Influence of geomagnetic activity on the occurrence of midlatitude ionogram-recorded spread-F

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Delayed spread-F occurrence as recorded by ionograms, following geomagnetic activity (GA) has been investigated using data from 88 stations located around the world. The spread-F occurrence is delayed progressively from one to three days, from subauroral to midlatitude regions. The equatorial latitudes show suppressed activity. An examination of daily spread-F occurrence values relative to the AE index reveals not only a main delay of one day, but also delays of two and three days. These delays involve principally GA occurring around 0600 hrs UT.

1 Introduction

This paper is concerned with the delayed occurrence of spread-F (as measured by ionograms) following geomagnetic activity (GA). The upper-atmosphere neutral particle density (NPD) fluctuations have been shown to have an important influence on the level of spread-F occurrence. For example, for midlatitudes (as shown in Fig. 3 of Ref. 1), spread-F is seven times more likely to be recorded during the June solstice months of sunspot-minimum years (when the NPD has minimum values) than for the equinoctial months of sunspot-maximum years (when maximum values are recorded). For all other conditions investigated when NPD changes occur, this well-defined inverse relationship has been recorded.

These experimental results can be considered quite independently of any hypotheses which might be advanced to explain them. The influence that NPD levels (which are known to increase after GA), will have on spread-F is also discussed here.

When nighttime spread-F conditions are considered, the role of propagating travelling ionospheric disturbances (MS-TIDs) becomes important. Evidence is now fairly conclusive that most spread-F traces involve specular reflections from tilted isionic surfaces in excess of about 15° and are associated with passing MS-TIDs (Refs 6 and 7). The experimental evidence shows that MS-TIDs are located in the ionosphere for most of the time, although their wave amplitudes may not always be large enough for spread-F to be recorded on ionograms. For an equatorial station, Subbarao and Krishna Murthy have found that the fluctuations associated with MS-TIDs are present on all days investigated and that "the fluctuations are stronger on spread-F than on non-spread-F days". For midlatitudes, during an equinoctial period when no spread-F was observed, Bowman found shallow wave amplitudes present on all the days examined. Other results relating to MS-TID wave amplitudes have been reported by Jayachandran et al., Balachandran Nair et al. and Sastri. The MS-TIDs with sufficient wave amplitudes to produce spread-F also generate small-scale irregularities (SSIs) as they propagate. Although the reason for this is not known, it has been suggested that the non-linear disintegration of associated atmospheric gravity waves may be responsible.

Here, the spread-F occurrence over many years at stations located around the world from sub-auroral to equatorial latitude has been considered first. The occurrence is investigated relative to geomagnetic activity (GA) with the NPD modulations effect neutralized. Secondly, the paper deals with the influence of GA on spread-F occurrence at a high midlatitude station, Canberra, over a sunspot-minimum period. The corrected geomagnetic coordinates of Canberra are - 45.2 and 223.7 and the local time is 10 hours ahead of universal time (UT).

2 Spread-F data analyses for station groups

The groups of stations (numbers indicated; labelled A to G plus ESF) used are listed in Table 1, together with the range of L shells in which each group is located. Station locations ranged from sub-auroral to equatorial regions. The spread-F occurrence at these
stations was examined by superposed-epoch methods for median $K_p$ sum values $\geq 20$ and $< 30$. The period covered was 1955-1971 (inclusive) and each analysis embraced a centre day $\pm 365$ days, with only small central sections of the results being presented. For these extended superposed-epoch analyses, the final set of points constitutes a normal distribution relative to the mean, so that accurate assessments of displacements can be made in terms of standard-deviation displacements from the mean. Error bars are also used. To neutralize the modulation effect, the data (measured in occurrence hours per night) are normalized by dividing each day in each 60-day interval by the average value for that interval.

The results are shown in Fig. 1 for groups A, B and C. Figure 2 shows the distributions for groups D and G and the equatorial region. Groups E and F have been omitted from these figures as no results of importance were recorded. For the groups A to D, spread-F is enhanced but delayed progressively from 1 to 3 days over this group range. The equatorial and G groups show significant negative displacements in all likelihood related to suppressed spread-F.

