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GREEN AURORAL EMISSION AT MID-LATITUDES IN THE POST-STORM PERIOD

by

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Abstract

Green auroral emission (IBC I to III) was observed at L-values between 3.0 and 3.4 in Southern Finland throughout the night of 1978 August 29... 30 in the recovery phase of a magnetic storm. The emission consisted of pulsating luminous patches, assembled along E–W arcs. The pulsation period ranged from 15 seconds to two minutes. We assume that the emission is associated with a post-storm effect at mid-latitudes and is caused by precipitating energetic electrons.

1. *Introduction*

On the night of 1978 August 29...30 an unusual luminous phenomenon was seen by more than 100 persons in Southern Finland. Four persons even took photographs of this rare event. Reports of these observations were collected at the Finnish Meteorological Institute.

The phenomenon resembled, in some features, an ordinary auroral arc, but also showed characteristic differences from it. In this paper the visual observations are described first. Secondly, the magnetic situation before and during the observation is discussed, and finally, suggestions as to the cause of the emission, are made.

2. *Visual observations of green emission in Finland*

The sun set in Helsinki on 1978 August 29 at 17.40 and was 12° below the horizon at 19.20 UT. By then the sky had darkened enough for a luminous arc to become visible in the southern sky about 50° to 70° above the horizon. In addition, a small luminous patch with angular dimensions of 5° x 10° (the longer axis being approximately aligned E–W), was seen in the SE about 20° above the horizon. The arc was seen in the direction SE to WSW. It was diffuse, some 10° broad and 100° long. There was no structure in the arc but it brightened and faded 2 to 3 times a minute. The auroral brightness index (IBC) was 0 to II or III, i.e. the brightness at maximum was some tens of kR. The arc was feebly bluish or greenish. It moved slowly westwards.

At 20.00 UT the arc was divided into patches 10° to 20° long. They were seen in the southern sky at an elevation of 40° to 50°, and were aligned along a straight line. They brightened and faded rapidly in a random fashion with periods ranging from 15 seconds to two minutes. The phenomenon resembled slowly pulsating auroral patches.

Between 20.00 and 20.30 UT the phenomenon was faint, but in the period 20.30–21.10 UT it was brighter again. The lower border was at an elevation of 30° to 35°. The direction was SE–SW of Helsinki. Two or three elliptical patches with a size of 10° x 20° were seen this time. They pulsated with the same frequency as before and moved slowly westwards. Below them fainter patches were seen at an elevation of slightly less than 20° and with an IBC of 0 to I. These patches also slowly moved westwards.

After 21.10 UT the bright forms faded, but SW of Helsinki faint patches were seen at an elevation of 20°. Soon these patches also faded and disappeared in the west.

Between 21.10 and 22.30 UT the activity was low. Between 22.50 and 23.15 UT a cloudlike luminous patch was seen at an elevation of 40° to 50°. Its brightness varied with a period of 30 to 90 seconds from almost being invisible to an IBC of II to III. The cloud remained stationary until 23.15. After this it gradually faded and had disappeared at 23.50 UT.

At about 21.00 and 22.15 UT faint, long parallel, vertical rays were observed in the northern sky. No ordinary aurora was seen at other times.

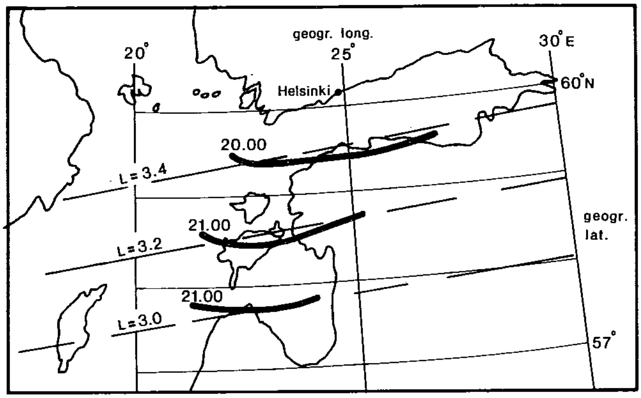

Fig. 1. Location of the emission at 20 and 21 UT on the night of 1978 August 29...30, as measured from the photographs, assuming an altitude of 105 km. The approximate L lines for an altitude of 100 km are also shown, taken from the model of CAIN *et al.* [3].

