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Signatures of TIDs and vertical drift of ionization spread F observed over Cyprus during high solar activity period

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Abstract

In an effort to explore the morphology of nighttime spread F at the lower mid-latitude European station of Nicosia, Cyprus (35ºN, 33ºE geographic; magnetic dip. 29.38°N), ionograms recorded by the DPS-4D digisonde during 2014 have been analyzed. Subsequent detailed investigation was performed to establish the possible effect of various triggering mechanisms on spread F within the framework of Perkins instability on a statistical basis by correlating particular spread F occurrence with particular wave pattern signatures (Satellite Trace/Multiple-reflected Echoes), travelling wave disturbances (TIDs), F layer uplift (h'F) and unstable sporadic E layers. Furthermore clear seasonal characteristics of spread F occurrence in lower European mid-latitudes is established

1. Introduction

In the last few decades several studies have been conducted to investigate mid-latitude spread F on a global scale. *Bowman* [1994] investigated the occurrence level of spread F with geomagnetic activity by using two high mid-latitude (50° to 60°) ionosonde stations Brisbane and Melbourne. Significant association was observed between geomagnetic activity recorded during early morning and the occurrence rate of spread F at one of the stations. *Bowman* [1985] discussed the distribution of mid-latitude spread E_s (sporadic E layer) according to diurnal, annual and solar activity variations and suggested that both mid-latitude spread E_s and spread F were generated by similar ionospheric disturbances. *Otsuka et al.,* [2007] have conducted a similar investigation over Japan on E region FAIs and MSTIDs from 630nm airglow images and MU Radars. These studies clearly point out that Es layers are somehow related to nighttime mid-latitude spread F generation, due to an electrodynamically coupled electric field between Es and F layer. *McNicol et al.* [1956] and *K.S.Paul et al.* [2018] using a set of mid-latitude stations had detected TID signatures, in the form of "Satellite Traces (ST)" in ionograms associated with mid-latitude spread F occurrence.

In the present paper, using the database of spread F observations over the ionosonde station located near Nicosia, Cyprus, a statistical characterization of spread F is presented over 2014. The detailed investigation was performed by correlating spread F occurrence with signatures of satellite traces (ST) and multiple-reflected echoes (MREs) in ionograms, TID signatures over drift measurements (Vz), F layer uplift (h'F) observations and spread E_s. Seasonal and diurnal occurrence of spread F is also investigated.

2. Methodology

A DPS-4D Digital ionosonde (Digisonde) has been operational since 2008 at the lower mid-latitude European station near Nicosia, Cyprus (35ºN, 33ºE geographic; magnetic dip. 29.38°N). It is capable of generating fast ionograms at an improved layer height resolution (~1250km) and plasma velocity measurements (e.g. meridional (V_x), zonal (V_y) and perpendicular (V_z)) by taking advantage of the Precision Group Height Measurement (PGHM) technique.

In the present analysis, the recorded ionograms over Nicosia, during 2014 have been considered with a resolution of 5 minutes. Once the ionograms were inspected, to determine the presence of nighttime spread F events over Nicosia, from 16:00 UT (UT=LT–2:30 hr) to 06:00 UT for each individual day during 2014 they were manually scaled in SAO explorer software (SAO). In the present paper, a case study of 27-28th June, 2014 (with Dst_{min} –8nT) is presented followed by statistical analysis of spread F observations, which has been performed for 2014. Based on this dataset, an effort has been undertaken to correlate possible triggering mechanisms and precursors to occurrence of nighttime spread F.

3. Results

3.1. Case study of June 27-28, 2014

The sequence of ionograms on 27-28 June, 2014 at Nicosia between 21:50-03:00 UT is shown in Figure 1 indicating the time evolution of range spread F (RSF).

The gradual development of RSF on the ionograms during that specific night indicates the presence of ionospheric irregularities with scale sizes of the order of kilometers [*Bowman,* 1990]. The oblique reflections as shown in the ionograms in accordance with the colour designation on the right of Figure 1 reveal the presence of wavelike structures in the form of ST [*McNicol et al.*, 1956; *K.S.Paul et al.* 2018] and MRE traces. In these ionograms the overhead O and X polarization traces are represented in red and green colour respectively and the direction of oblique traces is indicated according to the colour designation shown on the right side of Figure 1. The blue shades represent echoes from the North/East direction and Yellow shades represent echoes from the South/West direction. Oblique reflections from the West are identified at 21:50 UT and again West and SSE reflections are simultaneously recorded at 22:05 UT when the range ambiguity also starts to become evident After the gradual dissipation of these irregularities at the lower F region, the persistence of spread F at higher F region altitudes in the form of frequency spread F (FSF) is clearly observed around 23:40-03:00 UT.

