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INTERACTION BETWEEN IONIZATION AND GRAVITY WAVES IN THE UPPER ATMOSPHERE *

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ABSTRACT

It is known that travelling ionospheric disturbances are produced by gravity waves. During their movement from the F region downwards to the E region, gravity waves can produce thin layers called transients on ionograms and, if the wave motion persists, 'h-type E_S can be produced.

To investigate the problem, the continuity equations for both the E and F regions are solved for a perturbation, the motion of which is taken to be a gravity wave.

Hitherto, N'/N_0, the ratio of the disturbed to the undisturbed electron density, has been calculated by using only the Hall conductivity and ignoring the diffusion term for the F region. In the present calculations we have used Pedersan and Hall conductivities and calculated the N'/N_0 ratio for both the E and F regions.

Using CIRA standard atmosphere data we find for the F region that N' can exceed N_0 by up to 4 percent, depending on the horizontal wind velocity. In the E region, N' reaches much higher values than in the F region. Thus at 120 km if we take a typical horizontal wind velocity of 80 m/sec (wavelength 150 km), N' is about twice as large as N_0. From these results we see that the diffusion term is important for the E region.

INTRODUCTION

Under certain conditions atmospheric oscillations can propagate with their characteristic Brunt-Vaisala frequencies. If we take gravitational effects into account, these types of waves are known as acoustic-gravity waves (AGW), or gravity waves. The existence of these waves at ionospheric levels is usually detected by ground based measurement of the ionization density and AGW is known to be the driving force of travelling ionospheric disturbances (TID's). AGW theory and observational results have been exhaustively studied by Testud (1972), Yeh and Liu (1974), Hines (1960) and Francis (1975). The influence of AGW on the ionosphere has been considered by Testud (1972) and Beer (1974).

We restrict our discussion to medium-scale AGW's which have horizontal wave speeds between 100 and 250 ms^{-1}, with mean wavelengths of several kilometers and periods of from 15 minutes to more than 1 hour.

To investigate the influence of AGW on the ionosphere, the continuity equations are solved for the E and F regions, where the theory of small perturbations is used.

INTERACTION OF GRAVITY WAVES WITH THE IONOSPHERE

The continuity equations of the ionization density in the ionosphere are

$$\frac{\partial N}{\partial t} + \nabla.(N v) = Q - \alpha N^2 - D \nabla^2 N \tag{1}$$

for the E region and

$$\frac{\partial N}{\partial t} + \nabla.(N \bar{v}) = Q - \beta N - D \nabla^2 N \tag{2}$$

for the F region, where

- N denotes electron density,
- Q denotes rate of production per unit volume,
- α denotes the recombination coefficient,
- β denotes the attachment coefficient,

$\nabla.(NV)$ is the transport term,

$D\nabla^2 N$ is the diffusion term and

D denotes the ambipolar diffusion coefficient.

If the perturbations are small, then the electron density N can be taken as $N = N_0 + N'$ and the charged particle velocity V can be taken as $V = V_0 + V'$. Here V_0 denotes the density in the undisturbed state and V' denotes the velocity in the disturbed state.

If we apply perturbation theory to Eqs.(1) and (2) we obtain

$$\frac{\partial N'}{\partial t} + \nabla.(N_0 V') + \nabla.(N' V_0) = -2\alpha N' N_0 + D \frac{\partial^2 N'}{\partial z^2} \qquad (3)$$

for the E region and

$$\frac{\partial N'}{\partial t} + \nabla.(N_0 V') + \nabla.(N' V_0) = -\beta N' + D \frac{\partial^2 N'}{\partial z^2} \qquad (4)$$

for the F region.

