SOME FEATURES OF NIGHTTIME *D* AND *E* REGION ELECTRON DENSITY PROFILES IN THE POLAR IONOSPHERE

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Abstract: The empirical formulae are deduced to infer the nighttime electron density during auroral disturbances from the 30 MHz CNA and geomagnetic disturbance levels. The results indicate that $\log N_e = -1.18 \times 10^{-3}\ \Delta H + 4.84$ at 105 km and $\log N_e = 0.362\ x + 4.12$ at 90 km where N_e is the electron density in cm^{-3}, ΔH is the variation of geomagnetic horizontal component in nT and x is the 30 MHz CNA level in dB.

1. Introduction

Even now there remain a great many problems concerning the ionization processes and maintenance mechanism of the ionosphere as well as auroral phenomena in the polar region. The structure and characteristics of the polar ionosphere are related to the magnetosphere located far from the earth. Recently, problems on the modeling of the global structure of the ionospheric parameters have become important, and so it is essential to have an exact knowledge of the physical state of the polar ionosphere. And it is also important to observe various phenomena occurring in the polar region in order to analyze and understand the ionosphere-magnetosphere coupling and the ionosphere itself.

After the successful rocket flights of S-160JA-1 and -2 at Syowa Station in Antarctica by the 11th Japanese Antarctic Research Expedition (JARE-11), JARE-12, -13 and -14 carried out firings of a total of twenty-one rockets to observe directly various basic quantities relating to the ionosphere and auroral phenomena in the period between 1971 and 1973. The electron density profiles in the lower ionosphere under various disturbed conditions were obtained by two S-160JA and twelve S-210JA rocket experiments.

During the period from 1976 to 1978, the nineteen rocket experiments (twelve S-210JA and seven S-310JA) were carried out by JARE-17, -18 and -19 in order to acquire a full understanding of disturbed ionosphere and auroral phenomena as one of the research projects in the International Magnetospheric Study, 1976–1979. Measuring instruments for the electron density profile were installed on these rockets.

As is well known, ionization processes occurring in the polar ionosphere are very complex compared with those in the ionosphere at low or middle latitudes, because

high-energy particle precipitation from the magnetosphere plays an important role in ionizing the lower ionosphere in addition to the solar radiation. Ground-based observations cannot give sufficient information about these problems. Therefore, it is useful to derive the relation between the electron density profiles from the rocket observations and the so-called disturbance factor such as the level of the cosmic noise absorption (CNA), magnetic variation, etc., under various disturbed ionospheric conditions.

MIYAZAKI (1975) deduced two empirical formulae regarding the nighttime electron density below 100 km; the maximum electron density increment from a quiet level and its altitude for a given CNA level from the experiments carried out during 1971–1973. OGAWA *et al.* (1978) discussed from another point of view relating to the nighttime electron density profiles by ionospheric disturbance level, and presented two semi-empirical formulae; one is the relation between the nighttime electron density at 90 km and the 30 MHz CNA level, and another relation between ΔH component and the electron density at 105 km by using the twelve profiles obtained during 1971–1976.

Here, semi-empirical formulae of a qualitative model of the lower ionospheric electron density profiles in the nighttime in the polar region under the conditions from very quiet to very active are deduced from the seventeen observational results obtained during 1971–1978.

2. Characteristics of the Electron Density Profiles in the Polar Nighttime Ionosphere

There held a total of forty-two rocket experiments at Syowa Station, of which thirty-five rockets (four S-160JA, twenty-four S-210JA and seven S-310JA rockets) were fired in order to measure the electron density profile. Fig. 1 shows the day and night diagrams at Syowa Station in Antarctica and the distributions of the firing times of thirty-five sounding rockets for measurement of the electron density. The numerals are the rocket serial numbers. The square, circular and triangular marks show the S-160JA, S-210JA and S-310JA types of rocket, respectively. In this section, in order to clarify some characteristics of the nighttime electron density profiles, the authors use the electron density profiles observed only in the nighttime condition because the effect by the solar radiation can be ignored.

