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DYNAMICS OF THE MESOSPHERIC SODIUM LAYER IN ANTARCTICA: LIDAR MEASUREMENTS AT SYOWA STATION, 1985

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Abstract: Lidar measurements of the mesospheric sodium layer were made on 42 nights from April to October in 1985 during the wintering period of the 26th Japanese Antarctic Research Expedition (JARE-26) at Syowa Station, Antarctica (69°00′S, 39°35′E). This work was carried out as a part of the Middle Atmosphere Program (MAP). There were no significant seasonal variations in sodium abundance. Especially, the enhancement of abundance in winter was not observed. These results differ from those obtained at midlatitudes in the northern hemisphere. However, it is interesting that the sodium abundance oscillated with a period of about 36 days. As for the nocturnal variations of the sodium layer, the semidiurnal oscillation in the abundance was not detectable, but the wavelike structure due to gravity wave activity was frequently observed in the sodium vertical profile. Moreover, it was found that the sodium layer was perturbed during an auroral breakup event.

1. Introduction

In the late 1920's, the sodium resonance line at 589.2 nm was discovered in the nightglow spectrum (SLIPHER, 1929). The existence of the mesospheric sodium layer has been known since the mid 1930's (*e.g.* see review by HUNTEN, 1967). Then, according to the development of optical techniques, the spatial variation of the sodium layer has been measured by means of a twilight resonant scattering method. Since the first application of a lidar using a tunable dye laser to measurements of the mesospheric sodium layer (BOWMAN *et al.*, 1969), several research groups have made lidar measurements of the sodium layer at various locations: Winkfield, UK (51°N) (GIBSON and SANDFORD, 1971); Haute-Provence, France (44°N) (MÉGIE and BLAMONT, 1977); São José dos Campos, Brazil (23°S) (SIMONICH *et al.*, 1979); Urbana, USA (40°N) (RICHTER *et al.*, 1981); Mt. Zao, Japan (38°N) (TOMITA and KAMIYAMA, 1984); and Fukuoka, Japan (33°N) (UCHIUMI *et al.*, 1985). The lidar technique has largely improved in terms of temporal and spatial resolutions as well as in the accuracy of measurement compared with the twilight photometric method. Recently it is possible to operate it in daytime (GIBSON and SANDFORD, 1972; GRANIER and MÉGIE, 1982; CLEMESHA *et al.*, 1982) and, moreover, to measure several metalic atoms and ions

(MÉGIE *et al.*, 1978; JÉGOU *et al.*, 1980; GRANIER *et al.*, 1985). Up to now, lidar measurements have given various interesting data to reveal the dynamical and photochemical mechanisms in the upper atmosphere. It is, however, still unable to clarify the global view of the upper atmosphere because lidar measurements have been made mainly at mid-latitudes in the northern hemisphere. Therefore it is very important and interesting to observe the sodium layer at high latitudes in the southern hemisphere.

The lidar facility based on a ruby laser was set up at Syowa Station, Antarctica (69°00′S, 39°35′E) in 1983 (the 24th Japanese Antarctic Research Expedition (JARE-24)). At first, the stratospheric aerosol was measured for 3 years (IWASAKA *et al.*, 1986). In 1985 (JARE-26), the lidar system was extended to measure the mesospheric sodium layer by use of a tunable dye laser (NOMURA *et al.*, 1985). With this system, lidar measurements of the sodium layer were made on 42 nights from April to October 1985. In this paper we report the results obtained and discuss dynamical behavior observed in the sodium layer.

2. Lidar System and Data Processing

The lidar system for observing the sodium layer consists of the transmitter based on a coaxial flashlamp pumped dye laser tuned to the sodium D_2 line (589.0 nm), a Cassegrainian type telescope of 50 cm in diameter, photon detection and counting system, and data processing system. Performance of the system was presented in detail in a previous paper (NOMURA *et al.*, 1985). Each vertical sodium profile at height interval of 1 km was obtained by accumulating the returns from 100 laser shots with a repetition rate of 10 ppm. Temporal resolution was about 15 min. One example of sodium profiles obtained by realtime processing is shown in Fig. 1.