To solve Eqs.(3) and (4), we must find the orthogonal components of the undisturbed and disturbed velocities: V_{0x}, V_{0y}, V_{0z}, V'_x, V'_y, V'_z. The x-axis is E-ω, y-axis, N-S and z-axis vertical. We get these velocities from the Lorentz force equations

$$\vec{J} = \sigma_1(\vec{E} + \vec{u} \times \vec{B}) + \sigma_2 \vec{B} \times (\vec{E} + \vec{u} \times \vec{B})/|\vec{B}| \quad , \qquad (5)$$

where

σ_1 denotes Pedersan conductivity,

σ_2 denotes Hall conductivity,

U denotes wind velocity,

B denotes magnetic field (assumed to be parallel to the y-axis) and

E denotes electric field.

If the wave motion is assumed to have components only in the x and z directions, the wave motion is given by

$$A \exp i(\omega t - K_x x - K_z z) \; . \qquad (6)$$

Then we can write

$$\bar{V}_x = \mu_1 (E_x - U_z B) + \mu_2 (E_z + U_x B)$$

$$\bar{V}_y = \mu_1 E_y \qquad (7)$$

and

$$V_z = \mu_1 (E_z + U_x B) + \mu_2 (-E_x + U_z B) \; .$$

Here μ_1 and μ_2 denote mobilities

$$\mu_1 = \nu e / m (\omega_H^2 + \nu^2)$$

$$\mu_2 = \omega_H e / m (\omega_H^2 + \nu^2)$$

and

$$\omega_H = e B / m \quad ,$$

where ν denotes the collision frequency (Beer 1974).

The velocities of the charged particles in the undisturbed and disturbed state are given by Eqs.(8) and (9), respectively:

$$V_{0x} = \mu_1 E_{0x} + \mu_2 (E_{0z} + U_{0x} B)$$

$$V_{0y} = \mu_1 E_{0y} \qquad (8)$$

$$V_{0z} = \mu_1 (E_{0z} + U_{0x} B) + \mu_2 E_{0x} \quad ,$$

$$V'_x = -\mu_1 U'_z B + \mu_2 U'_x B$$

$$V'_y = 0 \qquad (9)$$

$$V'_z = \mu_1 U'_x B + \mu_2 U'_z B \; .$$

From Eqs.(3) and (4) we obtain for the E region

$$N_0 \frac{\partial v_x'}{\partial x} + V_{0x} \frac{\partial N'}{\partial x} + N_0 \frac{\partial v_y'}{\partial y} + V_{0x} \frac{\partial N'}{\partial y} + V_z' \frac{\partial N_0}{\partial z} + N_0 \frac{\partial v_z'}{\partial z}$$

$$+ V_{0z} \frac{\partial N'}{\partial z} + \frac{\partial N'}{\partial t} + 2\alpha N_0 N' - D \nabla^2 N' = 0 \tag{10}$$

Similarly, for the F region, we obtain

$$N_0 \frac{\partial v_x'}{\partial x} + V_{0x} \frac{\partial N'}{\partial x} + N_0 \frac{\partial v_y'}{\partial y} + v_{0x} \frac{\partial N'}{\partial y} + v_z' \frac{\partial N_0}{\partial z} + N_0 \frac{\partial v_z'}{\partial z}$$

$$+ V_{0z} \frac{\partial N'}{\partial z} + \frac{\partial N'}{\partial t} + \beta N' - D \nabla^2 N' = 0 \tag{11}$$

If we substitute the velocities of Eqs.(8) and (9) into Eqs.(10) and (11) and use Eq.(6) we get the ratio N'/N_0 for the E and F regions

$$N'/N_0 = U_x' X / Y + 2\alpha N_0 \qquad \text{for the E region} \tag{12}$$

and

$$N'/N_0 = U_x' X / Y + \beta \qquad \text{for the F region} \tag{13}$$

Here

$$X = iK_x \mu_2 B - \mu_1 B \frac{1}{N_0} \frac{dN_0}{dz} - \mu_2 B \frac{1}{N_0} \frac{dN_0}{dz} \left(\frac{\omega^2 - K_x^2 c^2}{K_x K_z c^2 - igK_x} \right) + i\mu_2 B K_z \left(\frac{\omega^2 - K_x^2 c^2}{K_x K_z c^2 - igK_x} \right)$$

$$Y = -iK_x \mu_1 E_{0x} - i\mu_2 K_x (E_{0z} + U_{0x} B) - iK_z \mu_1 (E_{0z} + U_{0x} B) + i\mu_2 K_z E_{0x} + D K_z^2$$

K_x denotes the x component of the (complex) wave number,

E_{0x} denotes the x component of the undisturbed electric field,

E_{0t} denotes the z component of the undisturbed electric field,

ω denotes the angular wave frequency and

C denotes the velocity of sound.

