Correlations between Strong Range Spread-F and GPS L-Band Scintillations
Observed in Hainan in 2004 *

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Data from the DPS-4 digisonde and the GPS L-band ionospheric scintillation monitor are employed to study the correlations between strong range spread-F (SSF) and GPS L-band scintillations observed in the ionosphere over Hainan Island, China (19.5°N, 109.1°E geogr., dip lat. 9°N) in 2004. The SSF in the ionogram is different from the general range spread-F because it extends in frequency well beyond FoF2 and makes FoF2 difficult to be determined. The observations show that the SSF phenomenon is frequently accompanied by the occurrence of GPS L-band scintillations. The SSF and GPS L-band scintillations occur frequently in the equinoctial months (March, April, September, and October), but rarely in the winter (January, February, November, and December) and summer (May–August); especially, occurrence variations of the SSF and GPS L-band scintillations nearly have a same trend. The SSF and scintillations may be associated with the occurrence of topside plasma bubbles and could be explained by the generalized Rayleigh–Taylor instability.

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The spread-F was first noticed by Booker and Wells.[1] These phenomena concerning the irregularities in the ionosphere have been studied by different available techniques, such as ground-based ionosondes, global positioning system (GPS) receiver, incoherent scatter radar (ISR), satellite borne topside sounders and in-situ measurements.[2–4] Their morphological characteristics at different longitudes of equatorial latitudes have been described as a function of spatial, temporal, solar cycle and magnetic activity variations.[4–9] Up to now, some basic features of these phenomena at low and middle latitudes (such as the variations with longitude, season, and from day to day) are not properly understood. The scintillations of radio waves are considered to be caused by ionospheric irregularities and they should associate to the spread-F. Good collocated spread-F and scintillation observation simultaneously can provide a better basis to study the mechanism and to understand the physical processes of ionosphere irregularities.

A great deal of attention has paid to concurrent scintillation and spread-F. De Medeiros et al.[10] made a comparison on VHF scintillation and the spread-F respectively observed in two Brazilian stations and found that they are closely associated in the occurrences and durations. Rastogi et al.[11] also compared the VHF scintillations with the spread-F respectively observed in two Indian stations and found that the scintillation will be strong and fast only when the spread-F is over the entire frequency range. Iyer et al.[12] made a statistical comparison between the spread-F and the VHF scintillation observations over two pairs of sites in India. Their results show that there is no similarity of the statistical patterns at both pairs of sites, unless in the duration of solar maximum epoch. Therefore, the relationship between the scintillation and spread-F is still an open question. In this Letter, we investigate the correlation between the strong range spread-F and L-band scintillations simultaneously observed at the same station in Hainan, and obtain some new results.

Since our DPS-4 digisonde and GPS ionospheric scintillation monitor (ISM) were established at Hainan station (with 19.5°N, 109.1°E, dip lat. 9°N) in March 2002 and in July 2003, respectively, ionograms were recorded at 15-min intervals and GPS ISM can log the signal intensity at high data rate (50 samples/s) up to 11 channels simultaneously.[13] Each detectable presence of frequency spread-F (FSF), range spread-F (RSF) and mixed spread-F (MSF) is just based on the URSI Handbook of Ionogram Interpretation and Reduction.[14] The branch type of spread-F is never found in Hainan by the DPS-4 digisonde. However, another type of RSF, which is called the strong range spread-F (SSF) (the relevant ionograms are shown in Plate 1 in the paper of Sales et al.[15]), is often observed in the ionosphere above Hainan station. In this study, the SSF in Hainan is identified by two criteria: i.e., RSF extends to such a high frequency that the FoF2 could not be determined and often lasts at least 1 h. In Fig.1, there is an example of the SSF event observed with DPS-4 digisonde at Hainan station on 22 January 2004; it spreads over 20 MHz and the duration of the SSF is more than 2 h (from 12:00

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There are four types of spread-F (RSF, SSF, FSF, MSF) observed with DPS-4 digisonde at Hainan station, it is important to study the characteristics of each type of spread F and the relationship between the SF and the F region irregularities such as the ionospheric scintillation. Therefore, we analyse the data from the DPS-4 digisonde and GPS IMS in 2004 to draw a comparison between SSF and GPS L-band scintillations and to reveal the relationship between the ionospheric SSF and the scintillation, furthermore to understand the physics.

By analysing the SSF and GPS L-band scintillation data from Hainan station in 2004, we found that SSF and the scintillation usually occur simultaneously in daily variation.

Figure 2 shows four segment examples of SSF and GPS L-band scintillations accompanied with each other in the periods of 3/21-3/23, 4/19-4/21, and 5/17-5/19 in 2004. In Fig. 2, the upper real line with its length indicates the amplitude scintillation index $S_4$ which is defined as the ratio of the standard deviation of the signal intensities to their average, is calculated every 1 min.\[^{16}\] The down star line indicates the SSF occurred.