Table 1 shows the list of characteristics of rockets fired in the nighttime condition, that is, name of rocket, launching time and date, peak altitude, geophysical condition, etc. Fig. 2 shows the nighttime electron density profiles in the ionosphere at Syowa Station in the ascending time obtained by the rockets listed in Table 1, except the case of the rocket S-210JA-24 because the instrument operated abnormally. The electron density in the nighttime E region is about 2×10^4 cm^{-3} in a quiet condition and is about 1×10^6 cm^{-3} in an active condition. The magnitude of difference between the maximum and the minimum in the electron density is over double figures

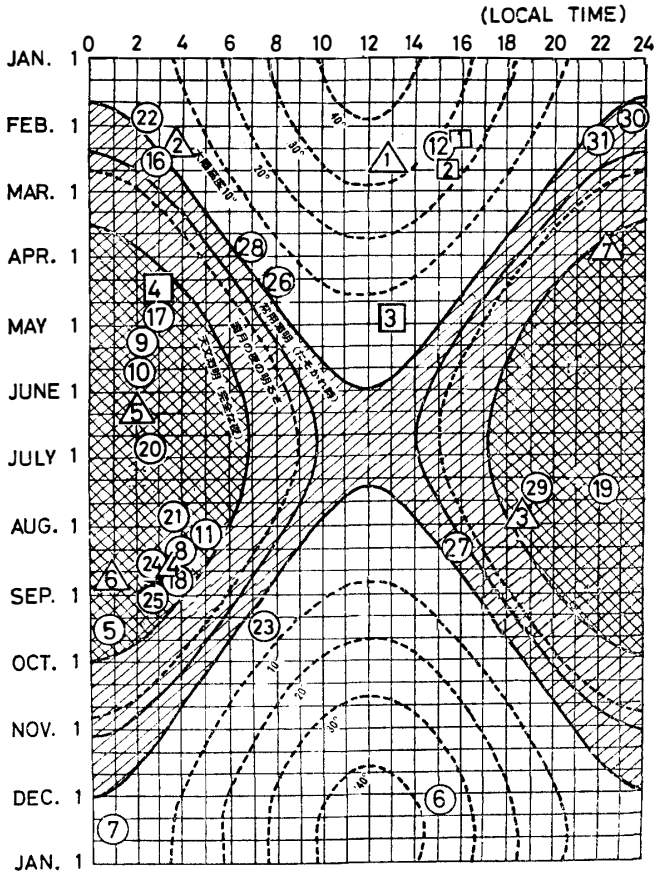


Fig. 1. Day and night diagrams at Syowa Station, Antarctica, and the distributions of the firing times of sounding rockets.

in the region between E layer and 150 km and is over four figures below E layer. Magnitudes of the electron densities at various altitudes greatly change with the degree of the disturbed condition of the ionosphere.

In the following discussions, the authors use the seventeen cases of the rocket experiments, and exclude the case of S-160JA-4 because of the low peak altitude. Electron density in the E region observed by rocket is known to be largely variable due to auroral activity and disturbed condition. In order to clarify this relation, Fig. 3 shows relations between the magnitude of variation of geomagnetic horizontal component ΔH and the electron density at 105 km around which the horizontal current affecting ΔH level flows (OGAWA *et al.*, 1978). The straight line in Fig. 3 shows the regression line by the least squares method, and the equation is expressed as follows;

$$\log N_e = -1.18 \times 10^{-3} \Delta H + 4.84 \qquad (1)$$

where N_e is the electron density in cm^{-3} and ΔH is in nT.

Table 1. List of sounding rockets for measurement of nighttime electron density profile at Syowa Station during 1971–1978.