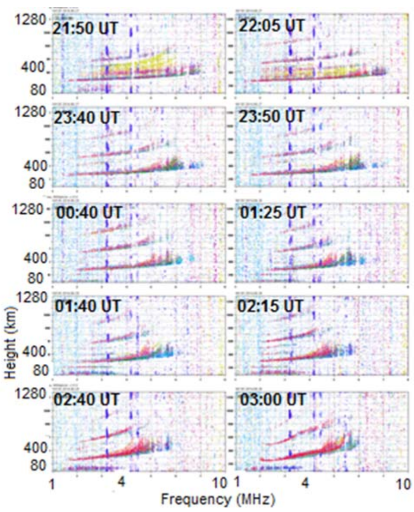


Figure 1: Case study of June 27-28, 2014. Ionograms recorded by the DPS-4D ionosonde on 27-28 June over Nicosia

A skymap is a product of the interferometry technique employed by digisondes to resolve individual echoes in terms of their position and velocity and therefore may reveal overhead bulk plasma motion. Figure 2 shows a series of skymaps during the night of June 27, 2014. Each skymap is based on a selection of reflection points corresponding to frequencies carefully selected from ionograms to match the 1F trace. The examples presented here display the reflection points in the F region within a 40^{o} cone at 10^{o} intervals around the zenith. Large-scale tilt of the ionosphere along NW-SE direction were noted prior to RSF development around 21:48 UT and the echoes from oblique directions as well as the east-west alignment of the irregularities and the presence of strong horizontal gradients, can be identified.

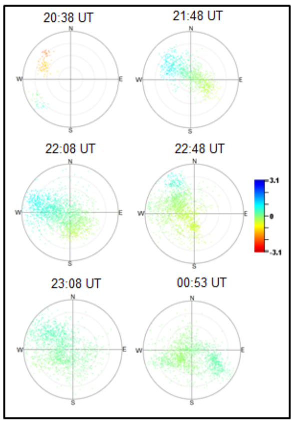


Figure 2: Skymaps over Nicosia on the evening to post midnight of June 27, 2014 showing eastward ionospheric motion

Vertical plasma drift indicates a view of the F layer electric field pattern which plays the dominant role over F region dynamo. *Jayachandran et al.* [1987] observed the presence of significant fluctuations in drift velocity with few minutes to few tens of minutes of periodicities prior to the onset of spread F over the equatorial region. Same type of fluctuation was noted in drift velocity (Vz) over the Cyprus digisonde. These fluctuations can be manifested as TID patterns which appear prior to the onset of spread F as a triggering agent. Figure 3 presents the plasma drift velocity component of June 27, 2014 from 0:00 UT to 24:00 UT. A clear fluctuation in plasma drift velocity has been noted around 18:00 UT to 22:00 UT which indicates the presence of TID patterns in the F layer which could have triggered SF formation as shown in Figure 1.

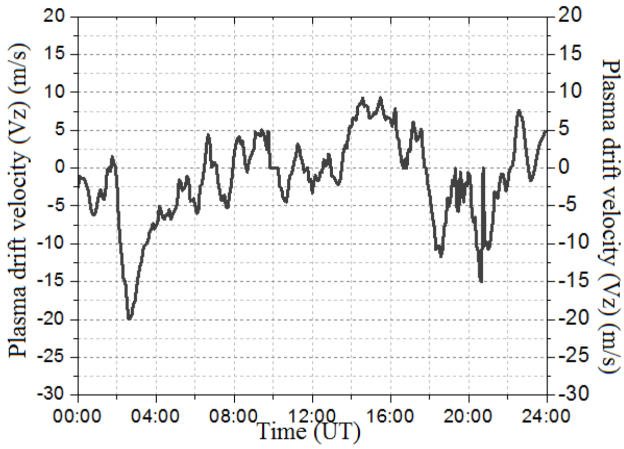


Figure 3: Vertical plasma drift velocity observed during June 27, 2014.

