IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Volume-2, Issue-4 E-ISSN: 2347-2693

Scattering of Sodar Signal by Turbulence in Homogenous, Isotopic and other Mediums

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www.ijcaonline.org

Received: 23/03/2014 Revised: 8/04/2014 Accepted: 24/04/2014 Published: 30/04/2014

Abstract: Turbulence is very difficult to define succinctly except by its contrast with laminar flow and there is no universally accepted model to describe quantitatively the details of medium. If it is difficult to understand about turbulence then it's also difficult to understand scattering of sound, i.e., sodar signal by turbulence. For the purpose of this analytical study, it is assumed that turbulence in the lower atmosphere with some considerations and developed mathematical algorithms and observed different plots to estimate the scope of the sound scattering in homogenous, isotopic and other mediums. All these mathematical algorithms and plots has developed in the scientific software MATLAB. These results are compared with the early studies and concludes that past and present studies found similar predictions for the scattering of sodar signal by turbulence.

Keywords: Atmosphere, Flow, Homogenous, Isotopic, Laminar, MATALB, Scattering, SODAR, Turbulence

I. INTRODUCTION

A SODAR signal, is a sound wave with 2 kilo Hertz frequency propagates through a turbulent medium which interacts with turbulent density fluctuations in the medium. Internal momentum fluctuations are induced by eddy motions, which cause changes in the internal pressure and radiate away as a scattered acoustic wave. These type of interactions is also referred to as local scattering or internal scattering. Internal and thermal scattering effects are to direct some of the incident acoustic energy, away from the actual propagation direction. Temperature fluctuations in the lower atmosphere and local change in the acoustic index also some extend responsible for scattering. However, there is no reduction in the total transmitted acoustic power but that power is diffused over a wide area. Therefore the received Intensity along the actual direction has diminished. There is a no way for the receiver to distinguish between this effect and a bona-fide absorption loss. Turbulence is also related to wind shear and gustiness which have been observed to produce large increases in the excess attenuations. (References. [1], [2], [3], [12] and [13]). The small effects observed and calculated for the other factors and the positive correlation between wind effects and the excess attenuation suggest that scattering due to turbulence is responsible for most of the excess attenuation measured out over non-horizontal propagation paths. Historically, the theory of sound propagation in a turbulent medium has advanced two parallel line of development. In first approach, the atmosphere is assumed to consist of an ensemble of vertical eddies. For this medium the problem of acoustic scattering reduces to an extension of single vortex theory to the case of multiple scattering among many vertical eddies. In the second approach, turbulence is described in terms of stochastic processes in the atmosphere in which such ensemble characteristics as means and correlations coefficients play a central role. The early theories which have been described briefly, all predict the same general features for the coefficient of attenuation due to scattering; namely it is a function of turbulent velocity or temperature fluctuations in the medium and it is proportional to a length scale. Both of these results are in harmony with intuitive expectations. Kneser, Knudsen and others found that it predicted an excess attenuation per wave length which would exceed the maximum measured molecular attenuation per wavelength when the mean-square turbulence velocity fluctuations exceed the rather modest value of 1.7 m/Sec, even if the turbulence scale L were as small as one wavelength. The turbulence scale is typically at least an order of magnitude larger than one wavelength for audio frequencies in the atmosphere.

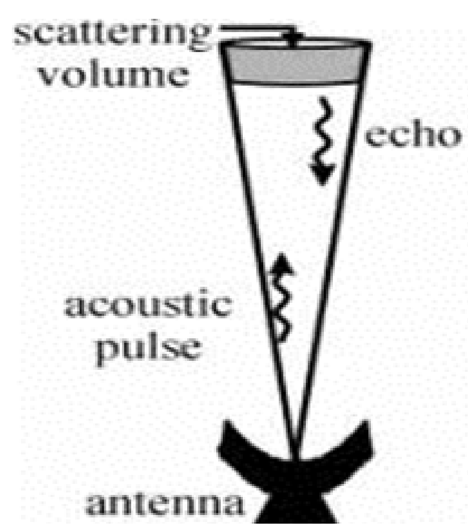

Figure.1: Phenomenon of the backscattered signal process.