No.	Rocket	Time (LT)	Date	Height (km)	CNA (dB)	ΔH (nT)	Ionogram	Remarks
1	S-210JA-5	0050	Sep. 14, 1971	115	0.8	−150	E_s	
2	S-160JA-4	0242	Apr. 17, 1972	86	1.2	−320	Blackout	Not used
3	S-210JA-9	0213	May 14, //	129	1.3	−290	Blackout	
4	-10	0202	May 16, //	115	0.3	−200	Spread F	
5	-11	0445	Aug. 7, //	126	4.8	−600	Blackout	
6	-8	0401	Aug. 11, //	127	2.6	−450	Blackout	
7	-17	0254	Apr. 23, 1973	125	5.0	−750	Blackout	
8	-19	2209	July 15, //	130	0.0	+50	E_s	
9	-18	0353	Aug. 23, //	129	0.5	−50	Unstable E_s	
10	-20	0240	June 25, 1976	118	0.3	−150	E_s	
11	-21	0323	July 26, //	116	0.2	−20	E_s	
12	-24	0254	Aug. 16, //	118	0.4	−180	E_s	Not used
13	-25	0301	Sep. 1, //	125	0.0	0	E_s	
14	-29	1915	July 12, 1977	118	0.0	0	Quiet	
15	S-310JA-3	1835	July 26, //	221	0.0	0	Quiet	OYA, TAKAHASHI
16	-7	2215	Mar. 27, 1978	220	3.9	−740	Blackout	Auroral break-up
17	-5	0156	June 10, //	225	0.0	−150	Quiet	OYA, TAKAHASHI
18	-4	0332	Aug. 18, //	198	0.5	−150	E_s	EJIRI
19	-6	0056	Aug. 28, //	234	0.3	−220	E_s	OYA, TAKAHASHI

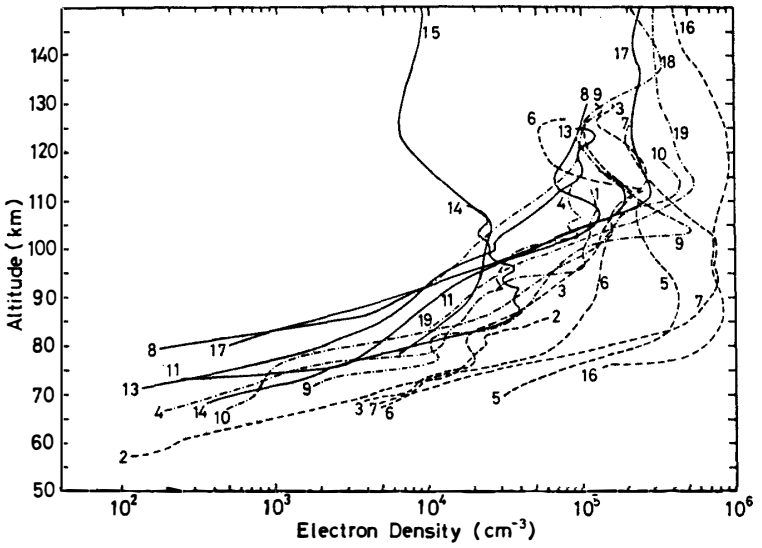


Fig. 2. Nighttime electron density profiles in the polar ionosphere at Syowa Station, Antarctica.

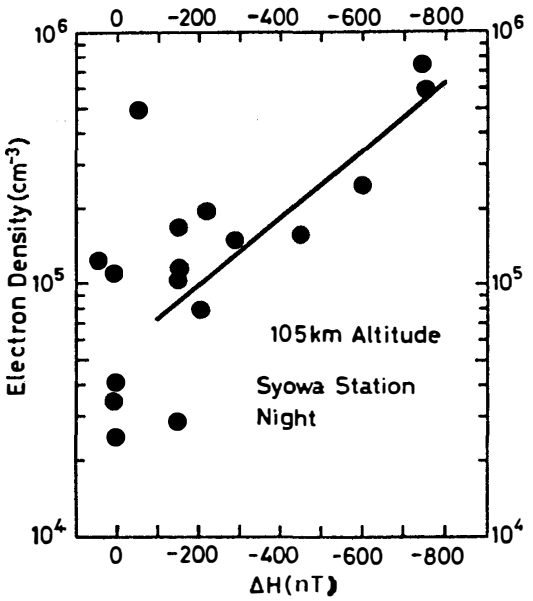


Fig. 3. Electron density at 105 km versus variation of geomagnetic horizontal component ΔH.