In order to calibrate the absolute sodium density, we adopt the procedure by TOMITA and KAMIYAMA (1984). In general the lidar equation is given by

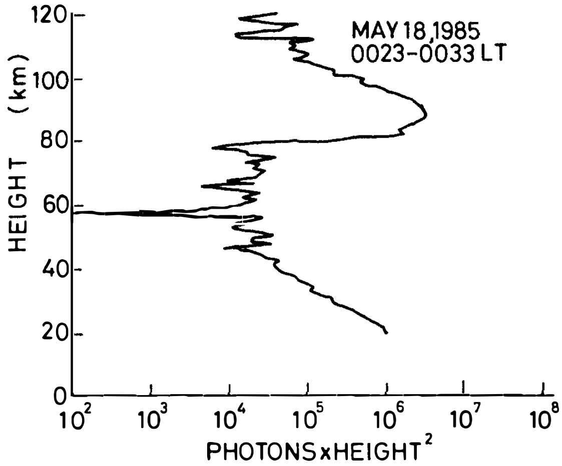


Fig. 1. Realtime displayed data of height vs. photon signals × squared height obtained by accumulating the returns from 100 laser shots.

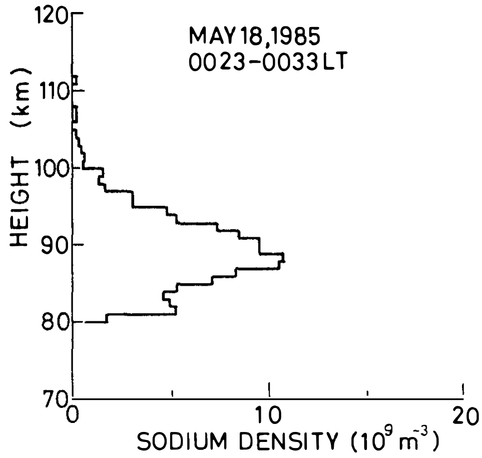


Fig. 2. Vertical profile of the sodium density calculated from the data shown in Fig. 1.

$$n_s = n_0 \frac{KA\Delta ZT^2\{N_{Na}(d\sigma/d\Omega)_{Na} + N_R(d\sigma/d\Omega)_R + N_M(d\sigma/d\Omega)_M\}}{Z^2}, \quad (1)$$

where n_s denotes the number of the received photons, n_0 the number of the transmitted photons, K the efficiency of the lidar system, A the area of the receiving telescope, Z the height, ΔZ the height interval, T the atmospheric transmittance, N_{Na}, N_R and N_M the number densities of sodium atoms, the Rayleigh scattering molecules and the Mie scattering particles, respectively, and $(d\sigma/d\Omega)_{Na}$, $(d\sigma/d\Omega)_R$ and $(d\sigma/d\Omega)_M$ the differential scattering cross-sections of the resonant, the Rayleigh and the Mie scattering, respectively. In this work, however, it is not necessary to take into account the term of the Mie scattering because the Mie particles such as aerosol exist only at the height of below 20 km in the polar atmosphere. Moreover, the term of the Rayleigh scattering can be ignored at the height of the sodium layer. Then, on the assumption that the attenuation of the laser beam takes place in the troposphere and the lower stratosphere, the ratio of the received counts of signal $n_{s,Na}$ from the height Z_{Na} to that $n_{s,R}$ from the height Z_R leads to the number density of sodium atoms N_{Na} as follows;

$$N_{Na} = N_R \frac{n_{s,Na}(d\sigma/d\Omega)_R Z_{Na}^2}{n_{s,R}(d\sigma/d\Omega)_{Na} Z_R^2}, \quad (2)$$

where the molecular number densities in the upper atmosphere were obtained from radiosonde measurements made twice a day at Syowa Station. With the procedure described above, we obtain the vertical profile of the sodium density, as shown in Fig. 2. The values of $(d\sigma/d\Omega)_{Na}$ and $(d\sigma/d\Omega)_R$ used here are 2×10^{-17} m^2 sr^{-1} and 4.1×10^{-32} m^2 sr^{-1}, respectively. The method of estimating $(d\sigma/d\Omega)_{Na}$ was presented in detail by MÉGIE and BLAMONT (1977) and SIMONICH *et al.*, (1979).

