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REMOTE PROBES FOR THE STUDY OF ATMOSPHERIC SOURCES OF FADING ON OPTICAL AND MICROWAVE LINE-OF-SIGHT PATHS

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Fading on microwave or optical line-of-sight paths may be due to either ground-reflection multipath, atmospheric multipath, or defocusing. The identification of the particular mechanism involved has been hampered by the lack of rapid fine-scale meteorological measurements in the immediate vicinity of the propagation path.

As early as 1968, acoustic radars had been developed[1] which could detect fluctuations of temperature (effectively fluctuations in the optical refractivities) in the lower atmosphere. The characteristics of these radars are amply described in the literature[2,3].

Recently a new tool, the FM-CW Radar[4,5] was developed which has the capability of detecting small fluctuations of the radio refractivity in the atmosphere. This is particularly appropriate for the microwave region where both temperature and water vapor fluctuations can play significant roles. Herein is described a study made in eastern Colorado where the propagation medium was monitored by each of these radars particularly at times when fading occurred over a line-of-sight path.

This experiment was conducted at Haswell, Colorado where a large bowl-like depression produces a variety of extreme refractivity structures by nocturnal radiative cooling with the attendant pooling of cool air. After sunrise, solar heating results in vertical motion. A 23 km microwave-optical path was established across the bowl to provide near grazing intersection with the atmospheric layers to maximize the effects of forward scattering during turbulent conditions and "specular" reflection during inversion conditions. The microwave antennas were tilted upward so that ground reflections would be minimized under well-mixed conditions. Standard surface meteorological measurements were made at each terminal. At midpath measurements were made at fixed points and on an instrumented carriage of a 150-meter meteorological tower.

At midpoint and near the meteorological tower (250 meters away in the direction of the prevailing wind) the radar was located to monitor the propagation medium. In the fall of 1969 the acoustic radar (950 Hz) was used, in the fall of 1970 the FM-CW Radar (3 GHz) was used.

In 1969, the phase of the microwave signal (9.5 GHz) and the modulation of the optical signal (3.2 GHz), the amplitudes and the angle of arrival of the optical signal were recorded. In 1970, the modulation on the optical signal was replaced by the relative phase between microwave signals recorded from two vertically spaced (4.25m) antennas. At the tower the radio refractivity and its structure function, and the three-dimensional wind were recorded at several fixed elevations as well as on the movable carriage. The FM-CW Radar provided a continuous measurement of the fluctuations of radio refractivity as a function of height. The acoustic radar provided a similar measurement of the temperature fluctuations. This permitted measurement of the atmospheric structure for vertical motion too rapid to be observed by the carriage on the meteorological tower.

Calibration of the FM-CW Radar returns in terms of meteorological parameters was conducted at a time when the atmospheric structure appeared to be stationary and when the line-of-sight signals were steady.

Comparison between the FM-CW Radar returns and the refractivity structure on the tower was surprisingly good. Agreement was obtained to within a factor of two between the reflectivities calculated from the radar and those calculated from the tower even though both varied from 10^{-13} to 10^{-15}. The radar sees fluctuations particularly at scales of approximately one-half the transmitted wavelength. These fluctuations occur in the region where there are sharp breaks in the vertical profile, and hence the radars can detect layers.

In most cases the layer was first detected by the FM-CW Radar which then permitted the operator at the tower to place the carriage in the appropriate location.

Both radars illustrated the difficulty of applying point measurements or tower measurements to line-of-sight paths. The atmospheric structure changes rapidly with time; layers form and move with surprisingly large vertical velocities. Very thin but very intense layers were noted by the radars and confirmed by the carriage on the tower; such layers could easily be missed by conventional tower measurements. Such layers have a strong influence on signal characteristics on a line-of sight path. Fades as deep as 30 db were noted at times when these layers were moving and crossed the zero angle of incidence region.

At times, particularly at sunup, considerable fluctuations of the amplitude and phase were observed over the microwave-optical path. On one occasion three distinct images of the laser beam were noted at the receiving terminal; concurrent observation at mid-path indicated that the optical path was incident upon the temperature inversion at a shallow angle.

On the occasions when rapid microwave amplitude and phase fluctuations occurred, both the radar and the tower indicated the presence of a layer intersecting the line-of-sight path at a shallow angle. When the layer rose well above the microwave optical path, the fluctuations on the line-of-sight path ceased.

From measurements made at midpath and from the surface meteorological measurements at the path terminals, various atmospheric models were constructed.

Ray tracing techniques were then applied to these model structures to obtain estimates of the received signal behavior for comparison with the observed fields.

This comparison indicated that the atmospheric layers were often tilted along the line-of-sight path. Although this was consistent with the radar observations, the radar does not definitively distinguish, at this time, between wave motion on the layers and a vertical motion of horizontal stratification.

The radio and optical refractivity structures introduced multiple-imaging or atmospheric multipath with appreciable variation of the take-off angles and angles-of-arrival and, in the case of the microwave path, a shifting of the centers of reflection on the terrain. These marked changes in the angles-of-arrival interfered with beam-tracking on the optical path and caused signal variation on the microwave path attributable to the effect of the antenna patterns.

These effects were most pronounced when the refractivity layers observed at midpath were positioned between the elevations of the line-of-sight path terminals; the effects disappeared when the layers dropped below the elevation of the lower terminal or rose above that of the higher terminal.

References

1. McAllister, L. G., J. R. Pollard, A. R. Mahoney, and P. J. R. Shaw. Proc. IEEE 57, 4, Apr. 1969.
2. McAllister, L. G. J. Atmos. Terr. Phys. 30, 1968.
3. Little, C. G. Proc. IEEE 57, 4, Apr. 1969.
4. Richter, J. H. Radio Sci. 12, 1969.
5. Bean, B. R., R. E. McGavin, R. B. Chadwick, and B. D. Warner. Boundary Layer Met., 4, Apr. 1971.