SODAR OBSERVATIONS OF THE NOCTURNAL BOUNDARY LAYER AT KHARAGPUR, INDIA

(Research Note)

B. S. MURTHY, T. DHARMARAJ and K. G. VERNEKAR
Indian Institute of Tropical Meteorology, Pune, India

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Abstract. Sodar has been installed at Kharagpur (22.2° N, 87.3° E) as a part of the MONTBLEX-90 experiment and data were collected during the monsoon period. The variation of the nocturnal boundary layer (NBL) during the monsoon period is discussed. The height corresponding to the low-level wind maximum in the sodar wind profile during night time is identified as the NBL height. Mean monthly winds for July and August, plotted as time-height cross sections, reveal the height of the ground-based stable layer. The average NBL heights in the months of July and August are found to be 324 m and 296 m respectively. It is observed that the NBL height is relatively high in the month of July (active phase of monsoon) compared to that during August (weak phase). The months of July (total rainfall = 901 mm) and August (total rainfall = 134 mm) are associated with cloudy and relatively clear sky conditions. This indicates that clouds (through their effect on longwave cooling to space) play an important role in determining the NBL height during the monsoon.

1. Introduction

One of the fundamental parameters characterising the atmospheric boundary layer (ABL) is its depth h. Knowledge of h plays an important role in environmental meteorology. It is also required in some problems of operational boundary-layer meteorology, as a basic input parameter to meso- and large-scale numerical weather and climate forecasting models, and as a scaling parameter in similarity theory.

During day time the ABL height can be identified with the base of an elevated inversion or stable layer capping a well-mixed convectively driven or even neutral boundary layer. Thus there is not much controversy on how to determine the depth of a convective ABL. The question is much more complicated in the case of a nocturnal boundary layer (NBL). At present there is no overall accepted definition for the NBL height and many different depth scales have been proposed by various authors. One of them is the dynamical height scale which defines the NBL height as the height of the low-level wind maximum. The other one is the thermal height scale, i.e. the height of the ground-based stable layer. The NBL height may also be defined as the level where turbulence kinetic energy decreases to 5% of its surface layer value (Beyrich and Weill, 1993).

Acoustic sounders (sodars) are now being widely used to measure the ABL height, wind profile and other turbulent structure parameters in the ABL. The NBL height usually depends on the rate of radiational cooling of the earth's surface

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during night time under clear sky conditions. Over Kharagpur (22.2° N, 87.3° E), one of the experimental sites of the monsoon trough boundary-layer experiment (MONTBLEX-1990) and located on the eastern end of the monsoon trough, the ABL is characterized by deep moist convection during the monsoon period (June–September). Sodar echograms present a qualitative picture of the thermal stratification of the NBL and the response of the boundary layer to the changing synoptic weather patterns during the monsoon period. We have used the height of the low-level wind maximum to determine the average NBL height during the months of July and August 1990. The variation of mean monthly NBL height during the monsoon period is then discussed in terms of the recorded rainfall over Kharagpur and cloud cover.

2. Theory

Sodar (Sonic Detection and Ranging), an acoustic remote sensing technique, is widely being used to probe the microstructure (thermal and wind) of the lowest 1 km of the atmosphere. Qualitative information about turbulent regions and their height above the sounder site, can be obtained by looking at the facsimile chart of the echograms received from a back-scattering sodar, while quantitative information about the structure parameters, turbulence and the wind field in the scattering volume can be computed by measuring the amplitude and the Doppler shift in frequency of the received signal from a combination of the monostatic and bistatic systems. Following the theoretical work of Tatarskii (1961) and Monin (1962), wherein acoustic scattering in air was considered to depend primarily on fluctuations in temperature and wind velocity, and using the Kolmogrov spectrum of turbulence, Little (1969) expressed scattering cross section as a function of scatter angle and structure parameters of wind and temperature fluctuations. Investigations comparing the height of the ground-based sodar echograms with the simultaneously recorded height of the inversion layer using *in situ* techniques have shown that the acoustic sounder can be confidently used to measure inversion heights for single, unambiguous ground-based layers (Wyckoff *et al.*, 1973; Goroch, 1976; Hicks *et al.*, 1977; Von Gogh *et al.*, 1978; Singal *et al.*, 1979; Singal *et al.*, 1986).