As for the uncertainty of data, shot noises near the peak of 100 shots profile are less than 10%, which can be reduced to below 5% by averaging over one hour. Background noises are below 0.1 count/gate·shot. The main source of error in the calibrating procedure of sodium number density may lie in the fluctuation of the effective resonant scattering cross section. However it is difficult to estimate it accurately. On the basis of the results obtained, we believe that the total error does not exceed 20%.

3. Results and Discussion

3.1. Semiseasonal variation

Figure 3 shows the semiseasonal variation in nightly and monthly average sodium abundance from April to October 1985, while Fig. 4 shows the variation of profile in the form of a contour plot, which adopts only the data measured for more than 5 h in one night. It is found that there is no pronounced seasonal variation in sodium abundance. Especially no enhancement of abundance in winter is detectable. These trends are different from those obtained at midlatitudes in the northern hemisphere (GIBSON and SANDFORD, 1971; MÉGIE and BLAMONT, 1977). The seasonal variation in the abundance obtained in Antarctica shows its own characteristic, that is, it cannot

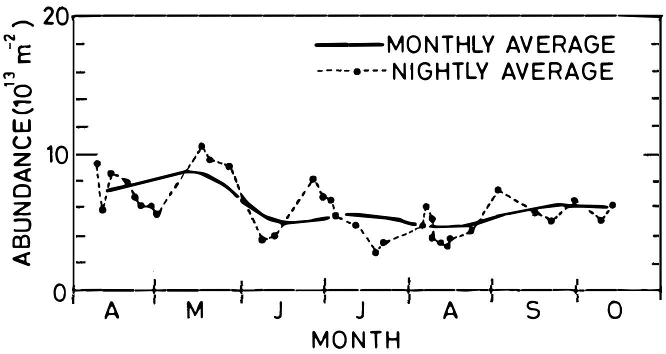


Fig. 3. Semiseasonal variation in nightly and monthly average sodium abundance during the period from April to October, 1985.

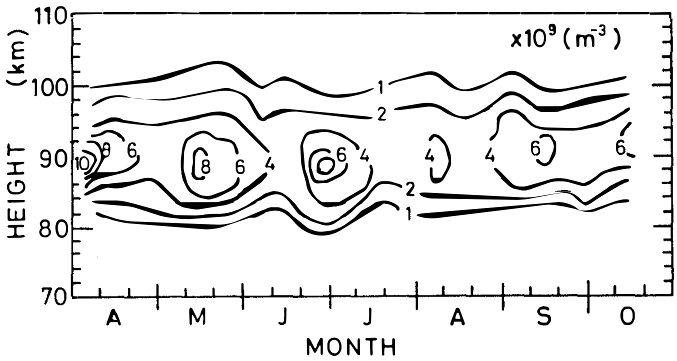


Fig. 4. Semiseasonal variation in nightly average vertical sodium density profile in the form of a contour plot from April to October, 1985.

be extrapolated from the latitudinal dependence proposed by SIMONICH *et al.* (1979). In the near future we will make clear this difference by comparing with the seasonal variation in the upper atmosphere wind measured by a meteor radar at Syowa Station.

The power spectrum of the semiseasonal variation in sodium abundance obtained by the fast Fourier transform analysis (FFT) is shown in Fig. 5. It is interesting that there is an oscillatory variation with a period of about 36 days. However we could

