Relationship between strong range spread $F$ and ionospheric scintillations observed in Hainan from 2003 to 2007

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[1] Data from a DPS-4 Digisonde and an ionospheric scintillation monitor, both located at the low–latitude station Hainan (109.1°E, 19.5°N; dip latitude 9°N), were analyzed to study the strong range spread $F$ (SSF) and its correlation with ionospheric scintillations observed in the period of declining solar cycle 23 from 2003 to 2007. The results show that the maximum and minimum of the occurrence of SSF appeared in nearly the same months as those of the GPS $L$ band scintillations. The variations in SSF occurrence were also similar to those of the scintillations. From 2003 to 2007, both the SSF and the scintillation occurrences decreased from the high solar activity year to the low solar activity year. The correlation coefficient between the occurrences of the SSF and the GPS $L$ band scintillation was as high as 0.93, suggesting associated mechanisms producing SSF and scintillations. Electron density depletions extending from the bottomside to the topside ionosphere are the likely cause explaining the high correlation.


1. Introduction

[2] More than 70 years ago, Booker and Wells [1938] interpreted the spread characteristics on ionospheric $F$ layer echo traces, named spread $F$ (SF), as being caused by irregularities in the ionosphere. This spread $F$ phenomenon has since been investigated using different techniques such as ground-based ionosondes, Global Positioning System (GPS) receivers, incoherent and coherent scatter radars, satellite-borne topside sounders, and in situ measurements [e.g., Fejer and Kelley, 1980; Basu and Basu, 1985; Reinisch, 1986; Mathews et al., 2001]. For equatorial latitudes the morphological characteristics of spread $F$ have been described for different longitudes as a function of spatial, temporal, solar cycle, and magnetic activity variations [e.g., Aarons, 1993; Abdu et al., 1983a, 1983b; Kil and Heelis, 1998; Wang et al., 2008]. Some basic features of SF at low and middle latitudes (such as the variations with longitude, season, and the day-to-day variability) are still not properly understood.

[3] Ionospheric scintillations observed on transionospheric satellite signals are also considered to be caused by ionospheric irregularities, and they are expected therefore to associate with SF. Simultaneous and collocated observations of spread $F$ and scintillation can provide the data to study the mechanism and understanding of the physical processes underlying the phenomena of spread $F$ and scintillation. Concurrent scintillation and spread $F$ studies have previously been conducted. For example, de Medeiros et al. [1983] analyzed very high frequency (VHF) scintillation and range spread $F$ observations made at two Brazilian stations in 1978 and found close associations in the occurrences and durations. Rastogi et al. [1989] compared VHF scintillation and spread $F$ occurrences at two Indian stations for April 1983 to December 1984 and found that scintillations will be strong and fast only when the spread $F$ occurs over the entire frequency range of the $F$ layer echo traces. Iyer et al. [2003] made a statistical comparison between spread $F$ and VHF scintillations observed at two pairs of sites in India for the years 1987–1989. Their results show no similarity of the statistical patterns at either one of the two pairs, except during the solar maximum epoch. We conclude therefore that the relationship between scintillation and spread $F$ is still an open question and that the analysis of concurrent Digisonde spread $F$ and GPS scintillation observations in the East Asian longitude sector during the declining solar cycle 23 from 2003 to 2007 can add to our understanding of the physics mechanisms involved.

2. Data Analysis and Results

were installed at Hainan, a low‐latitude station in southern China (109.1°E, 19.5°N; dip latitude 9°N), in March 2002 and July 2003, respectively. The Digisonde recorded ionograms at 15 min intervals, and the GPS Ionospheric Scintillation Monitor logged the signal intensity at a high data rate of 50 samples per second simultaneously in up to 11 channels [Shang et al., 2008].

The Digisonde observed four types of SF at Hainan: range SF (RSF), strong range SF (SSF), frequency SF (FSF), and mixed SF (MSF). The definitions of FSF, RSF, and MSF are given in the handbook issued by Piggott and Rawer [1972]. The branch type of spread F (BSF), also described in the handbook, is never seen at Hainan; however, another type of RSF, which we call strong range SF (SSF), is often observed. It is similar to the spread F shown by Sales et al. [1996, Plate 1]. Figure 1 shows an example of the SSF observed at Hainan.