The phenomenon was observed still later in the morning at Turku. It consisted of one or more cushionlike parts. When they were at their brightest, they were aligned more or less along an E–W line (at 23.20, 23.55 and 00.20 UT). The phenomenon disappeared at about 01 UT.

At 01.20 UT the sun was again 12° below the horizon, and the brightness of the sky prevented further observations.

Four persons took photographs of the phenomenon; some of these are in colour. As the exposure times were about 30 seconds, the patchy structure of the emission is smoothed out in the pictures, and the phenomenon looks like broad auroral arcs in the E–W direction. In the colour pictures the colour was greenish, originating very likely from the green auroral line of atomic oxygen (557.7 nm).

The location of the arcs has been determined from the photographs assuming an altitude of 105 km for their lower border. Fig. 1. depicts the results at 20 and 21 UT. The length of the arcs on the map is limited by the small viewing angles of the cameras used (36° and 54°); in reality the arcs were longer. Two arcs are shown at 21 UT, corresponding to the two groups of patches seen visually at this time.

The geographic latitude of the arc at 20 UT is seen to be 59.4° to 59.5° (L = 3.4), and those of the arcs at 21 UT, 58.6° to 58.8° (L = 3.2) and 57.7° to 57.8° (L = 3.0), respectively.

No auroral all-sky photographs are available for the night of August 29...30.

3. *Background situation*

The visual observations described above are most probably related to the relatively strong magnetic storm which according to the recording at Nurmijärvi Geophysical Observatory started with a SSC at 02.46.54 UT on August 27.

The variations of the geomagnetic activity index Ap and of the Dst index, shown in Fig. 2, indicate that the geomagnetic disturbance reached its maximum on August 28, and that the recovery of the Dst field lasted for about ten days. During the subsequent magnetospheric storm the magnetosphere was so exceptionally compressed that GEOS-2 stayed outside the magnetopause on August 28 for about 4 hours, starting at 05.30 UT (Daily Summaries of GEOS-2 Data, ESA).

The polarity of the interplanetary magnetic field (IMF) during the period in question is shown in the lowest part of Fig. 2. The geomagnetic storm took place during away polarity, well in accordance with the finding of RUSSELL and

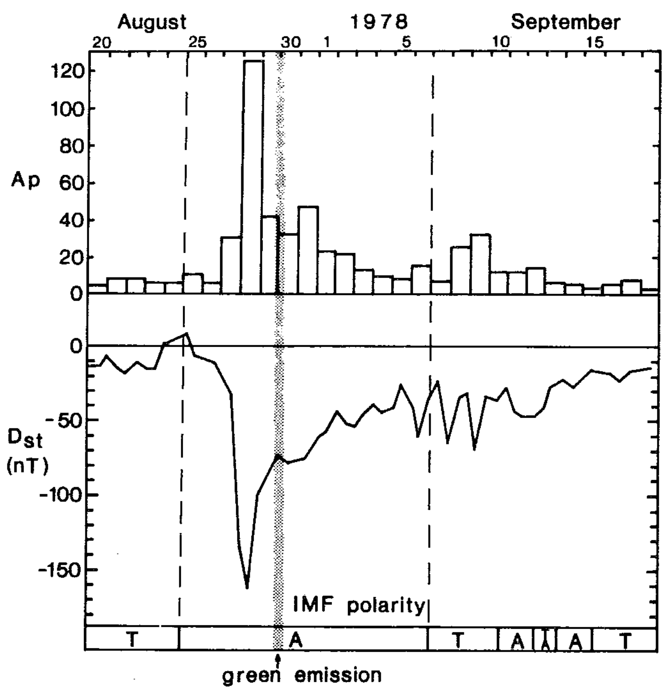

Fig. 2. The geophysical situation around the observation of the green emission. Values of the daily planetary activity index Ap (top), values of the Dst index (centre), and the polarity of the interplanetary magnetic field (bottom) (T = towards, A = away polarity).

