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SAR ARC AND ITS RELATIONSHIP TO POLAR SUBSTORM

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Abstract: Photometric observations of two events of the SAR arc, occurred on the nights of September 26, 1978(UT) and September 27, 1979(UT), were made from Albany (42.68°N, 73.82°W), New York for both cases and from two ground stations; one at Albany and the other at Plattsburgh (44.69°N, 73.53°W), New York, for the arc of September 27, 1979. Observations of the SAR arcs were compared with concurrent ground-based magnetometer observations of the auroral electrojets. Results of the combined observations reveal that: (1) the intensity variation of the arc of September 26, 1978 followed closely that of the westward electrojet, with a time lag of 10–20 min after the arc reached its peak intensity; (2) there was a striking coincidence of the onset of the arc of September 27, 1979 and that of an isolated substorm whose westward electrojet center was located well apart poleward of the arc. The observational results indicate that there is a relationship between the SAR arc which is a phenomenon occurring at the plasmapause and the auroral electrojet which is connected to the plasmasheet through field lines.

1. Introduction

The close association of the SAR arc with the ring current and the plasmapause is well known; readers are referred to a review by REES and ROBLE (1975) and references therein. The SAR arc is usually observed with a concurrent visible aurora that occurs poleward of the arc, with a separation of several degrees in geomagnetic latitude (CRAVEN *et al.*, 1982). Since both phenomena have their origin in the deep magnetosphere, it is evident that a study of the SAR arc and the concurrent auroral substorm must be useful in understanding the morphology and dynamics of the magnetosphere. However, very little work has been done on the study of SAR arcs and the concurrent auroral substorm.

The purpose of this paper is to present the combined results of photometric observations of two events of the SAR arc occurred on the nights of September 26, 1978 (UT) and September 27, 1979 (UT), and the concurrent ground-based magnetometer observations of the auroral electrojet. A close relationship of the arc to the auroral electrojets was discovered for the arc of September 26, 1978 through an analysis of both the optical and ground-based magnetometer data. It was also suggested that an appearance of SAR arc may have a strong connection to the development of substorm related current patterns for the arc of September 27, 1979.

The photometric observations of the SAR arcs were made at Albany (42.68°N, 73.82°W; geomagnetic latitude 54.3°), New York for both cases. In addition, the arc of September 27, 1979 was photometrically observed from two ground stations; one at Albany and the other at Plattsburgh (44.69°N, 73.53°W; geomagnetic latitude 56.3°).

2. Observations

2.1. September 26, 1978

2.1.1. Optical data

The instrument used for the observation of the SAR arc is a multicolor meridian-scanning photometer. It swept the sky every 5.5 min in a vertical circle along the geomagnetic meridian and recorded the emissions at 630.0, 557.7, 610.0 and 530.0 nm. The field of view of the photometer is 4.7°. The SAR arc appeared as a bulge over the background 630.0 nm emission on a chart record. Intensities and positions (in zenith angle) of the arc were measured from the chart record; and the latter were transformed into the positions in geomagnetic latitude, assuming the height of the arc to be 400 km.

In order to see auroral electrojet activity, if any was present at the same L-shell threading the arc, the positions of the arc were further used to calculate the geomagnetic latitude of the intercept point of the magnetic field line threading the arc at an assumed auroral height of 110 km.

2.1.2. Magnetometer data

Magnetic data used for the SAR arc of September 26, 1978 are the three-component magnetic records of 1-min averages from the IMS Fort Churchill meridian chain of stations. The locations of magnetic observatories and Albany are shown in Fig. 1. Baselines for these magnetic data were determined by choosing the quitest period closest to the onset of the substorm, using the published AE index (KAMEI and MAEDA, 1981).

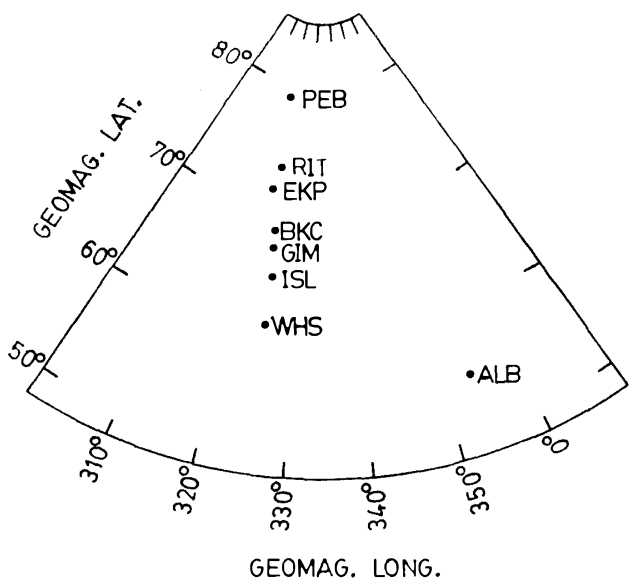

Fig. 1. Locations of magnetic stations, used for the study of the SAR arc of September 26, 1978 (UT), and Albany, New York in geomagnetic coordinates.