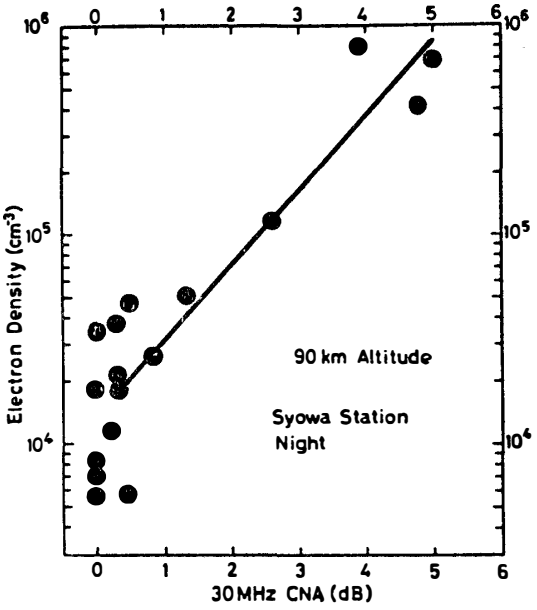


Fig. 4. Electron density at 90 km versus 30 MHz CNA level.

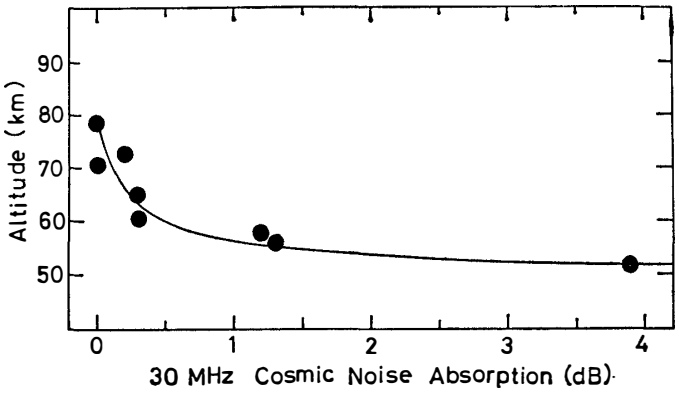


Fig. 5. Altitude of the lower ionosphere, whose electron density is 1×10^2 cm^{-3}, versus 30 MHz CNA level.

It is shown that the CNA level is determined by both collision and electron density. Fig. 2 shows that the electron densities between about 70 km and 100 km increase with the increase in the CNA level. To investigate how the electron density in this region is related with CNA, Fig. 4 shows relations between the 30 MHz CNA level and the electron density at 90 km around which the maximum absorbing layer is assumed to exist. The equation of the regression line by the least squares method is expressed as follows;

$$\log N_e = 0.362\, x + 4.12 \tag{2}$$

where x is the 30 MHz CNA level in dB. The relations between eqs. (1) and (2) mean that energetic particles, being associated with a large substorm, ionize strongly the E region to enhance ΔH and simultaneously the D region to raise the CNA level.

Fig. 5 shows the relation between 30 MHz CNA and the altitude of the lower ionosphere, whose electron density is $1 \times 10^2\ \mathrm{cm}^{-3}$. The following equation is obtained from Fig. 5 by assuming a parabolic equation.

$$h = 80 - x/(0.0338\, x + 0.00760) \tag{3}$$

where h is the altitude in km.

