4.4D EVIDENCE FOR PARALLEL ELONGATED STRUCTURES IN THE MESOSPHERE

G. W. Adams*, J. W. Brosnahan** and D. C. Walden***

*Center for Atmospheric and Space Sciences, Utah State University,
Logan, UT 84322
**Tycho Technology, Inc., P. O. Box 1716, Boulder, CO 80306
***Space Environment Laboratory, NOAA/ERL, Boulder, CO 80302

ABSTRACT

The physical cause of "partial reflection" from the mesosphere has been sought for some time. We present data from an image-forming radar at Brighton, Colorado, that suggest that some of the radar scattering is caused by parallel elongated structures lying almost directly overhead. Possible physical sources for such structures include gravity waves and roll vortices.

INTRODUCTION

Radar soundings of the mesosphere have indicated anisotropic scattering since the initial work of GARDNER and PAWSEY (1953) and GREGORY (1961). Signals scattered from this region are often characterized by well-defined amplitude fading, or pulsation, patterns, with quasi-periods of one to some tens of seconds, and by scattering that is stable in altitude for minutes to days. A number of models have been proposed to explain the "partial reflection" results: (GARDNER and PAWSEY, 1953; HINES, 1960; GREGORY, 1961; BELROSE and BURKE, 1964; PIGGOTT and THRANE, 1966; FLOOD; 1968; AUSTIN et al., 1969; AUSTIN and MANSON, 1969; GREGORY and MANSON, 1969; MANSON et al., 1969; VON BIEL, 1971; BEER, 1972; COHEN and FERRARO, 1973; MANSON et al., 1973; MATHEWS et al., 1973; NEWMAN and FERRARO, 1973; TANENBAUM et al., 1973; HARPER and WOODMAN, 1977; SCHLEGEL et al., 1978; HOCKING, 1979; JONES and GRUBB, 1980; SCHLEGEL et al., 1980; and JONES et al., 1982).

We report here on mesospheric measurements made with an imaging radar at Brighton, Colorado, that indicate occasional large differences in returns on two orthogonal linear polarizations. Echo location indicates that these returns come from within 2.5 degrees of zenith. We present first a description of the experiment and of the resulting data. Our interpretation of the data in terms of parallel elongated structures is then given, followed by speculation about the possible physical cause of the inferred structures.

EXPERIMENTAL CONFIGURATION

The data reported here were obtained with the NOAA/NSF HF Radar (GRUBB, 1979) and the Middle-Atmosphere Image-Forming Radar (MAIFR) which are located near Brighton, Colorado. The HF radar is a flexible dual-Doppler radar, used in the work described here to drive the large 2.66-MHz MAIFR antenna array, and to sample the ten antennas that comprise the array sequentially in pairs. Each of the ten antennas consists of a coaxial-collinear (BALSLEY and ECKLUND, 1972) string of eight half-wave dipoles as shown in Figure 1, fed at the center. The pattern of a single antenna is fan-shaped, being 16 degrees wide in the direction parallel to the antenna, and 100 degrees wide in the transverse direction (Figure 2). Five of the antennas are parallel to each other and to the north-south axis; the other five are parallel and east-west. Dipole-to-dipole spacing along an antenna is 0.33λ; antennas are spaced 0.707λ apart. Pulses of length 4.5 km (30 μsec) were transmitted at 50 pulses/sec, with 50 kW peak-pulse-power at the antenna terminals. For transmission, we used either the center antenna of each linear array, giving a crossed-fan-shaped beam, or all ten antennas, giving an approximately circular beam about 16 degrees wide. In both configurations, the two polarizations were fed together and in phase. For reception, a

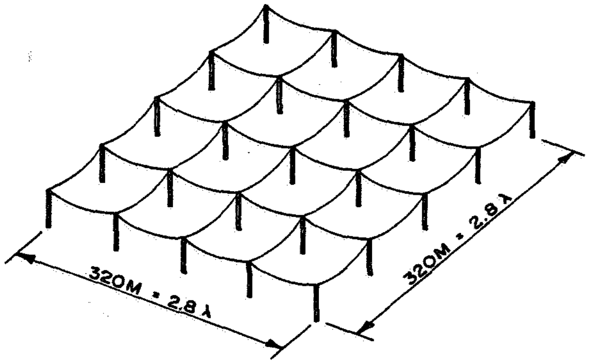

Figure 1. Middle-atmosphere image-forming radar antenna. Location: Boot Lake (Brighton) Colorado, Area: 25.6 acres = 10^5 m^2, height: 0.15 λ, frequency: 2.66 MHz, λ: 112 m.

four-pulse average was used on each antenna, so that one complete data set was obtained every 0.4 seconds.

