ANALYSIS OF PARTICLE SIZE DISTRIBUTION DURING SAND/DUSTSTORM IN RIYADH, SAUDI ARABIA

Abobakr S. Ahmed, Adel A. Ali and Mohammed A. Alhaider

College of Engineering, King Saud University
Riyadh 11421, Saudi Arabia

Abstract: The assessment of particle size distribution is important for predicting the effect of sand/duststorms on millimetric wave propagation. However, only equisized and exponential distributions are employed in the literature. Other measured distributions in atmospheric science vary considerably and depend on location. In this paper, the distributions during different storms in Riyadh are analysed at various heights relevant to millimeter wave towers. For the measured sixteen samples, it is found that the particle size distribution can be described by lognormal and normal. The distributions depend on the storm conditions and the tower height. The average diameter of the distribution decreases with the increase of tower height increase according to:

$$D_{av} = D_o H^{-\alpha}$$

1. Introduction

The propagation of millimeter wave (MMW) into sand/duststorm is a function of frequency of propagation, particles number concentration, particle's permittivity and size distribution function [1-4]. To predict the effect of sand/duststorm on the MMW propagation, it is necessary to assess these storm parameters. However, with MMW propagation in mind, the data on particle size distributions is lacking. Unrealistic equisized distribution is assumed [1] and only exponential distribution is measured [4,5] and employed for attenuation prediction in a storm [2-5]. The investigations carried out by many researchers in atmospheric science have resulted in a variety of particle size distributions such as normal [6], lognormal [7], power law [8]. It is difficult to establish a global distribution during storms and the distribution may depend on the location and the storm conditions.

The aim of this paper is to assess the particle size distribution functions during sand/duststorms in Riyadh, Saudi Arabia. Samples are collected at different heights and the variation of settling mass vs time is analysed using sedimentation technique. The probability density functions are calculated from the measurements and fitted to several possible functions using the least square method. The tested functions are: normal (N), lognormal (LN), power law (PL) and exponential. The paper summarizes the sample collection routine, analysis and resulting particle-size distribution.

2. Experimental Set-up

The samples are collected during sand/duststorm at the receiving site of MMW links system. Passive collectors are manufactured according to the ASTM-D1739 [9], and are located at different heights above ground, namely: 1, 6, 15 and 21 m. The last height is the height of the receiving tower. This type of collector has the advantages of collecting the total suspended particles without filtration and avoids the bouncing of large particles.

The collected dry sample is mixed in a watch-glass with a few drops of sedimentation fluid (destilled water) with a small brush, and then this slurry is diluted up to about 100 ml. It is boiled under reduced pressure to remove any residual air bubbles and then stirred with a rotating brush.

A sedimentation Chan balance system is used to obtain a record of particles settled weight M falling in the sedimentation fluid of height h vs elapsed time t. The particle diameter D is calculated using Stokes law:

$$D = K/\sqrt{t} \tag{1}$$

where K is a constant which depends on the sedimentation fluid and the particle density. The fraction weight W of particles of diameter coarser than D is given by Oden's equation [10]:

$$W = \frac{1}{M_t}\left[M - t\,\frac{dM}{dt}\right] \tag{2}$$

where M_t is the total weight of the sample. The probability density function PDF is calculated as the fraction of particles per unit diameter interval range ΔD:

$$PDF = \frac{1}{N_t}\left[\frac{\Delta W/D^{-3}}{\Delta D}\right] \tag{3}$$

where N_t is the total number of particles, Δw is the weight of particles in diameter range ΔD and D is the average of ΔD.

3. Results and Discussion

Fig. (1) shows an example of the results of calculating the probability density function (PDF) from the measured samples and the fitted PDF. In Table (1) the average, standard deviation and the fitted PDF for 16 samples at different height are summarized. Shown also is the optical visibility during sand/duststorms. It is seen from the table that the samples cannot be represented by a single PDF. Out of the measured 16 samples, 40% can be fitted to either normal or lognormal distribution. It can be concluded that, each sand/duststorm may have different distribution and even this distribution is height dependent.

