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INITIAL OBSERVATION RESULTS WITH IMAGING RIOMETER AT NY-ALESUND ($L=16$)

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Abstract: An imaging riometer was installed at Ny-Alesund (invariant latitude, 75.6°) for observations of spatial structure and motion of auroral absorption regions. The antenna consists of a two-dimensional dipole array with 64 elements, and a phasing matrix produces 64 pencil beams viewing an ionospheric area of about 200 km square at 90 km altitude. The instrument provides us with a two-dimensional image of enhanced absorption at 30 MHz with spatial resolution of 20 km and time resolution of 1 s by using an 8-channel radio receiver. With the aid of a personal computer we can monitor the absorption images in real time by using a quiet day curve produced from daily variations of cosmic radio noise intensity during initial ten days. Three examples of the absorption images are presented for the events occurred in day, evening and night time.

1. Introduction

Riometer (Relative Ionospheric Opacity Meter) has been used primarily to measure the absorption of cosmic radio noise in the ionosphere. The cosmic noise absorption (CNA) is caused by the precipitation of the magnetospheric electrons and/or flare-associated solar energetic protons. In the auroral region, riometers have been used to measure auroral absorption caused by electrons with the energy range of a few tens keV to a few hundreds keV. However, riometers have been improved to be of multiple narrow-beam type for investigating dynamics and spatial scale of auroral absorptions (*e.g.*, NIELSEN, 1980; YAMAGISHI and KIKUCHI, 1989).

Recently an imaging riometer for ionospheric studies (IRIS) was first developed in 1988 at the South Pole Station, Antarctica (invariant latitude $-74°$, $L=13$) in order to achieve higher resolution of temporal and spatial variations in auroral electron precipitation (DETRICK and ROSENBERG, 1990). This instrument attained a spatial resolution of 20 km in the ionosphere at 90 km altitude and time resolution of 1 s by using a two-dimensional phased array of 64-element dipoles at 38.2 MHz which produces 49 independent beams viewing an ionospheric area of about 200 km square. Such an imaging riometer was then installed in 1990 at Tjorness in Iceland located at an invariant latitude of 67° (YAMAGISHI *et al.*, 1992). The instrument was equipped with 64 beams operating at 30 MHz with a two-dimensional phased array of 64-element dipoles.

Furthermore a 49 beam imaging riometer of the same type as that at the South Pole Station was installed at Sondre Stromfjord, Greenland (invariant latitude, 73.7°) to study dynamics of cusp-latitude ionospheric absorption events (STAUNING and ROSENBERG, 1992).

This paper presents the imaging riometer at 30 MHz installed at Ny-Alesund, Svalbard (invariant latitude 75.6°, $L=16$) in September, 1991, along with an initial observation result of absorption events in the dayside cusp, auroral and polar cap regions.

2. Instrumentation

The imaging riometer installed at Ny-Alesund employs a two-dimensional array (8×8) of 64-element half wavelength dipoles at 30 MHz. Each element is a linearly polarized dipole placed at a quarter wavelength above the ground plane. The horizontal separation of the elements is 0.65 wavelength along each of two perpendicular axes: one axis is aligned with deviation of 9° eastward from the geomagnetic north at Ny-Alesund. The deviation of 9° is caused by setting all dipoles on the flat ground. Each dipole is connected to a transformer balun (balance–unbalance circuit) and is matched to 50 Ω through an open-stub circuit. The impedance-matched signals from 64 dipoles are led to a phasing combiner (Butler matrix) through coaxial cables to produce 64 pencil beams with a beam width of approximately 11°. A portion of the 64 dipoles installed at Ny-Alesund is shown in Fig. 1. The ground plane consists of cupper wires (diameter, 1.5 mmϕ) separated 50 cm along the north–south line of the dipoles.

Butler matrix and an 8-channel radio receiver tuned at 30 MHz are placed in a wooden box with a thermostat installed at the center of the 64 dipoles. The receiver IF bandwidth is ±100 kHz, and the time constant of the integrator is 60 ms. The DC output signals of the 8-channel receiver are led to a personal computer (PC 9801RX) in the observation room through a multi-wire cable of 300 m length, as shown in the block

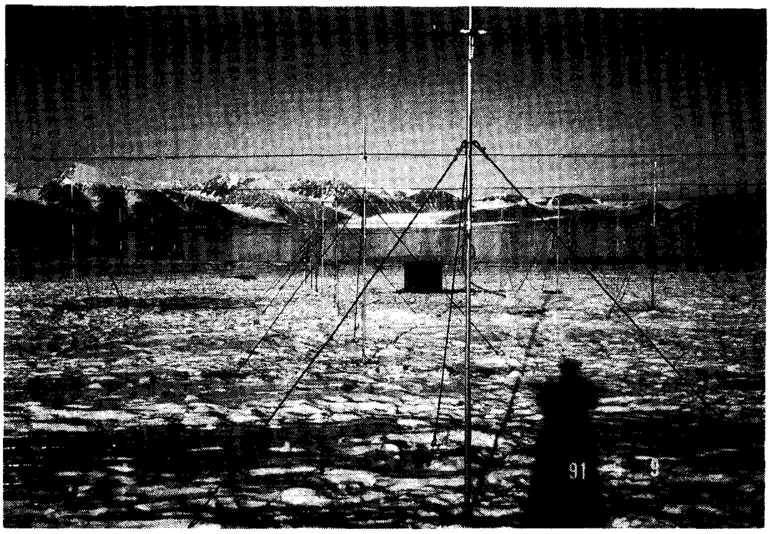

Fig. 1. A portion of the 64-dipole phased array installed at Ny-Alesund. The phasing/receiver box is located at the center of the array.

