Attenuation Statistics Derivation in the V&W Band Using Weather Cubes

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Abstract— **This paper presents an investigation into the use of Weather Cubes compiled by the atmospheric characterization package Laser Environmental Effects Definition and Reference (LEEDR) to develop accurate, long-term attenuation statistics for link-budget analysis. A Weather Cube is a three-dimensional mesh of numerical weather prediction (NWP) data plus LEEDR calculations that allows for the quantification of rain, cloud, aerosol, and molecular effects at any UV to RF wavelength on any path contained within the cube. The development of this methodology is motivated by the potential use of V (40-75 GHz) & W (75-110 GHz) band frequencies for the satellite communication application, as V & W band frequencies incur very significant lower atmospheric attenuation, thus accurate modelling based on relevant climatology is essential.**

Keywords—propagation; V band; W band

I. INTRODUCTION

The use of V (40-75 GHz) and W (75-115 GHz) band carrier frequencies is under consideration for high-bandwidth satellite communication. A deterrent from using the V & W band for this application in the past is the high attenuation from lower atmosphere impairments including absorption and scattering from rain, clouds, and dry molecular gases. In particular, there are significant molecular absorption lines, and substantial rain scattering. The development of reliable satellite communication links requires accurate, long-term attenuation statistics derived using relevant climatology. This paper presents a preliminary investigation into the use of Weather Cubes compiled by the atmospheric characterization package LEEDR (Laser Environmental Effects Definition and Reference) for the purpose of acquiring long-term attenuation statistics for satellite links. Using numerical weather prediction (NWP) data from the National Oceanic and Atmospheric Administration's Global Forecast System (GFS), a three-dimensional mesh of weather data is created from which an extinction coefficient can be calculated at each point within the mesh. This methodology could enable attenuation studies to be performed at any location in the world, for any time at which GFS data is available.

II. BACKGROUND

A Weather Cube consists of profiles of atmospheric and weather data for a desired mesh of geographic locations, extending from the surface to an altitude of 100 km above the surface. NWP data is incorporated into each profile up to an altitude of 30 km, while data above 30 km altitude is taken primarily from the 1976 Standard U.S. atmosphere. Fig. 1 gives an example of a Weather Cube considered in this study, where the green portion of each profile represents altitudes in which the numerical weather prediction data is incorporated. GFS data is reported four times a day at 0000, 0600, 1200, and 1800 Coordinated Universal Time (UTC) with an available spatial resolution of one-half degree latitude by one-half-degree longitude. The vertical resolution of each profile is 100 m.
Rain and clouds are placed at any point in the mesh through the use of a weather placement algorithm. Based on vertical velocities and 3-hr surface rainfall amounts, the algorithm assigns a weather event with a realistic rain rate and drop size distribution using relative humidity and the Lagrangian rate of change of pressure at each pressure level in the GFS model [1]. Fog, stratus, and cumulous clouds can be placed within the boundary layer (WBL) or above the boundary layer (ABL), where the boundary layer is defined as the lowest portion of the troposphere that is in contact with the Earth's surface [1]. Rain is placed within the cube if a cloud is determined to exist and a total precipitation value is reported during the six-hour weather forecast interval. Five different types of rain can be placed within the cube including very light rain (2 mm/hr), light rain (5 mm/hr), moderate rain (12.5 mm/Hr), heavy rain (25 mm/hr), and extreme rain (75 mm/hr) [1]. Fig. 2 gives an example of a Weather Cube located near Rome, NY compiled for a day in which rain is present.

Radiative-transfer calculations are performed using LEEDR to calculate a total extinction coefficient in units of inverse kilometers at each point in the mesh for four different physical attenuation mechanisms including rain extinction, cloud extinction, aerosol extinction, and molecular extinction. A validated and verified atmospheric radiative transfer code, LEEDR calculates an extinction coefficient inclusive of absorption and scattering effects for each physical mechanism [2,3]. A slant path through the Weather Cube is defined as the straight line from a platform located on the surface of the Earth to a target at an altitude of 100 km above the surface of the Earth. For a given path resolution a linear, three-dimensional interpolation is used to determine the extinction coefficient for each incremental length along the path. Integrating the extinction coefficient along the slant-path allows for the calculation of total attenuation incurred by molecular, aerosol, cloud, and rain effects.