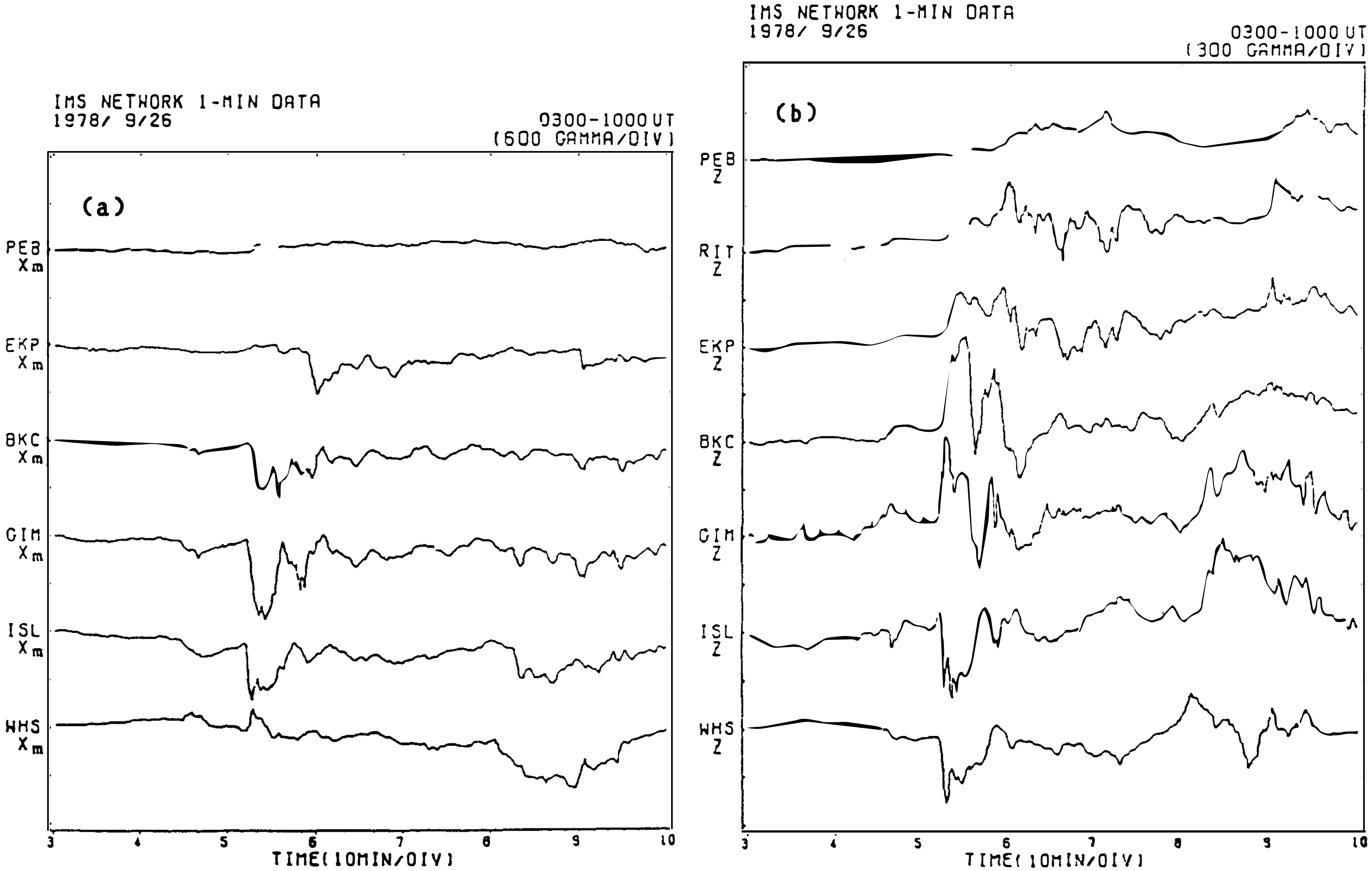

Fig. 2. Plots of the one-min averages of (a) X_m (magnetic north) and (b) Z (downward) components observed at stations in the Fort Churchill chain on September 26, 1978 (UT).

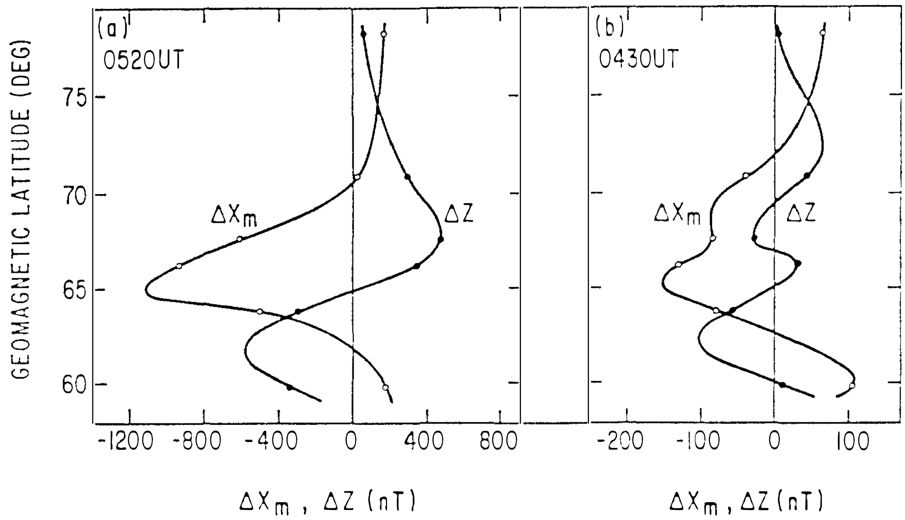

Fig. 3. Latitudinal profiles of ΔX_m and ΔZ at two typical times: (a) 0520 UT, (b) 0430 UT on September 26, 1978.

