SOME SHORT-TERM AURORAL BREAKUP EFFECTS ON SPORADIC-E*

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The development of the auroral substorm and the auroral breakup has been described in detail by Asafoku (1964). Swift (1967) gives some striking examples of the breakup from all-sky camera records and from his study he has separated the breakup into three phases:

(1) The quiet phase before the breakup. During 1967 at Mawson, Antarctica (67.6°S., 62.9°E. geographic; 73.3°S., 104.5°E. geomagnetic), the evening auroral display usually commenced with quiet, low intensity forms appearing near the north-eastern and eastern horizons. The general direction for the first auroral occurrence lay between the south-east and north geographic directions (SE. 18%, E. 21%, NE. 24%, N. 15%). The more northerly directions displayed increasing local magnetic disturbance and later times of first appearance. The forms initially appearing to the north-east tended to brighten and travel towards the west along the line of invariant latitude. Quiet, almost subvisual, forms appeared occasionally from the geographic east some 2–3 hr before local auroral midnight. The extent of the equatorwards expansive component of the auroral motion was found to depend on the strength of the planetary magnetic disturbance.

(2) The brightening phase in which an arc appears and brightens. Usually a long, low (elevation 10°–15°) arc is formed extending along approximately the iso-$\theta_4$ curve through Mawson. The arc remained stationary and brightened to about international brightness coefficient (IBC) II. Rays formed in the arc in the geographic north-east and travelled along the arc towards the geographic south-west. This phase lasted about 5 min.

(3) The expansive phase when the arc lifts to about elevation 30° and moves rapidly towards the magnetic zenith, the greater part of the motion occurring within 1–2 min. The arc brightened to IBC III or IV and the auroral forms became very active and moved rapidly.

During phase (3) the auroral breakup begins, marking the beginning of the auroral absorption event. Breakup times can be determined within 1–2 min from all-sky camera, riometer, photometer, and magnetometer records. They were identified on 30 MHz riometer records by correlation with magnetometer (H-component) records which revealed negative magnetic bays for breakup auroral absorption events. A scanning photometer record of the $\lambda$5577 Å (OI) emission line was also used to determine the breakup times from the sudden increase in the total emission intensity. The photometer, which had a circular field of view of 4°, was directed at azimuth 316.2° east of geographic north and elevation 69.9°, thus

* Manuscript received April 28, 1969.
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encompassing both the $\theta_4$-predicted, and the local field-adjusted, magnetic zenith as well as the local auroral zenith. The azimuth was chosen to be perpendicular to the $\theta_4$ ($= 19.47$) isochasm (Bond 1968).

The ionosonde used was a Cossor Mk II, with a 17 sec, 1–20 MHz frequency sweep and 1 kW peak output power. The all-sky camera equipment was conventional.

An interesting class of absorption events was observed at the time of the auroral breakup from 1 min ionogram sequences recorded during auroral displays in 1967; the sequences examined are listed in Table 1.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sequence</th>
<th>Riometer</th>
<th>Photometer</th>
<th>Ionosonde</th>
<th>All-sky Camera</th>
</tr>
</thead>
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<tr>
<td>23.vi.1967</td>
<td>2103–2113</td>
<td>2104</td>
<td>—</td>
<td>2104</td>
<td>2104</td>
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<tr>
<td>5.vii.1967</td>
<td>2222–2245</td>
<td>2235</td>
<td>2234</td>
<td>2235</td>
<td>—</td>
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<tr>
<td>16.vii.1967</td>
<td>2245–2300</td>
<td>2251</td>
<td>2247</td>
<td>2252</td>
<td>2251</td>
</tr>
<tr>
<td>17.vii.1967</td>
<td>2145–2219</td>
<td>2202</td>
<td>—</td>
<td>2202</td>
<td>—</td>
</tr>
<tr>
<td>24.vii.1967</td>
<td>1906–1940</td>
<td>1911</td>
<td>—</td>
<td>1911</td>
<td>—</td>
</tr>
<tr>
<td>7.viii.1967</td>
<td>2029–2054</td>
<td>2034</td>
<td>2032</td>
<td>2034</td>
<td>2032</td>
</tr>
<tr>
<td>9.viii.1967</td>
<td>2210–2300</td>
<td>2238</td>
<td>(2216)*</td>
<td>2237</td>
<td>—</td>
</tr>
<tr>
<td>28.viii.1967</td>
<td>2304–2337</td>
<td>2328</td>
<td>(2320)*</td>
<td>2328</td>
<td>2327</td>
</tr>
</tbody>
</table>


* Photometer not aimed at magnetic zenith but at azimuth 316.2°, elevation 75°.

The curves in Figure 1 were obtained from these 11 ionogram sequences by averaging, with breakup times coincident, $f$-plots of $f_0E_s$, the maximum frequency of the sporadic-$E$ layer, and $f_{\text{min}}$, the minimum frequency not absorbed by the $D$-region, together with plots (on the same time scale) of $h'E_s$, the virtual height of the sporadic-$E$ layer. The ionograms showed a general pattern of behaviour around breakup time that is similar to the mean curves in Figure 1, although not as regular in individual sequences. This pattern was:

(i) Approximately 4 min before breakup $f_0E_s$ began to increase rapidly and $h'E_s$ rose to a peak and then began to decrease.

(ii) From 1–2 min before breakup, $h'E_s$ decreased to 100 km, $f_0E_s$ continued to increase (generally $> 9$ MHz), and $f_{\text{min}}$ began to increase rapidly.

(iii) At the time of breakup $f_{\text{min}}$ increased very rapidly and total absorption occurred.

