LOWER IONOSPHERE (D-LAYER) IN POLAR AND MID-LATITUDE REGIONS

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1. Introduction

The lower ionosphere (D-layer) has been observed in polar regions [1-3], in mid-latitude regions [4,5] and in the equatorial region [6], but the amount of data is not large. One of the D-layer characteristics is the existence of negative ions. In our previous observation, there was a trace of negative ions in the lower region of the E layer [7]. The observation in Kagoshima (Japan) and Andϕya (Norway) by using Japanese S-type rockets [8,9] indicated that the negative ion-layer of the D-layer in the mid-latitude region extended more than that in the polar region: from about 60 km toward the height near 90 km .

The aim of the present paper is to present further recent results on both regions by using S-310-23, 24, and 27 rockets and to discuss the regional dependence.

2. Method

Measurements have been made by using a Faraday cup and a Langmuir probe on board the rockets of the Institute of Space and Astronautical Science (ISAS). Rockets of S-310 series were launched from Andϕya in Norway (69.30°N, 16.05°E) and from Kagoshima Space Center (KSC) in Uchinoura, Japan (31.15°N, 131.08°E), as follows.

KSC	Andϕya
S-310-20 Jan. 28, 4h30m (JST), 1990	S-310-22 Feb. 16, 7h52m (UT), 1994
S-310-24 Feb.11, 20h00m (LT), 1996 S-310-27 Jan.25, 17h35m (LT), 1998	S-310-23 Nov.24, 10h20m (UT), 1994

Table 1. Rockets used.

Figure 1 shows the height *h* vs. the range *r* of the S-310-23, -24 and -27 rockets. At the height of about 60 km the nose-cone was opened and the Faraday cup was deployed.

Figure 2 shows the schematic of the pre-amplifier circuit of the Faraday cup, which was made of a grid G and a collector C. The circuit consists of pre- and main-amplifiers, the former being connected at the bottom of the housing H of the Faraday cup to measure the current directly in the Faraday cup mode (FP). The surface of the cup was made parallel to the flight vector to avoid the influence of the plasma flow. Positive and negative voltages were applied alternately to the electrodes with an interval of 0.2 s and the saturated currents at both biases were detected as I_e and I_+. In the main amplifier, the currents were amplified and sent to telemeter channels where the signals were FM-FM modulated. Above the D-layer, the probe characteristic and the second derivative were measured in the Langmuir probe mode (LP). The floating potential V_F was also measured to detect any change between D- and E-layers.

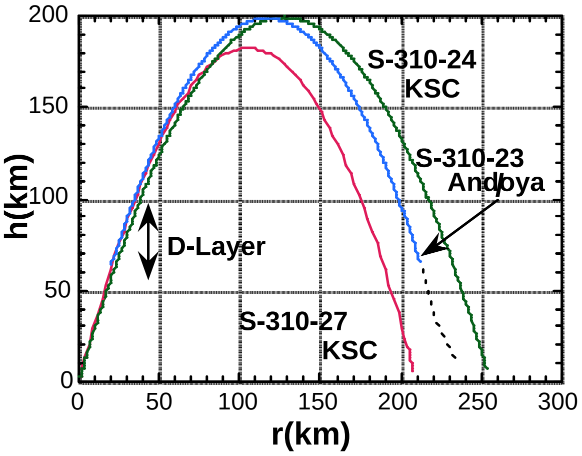


Fig. 1. Height h vs. range r of the rockets.

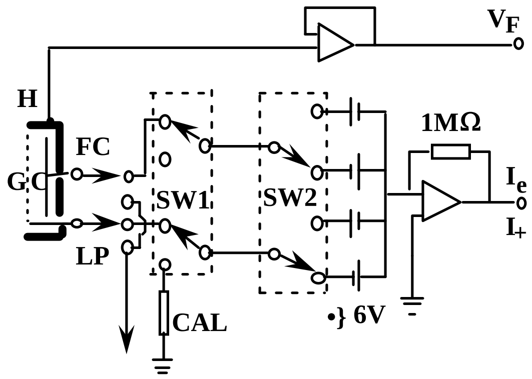
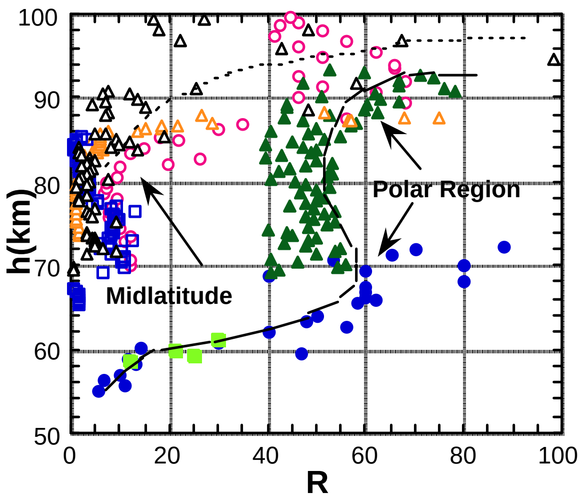


Fig. 2. Pre-amplifier for the Faraday cup.

