# Investigation of spread F over Nicosia and Moscow during low and high solar activity

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## Abstract

Spread F is an ionospheric phenomenon which has been reported and analyzed extensively over equatorial regions. It has also been investigated over midlatitude regions, mostly over the Southern Hemisphere. Over midlatitudes it has, been correlated with geomagnetic activity, travelling ionospheric disturbances (TIDs) and F region uplifts, with Perkins instability proposed as the primary seeding mechanism. The present study deals with the diurnal and seasonal occurrence rate of spread F events observed over two stations at the same longitude namely Nicosia (geographic Lat: 35.29 °N, Long: 33.38 °E) and Moscow (geographic Lat: 55.50 °N, Long: 37.30 °E) during 2009 and 2014 encompassing periods of low, and high solar activity. The main finding of this investigation is the inverse solar cycle and significantly different annual temporal dependence of the spread F occurrence rate over Nicosia and Moscow.

## 1 Introduction

Range or frequency spread of the ionospheric F layer (spread F) is defined as the ionogram signature attributed to sudden plasma distribution at F-region due to the generation of field aligned irregularities with different scale sizes [1] or the tilted ionospheric surface produced by travelling ionospheric disturbances (TIDs). King observed spread F development over several midlatitude stations as large scale tilts of the bottomside F layer isodensity contours [2]. He suggested that rather than small scale irregularities, these large tilted patterns are primarily responsible for spread F generation in the nighttime midlatitude ionosphere.

The enhanced amplitude of gravity waves can accelerate the growth rate of the instabilities and induce irregularities in the nighttime midlatitude F layer. Singleton had presented the temporal variation of spread F occurrence throughout half a solar cycle over a network of stations (around 36 °S to 76°N) over the American longitudinal sector [3]. He suggested that during low solar activity, spread F would diffuse towards higher latitudes from lower latitude regions, whereas during high solar activity, high occurrence of spread F events may be observed frequently at higher latitudes. He also observed a clear difference between spread F characteristics during low and high solar activity periods in the vicinity of 50° (N and S) latitude.

In the midlatitude ionosphere, the occurrence of nighttime spread F is frequent, when compared with both high (≥60°) and equatorial (0°–±30°) latitude regions. Shimazaki studied the global latitudinal distribution of spread F. It was observed that the occurrence of equatorial spread F is limited to 20° latitude with maximum probability of occurrence at the equator, whereas the occurrence probability of high latitude spread F increases from 40° to 60° and maximizes beyond 60°[4]. He also noted that high latitude spread F is more severe than equatorial spread F. The occurrence of spread F also exhibits a significant latitudinal and longitudinal variability over midlatitude regions [5]. Singleton observed clear latitudinal variations in spread F occurrence [3]. He investigated seasonal and solar activity effects on spread F development with reference to latitude differences. Hajkowicz noted a sharp gradient of spread F occurrence along the equatorward direction at the latitude range between 52° to 48°S [6]. Huang investigated the longitudinal characteristics of the spread F occurrence using the IRI model which, provides lower accuracy over African and Indian low latitude stations [7]. Igarashi & Kato have carried out similar studies over different Asian longitudes [8]. The present preliminary study aims to investigate the underlying differences in the temporal variation of spread F statistics over Digisonde stations at Nicosia (Cyprus) (geographic Lat: 35.29 °N, Long: 33.38 °E) and Moscow (Russia) (geographic Lat: 55.50 °N, Long: 37.30 °E) during 2009, and 2014. It is necessary to mention that 2009 was an extremely low solar activity year, whereas 2014 was a relatively high solar activity year. The two stations Nicosia and Moscow lie almost along the same geographic meridian (the longitudinal difference between these two stations is ~4°). The diurnal, seasonal and annual occurrence of spread F and possible precursory spread F signatures on ionograms over Nicosia has been examined [9,10]. Over Moscow a study reported seasonal variability of nighttime spread F over the time interval 1975-1985, and a more recent one has established spread F detection using the results of an automatic spread F detection algorithm [11,12]. Another recent study focused on the longitude and latitude spread F occurrence differences over three European digisonde stations [13].

