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Reply to H. F. Bates', Comments

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In the following we reply to Bates' comments in the order of their presentation.

1. Our calculations show that on 28 June 1963 the average solar zenith angle (χ) over the NPG-College path varies from 90° to 94° during the measurement period (0600 to 0800 UT), and for the NBA-College path varies from 90° to 94° during the measurement is from 94° to 96°. On the basis of these calculations we have called the path totally dark when the average zenith angle is greater than 90°. However, we agree with Bates that portions of the two College paths were weakly illuminated, but the paths can be considered to be more nearly representative of nighttime conditions than of daytime conditions. Nevertheless, the inclusion of the College data in the computations of the nighttime phase velocities might seem questionable. Let us assume for the moment that the College, Alaska, data are marginal. Eliminating these data from the analysis does not change the result, i.e., the calculated average value of the phase velocity remains the same.

2. Whether or not the nighttime second mode propagation effects can be ignored depends on the relative attenuation (α) of the second-order mode compared to the first-order mode, and the magnitude of the excitation factor (Λ) for the second-order mode compared to the first-order mode. For frequencies greater than 20 kc/s both theory [Wait and Spies, 1964] and experiment [Watt and Croghan, 1964] indicate that there may very well be an appreciable second-order mode effect. However, for frequencies less than 20 kc/s both theory [Wait and Spies, 1964] and experiment [Wait, 1961; Watt and Croghan, 1964] indicate that the effect of the second-order mode is small if not negligible at distances greater than 3000 km. In point of fact, our measurements were made at 18 kc/s, and all but two of the eight propagation paths had distances greater than 4000 km. The results obtained using the two shorter paths do not appear to be inconsistent with those obtained from the rest of the data. In regard to Bates' interpretation of Crombie's [1964] explanation of the sunrise fading effects, this theory does not necessarily require a "strong nighttime second mode propagating to distances well over 7500 km," but the observed results could possibly be due to additive effects of mode conversion in a distributed sunrise region [Crombie, 1965 private communications]. In addition, it should be remembered that Crombie's published results refer to paths where propagation was to the east, whereas the paths in the paper under discussion were mainly for propagation to the west, in which case attenuation of the second-order mode is considerably increased relative to that of the first-order mode.

3. The M_i are the integral number of wavelengths in the respective propagation paths. In the equation (3), used to calculate the relative phase velocity, they are additively summed: $[(M_1-M_2)-(M_3-M_4)]$. We did not attempt to evaluate an absolute M_i for each path, because (a) the M_i are not initially known or measured but are obtained as a first approximation by calculation assuming the velocity of light as the phase velocity, and (b) there is a cycle ambiguity, inherent in each measuring equipment (see fig. 2), which could amount to a wavelength. It was therefore necessary to vary the estimated M_i, and thus the sum, by integral numbers of wavelengths. However, we agree with Bates that the M_i are important parameters in VLF propagation and, if one assumes our values of phase velocity at 18 kc/s, they can be calculated for each path by evaluating the expression [Wait, 1961] that relates the phase velocity to the total phase path between the transmitter and receiver in the earth-ionosphere waveguide.

References

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