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A LOW-LATITUDE AURORA OBSERVED AT RIKUBETSU ($L=1.6$) DURING THE MAGNETIC STORM OF SEPTEMBER 13, 1993

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Abstract: A low-latitude aurora was observed at Rikubetsu ($L=1.6$), Japan during the main phase of the moderate magnetic storm of September 13, 1993. Although the sky at Rikubetsu was covered by thick clouds on this day, the aurora was identified as a significant enhancement in the 6300-Å emission. It is likely that this aurora occurred in association with the expansion onset of an intense magnetospheric substorm, lasting approximately 1 hour. A notable point is that this aurora was observed during the moderate magnetic storm, indicating that low-latitude auroras are not always associated with intense magnetic storms. It is argued that the so-called Stable Auroral Red (SAR) arc and the substorm-associated low-latitude aurora should be distinguished in their production mechanisms, since the latter aurora must be accounted for in terms of substorm processes.

1. Introduction

Auroras observed at latitudes lower than auroral latitudes have been referred as low- or mid-latitude auroras (*e.g.*, SEATON, 1956; VALLANCE JONES, 1974; NOXON and EVANS, 1976; TORR and TORR, 1984). It has been reported that optical emissions of low-latitude auroras are produced by precipitation of low-energy electrons and/or heavy particles during magnetic storms (TINSLEY *et al.*, 1984, 1986; RASSOUL *et al.*, 1993). On the basis of their spectral characteristics and precipitating particles, RASSOUL *et al.* (1993) attempted to clarify nomenclature for several types of low-latitude auroras.

Difficulties in studying the low-latitude auroras lie in their rare occurrence. It has been believed that low-latitude auroras appear only during extremely large magnetic storms (*e.g.*, MIYAOKA *et al.*, 1990). However, on the basis of observations of four low-latitude aurora events in Japan during 1992, SHIOKAWA *et al.* (1994) and YUMOTO *et al.* (1994) suggested that low-latitude auroras can occur even during moderate magnetic storms. In order to examine the occurrence frequency of auroras during magnetic storms, it is necessary to accumulate low-latitude aurora events.

In this paper, we shall report on a low-latitude aurora event observed in Japan during the moderate magnetic storm of September 13, 1993. Variations of the associated optical emissions and geomagnetic perturbations are shown, and the nomenclature and the production mechanisms of the low-latitude aurora are also discussed.

2. Observations

Unmanned, ground-based observations of optical emissions have been conducted routinely since April 10, 1993 at Rikubetsu (RIK), Japan using a photometer. The magnetic coordinates of Rikubetsu are 36.8°N ($L=1.6$) and 214.3°E. The photometer is capable of measuring the intensity of an emission line at 6300-Å ($O(^1D)$) at the elevation angle of 20° from the northern horizon. The band width (full width at half maximum) of the 6300-Å filter is 58-Å. The absolute sensitivity of the photometer was calibrated at Niigata University: see YANO and KIYAMA (1975) for calibration details. The unmanned measurements have been made in such a way that the photometer is automatically turned on when the elevation angle of the sun becomes less than $-12°$.

The thick line in the top panel of Fig. 1 shows variations of optical emissions observed at Rikubetsu on September 13, 1993. Magnetic field variations in the H and D components at Moshiri Observatory (MSR), Japan are shown in the lower two panels. The Moshiri Observatory (MLAT=37.8°N, MLON=213.0°E) is located $\sim$150 km north-west of Rikubetsu. On September 13, the photometer was turned on at 0943 : 01 UT when the elevation angle of the sun reached $-12°$.

