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EHF ATTENUATION THROUGH THE MELTING LAYER

Arnold A. Barnes, Jr.

Atmospheric Sciences Division
Air Force Geophysics Laboratory
Hanscom AFB, MA 01731-5000, U.S.A

ABSTRACT*

From 15 March 1986 to 22 May 1986 the Air Force Geophysics Laboratory (AFGL) conducted an experiment in the greater Boston area to measure attenuation in the K_a-band due to precipitaton in storms. Emphasis was placed on attenuation in the melting layer (where mixed phase snow and rain coexist) since some previous work indicated that for a unit path-length at these frequencies, attenuation in the melting layer could be as much as ten times the attenuation in rain for the same precipitation rate. Total attenuation through the storms was measured by Lincoln Laboratory at Hanscom AFB using the 38.04 GHz beacon on satellite LES-8 which was located over the Pacific Ocean. Meteorological conditions were monitored by weather radars at AFGL/LYR (Sudbury) and at MIT (Boston), by cloud physics equipment on the PMS Beech Baron aircraft, by sounding balloons, and by ground based equipment at Sudbury and Hanscom AFB. Results of the analyses will be presented. This work has applications to the effects of clouds and precipitation on satellite communication systems operating in the EHF range.

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EHF ATTENUATION THROUGH THE MELTING LAYER

Arnold A. Barnes, Jr.

Air Force Geophysics Laboratory: AFGL/LYA
Hanscom AFB, MA 01731-5000 U.S.A.

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1 INTRODUCTION

Recently there has been a move to higher frequencies as the lower EHF communication bands have become more crowded. Above 20 GHz the signals are attenuated by intervening precipitation. For those satellite communication systems which operate at low signal-to-noise ratios, the attenuation due to precipitation can cause systems outages which for some operations cannot easily be circumvented by alternate routes or equipment.

A 35 GHz signal from a satellite experiences very little attenuation while passing through the ice and snow regions in the upper parts of the storm. However, as soon as it encounters wet snow in the melting layer, the attenuation increases markedly because of the change in the index of refraction of the precipitation particles. As the snow particles melt they collapse into raindrops which fall faster than the snow. Below the melting layer the spherical rain drops attenuate the signals. Rain attenuation has and is being studied by other groups, and relationships have been established between attenuation, rain rates and drop size distributions. Studies have reported that attenuation in the melting layer is two to ten times that in rain (Nishitsugi, et al, 1971; Oguchi, 1983). Since the large wet snow flakes in the melting layer are about the same size as the wavelengths (~ 8mm), this should not be unexpected. In designing our Weather Attenuation Program emphasis was given to studies in the melting layer, and we drew heavily on our previous cloud microphysical studies of the melting layer, (Schaller, et al, 1982; Fukuta, et al, 1983; Cohen and Sweeney, 1983) and our studies of large scale storm systems (Barnes, et al, 1982).

2 PROGRAM OVERVIEW

Signal strengths from the 38 GHz transmitter aboard satellite LES-8 were recorded and they clearly demonstrated the attenuation due to the precipitation between the satellite and the ground receiving site at Lincoln Laboratory which is located on Hanscom AFB. Airborne meteorological data were collected by the instrumented aircraft. End products included ice/water content, particle size distributions, temperature, humidity and aircraft position. A new instrument designed to measure the mass of ice and/or water was also tested for collection of precipitation mass information within the melting layer where both snow and rain coexist (Plank, 1987). The program was conducted in the greater Boston area from 15 March through 22 May 1986 and ten cases were obtained even though rainfall during this period was much below normal. Figure 1. depicts the program.

3 LES-8 ATTENUATION

Satellite LES-8 was in a quasi-geostationary orbit which moved north and south during a siderial day. It was always above the horizon as seen from Lincoln Laboratory, and varied in elevation angle from 8 to 49 degrees above the horizon. Its 38.04 GHz transmitter fed into a steerable dish which operated in an autotrack mode to point its 1° beam at the Lincoln Laboratory dish receiving antenna. The received signals were recorded and compared with signals recorded during periods of clear weather. We observed attenuation in excess of 15 dB during periods of moderate to heavy showers and 6db in steady rain. Figure 2. is an example of observed precipitation attenuation.