## 2 Data and findings

Figure 1 shows the locations of the stations involved in the analysis. In 2009, the yearly average sunspot number was 4.8 and in 2014, 113.3. Therefore the datasets that have been used correspond to the lowest, and highest solar activity levels of the previous solar cycle.


**Figure 1.** Digisonde locations in Nicosia and Moscow.

To identify the diurnal behavior of spread F, all ionograms corresponding to 2009 and 2014 over the two stations were visually inspected (noting the starting and ending times of the spread F cases under consideration) and the events have been depicted on annual-diurnal plots centered at midnight as spread F is considered primarily a night-time phenomenon. Figures 2-3 and Figures 4-5 represent the annual-diurnal occurrence characteristics for 2009 and 2014 over the stations of Nicosia and Moscow, respectively. The x axis represents the day of the year and the y axis represents the time of day (in UT). Therefore each black vertical line represents a certain spread F event indicating clearly the onset and ending time to reveal its actual duration, irrespective of its type which is usually categorized as FSF (Frequency Spread F), RSF (Range Spread F) or MSF (Mixed Spread F). Missing data intervals are represented with grey-shaded bars. According to Figure 2, spread F over Nicosia is observed during all four different seasons during the low solar activity year of 2009 with a clear spread F occurrence maximum during summer followed by winter and spring. A very limited number of spread F cases have also been recorded during fall. An interesting detail, that can be identified, is that during winter the duration of spread F maximizes followed by summer and spring. In spring, the maximum number of cases for spread F onset was observed during postmidnight periods whereas in summer and winter, the onset time is more random. For the same year (2009), over Moscow, we can see that spread F is almost a daily phenomenon during winter, spring and fall with lower occurrence during summer.

A certain lower time (~18:00 UT) for the onset time of spread F can be noted over Nicosia. In 2009 over Moscow we can also observe a clear seasonal variability of spread F occurrence with the onset and ending times coinciding with the solar terminator, therefore exhibiting a significant duration increase, compared spread F duration over Nicosia.

In 2014 the occurrence over Nicosia diminishes significantly with respect to 2009 with almost no spread F activity registered in any season, other than summer. A notable reduction in the spread F occurrence is also observed over Moscow although a seasonal pattern similar to 2009 can still be clearly identified in Figure 5. Based on the findings mentioned above, we can deduce that there is a clear inverse solar activity dependence over the probability of spread F occurrence rate over both stations. The onset time of spread F activity appears to be unaffected from solar activity, over both stations, though.

The notably higher occurrence rate over Moscow can be attributed to auroral activity that may excite TIDs. These TIDs are considered as an established spread F driver, especially under high geomagnetic activity. The equatoward propagation of generated LSTIDs as they propagate can also cause spread F activity over lower latitude stations such as Nicosia but most likely, these waves will dissipate or break up into MSTIDs as they propagate towards lower latitudes. According to Bowman and during high solar activity, the nighttime irregularity generation at lower midlatitudes is expected to diminish due to the increase of the neutral particle density in the upper atmosphere, which will tend to impose a lower TID wave amplitude. This in turn, will reduce and probability for nighttime TID excitation that will be reflected on a lower probability for spread F manifestation [14].