DATA

Figure 3 shows log amplitude vs. altitude plot for one of the east-west antennas (top), one of the north-south antennas (center), and a composite of the two plots (bottom). The feature of interest here is the well-defined layer around 70 km, which is much more noticeable on the east-west antenna than on the north-south. (This figure was taken with a camera directly from the HF radar's on-line graphics display, and relabeled. This display shows the six most recent soundings for a single antenna, which corresponds to a time spread of 2.4 seconds in this experiment.)

Figure 4 is a time history of the linear voltage amplitude at 70 km for the same pair or antennas as in Figure 3. Notice that the north-south antenna shows a smaller but quite distinct signal which is often correlated, but sometimes anticorrelated, with the voltage on the east-west antenna. Notice also the characteristic fading pattern and deep nulls.

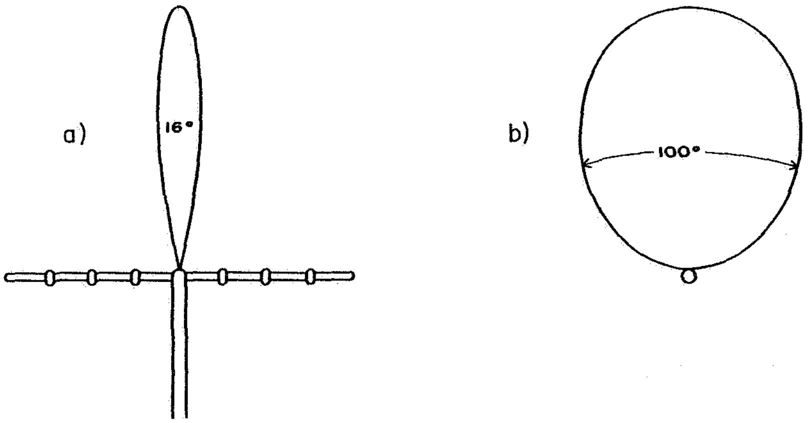

Figure 2. Single antenna (a) longitudinal view, (b) transverse view.

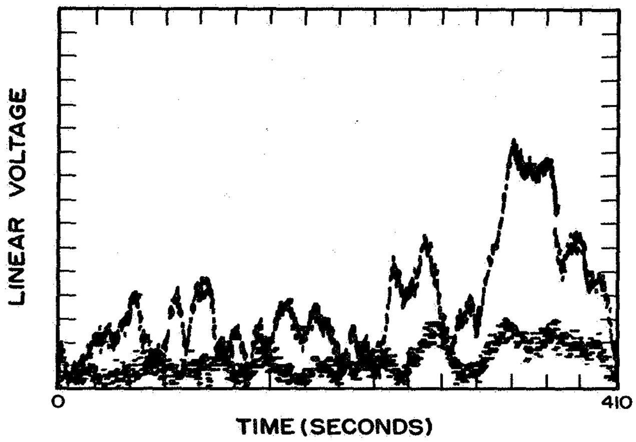

Figure 4.

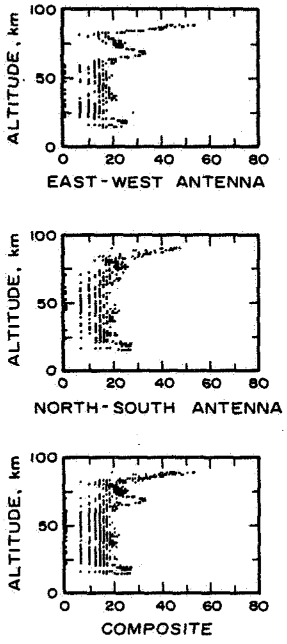

Figure 3.