It was discovered that there was a 1 to 2 dB loss of signal when the radome covering the receiving antenna was wet. This was measured by spraying the radome with water on a clear, dry day. There is also increased attenuation as the radome gets dirty. Cleaning of the radome every four years or so reduces the attenuation by approximately 1dB (H. Hoover, 1986, personal communication).

4 GROUND BASED EQUIPMENT

At the Sudbury site a Joss distrometer was used to measure drop size distributions, and the total rainfall was measured with a tipping bucket raingauge. At Hanscom AFB a second Joss distrometer was used during the latter half of the program. A fast response rain-rate meter, a fall velocity meter and standard meteorological equipment which provided temperature, dewpoint and wind velocity were used. The non-standard equipment was developed by the Cloud Physics Branch and has been patented by the Air Force (Gibbons, et al, 1983; Plank and Berthel, 1983). Loransondes (rawinsondes using LORAN to obtain winds) which were developed for AFGL under contract, provided detail soundings.

5 THE M-METER

Past work suggests that EHF attenuation is a function of the relative mass of ice, snow and rain in the volume through which the signals pass (Ebersole, et al, 1984). Airborne measurement of the precipitation mass has been difficult. The PMS instruments which measure

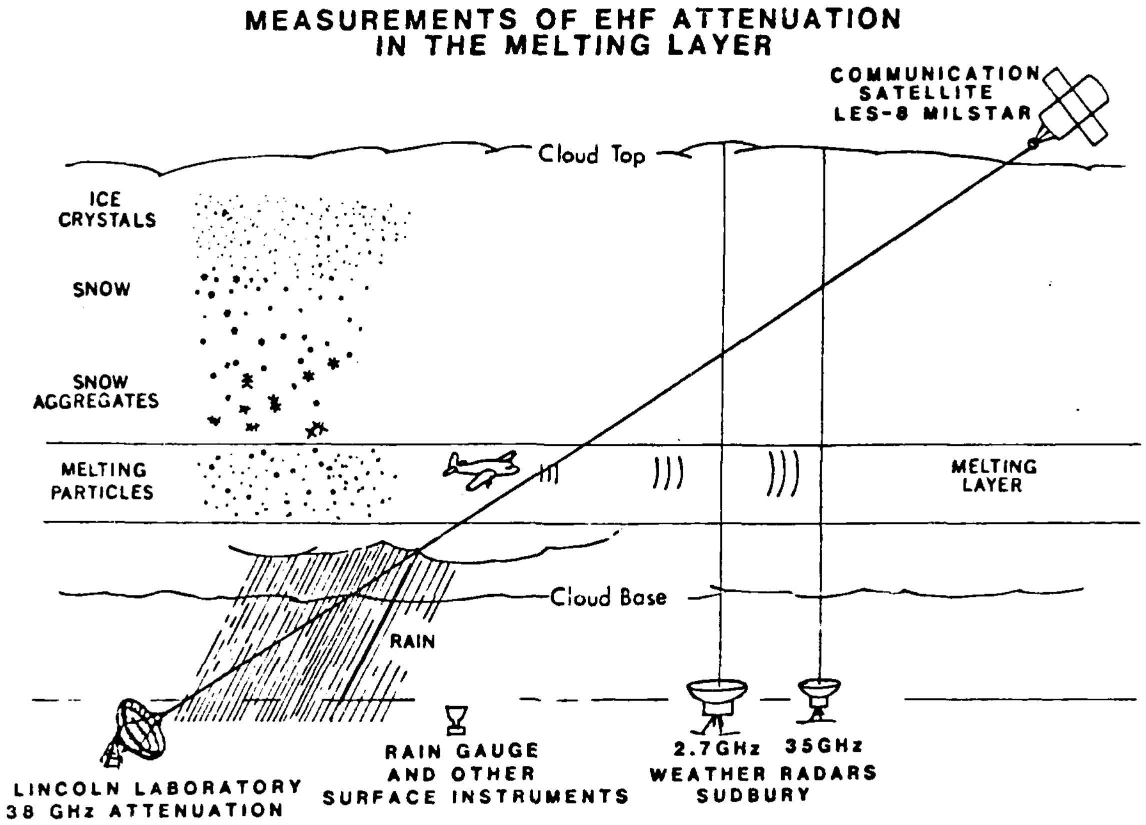

Figure 1. Depiction of the AFGL 1986 Weather Attenuation Program

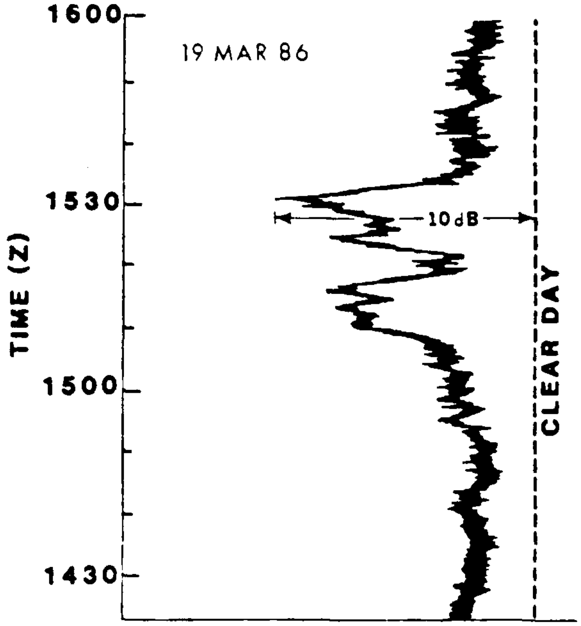

Figure 2. Attenuation of the LES-8 36 GHz signal due to precipitation

particle size and shape give very good measurements of mass when operating in rain where the particles are spherical and the density is essentially constant at 1.0 gm/cm^3. In ice and snow the particles are irregular, the densities vary widely, and so called "L-to-D" *relationships are used depending on* the crystal habit and size (Cunningham, 1978; Heymsfield, 1972; Heymsfield and Knollenberg, 1972; Knollenberg, 1975; Plank, 1977). As mentioned above, we are particularly interested in the melting layer, and it is in this layer where "L-to-D" relationships are practically useless.