The emission intensity decreased with decreasing elevation angle from 0934 to 1000 UT. The local time (LT) at Rikubetsu is given by LT=UT+9. Although there was no moon in the sky on this day, the sky at Rikubetsu was, unfortunately, completely covered by thick clouds during the observation period. As is evident from the top panel in Fig. 1, an enhancement in 6300-Å emissions of $\sim$25 R relative to the background level occurred at around 1022 UT. In order to verify whether this enhancement is caused by auroral emissions or artificial ground lights reflected by the clouds, we plotted the variations in optical emissions for 51 no-moon days from April 10, 1993 to September 16, 1993. These are indicated by thin lines in the top panel. Both overcast and fine days are included in these 51 day plots. The various emission levels in the plots are produced by various intensities of the artificial ground lights reflected by clouds. It is clear that the enhancement in 6300-Å on September 13, 1993 does not represent the effects of ground lights. That is, the enhancement is significantly larger than that on any of the other 51 days. It is quite conceivable then that this enhancement is caused by auroral emissions. It is possible that the weak enhancement of $\sim$25 R results from scattering of the auroral emissions through the thick clouds. The duration of the 6300-Å enhancement is approximately 1 hour.

In the bottom panel of Fig. 1, there is a positive excursion in the H-component magnetic field at Moshiri, signaling that a magnetospheric substorm occurred at this

