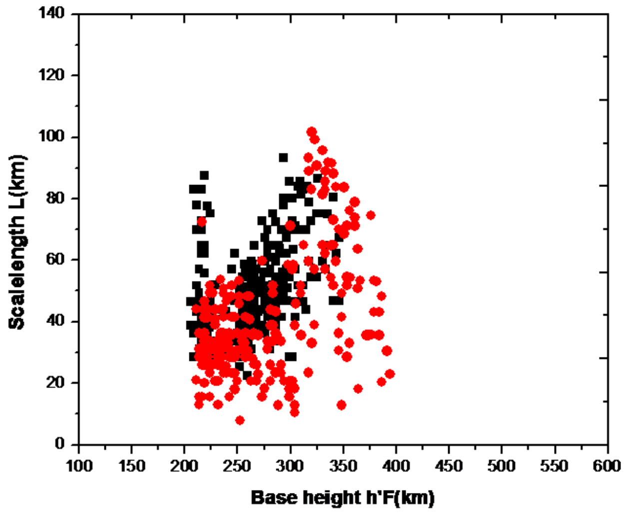

Fig: 1.b

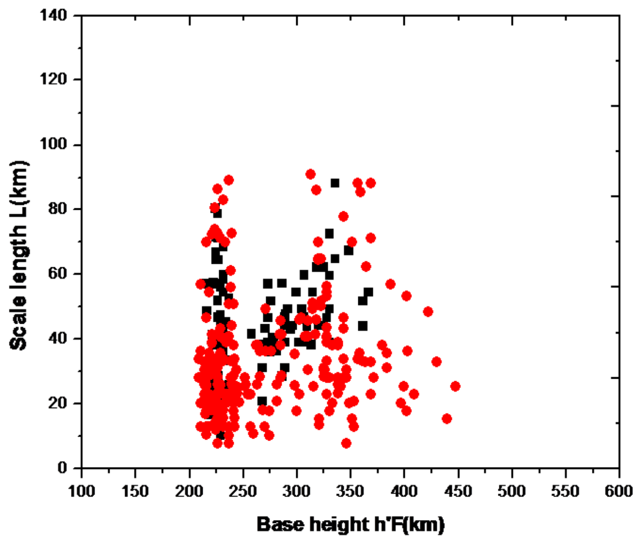

Fig: 1.c

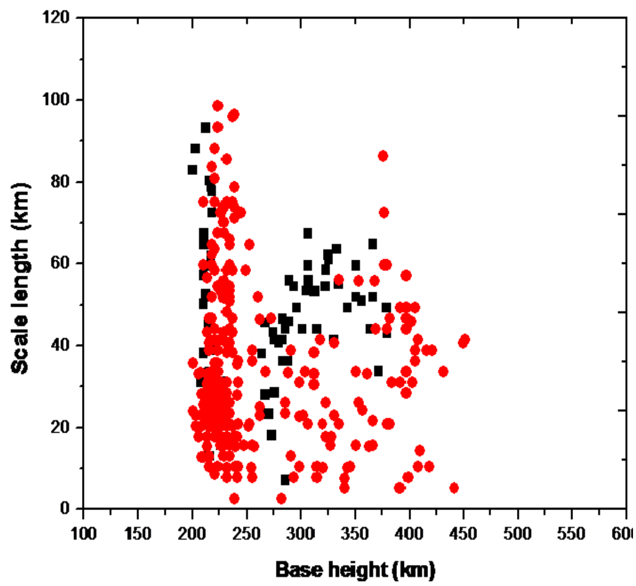

Fig: 1.d

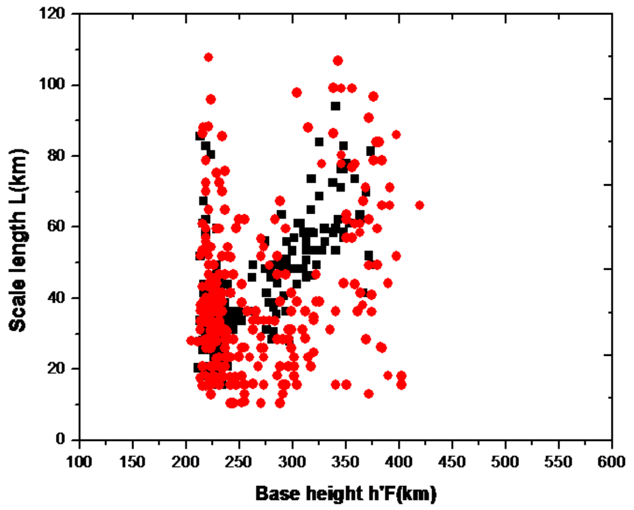

Fig: 1.e

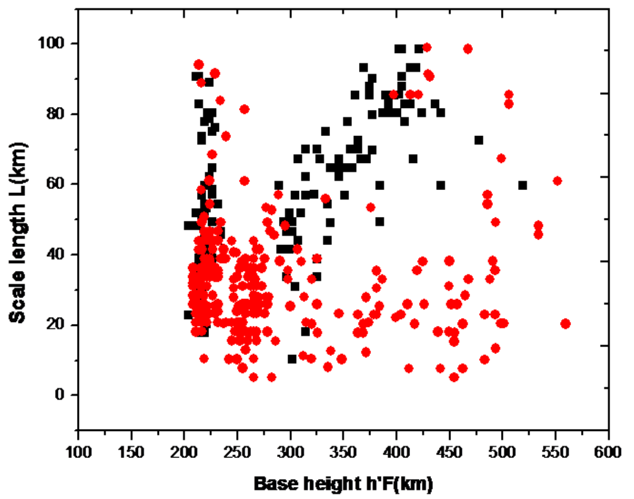

Fig: 1.f

In the graph, red spots or scatter shows spread F and black colour spots indicates non spread F. From the graph it is clear that from low solar activity period to high solar activity period plasma scale length of spread F region comes closer to a range between 10 km to 45 km. This indicates solar activity depends on the plasma scale length L.

IX. CONCLUSION

This paper is intended to provide a brief overview of equatorial spread f (ESF) and linear theory behind ESF. From RT instability theory it is clear that Plasma Scale Length L varies inversely to the linear growth rate. Hence L plays an important role in determining instability growth rate. Therefore, it is necessary to find out the factors which affect the value of L and has any dependence on solar activities. From the figures it is clear that L value has some change in response to low solar activity time to high solar activity period. So a detailed study regarding this is required.

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