3.2. Seasonal variation of spread F:

Figure 4 represents the time duration of spread F events during 2014 in different seasons. It can be observed that from 20:00 UT to 26:30 UT (02:30 UT) the occurrence of spread F maximized during spring and summer whereas in winter no such feature was identified. The number of days affected by spread F during spring 2009-2016 was 53; in summer 254; in September-October (fall) 8 and in winter 77.Thus the annual primary maximum of spread F occurrence over Nicosia is observed during summer and the minimum in September-October.

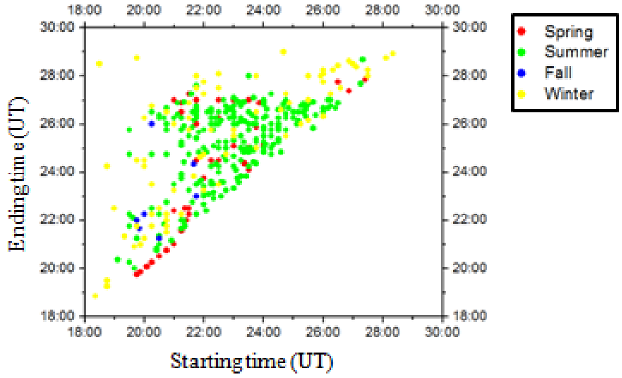
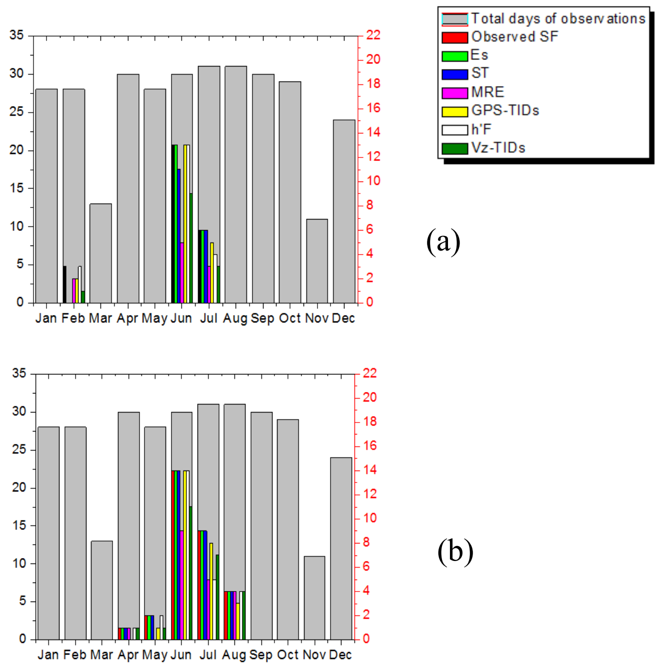
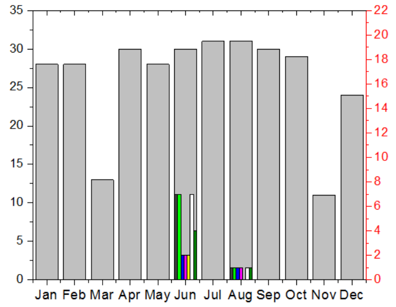


Figure 4: Diurnal variation of spread F occurrences for different seasons observed from Nicosia during 2014.

3.3. Overall spread F statistics:

To analyze the morphological aspects of nighttime spread F over Nicosia and investigate its correlation with different triggering agents, the overall spread F events recorded from Nicosia during 2014 have been divided into FSF, RSF and mixed spread F (MSF) respectively. The RSF patterns, observed during late evening hours which were converted into FSF during postmidnight hours has been designated as separate RSF and FSF in the following statistics. The monthly statistics of FSF, RSF and MSF correlated with different triggering mechanisms observed prior to the onset of spread F are presented in Figures 5 (a-c).





(c)

Figure 5: Monthly overall occurrence of spread F. (a) Overall statistics of different driving mechanisms and precursors noted prior to the onset of nighttime FSF form Nicosia during 2014 (b) Overall statistics of different driving mechanisms and precursors noted prior to the onset of nighttime RSF form Nicosia during 2014 (c) Overall statistics of different driving mechanisms and precursors noted prior to the onset of nighttime MSF from Nicosia during 2014.