RESULTS

The observed fluctuations in the ionograms due to TID's are shown in Fig.1. Similar fluctuations recorded as equivalent height versus time [h;t] are shown in Fig.2. From these two examples we note that these fluctuations travel from the F region down to the E region.

We now attempt to find the increase in the ratio N'/N_0 for the perturbations which are produced by acoustic gravity waves. For this purpose Eqs.(12) and (13) have been evaluated for different attitudes. The ionospheric parameters and the values of N'/N_0 for 120 and 250 kms, are given in Table I. Most of the data are taken from CIRA (1973) and the ratio N'/N_0 is calculated.

Values of the ratio N'/N_0 for the E and F regions are shown in Fig.3, from which we see that the perturbation ratio N'/N_0 is about 0.04 in the F region and can increase to as much as 2 in the E region.

CONCLUSIONS

In all previous calculations the diffusion term has been neglected (e.g. Testud 1972, Hines 1974, Beer 1974, Francis 1975). This may be a valid assumption for the F region but is certainly not valid for the E region. In our approach, the diffusion term is shown to be dominant when its value $D > 10^3$.

It is also found that the effective terms are $2\alpha N_0 K_z C^2$ and $K_z^2 C^2 \mu_1 (E_{0z} + U_{0x} B)$ in the denominator of Eqs.(12) and (13). If

$$2\alpha N_0 \simeq K_z \mu_1 (E_{0z} + U_{0x} B) \tag{14}$$

the ratio N'/N_0 may reach greater values than those calculated here. The most variable parameter with altitude in Eq.(14) is μ_1 and its variation with altitude is shown in Fig.4. We may say that μ_1 is the dominant parameter causing E_s (especially h-type E_s) by acoustic gravity waves in the E region.

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Table I

	h = 120 km	h = 250 km
k_z	6.10^{-4} m^{-1}	3.10^{-5} m^{-1}
k_x	3.10^{-5} m^{-1}	$9.8\ 10^{-6}$ m^{-1}
ω	2.4×10^{-3} s^{-1}	2.4×10^{-3} s^{-1}
T	43 min	43 min
U_{Ox}	80 ms^{-1}	250 ms^{-1}
$E_{Oz} = E_{Ox}$	$10^3 Vm^{-1}$	10^{-3} Vm^{-1} (Beer 1974)
g	9.5 ms^{-2}	9.22 ms^{-2}
N_0	8×10^{10} m^{-3}	3×10^{11} m^{-3}
α	10^{-13} $m^3 s^{-1}$	-
β	-	10^{-4} s^{-1}
H	11.4 km	47.5 km
c^2	1.5×10^5 m^2/s^2	6.13×10^5 m^2/s^2
B	0.4×10^{-4} Tesla	0.4×10^{-4} Tesla
μ_1	9.083×10^3	-
U'_x	~ 100 ms^{-1}	100 ms^{-1}
μ_2	1.42×10^4	2.5×10^4
$\frac{1}{N}, \frac{dN_0}{dz}$	0.065	0
$\frac{N'}{N_0}$	[illegible]	~ 0.04

FIGURE CAPTIONS

Fig.1 Travelling ionospheric disturbance recorded in the Ionospheric Research Cen[illegible]tanbul (25 June 1973).

Fig.2 TID's in h'(t) recording system recorded in Istanbul (9 June 1963).

Fig.3 N'/N_0 percent for different heights in the E and F regions (note that the absicca is logarithmic).

