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

By B. J. Cheney†

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 formed extending along approximately the iso-θ_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 λ5577 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

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† Ionospheric Prediction Service Division, Bureau of Meteorology, Department of the Interior, Sydney, N.S.W. 2000.

encompassing both the θ_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 θ_4 ($= 19 \cdot 47$) 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 1

BREAKUP COMMENCEMENT TIMES (G.M.T.)

Date	Sequence	Riometer	Photometer	Ionosonde	All-sky Camera
23.vi .1967	2103–2113	2104	—	2104	2104
5.vii .1967	2222–2245	2235	2234	2235	—
13.vii .1967	1939–2003	1951	—	1951	1952
15.vii .1967	2013–2100	2020	2018	2019	2019
16.vii .1967	2245–2300	2251	2247	2252	2251
17.vii .1967	2145–2219	2202	—	2202	—
24.vii .1967	1906–1940	1911	—	1911	—
7.viii.1967	2029–2054	2034	2032	2034	2032
9.viii.1967	2210–2300	2238	(2216)*	2237	—
26.viii.1967	1920–2000	1957	(1957)*	1957	1956
28.viii.1967	2304–2337	2328	(2320)*	2328	2327

* 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 $f_0 E_s$, the maximum frequency of the sporadic-E layer, and $f_{\min}$, 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 $f_0 E_s$ 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, $f_0 E_s$ continued to increase (generally > 9 MHz), and $f_{\min}$ began to increase rapidly.

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

(iv) At 1–2 min after breakup $f_{\min}$ and $f_0 E_s$ 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 ± 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_0E_s to increase and recover, and (2) there is a good correlation ($r = -0\cdot9$) between the initial value f_i of f_0E_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_0E_s is plotted against f_i 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.

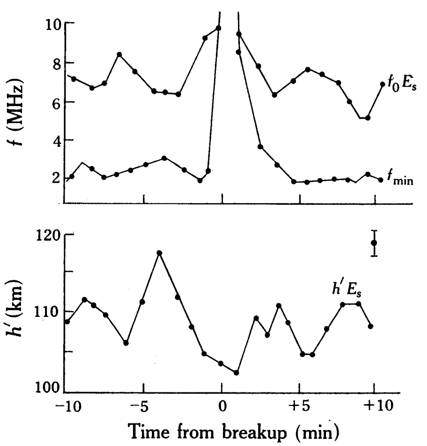

Fig. 1.—Patterns of behaviour of f_0E_s, f_{min}, and $h'E_s$ within ±10 min of the breakup time.

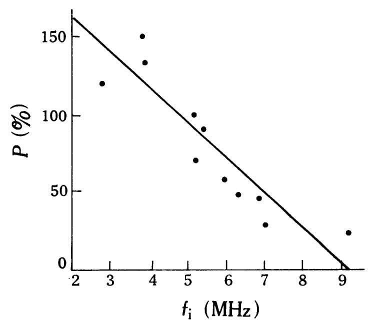

Fig. 2.—Percentage enhancement P of f_0E_s at breakup plotted against its initial value f_i before the pre-breakup increase.

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 $h'E_s$ 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 $h'E_s$ to rise after breakup. Investigations by Johansen (1965) into the variations in electron spectra during aurorae using photometer (λ5577 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 $h'E_s$ 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. Ohmholt (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.

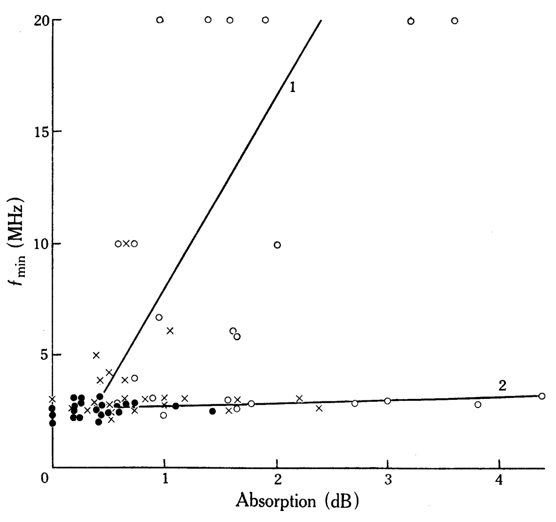

Fig. 3.—Scatter plot of ionosonde f_{min} against riometer absorption data for the 10 min before and after breakup for the July sequences:
● before breakup,
○ during breakup,
× after breakup.
The points with f_{min} greater than 9 MHz are somewhat inaccurate owing to partial and total blackout, and they are plotted at 10 MHz and 20 MHz. See the text for an explanation of lines 1 and 2.

It is interesting to compare the riometer and ionosonde absorption data. A scatter plot (Fig. 3) of f_{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_{min} and riometer absorption when an auroral absorption event takes place at breakup. Line 2 represents the situation when f_{min} has returned rapidly to its pre-breakup value but the riometer absorption remains high. The ionosonde observed the D-region (indirectly via f_{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.

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