<table>
<thead>
<tr>
<th>Label</th>
<th>L-shell range</th>
<th>Station numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$2.6 \leq L &lt; 3.3$</td>
<td>9</td>
</tr>
<tr>
<td>B</td>
<td>$2.2 \leq L &lt; 2.6$</td>
<td>12</td>
</tr>
<tr>
<td>C</td>
<td>$1.8 \leq L &lt; 2.2$</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
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</tr>
<tr>
<td>E</td>
<td>$1.25 \leq L &lt; 1.5$</td>
<td>8</td>
</tr>
<tr>
<td>F</td>
<td>$1.10 \leq L &lt; 1.25$</td>
<td>10</td>
</tr>
<tr>
<td>G</td>
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<td>9</td>
</tr>
<tr>
<td>ESF</td>
<td>$L &lt; 1.04$</td>
<td>10</td>
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</tbody>
</table>

Fig. 1 — Spread-F occurrence for groups A, B and C relative to medium $\Sigma K_p$ controls.
occurrence associated with NPD increases following geomagnetic activity\textsuperscript{14,15}. Figure 1(a)-(c) shows clear evidence of the geomagnetic 27-day periodicity, while there is some evidence in Figures 1(a) and 1(b) for the 13.5-day periodicity which is known to exist\textsuperscript{16}.

Similar analyses on these data performed earlier\textsuperscript{17,18} used the \(A_p\) index for 4 different index levels and plotted the results from -10 to +10 days. Not only, as is the case in Figs 1 and 2, the larger delays were found for the lower latitude station groups, but also the delays were smaller for the higher levels of geomagnetic activity. Table 2 summarizes approximate estimates of these delays not only as a function of latitude, but also of the levels of geomagnetic activity. For example, group C (which includes Canberra) delays vary from 0.5 days for the high \(A_p\) index to 2.8 days for the lower range of \(A_p\) index used. Any mechanism which might be proposed for the generation of AGWs (and related MS-TIDs) responsible for the spread-F occurrence, needs to be consistent with these results.

### Table 2 — Spread-F delays (in days) for the groups

<table>
<thead>
<tr>
<th>(A_p) index</th>
<th>(A)</th>
<th>(B)</th>
<th>(C)</th>
<th>(D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(70 &lt; A_p \leq 130)</td>
<td>0.2</td>
<td>0.6</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>(35 &lt; A_p \leq 70)</td>
<td>0.5</td>
<td>1.0</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>(15 &lt; A_p \leq 35)</td>
<td>1.0</td>
<td>2.0</td>
<td>2.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>

3 Canberra spread-F occurrence

The level of spread-F occurrence at Canberra was assessed for each night (1800-0600 hrs LT), the date of the first half of the night being recorded, for a sunspot-minimum period (1971-1977). Using a superposed-epoch method (as described by Bowman and Shrestha\textsuperscript{19}) the AE index has been investigated
relative to both high and low occurrence levels. In determining these controls the influence of the NPD has been neutralized by dividing the levels for any month by the average level for that month. Controls for high occurrence were determined for days when the spread-F was \( \geq 1.33 \) times the monthly average, and for the low occurrence the levels needed to be \( \leq 0.50 \) times the monthly average. The central locations on the plots to be presented indicate 0000 hrs UT or 1000 hrs LT on the control day, and the standard-deviation values are blackened above an arbitrary value of 2\( \sigma \) (Fig. 3). The asterisks in Fig. 3 indicate midnight for the control dates. Figure 3(a) indicates a delay at Canberra following enhanced GA which occurs mainly around 0600 hrs LT, the standard-deviation displacement being around 5.0\( \sigma \). Other delays are recorded for two and three days. Figure 3(b) shows that when low controls are used, significant negative displacements are recorded with the results approximating a mirror image of the high level results. Comments on this are made in Sec. 4. Controls for the months of September - April were used to obtain Fig. 3(a), because better results were obtained for these months than for the remaining months of the year.

4 Discussion and conclusions

After adjusting for NPD associated modulation effects for spread-F at stations around the world, it is shown in Figs 1 and 2 that GA, possibly associated with delayed events generating AGWs, occurs from one to three days earlier, depending on the geomagnetic latitudes of the stations involved (see groups A to D). However, for low latitudes [Fig. 2(b) and 2(c)], spread-F is suppressed significantly because of the NPD changes associated with GA (Ref. 5). For the midlatitude station of Canberra, after the NPD effects on spread-F were normalized, delays in spread-F occurrence of several days is shown in Fig. 3. What is difficult to understand and needs explanation is why the GA of importance is recorded for the pre-sunrise period, particularly, one day earlier. There is also a need to explain the delays being registered on consecutive days. The superposed-epoch method will register activity levels (spread-F in this case) relative to average levels of the parameter used. This means that the negative displacements recorded in Fig. 3(b) indicate the probability of the delays being associated with more modest GA levels, including the average levels.

Fig. 3—(a) AE index relative to Canberra spread-F highs (967 events) and (b) relative to Canberra spread-F lows (1144 events)
References