URSI AP-RASC, Sydney, Australia, 17 – 22 August 2025

Evaluation of Spread F Detection Methods over Midlatitude

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Abstract

The midlatitude nighttime ionosphere exhibits multiple diffused plasma structures, collectively referred to as midlatitude Spread F (SF), which can persist from a few minutes to several hours. Numerous authors have contributed to identifying the climatology of midlatitude SF; however, the methodologies used for SF detection have raised concerns regarding their accuracy and reliability. With the widespread availability of ionograms, automatic SF detection techniques have become a common approach for identifying SF occurrence. Ionospheric parameters, such as QF and FF, are used as SF indicators. These parameters serve as essential indices for nowcasting SF activity; however, their reliability in accurately identifying SF occurrence remains questionable, particularly when using Auto-scaled ionospheric data. In this study, we aim to evaluate the accuracy and validity of these SF detection parameters by comparing the results with manually identified SF cases over Nicosia and Moscow. By conducting this comparative analysis, we seek to determine the effectiveness of these automated indices and assess whether they can serve as reliable tools for detecting SF activity**.**

1. Introduction

The midlatitude nighttime F-region frequently exhibits diffuse plasma structure irregularities, commonly referred to as midlatitude Spread F (SF), which can persist from several minutes to several hours [1, 2]. These irregularities have significant implications, as they can disrupt high-frequency (HF) communication systems, compromise the robustness of life-critical navigation and positioning services, and degrade the quality of scientific data from remote sensing applications [3]. The primary driver of SF in the midlatitude F-region is spatial perturbations in electron density, often triggered by gravity wave (GW) propagation [4]. Miller (1997) [5] suggested that GW-induced vertical motion of the ionosphere, when combined with the tilted midlatitude magnetic field, creates divergence in global currents, thereby generating local electric fields. These GW-driven electric fields may introduce diurnal variations in the ionospheric electric field, acting as seeds for plasma instabilities that contribute to SF development.

Numerous studies have examined the plasma dynamics and underlying mechanisms responsible for SF formation, highlighting its complex nature [1, 6 − 7]. Bowman (1996) [2] found that SF occurrence rates are inversely correlated with solar flux, potentially due to variations in Upper Atmosphere Neutral Particle Density (UA-NPD) affecting the amplitude of Traveling Ionospheric Disturbances (TIDs). TIDs result from GW coupling between the neutral atmosphere and the ionosphere [8], causing ionospheric tilts that can lead to SF when their amplitudes are sufficiently large. The relationship between SF occurrence and UA-NPD can thus be explained by the influence of neutral density on TID amplitudes, emphasizing the coupling between atmospheric dynamics and ionospheric plasma instabilities.

SF events can be broadly categorized into two types based on the distribution of plasma structures within the spread echoes recorded in ionograms. Range Spread F (RSF) is characterized by diffused echoes appearing in the low-frequency segments (<2–2.5 MHz) of the F-region traces. These echoes extend approximately 10 km or more beyond the true range of the main echo, indicating substantial irregularities in the range dimension [7]. In contrast, Frequency Spread F (FSF) is identified when minimal spreading occurs at low frequencies, but diffused echoes are concentrated near the critical frequency of the F-region trace, reflecting irregularities in the frequency domain [7].

Detecting SF events has been a critical task in the climatological study of SF over the globe. While manual inspection of individual ionograms remains the most accurate method for identifying SF occurrences, it is highly time-consuming and labour-intensive. To address this challenge, various software tools have been developed to automate the ionogram interpretation process. One such tool is SAO Explorer [9], which offers several parameters to assist in detecting SF events through an auto-scaling mechanism. With the widespread availability of ionograms, automatic SF detection techniques have become increasingly common. Key ionospheric parameters, such as QF and FF, [10] are used as indicators for SF detection and nowcasting. However, the reliability of these auto-scaled parameters in accurately identifying SF occurrences remains questionable, as automated methods may introduce errors or overlook subtle features of SF events.