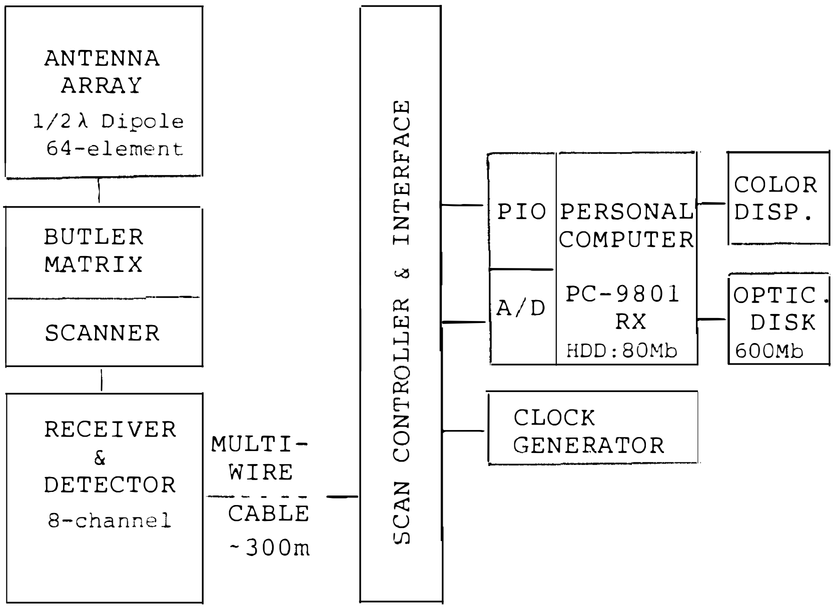

Fig. 2. Block diagram of the imaging riometer at Ny-Alesund.

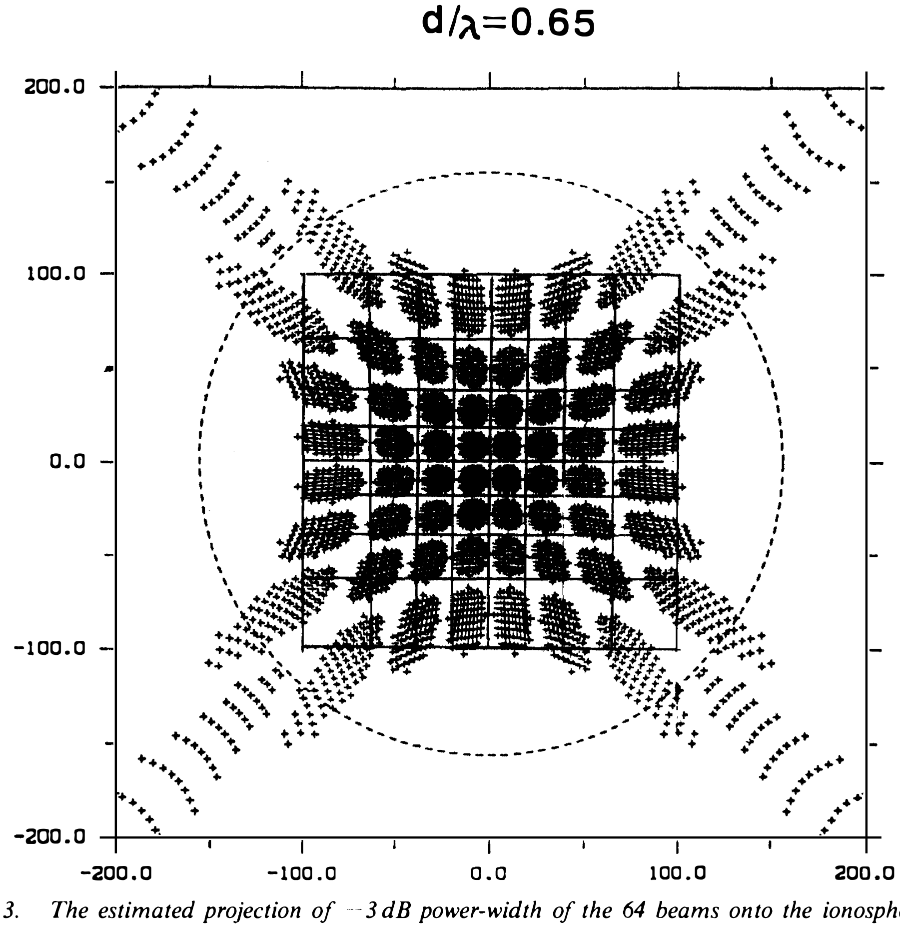

Fig. 3. The estimated projection of −3 dB power-width of the 64 beams onto the ionosphere at 90 km altitude. The output intensities from 64 beams are given to the corresponding 64 square segments by color images on the monitor display attached to a personal computer.

diagram of Fig. 2.

The personal computer sends scan control pulses to the 8-channel receiver through the multi-wire cable, and then acquires digital signals of the cosmic noise intensity through an interface and an A/D converter. The scanning interval is selected as 1 s, 2 s, 4 s, and 8 s. The data processing by the personal computer has menus to display time variations of cosmic noise intensity for 64-segments of north–south (N1 to N8) and east–west (E1 to E8) directions and two-dimensional images on the display monitor. Figure 3 shows the estimated projection of the 64 beams (−3 dB power-width) onto the ionosphere at 90 km altitude. The output intensity from 64 beams are given to the corresponding 64 square segments by color images on the monitor display attached to the personal computer. It is noted that the beams at four corners are located outside of the field of view of ±100 km square. A detailed description concerning the instrument and the data processing by the personal computer is given by two technical papers written in Japanese (YAMAGISHI *et al.*, 1992; SATO *et al.*, 1992).

3. Determination of Quiet Day Curves

In order to estimate the ionospheric absorption from time variations of cosmic noise intensities of 30 MHz, it is necessary to determine a quiet day curve (QDC) indicating minimum attenuation on the condition of the "quiet ionosphere". ARMSTRONG *et al.* (1977) first proposed the inflection point method (IPM) for determining the QDC. KRISHNASWAMY *et al.* (1985) compared the QDC by IPM with that obtained by an earlier method of percentage criterion. As the result, IPM has a merit of little or no interference to cosmic signals caused by artificial radio noises. So, we adopt IPM by KRISHNASWAMY *et al.* (1985).