3. Results

The ionosphere showed the E-layer at 90-100 km followed by an E-F valley and the F-layer above ~170 km. Sometimes, E_s-layer was observed. In the D-layer, the saturation electron and positive ion currents I_e and I_+ increased with height h. This indicates that the plasma density increases with h. The current ratio R ($=I_e/I_+$) also increased with h. Considering that R is an indicator of the negative ion density ratio α, we can see that α decreases with h.



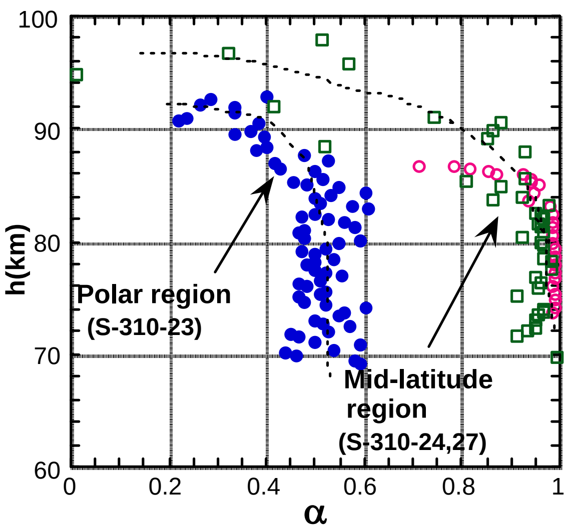


Fig. 3. $R=I_e/I_+$ vs. height h.

Fig. 4. $\alpha=N_-/N_+$ against height h.

Figure 3 shows the current ratio R ($=I_e/I_+$) vs height h for all the rockets together, where open triangle, circle and square denote data on KSC by S-310-20, -24 and -27 respectively while solid triangle, circle and square denote data on Andϕya by S-310-22 n(up-leg) , -22 (down-leg) and -24 respectively. It is seen that$R$ becomes smaller for lower h. This feature suggests the abundance of negative ions particularly at lower heights, h <70 km. In the

E-layer (>90 km), the existence of negative ions is negligible. The down-leg data showed similar natures in spite of a possible effect of wake. R is found to be larger in the polar region compared with that in the mid-latitude. At a particular height near h=76 km where the depletion of ozone occurs [11], R has a larger value in the polar region. This difference of R between mid-latitude and polar regions suggests that the negative ion density ratio α is smaller in the polar region.

The following relation was used to obtain $\alpha(h)=N_-/N_+$ from the current ratio $R(h)$. Saturation currents I_e and I_+ at positive and negative biases are given respectively by

$$I_e=\xi[(1-\alpha)\sqrt{\frac{\kappa T_e}{2\pi m}}+\alpha\sqrt{\frac{\kappa T_-}{2\pi M_-}}], \qquad I_+=\eta\sqrt{\frac{\kappa T_+}{2\pi M_+}}, \tag{1}$$

where ξ and η are correction factors for imperfect saturation due to perturbation and presheath, respectively. From (1), α becomes

$$\alpha=\frac{\sqrt{M_+T_e/mT_+}-\zeta R}{\sqrt{M_+T_e/mT_+}-\sqrt{M_+T_-/M_-T_+}/\xi}\cong 1-\frac{R(h)}{R_E}\cdot\frac{(\sqrt{M_+T_e/mT_+})_E}{\sqrt{M_+T_e/mT_+}}, \tag{2}$$

where $\zeta=\eta/\xi$, $R_E=(M_+T_e/mT_+)^{1/2}/(\xi/\eta)$, the suffix E refers to the values at the E-layer and M_+ is the effective positive ion mass number, $M_+= 1/[\Sigma_j\beta_j/M_j^{1/2}]^2$; β_j: the component of positive ion species. M_+ was fitted from existing data by $M_+(h)$=42-11(h -60)/20 for h < 80 km and $M_+(h)$ = 31 for 80 km < h < 90 km. At h < 90 km, dominant positive ions are hydrated while at h > 90 km, NO^+ and O_2^+ are dominant. The effective negative ion mass number M_- was obtained from [1,2]. However, M_- appears only for the case of α~1: the plasma is almost electron-free. Ion masses may change under special conditions: e.g. in the eclipse time, the time with a strong tidal effect and the cold summer time, etc. However, under the present observation conditions of winter time and lower solar activity it may be assumed here that M_+ can be applied commonly to the data of KSC and Andϕya.