III. METHODOLOGY

As an initial proof of concept, attenuation statistics are derived for a single slant path at an elevation of angle of 36° originating from Rome, NY (43.2°,75.4°W). The decision to use this particular configuration is motivated by the availability of ground based radiometric measurements of slant path attenuation data in the V&W band to compare against. The measured attenuation data at frequencies 82, 72, 34, and 23 GHz from Rome, NY was derived from an attenuation retrieval algorithm that was applied to ground based radiometric measurements made over the course of a single year (2011) with a 1 Hz sampling rate [4]. Using 1459 GFS weather "observation" events from 2011 (the GFS analysis or short-term forecast data are considered as observations in this study), Weather Cubes containing twenty-five vertical profiles were compiled. To calculate the total path attenuation for the slant path described previously A_t, in decibels,

$$A_t = \frac{10*\log_{10}(e)*L}{N*\sin(\theta)} * \sum_{n=1}^{N} \beta_e(n) \quad (1)$$

is used where L is the total path length in km, N is the number of points or resolution along the slant path, θ is the elevation angle, and $\beta_e(n)$ is the extinction coefficient calculated by LEEDR in units of inverse kilometers of the nth section of the interpolated slant path.

IV. RESULTS

The comparison of the Weather Cube derived total probability of exceedance curves and the measured radiometric curves are given in Fig. 3, attenuation data created by Weather Cube method (abbreviated "Wx") plotted as solid curves and the comparison data plotted as broken curves. The results show that the exceedance curves derived using the Weather Cube method match well with the measured radio sound data for exceedance percentages greater than 50% while exceedance percentages less than 50% do not agree well. The large discrepancy at the lower exceedance values may be accounted for the relatively coarse sampling of Weather Cube derived attenuation data as compared to that of the measured. The highest exceedance values captured are the result of the worst-case scenario weather events, which for this methodology would be rain with the worst possible rain rate. As the rain placement algorithm uses Weather Data reported only four times a day, it is unlikely that these events would be captured by the Weather Cube method as compared to radiometric data. In order to verify that this is the cause of the discrepancy and to improve the accuracy of the Weather Cube method, it is recommended that more years of GFS data should be used to create exceedance curves.

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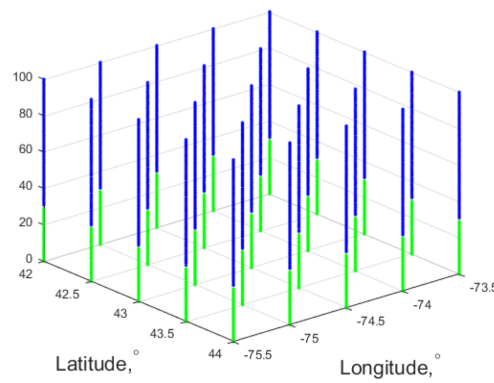

Figure 1: Weather Cube consisting of 25 vertical profiles

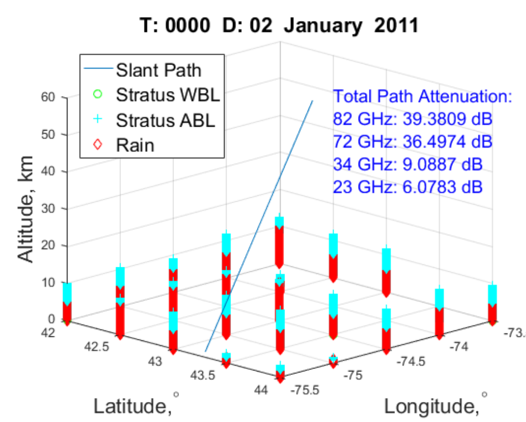

Figure 2: Weather Cube showing placement of rain and clouds

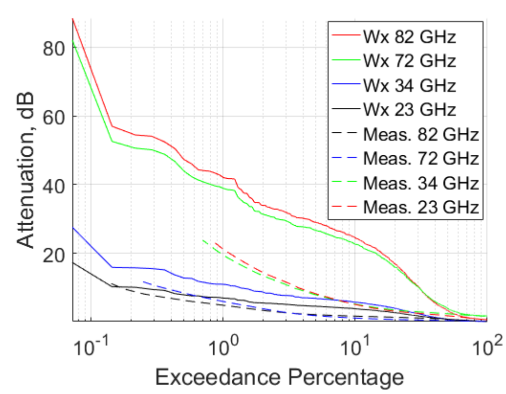

Figure 3: Comparison of Total Path Attenuation with Measured Radiometric Data [4]