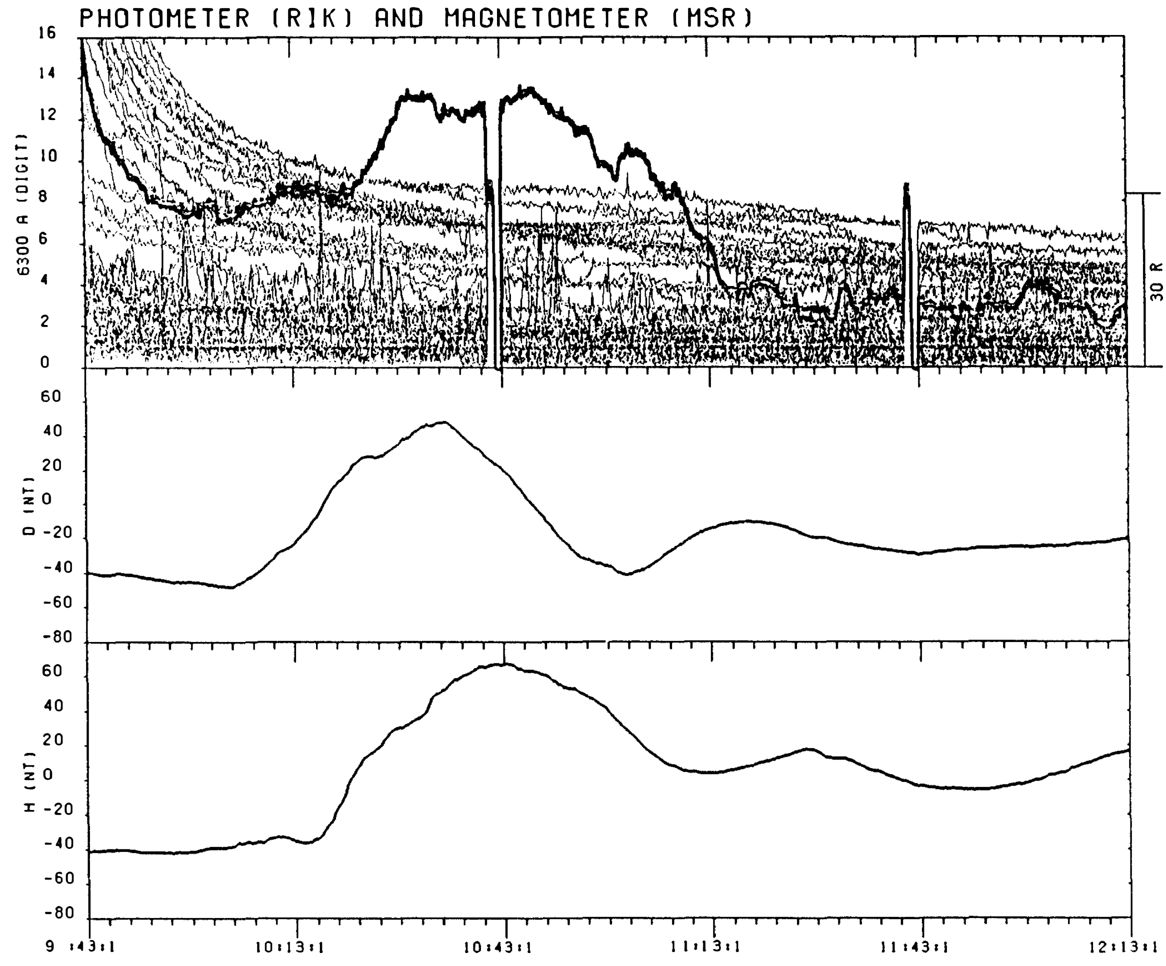

Fig. 1. From top to bottom, optical emissions at 6300-Å observed at Rikubetsu (MLAT=36.8°N, MLON=214.3°E) and magnetic field variations in the D and H components at Moshiri Observatory (MLAT=37.8°N, MLON=213.0°E) for 0943:01–1213:01 UT (1843:01–2113:01 LT) on September 13, 1993. The thick line in the top panel indicates the optical emission on September 13, 1993, while the thin lines in these panels indicate the optical emissions of 51 no-moon days from April 10, 1993 to September 16, 1993. These emissions are plotted from the time when the elevation angles of the sun become less than −12°. The notches at 1043 UT and 1143 UT in the top panel are produced by calibrations of the photometer. The sky at Rikubetsu was completely covered by thick clouds during the interval on September 13, 1993.

time. The intensity of this positive H bay is ~100 nT. It is also notable that the onset time of the positive D-component perturbation (at 1004 UT) is earlier than that of the positive H-component perturbation (at 1016 UT).

Figure 2 shows the H component magnetic field observed at six low-latitude stations along the 210° magnetic meridian on September 13, 1993. The low-latitude aurora and the associated positive H bay shown in Fig. 1 occurred during the main phase of a gradual magnetic storm, which took place at around 1200 UT on September 12, 1993. Sudden commencement (sc) of this storm is not clear. The