McPHERRON [11], and BURCH [2] that in the autumn the away polarity is connected with higher geomagnetic activity than the toward polarity.

The period of visual observations of the green emission is shown in Fig. 2 by means of a dotted stripe. The phenomenon is seen to take place during the decay period of the storm, just when the steep recovery of the Dst field is replaced by a more gradual one.

4. *Comparison with ordinary auroras*

The description of the observed emission given in Chapter 2, shows that the phenomenon resembled in some features (green colour, E-W elongation, pulsation) an ordinary aurora, which can be observed at mid-latitudes during severe magnetic disturbances. But as shown in Chapter 3, the magnetic storm was already in the recovery phase during the observations.

That the optical phenomenon in question was different from ordinary auroral forms observed at mid-latitudes, can also be seen from Figure 3, which shows the geomagnetic recording from Nurmijärvi observatory near Helsinki: No disturbance current system was present in the vicinity of Helsinki during the night of August 29...30.

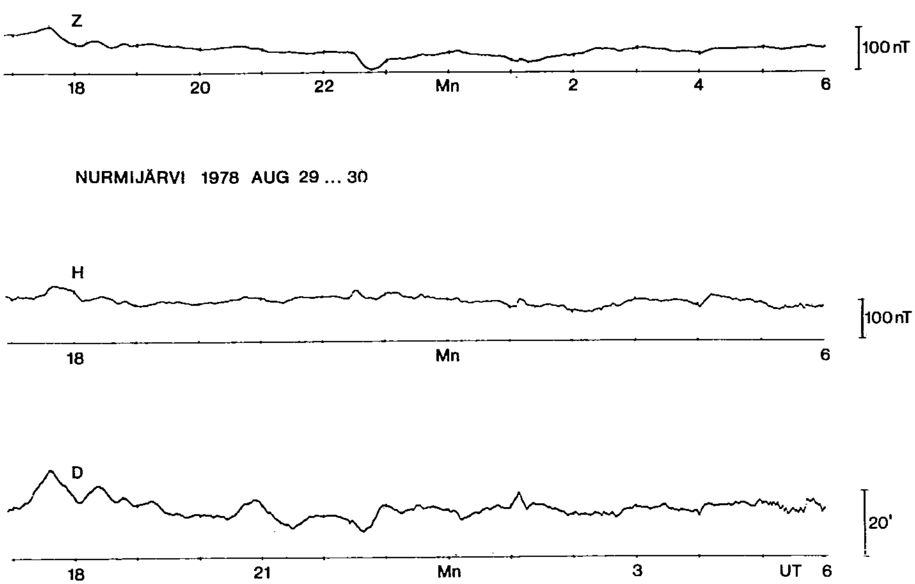

Fig. 3. Geomagnetic recording from Nurmijärvi observatory, near Helsinki, for the night of 1978 August 29...30.

Other differences from ordinary auroras are:

– Ordinary mid-latitude auroras never stay at an almost constant latitude the whole night.

– Ordinary pulsating auroras are generally seen in the post-midnight local time sector and their patches usually have an eastward movement (DAVIS [4]).

– Ordinary pulsating auroral forms very seldom occur alone, but are associated with other active auroral forms, adjacent to but equatorwards of them (DAVIS [4]).

5. *Earlier possibly similar observations*

The facts mentioned above make us believe that we have observed a rare phenomenon. We have only found a few descriptions of phenomena in literature which might be related to our observation.

The earliest description that we found was from 1898 September 11 by NEWCOMB [10]. He saw, at 7.50 to 8.30 E.S.T., a white auroral cloud in the southern sky at Harper's Ferry in West-Virginia (about L = 2.9). »It was oval in form, the longer axis parallel to the horizon, bright in the central part and fading out gradually at the border. ... it moved a little to the west, ... lasted in all at least 40 minutes, during which time it brightened up and nearly or quite disappeared again perhaps ten or twenty times. ... there was nothing like an auroral streamer and no aurora elsewhere, ...»

