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SODAR IN AIR POLLUTION METEOROLOGY

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Abstract—Information concerning atmospheric stability and turbulence is basic in studies related to air pollution meteorology. In this context a monostatic sodar has been operating at the National Physical Laboratory, New Delhi, for many years to probe the thermal structure of the lower atmosphere in real time and space.

Various observed thermal structures viz. nocturnal inversion, thermal plumes, formation and break-up of inversion, orographical mixing, multilayered structures and waves etc., are the result of the different atmospheric stabilities and turbulence conditions. These structures have been studied in the light of surface measurements of wind speed and direction for organized indexing of the structural details to infer meteorological conditions concerning Pasquill stability classifications.

The height of the ground-based thermal structure has been correlated with the Richardson number, *Ri*, for quantitative estimation of the turbulence parameter. Estimated values of *Ri* have been further used to determine the cross wind dispersion coefficient, σ_y. The results obtained are realistic and can be used as input parameters for air pollution modelling.

Key word index: Acoustic sounding, sodar, air pollution, inversion, thermal structures, Pasquill stabilities, Richardson number, dispersion coefficient, Monin–Obukhov length.

1. INTRODUCTION

The effluents emanating from stacks of industrial plants, cottage industries, motor vehicles and domestic ovens, etc. disperse according to the conditions of stability and wind vector. The possible plume behaviour under various conditions of lapse rate can be seen in Fig. 1 which clearly indicates that a monitor of the meteorological parameters of stability and wind vector is required continuously in any industrial area to determine the concentration of pollutants in the atmosphere for a given distribution of the sources of air pollution.

Traditional weather forecasting is not very helpful in this monitoring since it gives only limited information. *In situ* techniques, though good and able to provide direct information of the relevant parameters, are very expensive. Remote sensing techniques need to be employed to give information about meso- and microscale weather systems and parameters. Out of the many remote sensing techniques developed to determine the atmospheric parameters, it has been seen that acoustic remote sensing (Little, 1969; Brown and Hall, 1978) is a relatively simple, inexpensive and effective technique for semiquantitative remote probing of the lower atmosphere.

Acoustic sounding (sodar) functions are an active sonar system or a pulsed rader system. Highly directional short bursts of sound energy are radiated into the atmosphere. After scattering from atmospheric inhomogeneities in temperature, wind speed and humidity of eddy sizes within the inertial subrange, these sound waves are received by a sensitive receiving system and processed to retrieve information about thermal structure and wind velocity at different levels in the lower atmosphere.

At the National Physical Laboratory, New Delhi, a monostatic (back-scattering) sodar system has been

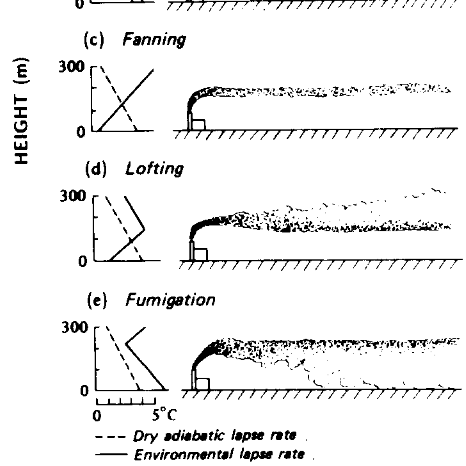

Fig. 1. Effluent behaviour under various conditions of lapse rate.

set up (Singal and Gera, 1982). Echoes from a height range of 700 m can be detected with the help of this system. Reflex images of the different atmospheric stabilities and turbulence conditions have been observed and studied in the light of surface measurements of wind velocity and temperature to infer stability information, depth of the mixing height and dispersion coefficients.

2. SODAR STRUCTURES AND WEATHER CONDITIONS

Sodar echograms have been broadly classified as thermal echoes (stalagmite-like structures rising from the ground) and shear echoes (horizontal layer echo regions impervious to vertical transport). These echograms of thermal structures can be linked in one form or another to all observed prevailing meteorological conditions in the atmosphere.

In the morning, solar heating erodes the surface-based stable layer forming thermal plumes rising from the ground with the stable layer rising above them (Fig. 2a). With continued solar heating, the stable layer rises sufficiently (to go beyond the detection range or change turbulence scale sizes to become insensitive to sodar detection) and thermal plumes dominate on the sodar echograms. Height and rate of occurrence of these thermal plumes have been observed to reach a maximum by the afternoon after which they start decreasing in line with the fall in solar heat flux.

During night-time, under slight or no wind conditions, strong short range echoes have an abrupt and an almost uniform upper limit exhibiting a nearly flat top layer (Fig. 2b). The thickness of these layers may slightly increase with time. Surface winds bring in mixing within the stable layer resulting in a random spiky structure at the top (Fig. 2c). During turbulent weather conditions and sometimes even under a clear sky, a stratified/multilayer structure may develop (Fig. 2d). Sometimes the layer structure also shows an oscillatory behaviour (Fig. 2e) with an amplitude around 100 m peak to peak. These undulating structures may exhibit features of either a sinusoidal wave motion (clear weather conditions) or a slightly rounded sawtooth (turbulent weather conditions) having periods of the order of a few minutes. Sometimes an elevated layer over and above the ground based structure may also be seen (Fig. 2f). Such a feature represents the presence of fog layer, subsidence or approaching or continuing turbulent weather conditions.

On the basis of the observed structures representing typical weather conditions, an analysis of the sodar echograms recorded by the NPL sodar system has been carried out to broadly characterize the stability (i.e. stable, unstable and neutral weather conditions) of the boundary layer at Delhi. It has been seen that the stable category exists during night-time, the unstable category exists during daytime and the neutral category exists both during day- and night-times. Further, the stable category has a longer duration during winter months, the neutral category has a longer duration during summer months and the unstable category is evenly distributed over the whole year.

3. PASQUILL STABILITY CLASSIFICATION

Different types of signatures traced on sodar records under varying atmospheric conditions have been used to give information about Pasquill stability classification of the atmosphere (Pasquill, 1962). Pasquill has defined six categories of stability from A to F which can be classified on the basis of data of various meteorological parameters like surface wind speed, wind direction, daytime insolation, night-time sky conditions and temperature lapse rate, etc. Out of the various schemes to classify Pasquill stability, we have used the scheme of wind direction fluctuations to characterize the various types of sodar structures for recognition of Pasquill stability class.

Based on the detailed analysis (Singal *et al.*, 1985) the following pattern recognition technique has been worked out.

(i) Category A, representing strongly unstable conditions, is marked on the sodar echograms by well-defined families of tall plumes.
(ii) Category B, representing moderately unstable conditions, is marked on the sodar echograms by thermal plumes of shallow height.
(iii) Category C, representing slightly unstable conditions, is represented on the sodar echograms by very shallow plumes formed during late afternoon hours.
(iv) Category D, representing neutral conditions, is marked on the sodar echograms either by no structure or by dark bands due to wind induced noise.
(v) Category E, representing slight stability conditions, is represented on acoustic sounder echograms either by a ground based layer of higher depth or by a tall spiky structure during night-time or by a stratified layer structure of higher depth.
(vi) Category F, representing moderate stability conditions, is depicted on sodar records either by a shallow and firm ground based layer or by a shallow stratified layer structure.

4. DETERMINATION OF CROSS-WIND DISPERSION COEFFICIENT

Richardson's number is generally used as a parameter to measure turbulence. It considers the effect of both the wind and temperature fields. The magnitude of this number gives a measure of turbulence while the sign determines the stability. Negative values represent unstable conditions when buoyant forces tend to