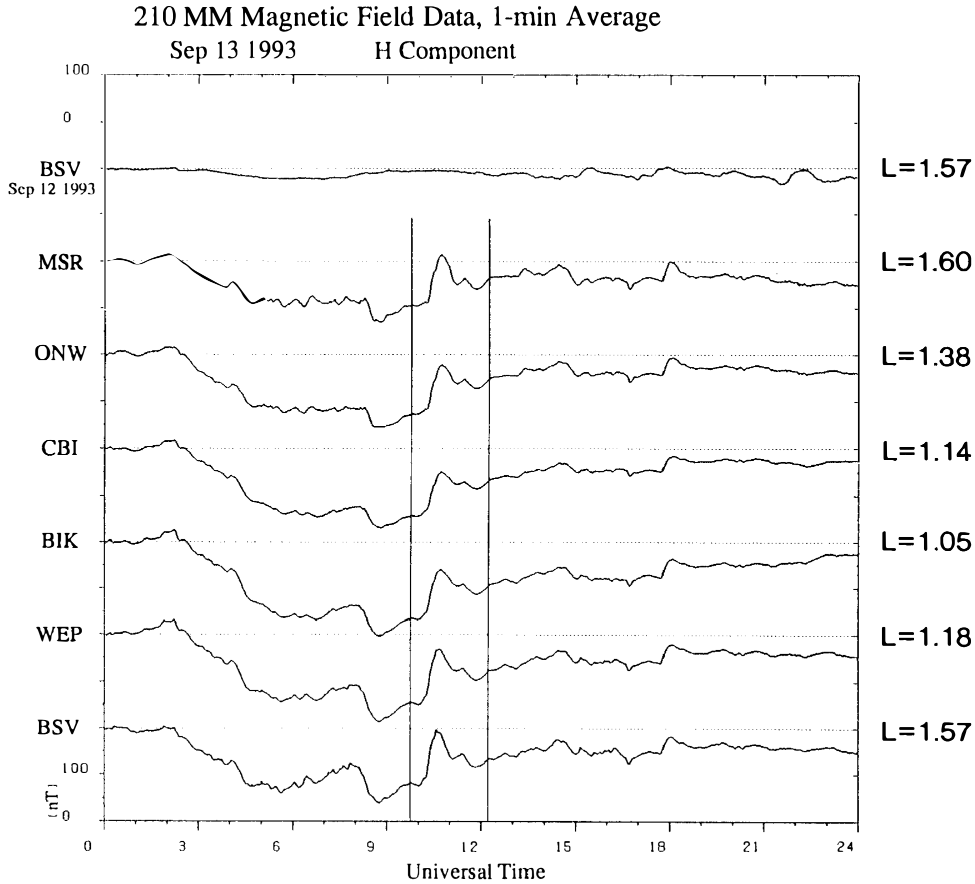

Fig. 2. H component magnetic variations at low-latitude stations along the 210° magnetic meridian on September 13, 1993. Moshiri (MSR), Onagawa (ONW) and Chichi-jima (CBI) are in the northern hemisphere, while Biak (BIK), Weipa (WEP) and Birdsbille (BSV) are in the southern hemisphere (YUMOTO et al., 1992). L-values of these stations are shown on the right side. H component magnetic field variations on September 12, 1993 at BSV are also shown at the top. The time interval between two vertical lines corresponds to that shown in Fig. 1.

maximum H depression during this storm was ~150 nT at MSR and ~200 nT at BIK.

In order to examine the timing of the onset of the low-latitude aurora and the magnetospheric substorm, we plot in Fig. 3 magnetic pulsations in the H component at low-latitude stations for 0940–1020 UT on September 13, 1993. The stations are the same as those shown in Fig. 2 except for BSV which is omitted due to a high noise level. Clear Pi 2 magnetic pulsations are seen at 1003 UT and 1014 UT, the former of which corresponds to the onset time of the positive D component bay shown in Fig. 1. The Pi 2 pulsation is widely used as an indicator of the expansion onset of magnetospheric substorms (*e.g.*, SAITO *et al.*, 1976). From Fig. 3, we can determine the onset time of the substorm of interest to be around 1003 UT (1903 LT).

In the top panel of Fig. 1, the change in the auroral 6300-Å emissions seems to start at around 1004 UT (1904 LT). However, it is very difficult to determine