[6] The SSF is characterized by extended range spread on F layer echo traces that significantly extend beyond the local $f_{0}F_2$ value, like the trace in Figure 1 that extends beyond 20 MHz, while the local $f_{0}F_2$ is estimated at ~11 MHz. Such conditions often last for more than 2 h. Our analysis categorizes SSF as an independent type of SF that is not included in the RSF classification.

[7] Our analysis of SSF and GPS L band scintillation data from Hainan reveals that SSF and scintillations usually occur simultaneously while FSF, MSF, and RSF do not correlate well with scintillations. Figure 2 shows SF and scintillation activities for four 3 d time intervals, 6 to 8 March (first panel), 9 to 11 May (second panel), 26 to 19 August (third panel), and 11 to 13 September (fourth panel) in 2004. The vertical lines show the amplitude scintillation index $S_4$ which is defined as the ratio of the standard deviation of the signal intensities to their average, which was calculated every 1 min [Kil et al., 2002]. Triangles, diamonds, dots, and squares show the occurrence of FSF, RSF, RSF, and SSF, respectively, and their positions show that the SF occurred in the corresponding time period only.

[8] For the four periods shown in Figure 2, scintillations are almost always accompanied by SF, but SF is not always accompanied by scintillations. However, SSF and scintillation always occurred together in the same nights. Although their durations and beginning and end times differ slightly,
Figure 3. Statistical result of the occurrence of SSF (blue dashed line) and GPS L band scintillations (red solid line) in 2004, which shows that SSF and scintillation have very similar variation trends in occurrences.

Figure 4. Seasonal variations of (a) RSF (blue squares), SSF (black diamond), and scintillation (red star) occurrences and (b) FSF (blue triangle), SSF (black dot), and scintillation (red star) occurrences from July 2003 to June 2007. Only the SSF has a good correlation with scintillation.
there is clear evidence of an excellent companion relationship between SSF and scintillations. The differences are likely explained by the different ionospheric volumes through which the satellite signals travel depending on the different azimuth and elevation angles of the GPS satellites and the temporal-spatial scales of the irregularities in the ionosphere [Aarons, 1993; Thomas et al., 2001].

Figure 3 provides a statistical assessment of the occurrence of SSF and GPS L band scintillations in 2004. The seasonal variations of SSF (blue dashed line) and GPS L band scintillations (red solid line) occurrences are very similar. The occurrence rate of SSF is the ratio of SSF days (days on which SSF occurred at the same time as the scintillations) to the total number of Digisonde observation days. The occurrence rate of scintillations is the ratio of scintillation days (days on which at least one scintillation event with $S_4 > 0.2$ occurred) to the total number of reliable ionospheric scintillation observation days.

Both distribution curves show maxima in the equinoctial months that are significantly higher than the summer and winter values. The SSF occurrence maxima are 31% in spring and 43% in autumn, and the corresponding scintillation maxima are 43% in the spring and 45% in autumn. The minimum occurrence rates in summer and winter are around 10% or less.

With the exception of June, Figure 3 shows that the scintillation occurrence rates are generally higher than the SSF rates. This is expected, since the Digisonde samples a smaller region in the ionosphere over Hainan than the scintillation measurements, which include zenith angles of arrival of up to 65°.

Just as for Figure 3, we also compared the scintillation occurrence with the occurrence of other SF (i.e., FSF, MSF, and RSF). The results show no similarity in variations of occurrences between the scintillation and any other SF.

Figure 4a shows the occurrence rates of SSF, RSF, and scintillation, and Figure 4b shows the occurrence rates of FSF, MSF, and scintillation for four consecutive years extending from high solar activity in 2003 to low solar activity in 2007. From Figure 4a we can see that the values of the maxima are significantly lower during solar minimum both for RSF/SSF and scintillation (there were no data from September to November 2005). Overall there is good correlation between SSF and scintillation occurrences, and the correlation coefficient is $r_{SSF} = 0.93$. The RSF occurrence rate has a much smaller correlation with the scintillation occurrence; the correlation coefficient is only $r_{RSF} = 0.58$. Figure 4b suggests that there is no correlation between FSF or MSF and scintillation occurrences since the correlation coefficients are $-0.15$ for FSF and $-0.29$ for MSF.