The quiet day value is defined as the higher voltage or decibel value at which the condition for the inflection point ($d^2N/dV^2=0$) is satisfied, as shown in Fig. 4. The

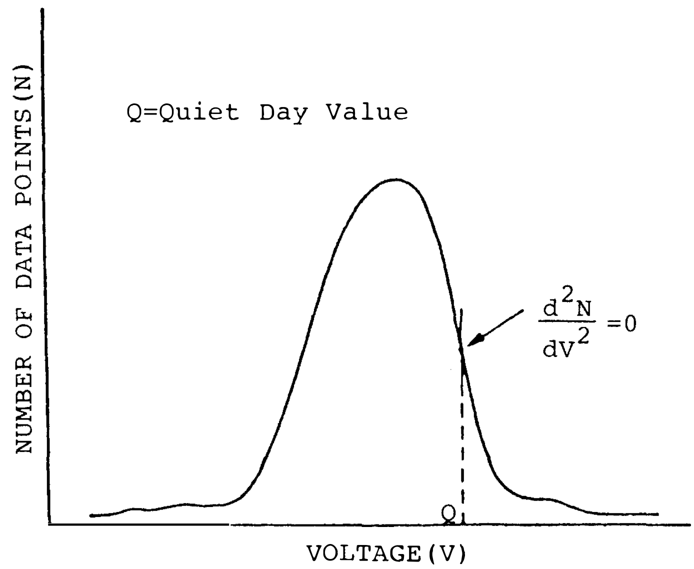

Fig. 4. Definition of the quiet day value in a distribution of data points for a given sidereal time according to the inflection point criterion.

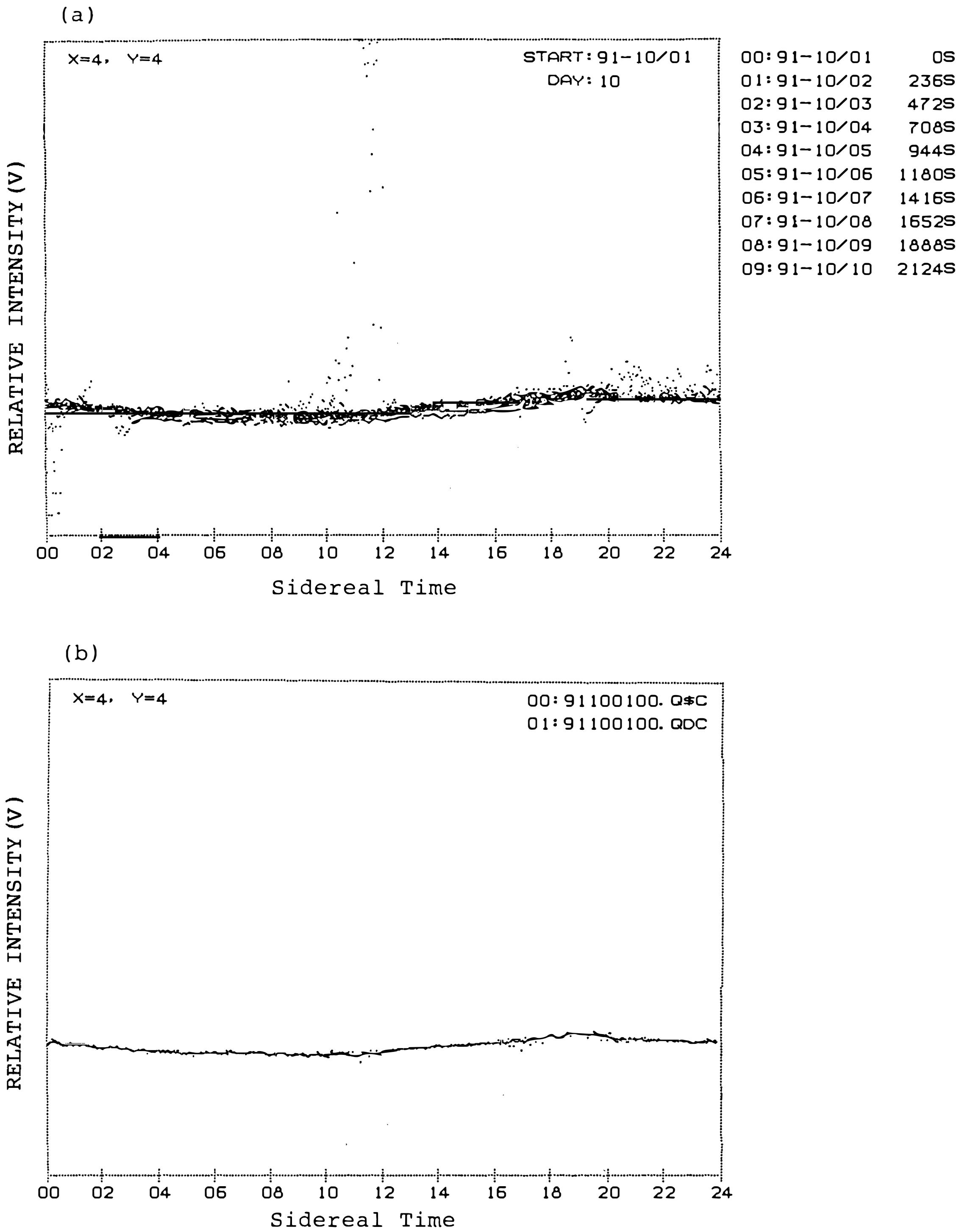

Fig. 5. (a) Time variations of cosmic noise intensity with sidereal time observed during 1–10th October 1991, on a specific beam (N4, E4) pointing near the zenith. The sidereal time is corrected by a rate of 236 s/day from the previous day, as shown in the top-right column outside the figure frame. (b) Time variation of the quiet day values determined by IPM and a quiet day curve (QDC) obtained by running average calculation.

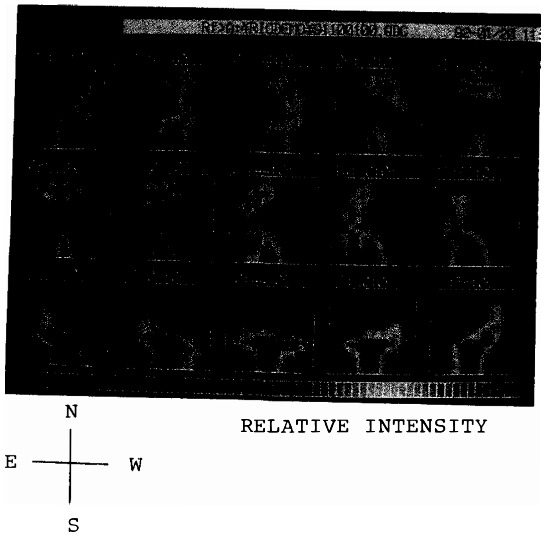

Fig. 6. Daily variation of two-dimensional images produced from 64 QDC's. A color bar below shows relative intensity of the cosmic radio noise.