Fig.4 Changes of the mobility parameter, μ_1, with heigh.

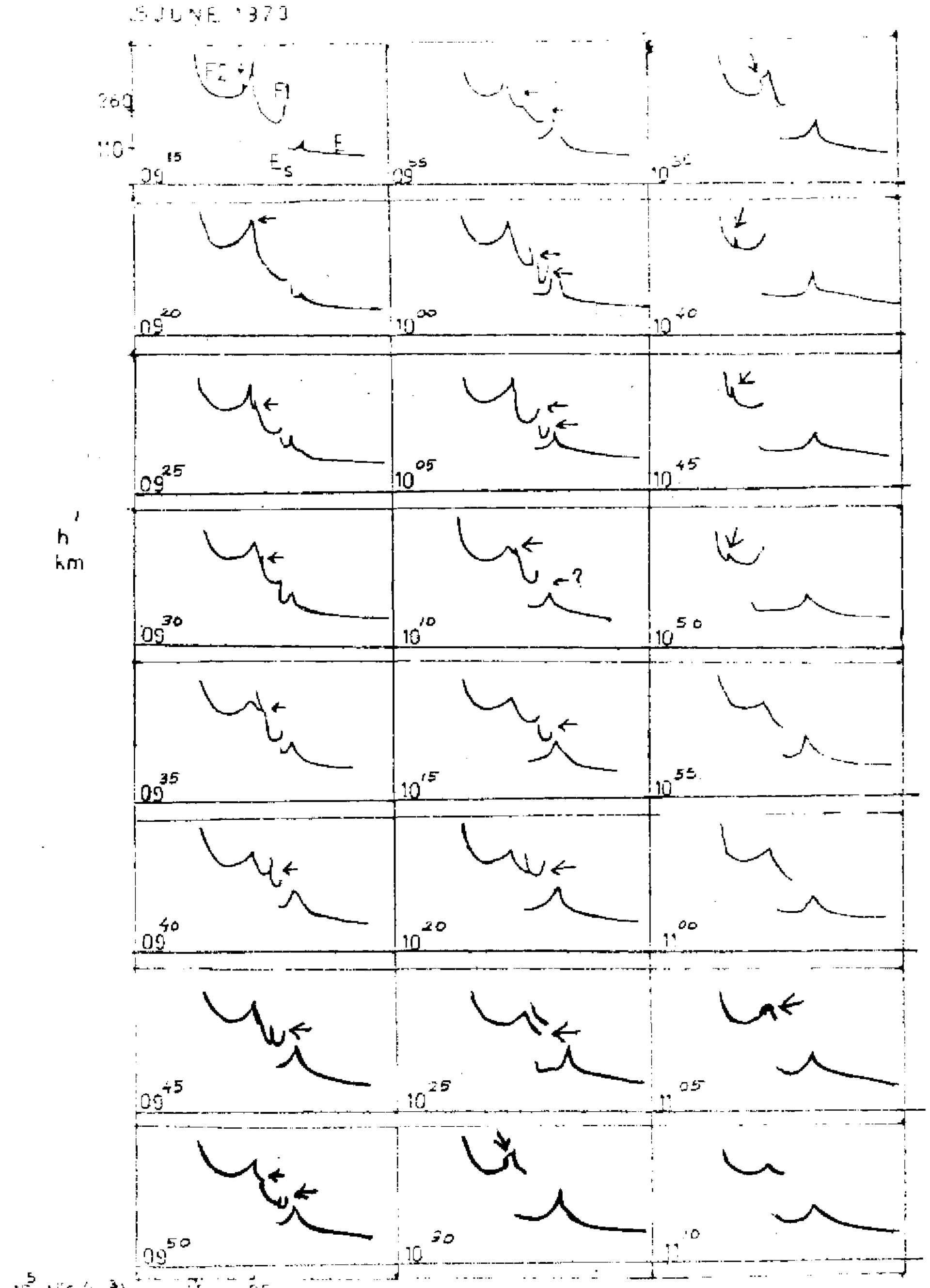

