Equatorial spread F echo and irregularity growth processes from conjugate point digital ionograms

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Abstract

Spread F irregularity signatures in the form of range spreading F layer traces are examined in Digisonde ionograms from dip equatorial and conjugate sites in Brazil, to determine the dominant process/mechanism of echo returns from the irregularity structures. A significant component of the ESF echo structures is found to be consistent with them originating from coherent back-scattering at field line perpendicular directions. The spread range of the echoes is found to increase linearly with the top frequency of the echo trace. Further, the irregularity strength is asymmetric at conjugate sites.

1.Introduction

Plasma irregularities of the nighttime F-region ionospheric are known to be magnetic field aligned density structures with wide ranging (several orders of magnitude) transverse scales sizes that are responsive to diagnostics by diverse types of radio, optical, and in situ observational devices. Ionosonde observation identifies them as diffuse echoes in the ionograms that constitute the spread in the F layer traces, in range and frequency, generally known as 'spread F'. Both the range and frequency types of the spread F have been the subject of extensive investigation at middle and low latitude since several decades. Over the equatorial latitudes the most widely investigated class is the range types spread F and the generic name, the equatorial spread F (ESF), is now representative of the composite of the equatorial night time F region plasma structuring that span from meter to several hundred kilometer scale sizes. A recurring question remains to be the one concerning the bandwidth of the irregularity structures required for interpreting the ionogram spread F traces, which inevitably should invoke mechanisms for radio signal returns from the irregularities. The considered mechanisms include total reflection from over dense structures (e.g., [1, 2, 3]), and references therein) (See also, [4]) to partial reflection or Rayleigh scattering from small irregularities [5, 6] and to Bragg backscattering (or coherent scattering) by plasma density fluctuations with scale size of $\lambda/2$, λ being the radio wavelength. Depending upon the detailed features that can be identified in well resolved spread F traces one or more of the above mechanisms can be invoked for interpreting them. For example, the midlatitude spread F traces often appear to be superposition of unresolved F layer traces arising from total reflection in oblique direction coming from surfaces of undulations with strong horizontal gradient in dense plasma. There have been suggestions in the literature [1, 3] favoring the total reflection processes as responsible also for the spread F traces in the equatorial ionograms. This question, however, appears to be far from being resolved as new results from modern digital ionosondes do show strong evidence of the dominating presence of field line perpendicular back scatter echoes [7] constituting the major features of spread F traces over equatorial latitudes. Based on the ionograms recorded at dip equatorial and conjugate point sites in Brazil we present evidence showing that the major characteristics of the spread F trace development during an instability growth process can be compatible with the process of coherent backscattering by irregularity scales sizes of half the radio wave length, even in the presence of multiple unresolved traces that could be originating from total/partial reflection process. The Digisonde ionograms also reveal the nature of irregularity cascading process during the growth of an event.

2. Results and Conclusions

Fig. 1 shows some examples of the ionograms to illustrate how the echo range spreading in the F layer trace and the top frequency of the received echoes evolve with time in successive ionograms. These echoes arise from the irregularity structures at the bottom side of a growing/decaying bubble as seen by the Digisonde. The left panel illustrates a growth phase of spread F trace over Fortaleza starting at 2150 UT (1850 LT) in which we note clearly

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that the echo range spread increases from around 60 km at 2150 UT to around 200 km at 2220 UT when correspondingly the top frequency (fop) of the spread echo trace increased from around 4 MHz to 15 MHz. An exactly opposite trend is evident in the ionograms on the right panels that illustrate the decay of an event over Boa Vista. If the signal returns originate from coherent back-scattering by irregularities having scale sizes half the wave length of the probing radio waves, then the fop would represent the smallest scales sizes of the evolving/cascading irregularities. Thus it is interesting to see that as the irregularity scale sizes become smaller in successive ionograms the range spread from larger scale size irregularities (that is, at smaller frequencies) increases within the antenna beam. It is our present understanding that large scale plasma bubble development by the Rayleigh-Taylor mechanism is accompanied by formation of smaller scale structures in cascading process through secondary instability processes operating at the steepening density gradients regions of the larger scales structures [8]. The consistency between this mechanism and the results in Fig 1 appears to suggest that the process of coherent backscattering is a dominant one in the formation of spread F traces in the ionograms recorded by the Digisondes, in addition to the contribution from unresolved oblique traces from total reflection that may also be present as discussed in the literature.