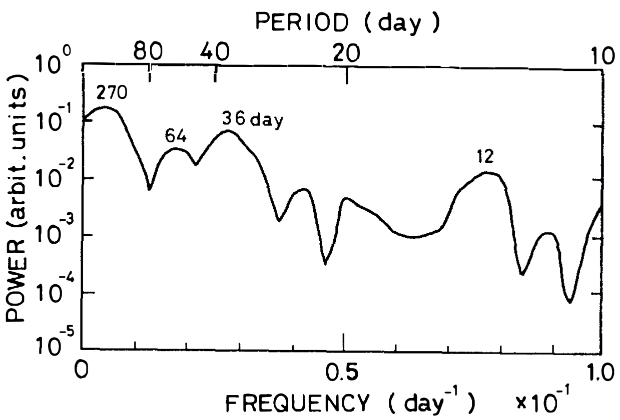


Fig. 5. Power spectrum of the semiseasonal variation in nightly average sodium abundance.

give no satisfactory explanation for this oscillation here.

3.2. Nocturnal variation

Figure 6 shows the monthly average nocturnal variations in sodium abundance for the period from April to October 1985. The results indicate no semidiurnal variation due to the solar tide which has been frequently observed at midlatitudes (TOMITA and KAMIYAMA, 1984; KWON *et al.*, 1986). Figure 7 shows the nocturnal variation in the abundance measured continuously for 4 nights in August and the variation averaged over 4 nights. The systematic variation in the average curve could not be found although each nocturnal variation shows a strong fluctuation with time. These results suggest that the effect of the tidal motion is weak in the polar region.

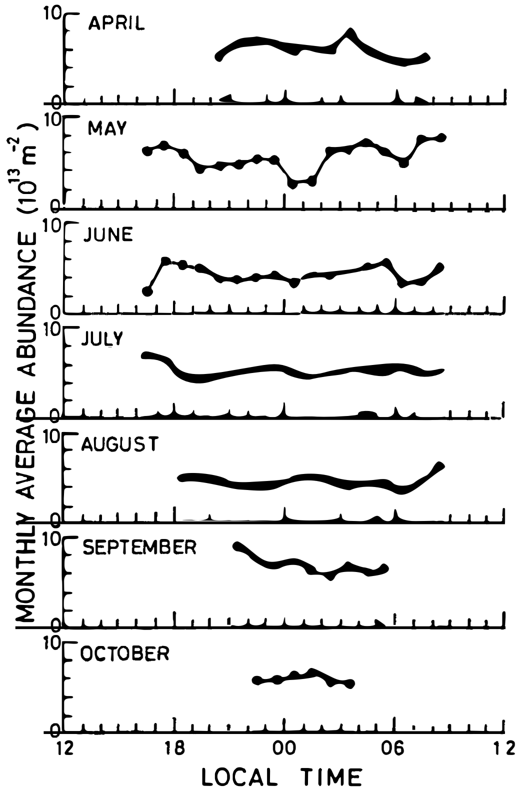


Fig. 6. Monthly average nocturnal variations in sodium abundance.

