Communications

Effects of Total Solar Eclipse on F-layer

N S CHAUHAN
Department of Astronomy & Space Sciences, Punjabi University, Patiala 147002

Received 12 October 1984; accepted 19 February 1985

The response of F-layer at Hyderabad to the total solar eclipse of 16 Feb. 1980 is studied by means of theoretical modelling. A model of the eclipse function based on the observation of 10.7-cm solar flux at Hyderabad, is used in solving the time-varying equation of continuity of plasma for the F-layer. It is found that the F2-peak electron density gets depressed and the layer goes up during the eclipse. The computed results so obtained are qualitatively similar to the observations made during the total solar eclipse on 16 Feb. 1980.

Many workers1-3 have studied the response of the ionosphere to the solar eclipse of 16 Feb. 1980 and found that the ionization (electron density and total electron content) decreases during the eclipse period and follows the optical obscuration of the eclipse. An attempt is now made to study the response of the ionosphere at Hyderabad during the eclipse by means of theoretical modelling.

The behaviour of ionospheric F-layer during the total solar eclipse of 16 Feb. 1980 is simulated. A numerical model of the ionosphere is built up through solution of the following equation of continuity of plasma4.

\[ \frac{\partial N}{\partial t} = Q - L - \nabla \cdot (N \mathbf{W}_1) - \nabla \cdot (N \mathbf{W}_2) - \nabla \cdot (N \mathbf{W}_3 \cos \hat{l}) \]  

... (1)

In Eq. (1) the letters have their usual meanings. The three divergence terms account for the transport of plasma because of electromagnetic \( \mathbf{E} \times \mathbf{B} \) drift, ambipolar diffusion and neutral wind, respectively4. Eq. (1) is solved for Hyderabad (lat., 17.3°N; long., 78.5°E) for eclipse and non-eclipse conditions. It is assumed that during an eclipse, the electromagnetic \( \mathbf{E} \times \mathbf{B} \) drift and neutral wind remain unchanged. The changes in the ionosphere during the eclipse are brought about by the blockade of solar flux because of occultation of the solar disk by moon. The production rate \( Q \) in Eq. (1) can be written as5

\[ Q = (F.G + H)Q_1 + Q_2 \]  

... (2)

where

- \( F \) Fraction of uneclipsed solar disk which accounts for the observation of EUV radiation (165 Å < \( \lambda \) ≤ 911Å) during the eclipse
- \( G \) Function which accounts for the effects of radiation from the localized sources on the sun
- \( H \) Fluctuating coronal source flux

\( Q_1 \) Rate of production of electrons by photoionization

\( Q_2 \) Non-solar source of ionization

Generally, the contribution from \( Q_2 \) is very small compared to \( Q_1 \) (i.e. \( Q_2 \ll Q_1 \)). The contribution from the fluctuating coronal source is negligible compared to the steady coronal flux \( (H \approx 0) \) and assuming that the EUV radiations are emitted uniformly over the solar disk \( (G = 1) \), Eq. (2) becomes

\[ Q = FQ_1 \]  

... (3)

Before and after the eclipse, i.e. on control day, \( F = 1 \) and during the eclipse, \( F < 1 \).

For the ultraviolet radiations which are responsible for the ionization at F-region height, the eclipse function decreases fairly uniformly with time6. The 10.7-cm (2800 MHz) radio flux is usually considered to be an excellent indicator of solar flux in the ultraviolet and extreme ultraviolet regions of the solar spectrum. Its variations with the progress of the eclipse were observed by Bhonsleeta for the 16 Feb. 1980 eclipse at Hyderabad. The first contact occurred at 1429 hrs LT and the last contact at 1656 hrs LT with maximum phase at 1547 hrs LT (Fig. 1). Keeping this in mind, the function \( F \) has been modelled (dashed line). At the maximum obscuration, \( F \) has only 25% of its original value (Fig. 1).

The continuity equation is solved for the control day when the eclipse function is equal to unity and for the eclipse day when the eclipse function varies as shown in Fig. 1. The detailed computational procedure involving reduction of the continuity equation into a tri-diagonal matrix and subsequent numerical solution using Crank-Nicolson method has already been discussed by the author8.

Fig. 2 shows the computed behaviour of the F-layer during the eclipse on 16 Feb. 1980. The peak electron density...
own way. The results presented in Figs 2 and 3 summarize all such processes.

The upward movement of the layer at Hyderabad is probably due to the reduction of ambipolar diffusion during the eclipse. The diffusion coefficient, $D_a$, is given by:

$$D_a = \alpha \left[ \frac{1}{n(0) + \eta_0} \right] \left[ b \times \left( \frac{T_g}{1000} \right)^{1/2} \right]$$  \hspace{1cm} (4)$$

where $\eta_0$ and $b$ are constants and $\alpha$ is the ratio of ion-to-electron temperature. The neutral temperature $T_g$ decreases during the eclipse according to equation:

$$T_g = T_\infty - (T_\infty - T_{120}) \exp(-\sigma \zeta)$$  \hspace{1cm} (5)$$

where $T_\infty$ is the exospheric temperature and depends upon solar flux; $\sigma$ and $\zeta$ are constants and $T_{120}$ is the temperature at the turbopause. The reduction in diffusion as seen from Eqs (4) and (5) should give rise to enhanced electron density. But it is not so. It seems that the effect of diffusion is dominated by production rate effects. A decrease in solar flux from the sun directly affects the production of plasma in the ionosphere. The production rate $Q$ as a function of altitude $h$ and zenith angle $\chi$ is given by:

$$Q = \sum_j \sum_j F_{\alpha,i} \exp[-\tau(h,\chi)] \sigma_{j,i} n_j$$  \hspace{1cm} (6)$$

where:

$F_{\alpha,i}$ Flux of solar radiation at zero optical depth

$\tau(h,\chi)$ Optical depth

$\sigma_{j,i}$ Photoionization cross-section

$\eta_{j,i}$ Ionization efficiency of the $j$th species

$n_j$ Concentration of $j$th species

The production rate will reduce, firstly, because of the reduction in $F_{\alpha,i}$, secondly, due to the reduction in the concentration of the neutrals and thirdly, due to the reduction in scale height during the eclipse period. The ionization will further reduce due to the increase of loss rate. The loss rate coefficients $r_1$ and $r_2$ are dependent on temperature through the relations:

$$r_1 = 2 \times 10^{-17} \sqrt{300/T_g}$$  \hspace{1cm} (7)$$

and

$$r_2 = 13.8 \times 10^{-16}/T_g$$  \hspace{1cm} (8)$$

There exist no direct measurements of electromagnetic $E \times B$ drift and neutral wind over the Indian Zone. Both the $E \times B$ drift and the poleward neutral wind are expected to decrease during the eclipse period. The thermal effects, affecting the ionosphere, should also be measured. Theoretically the transport of ionization ($Z$) due to thermal expansion or concentration of the atmosphere (as happens during the eclipse) is given by:

$$Z = -\nabla(\nabla T \sin \theta)$$  \hspace{1cm} (9)$$
where $I$ is the magnetic dip angle, $\hat{t}$ is a unit vector along field line and $W_4$ is the velocity of neutral air due to thermal expansion or contraction given by

$$W_4 = -H \int_{h_0}^{h} \frac{\partial}{\partial t} \left( \frac{1}{h} \right) dh$$

... (10)

where $H$ is the scale height and $h$ is the height above the earth's surface. For a rigorous study of the eclipse-time effects of the ionosphere, all the above mentioned parameters together should be taken in the time-dependent continuity equation.

References