Spread-F occurrences prediction and comparison with VHF scintillation observations in India

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Contour diagrams for the occurrence of spread-F have been drawn using data from a number of Indian stations for both high and low solar activity periods. This has been done separately for pre-midnight, midnight and post-midnight periods during summer, equinoxes and winter. A positive correlation is observed between the occurrence of spread-F and solar activity during pre-midnight period, while negative correlations were found during midnight and post-midnight periods. Similar correlation has been found between the occurrence of spread-F and monthly sunspot numbers. These correlations have some similarity for range and frequency types of spread-F. However, seasonal variations of spread-F occurrence with sunspot numbers are found to be somewhat different. Contour diagrams can predict the occurrence of spread-F and should be useful for HF/VHF propagation and can also be compared with scintillations in VHF/UHF satellite signals.

1 Introduction
Worldwide occurrences of spread-F have been studied by a number of workers. Shimazaki\(^1\) made a statistical study of probability of spread-F using IGY data of July 1957-June 1958 and compared with 1954 data for the whole world. Contour maps on worldwide basis were attempted for the occurrence of spread-F by Tao\(^2\) for 1954 and the IGY period, while Davis\(^3\) has drawn world maps of spread-F for 1958, and 1964. Some recent works on midlatitude spread-F occurrences have been reviewed by Bowman\(^4\).

A number of workers\(^5\)\(^\text{--}\)\(^12\) have studied spread-F at low and midlatitudes on regional basis, but no attempt was made to draw contour maps. Regional maps have better resolution and have some advantages over world maps. As such an attempt has been made, in this paper, to draw contour maps of spread-F occurrences over India.

2 Data
Spread-F data from different Indian stations (Table 1) have been used for 1964 and 1968 representing low and high solar activity periods. However, recent available spread-F data between high and low solar activity periods (1989-96) of Ahmedabad and Kodaikanal have been utilized.

3 Results
At Indian stations spread-F occurrence was found only between 1800 and 0600 hrs LT. In order to study spread-F, time blocks of 1900-2200 hrs LT, 2300-0100 hrs LT and 0200-0500 hrs LT were chosen as pre-midnight, midnight and post-midnight periods, respectively. The data for 1800 hrs LT and 0600 hrs LT have been ignored due to rare occurrence of spread-F at these hours.

The percentage occurrences of spread-F have been calculated for the above three time blocks during summer, equinoxes and winter for all the stations given in Table 1. This has been done separately for both high (1968) and low (1964) solar activity periods.

The latitudinal and longitudinal variations of percentage occurrence of spread-F during pre-midnight, midnight and post-midnight periods in summer, equinoxes and winter for high and low solar activity periods are drawn (not shown). For each latitude and longitude at the interval of 3° between

<table>
<thead>
<tr>
<th>Station</th>
<th>Geogr. lat.</th>
<th>Geogr. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delhi</td>
<td>28°38'N</td>
<td>77°13'E</td>
</tr>
<tr>
<td>Ahmedabad</td>
<td>23°01'N</td>
<td>72°36'E</td>
</tr>
<tr>
<td>Haringhata</td>
<td>22°58'N</td>
<td>88°34'E</td>
</tr>
<tr>
<td>Bombay</td>
<td>19°00'N</td>
<td>72°50'E</td>
</tr>
<tr>
<td>Hyderabad</td>
<td>17°21'N</td>
<td>78°28'E</td>
</tr>
<tr>
<td>Tiruchirapalli</td>
<td>10°49'N</td>
<td>78°28'E</td>
</tr>
<tr>
<td>Kodaikanal</td>
<td>10°14'N</td>
<td>77°29'E</td>
</tr>
<tr>
<td>Trivandrum</td>
<td>8°14'N</td>
<td>76°57'E</td>
</tr>
</tbody>
</table>
8°N and 29°N, and between 72°E and 90°E, respectively, it has been possible to calculate (by averaging) the percentage occurrence of spread-F for number of points over India from latitudinal and longitudinal variations.

As such contour diagrams can be drawn over the map of India. Figure 1 shows the contour diagrams of percentage occurrence of spread-F during pre-midnight time block in summer, equinoxes and winter. It has been observed, in general, that spread-F is predominant in high solar activity as compared to low solar activity period.

Similar contour diagrams for midnight periods are shown in Fig. 2. In general, the higher percentage of spread-F occurrence has been observed during low solar activity period. Figure 3 shows the contour maps for post-midnight period. A clear negative correlation between the occurrence of spread-F and solar activity has been observed for all the seasons over India.