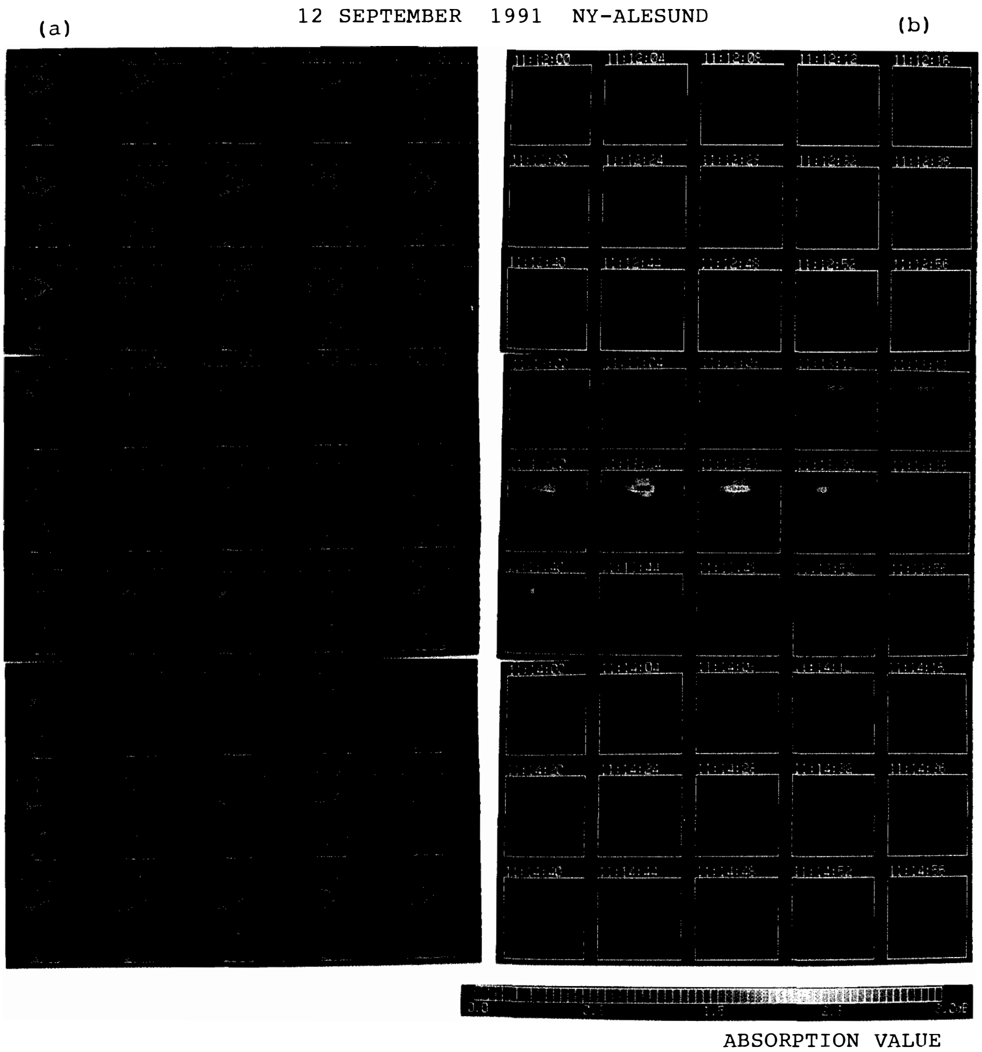

Fig. 7. (a) A time series of images of cosmic noise every 4 s during about 5 min at 11 UT on 12 September 1991. (b) A time series of images of the absorption reduced from QDC's. The absorption value in dB is represented by a color bar below.

details of the procedure for determining QDC by the personal computer are described in the paper by SATO *et al.* (1992).

Figure 5a shows time variations of cosmic noise intensity during 1–10 October 1991, for a specific beam (N4, E4) pointing near the zenith. The time variation on each day is plotted as a function of sidereal time: the time is advanced by a rate of 236 s/day from the previous day. Two negative swings from dense distribution of points from 0200 to 0230 and 1900 to 2000 indicate the decrease in the cosmic noise intensity due to the ionospheric absorption. A curve shown in Fig. 5b is the quiet day curve calculated with running averages of quiet day values over 192 s. The QDC fluctuates slightly around 11 h and 18 h sidereal time, but these fluctuations are less than 0.15 dB, which indicates uncertainty for estimating the absorption. Therefore, it is essential in practice to determine stable QDC from as many quiet time variations of the cosmic noise intensity as possible.

Figure 6 shows a daily variation of two-dimensional images of quiet time intensity of cosmic noise shown in Fig. 5. It is found that the cosmic noise sources rotate counterclockwise in Fig. 6 diagrams in the sequence of west, north, east and south centered at the zenith. Comparing the cosmic noise sources with an all-sky constellation map, the sources correspond to Cygnus and Cassiopeia. A red portion located at the southern region seems to be due to radio noise propagated from the south.

The evaluation of the directivity of the antenna installed at Ny-Alesund was carried out by the comparison between the time variation of the observed cosmic radio noise intensity from each beam and that estimated from a cosmic radio noise map of the whole sky at 30 MHz (CANE, 1978), as has been done by YAMAGISHI *et al.* (1992) for the antenna installed at Tjorness, Iceland.

Figure 7 shows a comparison between (a) a time series of images of cosmic noise every 4 s at 11 UT on 12 September 1991 and (b) images of the absorptions obtained by subtractions of the QDC from the observed cosmic noise intensity. It is evident in Fig. 7a that the intensity of the cosmic noise source at the northeast region of the zenith is decreased due to the ionospheric absorption around 1113 UT.

4. Initial Observation Results

Ny-Alesund is located at the cusp/cleft in the magnetic noon, within the auroral oval in the morning and evening, and at the polar cap in the nighttime. Continuous observations by the imaging riometer were started on 12 September 1991, with the time resolution of 4 s. We show three examples of the absorption events observed at different local time among initial observations.

