Monitoring Air Pollution Related Meteorology Using SODAR

State of the Art

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Abstract. Hazardous situations in air pollution can many a times be avoided in case short term local weather forecasting of the boundary layer meteorology becomes available. Amongst the various remote sensing techniques, it has been seen that acoustic remote sensing (SODAR) of the lower atmosphere can be employed to determine and predict the atmospheric boundary layer meteorological parameters. In specific, information can be obtained about thermal stratification, mixing height, low level disturbances, depth of the planetary boundary layer, stability classification, wind velocity, wind variances, turbulence parameters, and diffusion characteristics etc. when SODAR is used in conjunction with surface level measurements of the usual meteorological parameters.

In the paper a brief description of the acoustic remote sensing technique and a review of the work done during the last two decades to determine the various air quality related meteorological parameters has been given. The methodology to determine mixing height, stability classification and diffusion and dispersion characteristics using mostly the information from the SODAR echograms has also been described. The SODAR echograms obtained at Delhi for the period May 1977 to April 1982 have been processed and analyzed using pattern recognition to determine these parameters. Doppler SODAR information of wind speed and direction have not been treated for the above purpose. Using the Gaussian dispersion model, pollution concentration downwind of a emission source (in the present case it is a cement factory at Nimbahera, Chittorgarh, India) has also been computed with the help of SODAR determined data. It has been found that measured values with the help of high volume sampler conform to the estimated pollution concentration. A peak in the value of the estimated pollution concentration during the fumigation period has also been seen.

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\[ FA \] Vertical flux of the buoyant plume
\[ K \] von Karman's constant equal to 1.4
\[ L \] Monin-Obukhov length [m]
\[ L_a \] Acoustic attenuation along the path inclusive of the transducer efficiencies
\[ P \] Ambient air pressure [hPa]
\[ P_0 \] Total pressure [hPa]
\[ P_r \] Received acoustic power
\[ P_t \] Transmitted acoustic power
\[ Q \] Quantity of stack emission per unit time [g s\(^{-1}\)]
\[ Q_0 \] Surface heat flux
\[ R \] Range to the scattering volume [m]
\[ R_i \] Richardson number
\[ R_s \] Inner stack radius at the top [m]
\[ R_{id} \] Flux Richardson number
\[ T \] Ambient air temperature [K]
\[ T_s \] Average temperature inside the stack [K]
\[ U \] Horizontal wind speed [m s\(^{-1}\)]
\[ U_z \] Horizontal wind speed at the stack height [m s\(^{-1}\)]
\[ V_s \] Average exit velocity at the stack top [m s\(^{-1}\)]
\[ Z \] Depth of the mixed boundary layer, i.e. the height of the atmospheric boundary layer [m]
\[ Z_i \] Inversion height, i.e. the distance between the ground and the base of the elevated inversion [m]
\[ Z_0 \] Length parameter of roughness [m]
\[ a \] Empirical constant equal to 1.5 in stable conditions and 10 in unstable conditions
\[ b \] Empirical constant equal to 1 in stable conditions and 10 in unstable conditions
\[ c \] Velocity of acoustic waves in air [m s\(^{-1}\)]
\[ d \] Distance from source to receptor [m]
\[ h \] Mixing depth as per Holzworth model [m]
\[ h_e \] Effective stack height [m]
\[ \Delta h \] Plume rise height [m]
\[ g \] Acceleration due to gravity
The rapid growth of industries and urban centres, coupled with the extraordinary accomplishments of modern technology during the last few decades, though responsible for a higher standard of living, has also become a cause of strong public concern because of the discharge of various types of hazardous and toxic gaseous and particulate matter in the atmosphere, which are altering the environmental quality of life at micro, macro and global levels. The air quality parameters of our environments are thus required to be monitored for necessary prediction and control.

Monitoring of ambient air quality can be carried out by the measurement of various air pollutants present in the atmosphere as also through monitoring of the atmospheric boundary layer meteorology assuming that the number and distribution of the sources of air pollution remain the same. In the latter case, low level stability, inversion topography, buoyancy, turbulence strength, mixing height, wind velocity, and meso-scale flow patterns are some of the meteorological parameters that need to be monitored.

Often conventional in situ techniques such as radio sonde, instrumented tower, tethered balloon, and instrumented aircraft etc. are used to monitor the essential atmospheric parameters. Out of these radiosonde is the most common in situ technique. Typical data consist of twice daily profiles of temperature, pressure, humidity, and wind at a place mostly in the vicinity of the airport. These data supported by hourly observations of surface parameters of pressure, temperature, humidity, visibility, and cloud cover help to interpolate and extrapolate stability, mixing depth and wind profiles in the lower atmosphere. However, available information is generally limited at the lower levels and is not adequate for air quality monitoring and forecasts since aviation requirements have often dictated the location of the sensors at sites which are not necessarily in the best interests of the air quality meteorologists. Slow ascent radiosonde or tethered balloon systems, instrumented towers and instrumented aircrafts can help to collect low level data to some extent but it may be difficult to afford the increase in the density of observations using these instruments, as the cost will increase enormously.

Remote sensors, in comparison to the in situ sensors, can provide data for the atmospheric parameters at lower heights continuously in both space and time and with higher resolution. They depend on the propagation characteristics of acoustical, optical and electromagnetic waves in the medium. Many of the remote sensing devices have the ability to scan rapidly large regions in three dimensions. Others can give line integrals of certain parameters giving spatially averaged values that may be nearer to the desired measurement.

Considering the overall cost of the system, availability of tracers, large scattering cross-section, stage of development, and reliability of measurements during the last two decades, it is felt that the measurement system can be made up entirely of an acoustic device [1–5]. The interaction of sound waves with the inhomogeneities of the lower atmosphere is very much stronger [1] than that of the electromagnetic spectrum as shown in Table 1. It is seen that 1 K fluctuation in temperature is equivalent to about 1700 N units change in sonic refractive index (1 N unit equals 1 part in 10^6) compared to only 1 N unit change in optical and radio refractive index. Similarly 1 m s^-1 variation in wind speed is equivalent to 3000 N units change in acoustic refractive index.

### Table 1. Refractive index variations per unit change in the characteristic parameters of the atmosphere (Data from [1])

<table>
<thead>
<tr>
<th>Parameter change</th>
<th>Change in refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Unit (N = 10^-6)</td>
<td></td>
</tr>
<tr>
<td>Acoustical</td>
<td>Radio</td>
</tr>
<tr>
<td>1 K fluctuation in temperature</td>
<td>1700</td>
</tr>
<tr>
<td>1 m s^-1 variation in wind speed</td>
<td>3000</td>
</tr>
<tr>
<td>1 hPa change in water vapour pressure</td>
<td>140</td>
</tr>
</tbody>
</table>