In this study, we aim to assess the accuracy and validity of these SF detection parameters by comparing automated results with manually identified SF cases over two ionospheric stations: Nicosia, representing a low midlatitude region, and Moscow, representing a high midlatitude region. Through this comparative analysis, we seek to evaluate the effectiveness of these automated indices and determine whether they can serve as reliable tools for detecting SF activity across different midlatitude ionospheric environments.

2. Data and Methods

In the present analysis, Figure 1 illustrates the geographic coordinates of the two Digisonde stations utilized in this study: Nicosia (35.18°N, 33.38°E) and Moscow (55.76°N, 37.61°E). The focus of this research is on the occurrence of SF events during 2016, a period characterized by moderate solar activity. Ionograms were recorded at 7.5-minute intervals at both stations to capture the temporal evolution of SF events. For manual identification of nighttime SF occurrences, ionograms were visually inspected over Nicosia from 18:00 UT to 06:00 UT the following day, and over Moscow from 12:00 UT to 06:00 UT of the next day. The start and end times of SF events were meticulously documented, and only events lasting longer than 15 minutes—corresponding to at least two consecutive 7.5-minute ionograms affected by SF—were considered for analysis, following methodologies outlined in previous studies [11–13]. After manually detecting SF events, they were classified into two categories: (a) RSF and (b) FSF, based on criteria established by Hajkowicz (2007) [7].

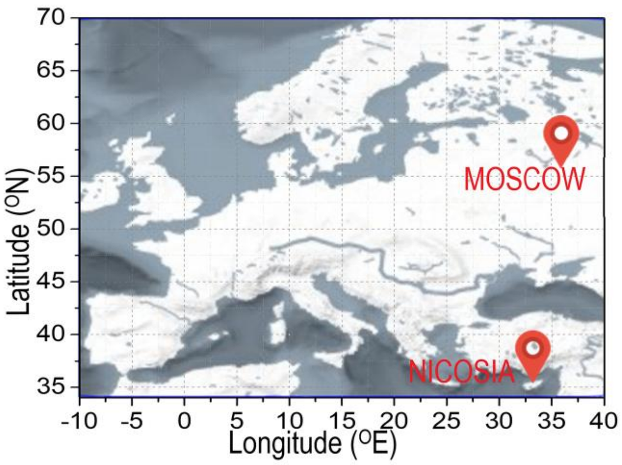

Figure 1. Coordinates of the Nicosia and Moscow Digisondes used for the present study.

To complement manual detection, we utilized Auto-scaled ionograms from the FastChar database (https://giro.uml.edu/didbase/scaled.php) for both Nicosia and Moscow for the year 2016. Since the primary focus of this study is on nighttime SF occurrences, we restricted our analysis to the same nighttime intervals: 18:00 UT to 06:00 UT for Nicosia and 12:00 UT to 06:00 UT for Moscow. Daytime SF anomalies were not considered in this investigation to ensure a consistent comparison of nighttime ionospheric behaviour. From the Auto-scaled datasets, we concentrated on two key parameters: QF and FF. The QF parameter indicates the presence of RSF activity by identifying range-spreading patterns in the ionogram. The FF parameter represents the frequency spread and is calculated as the difference between the maximum F2 layer frequency (foF2) and the maximum frequency of the F-region trace (fxl). To identify FSF events, we adopted the threshold FF > 0.5 MHz [10], applying this criterion uniformly to both Nicosia and Moscow data.

3. Results

In the present analysis, our primary objective is to conduct a comparative study between manually identified and automatically detected SF occurrences over Nicosia and Moscow to evaluate the accuracy and validity of the auto-scaled SF detection parameters. Additionally, this study will explore the potential latitudinal dependence on the accuracy of these detection methods. Since Nicosia represents a low midlatitude station and Moscow represents a high midlatitude station, comparing the performance of auto-scaled SF detection parameters at these two locations will help determine whether the effectiveness of these methods varies with latitude.