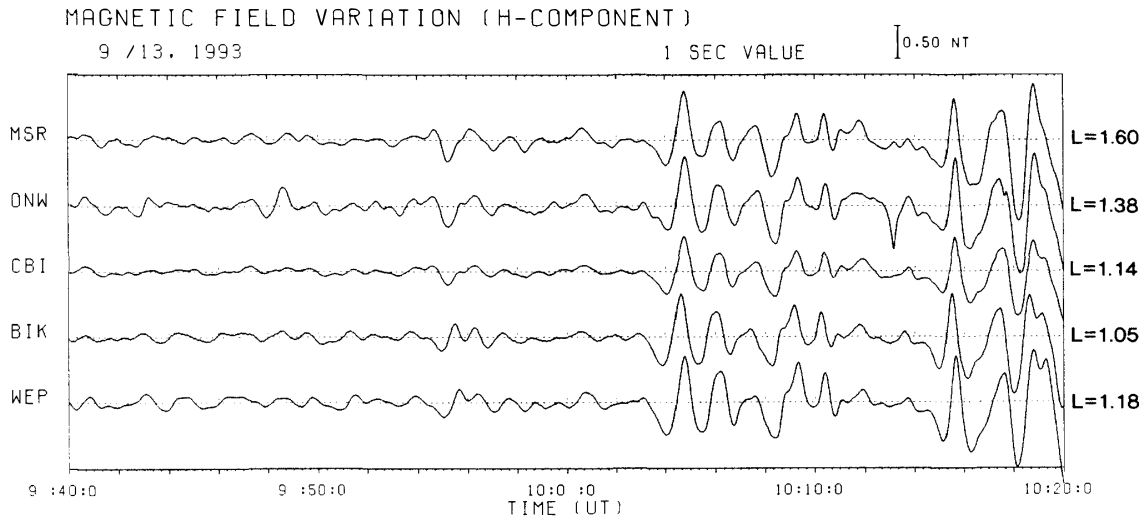

Fig. 3. Pulsations in the H component magnetic field observed at low-latitude stations for 0940 UT–1020 UT on September 13, 1993. These stations are the same as those shown in Fig. 2 except for BSV which is omitted due to a high noise level. The peak period of the band pass filter used in this plot is 80 s, while the gain of the filter becomes 0.5 at the periods of both 40 and 160 s.

accurately the onset time of the auroral emission enhancement because of the scattering of optical emissions through thick clouds. There is a clear increase in the 6300-Å emission at around 1022 UT (1922 LT) which is 19 min after the first onset of the substorm. Thus, we can conclude that the observed low-latitude aurora occurs in association with the expansion onset of the magnetospheric substorm.

3. Discussion

The low-latitude aurora reported in this paper took place after the expansion onset of a magnetospheric substorm during the main phase of a moderate geomagnetic storm. The duration of the aurora was approximately 1 hour. These characteristics are very similar to those of the low-latitude aurora reported by SHIOKAWA *et al.* (1994). TINSLEY *et al.* (1986) and RASSOUL *et al.* (1992) also pointed out similar characteristics of low-latitude auroras; that is, the auroras occur in association with magnetospheric substorms during intervals of enhanced ring current intensity.

TINSLEY *et al.* (1984) and RASSOUL *et al.* (1993) proposed some classifications of low-latitude auroras. Low-latitude auroras can be divided into those produced by heavy particles (ions and/or neutrals) and those produced by low-energy electrons, since observed spectral characteristics and precipitating particles are different for these two types of auroras. RASSOUL *et al.* (1993) proposed further that the low-latitude auroras produced by low-energy electrons can be divided into the Stable Auroral Red (SAR) arcs and the type d auroras. They defined that the former arcs are produced by electrons of energy less than 10 eV and the duration time is ~10 hours (REES and ROBLE, 1975), while the latter auroras are produced by electrons of energy ~10–1000 eV and the duration time is ~1 hour. The red to green line emission ratio for the former arcs is of the order of 10 or greater, while that for the latter arcs is ~4.

It is very important to note that the low-latitude auroras described in this paper and by TINSLEY *et al.* (1986), RASSOUL *et al.* (1992), MIYAOKA *et al.* (1990), SHIOKAWA *et al.* (1994), and YUMOTO *et al.* (1994) occur in association with the occurrence of magnetospheric substorms during the main phase of magnetic storms. The production mechanisms of the observed auroras should relate to some substorm processes. Thus, it should be noted that the type d low energy electron auroras in RASSOUL *et al.* (1993) relate to the substorm processes. There is a possibility that the SAR arcs expand to lower latitudes when the substorm occurs and form type d low-latitude auroras. Even if this is actually the case, the SAR arcs and the substorm-associated low-latitude auroras should be distinguished, since the latter auroras include additional substorm processes in the production mechanism.

CORNWALL *et al.* (1971) have presented a possible production mechanism of the SAR arcs, in which ion-cyclotron waves generated by ring current protons of energy ~20 keV interact with plasmaspheric electrons through Landau resonance and produce low-energy electron precipitation. KOZYRA *et al.* (1987) have contended that Coulomb collisions between ring current protons and thermal electrons in the plasmasphere can be an energy source of the SAR arcs. Similar mechanisms can occur in the production of substorm-associated low-latitude auroras, although additional plasmapause dynamics during substorms should play an important role in the production processes.