Fig.1

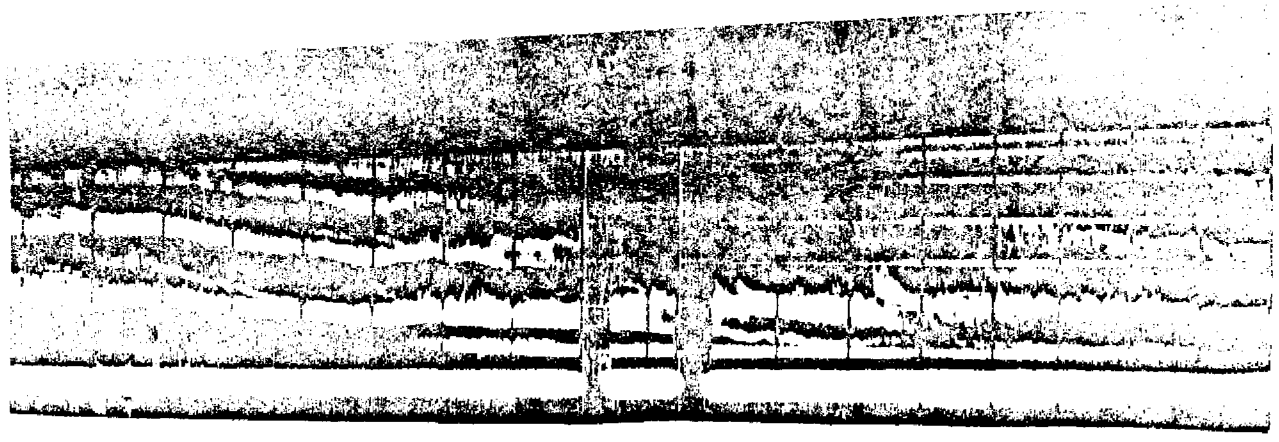

Fig.2

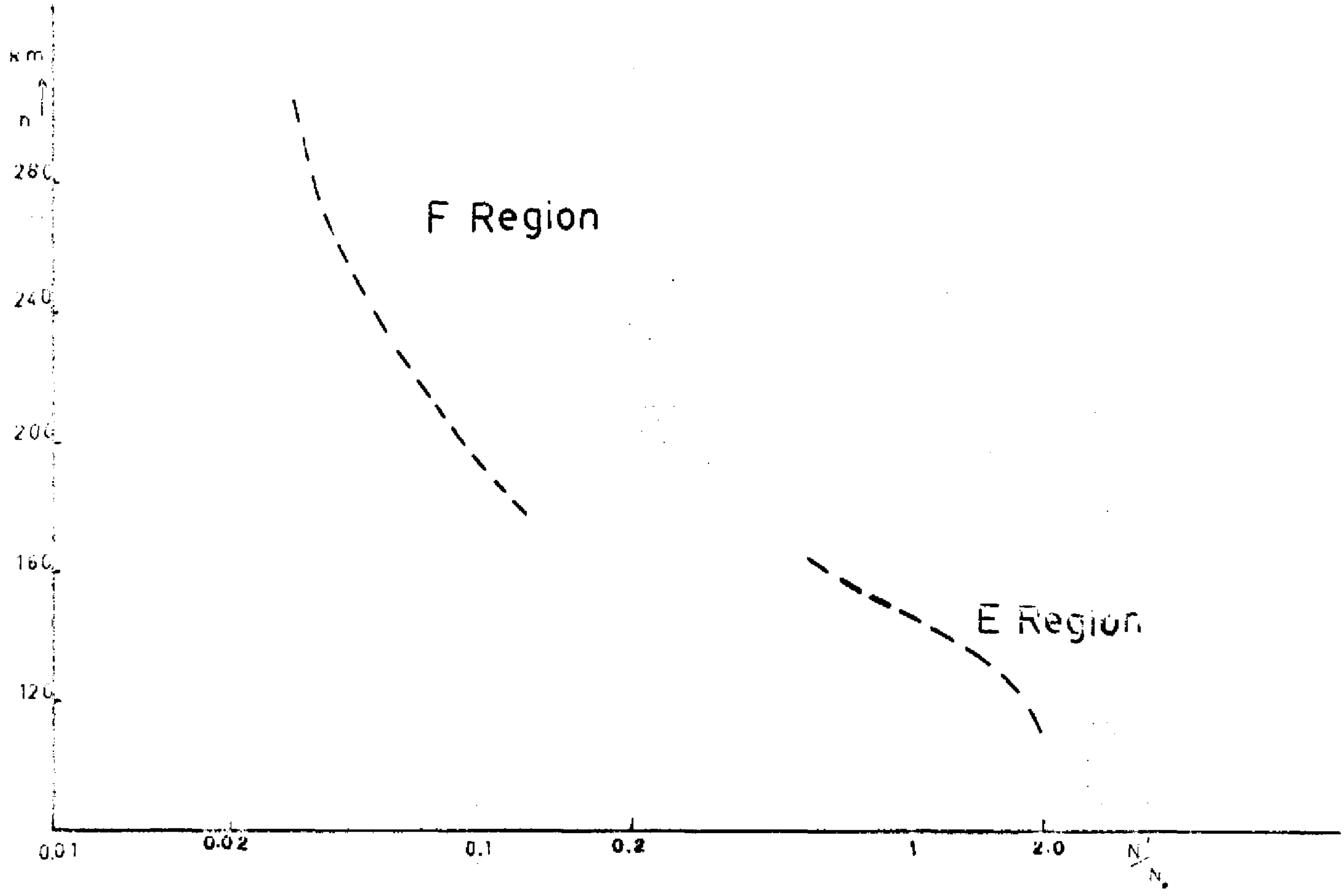

Fig.3