(a) Daytime absorption: 07–09 UT, 8 October 1991

Figure 8 shows time variations of the absorption values for 64 beams from 0708 to 0907 UT, 8 October in the magnetic midday (local magnetic noon, ~0830 UT). The absorption values were weak (< 1 dB) throughout this interval. Figure 9 shows a time series of the absorption images averaged every 1 min obtained from the time variations given in Fig. 8. It is found from Fig. 9 that the first absorptions with patchy-type structure of several spots occurred at about 0725 UT. Thereafter, the southern spots

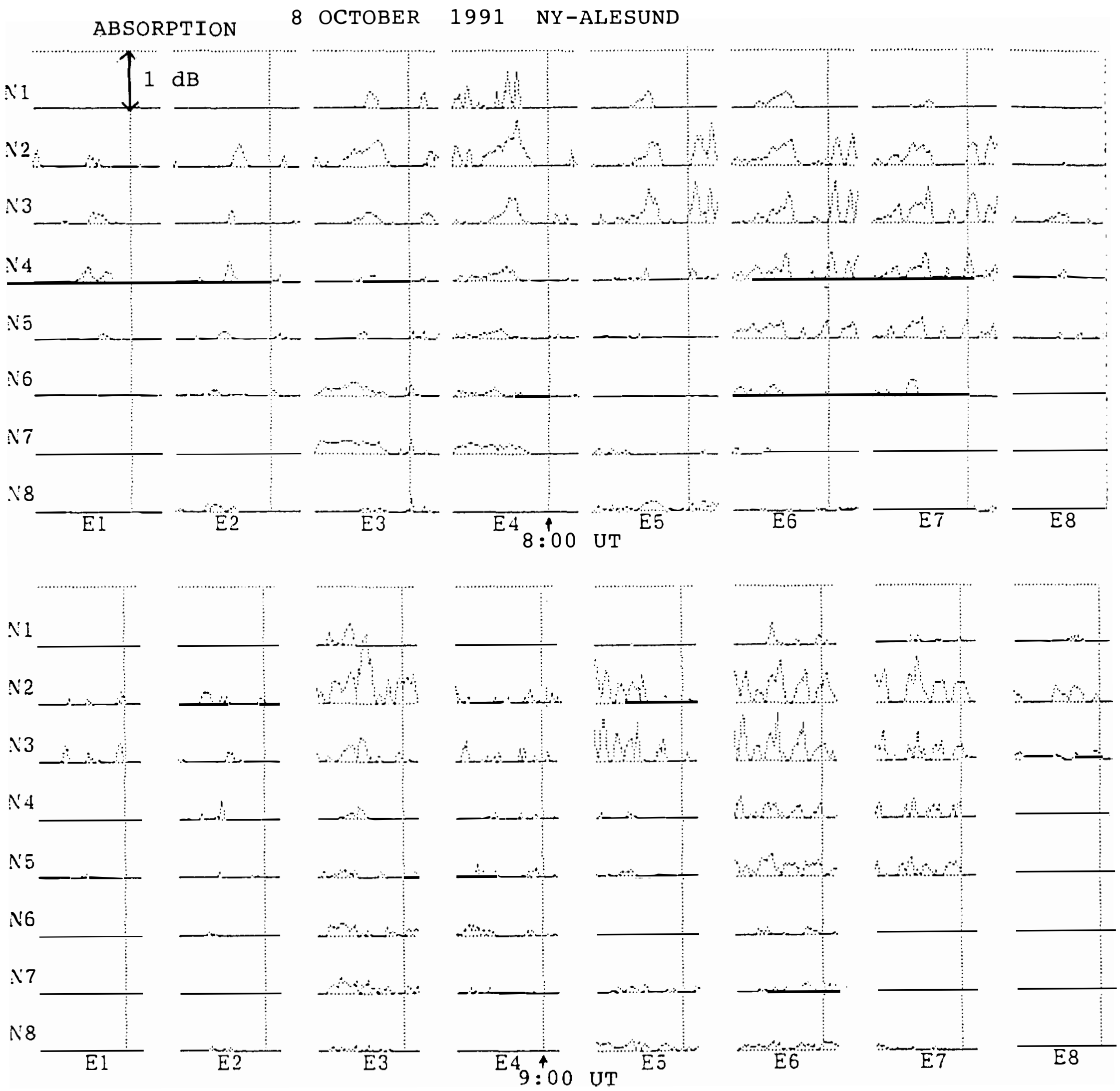

Fig. 8. Time variations of the absorption value of the 64 beams (N1 to N8, E1 to E8) during 0708 to 0907 UT, 8 October 1991 (upper and lower panels).

moved poleward with a speed of about 150 m/s, and were merged with the northern absorption spots. Around 0738 UT, the northwest absorption was enhanced ($\sim$1 dB) forming an L-shape with a sharp boundary at the equator-side, and then the absorption was localized at the northern region around 0741 UT.

It is found from a few beams in the northwest region of Fig. 8 that pulsating absorptions with a 10–15 m period appeared during one-hour from 08 to 09 UT. A localized absorption of about 50 km square appeared in the western region at 0758 UT, and it moved poleward with a speed of 140 m/s from 0800 to 0806 UT, whose aspect is evidently seen from the time variations along the two columns of E6 and E7 beams of the upper panel of Fig. 8. At 0810 UT, a localized absorption appeared again in the northwest region, but it showed no poleward motion.