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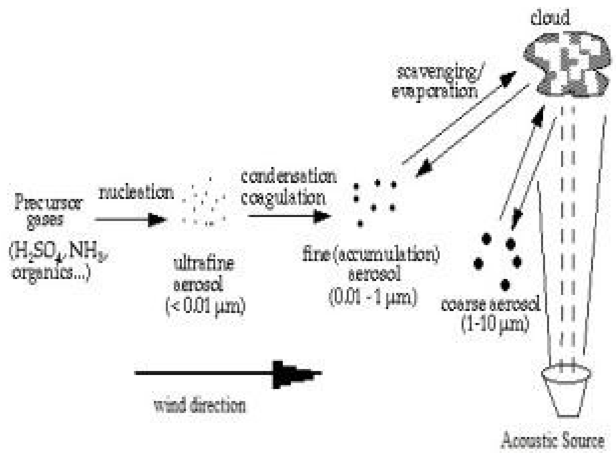

Figure.2: Sketch of SODAR signal process in lower Atmosphere.

Figure.3: SODAR antenna at Dept. of Systems Design, Andhra University. Sponsored by UGC and ISRO

II. PREDECTIONS AND DEVELOPMENTS.

Here in this paper, for the purpose of the study, it is assumed that turbulence in the lower atmosphere has the following properties. 1. The atmosphere is assumed to consist of an ensemble of turbulent eddies, each of which is characterized by a length by a length scale "l" which some sense represent the size of the eddy. 2. There exist a bounded spectrum of eddy sizes ranging from a minimum value "l_0" called the inner scale of turbulence, to some maximum outer scale size. 3. The spectrum of eddy sizes is continuous between in the inner and outer scale; that is, there are no "forbidden" eddy sizes within the spectrum. 4. Each eddy is classified as either a "small-scale" eddy or a "large-scale" eddy. The small scale eddies are basically homogeneous and isotropic whereas the large-scale eddies generally are not. 5. An eddy is called homogeneous, if the mean values of the random meteorological fields which characterize that eddy are constant and if the correlation functions describing those fields are insensitive to displacement within the eddy.

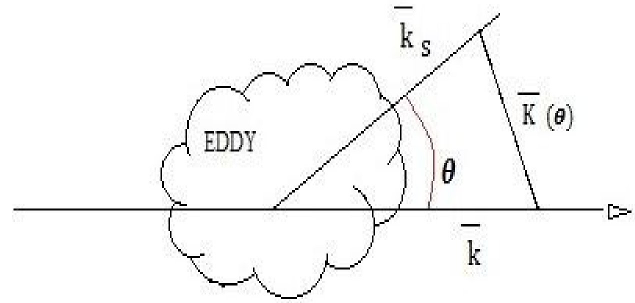

Figure.4: Scattering of sound by turbulence.

Consider a plane wave with wave number "k" incident on a turbulent eddy as in figure.4, some of the incident energy is scattered at an angle $\boldsymbol{\theta}$. The scattered wave has a wave number "ks" where, Doppler shift being neglected, | ks | = | k |. It is customary to characterize a turbulent eddy by a vector K ($\boldsymbol{\theta}$) which presents the vector difference between the incident and scattered wave vectors

$$K(\boldsymbol{\theta}) = k - ks$$

Equation.1: Vector difference between the incident and scattered wave vectors.

Since | ks | = | k |, equation.1 can be shown to have the following equation.2

$$K = 2k \sin(\boldsymbol{\theta}/2)$$

Equation.2: Vector difference between the incident and scattered wave vectors in sign format.

If the customary assumption is made that K can be expressed in terms of an eddy size "l" in the same way that an acoustic wave number is expressed in terms of wavelength, then equation.2 can be rewritten as

$$\lambda = 2l\sin(\boldsymbol{\theta}/2)$$

Equation.3: Angle of Incident acoustic plane wave with wave length.

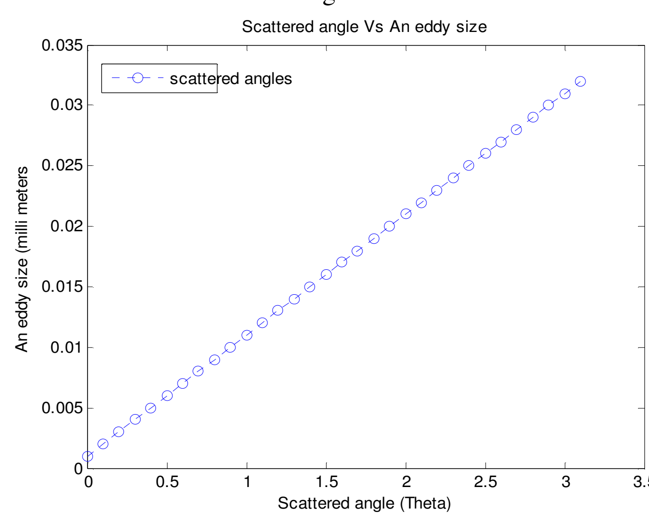

Figure.5: Influence of Scattered angle on eddy size.