From Fig. 2, we can see in these periods that the SSF and scintillation occurred together in the same night. Although their duration, and beginning time and end time have a little difference, we can say that the SSF and scintillation have a good company relationship. The differences may owe to the different azimuth and elevation distribution of GPS satellites above Hainan station and tempo-spatial scale of the irregularities in the ionosphere.\[^{5,17}\] Maybe it also concerns the motion of the irregularities.

According to the observation, we made a statistic study on the correlation between the SSF and the GPS L-band scintillation. It shows a very interesting result that the SSF and the GPS L-band scintillation have a good correlation.

Figure 3 shows the seasonal variations of the occurrence rate of SSF (solid line) and GPS L-band scintillations (dashed line) in 2004. In Fig. 3, the occurrence rate of SSF is the ratio of SSF day (the number of days on which at least one SSF event observed at night of that day) to digisonde observation day (the number of days of digisonde observation). The occurrence rate of scintillations is the ratio of scintillation day [the number of days on which at least one scintillation ($S_4 > 0.2$) event is observed at night of that day] to the all observation day (the number of days on which ISM worked at night of that day).

Fig. 1. Examples of the SSF observed in Hainan station, and the duration of SSF is more than 2 h (from 12:00 to 14:15 UT) on 22 January 2004. Here, SSF is mainly different from the general range spread F because it extends in frequency well beyond FoF2 and makes FoF2 difficultly be determined. The different colours present the echoes from different directions.
For the SSF, the highest and lowest occurrence rates are 42% in October and 0 in December, respectively. During the equinoctial months, the SSF occurrence rate is nearly 30% in spring and about 40% in autumn. However, the monthly SSF occurrence rates both in the summer and winter are below 20%. Thus, we can obtain a conclusion that SSF occurrence rate is higher in the equinoctial months than those in the summer and winter. For the scintillation, the highest and lowest scintillation occurrence rates are 57% in September and 0 in December. During the equinoctial months, the scintillation occurrence rate is more than 45%, whereas it is below 25% during the summer and winter. Thus, we can also reach a conclusion which is the same as that for SSF, i.e. the scintillation occurrence rate is higher in the equinoctial months than that in the summer and winter.

From Fig. 3, we can also find the trend of SSF variation. In 2004, from January to April in which the occurrence rate increases, from April to May it turns to decrease, from May to June, it increases again, from June to July it turns to decrease again, from July to October it increases, and from October to December, it turns to decrease. For the trend of scintillation variations, we can also see from Fig. 3 that the occurrence rate exhibits a slight decrease from January to February, a sharp increase from February to April, and a rapid decrease from April to May and a little increase in June, then a decrease in July again, and then a sharp increase from July to September and a rapid decrease from September to December. We can see that SSF and scintillation variations nearly have a same trend in 2004.

The result of the investigation also indicates that SSF is usually accompanied with GPS L-band scintillations. Since GPS ISM can monitor a wider region of ionosphere above Hainan station than that of DPS-4, the number of scintillation days is usually larger than the number of SSF days in each month except for May and June in 2004.

From Figs. 2 and 3, it is found the SSF is significant associated with GPS L-band scintillations in daily and seasonal variations, and in the other word, SSF and scintillations could represent each other. In fact, Sales et al.[15] have used retracking to establish that the spread traces on equatorial region ionograms are the result of off-vertical echoes that return from field-aligned irregularities in the depleted region. The field-aligned F region irregularities produce strong coherent backscatter that appears as SSF on the ionograms and usually are associated with equatorial topside plasma bubbles, and cause scintillations.[6,7,18] The irregularities predicted by the generated Rayleigh–Taylor instability process[19] which concerns the ionospheric electric field, wind and conductivity, and so on. Therefore, the ionospheric SSF and scintillation seem to have the same mechanism, but they still need to be studied further.

We analyse the data of SSF and GPS L-band scintillations observations in the low latitude ionosphere over Hainan station. This analysis attempts to investigate the relationship between the low latitude SSF and GPS L-band scintillations occurrences, respectively, obtained by the DPS-4 digisonde and GPS ISM. The occurrence dependences of SSF and scintillations on season have also been examined in this work. The results show that the phenomenon of SSF frequently is accompanied with the GPS L-band scintillations, the SSF and GPS L-band scintillations occur frequently in the equinoctial (March, April, September, and October) months, but are rarely observed in winter (January, February, November, and December) and in summer (May–August). The occurrence variations of the SSF and GPS L-band scintillations nearly have the same trend and they seem to have the same mechanism.
References