In order to study the solar cycle variations, the percentage occurrences have been compared with the monthly sunspot numbers. This has been done for Ahmedabad (temperate latitude) and Kodaikanal (equatorial latitude) during pre-midnight, midnight and post-midnight periods separately and shown in Fig. 4. A positive correlation trend has been observed between the percentage occurrence of spread-F and sunspot number during pre-midnight period both at Ahmedabad and Kodaikanal. However, spread-F has been almost absent during 1993-96 at Ahmedabad. A negative correlation between the two can also be observed, to some extent, during midnight and post-midnight periods at Ahmedabad. At Kodaikanal, similar trend has been found only in post-midnight period.

4 Discussion
The contour maps shown in this paper are based on ionosonde observations of spread-F at stations given in Table 1. It has been observed\textsuperscript{13-15} that the high power short-wave transmitters with power flux density of 0.1 \( \mu \text{Wm}^{-2} \) or more can heat the ionosphere and modify it in the form of artificial spread-F. Number of high power short-wave broadcast transmitters are in operation in India which can modify the ionosphere at the control points in the form of artificial spread-F. There may not be any ionosonde at these control points and, therefore, the percentage occurrence of spread-F cannot be assessed accurately for these locations only. In fact, a large number of anomalous long distance TV receptions have been observed through such artificial spread-F (Refs 15-19) which cannot be explained by other
modes of propagation. The present spread-F maps are useful for prediction of its occurrence at any place over India with certain reservation as described above. However, these spread-F prediction and observed data show only about 10 - 20% deviations in many cases when compared for locations where ionosonde is present. Estimation of percentage occurrence of spread-F can be made at the locations

![Image 1](image1.png)

Fig. 2—Contours showing occurrence of spread-F during midnight in (a) summer, (b) equinoxes and (c) winter for high (---) and low (-- -- --) solar activity

![Image 2](image2.png)

Fig. 3—Contours showing occurrence of spread-F during post-midnight in (a) summer, (b) equinoxes and (c) winter for high (---) and low (-- -- --) solar activity
where the ionosondes are not located.

A general trend of positive and negative correlations between the percentage occurrence of spread-F and solar activity has been observed in various conditions as illustrated in Figs. 1-4. Rastogi and Kulkarni\(^9\) have compared the percentage occurrence of the spread-F with mean sunspot number (one sunspot number for each season per year) during 1953-66. In this study, Figs 5 and 6 show the variations of percentage occurrence of spread-F with mean sunspot numbers (four sunspot numbers for each month of a season per year) during 1989-96 for both Ahmedabad and Kodaikanal, respectively. This has been done again for pre-midnight, midnight and post-midnight periods separately during summer, equinoxes and winter.

At Ahmedabad no correlation between the two has been found (Fig. 5) during pre-midnight summer. However, negative correlations have been observed between the percentage occurrence of spread-F and sunspot numbers during midnight and post-midnight summer. Rastogi and Kulkarni\(^9\) found negative correlation between the two in summer and no correlation during equinoxes and winter. These workers\(^9\) did not divide the data for pre-midnight, midnight and post-midnight periods, separately. During non-summer months in pre-midnight and midnight periods a positive correlation between the two can be seen to some extent and no correlation exists for post-midnight (Fig. 5). At Kodaikanal, a positive correlation between the percentage occurrence of spread-F and sunspot numbers has been observed during pre-midnight and midnight periods for all the three seasons and a negative correlation trend in post-midnight summer with no correlation in equinoxes and winter (Fig. 6).

Range spread-F (which occurs during pre-midnight period at low latitudes) is positively correlated with solar activity, while reverse is true for frequency spread-F which occurs during post-midnight period\(^6,9,12\). There is an increase in pre-midnight and midnight spread-F occurrences both at Ahmedabad and Kodaikanal (except Ahmedabad summer) with the increase of solar activity. Whereas post-midnight spread-F occurrence decreases with increase of solar activity during summer at Ahmedabad and, to some extent, at Kodaikanal. Similar situation exists at Ahmedabad during midnight (Figs 5 and 6). At Japanese stations\(^7\), it is prominent in the post-midnight period, especially, during low solar activity.