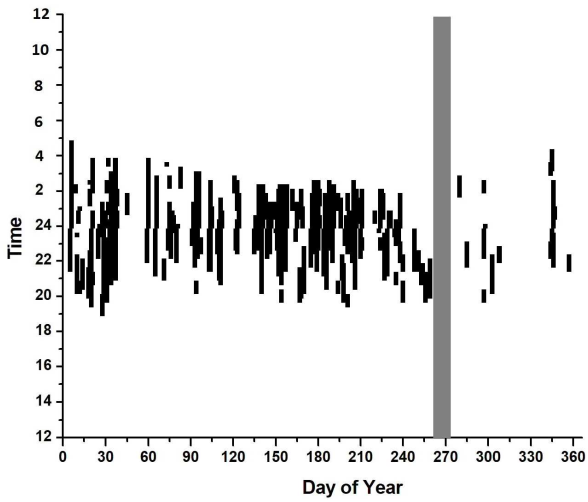


**Figure 2.** Daily-hourly occurrence of spread F over Nicosia during 2009.

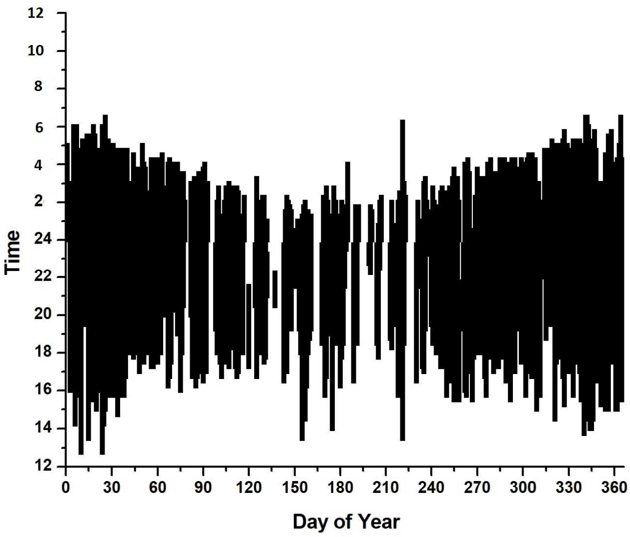


**Figure 3.** Daily-hourly occurrence of spread F over Moscow during 2009.

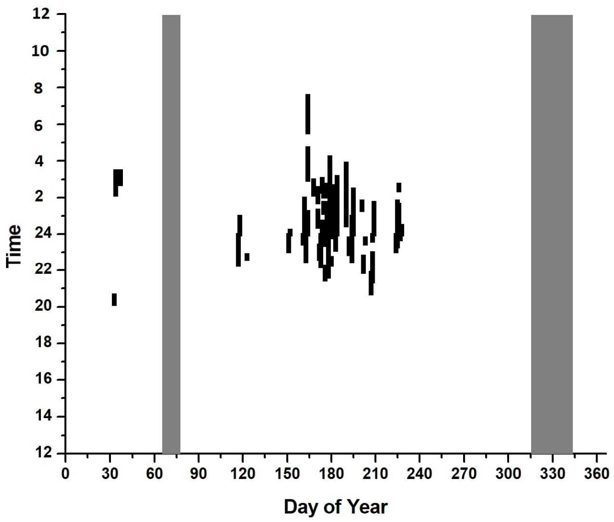


**Figure 4.** Daily-hourly occurrence of spread F over Nicosia during 2014.

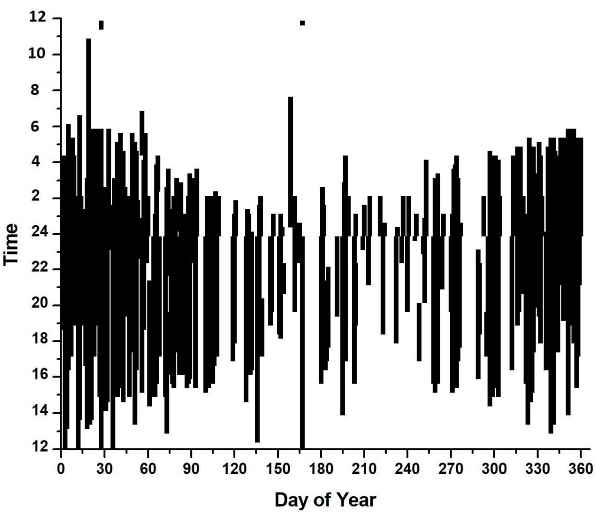


**Figure 5.** Daily-hourly occurrence of spread F over Moscow during 2014.

## 3 Conclusions

The present study deals with the occurrence rate of spread F events and their diurnal, seasonal and solar cycle variations observed from two stations in the same longitude sector (Nicosia and Moscow) in 2009 and 2014. The latitudinal characteristics over the same longitude range were therefore investigated The preliminary results presented here suggest that the annual peak of spread F occurrence over Nicosia which is located in the lower midlatitude region is observed during summer and is independent of solar activity followed by secondary occurrence maxima, which seem to depend on solar activity. Over Moscow, spread F seems to manifest almost every day during low solar activity with the annual maximum of spread F noted in winter. This feature is also during high solar activity.

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