The selected time was 0030 UT on September 26, 1978.

The three component data were transformed into X_m (magnetic north), Y_m (magnetic east), and Z (downward) components using magnetic dipole coordinates; magnetograms thus obtained for September 26, 1978 (UT) are shown in Figs. 2a and 2b. From Fig. 2b we can see that a westward electrojet was centered between Gillam (GIM) and Island Lake (ISL) at 0520 UT. This is inferred from the positive ΔZ variations recorded at GIM and at higher latitudes, and from the negative ΔZ variations recorded at ISL and at lower latitudes. In order to determine the position and intensity substorm activity had reached its maximum, ΔX_m and ΔZ values at 0520 UT from each station were plotted as in Fig. 3a. The best-fitted curves were drawn by eye for ΔX_m and ΔZ plots, respectively. The position of the center of the westward electrojet was located at the point where ΔZ values changed their sign from positive to negative and the corresponding intensity of ΔX_m at that location was determined by measuring the maximum negative excursion of ΔX_m on the curve drawn for ΔX_m plots. This was taken to be the measure of the electrojet intensity. In this manner, the positions and intensities of auroral electrojet at the Fort Churchill meridian were determined every 10 min, whenever it was possible. The method described above is well established for the determination of positions and intensities of the auroral electrojet (*e.g.*, KISABETH and ROSTOKER, 1971; KAMIDE *et al.*, 1984; OKANO *et al.*, 1985).

Before 0440 UT, the presence of an eastward electrojet across the Harang discontinuity, equatorward of westward electrojet, is also identified from the latitudinal profiles of magnetic records. An example at 0430 UT is shown in Fig. 3b.

2.1.3. Results

Figure 4 shows the combined results obtained from the analyses of optical and magnetic data that were described previously. From top to bottom, it shows the time variation of: (a) positions of the intercept points of the field line threading the arc at heights of 400 km (solid circles) and of 110 km (open circles); and locations of the center of the concurrent auroral electrojets (both westward and eastward), all in geo-

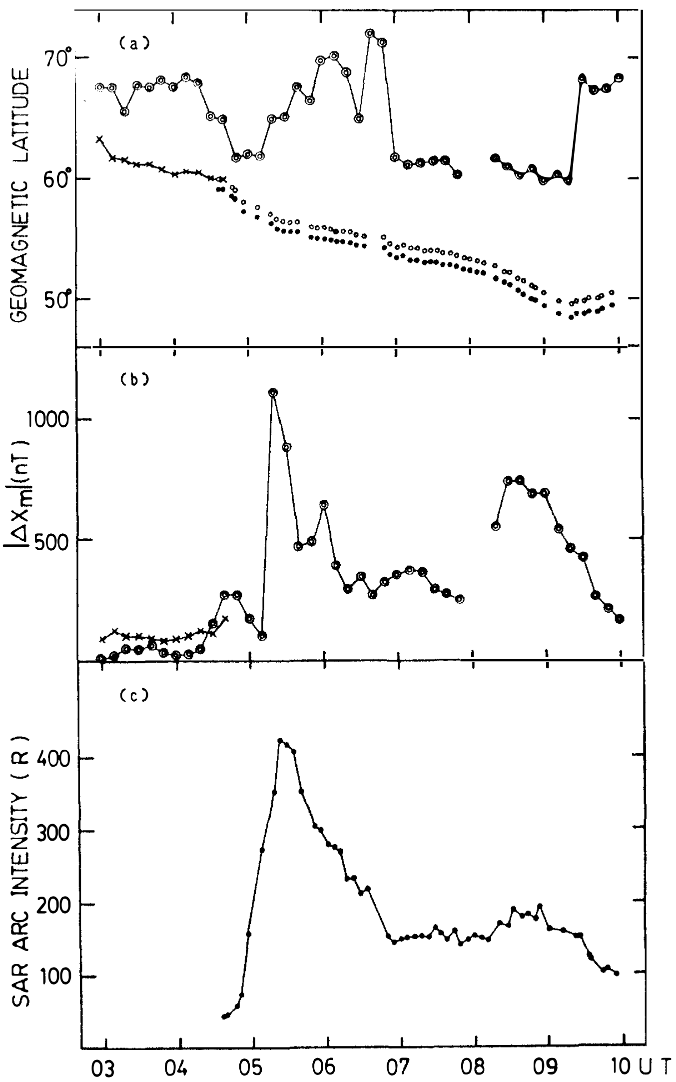

Fig. 4. *Time variations of, from top to bottom, (a) positions of the intercept points of the field line threading the arc at heights of 400 km (solid circles) and of 110 km (open circles), and locations of the center of the concurrent westward (double circles) and eastward (crosses) auroral electrojets, all in geomagnetic latitude. The height of the peak emission of the arc was assumed to be 400 km. (b)* $|\Delta X_m^{max}|$, *absolute values of determined extremum in latitudinal profiles of* ΔX_m *and (c) peak intensities reduced to the zenith values of the arc over the background 630.0 nm emission.*

magnetic latitude; (b) $|\Delta X_m^{max}|$, absolute values of the determined extremum in latitudinal profiles of ΔX_m; and (c) peak intensities reduced to the zenith values of the arc over the background 630.0 nm emission. Positions and intensities of the eastward electrojet and those of the westward electrojet are denoted by crosses and double circles, respectively (Fig. 4a and 4b). In Fig. 4a, the height of the peak emission of the arc was assumed to be 400 km.

