Letters

Mid-Latitude Electron Density Profile in the Low Solar Activity

(Received November 13, 1970)

1. Introduction

In the former paper (Maeda, 1969) the electron density profile based on rocket measurement was given for the altitude range from about 60 to 230 km. The used data were those obtained at ten rocket launching stations located in latitudes less than about 40° and included the periods of different solar activity.

By more careful and detailed study on the nature of all material it has been felt that some certain improvement or correction in grouping the data will be necessary. The first point is to eliminate the data obtained in medium and high solar activity periods which are relatively few in number and to concentrate to the majority of data which were obtained in low solar activity (1950–1954 and 1963–1965). The second point is to exclude the material obtained in the equatorial region, which is few in number, for the reason that we are working on the electron density at mid-latitude region.

The principle of grouping the daytime data is not changed, but this time the data for 35°<χ<55° is grouped in D1, those for 60°<χ<80° in D2, and those for 10°<χ<30° in D3. But by careful check of χ value at the time of firing some material previously defined as D1 group in the former paper was moved to D3 or D2 group and vice versa. Moreover the data for χ>80° were excluded from D2 group, which were obtained near sunrise or sunset in winter.

2. Presentation

The value of electron density is read out by 2.5 KM height step from published and unpublished material. After sorting the data into D1, D2 and D3 groups, the median value is obtained for each height (e.g. ...80.0, 82.5, 85.0, 87.5...). The result is shown in Figs. 1, 2 and 3. Fig. 3 contains the data above 120 KM at medium solar activity for reference. As shown in the figures an isolated black point stands for the median value obtained from only two or three available data. In case when only one data is available, it is not presented. Two horizontal bars (|=|) show the range of electron density value, excluding the least and the greatest, obtained from four to six available data. A black point in this range shows the median. Three horizontal bars (|=|=) mean the same as above, except the number of available data is seven or more. The median values are connected by a solid straight line, but the isolated points are connected by a dotted line.

The smooth curves in the figures are the results of theoretical calculation as explained
later.

\(D_1\) and \(D_2\) contain the material for winter (Nov., Dec., Jan. and Feb.), spring (Mar. and Apr.) and fall (Sep. and Oct.). \(D_3\) contains the data for summer (May, Jun., July and Aug.). Places of rocket firing are listed in the former paper and to these Chamical (Argentina, 30.6°S) and Greece are added.

3. Theoretical Background

3.1 Temperature profile and neutral particle density distribution

The atmosphere models (30–80 KM) for each month and different latitudes are given by CIRA 1965. These are based on the temperature profile obtained by rocket and other measurements and on the pressure data at 30 KM. On the other hand, the average temperature profiles for winter and summer over Wallops Island are given by Nordberg et al. (1965).

The summer temperature profile of CIRA as averaged over June and July at 40° latitude (N profile calculated for this case is denoted by \(S_{40}\), see Fig. 3) is not much different from that by Nordberg et al. The average spring (Mar. and Apr.) profile of

![Daytime electron density profile of \(D_1\) group (low solar activity)](image)
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**Fig. 2** Daytime electron density profile of $D_2$ group (low solar activity)

**Fig. 3** Daytime electron density profile of $D_3$ group (low solar activity). A profile above 120 KM for medium solar activity is shown for reference.
K. MAEDA

CIRA at 45° latitude is very close to the Wallops winter profile by Nordberg et al.

To calculate the neutral particle density up to 120 KM the temperature profile from 80 to 120 KM is assumed. Generally speaking, the temperature at 80 KM is kept constant up to 90 or 95 KM and then rises to 355°K at 120 KM. Based on this assumption the neutral particle density is calculated for winter (Dec., Jan. and Feb. average at 40° latitude of CIRA, \( W_{40} \)) and winter by Nordberg et al. (WN), fall (Oct. at 40° latitude of CIRA, \( F_{40} \)) and summer (\( S_{40} \)).

It is to be remarked that the summer density is larger than winter density up to about 80 KM, but this relation is reversed from about 85 to 120 KM.

### 3.2 Calculation of Electron Density

The rate of electron production (\( Q \)) is calculated by the following equation.

\[
Q = \frac{\dot{n}}{\nu} = \frac{\Phi_0}{\eta} \alpha
\]

#### Table 1. Parameters for the calculation of the electron production rate (\( Q \)).

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>( \alpha )</th>
<th>( \eta )</th>
<th>( \eta \phi_0 )</th>
<th>( \alpha )</th>
<th>( \eta )</th>
<th>( \eta \phi_0 )</th>
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<td>1.4-19</td>
<td>7.4-22</td>
<td>1.4-19</td>
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<td>6.4-18</td>
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<td>1.7—19</td>
<td>6.0—10</td>
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<td>1.15—19</td>
<td>4.0—10</td>
<td>1.9—19</td>
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</table>

Unit: \( \lambda \) (wave length)...Å, \( \alpha \) (absorption cross section)...cm², \( \eta \) (ionization yield)...electrons per photon \( \phi_0 \) (photon flux density)...photons cm⁻² sec⁻¹. \( 9.2—22=9.2×10^{-12} \).

