Study of vertical wind and temperature turbulence in a convective boundary layer from sodar observation at Thumba

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Received 18 August 1988; revised received 2 November 1988

Sodar data obtained during convective condition at the coastal station, Thumba, have been analysed to study the turbulent nature of vertical wind \( w \) and the temperature structure parameter \( C_T \). The height profile has a slope of \(-4/3\) indicating that the boundary layer was convectively driven during the period of observation. From the autocorrelogram of \( w \), the eddy sizes during convection have been estimated. The frequency distribution of \( w \) and \( C_T \) shows a non-Gaussian behaviour with positive skewness and the coefficient of skewness has a lower value at a lower height.

1 Introduction

The convective boundary layer (CBL) on a clear sunny day is dominated by well-defined thermally driven updrafts from the surface layer and downdrafts from above. The vertical wind is a measure of convective motion and its second and third moments quantify, respectively, the vertical turbulent energy and skewness in the velocity distribution.

In this paper, a study on the vertical wind \( (w) \), the temperature structure parameter \( (C_T^2) \) and their frequency distribution with emphasis on the skewness and its variation with height is presented for a vertically pointing Doppler sodar with digital data acquisition system, being operated at Thumba, Trivandrum. The sodar is situated about 500m inland off the Arabian Coast in a terrain which is fairly flat and vegetation free. The specifications of the sodar are given in Table 1.

2 Computation of \( C_T^2 \) and \( w \) from sodar

For monostatic operation (the scattering angle \( \theta = 180^\circ \)) the acoustic scattering cross-section is given by

\[
\sigma (\theta) = 0.008 K^{1/3} \frac{C_T^2}{T^2}
\]  

(1)

where \( \sigma(\theta) \) is the scattered power per unit solid angle per unit incident flux at scattering angle \( \theta \), \( K \) is the wave-number, and \( T \) is the temperature in the scattering volume.

The received backscattered acoustic power, \( P_r \), is given by

\[
P_r = P_i \left( C_T^2 / 2 \right) \sigma (180) A_r \frac{B}{R} \exp (-2\alpha R)
\]  

(2)

Here \( P_i \) is the transmitted acoustic power, \( \tau \) the pulse length, \( A_r \), the collecting area of the acoustic antenna, \( R \) the range of the scattering region, \( \alpha \) the attenuation coefficient and \( C \) is the velocity of sound; \( B \) includes the beam shape compensation factor and the antenna efficiency.

Using Eqs (1) and (2) an expression for \( C_T^2 \) can be written as

\[
C_T^2 = \left( \frac{P_i}{P_r} \right) \left( \frac{T^2}{A_r B \exp (-2\alpha R)} \right) 0.008 K^{1/3}
\]  

(3)

With the vertically directed monostatic sodar, \( w \) can be obtained from the relation

\[
w = \left( \frac{C_T^2}{2} \right) \left( \frac{B}{R} \right)
\]  

(4)

Table 1—Specification of tristatic Doppler sodar

<table>
<thead>
<tr>
<th>Mode of operation</th>
<th>Three co-located monostatic antennae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna direction</td>
<td>(i) Vertical</td>
</tr>
<tr>
<td></td>
<td>(ii) 20° off zenith in E-W plane</td>
</tr>
<tr>
<td></td>
<td>(iii) 20° off zenith in N-S plane</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2 kHz</td>
</tr>
<tr>
<td>Pulse repetition rate</td>
<td>one pulse/5 s</td>
</tr>
<tr>
<td>Pulse width</td>
<td>64/100 ms</td>
</tr>
<tr>
<td>Peak power (electrical)</td>
<td>150 W</td>
</tr>
<tr>
<td>Antenna</td>
<td>Parabolic dish 1.2m dia</td>
</tr>
<tr>
<td>Minimum detectable wind speed</td>
<td>0.1 m/s</td>
</tr>
</tbody>
</table>
where $f_0$ is the transmitted frequency and $f_0'$ the Doppler shifted frequency of the scattered signal.

3 Data analysis and results

The values of $w$ and $C_1^2$ are obtained every five seconds for six different heights, viz. 39, 50, 61, 72, 84 and 95 m. Data of one hour duration from 0930 to 1030 hrs IST (typical convective condition) of 17 Dec. 1985 have been chosen. The data have been averaged over 6 blocks (i.e., 30 s) thereby obtaining 120 data points in the time interval 0930 to 1030 hrs.

In Fig. 1, the facsimile record of 17 Dec. 1985 from 0800 to 1200 hrs is shown, which reveals thermals that are spiky (typical of low wind condition) and heights of about 200 m. The $C_1^2$ height profile shown in Fig. 2 has a slope approximating a convective condition ($-4/3$) in the height range 39 to 110 m. The shallow CBL at Thumba could be due to coastal proximity. The range of the $C_1^2$ values is typically that for a fully convective condition.

The autocorrelation functions $R(\tau)$ of $w$ have been computed for time lags up to 15 min for two

![Fig. 3-Autocorrelation function $R(\tau)$ of vertical wind for 17 Dec. 1985 during 0930 to 1030 hrs IST for heights 39 and 95 m](image)

![Fig. 4-Frequency distribution of vertical wind velocity during 0930 to 1030 hrs IST for 17 Dec. 1985](image)
heights, viz. 39 and 95 m and are shown in Fig. 3. The $R(\tau)$ falls to $1/e$ at 24 s for 39 m and 36 s for 95 m. The confidence limit is very high in this case as 120 data points have been used for computing $R(\tau)$. This trend in the behaviour of $R(\tau)$ at greater heights can be attributed to larger eddies being present at greater heights. Assuming Taylor's hypothesis of frozen turbulence, the maximum eddy sizes have been estimated from the mean horizontal wind speeds available for the site. The eddy sizes are 86 and 126 m for 39 and 95 m respectively.

The frequency distributions of $w$ and $C_T^2$ exhibit a non-Gaussian behaviour at 39 and 95 m as shown in Figs 4 and 5. The quantity $(C_T^2 - \bar{C}_T^2)/\bar{C}_T^2$ has been chosen for the convenience of comparing the $C_T^2$ frequency distribution with that of the $w$ distribution.

To quantify the asymmetry in the distribution of the quantities $w$ and $C_T^2$, the statistical quantity skewness, $S_w$, has been computed. The distribution of $w$ is seen to be positively skewed. These features of vertical wind distribution suggest that updrafts must be stronger than downdrafts. At 39 m, the coefficient of skewness of $w$ is estimated to be 0.5 and at 95 m it is 1.0. Similarly, for $C_T^2$ it is 0.6 at 39 m and 1.7 at 95 m. The low value of the skewness at 39 m compared to that at 95 m may be due to the inhibition of low frequency fluctuation by ground proximity. Also, the non-Gaussian distribution in $w$ indicates a spatial gradient in the turbulent kinetic energy during the period of observation. These results, in general, agree well with earlier investigations.

References
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