The photometric observation commenced at 0000 UT on September 26, 1978, recording 630.0 nm emission. The first appearance of the arc was noted on the photometer record at 0436 UT as a small bulge on the background slope of the 630.0 nm emission due to intense poleward aurora.

The filter of the photometer was temporarily switched to 557.7 nm from time to time in order to check whether the arc contained a conventional auroral emission. Each time no enhancement of the 557.7 nm emission was seen on the photometer record at the position of the arc. Thus, the confirmed spectral purity, together with the continuity both in position and intensity of the arc, supports the fact that the arc observed on this night is indeed a SAR arc.

At the beginning, intensity of the arc was as low as (or even less than) 50 R (Fig. 4c). It is noted that the geomagnetic latitudes of the intercept point at an auroral height of 110 km during the very beginning period of the arc and the positions of eastward electrojet showed remarkable agreement. It is also seen that when the arc was first detected both eastward and westward electrojets were in their developing stages. After 0440 UT, the eastward electrojet faded out, at least within the latitudinal span of the magnetic stations used. After the eastward electrojet became undetectable, the intensity of the westward electrojet decreased until 0510 UT and then suddenly increased, reaching a maximum value of 1110 nT at 0520 UT. During the period 0440–0520 UT, intensity of the arc showed a rapid and monotonic increase. The time when the value of $|\Delta X_m^{max}|$ reached its maximum coincided with the time of the highest intensity of the arc throughout the night (around 0520 UT). After the value of $|\Delta X_m^{max}|$ and the intensity of the arc reached their maximum values almost simultaneously, the time variations of the intensity of the arc appeared to be closely related to the intensity changes of the westward electrojet. We can see that a shoulder in the intensity of the arc around 0610 UT, a minimum around 0655 UT, a small maximum around 0730 UT and a second largest maximum around 0830–0850 UT coincided closely to those appearing on the curve of $|\Delta X_m^{max}|$ variation; each with the intensity of the arc being lagged by 10–20 min, respectively.

2.2. September 27, 1979

2.2.1. Optical data

Photometric observations on the night of September 27, 1979 were made, as stated before, from two ground stations; one at Albany and another at Plattsburgh. The photometer located at Plattsburgh is identical to the one at Albany except that interference filters with bandwidth of 2.0 nm (FWHM) and centered at 630.0, 557.7, 427.8, and 415.0 nm are used. Both photometers swept the sky in a vertical circle containing the two stations.

An example of chart records of the photometers is shown in Fig. 5. As seen in the figure, the arc appeared as a bump over the background 630.0 nm emission. Throughout the entire period of the arc duration, the emission peak of the arc was seen to the north of zenith from Albany and to the south of zenith from Plattsburgh as seen in the Fig. 5. The spectral purity of the arc was confirmed also on this night by temporarily switching the filter of the photometers to 557.7 nm at Albany and to 427.8 nm at Plattsburgh from time to time. Each time no enhancements of the 427.8 nm or 557.7 nm was seen on the photometer record at the position of the arc. Intensities and positions (in zenith angle) of the arc were measured from the chart records obtained at both stations. Figure 6 shows the time variations of the arc intensity ob-