(iv) At 1–2 min after breakup $f_{\text{min}}$ and $f_0E_s$ decreased rapidly to approximately their pre-breakup values, while $h'E_s$ tended to rise towards its pre-breakup value also, although this did not always occur.

The above absorption pattern appeared in the 1 min ionogram sequences as single, or occasionally two, blank ionograms which occurred within $\pm 1$ min of the indicated breakup time.
It is noted that (1) the time taken for the decrease and recovery of $h'E_s$ appears to correspond closely to the time taken for $f_0 E_s$ to increase and recover, and (2) there is a good correlation ($r = -0.9$) between the initial value $f_1$ of $f_0 E_s$ before it begins to increase, as in (ii) above, and the value it reaches at the time of breakup. The percentage increase $P$ in $f_0 E_s$ is plotted against $f_1$ in Figure 2.

The types of sporadic-E present during breakup were $r$, $f$, and auroral-a (as classified by Piggott and Rawer 1961). Overall there was no preference for any one type and, although it was clear from the ionograms that the same layer was being observed, the type often changed from minute to minute. Above the main echo there were generally a lot of diffuse echoes, which were most probably oblique because of their height. Some suggestion has been made that the drop and rise in the apparent height of the $E_s$ layer might be due to patches of ionization, at lower height than the main $E_s$ layer, drifting horizontally past the field of view of the ionosonde during breakup. However, the present data are insufficient to either support or reject this suggestion.

![Fig. 1.—Patterns of behaviour of $f_0 E_s$, $f_{min}$, and $h'E_s$ within ±10 min of the breakup time.](image1)

![Fig. 2.—Percentage enhancement $P$ of $f_0 E_s$ at breakup plotted against its initial value $f_1$ before the pre-breakup increase.](image2)

Bailey (1968) in a study of electron precipitation during auroral displays, assuming an energy spectrum of the form $\exp(-E/E_0)$, has suggested that before the onset of the auroral substorm the precipitated electrons have a very soft energy spectrum, with $E_0$ less than 5 keV. After the breakup $E_0$ might be as large as 60 keV. Using curves given by Bailey (1968) relating $E_0$ to the height of the maximum ionization density of the $E_s$ layer, it can be calculated roughly from the present data that $E_0$ before breakup is less than 5 keV and at breakup is about 15 keV. The corresponding electron flux increases by a factor of about two. For a monoenergetic and isotropic flux of precipitated electrons of 15 keV energy, 80% of their absorption takes place between 83 and 98 km (Tables 2 and 3 of Bailey 1968). This agrees with the observation above that $h'E_s$ is close to 100 km and thus the real height is close to 95 km at breakup.
The rapid decrease in $k'E_s$ and the increase in $f_0E_s$ before breakup would be explained by a sudden hardening of the electron spectrum (i.e. increase in $E_0$). A similar softening of the spectrum would explain the rapid decrease in $f_0E_s$ and the tendency for $k'E_s$ to rise after breakup. Investigations by Johansen (1965) into the variations in electron spectra during aurorae using photometer ($\lambda 5577$ Å) and riometer (27·6 MHz) data have revealed sudden changes in the electron spectrum. These changes occurred in very short times, usually much less than 15 min. Increases in $E_0$ values (e.g. from 14 to 30 keV, assuming an exponential spectrum) followed by decreases were observed, sometimes in connection with auroral outbursts (breakups?) and sometimes not.

These rapid changes in energy spectra, if further correlated with auroral breakups, might explain the observed fluctuations in the $k'E_s$ and $f_0E_s$ values. They might also explain the observed rapid and transient enhancement of the $D$-region ionization, in terms of the deeper penetration of the higher energy electrons into the $D$-region. Ohmolt (1960) suggested that bremsstrahlung X-rays are responsible for the majority of the absorption, though later authors (e.g. Bengt 1964) tend to disagree with this. It is worth noting in this respect that impulsive bursts of X-ray fluxes have been observed during auroral breakup events (Clarke and Anger 1967; Hartz and Brice 1967; Pilkington, Anger, and Clarke 1968). The total picture is probably not quite as simple as presented above.

It is interesting to compare the riometer and ionosonde absorption data. A scatter plot (Fig. 3) of $f_{\text{min}}$ against the riometer absorption, for the 10 min before and after breakup, shows the disparity between the two sets of data. The points appear to be distributed about two different lines. Line 1 represents the expected relationship between $f_{\text{min}}$ and riometer absorption when an auroral absorption event takes place at breakup. Line 2 represents the situation when $f_{\text{min}}$ has returned rapidly to its pre-breakup value but the riometer absorption remains high. The ionosonde observed the $D$-region (indirectly via $f_{\text{min}}$) and the $E$-region, since the $E_s$ layers totally blanketed...
the $F_2$ layer, while the riometer observed all layers of the ionosphere. Figure 3 indicates that, at breakup, only $D$- and $E$-regions are affected transiently, while the layers above the $E$-region are more permanently affected. This is seen on the riometer traces which took up to an hour to recover from the auroral absorption event.

The author wishes to thank the staff of the Ionospheric Prediction Service Division for help received in the preparation of this paper. Thanks are also due to Mr. A. Kerr, Mr. I. Thomas, and Dr. I. A. Bourne of the RAAF Academy, Melbourne University, for helpful discussions. The ionospheric programme at Mawson in 1967 was carried out with the logistical support of the Antarctic Division, Department of Supply, Melbourne. This article is published with the permission of the Director, Commonwealth Bureau of Meteorology, Australia.

References