The average diameter increases consistently with the decrease of height; as may be expected. The variation in the average diameter at low height is considerable if compared to the variation at higher height. For example, D_{av} varies from 42.5 μm to 21 μm at a height of 1 m compared with a variation from 16 μm to 18.4 μm at a height of 21 m. This may be attributed to the different conditions of the storms. It is likely that larger particles have higher fall velocity and settle down rapidly while smaller size particles can rise to higher levels and remain suspended for a relatively appreciable time. For all the samples the relation between the average diameter D_{av} in μm and the height in meters can be represented by:

$$D_{av} = D_o H^{-\alpha} \qquad (4)$$

For the measured samples, D_o = 32 μm and α = 0.155, as shown in Fig. (2).

Compared with other measurements, it is seen that the exponential distribution measured by Ghobrial [4] and Haddad [5] is not indicative since the measurement is based on one sample only. The normal and the lognormal functions are in accordance with the results of [6] and [7] respectively and the variation of size distribution during sand/duststorms is conformed by [11].

Table (1) Results of Particle Size Distribution Measurements for Some Duststorms.

Sample No.	Height (m)	D_{av} μm	σ	Fitted PDF Distribution	V_o km
1	21	18.4	8.9	Normal	1.6-2.0
2	15	19.6	10.3	Normal	
3	1	28.0	13.0	Exponential/ lognormal	
4	21	17.0	7.7	Normal	1.6-2.0
5	15	18.0	9.7	Power law	
6	1	37.0	19.0	Power law	
7	21	16	6.3	Normal	5.0-6.0
8	15	17.0	9.4	Lognormal	
9	1	21.0	6.0	Lognormal	
10	21	16.4	8.8	Lognormal	3.0-4.0
11	15	17.0	7.0	Normal	
12	6	17.0	6.9	Normal	
13	21	16.5	7.5	Lognormal	0.6-1.0
14	15	19.3	8.9	Lognormal	
15	6	30.6	10.8	Lognormal	
16	1	42.5	16	Normal	

D_{av} = Average diameter; σ = standard deviation;
V_o = optical visibility,
PDF = probability density function.

[3] J. Goldhirsh, "A parameter review and assessment of attenuation and backscatter properties associated with dust storms over desert regions in the frequency range of 1 to 10 GHz", IEEE Trans. on Antenna and Propagation, vol. AP-30, No. 6, Nov. 1982.

[4] S.I. Ghobrial, "The effect of sand storms on microwave propagation", Proc. Nat. Telecommun. Conf., Houston, TX, vol. 2, pp 43.4.1.-43.5.4, 1980.

[5] S. Haddad, M.J.H. Salman and R.K. Jha, "Effect of Dust/Sand storms on Some Aspects of Microwave Propagation", Proc. Ursi Commission F 1983 Symp., Belgium, pp. 153-162, June 1983) (ESA-SP-194).

[6] D.R. Row, M.A. Nouh, K.H. Al-Dhowalia and M.E. Mansour, "Indoor-outdoor Relationship of Suspended Particulate in Riyadh, Saudi Arabia", J. Air Pollution Control Association, pp 24-26, 1985.

[7] E.M. Patterson and D.A. Gillette, "Commonalities in Measured Size Distribution for Aerosols Having Soil Derived Component", J.G.R., Vol. 82, No. 15, pp 2074-2082, 1977.

[8] Z. Levin, J.H. Joseph and Y. Mekler, "Properties of sharav (Khamasin) dust - Comparison of optical and direct sampling data", J. Atmosph. Sci. Vol. 37, pp. 882-89, 1986.

[9] ASTM D1739-70, Collection and Analysis of Dustfall.

[10] J.D. Stockham and E.G. Fochtman, Ed., "Particle Size Analysis", Ann Arbor Science Pub., 1977.