The morphology of plasma bubbles show its activity begins at 1900 hrs LT and peaks around 2130 hrs LT. Deeper bubbles become shallow afterwards and appeared to be associated with range and frequency spread-F (Ref. 20). However, there is a general increase of range spread-F with the increase of solar flux in the American zone\(^21\). Various instability mechanisms for the growth of equatorial spread-F irregularities of different scale sizes have been discussed by Krishnamurthy\(^22\). The VHF backscatter radar observations show the presence of small scale irregularities\(^23,24\) of sizes of few metres as VHF and UHF scintillations in satellite monitoring\(^25\). The existence of equatorial spread-F irregularities from small to large scale sizes has also been discussed at length during ionization hole campaign experiment by a number of workers\(^26\).
Fig 5—Seasonal variation of percentage occurrences of spread-F with sunspot numbers at Ahmedabad

Fig 6—Seasonal variation of percentage occurrences of spread-F with sunspot numbers at Kodaikanal
Table 2—Locations of the scintillation recording stations in the Indian region along with the percentage occurrence of scintillations and that of the predicted spread-F

<table>
<thead>
<tr>
<th>Station</th>
<th>Geogr. lat. deg.</th>
<th>Geogr. long. deg.</th>
<th>% scintillations/spread-F*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre-midnight</td>
</tr>
<tr>
<td>Trivandrum</td>
<td>8.3</td>
<td>76.9</td>
<td>34/45</td>
</tr>
<tr>
<td>Tiruchendur</td>
<td>8.3</td>
<td>78.1</td>
<td>34/46</td>
</tr>
<tr>
<td>Annamalainagar</td>
<td>11.4</td>
<td>79.4</td>
<td>32/30</td>
</tr>
<tr>
<td>Goa</td>
<td>15.2</td>
<td>74.0</td>
<td>25/22</td>
</tr>
<tr>
<td>Kolhapur</td>
<td>16.7</td>
<td>74.2</td>
<td>20/18</td>
</tr>
<tr>
<td>Waltair</td>
<td>17.7</td>
<td>83.3</td>
<td>30/18</td>
</tr>
<tr>
<td>Bombay</td>
<td>19.0</td>
<td>73.0</td>
<td>29/15</td>
</tr>
<tr>
<td>Nagpur</td>
<td>21.1</td>
<td>79.1</td>
<td>11/15</td>
</tr>
<tr>
<td>Rajkot</td>
<td>22.3</td>
<td>70.7</td>
<td>17/5</td>
</tr>
<tr>
<td>Calcutta</td>
<td>22.6</td>
<td>88.4</td>
<td>22/10</td>
</tr>
<tr>
<td>Ujjain</td>
<td>23.2</td>
<td>75.8</td>
<td>19/18</td>
</tr>
<tr>
<td>Ahmedabad</td>
<td>20.0</td>
<td>72.4</td>
<td>17/8</td>
</tr>
<tr>
<td>Bhopal</td>
<td>23.2</td>
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<td>15/18</td>
</tr>
<tr>
<td>Varamasi</td>
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<td>15/15</td>
</tr>
<tr>
<td>Agra</td>
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<td>78.0</td>
<td>6/16</td>
</tr>
<tr>
<td>Delhi</td>
<td>28.6</td>
<td>77.2</td>
<td>3/10</td>
</tr>
</tbody>
</table>

*The predicted values correspond to sub-ionospheric point for FLEETSAT at 400 km for these locations.

Cohen and Bowles\(^\text{27}\) found that VHF signals are propagated by the presence of spread-F at Huancayo (equatorial station) near the midpoint between transmitter and receiver over a trans-equatorial path. It has also been reported\(^\text{1}\) that the propagation of VHF signals between Philippines and Okinawa corresponds in time with spread-F occurrence of Baguio (low latitude station) near the midpoint. The signal enhancement usually occurs before midnight like range spreading\(^\text{2}\). As such range spread-F which occurs during pre-midnight in high solar activity period would be very useful for HF/VHF propagation. Recently, possibility of predicting the long range ionospheric propagation channels by using different kinds of natural and artificial ionospheric plasma modification has been discussed by various workers\(^\text{28,29}\).

Nighttime scintillations are closely correlated\(^\text{30}\) with spread-F. It is the range type of spread-F which is associated with VHF scintillations, while frequency spread-F is associated with weak fluctuations\(^\text{31}\). Coordinated multi-station VHF scintillation observations have been conducted during 1991 using 244 MHz radio beacon FLEETSAT (73°E) at sixteen stations in India\(^\text{32}\). The average percentage occurrences of scintillations for March 1991 during pre-midnight, midnight and post-midnight periods have been calculated from the above work\(^\text{32}\) at all the sixteen stations and compared with the percentage occurrence of spread-F, as shown in Figs 1(b), 2(b) and 3(b) for equinoxes during high solar activity. On comparing the two, similarity has been observed in their variations (Table 2). Considering the difference in the solar activity of 1968 equinoxes and March 1991, such correlation may be regarded as reasonable. As such these contour maps can be utilized to compare scintillations received from beacon satellites.

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References

10 Chandra H & Rastogi R G, Ann Geophys(France), 1 (1972) 37.
16 Saksena R C, Indian J Radio & Space Phys, 8 (1979) 351.