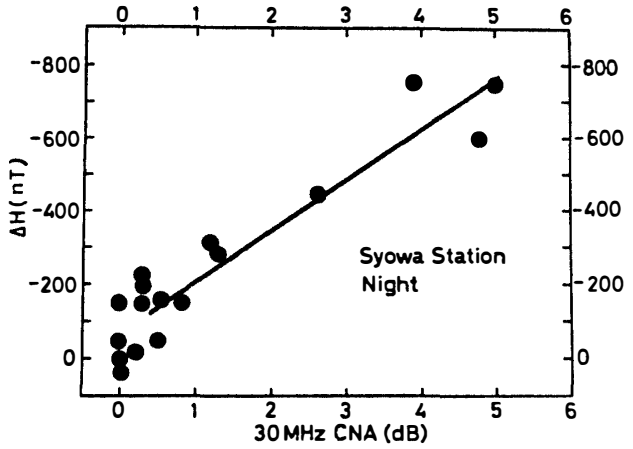


Fig. 6. Variation of geomagnetic horizontal component ΔH versus 30 MHz CNA level observed at Syowa Station during rocket experiments in 1971–1978.

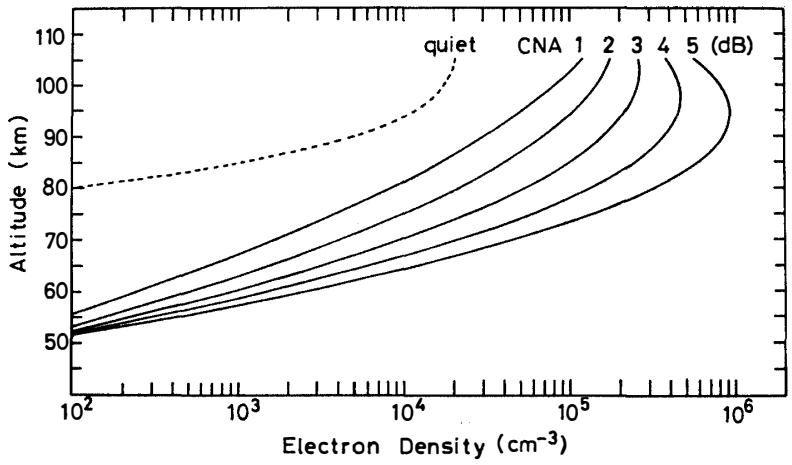


Fig. 7. Schematic electron density profiles in the polar ionosphere in quiet and disturbed conditions.

Fig. 6 shows the relation between the 30 MHz CNA and ΔH levels observed at the same time of each rocket firing. The following regression line is obtained from the least squares method.

$$-\Delta H = 140\, x + 64. \tag{4}$$

The eq. (4) does not pass the origin. This fact may indicate that causes of the variations of the 30 MHz CNA level and the horizontal component ΔH are not all the same.

The simple empirical models of the lower ionospheric electron density profile *versus* the 30 MHz CNA level are obtained from the above-described eqs. (1)–(4). The shape of the model is assumed to be expressed by parabolic curve. The result is shown in Fig. 7. The schematic profile at the quiet time is also shown in Fig. 7. Fig. 7 shows that the electron density around 90 km increases abruptly with the severe disturbances, and the lower level of the ionosphere decreases to 50–60 km in the disturbed time.

3. Summary

A total of forty-two rocket experiments were performed at Syowa Station in Antarctica during 1970–1978, the thirty-five electron density measurements were designed and seventeen nighttime profiles among them were obtained under the various auroral activities. By using these seventeen profiles, the relations between the electron density at 90 km and the 30 MHz CNA level and between the electron density at 105 km and ΔH were deduced, and also simple models of the lower ionosphere are gained as a function of the CNA level.

As a future problem, in order to know a precise structure of the polar ionosphere, detailed calculations of the production mechanism of the polar ionosphere by using the charged particle precipitation data must be necessary and also the measurement of the ion composition in the lower ionosphere is essential.

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