[11] M.D. King, D.M. Byrene, M.H. Herman and J.H. Reagan, "Aerosol Size Distribution Obtained by Inversion of Spectral Optical Depth Measurement", J. Atmosph. Sci., Vol. 35, pp. 2152-2153, Nov. 1978.

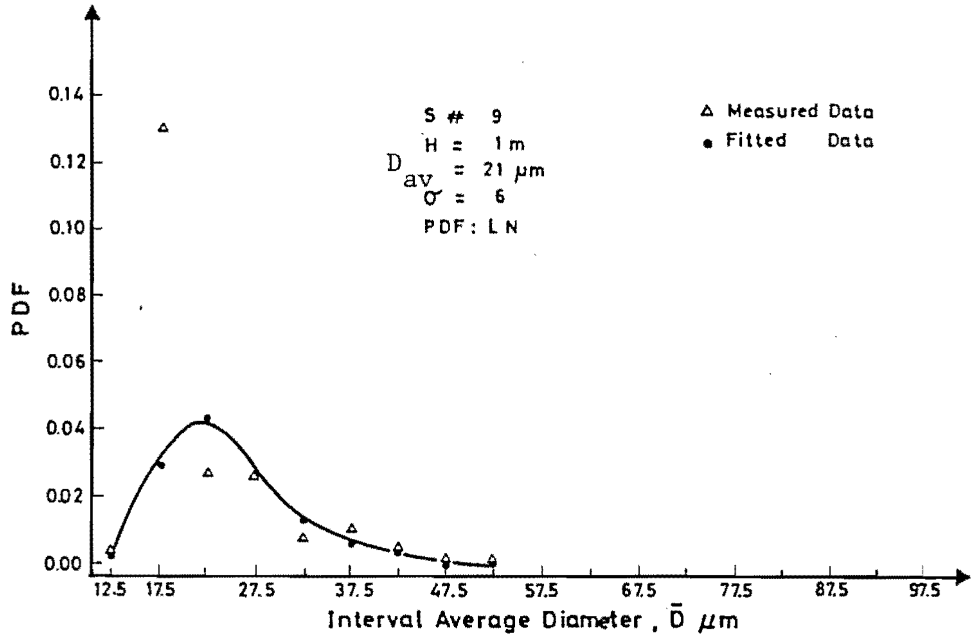

Fig. (1) Measured and fitted probability density function PDF of sample #9, H is the height of collection, D_{av} and σ are the average and standard deviation of PDF, LN = lognormal.

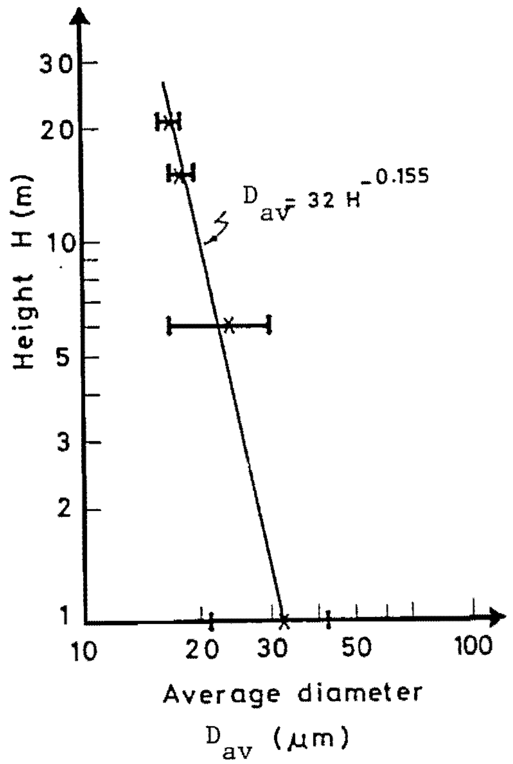

Fig. (2) Variation of the average diameter D_{av} with height H.