At about 0823 UT, absorptions with patchy-type structure appeared again over Ny-Alesund. The structure in the eastern region seems to be a stripe of narrow width

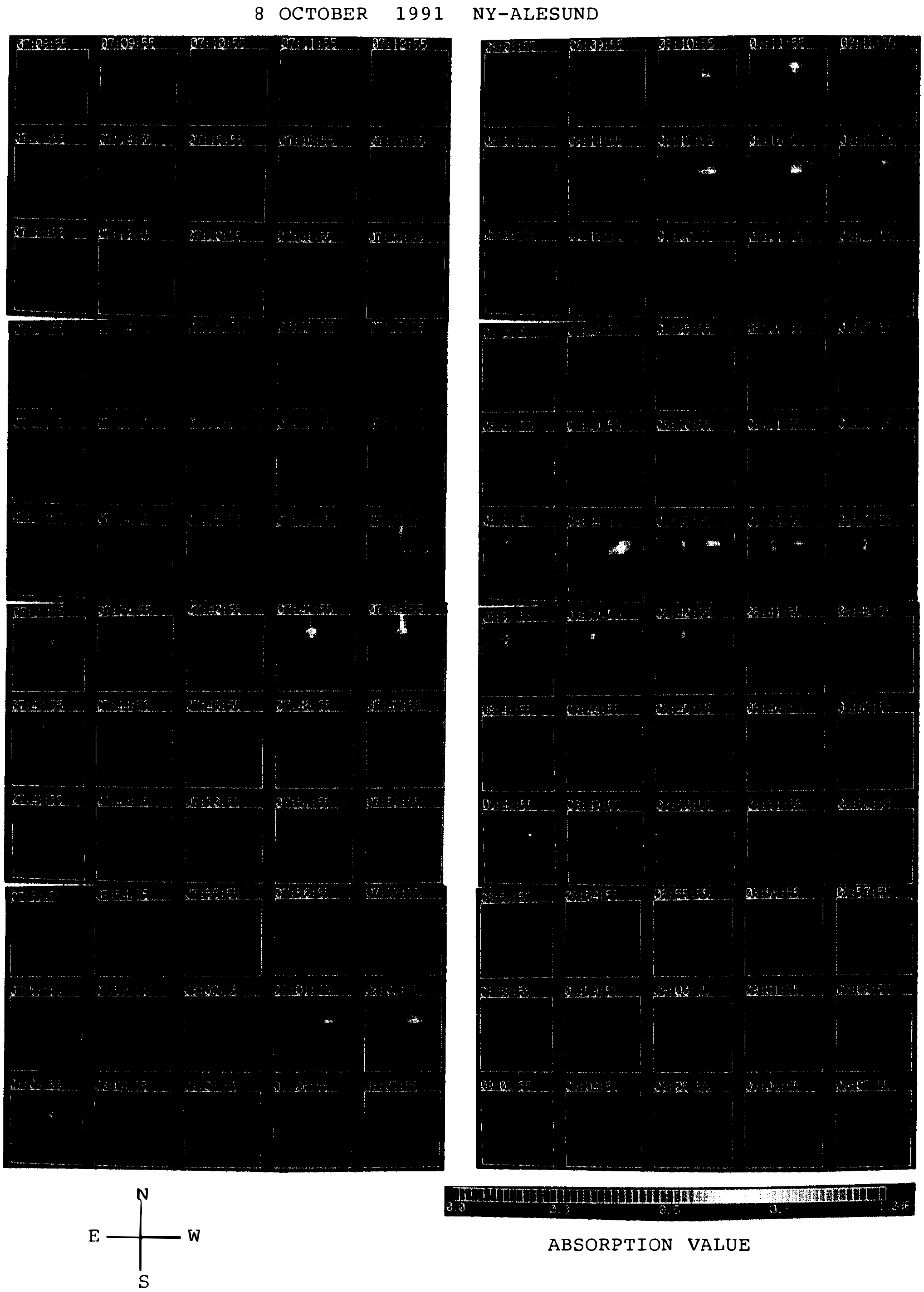

Fig. 9. Time series of the absorption images averaged every 1 min on 8 October 1991.

(~20 km) stretched in the meridian. Spots (~20 km) appearing at the northeast region during 081955–082355, 083355–084255 and 085555–090555 UT are due to an effect of ionospheric scintillations from radio stars. The absorption in the northwest region expanded and schrinked without changing its location after 0843 UT.

(b) Absorption in the evening: 14–15 UT, 27 September 1991

Figure 10 shows a time series of the absorption images in the evening averaged every 32 s. At about 1448 UT, an arc-shaped absorption (~1 dB) appeared at the

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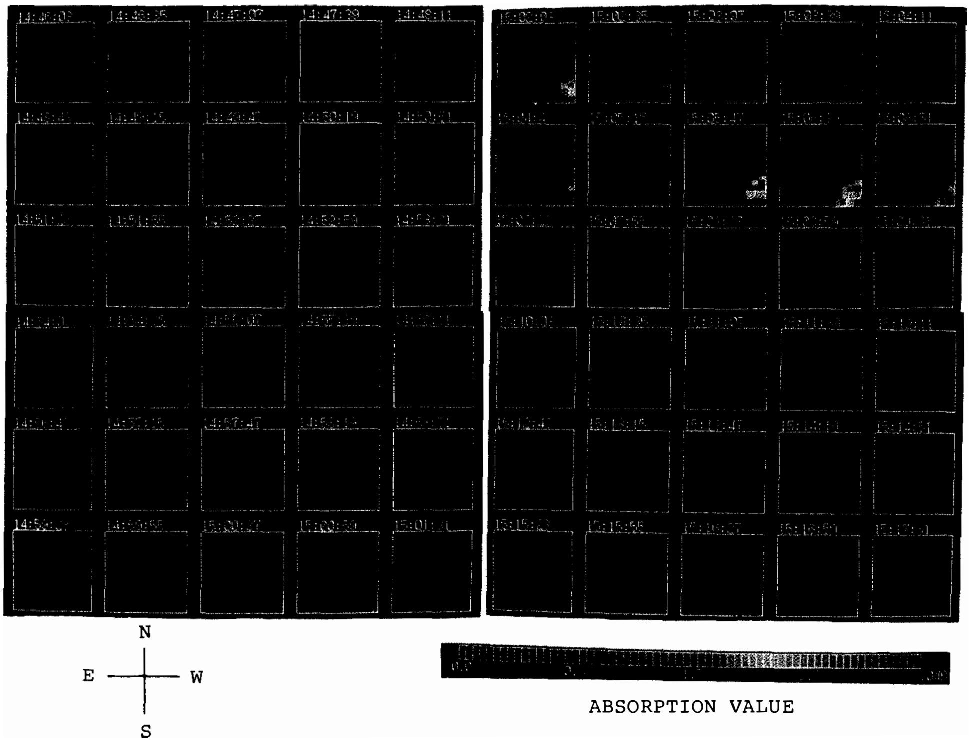

Fig. 10. Time series of the absorption images averaged every 32 s on 27 September 1991.

