## Reply

D. Atlas and J. I. Metcalf
*Dept. of the Geophysical Sciences, The University of Chicago*
and J. H. Richter and E. E. Gossard
*Naval Electronics Laboratory Center, San Diego, Calif.*
8 March 1971

We are pleased to receive the comments of Dr. Hay which provide supplementary information pertinent to our paper and the others dealing with high-resolution observations of waves and turbulence with the Naval Electronics Laboratory Center FM-CW radar. The studies by Dr. Hay and his colleagues which he summarizes are indeed relevant and we regret not having cited them.

The main points of Hay's comments appear to be that transient internal gravity-shear waves may appear at the upper extremities of convective plumes in free convection; the shorter of these waves may become unstable (especially at the wave crests) and break down to produce turbulence, and this is an alternative mechanism for the origin of low level CAT. He also suggests that the weak, isolated (in time), quasi-periodic echoes observed on his own FM-CW radar are due to reflections from laminar reflectors of at least a few meters in horizontal extent at the shear-density (and refractivity) interfaces where the wave amplitudes are maximized (Naito, 1966). Although Hay (1967b) previously clearly attributed his echoes to specular reflections from laminar interfaces no greater than a few centimeters in depth, and their periodicity to the internal waves, his last paragraph suggests that he now believes them to be associated with "transient volumes of local turbulence cast off occasionally by the transient internal waves."

Dr. Hay seems to imply that convective activity is a major source of both internal gravity waves and Kelvin-Helmholtz (K-H) waves, and thus of the wave-like echo layers which we have reported. While convective motions may occasionally provide a trigger to initiate wave motion at a stable layer, the following points are cited to indicate that this is not often and certainly not necessarily the case:

1) Both stable internal gravity waves and breaking K-H waves occur (in our echo patterns) at least equally often at night as during the day; indeed, they are most common in hydrostatically stable layers.

2) The occurrence of reflective scatter zones at preferred heights, such as the base of a strong inversion, most commonly precedes any convective activity. When convective plumes reach the pre-existent echo layers they perturb the layers and the associated inversion, but there is no evidence to date of significant changes in reflectivity.

3) While the convectively produced perturbations of the inversion are sometimes periodic in nature and thus suggestive of wave motion, detailed study of the three-dimensional echo structure shows them to be closed convective cells and not waves (Konrad, 1970).

With respect to Hay's suggestion that his echoes are due to backscatter from laminar reflections (or as he now implies, from thin layers comprised of turbulent eddies), this is most difficult to accept because of the typical 1-sec duration of his echoes. Our observations show virtually continuous backscatter with time from thin undulatory layers. (The height undulations would hardly be detectable by Hay's radar because they are rarely in excess of 100 m peak-to-peak, while his vertical resolution is 150 m.) Although the layer reflectivity often varies periodically with a maximum somewhat ahead of the leading edge of the wave crest, the total variation of the reflectivity fluctuation along the wave is rarely as much as 10 db. Thus, it would be odd indeed if his radar were just sufficiently sensitive to detect only the peak reflectivities for a duration of about 1 sec out of total wave periods of 2–10 min. The possibility of brief specular reflections from the crests or troughs of the waves is also precluded because the maximum reflectivity occurs on the sloping wall of the wave whose orientation is not perpendicular to the radar beam.

Dr. Hay argues that his brief echoes are not attributable to insects because 1) the cross sections appear too small, and 2) the range dependence (assuming target cross section independent of height) does not fall off as sharply as $r^{-4}$ ($r$ = range). However, we have shown elsewhere (Atlas *et al.*, 1970) that point-target cross sections are underestimated by a factor of 3.3 on the average if one considers targets with equal probability out to the −20 db points of the beam. For targets further off the beam axis, the cross sections would be even more greatly underestimated. Moreover, it is entirely possible that the insects of southern Ontario are smaller than those observed in Virginia (Hardy and Katz, 1969) or at San Diego. With respect to the range dependence, we question the assumption of cross sections independent of height. We have observed that the larger cross-section insects are frequently the higher flyers (Atlas *et al.*, 1970). Thus, if we assume an average target cross section, $\sigma \propto r^n$, we could account for Hay's echo power dependence on range with $n$ between 1 and 2. In short, Hay's echoes are certainly not inconsistent with the insect hypothesis. Indeed, we believe insects to be their most probable origin.

It should also be noted that the minimum detectable volume reflectivity for Hay's radar (his Table 1) assumes that the entire 150 m range resolution element is filled. In fact, it is uncommon that the scatter layers exceed 15 m in depth, so that his minimum detectable reflectivity should be increased by about a factor of 10, and more for thinner layers. Moreover, since there is no way by which he can deduce the thickness of strata thinner than 150 m, his estimates of volume reflectivities will always be smaller than the actual values, perhaps by as much as 150 for a 1 m thick layer. Accordingly, the reflectivities quoted are probably $10-10^2$ too low. In his Table 1, Hay also compares the minimum detectable volume reflectivity of his radar with 150 m resolution to that of ours with 1 m resolution. Had we employed 150 m resolution (a capability which we have) for scatter regions equal to or greater than such a depth, then our minimum detectable volume reflectivity at 1 km would be $2.7\times10^{-17}$ cm$^{-1}$. Thus, his statement that the two radars compare in sensitivity is incorrect. Moreover, it is not clear how the $-157$ dbm minimum detectable signal quoted for his radar in Table 1 relates to the $-150$ dbm value stated in prior papers (Hay, 1962; Bell *et al.*, 1964).

Finally, none of the data in the earlier references listed by Dr. Hay gives any indication that he utilized the resolution capability of his radar, i.e., that he simultaneously observed returns from different heights. In fact, he did not mention a value for height resolution in earlier papers. Only in his present note does he show a listing of data from different height ranges. It is not clear whether these data points were accumulated simultaneously or successively. Also, no indication is given of the year in which the data were obtained. Hay is correct in his statement that the resolution capability of the radar depends only on the bandwidth of the transmitted signal. He criticizes an unfortunate formulation in III which also refers to the receiver bandwidth in connection with resolution. What we meant to say in this statement was that in order to *realize* the resolution capability one has to have a sufficiently narrow receiver bandwidth.

## REFERENCES[1]

Atlas, D., F. I. Harris and J. H. Richter, 1970: Measurement of point target speeds with incoherent non-tracking radar: Insect speeds in atmospheric waves. *J. Geophys. Res.*, **75**, 7588–7595.

Konrad, T. G., 1970: The dynamics of the convective process in clear air as seen by radar. *J. Atmos. Sci.*, **27**, 1138–1147.

[1] Not including those given by Hay.