matters arising

Interpretation of short-period oscillations in ionospheric group heights

DEVLIN *et al.*[1] observed oscillations in the group height of reflections from a sporadic-E layer, with peak-to-peak amplitudes of about 200 m and periods around 10 s. As the sounding frequency increased, the oscillations were phase shifted in time and their period changed slightly. They ascribed these events to real oscillations in the reflecting surface possibly due to sound waves or an instability. Here we show that an interference mechanism is more likely.

The results indicate a reversal in phase as the sounding frequency changes by about 0.2 MHz. As the plasma frequency increases by about 1 MHz in 100 m the vertical wavelength of any wave motion is about 40 m, and the corresponding vertical trace velocity is 4 m s^{-1}. Devlin *et al.* assert that there is only one reflection point. This implies that the radius of curvature of the reflector is greater than the reflection height. Equating the wave amplitude to the group-height oscillations makes the horizontal wavelength more than 20 km, and the horizontal trace velocity more than 2 km s^{-1}. Clearly, a wave interpretation requires an almost vertical wave normal and a phase velocity of about 4 m s^{-1}; this eliminates sound waves as a possibility. We suggest that instabilities with these characteristics are also extremely unlikely because these must travel either with the electron drift due to electric fields and thus at right angles to the field, or with the ion drift which is nearly horizontal. Both drift velocities would be expected to be some tens of m s^{-1}.

To show that the oscillations are due to interference effects, consider two echoes from group heights h' and $h'+\Delta h'$ where $\Delta h'$ changes with time but is so small that the radar pulses overlap. The two echoes at any frequency f interfere to give a resultant signal whose phase ϕ may be calculated. If the usual formula $h'=(c/4\pi)(\partial\phi/\partial f)$ is applied to the resultant signal, the apparent group height is given by

$$h'_{\text{App}} = h' + \frac{\Delta h'(1+R\cos\theta)}{1+R^2+2R\cos\theta} \qquad (1)$$

where R is the ratio of the two echo amplitudes, and $\theta = 4\pi\,\Delta h' f/c$ is their phase difference. Devlin *et al.* calculated $\partial\phi/\partial f$ using two frequencies 200 kHz apart, so we have done the same in Fig. 1. This plots h'_{App} against time for various frequencies, taking $R=2.5$ and $\Delta h' = 0.007t$ km. Many features of the results of Devlin *et al.* are reproduced. The phase shifts result from a slight decrease in the period of oscillations as the sounding frequency increases which, in turn, is due to a more rapid interference cycle at the smaller wavelengths. The plot has the appearance of beating waves but this is due to the method of analysis. Strict use of equation (1) gives continuous oscillations of considerably larger amplitude. If a third echo is included, it is possible to model the results even more closely. The phase deviations extend no more than ±24°, so that the apparent phase height variations are very small. Devlin *et al.* believe that there is only one point of reflection but we suggest that two echoes with a difference in group heights less than 800 m could not be resolved in the synthesised pulses they present which have lengths considerably greater than the 293 m quantisation level mentioned.

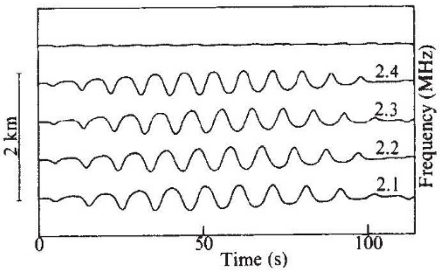

Fig. 1 Model variations of apparent group height at several frequencies and phase height (top trace) at 2.4 MHz for conditions described in the text.

Figure 2 shows a result from the University of Queensland phase ionosonde which has four receiving aerials situated approximately at the four corners of square of side 140 m. The time variations of group height recorded from each aerial at a frequency of 3.75 MHz are shown with the variations of phase height recorded from one of the aerials. The four group-height variations are similar and there are time shifts up to 2 s between the recordings. This is typical of an interference-induced effect, whereas the time shifts would be a small fraction of a second if the horizontal velocity of the wave motion were 2 km s^{-1}. The variations of phase height are very small and have values of the same order as those predicted by the interference model.

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DEVLIN *et al.* REPLY—Short period, small amplitude oscillations observed in group height were claimed in our paper[1] to be associated with a sporadic-E layer being observed. It was also suggested that the actual phenomenon responsible may be sound waves or waves associated with plasma instabilities. Munro and Whitehead[2] agree that the observations were produced by a real ionospheric effect, but they suggest that the oscillations in group height are not a direct result of oscillations in the ionosphere, and are due to interfering echoes (from an undefined irregularity structure in the ionosphere).

Munro and Whitehead first reject our explanation on the basis of characteristics of possible waves indicated by the data. However, the results depend very much on the assumptions made. For example, the results indicate that the phase reverses within a frequency change of 0.2 MHz, but this is a very approximate value and it could be closer to 0.1 MHz. Similarly it is equally valid to assume that the plasma frequency changes by 1 MHz in 50 m rather than 100 m. The ionosonde steps 0.1 MHz in 0.02 s, so that with the above assumptions, waves with apparent vertical velocities close to multiples of 200 m s^{-1} will have very slow apparent vertical velocities. For the assumptions made by Munro and Whitehead the same effect occurs for vertical velocities near 500 m s^{-1}. Other reasonable assumptions give intermediate values so that almost any reasonable vertical trace velocity could give a small apparent velocity.

In deducing an apparent horizontal wavelength, Munro and Whitehead ignore any retardation effects. However, these may be important in the E-region when such small changes are being