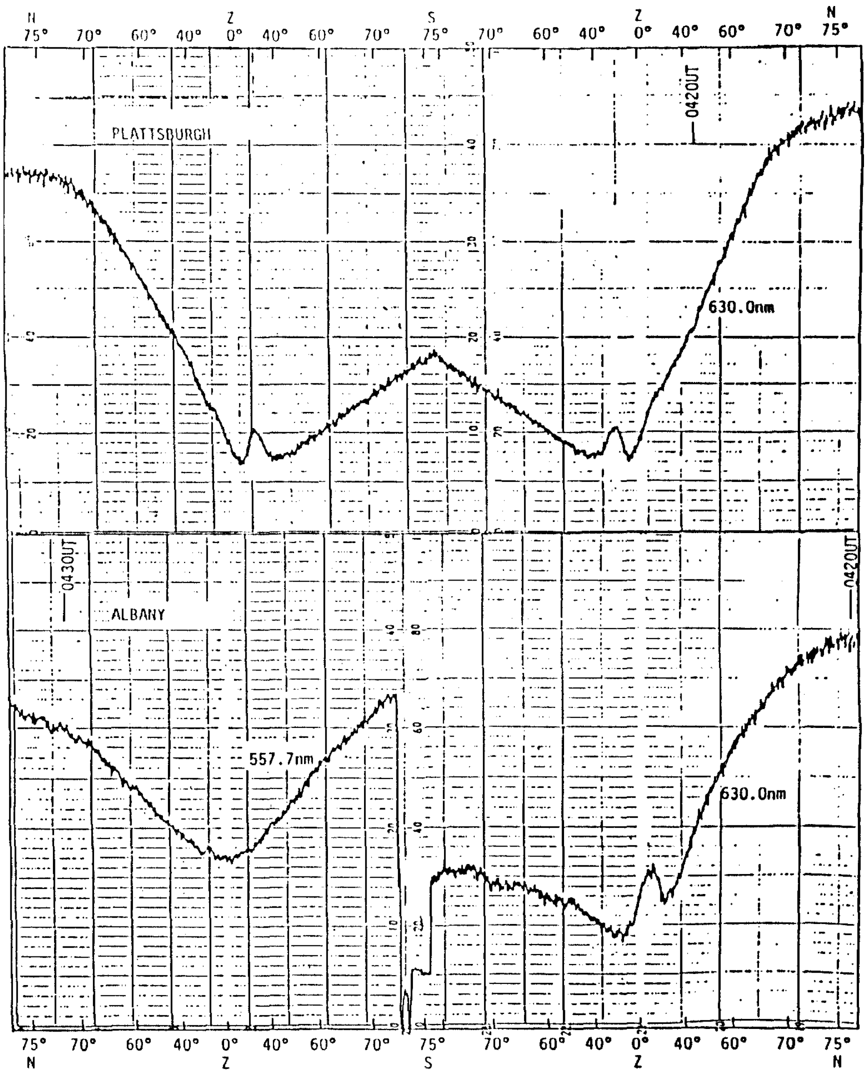

Fig. 5. An example of raw data on chart record of the photometer for the SAR arc of September 27, 1979 (UT).

served from Albany and Plattsburgh, separately. The detection threshold for the arc and errors in emission rate for both stations are included in the figure. The arc intensity detected from Albany shows a steep increase immediately after its appearance at 0307 UT and it reached its maximum around 0410 UT. Then the arc intensity decayed slowly and became undetectable after 0643 UT. The numbered tick marks in the upper part of Fig. 6 are 10-min time marks starting at 0320 UT. The maximum intensity positions (in zenith angle) of the arc were measured at both stations and smooth curves were drawn through data points in order to make triangulation of emission peak (integrated along the line of sight) position of the arc. At the times shown by the tick marks in Fig. 6, emission peak positions of the arc in a vertical plane containing Albany and Plattsburgh were calculated using spherical trigonometry. The results are shown in Fig. 7. The number of each data point in the figure corresponds to that of tick marks in Fig. 6. For points 1, 4, 10 and 17, the areas of uncertainty arising from an error in zenith angle measurements ($\pm 1°$) are shown by rhombuses. Projection

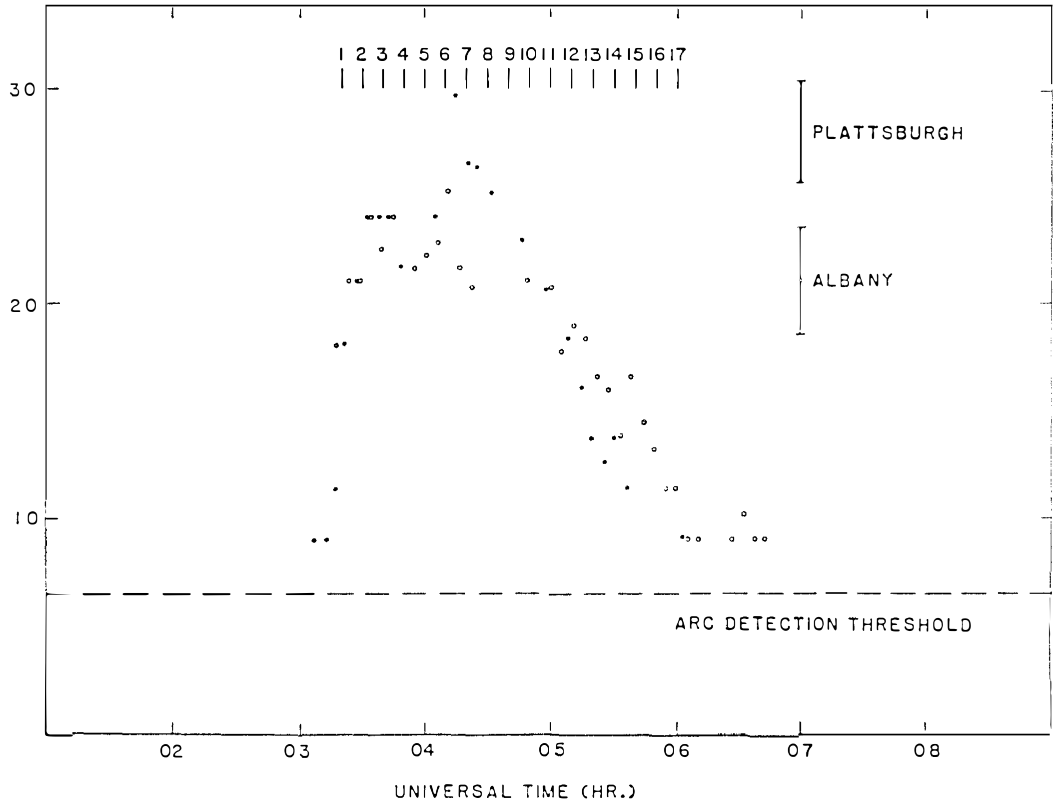

Fig. 6. Variations of the SAR arc intensity from the two stations. Typical observational uncertainties for each station are indicated by error bars.

of two magnetic field lines which envelope the arc position on the plane are included in Fig. 7. It is seen from both Figs. 6 and 7 that the arc moved rapidly equatorward and downward during the period of steep increase of intensity. Thereafter, the arc reversed its direction of motion and moved poleward while moving up and down around an altitude of 400 km along field lines. As seen in Fig. 6 there is a considerable difference in arc intensity between the two stations around 0420 UT, the value for Plattsburgh being greater. This can be understood easily if the arc has a structure elongated along a field line. Since the zenith angles of the arc seen from Plattsburgh are roughly identical to the dip angle of the field line, the integrated intensity of the arc would be greater for Plattsburgh if the arc had such field aligned structure. As seen in Fig. 6, the arc on this night is considerably weak, with a maximum intensity of less than 30 R. However, the confirmed spectral purity, together with the characteristic height of this arc, supports that the arc observed on this night is indeed a SAR arc.