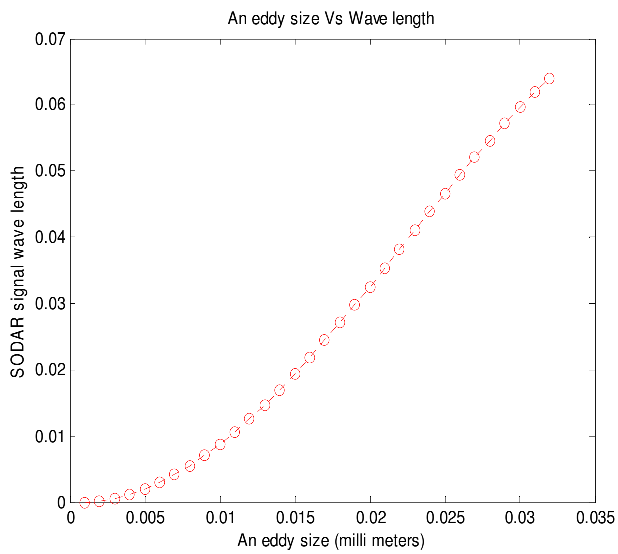

Figure.6: Influence of eddy size on wavelength of scattered SODAR signal

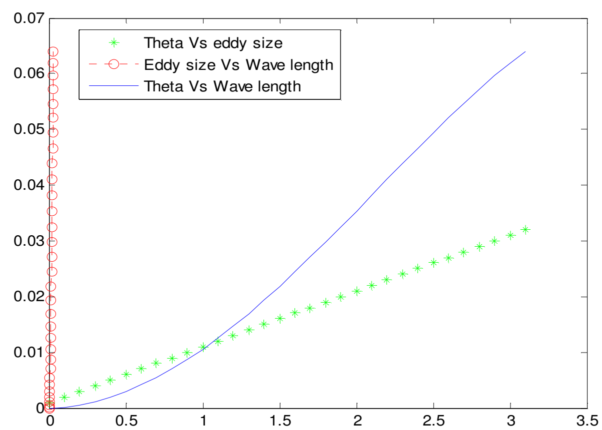

Figure.7: Common plots for relation among Incident angle, size of the eddy and Scattered sound wavelength.

Equation.3 describes the angle through which an incident acoustic plane wave with wave length (λ) will be scattered when it encounters an eddy characterized by a scale length (l). This is just a statement of the familiar Bragg condition which describes the X-ray diffraction in crystals. Thus, the scattering of sound by turbulence can be modeled as a Bragg diffraction phenomenon in which the turbulence eddies from diffraction gratings in the atmosphere which are responsible for scattering the incident sound just as the atoms of crystal from the diffraction grating which cause X-rays to scatter in crystal, because there is a continuous spectrum of eddy sizes in a turbulent medium. The atmosphere is really a continuous superposition of grating, each with a different period "l" and each responsible for scattering a given wavelength in a particular direction, according to equation.3. The 'atmosphere crystal' model might be expected to hold in the case of small-scale eddies which are sufficiently homogeneous to have the same general effects on an incident acoustic plane wave as crystalline atoms have on an incident electromagnetic plane wave, but the crystal model should break down for the outer scale eddies, which are patently inhomogeneous. Hence, the Bragg condition applies for all eddies according to equations.3. Figure.5: explains the relation between angle of scattered sound wave and eddy size, which concluded that length of eddies increases proportionally to angle of the scattered sound wave. Figure.6 concluded that if the size of eddies increases then the scattered sound wavelength will also increases proportionally but in non-homogeneously. Figure.7 is Common plots for relation among Incident angle, size of the eddy and scattered sound wavelength. The remainder of this section is divided into two parts. In the first part, a homogeneous and isotropic medium will be considered in which the Bragg condition applies for all eddies, which includes those on the order of the outer scale. In the second part a different medium is considered in which the conventional Bragg condition represents only a first approximation to the scattering process.

Homogeneous and Isotropic Turbulence

The differences between result of this paper and earlier results of lighthill and Chernov is that the numerical coefficient an order of magnitude smaller than the corresponding numerical coefficient in these earlier results. This is consistent with the experimental results of Ingard and Wiener (reference.[14]) whose field measurements of the excess attenuation were much smaller than the lighthill theory predicts. Ingard and Wiener also reported a milder frequency dependence than that predicted by equation.4, or the earlier excess attenuation theories. This observation, which is also reported in references [1] to [3], [12] and [13]. But cannot be explained with the simple scattering model considered.

$$\alpha_s = 0.2\, L_0 k^2 \left(\frac{\Delta V^2}{c^2} + \frac{\Delta T^2}{4T^2} \right)$$

Equation.4: Coefficient of attenuation due to scattering.