3.1. Several case studies:

In this sub-section, we present several case studies comparing manually identified SF events with those detected using QF and FF parameters. Figure 2(a-c) illustrates three representative cases from Nicosia in 2016.

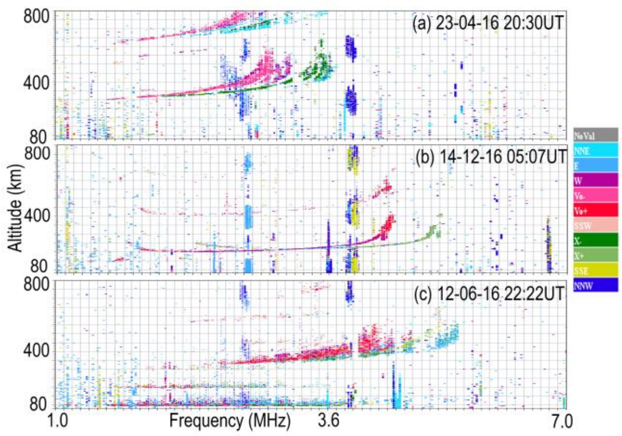

Figure 2(a-c). Case studies (a) Manually detected SF but no Auto-scaled SF detection (b) Auto-scaled SF detection but no SF in manual observation (c) SF detected both in Auto-scaled and manually.

In Figure 2(a), a nighttime SF event was manually identified in the ionogram at 20:30 UT on 23rd April 2016. However, during this period, the Auto-scaled data recorded no value for QF, and the FF value was approximately 0.22 MHz—below the 0.5 MHz threshold required to indicate FSF. This suggests that the Auto-scaled detection failed to capture the manually confirmed SF event. Conversely, Figure 2(b) shows an ionogram from 05:07 UT on 14th December 2016, where no SF event was observed through manual inspection. However, the Auto-scaled data incorrectly detected an SF event, with a QF value of around **7.5**. This discrepancy suggests that auto-scaled parameters can misidentify normal ionospheric variations as SF events, leading to inaccuracies in automated detection.

In contrast, Figure 2(c) presents a case from 22:22 UT on 12th June 2016, where both manual inspection and Auto-scaled data consistently identified an SF event. The ionogram clearly displayed SF signatures, and the QF and FF values were both elevated, with FF exceeding 0.5 MHz, confirming the presence of SF in both detection methods. This example demonstrates a case of successful alignment between manual and automated SF identification.

3.2. Comparison of Manual and Automatically Detected RSF:

Figure 3(a-b) presents a comparative yearly analysis of RSF occurrences in 2016, comparing manually detected RSF events with those identified using Auto-scaled QF parameters over Nicosia and Moscow. In this analysis, only the QF parameter was employed to detect RSF events, as QF in the SAO Explorer software represents the range spread of the F2 layer [14]. In the figures, black markers denote manually detected RSF events, while the colour scale represents the range of QF values. The x-axis indicates the day of the year (DOY), and the y-axis represents the hour of the day, spanning from 18:00 UT to 06:00 UT of the following day.

