Determination of the Gravity Wave Induced Wind Field with the Help of Phase Path Measurements

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A typical record of amplitude and phase path changes at three closely spaced aerials showing the presence of a travelling ionospheric disturbance (TID) is analyzed to yield the value of the wind velocity, induced by internal atmospheric gravity waves. The computed wind velocity comes out to be about 7 m sec⁻¹ which is in good agreement with the results of other workers using more extensive techniques.

1. Introduction

Three spaced antenna technique has been extensively used throughout the globe to determine the characteristics of ionospheric irregularities. Kent and Wright have reviewed the results of such measurements and showed that remarkable success has been achieved in understanding many features of the ionospheric dynamics. Simultaneous measurement of amplitude and phase path changes of reflected radiowaves at three closely spaced aerials have added significant information about the ionospheric processes causing different irregularities. It is often observed that the phase path variations of the received echoes show wave type changes with time (with periods of a few tens of a minute) accompanied by amplitude burst in simultaneous fading records. These amplitude and phase path variations are attributed to the passage of TIDs near the level of reflection, the generation of which has been successfully explained in terms of internal atmospheric gravity waves. Hence the simultaneous measurements at three closely spaced receivers have emerged as effective probing technique to various characteristics of TIDs and other related features of the ionosphere.

Though the phase path measurements have been extensively made to derive characteristics of TIDs, yet no attempt has been made to derive the magnitude of wind velocity induced by gravity waves. So in the present paper, an attempt has been made to derive the magnitude of gravity wave induced wind from the simultaneous amplitude and phase path records and the theoretical processes giving rise to TIDs by gravity waves.

2. Experimental Records

The phase path records show sometimes undulations or the reversals. Fig. 1 shows a typical phase path change record taken on the night of 16 Dec. 68 at Varanasi. Letters E, C and N represent the different aerials, viz. eastern, central and northern. The record shows that from 2047 to 2048 hrs the...
phase path changes show an increasing trend. After being almost constant during 2048-2049 hrs the rate of phase path change reverses during 2049-2050 hrs. For clarity the phase path fringes are traced just below the original records. Different points A, B, C and A', B' and C' represent the completion of one wavelength (100 m) of phase path change. Fig. 2 shows the simultaneous amplitude record corresponding to Fig. 1.

A minute to minute plot for amplitude and phase paths changes for this TID event is shown in Fig. 3. It is noticed that the phase path changes are oscillatory in nature. An upward lifting trend is also evident. The amplitude bursts are observed corresponding to 2039 and 2049 hrs, which correspond to the crest of the TID. Whitehead has attributed such bursts in amplitude to the focusing of the radio waves by TIDs and has given a method to determine the speed of the TID. Reddi and Rao have given a method to determine the direction of movement of TID with the help of three spaced phase path records alone. Using these methods the velocity of this TID comes out to be 101 m/sec and it is moving at an angle of 45° with the north-south direction.

It has been shown by Fooks that the phase path changes are caused mainly by the irregularities just below the level of reflection and also that the magnitude of phase path change does not depend strongly on the thickness of the irregularities. The measure of the phase path change on the other hand depends on the intensity of the irregularities. Fooks computed the phase path changes caused by Gaussian irregularities superimposed on a linearly increasing background electron density and showed that

$$A_i = (6 \Delta P/\mu_0) \% \quad \text{for F region} \quad (1)$$

where $A_i$ is the intensity of the irregularities (magnitude of the ratio of electron density perturbation due to isospheric irregularity and the electron density at the level of reflection), $\Delta P$ is the amplitude of the phase path undulations produced by an irregularity passing overhead and $\mu_0$ is the mean height of irregularity. The above equation is valid for a probing frequency around $4 \text{ MHz}$. Since $\Delta P \propto f^{-2}$ (ref. 23) and the probing frequency used by us is $3 \text{ MHz}$ Eq. (1) can be modified as

$$A_i = (3.4 \Delta P/\mu_0) \% \quad (2)$$

It is interesting to note that the above simple relationship is more versatile than what it looks to be. It gives the advantage of using phase path changes to determine the magnitude of electron density perturbation.

3. Interaction of Internal Gravity Waves with the Ionosphere

Gravity waves interact with the ionization either through collisional processes or by changing the local value of photoionization and loss rates. It has emerged from the works of Hooke that in F region during nighttime gravity waves cause TIDs only through collisional effects. Starting with the equation of continuity for electrons in the ionosphere and applying the linear perturbation technique, the following relationship can be derived for the fractional electron density perturbation caused by gravity waves in F region.

$$\frac{Ne'(t,z)}{Ne_0} = U_{se} \omega \exp \left( \frac{z - Z_0}{2H} \right) \left[ \frac{\sin I}{2H} \right]^2 k br^2 \times \left[ \cos \left( \omega t - k z - \frac{2H}{\sin I} \right) \right] \quad (3)$$
where

\[ Ne'(t,z) \] perturbation caused by the gravity wave in the electron density

\[ Ne_0 \] background electron density

\[ U_{bo} \] component of gravity wave wind field parallel to the geomagnetic field

\[ k_{br} \] component of real part of \( k \), the wave vector of gravity wave along the geomagnetic field

\( I \) angle of dip

\( H \) scale height of the atmosphere

and \( z \) and \( t \) represent the height and time at a fixed horizontal location respectively. It is assumed here that there are no horizontal and vertical gradients in the background electron density. No doubt this assumption simplifies the problem but may cause serious error when there exists a steep vertical gradient and also horizontal gradients particularly at the sunrise and sunset. In the present case, however, nighttime observation is reported with probing frequency much lower than \( f_0 \) F2. Therefore, the validity of the assumption regarding the vertical and horizontal gradients in electron density is justified.

4. Determination of Gravity Wave Wind Field from the Phase Path Records

A plot of \( dP/dt \) versus local time for the TID record of 16 Dec. 1968 (Fig. 3), is shown in Fig. 4. The horizontal axis in Fig. 4 is shifted upward to make the \( dP/dt \) curve symmetrical about this new dotted line. The value of \( dP/dt \) for this line can be used for the determination of vertical lifting of F layer. On the dotted line we have also plotted the value of \( Ne'(t,z)/Ne_0 \). \( U_{bo} \) computed with the help of Eq. (3) and using the velocity and time duration of the parent gravity wave from the phase path records. In this curve the portion above the dotted line indicates a perturbation which decreases the background electron density and the portion below the line a perturbation which increases the background electron density. The duration of the TID is taken as 14 min and the horizontal phase velocity \( (\omega/kx) \) has been found to be 101 m/sec. Angle of dip \( I \) is taken as 30° for Varanasi. It is further assumed that the height of reflecting layer and the reference height \( z_0 \) are almost equal. This assumption is justified in light of the flexibility of the choice of reference height. It is seen from Fig. 4 that the maximum electron density perturbation is \( 0.67 \times 10^4 \) \( U_{bo} \). In Fig. 4 however, a constant upward lifting is clear. But it does not make significant contribution to the terms in Eq. (3) containing \((z-z_0)\).

As described by Eq. (2) of Sec. 2 we can determine the value of \( Ne'/Ne_0 \) from the phase path records. Taking \( z_0 = 35 \) km (ref. 22), \( Ne'/Ne_0 \) for the phase path record of 16 Dec. 1968 is found to be \( 4.42 \times 10^4 \) \( U_{bo} \). Further, we obtain \( U_{bo} \sim 7 \) m sec\(^{-1}\) which is also comparable to the results of other workers for F region. Yet, at times this value may be very much in error if \( z_0 \) is not known precisely.

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References