The description and the details are very similar to that of 1978 August 29. The author doesn't mention whether any bright aurora was seen on earlier nights or not. The aa indices of Mayaud show that Newcomb's observation was made in the recovery phase of an exceptionally severe magnetic storm, which took place on 1898 September 9...10.

CARL STÖRMER [12], [13] describes a phenomenon seen on 1919 December 19. At Dombås (L = 4.0) he saw a very strange aurora. »Near the horizon to the southwest there was a very feeble bit of an arc which was pulsating. Nowhere in the dark sky were any other aurorae to be seen, not even near the northern horizon. The arc was quite isolated.» It was visible for about 15 seconds each time, then disappeared for some seconds, and brightened again to repeat the process anew. »The arc had continued pulsating during about 2 hours and lay over the North Sea west of Stavanger at an altitude of between 90 and 120 km.»

This phenomenon also looks very similar to that of 1978, but it is not known whether there had been auroras on previous nights or not. The activity index K from Sodankylä had been 2 to 6 on the previous night, and on the evening of December 19 only 0 to 2. Thus the phenomenon happened during the recovery phase of a geomagnetic storm.

The third similar pulsating arc reported was seen on 1929 February 28 (STÖRMER [13]). »The arc appeared in the southern sky and none of the observers could see traces of other aurorae in the sky; however some interesting rays appeared on the plates, which were sensitive also to the ultraviolet.» The isolated arc appeared about 18 UT and lasted until 22 UT. The pulsating arc was in the southern sky as seen from Oslo, and the height measurements gave a mean height of 115 km. It was located at $L \approx 3.3$.

On the previous nights, in particular on the 27th, fine auroras had been observed in Oslo. Also the activity index K from Sodankylä shows that the nights of February 26...27 and 27...28 were active; the indices were 5 to 7 and 5 to 8, respectively. By the evening of the 28th the index had decreased to 2 to 4, indicating that the pulsating arc occurred in the recovery phase of a geomagnetic storm.

The strongest pulsating arcs and spots observed by Störmer occurred during the period 1941 September 19...23 (STÖRMER [12]). »As on February 28th, 1929, the phenomenon occurred after some nights of great auroral activity. In fact, on September 18th – 19th a gorgeous aurora was seen over Europe and even so far south as the Azores. ... On the next night, September 19th – 20th, a fine aurora was seen again. ... But at about 3^h MET a remarkable pulsating arc appeared low down in the south...»

On the next night, September 20...21, his assistant saw small pulsating spots between 19.45 and 20.00 UT. Later on that night the pulsation begun again. »The aurora on the next night, September 21st – 22nd, was most remarkable. From sunset to dawn pulsating bits of arcs appeared in different parts of the sky; other aurora forms than this were not seen, not even a glow in the north. ... Also on the next night, September 22nd – 23rd, an isolated spot in the east was seen...»

The aurora of September 22...23 pulsated the whole time, but the periods of pulsation varied in general from 15 seconds up to one minute. Sometimes the aurora disappeared for some minutes but reappeared later.

This series of pulsating arcs and spots again occurred in the recovery phase of a great geomagnetic storm. The Kp index had been 9 on September 18...19, and the recovery had begun near noon on the 19th. During the four nights similar phenomena occurred, but the strongest pulsating aurora was seen about three days after maximum disturbance. Strong green emission (557.7 nm) was identified in many spectra taken of that aurora in Norway. From the descriptions and drawing given by Störmer it can be concluded that the pulsating forms discussed above occurred at L-values between 3.1 and 3.8.

6. *Discussion*

The green emission observed in Finland at low L values during the night of 1978 August 29...30, seems to have occurred in the recovery period of a magnetic storm.