Our analysis indicates that occurrence of RSF, FSF, and/or MSF is not a reliable indicator of scintillations, while SSF has a good correlation with GPS L band scintillations.

3. Discussion

Our analysis, summarized in Figures 2, 3, and 4, indicates that SSF is closely associated with GPS L band scintillations in terms of the daily and seasonal variations at Hainan station; in other words, SSF can serve as a proxy for scintillations. Some authors also have studied correlations between SF and scintillation. For a comparison, Table 1 lists the correlations between SF and scintillation at low-latitude stations in Brazil, India, and China, as our Hainan station is located in a low-latitude region. In Table 1, we should note that for studies 1 and 2, SF and scintillation were observed at different stations and in only 1 year or less than 2 years, respectively [de Medeiros et al., 1983; Rastogi et al., 1989]. For study 3 (the current study), they were observed at the same station from the high solar activity year to the low solar activity year (about 4 years).

From Table 1, we can make a comparison for the correlations. In study 1, only RSF had close associations with scintillation in occurrences and durations [de Medeiros et al., 1983]. In study 2 the result showed that scintillation will be strong and fast only when SF over the entire frequency range from April 1983 to December 1984. However, in study 3 (the current study), it was the SSF that had a good correlation with scintillation.

Sales et al. [1996] had used retracing to establish that the spread traces on equatorial region ionograms are the result of off-vertical echoes that return from field-aligned irregularities in depleted density regions. They had identified the equatorial density depletions or ionization troughs using 660 nm all-sky imagers and compared them with Digisonde sky map [Reintisch et al., 1998]. During SSF conditions the bottomside depletions reach to the topside ionosphere where they are generally classified as plumes [e.g., Kelley, 1989, and references therein]. Field-aligned F region irregularities at the walls of the depletions produce strong coherent backscatter that appears as SSF on the ionograms [Sales et al., 1996]. Abdu et al. [1983a, 1983b] and Whalen [1996, 1997] reported that the equatorial “plasma bubbles” or “plumes” at and above the F2 peak are the cause for scintillations. Rodrigues et al. [2004] found that strong scintillations (high S4 values) were observed concurrently with strong coherent VHF radar echoes. Chen et al. [2006] had shown a good correlation of GPS phase fluctuations with Digisonde SF in western South America and that strong GPS phase fluctuations are associated with the occurrence of topside plumes.
In the present paper we have shown that only the strong range spread $F$, SSF, has a high correlation with ionospheric scintillations. We therefore conclude that the plasma configurations causing ionospheric SSF and scintillation are the same, namely, the existence of plasma depletions that reach from the bottomside to the topside of the F2 layer. Observation of these equatorial density depletions at Hainan confirms the results that were previously obtained mainly for the American sector [Sales et al., 1996; Whalen, 1996, 1997; Lee et al., 2009].

4. Summary and Conclusions

We have analyzed strong range spread $F$ (SSF) and ionospheric scintillation data from a low-latitude station, Hainan, recorded from 2003 to 2007 and have established the relation between low-latitude SSF and GPS L band scintillations. The results show that seasonal SSF and scintillation occurrence patterns are very similar with maxima and the minima occurring in the same months. From 2003 to 2007, the occurrence rates for both the SSF and the scintillation were decreasing from higher solar activity year to lower solar activity year. The correlation coefficient between the occurrences of the SSF and the GPS L band scintillation was as high as 0.93, indicating a good correlation of SSF with GPS L band scintillations in the low-latitude ionosphere. Since the scintillations are caused by topside density bubbles while spread $F$ is mainly caused by bottomside irregularities, it can be concluded that during SSF conditions $F$ layer depletions extend from the bottomside to the topside ionosphere.

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References