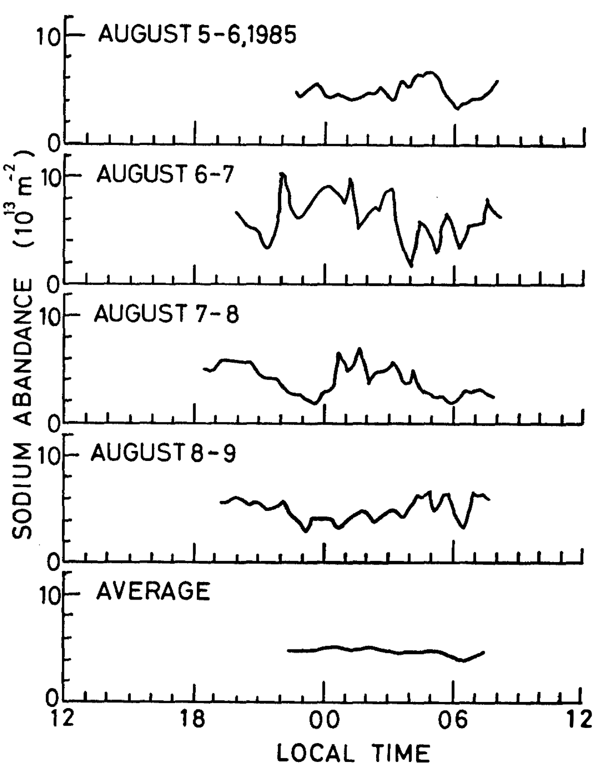
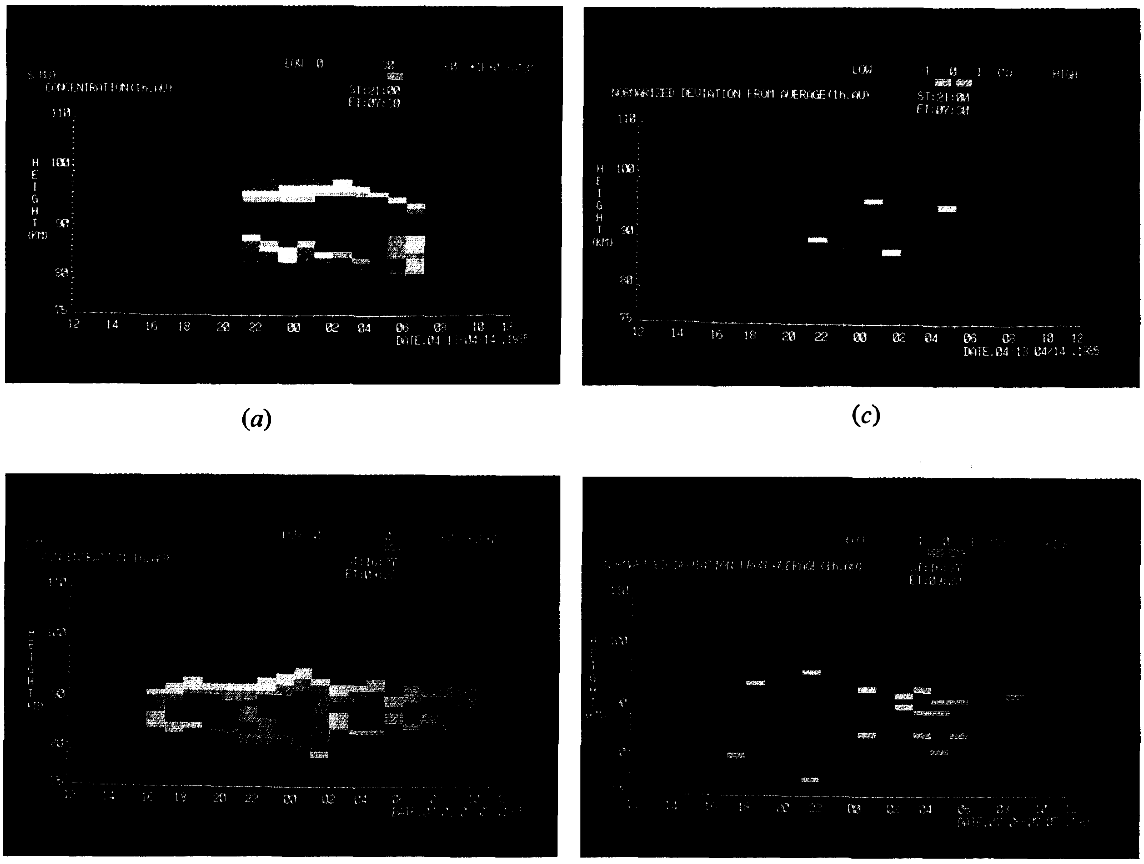


Fig. 7. A series of nocturnal variations in sodium abundance for 4 nights and average variation of them.

On the other hand, it is found that the nocturnal variation in the vertical profile of the sodium layer contains the wavelike structure showing a downward progression of the phase angle. Some examples showing the nocturnal variations in the vertical profile and in its deviation from each nightly averaged profile are given in Figs. 8a–8d in the form of colored contour maps, where the deviations mean the difference of the normalized sodium profile averaged over one hour from that averaged over each night in terms of percentage units. The contour maps of the deviation apparently indicate downward propagation of the phase angle with a period of 6–8 h and with a



(*a*) (*c*)

(*b*) (*d*)

Fig. 8. Nocturnal variations in hourly average vertical profile (a and b) and in the deviation of the normalized hourly average profile from the normalized nightly average one (c and d).