As was discussed in the previous chapter, similar optical events have been observed in some other but very rare cases. In most of these cases the phenomenon appeared far south of the auroral zone some days after a bright aurora was seen, indicating that a strong magnetic disturbance had preceded these events. In all these cases the magnetic disturbance was decaying, or had already decayed.

It is interesting to compare the observed optical emissions with other geophysical phenomena observed in the recovery period of magnetic storms.

Both indirect absorption and propagation measurements (LAUTER and KNUTH [8]; BELROSE and THOMAS [1]), and direct electron density measurements (LARSEN *et al.* [7]), have revealed that the ionization in the mid-latitude D-region is often enhanced following magnetic storms ('post-storm event' = PSE). The delay between maxima in magnetic disturbance, and the PSE, is usually several days.

A similar statistical behaviour has been found in the atomic oxygen emission component (557.7 and 630.0 nm) of airglow at mid-latitude (WEILL and CHRISTOPHE-GLAUME [14], NASYROV [9]): Weill and Christophe-Glaume discovered, in addition to an increase during the main phase of a geomagnetic storm, a positive postperturbation in the green line with a marked intensity increase 35 hours after the SSC, Nasyrov found that the probability maximum of latitudinal (east-west) isophots of the green line, and the intensities of both the green and the red line, lag three to five days behind the maximum storm phase.

No information is available on possible PSEs in association with the early optical events discussed in Chapter 5, but a clear PSE was observed in the period coinciding with our optical observations. Both ionosonde measurements and A3-LF absorption measurements at mid-latitudes show an enhancement of the D-region ionization, simultaneously with the appearance of the optical emission. A thorough treatment of the whole post-storm event associated with our observation is in preparation.

The association of the PSE in absorption with our optical emission is confirmed by ELLING and SCHWENTEK [5], who observed a rare event of excessive radiowave absorption in the mid-latitude ionosphere, in the period of 1978 August 30... September 8. Since the start of their measurements in 1946 they have seen similar absorption phenomena only five times before this.

Also the amplitude of the time signal on 77.5 kHz from the station DCF in FRG, received in Helsinki, experienced strong damping on the night of August

29...30 from 20 UT to late morning (LAPPALAINEN [6]).

It is thus obvious that the optical emission on the night of August 29...30 was associated with a PSE in absorption. We assume that such association is normal. The rarity of visual observations, as compared with the relatively high occurrence frequency of PSEs, can be explained by assuming that the optical emissions are normally subvisual, and can be detected by photometers only (*cf.* the airglow measurements cited earlier), and that in only rare cases is the emission intense enough to be seen by the naked eye.

The optical emission discussed above can be considered to be an auroral phenomenon, because it is associated with a magnetic disturbance and is assumed to be caused by electron precipitation. But to distinguish it from ordinary auroras we would like to call it 'post-storm mid-latitude green aurora'.

7. *Conclusions*

A visual auroral emission was observed on the night of 1978 August 29...30, in southern Finland with the following characteristics:

– It lasted the whole night.

– It appeared at relatively constant L values between 3.0 and 3.4.

– It consisted of pulsating cloudlike patches, mainly assembled along straight latitudinal lines.

– The colour of the patches was green, most probably originating from the green oxygen line 557.7 nm.

– The pulsation period ranged from 15 seconds to two minutes.

– The patches had a slow westward drift, and the phenomenon shifted somewhat southwards during the evening.

– No other auroral forms were observed during the night, except for some faint long rays on two occasions in the north.

The emission occurred in the recovery phase of a major magnetic storm, following an unusually strong compression of the magnetosphere.

The observed emission seems to be rare, but some previous reports on similar emissions have been found in the literature. We think that emissions of this kind often take place in the recovery phase of magnetic storms but are, as a rule, subvisual and can be detected with photometers only. This assumption might also explain the reported delay of maximum intensity of the oxygen lines in airglow measurements, from the maximum in magnetic disturbance.

An association of post-storm auroral emission at mid-latitudes with post-storm effects in absorption seems to exist.

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