The M-Meter (Plank, 1987) makes use of the mass of the precipitation directly to obtain measurements (see Figure 3.). The housing is attached to the aircraft and contains the detector which measures the rotation speed of the spinner, which is located at the base of the cone shaped deflector. The spinner has slanted fins which causes it to spin as it passes through the air. When precipitation particles get into the fins they slow the rate of rotation (reduce the angular momentum) because they are more dense than air. To keep the particles from bouncing off of the cone shaped deflector and not passing through the fins, there is an outside deflector supported from the housing by four outriggers.

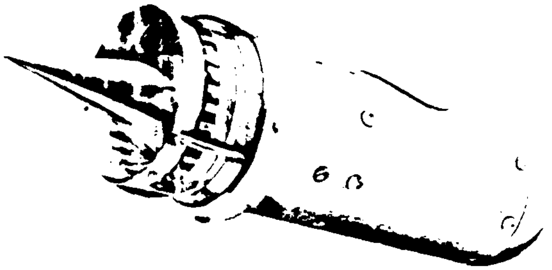

Figure 3. The M-Meter

This instrument was first flight tested on the Weather Attenuation Program and was found to be more sensitive than anticipated. In fact, the accuracy was limited on these test flights due to the inaccuracy of the calculated true air speed. We believe that accuracies of .01 gm/m^3 are achievable. The present design works well from 100 to 180 knots (50 to 93 m/s) and can be extended to 200 knots (103 m/s). In order to operate at higher true air speeds, the spinner must be redesigned.

6 RESULTS

Ten different precipitation events were investigated even though the amount of rainfall was much below normal for this 69 day period.

The 38 GHz signals from satellite LES-8 showed attenuations in excess of 15dB during some of the showers while light continuous precipitation gave attenuations of about 6dB. We were concerned about the attenuation due to the radome covering the receiving dish at Lincoln Laboratory being wetted by the rain, so we sprayed the radome on a clear, dry day and found a loss of one to two dB.

The other ground based and airborne equipment operated normally on almost all occasions, but one Joss distrometer did not operate properly prior to the first of May.

Tests with the M-meter went better than expected. Speed and altitude corrections were close to predicted, but the sensitivity was greater than expected and was found to be limited by the accuracy of the calculated true air speed.

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