2.2.2. Magnetometer data

Magnetograms obtained at 9 stations in Canada were used to study magnetic disturbances associated with the SAR arc. The locations of magnetic stations and the two stations used for the photometric observations are plotted in Fig. 8 in geomagnetic coordinates. Figures 9a, 9b and Figs. 10a, 10b show variations of the horizontal component and the vertical component of magnetic field for the Albany meridian stations and for the rest of seven stations, respectively. The time when the SAR arc was first

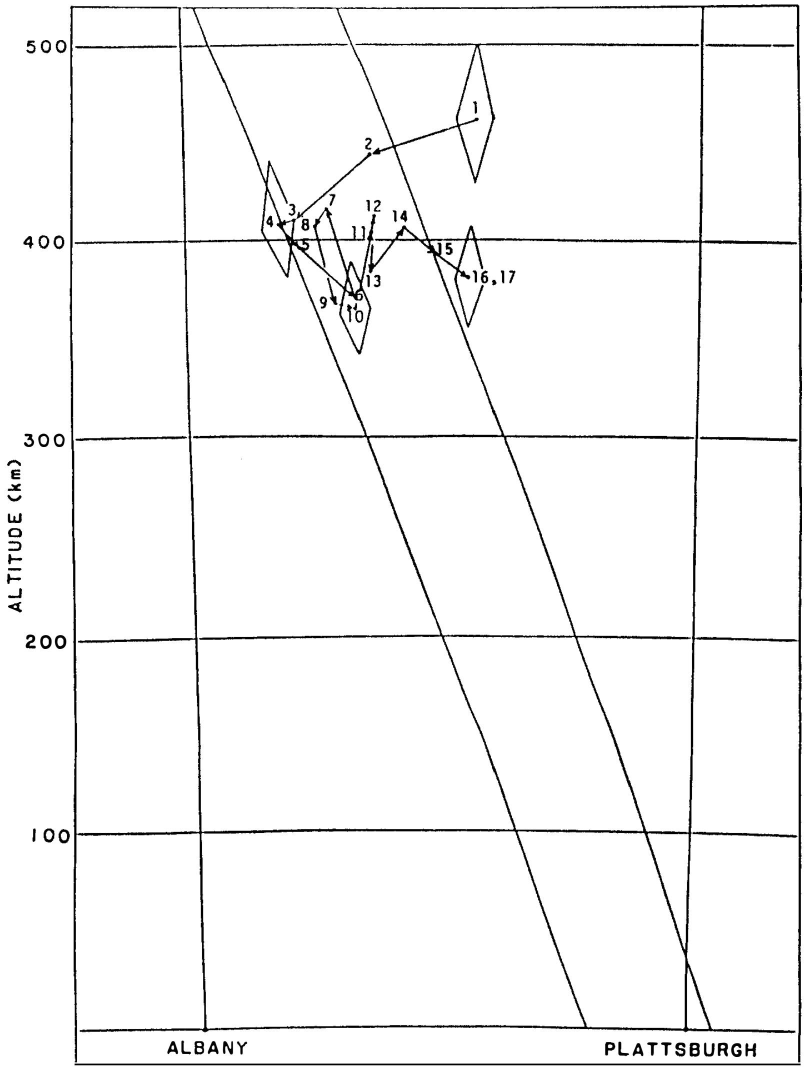

Fig. 7. Movements of emission peak positions of the SAR arc in a vertical plane containing the two stations from which triangulation was made. The number of each point corresponds to that of the time marks in Fig. 6. For points 1, 4, 10, 17, the areas of uncertainty arising from an error in zenith angle measurements ($\pm 1°$) are shown by rhombus. Projection of field lines are also included.

detected from Albany (0307 UT) is indicated by a vertical line in the figures.

2.2.3. Results

Unfortunately, it is impossible to determine the intensities and positions of the westward electrojet at either the Albany or Fort Churchill meridian for this night, because there were too few stations operating at either of the meridians. However, in Fig. 9a and 10a, an isolated substorm activity confined within the period 0300–0400 UT is clearly seen. We can infer from Fig. 8, Fig. 9a and Fig. 10a that the substorm activity propagated poleward and westward. The negative excursion in horizontal component occurred earlier in the Albany meridian around 0307 UT (Fig. 9a), indicating that the appearance of the SAR arc is coincident with the commencement of the magnetic disturbance at the Albany meridian. As stated before, an arc located close to

