Effect of Ion Drag on the Propagation of Atmospheric Gravity Waves in the F region

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The variations of fractional energy loss with azimuthal angle for different gravity wave periods have been studied. The losses are more for larger period gravity wave and they increase with altitudes. The attenuation of 30 min-wave is almost constant up to 90° azimuth and then decreases monotonically, whereas for 60 min-wave the attenuation coefficient first increases and then decreases showing a peak at 80° azimuth.

1. Introduction

Theoretical studies of the internal atmospheric gravity waves lead to the conclusion that TIDs are mainly caused by the collisional interaction between the ionization and the internal atmospheric gravity waves. Collisional interaction of internal gravity waves and the ionization is of two types. In one case, the ionization moves with a velocity equal to the component of the gravity wave wind field along the geomagnetic field lines, and in the other the ionization tries to move the neutral gas. The latter reaction is known as "ion drag" and it causes a loss of energy from the atmospheric gravity waves generally known as ohmic or hydromagnetic loss. Hines studied the ohmic loss of the gravity wave analytically and showed that the presence of ion drag caused a southward preference of the TID movement.

In this paper, we have studied the effect of ion drag on the propagation of internal gravity waves. The effect of period, angle of dip and height on the loss induced by ion drag has been calculated for two different wave periods, angles of dip (which are representative of low and mid-latitude F regions) and height. The results show a southward preference of TID movement, as indeed to be expected from the analytical results of Hines. The computed results are discussed in detail in light of earlier calculations and experimental measurements.

2. Numerical Results

Applying asymptotic approximations, the fractional loss of energy (ratio between the ohmic loss per unit volume of the ionosphere and the total energy carried by the gravity wave per unit volume in a loss-free atmosphere), Hines writes \( f' = \left( \frac{\tau_{\alpha}}{\tau_{nl}} \right) \left( r^2 \left( S_2^2 + C_2^2 S_1^2 \right) + 2r C_\alpha S_1 C_I + C_I \right) \left( 1 + r^2 \right)^{-1/2} \)

where \( \tau_{\alpha} \) is the isothermal Brunt-Vaisala period; \( \tau_{nl} \) represents \( \rho_0/\alpha_0 B_0^2 \), \( S \) and \( C \) denote sine and cosine of the subscripted angle, \( \alpha \) is the azimuth of propagation measured from magnetic north; \( I \) is the angle of dip, and \( r \) is the tangent of the angle by which the wave normal is depressed below the horizontal plane; \( \rho_0 \) is the mass density of the atmosphere; \( B_0 \) earth's magnetic field and \( \alpha_0 \) Pederson conductivity of the ionosphere.

The fractional energy losses are calculated for two waves of periods 30 and 60 min at dip angles of 30 and 40°. The calculations are repeated for two altitudes, 200 and 400 km in the ionosphere, and also the angle of azimuth is varied from 0 to 180° by steps of 10°. The model atmosphere adopted in these calculations is taken from CIRA 1965 and \( \tau_{nl} \) from Kato and Matsushita.

The calculated results are shown in Fig. 1. The following points emerge from the figure.

(a) Losses are more for larger period gravity wave, which explains the absence of higher period modes of TIDs.

(b) The 30 min wave suffers less ohmic attenuation below 60° azimuth of propagation and beyond that the behaviour is reversed.

(c) The anisotropy in the fractional loss is less marked in the case of the 30 min-wave than in the 60 min - wave. Ohmic dissipation becomes very high for east-west propagation, however, in both the cases.

(d) The 60 min-wave suffers less attenuation at 30° dip angle than at 40° dip angle for near
Altitude = 200 km

(a) Variation of fractional energy loss with azimuthal angle for the wave periods of 30 and 60 min at dip angles of $I = 30$ and 40°. 

Altitude = 400 km

(b) For the 30 min-wave, the losses remain approximately constant up to 80° azimuthal angle and then decrease as the azimuthal angle increases and it becomes negligibly small around 180°. For the 60 min-wave the losses are comparatively larger around 180° azimuthal angle.

3. Discussion

The dip angles of 30 and 40° particularly chosen for the calculations are arbitrary but perhaps are representative of the midlatitude and at least the mid or low latitude TID results can be compared with the calculations. It appears from the calculations that the 30 min-wave will be more probable at these dip angles than the 60 min-wave and in northern hemisphere the propagation in the north-east quadrant will be less probable. However, southward propagation will be more probable and this type of observational bias is clearly seen from the various reported observations. For 60 min-wave, however, this type of behaviour cannot serve as the basis of such simple calculations because the assumptions of the perturbation technique applied in the derivation of the fundamental equations used in the present calculation are not valid. In this situation a more sophisticated analysis of TIDs should be used. Nevertheless, our results are in accordance with the observation that 60 min-waves are very few in the F region. The anisotropic response of the ohmic dissipation can be tested easily with the help of the observations of the TIDs. For a 30 min-wave the whole north-east quadrant will be less probable, but for a 60 min-wave the eastward propagation will be difficult, but towards the poles and the equator it will be easier. Other loss processes like those due to viscosity and thermal conductivity are important but Klostermeyer shows that near F region peak ion drag plays the important role for larger period gravity waves.

The results of Volland and Klostermeyer show that thermal conduction in F-region is also an equally important loss process. But as already mentioned thermal conduction does not show any azimuthal variation and so the azimuthal distribution of the TIDs can be simply attributed to the collisional interaction and losses due to ion drag. Apart from the above-mentioned interaction, certain other agencies like the source of gravity waves, presence of F-region tidal winds and the time of observation can influence the azimuthal distribution.

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