Where;

α_s = Coefficient of attenuation due to scattering.

L_O = Inner scale of turbulence in direction of Propagation.

k = Acoustic wave number.

ΔV = Velocity Fluctuation.

ΔT = Temperature Fluctuation.

c = Sodar Sound wave speed.

III. EXTENSION OF MODEL TO REAL - ATMOSPHERE

It has been assumed previously that the scattering of acoustic plane waves by atmospheric turbulence is described by Equation.2, the Bragg condition. The simple model upon which this assumption is based is not likely to be entirely valid for the real atmosphere, where the inhomogeneity and anisotropy of the outer scale eddies, fluctuations in the size of the eddies, and other departures from the simple model considered above influence the scattering process. It is appropriate to ask how the vector representing a scattered wave in the real atmosphere would differ from a scattered sound wave vector in the ideal medium considered previously. Figure.8, describes the scattering process in the real atmosphere.

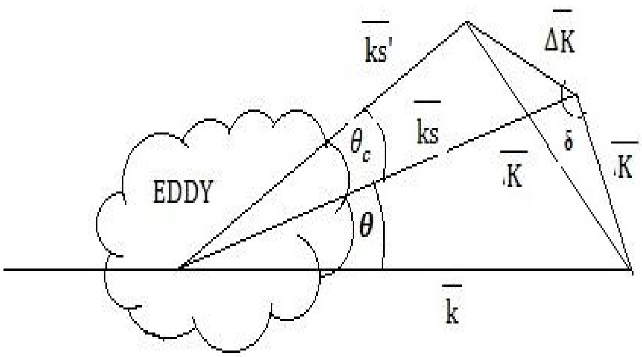

Figure.8: Scattering by large scale eddy.

$$\alpha_s = 0.455\left(\frac{C_v{}^2}{c^2}+0.136\,\frac{C_T{}^2}{T^2}\right)_{-5/3}$$

$$k^{1/3}\left(\frac{\pi}{kL}+Sin\,\frac{\theta_c}{2}\right)$$

Equation.5: Excess attenuation coefficient in terms of turbulence structure constants.

The $\boldsymbol{\theta}_c$ is in some sense a measure of the difference between the real atmosphere and the simple model. If the Bragg condition were in fact exactly applicable to the scattering process, then $\boldsymbol{\theta}_c$ would be zero and Equation.5 would reduce to Equation.6, for which case the excess attenuation coefficient would display the square-law frequency dependence predicted by previous theories.

$$K = 2k\left(Sin\,\frac{\theta}{2}+Sin\,\frac{\theta_c}{2}\right)$$

Equation.6: Excess attenuation coefficient in terms of turbulence structure constants when $\boldsymbol{\theta}_c = 0$.

IV. EXPERIMENT RESULT

Consider a plane sound wave with a frequency of 2 kilo Hertz propagating in a medium, where 'L' has a value of 50 meters, the Π/kL term has a value of $1.7\text{x}10^{-3}$. Therefore, if $\boldsymbol{\theta}_c$ less than or equal to 0.2^0 , the Sin ($\boldsymbol{\theta}_c$ /2) term will be larger than the Π/kL term. That is under, ordinary condition, if a sound wave is actually scattered in a direction which differs by as little as 0.2^0 from the direction it would have been scattered in idealized medium, then the frequency dependence of the excess attenuation coefficient is much milder than the square law dependence predicted by earlier theories.

V. CONCLUSION

The excess attenuation coefficient in terms of the turbulence structure constant has calculated with help of equation.5. However, it would be difficult to determine either $\boldsymbol{\theta}_c$ or L experimentally and measurements of the structure constant C_v. Without such data to support measurement of the excess attenuation, it is difficult to confirm the present calculation conclusively. However, it can be shown that equation.5 does in fact explain those experimental reported earlier as well as some other experimental results. The purpose of developing the excess attenuation theory in this paper is to provide an improved scheme for correcting raw acoustic field data for atmospheric effects and also to understand the SODAR sound wave attenuation characteristics. Here in this experiment has concluded that if a sound wave is actually scattered in a direction which differs by as little as 0.2^0 from the direction it would have been scattered in idealized medium, then the frequency dependence of the excess attenuation coefficient is much milder than the square law dependence predicted by earlier theories.

VI.ACKNOWLEDGEMENT

The work has been carried out with the financial support by UGC, New Delhi through a major research project entitled "DEVELOPMENT OF PORTABLE DOPPLER SODAR SYSTEM FOR WIND FARM SITING APPLICATION".

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