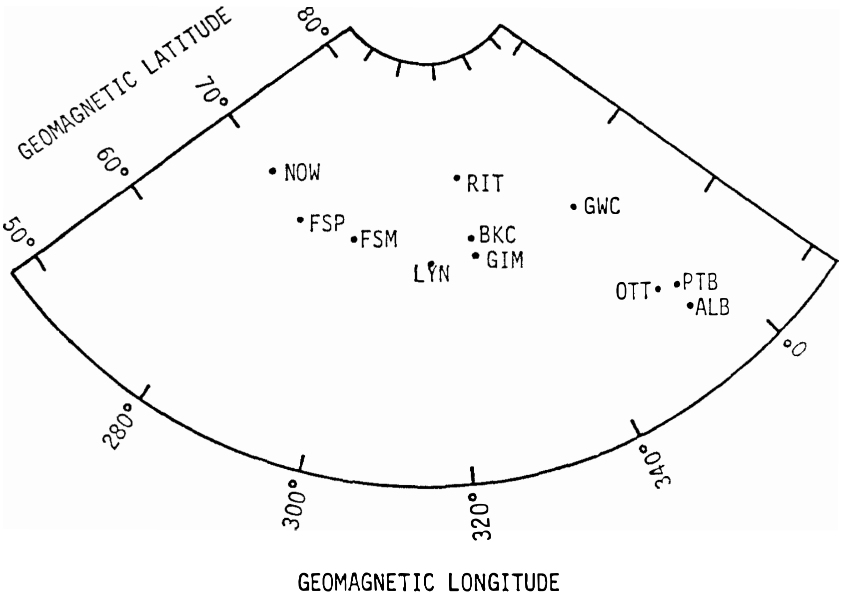

Fig. 8. Locations of magnetic stations and the two optical stations, used for the study of the SAR arc of September 27, 1979 (UT), in geomagnetic coordinates.

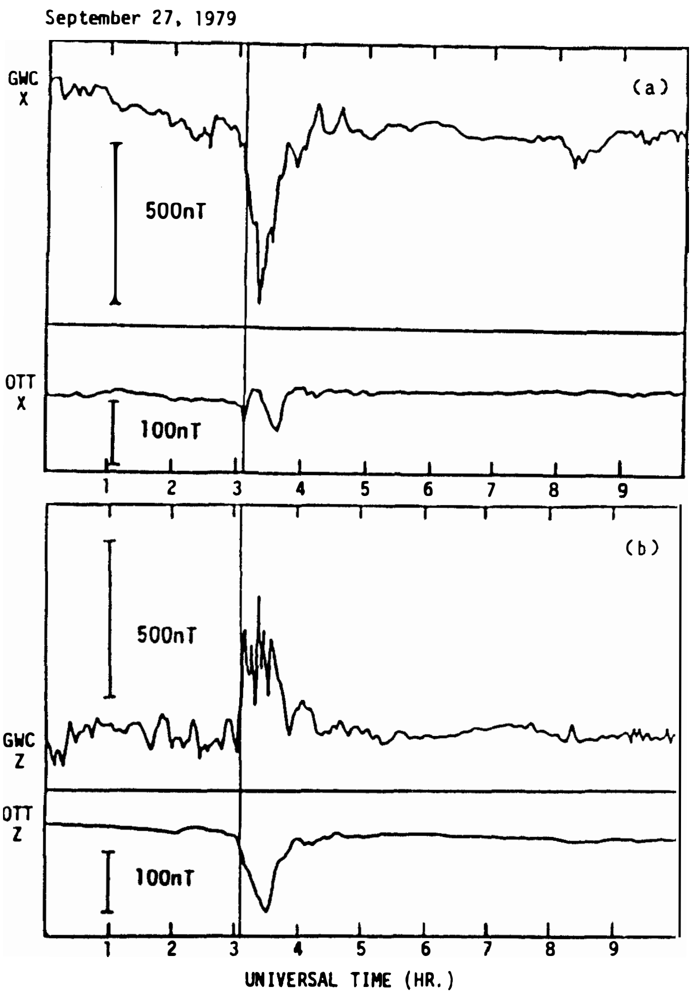

Fig. 9. Variations of (a) X (geographic north) and (b) Z (downward) components observed at stations in the Albany meridian on September 27, 1979 (UT).