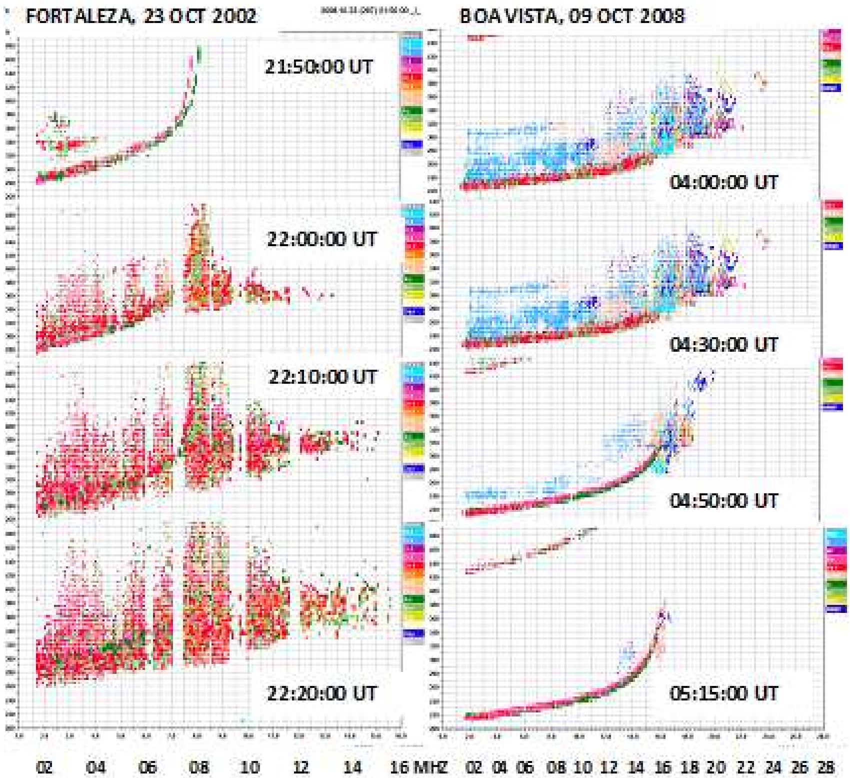


Figure 1: (left panels) Ionograms from the DPS-4 over Fortaleza showing the initiation and growth of the spread F trace at successive 10 minute interval starting at 2150 UT (1916 LT). The top frequency of the spread F trace (fop) varied from 4 MHz at 2150 UT to 16 MHz at 2220 UT and the spread range correspondingly increased from approximately 60 km to 200 km. The right panels show the recovery of an event over Boa Vista. (The x-axis frequency scale is also shown magnified)

Fig. 2 shows the monthly mean values of the fop plotted against the corresponding monthly mean of the spread range (in km) of the F layer trace over Sao Luis for all the months of the year 2002. The near linear dependence between the two parameters is consistent with the result presented in Fig.1, which therefore suggests that the intensity of a range spread F event (or plasma bubble event) can be quantified in terms of the parameter, fop. This appears to be a more reliable indicator of the spread F intensity than the (widely used) spread range index that can