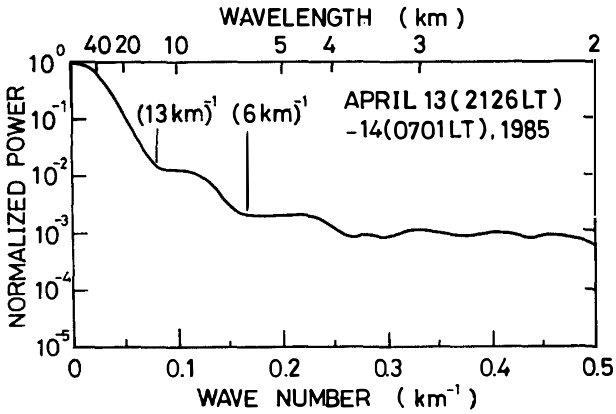


Fig. 9. Normalized average periodogram of 34 profiles measured in the night of April 13–14, 1985.

vertical wavelength of about 10 km. These results show the presence of gravity waves in the sodium layer. In order to examine in more detail, the spatial power spectra of the sodium vertical profile were calculated using FFT analysis. One example of the nightly average spectra is shown in Fig. 9. The spectrum shows clearly the presence of gravity wave with a vertical wavelength of about 10 km. From the results of each spatial power spectrum, we can present the motion of gravity waves by use of the inverse FFT, as shown in Fig. 10. This result shows the downward progression of the phase angle with a velocity of 1.5 km/h. In our observation, such a gravity wave activity was frequently observed during the period from April to October. On the

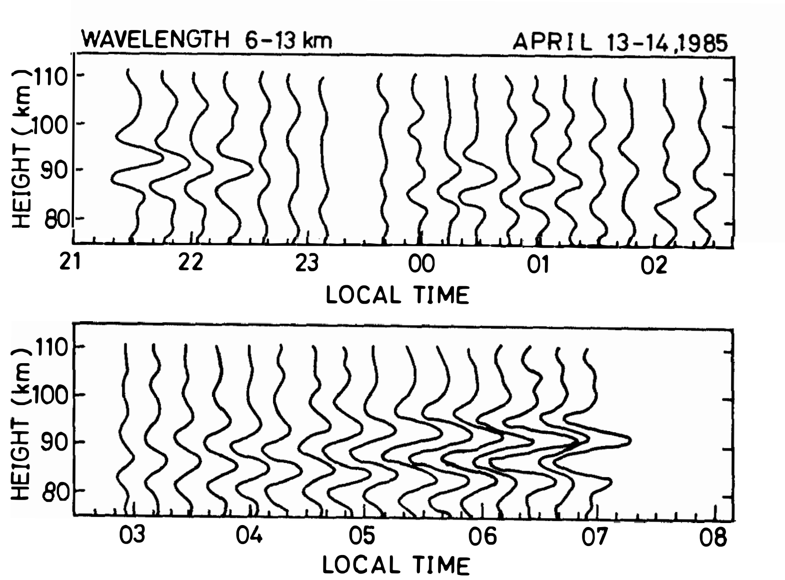


Fig. 10. Time history of the sodium vertical profile passing through the bandpass filter with a wavelength of 6–13 km.

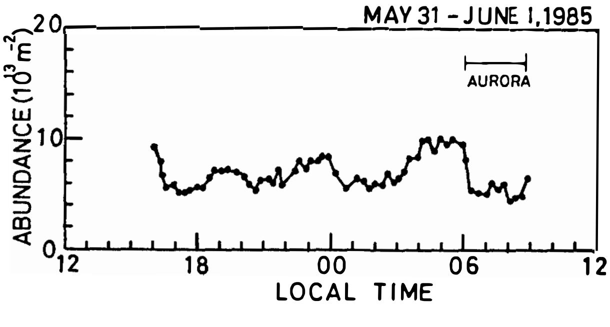


Fig. 11. Nocturnal variation in sodium abundance on May 31–June 1, 1985.

