Azimuthal Variation of Gravity Wave Induced Perturbations in the F2 Region Electron Density

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It has been established theoretically that ionospheric response to atmospheric gravity waves is anisotropic and depends, among other parameters, on the azimuth of the wave propagation. With this point in view, measurements on 24 occasions are made to study the magnitude of gravity wave-induced perturbations in the F2 region electron concentration at Delhi as a function of the wave-azimuth. The perturbations are indeed found to be azimuth-dependent and the results agree qualitatively with the theoretical predictions.

1. Introduction

It is well known that the electron density disturbances produced by atmospheric gravity waves in the F2 region are mainly through momentum transfer between the charged and the neutral particles. The waves set the atmospheric neutral particles in motion, which in turn impart motion to the charged particles of the ionosphere. In the F2 region, however, the electron-neutral and the ion-neutral collision frequency are much lower than gyro-frequencies of the corresponding charged species. This results in a constraint on the charged particles to move along the geomagnetic field lines only. Thus the interaction of the wave-induced neutral particle motion and the charged particles results in the oscillation of the latter along the field lines with speeds corresponding to the component of the neutral gas velocity in that direction. It has been proved theoretically by Hooke and confirmed experimentally by Setty et al., Gupta and Nagpal that the ionospheric response depends strongly on the relative inclination of the wave-front of the gravity waves to the geomagnetic field lines. Since the tilt of the gravity wave-front varies with the wave period, the wave-induced electron density perturbations will vary with (a) the wave period, (b) the magnetic inclination of the place under study, and (c) the azimuth of wave propagation. Effects (a), and (b) have been exhaustively discussed earlier. It is the effect (c), the azimuth variation of ionospheric response to gravity waves, which is the subject matter of this paper.

2. Theoretical Background

It is shown by Hooke with some justifiable assumptions, that the fractional electron density perturbations, $A$, at the F2 peak caused by gravity waves obeys the equation

$$A = \frac{N_{e'}}{N_{eo}} = \frac{1}{\omega} (k \cdot l_b) (U \cdot l_b)$$

...(1)

where $N_{e'}$ = perturbation in the unperturbed value of electron density $N_{eo}$,

$\omega$ = the circular wave frequency,

$\rightarrow k$ = the wave number,

$\rightarrow U$ = the gravity wave-induced neutral particle velocity,

and $\rightarrow l_b$ = the unit vector in the direction of the geomagnetic field.

Eq. (1) shows that the ionospheric response to gravity waves (or the fractional electron density perturbations caused by gravity waves) is a function of the relative inclinations of the vectors $\rightarrow k$ and $\rightarrow U$ to the geomagnetic field lines. Since for a given station, the directions of the vectors $\rightarrow k$ and $\rightarrow U$ are uniquely determined for gravity waves of a given period, the ionospheric response will be sensitive to the azimuth of wave propagation.

Fig. 1 shows the geometry of the wave interaction with the ionization. We can see that

$$A = \frac{U \cos \theta}{\omega} (k_x \cos I + k_z \sin I)$$

...(2)
Here $\tau_\varphi$ is the Brunt period, $\tau$ is the wave period ($= 2\pi/\omega$) and $\lambda$ is the wavelength ($= 2\pi/k$).

Eq. (4) clearly indicates that for a given station (or fixed value of the magnetic inclination, $I$), the ionospheric response to gravity waves is a function of the azimuth $\alpha$. Hooke and Hooke have made numerous computations on the ionospheric response to internal gravity waves. He calculates the amplitudes of the fractional electron density perturbations produced by a given wave as a function of its azimuth. One such response curve, reproduced in Fig. 2, shows the response of the F2 peak at magnetic inclination $I = 55^\circ$ to a typical internal gravity wave. The radial distance from the points of the curve to the plot origin gives the amplitudes of the fractional electron density perturbation occurring during the wave passage. The parameters $\lambda_h$ and $\lambda_z$ are the horizontal and vertical components of the wavelength $\lambda$; $V_{ph}$ is the horizontal phase velocity of the wave; and $U_h$ is the horizontal component of the wave-induced neutral particle velocity perturbation. Fig. 2 clearly indicates the ionospheric anisotropy to internal gravity waves and shows that the magnitudes of the electron density perturbations are different for the same wave propagating at different angles from the meridian.

3. Experimental Results

The experimental technique consists in measuring the f0F2 values very accurately at 1-min intervals; the average length of a record being about 5 hr. These records contain small fluctuations superimposed on the larger ones due to diurnal production and recombination. These small fluctuations are extracted from the records and spectrum analyzed. The resulting power spectrum is normalized to show contributions from 1-min intervals. Square roots of the powers then give the amplitude of fluctuations. The details of the methods of observation and data analysis have been already discussed and will not be reproduced.
Fig. 4—Average spectra for the small fluctuations observed at Delhi, classified into three groups depending upon the azimuthal direction of wave propagation: (a) 0-60°; (b) 61-120°; (c) 121-180°.

Here, the f0F2 fluctuations were observed on 72 occasions during the period September 1969 to March 1973 and each record is processed separately.

An average normalized spectrum, weighted according to the record length, is shown in Fig. 3. The main characteristics of the spectrum are: (a) the low cut-off period near 8 min; (b) the high cut-off period near 70 min; and (c) a dip in the spectrum around 30 min.

The characteristics of the spectrum have been exhaustively discussed earlier by Gupta and Nagpal, Gupta et al., Nagpal et al., and Setty et al. To summarize, the low cut-off period at 8 min represents an "effective" Brünt period at the F2 region peak. It is called "effective" because it is not the true Brünt period but is Doppler shifted due to the presence of background winds. The high cut-off period is determined by the dissipation of wave energy by molecular viscosity, thermal conduction, and ion drag. The dip in the spectrum is a manifestation of the ionospheric aniso-

tropy to the atmospheric gravity waves in the F region.

On 24 occasions, it was possible to measure the speeds and directions of the observed disturbances caused by gravity waves. The interested reader is referred to the paper by Gupta et al. for the results and the method for determination of the speeds and directions. These 24 events are classified into three groups depending upon whether the azimuthal direction is between 0-60° or 61-120° or 121-180°. Separate averages in these three categories are taken and the resulting spectra are shown in Fig. 4. It is noticed that the amplitudes of fluctuations are less for waves propagating in the directions between 61-120°, i.e., for waves travelling close to east-west direction, compared to those propagating nearly meridionally.

To make a theoretical comparison with the spectra of Fig. 4, Eq. (4), is used to compute theoretical spectra for azimuth of the wave propagation from 0 to 180° at an interval of 21°. Averages were then

Fig. 5—Theoretically computed [from Eq. (4) of the text] average spectra for the three azimuthal ranges: (a) 0-60°; (b) 61-120°; (c) 121-180°.
taken in the three ranges of 0-60°, 61-120°, and 121-180°, corresponding to the averages of Fig. 4. Such average spectra are shown in Fig. 5. It is evident from Fig. 5 that the fractional electron density perturbations produced by waves travelling close to east-west direction (between 61° and 120°) are an order of magnitude smaller compared to those produced by the meridional waves. This theoretical prediction is authenticated by the experimental observations.

The theoretically computed spectra of Fig. 5 differ from the experimentally observed ones in at least one respect, i.e. while the experimental spectra show a high period cut-off near 70 min, the theoretical spectra, on the contrary, do not show any signs of a cut-off at higher periods. This is perhaps because the theory used neglects the wave dissipation in the atmosphere. Nagpal et al.⁸ show that when the effects of dissipation are taken into account, the theoretical spectra do show a high period cut-off.

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References