Figure 5 shows the corresponding phase histories of four of the east-west antennas. Unfortunately, the northernmost antenna was not operative at this time, so we show data from the #1 (southernmost) through #4 (next-to-northernmost) antennas. While there are some differences in detail among the four plots, the largest significant differences across the array are less than 30 degrees. The antenna spacing is 0.707λ, so a maximum 30-degree phase difference between #1 and #4 corresponds to a location within 2.5 degrees of zenith in the north-south meridian. The north-south antennas have phase histories (not shown) that also indicate a location within 2.5 degrees of zenith in the east-west meridian. The main transmit beam is 16 degrees wide, so the indicated centroid

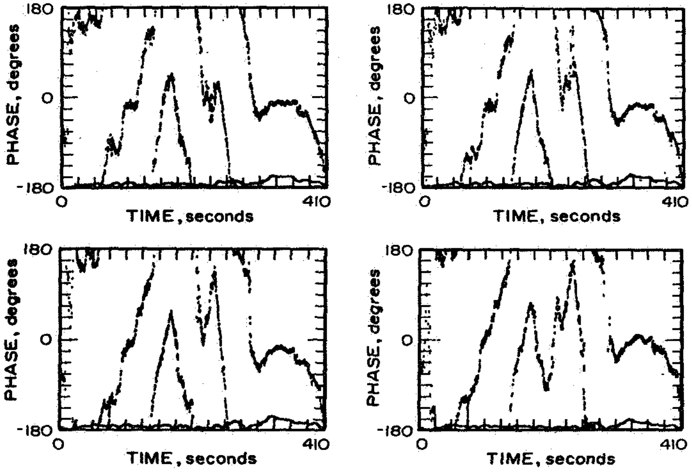

Figure 5.

of the scatterer is well within the main beam. Notice that there is less than 90 degrees net phase difference across the almost 7-minute phase history of the first three antennas. However, there is a 180-degree phase discontinuity, indicative of interference among multiple targets, at t = 200 seconds. The fourth antenna recovers from this discontinuity oppositely from the other three, indicating that the "perfect" discontinuity lay between the third and fourth antennas.

These measurements were made using a narrow transmit beam (all ten antennas). Measurements at other times using a much wider beam gave results not noticeably different from these.

DISCUSSION

The first suspicion, of course, is that the observed differences between the two polarizations were caused by sidelobe activity. The echo-location results in Figure 5, however, show that the radar returns come from very nearly overhead.

Since the individual antenna beams are fan-shaped, it would be possible for a large elongated structure (20 x 170 km, say) to fill one antenna beam while only intersecting the orthogonal beam. Indeed, we have recently found a high correlation between the occurrence of infrared structures of similar dimensions and increased radar scattering, particularly around 85 km (PETERSON and ADAMS, 1983; ADAMS et al., 1983). However, such large structures seem unlikely to explain the results presented here for two reasons. First, the first Fresnel zone is 4 km in diameter at 70 km, so a continuous scatterer much larger than this would not return much more power. Second, our measurements made at other times with alternating wide and narrow transmit beams also indicate that there is no substantial off-vertical scattering. (There is no requirement that the observed radar scattering correspond in scale to the observed infrared structures, of course. The radar scattering may be specular, caused by the overhead gradient maxima of some very large structure.)

The voltages shown in Figure 4 indicate power ratios of as high as 20 to 1. If we suppose that the scattering results from the presence of a simple elongated structure, and that the structure lies within the first Fresnel zone, then maximum dimensions of 4 km x 200 meters are indicated. Notice, however, that if the transverse dimension is less than the radar's half-wavelength of 56 meters, then the transverse cross section will be much smaller than dimensional scaling would indicate. A single elongated structure, however, would not explain the fading pattern and deep nulls seen in Figure 4. Multiple structures might. Such deep fading is frequently accompanied by 180-degree phase discontinuities such as the one at t = 200 seconds discussed above. Deep fading and phase discontinuities are symptomatic of multitarget interference patterns. KELLEHER (1966) reported frequent quasi-periodicities in the spatial structure of the ground diffraction pattern of radar pulses. MARKER (1981) has directly observed groups of parallel rolls in the troposphere. Optical observations (PETERSON and ADAMS, 1983, and references therein) typically show several parallel bands. Such a model seems to have potential for explaining our observations.

SUMMARY AND CONCLUSIONS

We have shown data indicating that returns on two orthogonal polarizations can differ by a factor of 20, while simultaneous echo-location measurements locate the scatterer to within 2.5 degrees of zenith. Deep fading and 180-degree pnase discontinuities are seen. These data can be explained by parallel elongated structures.

Either gravity waves or roll vortices are possible sources for parallel elongated structures. The polarization-dependent returns, when they are present, tend to be stationary in altitude for many minutes, so we would suggest that either horizontal waves or long columnar rolls, probably generated by passing gravity waves or local wind shears, are the most likely cause. Since such waves or rolls would manifest themselves in the manner presented here only when they were in alignment with one of the polarizations (we see both east-west and north-south domination at different times), our casual observation that such phenomena are present about 10% of the time would indicate that such scatterers are actually present most of the time.

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