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References

CORNWALL, J. M., CORONITI, F. V. and THORNE, R. M. (1971): Unified theory of SAR arc formation at the plasmapause. J. Geophys. Res., **76**, 4428–4445.

KOZYRA, J. U., SHELLEY, E. G., COMFORT, R. H., BRACE, L. H., CRAVENS, T. E. and NAGY, A. F. (1987): The role of ring current O^+ in the formation of stable auroral red arcs. J. Geophys. Res., **92**, 7487–7502.

MIYAOKA, H., HIRASAWA, T., YUMOTO, K. and TANAKA, Y. (1990): Low latitude aurorae on October 21, 1989. I. Proc. Jpn. Acad., **66**, 47–51.

NOXON, J. F. and EVANS, J. V. (1976): Simultaneous optical and incoherent scatter observations of two low-latitude auroras. Planet. Space Sci., **24**, 425–442.

RASSOUL, H. K., ROHRBAUGH, R. P. and TINSLEY, B. A. (1992): Low-latitude particle precipitation and associated local magnetic disturbances. J. Geophys. Res., **97**, 4041–4052.

RASSOUL, H. K., ROHRBAUGH, R. P., TINSLEY, B. A. and SLATER, D. W. (1993): Spectrometric and photometric observations of low-latitude aurorae. J. Geophys. Res., **98**, 7695–7709.

REES, M. H. and ROBLE R. G. (1975): Observations and theory of the formation of stable auroral red arcs. Rev. Geophys. Space Phys., **13**, 201–242.

SAITO, T., YUMOTO, K. and KOYAMA, Y. (1976): Magnetic pulsation Pi 2 as a sensitive indicator of magnetospheric substorm. Planet. Space Sci., **24**, 1025–1029.

SEATON, M. J. (1956): Excitation processes in the aurora and airglow, 3, Low latitude aurorae. The Airglow and the Aurora, ed. by E. B. ARMSTRONG and A. DALGARNO. New York, Pergamon, 225–243.

SHIOKAWA, K., YUMOTO, K., TANAKA, Y., OGUTI, T. and KIYAMA, Y. (1994): Low-latitude auroras observed at Moshiri and Rikubetsu ($L=1.6$) during magnetic storms on February 26, 27, 29, and May 10, 1992. J. Geomagn. Geoelectr., **46**, 231–252.

TINSLEY, B. A., ROHRBAUGH, R. P., RASSOUL, H., BARKER, E. S., COCHRAN, A. L. *et al.* (1984): Spectral characteristics of two types of low latitude aurorae. Geophys. Res. Lett., **11**, 572–575.

TINSLEY, B. A., ROHRBAUGH, R., RASSOUL, H., SAHAI, Y., TEIXEIRA, N. R. and SLATER, D. (1986): Low-latitude aurorae and storm time current systems. J. Geophys. Res., **91**, 11257–11269.

TORR, M. R. and TORR, D. G. (1984): Energetic oxygen in a mid-latitude aurora. J. Geophys. Res, **89**, 5547–5553.

VALLANCE JONES, A. (1974): Aurora. Dordrecht, D. Reidel, 301 p. (Geophysics and Astrophysics Monographs, Vol. 9).

YANO, K. and KIYAMA, Y. (1975): Nightglow photometer calibration-I: A low brightness standard. Rep. Niigata Airglow Obs., **2**, 1–14.

YUMOTO, K., TANAKA, Y., OGUTI, T., SHIOKAWA, K., YOSHIMURA, Y. *et al.* (1992): Globally coordinated magnetic observations along 210° magnetic meridian during STEP period: 1. Preliminary results of low-latitude Pc 3's. J. Geomagn. Geoelectr., **44**, 261–276.

YUMOTO, K., SHIOKAWA, K., ENDO, T., TANAKA, Y., OGUTI, T. and MENK, F. W. (1994): Characteristics of magnetic variations caused by low-latitude aurorae observed around 210° magnetic meridian. J. Geomagn. Geoelectr., **46**, 213–229.

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