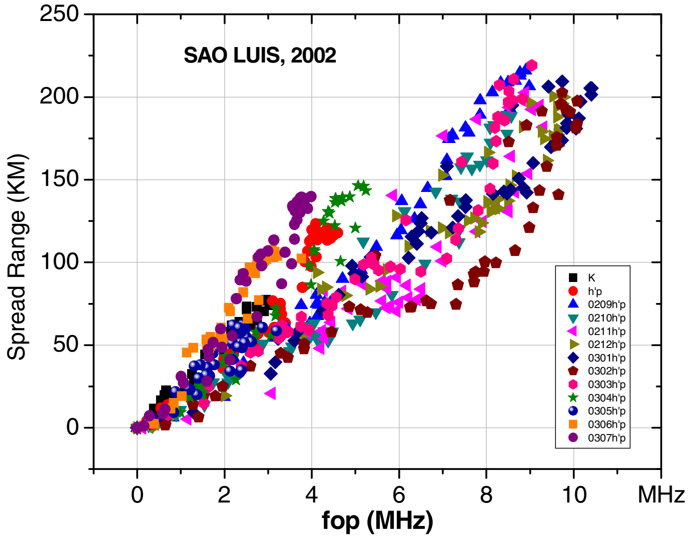
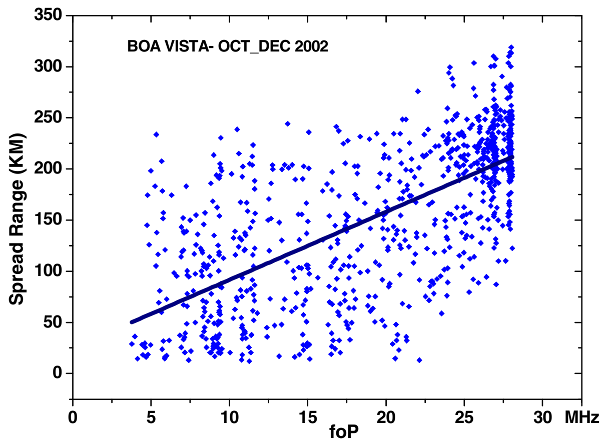


Figure 2: Monthly mean fop values at 15-minute data cadence over Sao Luis plotted against the corresponding mean spread range in km for all the months of the year 2002.

vary drastically with frequency. Fig. 3 shows similar plots as in Fig.2 but for all the individual data points at five-minute cadence over Boa Vista (BV) obtained for all the COPEX Campaign days [9]. Large degree of scatter of points may be noted.



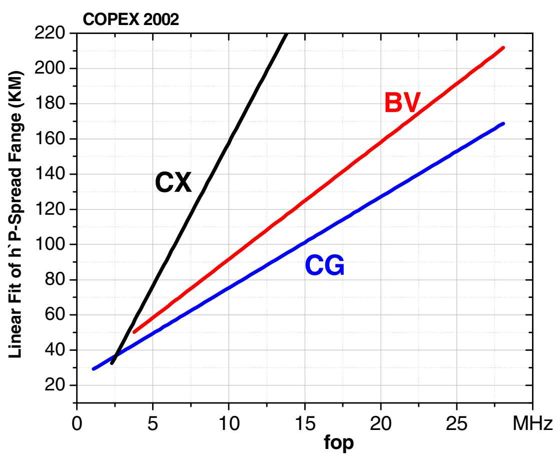


Figure 3: fop values and the corresponding spread range in km from 5-minute ionograms over Boa Vista, the northern conjugate site of the COPEX -2002 campaign in Brazil. A linear fit line is also shown. Note that the fop values are truncated at the 28 MHz which is the upper limit of the DPS-4 frequency sweep.

Figure 4: The linear fit lines similar to that shown in Fig. 3 obtained for the COPEX equatorial site Cachimbo (CX) and the conjugate sites Boa Vista (BV) and Campo Grande (CG) all plotted together for comparison.

In Fig 4 we compare the means trends of the range spread versus fop distribution (linear fit curves) over the two magnetically conjugate sites, BV, and Campo Grande (CG) and over the equatorial site Cachimbo (CX) of the COPEX campaign. We note significant difference in the mean trends between the magnetic equatorial site as compared to the conjugate sites. Also there is significant asymmetry in the trends between the conjugate sites, the spread range over BV being larger than that over CG, for a given value of fop, which might attest to the fact that the irregularity strength and therefore the polarization electric fields that drive them do not map along the entire field line connecting the conjugate points. This is due to the smaller scale sizes of the irregularity structures producing the range spread traces at the conjugate sites, although the larger scale bubble polarization electric field must be the basic driver for the irregularity cascading process at both ends of the field line. In contrast to this, the larger structures (of the order of 10 km-sizes for the first Fresnel zone) required for total reflection process should map along the entire field lines between the conjugate points that should provide a degree of symmetry of the spread F traces, which is not fully observed. The shorter scale size of the irregularities responsible for the range spread echoes as suggested in these results could lead us to the conclusion that coherent back-scattering is a dominant process responsible for a significant proportion of the spread F echoes in equatorial ionograms recorded by digital ionosondes (Digisondes in this case). More discussion and explanation will be given in an extended paper.

3. References

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