Figure 4 shows the negative ion density ratio α (α+N_-/N_+) for polar and mid-latitude regions where the same symbols are used as in Fig. 3 to show only the very recent results. It is seen that α is larger and the upper limits of the negative ion layer is higher by about 6 km for the mid-latitude. These tendencies in the polar region suggest that the negative ion layer there is compressed by some mechanisms of destroying negative ions.

4. Discussion

4.1. Difference of D-layer between mid-latitude and polar regions

The mechanism of the difference of negative ion-layer between polar and non-polar regions may depend on whether it is inside the aurora oval or not. Inside it, the precipitation of higher energetic particles can destroy negative ions. They also collapse ozone directly or through the NO process for the winter season [10]. This may be a reason for the coincidence of the depletion of ozone and negative ions in the polar region. The ozone density measured by Rikkyo University by the same rockets has indicated a deeper dip of ozone density around 76 km [11] in the polar region. As another reason, dust or clouds may be responsible for the depletion of ozone in the polar region. Negatively charged dust can influence the charge balance by, $N_d Q_d + N_- + N_e = N_+$, where Q_d and N_d are the dust charge and density respectively. They cause a decrease in N_-.

4.2. Relation of negative ion density to the ozone density

Besides aeronomical reactions by neutral particles to form ozone, there are reactions involving negative ions to create and destroy ozone. Those which have large rate constants *k*'s are [12]

$$O_2^- + O \rightarrow O_3 + e ; \qquad k_1 \qquad (3)$$

$$O_3 + O_2^- \rightarrow O_3^- + O_2 ; \qquad k_2 \qquad (4)$$

The condition for which the ozone creation prevails over destruction can be fulfilled in mid-latitude regions above 76 km. The first reaction creating negative ions in the D-layer is

$$O_2 + e + M \rightarrow O_2^- + M ; \qquad k_3 \qquad (5)$$

where M is a third body. The combination of the reactions (3) and (5) gives

$$O_2 + O + M \rightarrow O_3 + M ; \qquad k_4 \qquad (6)$$

which is the normal reaction for the ozone generation. If negative ions act like a catalyzer without being lost effectively, they benign ozone. This is similar to the decatalyzation of Cl against ozone by negative ionization [13]. It is desirable to determine the efficiency of negative ions for such a reaction cycle in the laboratory.

5. Conclusion

The result of recent observation of the D-layer, particularly the negative ion layer, has shown that the region where the negative ion density ratio is large (negative ion region) is thinner in the polar region than in the mid-latitude. The reason may be attributed to the precipitation of high energetic particles and also dust particles in the polar region which destroy negative ions. This would be one of the mechanisms for the correlation between the densities of negative ions and ozone, particularly at the height 76 km in the ozone depletion layer. Finally, the authors thank the staff of ISAS for the support in the rocket observation.

References

[1] F. Arnold, J. Kissel, D. Krankowsky, et al., J.Atm.Terr.Phys. **33**, 1169 (1971).
[2] R.S. Narcisi, A.D. Bailey, et al., J.Atm.Terr.Phys. **33**, 1147 (1971).
[3] A.A. Viggiano, F. Arnold, D.W. Fahey, et al., Planet.Space Sci. **30**, 499 (1982).
[4] H.U. Widdel, G. Rose and R. Borchers, J.Geophys.Res. **81**, 6217 (1976).
[5] M. Takagi, Y. Kondo and A. Iwata, J. Geomag.Geoelect. **32**, 715 (1980).
[6] S. Sampath, V. Sasikumar and S. Muralidas, J.Atm.Terr.Phys. **54**, 347 (1992).
[7] H. Amemiya, K. Oyama and K. Hirao, Planet.Space Sci., **33**, 875 (1985).
[8] H. Amemiya and Y. Nakamura, J .Geomag.Geoelect. **45**, 219 (1993).
[9] H. Amemiya and Y. Nakamura, J.Geomag.Geoelect. **48**, 391 (1996).
[10] S. Solomon, P.J. Crutzen and R.G. Roble, J.Geophys.Res. **87**, 7206 (1982).
[11] H. Yamamoto, K. Yajima, et al., J.Geomag.Geoelect. **49**, 675 (1997).
[12] G.M. Milikh and L.M. Duncan, in *Controlled Active Global Experiments*, 227 (1990).
[13] A.Y. Wong, et al., in *Controlled Active Global Experiments*, 129 (1990).