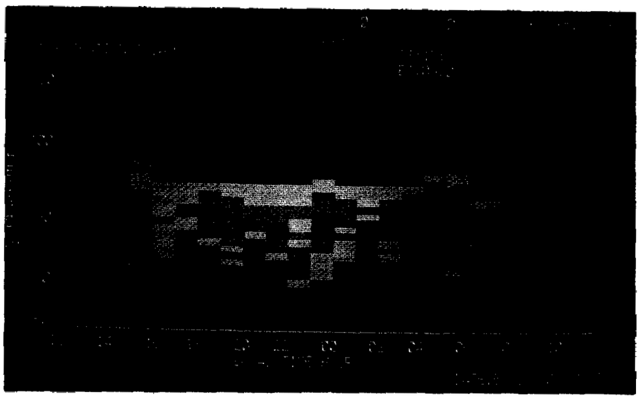


Fig. 12. Nocturnal variation in vertical profile of sodium abundance on May 31–June 1, 1985.

basis of the data measured for more than 10 h, it is found that wavelength and period range from 10 to 16 km and from 3 to 8 h, respectively. These values are almost in agreement with the result by GARDNER and VOELZ (1987).

Most of the perturbations observed in the sodium layer is thought to come from gravity wave activities. Figures 11 and 12 show a rare case of perturbation, which seems to be attributed to a cause other than gravity waves. After 0540 LT, the sodium abundance suddenly decreased and its layer was compressed in upper part. What is this sudden decrease? Just at 0540 LT, an auroral breakup occurred. The time variation in geomagnetic field *H*-component and that in cosmic noise absorption (CNA) are shown in Fig. 13. At Syowa Station, auroral phenomena were observed almost every night, but such an auroral activity associated with a large decrease of CNA as shown in Fig. 13 rarely happened. It may be concluded that the sodium layer is perturbed by the auroral breakup event in the polar region.

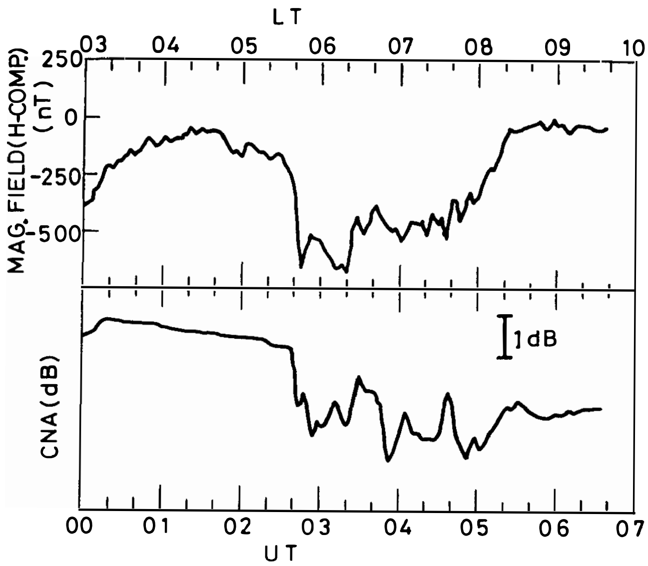


Fig. 13. Time variations in geomagnetic field H-component and cosmic noise absorption (CNA) on June 1, 1985.

4. Conclusions

Lidar data of the mesospheric sodium layer obtained at Syowa Station, Antarctica show several interesting features, which are different from those obtained at other locations over the world.

The sodium layer does not show any significant seasonal variations in the abundance and vertical profiles. In particular, it is interesting that there is no enhancement of sodium abundance in winter. However, attention must be paid to an oscillatory variation of the sodium abundance with a period of about 36 days.

The nocturnal variations of sodium abundance show no pronounced tidal oscillation such as semidiurnal or diurnal, but its vertical profiles show the wavelike structures, which are originated from gravity wave activity. Moreover it is confirmed that the sodium layer is also perturbed by auroral activity besides gravity waves.

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