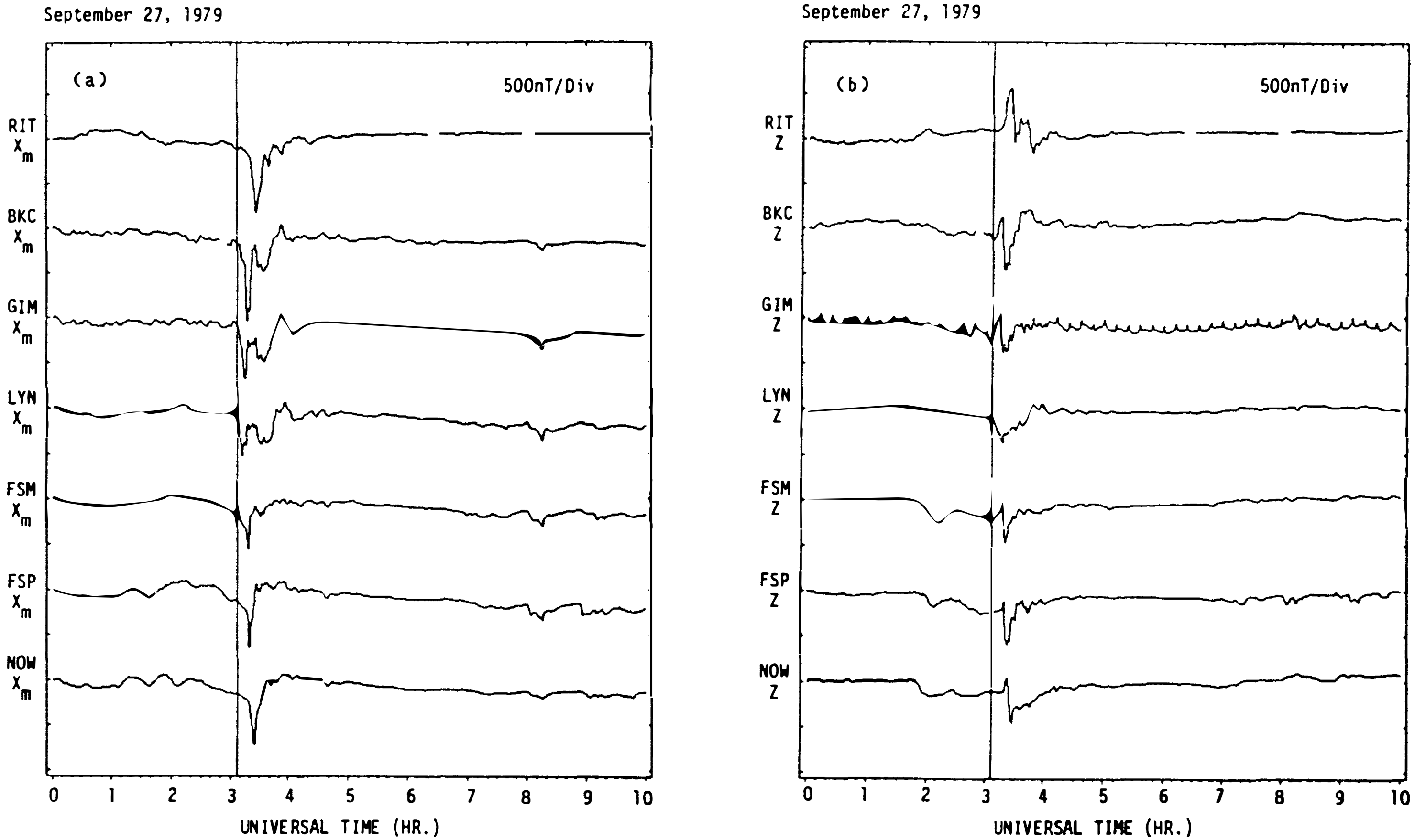

Fig. 10. Plots of the one-min averages of (a) X_m (magnetic north) and (b) Z (downward) components observed at stations in the Fort Churchill meridian and the East-West chain on September 27, 1979 (UT).

the zenith can only be detected by the meridian-scanning photometer every 5.5 min. Therefore, more exact determination of the onset time of the substorm using a method such as the Pi2 pulsation is meaningless in our case. From the sense of variations of the vertical component shown in Fig. 9b and 10b, we can also infer that the westward electrojet center associated with this substorm is located between Great Whale River (GWC) and Ottawa (OTT) at the Albany meridian, between Rankin Inlet (RIT) and Back (BKC) at the Fort Churchill meridian, and north of the East-West chain. Therefore, the westward electrojet center is located well apart from the SAR arc which is located between Albany and Plattsburgh.

3. Discussion

The arc observed on the night of September 27, 1979 is believed to be a typical SAR arc, although its intensity is low, due to the observed spectral purity and its height ($\sim$400 km). The auroral activities were well separated from the arc, since the westward electrojet center which was inferred from the magnetograms was located far poleward of the arc. Accepting the observed arc to be a real SAR arc, the coincidence of the onset of the negative excursion of horizontal component of magnetic field along the Albany meridian associated with the isolated substorm and the appearance of the arc within observational uncertainty is remarkable.

In the case of the SAR arc on the night of September 26, 1978, the appearance of the arc was during a period when the poleward electrojet intensity was increasing, and the intensity variation of the arc followed closely that of the westward electrojet, with a time lag of 10–20 min after the arc reached its peak intensity.

In the case of the SAR arc on the night of September 27, 1979, the intensity variation of the arc does not have one-to-one correspondence with substorm activities; after the simultaneous onsets, substorm activities subsided within one hour while the arc remained detectable until 3.5 hours after its appearance. Nevertheless, the coincidental occurrence of both phenomena strongly suggests that the coincidence was not a mere accident but that there must be some physical link between the initiation of the SAR arc and the substorm.

A scenario which explains the observed relationship between the SAR arc and the substorm can be described as follows: Since the primary cause for intensification of both the westward electrojet and the energy density of the ring current is the plasma injection into the plasma sheet and the ring current, respectively, it is conceivable that the substorm-associated plasma injection causes development of the westward electrojet as well as an increase of the SAR arc intensity that is believed to be related to the energy density of the ring current. While the energy injected into the plasma sheet is immediately exhausted through the Joule dissipation in the polar ionosphere where the conductivity is high, the time constant of the decay of the ring current is considerably larger. Therefore, a lesser degree of variation in the arc intensity compared to that of the intensity of westward electrojet is expected. Since this scenario explains the observed results well, it is concluded that the observed relationship between the SAR arc and the substorm is an indirect evidence for the theory that the energy source of the SAR arc is the ring current. However, the actual mechanism of the energy transfer from the ring current to the SAR arc has still to be investigated.

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