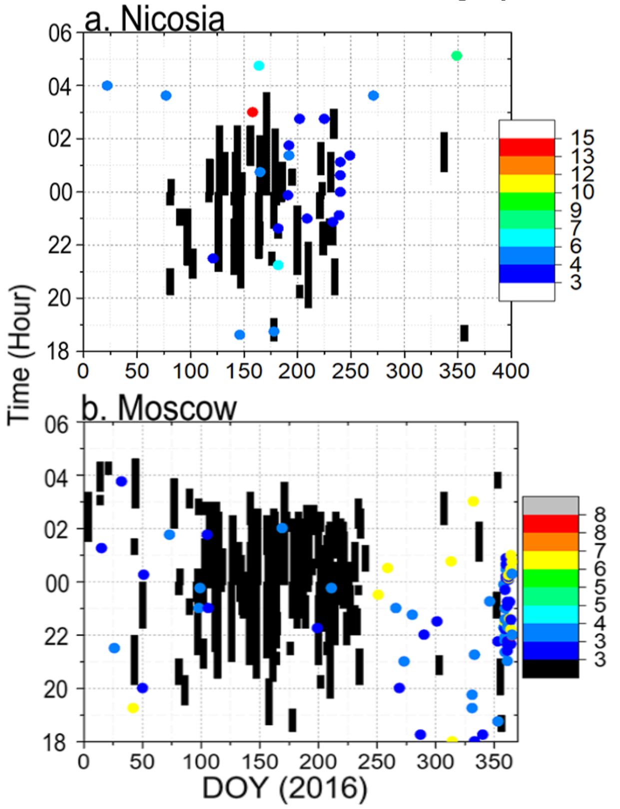

Figure 3(a-b). Comparative yearly analysis of RSF detection techniques in 2016 over (a) Nicosia and (b) Moscow.

Figure 3(a) illustrates the comparison of RSF events over Nicosia for 2016. The manually detected RSF events predominantly focused on the summer months, aligning with previous studies [11–13], which report a seasonal peak in RSF during summer at low midlatitudes. In this analysis, a total of 42 RSF-affected days were identified through manual inspection. Conversely, the QF-detected RSF events were not only concentrated in summer but also scattered across the winter months, indicating a divergence from manual detection patterns. The automated method identified only 20 RSF events during nighttime over Nicosia in 2016. Importantly, only 14% of RSF events were commonly detected by both manual and Auto-scaled methods, suggesting a low association between the two detection approaches in this low midlatitude region.

To further validate these findings, we conducted a similar analysis for Moscow as shown in Figure 3(b). Although Moscow is situated at a higher latitude than Nicosia, the seasonal distribution of manually detected RSF events exhibits similar patterns, with a peak in summer, followed by winter, as previously reported by Paul et al. (2022) [12]. The manual inspection revealed 78 RSF-affected days over Moscow, indicating a higher RSF occurrence compared to Nicosia, which can be attributed to the high ionospheric instabilities at higher latitudes [12–13]. However, the distribution of QF-detected RSF events over Moscow deviates from this pattern. As shown in Figure 3(b), most Auto-scaled RSF detections were concentrated in December, a period during which manual RSF detections were minimal. The overlap between manually detected and QF-detected RSF events in Moscow was approximately 12%, slightly lower than in Nicosia.

3.3. Comparison of Manual and Automatically Detected SF events:

A yearly comparative analysis between manually detected and Auto-scaled SF events over Nicosia and Moscow is presented in Figure 4(a-b). In these figures, the x-axis represents the DOY, while the y-axis denotes the hour of the day. Since this study focuses on nighttime SF occurrences, the analysis for Nicosia covers observations from 18:00 UT to 06:00 UT, whereas for Moscow, the timeframe extends from 12:00 UT to 08:00 UT. This extended period for Moscow accounts for prolonged SF events, as suggested by Paul et al. (2022; 2023) [12–13]. In the figures, black markers represent manually detected SF events, while red and blue markers denote SF events identified through QF and the FF > 0.5 MHz threshold over Nicosia and Moscow.

Figure 4(a) illustrates the comparison of SF detection techniques over Nicosia for the year 2016. Consistent with previous studies [11–13], the maximum manually detected SF occurrences were observed during the summer months, followed by a secondary peak in winter. Over the entire year, 103 days exhibited SF events based on manual ionogram inspection. In contrast, SF events detected using the Auto-scaled QF and FF > 0.5 parameters were more evenly distributed throughout the year, though a peak in summer was still evident. The automated detection methods identified 68 SF-affected days over Nicosia in 2016. Importantly, the common SF events—those identified by both manual and Auto-scaled methods—accounted for approximately 35% of the total manually detected events.