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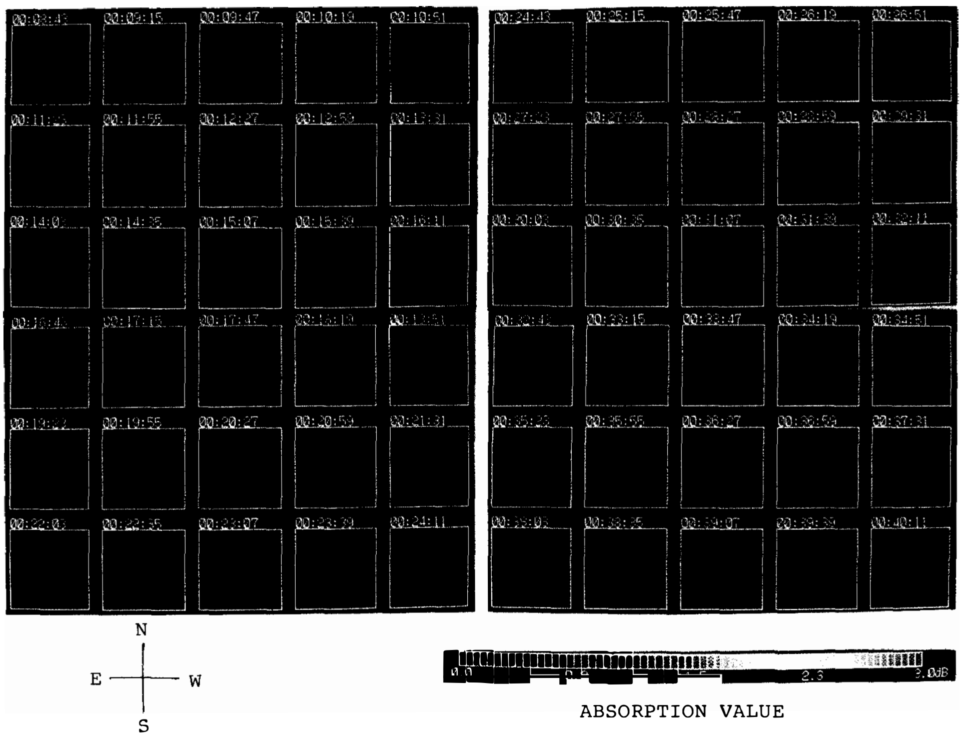

Fig. 11. Time series of the absorption images averaged every 32 s on 30 September 1991.

southwest corner in the field of view, and became weak in a few minutes. Around 1456 UT, the absorption was slightly enhanced as a whole, and then was enhanced rather suddenly at about 1502 UT at the western edge of the arc. The enhancement attained to a peak (~2 dB) around 1506 UT, and the intense area extended southeastward in a short time. However, the whole of the arc showed no poleward motion further.

(c) Absorption in the nighttime: 00 UT, 30 September 1991

Figure 11 shows a time series of absorption images in the nighttime averaged every 32 s. A weak absorption (< 1 dB) of a spot-shape first appeared at the west of the zenith around 0010 UT, and formed spots like 'beads' directing to the northwest about 0011 UT, and the southern part of the beads became weak. Then a spot appeared again at 002131 UT, and the spot extended to the northwest direction in a torch-shape with the maximum absorption of 1.5 dB. The absorption intensity of the torch decreased from the southern area around 0032 UT.

5. Summary and Discussion

CNA observations by the imaging riometer are available for the measurement of auroral electron precipitation even on the conditions of sunlit or overcast sky. Initial results described in the previous section were CNA events in the summer when auroral photometric observations were impossible. The authors compared the image data obtained at Ny-Alesund with the ones observed at the South Pole Station and Sondre Stromfjord, which are located at nearly the same invariant latitude, in order to understand characteristics of the absorption images obtained with our instrument. However, at present, the image data from the both stations have been published so few that the discussion is limited to identify tentative characteristics.

(a) Daytime absorption

On IRIS images observed at the South Pole Station, the daytime absorptions (09–11 MLT) in July (winter) revealed that the most prominent large-scale pulsating absorption reaching 0.75–1.25 dB occurred with a separation of 5–10 min and occupied most of the central portion of the field of view ($Kp=5$ during this event). There was very little apparent motion of these images; mainly they represented temporal variations of an essentially stationary perturbed region (ROSENBERG *et al.*, 1991). At Sondre Stromfjord, a pulsating absorption event of a shorter period of a few minutes (Pc–4) and a long period of 20–30 min (Pc–5) was observed around 11 MLT in July (summer) (STAUNING and ROSENBERG, 1992). The pulsations were mostly stationary intensifications and fadings without much drift, and the most intense part in the absorption region was a small spot (~50 km) within the torch-shape extending from the equator-side of the station. The intensity of the absorption was less than 0.7 dB during the event. At Ny-Alesund, as shown in Fig. 9, a pulsating absorption event with a long period of 10–15 min (Pc–5) was observed at the northern sky of the station during 1030–1230 MLT ($Kp=5$ during this interval). The intensity of the absorption was in the range of 0.5–0.7 dB throughout the event.

As described above, the intensity of the daytime absorptions is relatively weak. We also obtained the absorption values of 0.5–0.6 dB on average in the summer cusp from the statistical analysis of about one-year observations by two-dimensional multi-beam scanning riometer at Ny-Alesund. STAUNING (1984) explained the value of 0.6 dB on the absorption event in the summer cusp by strongly enhanced electron-neutral collision frequencies in the heated E region in case of absence of substorm-associated auroral particle precipitation. However, the pulsating absorption event at Ny-Alesund is likely to be caused by precipitating electrons because of relatively high Kp index during the event. According to the particle data from the DMSP satellite at 825 ± 50 km altitude, the average flux density of precipitating electrons of about 1 keV was 10^7 el/(cm^{2}s sr keV) in the cusp latitude for $Kp < 2$ (CANDIDI *et al.*, 1983). EXOS-D satellite presented energy spectrum less than 1 keV for the precipitating electrons and the energy flux of 0.8 erg/(cm^{2}s sr eV) in the dayside cusp of about 1000 km altitude (MUKAI *et al.*, 1990). It is easily estimated that these electron energies are too weak to produce the observed absorption due to the enhanced ionization around 100 km altitude ionosphere. TIROS-N satellite at 850 km altitude observed the energy spectrum showing a higher electron intensity of 10^9 el/(cm^{2}s sr keV) on 1 keV energy range in the 1400 MLT sector (EVANS, 1985). Direct estimation of the absorption values should be performed by the use of electron density profile in the cusp ionosphere measured by an incoherent scatter (IS) radar.