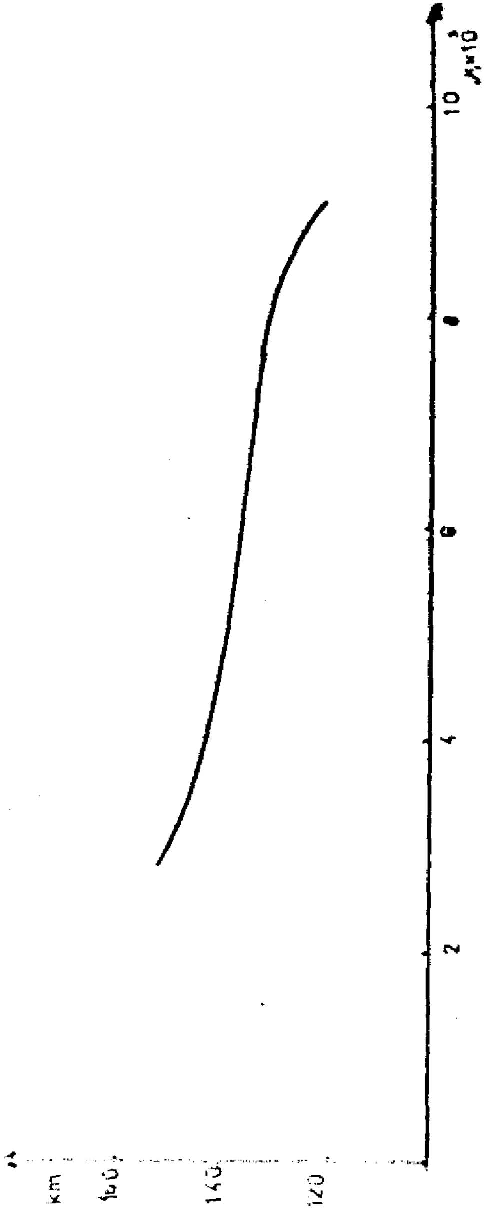

Fig.4

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