Figure 4(b) presents the SF detection comparison over Moscow. As previously noted by Paul et al. (2022; 2023) [12–13], the SF occurrence over Moscow is significantly higher than over Nicosia, reflecting the latitude dependence of SF events. Manual inspection of ionograms identified SF events on 256 days throughout 2016. The Auto-scaled detection methods, utilizing both QF and FF > 0.5 parameters, detected SF events on 253 days, indicating a high level of detection capability by automated methods at this latitude. The overlap between manually detected and Auto-scaled SF events in Moscow was approximately 77%, demonstrating a strong agreement between the two detection methods. This high concordance suggests that Auto-scaled parameters are more reliable in higher midlatitude regions like Moscow, likely due to the more pronounced and frequent ionospheric disturbances that are easier to detect automatically.

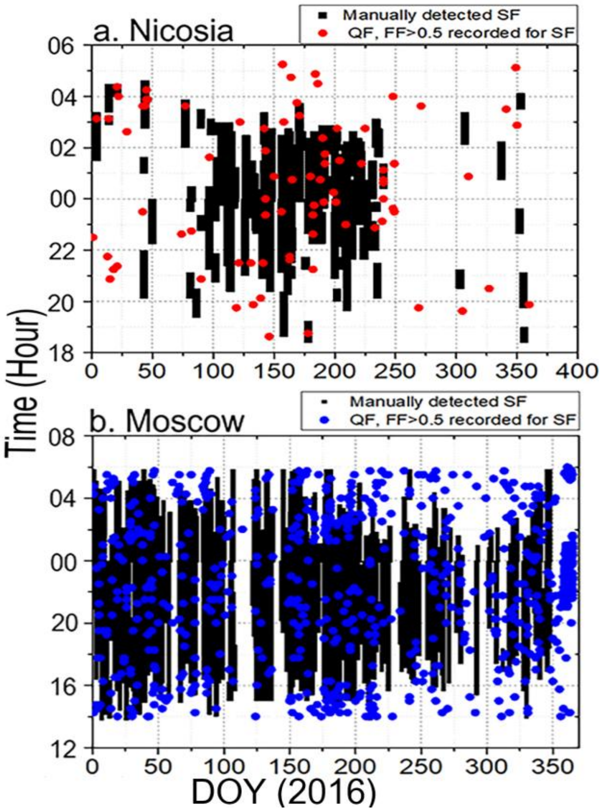

Figure 4(a-b). Comparative yearly analysis of SF detection techniques in 2016 over (a) Nicosia and (b) Moscow.

4. Conclusions

The present study focuses on a comparative analysis of the manually and Auto-scaled detected nighttime SF events over Nicosia and Moscow, aiming to explore the potential accuracy and validity of the Auto-scaled SF detection parameters during 2016. The key findings are:

1. Over Nicosia and Moscow, the QF detected nighttime RSF events had an accuracy rate of 14% and 12% over 2016 which was below average.
2. The Auto-scaled detected SF events over Nicosia provided an average accuracy rate of 35% whereas over Moscow this rate increased to 77%.

Thus from the above results we can suggest that over the places with high SF occurrences like Moscow, the SF detection parameters can identify the events with substantial accuracy but in the places with low SF occurrences, the SF detection accuracy is required to be improved.

6. Acknowledgements

The authors are thankful to Digital Ionogram DataBase (DIDBase) which is part of the Global Ionospheric Radio Observatory (GIRO) portal (http://giro.uml.edu). Funding for this research was provided by the project "Towards A Global Model for Spread F" – TAGMOS-F, (Ref No: EXCELLENCE/0524/0526) is co-funded by the Republic of Cyprus and the European Regional Development Fund (ERDF) through the 'EXCELLENCE HUBS' Program, in the frame of the Operational Program "ΘΑλΕΙΑ" 2021-2027.

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