Among the absorption events at the three stations, a common feature is the pulsating absorption events with a long period of Pc–5 range. Pc 4–5 geomagnetic pulsations were frequently observed by the magnetometers installed along a geomagnetic meridian, and the high latitude ($>75°$) Pc 4–5 would be generated by three possible mechanisms of Alfvén-wave instability, the drift-wave instability and the Kelvin-Helmholtz instability in the daytime cusp (ROSTOKER *et al.*, 1972). The Goose Bay HF radar which measures the backscatter intensity of irregularities in the F layer in the ionosphere observed a long-period (10–15 min period) pulsation event in the radar data. At this time, the field of view of the radar included a region of the cleft immediately to the east of the cusp (WALKER *et al.*, 1986). The daytime absorption events at the South Pole Station and Sondre Stromfjord occurred more than 1 h prior to the local magnetic noon, which would be located at the cleft. SANDHOLT (1990) observed a periodic photo-emission (557.7 nm) event with the recurrence period of near 10 min within 1040–1145 UT ($\sim$14–15 MLT) after the magnetic noon in winter at Ny-Alesund. However, the periodic absorption event at Ny-Alesund took place during 08–09 UT near the magnetic noon (in the cusp), and the absorption area was small ($\sim$50 km), as shown in Figs. 8 and 9. Therefore, the periodic absorption event at Ny-Alesund might be the recurrence of midday breakup events; precipitating electron flux of 0.3–2 keV energy, poleward motion ($<$ 1.5 km/s) of the discrete auroral structure (SANDHOLT *et al.*, 1990). The simultaneous data of the magnetogram in the meridian chain and IMF data will be needed in order to discuss this midday absorption event.

A difference in the image data at the South Pole Station and Sondre Stromfjord is an apparent poleward motion ($\sim$150 m/s) of the small-scale absorptions ($<$50 km) around 0736, 0800 and 0836 UT during the event at Ny-Alesund. At Syowa Station in the auroral latitude, the absorption drifted poleward (velocity, 106 m/s) around 10 MLT according to the scanning-beam riometer (KIKUCHI *et al.*, 1990). This drift coincided to the ionospheric projection of the magnetospheric convection deduced from IS radar and balloon observations (FOSTER *et al.*, 1981). It is uncertain at present whether or not observed poleward drift of the absorption corresponds to the reversal of the magnetospheric convection in the cusp latitude. The poleward motion of the absorption may be associated with the midday auroral breakup mentioned above. In order to clarify the characteristics of the midday absorption event, simultaneous observations with the imaging riometer and all-sky TV must be carried out in the near future.

(b) Absorptions in the evening time

ROSENBERG *et al.* (1991) obtained the absorption images of an auroral surge with an intense (several dB) leading edge moving westward/poleward with the velocity of 1–2 km/s at about 1830 MLT in winter at the South Pole Station. HARGREAVES *et al.* (1991) also observed an elliptical absorption patch of about 150×60 km size coming from the equator side in the field of view in the premidnight sector in winter. The absorption increased rapidly and decayed, and retreated toward the equator ($Kp = 4-$ during this event). STAUNING and ROSENBERG (1992) observed a poleward expanding absorption (maximum, 1 dB) appearing at the southernmost field of view over Sondre Stromfjord during the time interval from 2006 to 2014 UT ($\sim$18 MLT) in summer. During the next 5 min the event expanded geomagnetically poleward to cover the entire field of view up to 120 km north of the station.

On the images at Ny-Alesund shown in Fig. 10, the extended arc-shaped absorption appeared in the southwest corner of the field of view at about 1830 MLT ($Kp = 5$ during this event) in the evening. The arc showed no noticeable poleward motion. The southwest corner might be the nothernmost location of the poleward expansion. NIELSEN *et al.* (1988) examined the characteristics of the absorption events at the substorm onset and expansion phase at Ny-Alesund by using a multi-beam riometer with 4 beams directing vertical, north, south and east regions to the ionosphere. The absorption events in the evening (20 MLT) first came from the geomagnetic south, and reached the zenith of the station. Thereafter, a different absorption occurred in the northern region after 5 min and propagated southward through the zenith. BERKEY *et al.* (1980) found auroral absorptions extending with large-scale structure from the auroral zone to the polar cap associated with substorm expansion, by using conventional riometers placed along the geomagnetic meridian. As described above, the substorm expansion is, in general, not of a simple moving pattern but rather characterized by the occurrence of multiple onsets or intensifications. Then the statistical determination of the scale and movement of the absorptions by the imaging riometer is indispensable for understanding the magnetospheric process and morphology during substorms.

(c) Absorptions in the nighttime

DETRICK and ROSENBERG (1990) presented the images of the absorption event in summer (January) at the South Pole Station. The absorption event occurred about 2 h prior to the local magnetic midnight during a quiet geomagnetic period ($Kp = 1-$). The main feature was a sun-aligned arc-like structure lying approximately along the magnetic meridian east of the station. The localized region of the intense absorption (reaching a maximum of 1 dB) showed poleward propagation velocity of 1 km/s. A smaller excursion of the H-component of the geomagnetic field compared with those of the *D*- and *Z*-components, confirmed the presence of ionospheric current aligned predominantly along the magnetic meridian (the direction of the Sun–Earth line at this time). On the other hand, the absorption images at Ny-Alesund shown in Fig. 11 represented a poleward extension from a brightened area near the zenith around 0400 MLT (0030 UT) ($Kp=3+$ during this interval). The shape of the absorption images is similar to that at the South Pole Station, but the extending direction of the arc is not sun-aligned at 04 MLT at Ny-Alesund. The absorption may have developed from a small localized intensification in the polar cap associated with substorm expansion. Further analysis of the absorption images is needed to understand behaviors of auroral absorption in the polar cap region.

Acknowledgments

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