#### Table 2. The effective recombination coefficient.

<table>
<thead>
<tr>
<th>Height (KM)</th>
<th>( \alpha ) (cm³sec⁻¹)</th>
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<tbody>
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<tr>
<td>75</td>
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<td>7.2—8</td>
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<tr>
<td>120</td>
<td>7.0—8</td>
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</table>

\( 9.0—7=9.0×10^{-7} \)
where \( n \) is the neutral particle density, \( \Phi_0 \) the unabsorbed solar photon flux density for its wave length \( \lambda \), \( \sigma_i \) the absorption cross section, \( \eta_i \) the electron yield and \( \overline{\sigma_i} \) and \( \overline{\eta_i \sigma_i} \) mean the average over particle species, \( N_2 \), \( O_2 \) and \( O \).

From \( Q \) the electron density \( N \) is calculated by the following equation.

\[
N = \sqrt{Q/\alpha},
\]

where \( \alpha \) is the effective recombination coefficient.

The values used in the calculation are given in the Tables 1 and 2. \( \Phi_0 \) given by Bourdeau et al. (1966) at solar minimum is shown. Modification is made for activity difference. \( \sigma_i \), \( \eta_i \) and \( \alpha \) are referred to the papers by Ohshio (1964) and Ohshio et al. (1966). As for the density of \( O \), Johnson's paper (1967) and CIRA 1965 are referred to.

The result is shown by smooth curves in Figs. 1, 2 and 3. \( F_{40} \) curve in Fig. 1 is for \( \chi = 45^\circ \), corresponding to \( D_1 \) in average. \( S_{40} \) curve in Fig. 3 is for \( \chi = 20^\circ \), corresponding to \( D_3 \). \( W_N \) curve in Fig. 2 is for \( \chi = 65^\circ \). \( W_N \) corresponds to \( D_2 \), better than \( W_{40} \) (CIRA model), although it is not shown.

It is to be noted that the curves calculated from one model like the CIRA mean atmosphere for \( \chi = 20^\circ, 45^\circ \) and \( 65^\circ \) do not fit to all of \( D_1 \), \( D_2 \) and \( D_3 \), that is, one curve may fit to one of \( D_i \) but fails to the others.

### 3.3 Maximum Electron Density Ratio at Noon for Summer and Winter

The monthly median of the maximum electron density at noon calculated from \( f_{0E} \) is averaged over nineteen years for Fort Belvoir (1950–1968) and Kokubunji (1951–1969). The ratio of these monthly values to that in winter (average of Dec. and Jan.) is plotted in Fig. 4. The above periods cover two phases of both maximum (1957–59 and 1968–69) and minimum (1952–54 and 1963–65) solar activity. The ratio of the maximum electron density of summer to winter \( (N_S/N_W) \) is also shown in the figure, indicating that \( N_S/N_W \) for Fort Belvoir is 1.34 for minimum activity (A in the figure) and 1.26 for maximum activity (B) and for Kokubunji 1.275 for minimum activity (A) and 1.24 for maximum activity (B). The curves of \( \sqrt{\cos \chi} \) for two stations are also shown.

It is clear that the above values of the ratios are smaller than \( \sqrt{\cos \chi} \) in summer. It appears that the ratio of two maxima in \( S_{40} \) (Fig. 3) and \( W_N \) (Fig. 2) is not able to explain the above ratio (1.34), being a little larger than it. In the above theoretical calculation, the atmosphere is divided into two regions separated by 100 KM level and for each region \( \overline{\sigma_i} \) and \( \overline{\eta_i \sigma_i} \) are taken as constant. But for the upper region, the density ratio of molecular oxygen to atomic oxygen is rapidly changing with the height and so the above parameters should be taken as continuously changing. This was done in an approximate way and it
Fig. 4 The monthly median noon maximum electron density in the $E$ region averaged over nineteen years for Fort Belvoir ($38.7^\circ$N) and Kokubunji ($35.7^\circ$N). The ratio to winter (Dec. and Jan.) average is shown.

can be said that the heights of maximum $N$ for winter and summer come closer, but it is not easy to explain the ratio of two maxima obtained from observation.

Concluding Remarks

Data available for medium and high solar activity are few. The problem remains unsettled that the electron density profile for these periods should be worked out and compared with theoretical calculation based on the knowledge on $\theta_0$ for the corresponding solar activity.

The part of theoretical work, which is very briefly outlined in this paper, will be published in full in the future.

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References


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