The solar activity reached its maximum level in the year of 2014. In this year, the annual maximum for FSF, RSF and MSF were noted during summer as shown in Figures 5(a-c) with all mechanisms and precursors appearing frequently. In 2014, 38 days were found to be affected by spread F. A total of 74 spread F cases were recorded throughout the 38 spread F affected days. Among those, 22 cases for FSF, 30 cases for RSF, 8 cases for MSF and 14 cases of RSF-to-FSF were observed.

4. Discussions

In the European longitude sector, the nighttime mid-latitude ionosphere often exhibits plasma density structures associated with small scale irregularities which are normally distributed from northwest to southeast (NW-SE). In addition to *Perkins and gradient drift instabilities*, *Tsunoda and Cosgrove* [2001] observed that at mid-latitudes during nighttime, Es and F layer act as an electrodynamically coupled system under the action of an **E layer Hall polarization process** [*Cosgrove and Tsunoda,* 2004]. Several studies have pointed out the possible existence of positive feedback between electric fields in E and F regions. The growth rate of the coupling instability increases much faster than the isolated *Perkins and gradient-drift instabilities* due to the occurrence of unstable conditions on both NW-SE structures of E and F region conductivity perturbations.

A typical behavior of spread F observed in the summer is that, if the onset of RSF is during premidnight hours and if it persists after postmidnight, then RSF will evolve into FSF. This may signify that during premidnight hours, irregularities maximize at the bottom of the F region and due to the presence of strong electric field mapping from E to F region in the direction perpendicular to the magnetic field, irregularities may be transported to the F region peak during postmidnight periods. As mentioned earlier, two distinct ionogram signatures for wave like structures often noted at the bottom of F region, are normally observed on ionograms over Cyprus. From the present study, it can be suggested that lower mid-latitude regions over Europe also exhibit similar patterns like STs and MREs, mostly before the onset of nighttime spread F, especially during summer solstices. At sunset, a rapid rise and fall of the F layer has also been noted at mid-latitudes especially during high solar activity. This in turn produces a curvature of the isodensity contour at the bottom of the F layer. This curvature may act as a precursor to the induced tilted pattern which eventually accelerates the plasma instability effects on F region at nighttime.

One of the most important triggering mechanisms of nighttime mid-latitude spread F is gravity waves which exploit E and F layer coupled polarized electric field mapping, to transfer energy into the F region from the lower ionosphere. This phenomenon amplifies the *Perkins instability* at the bottom of the F layer and creates plasma irregularities that develop into spread F.

Bowman [1990] observed a strong correlation between nighttime mid-latitude spread F with day time TIDs. *Kotake et al.*, [2006] reported the seasonal variation of nighttime TID activity over several longitude sectors in the mid-latitude ionosphere. They claimed that MSTIDs were more effective at Japanese and Australian longitude sectors during June solstice and in the European longitude sector during December solstice, with a secondary peak in June solstice. In this paper, the statistical and seasonal behavior of TIDs observed prior to FSF, RSF or MSF occurrence has been studied in detail. As mentioned above, both GPS TEC and plasma drift velocities have been used to identify nighttime TID signatures prior to the onset of spread F. From Figures 5 (a-c), the maximum occurrence of GPS-TIDs was observed during May-August and January whereas the maximum TID signatures in drift measurement (Vz-TIDs) occurrence were noted during summer. During equinoctial months, the neutral density of the upper atmosphere maximizes whereas during solstices, the density reduces significantly [*Bowman,* 1992]. Since the gravity wave amplitude and the linear growth rate of *Perkins instability* are inversely proportional to neutral density, during solstices the upper atmosphere provides better conditions to amplify TIDs [*Bowman,* 1992]. It has to be mentioned based on Figures 5 (a-c) that both GPS-TIDs and Vz-TIDs follow similar seasonal trend throughout 2014 respectively. Figures 5(a-c) suggest that the effect of spread Es is one of the dominant aspects of spread F generation observed in the European longitude sector. During summer, almost one-to-one correspondence has been observed between spread Es and spread F. Another dominant phenomenon observed prior to the onset of spread F in the European longitude sector is F layer uplift.

5. Acknowledgements

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