3. Data

The sodar site at Kharagpur has a long stretch of open and flat surface towards the south (2 km) which is the mean direction of prevailing wind during the monsoon season. Since Kharagpur is located about 50–100 km from the sea, it is very much affected by depressions in the Bay of Bengal. Sodar was operated throughout the night in the months of July and August 1990. The specifications of the monostatic Doppler sodar are given in Table I. The basic parameters that can be obtained from

Table I
Doppler sodar specifications

Made	Aerovironment Inc., USA
Mode	Monostatic, pulse mode (three antennae)
Operating frequency	1500 Hz
Range	1500 m
Height resolution	30 m
Pulse width	180 msec
Pulse interval	27 sec (9 sec for each antenna)

Table II
Output data set of sodar

Vertical antenna (V)
$\overline{W}$ mean velocity
σ_w standard deviation of velocity
$\overline{IV}$ mean signal intensity
Tilted antenna (N, E)
$\overline{V}, \overline{U}$ mean horizontal velocity
σ_u down wind standard deviation
σ_v cross wind standard deviation
σ_N, σ_E radial velocity standard deviation
$\overline{IN}, \overline{IE}$ mean signal intensities

sodar are given in Table II. Mean hourly wind profiles were measured and they are averaged over a month to get a picture of the mean wind structure up to a height of 1.5 km. We have taken the precaution of averaging hourly wind profiles of only those nights characterised by a ground-based stable layer on the sodar echogram, because the presence of a ground-based shear echo layer indicates that the atmosphere is stable (Singal *et al.*, 1984, 1986). The time-height cross-sections of winds in the months of July and August are presented in Figures 2 and 3. It is not possible to present the mean nocturnal wind structure for the months of June and September because the sodar was not operated during night time in those months. All times are IST (Indian Standard Time). In Figures 2 and 3, read 25 = 1 am, 26 = 2 am ... etc.

4. Results and Discussion

Figure 1 shows the sodar echogram in the early morning hours along with profiles of temperature and wind speed observed by the Kytoon system at the same time. The ground-based shear echo structure is supported by the positive temperature gradient indicating the inversion layer. The low-level wind maximum coincides

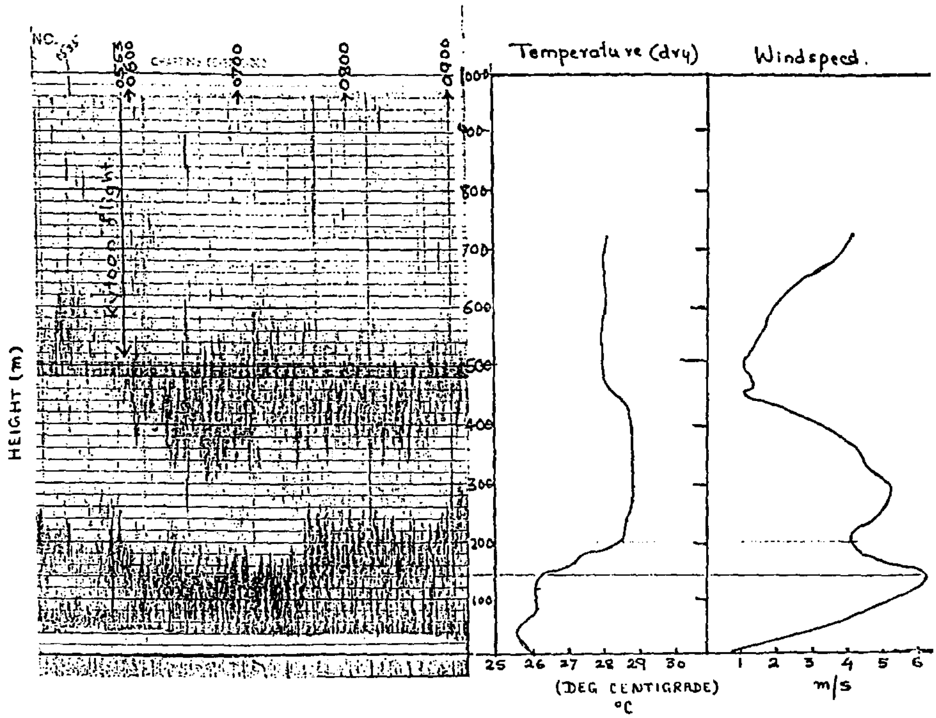

Figure 1. Profiles of wind and temperature (Kytoon system) along with sodar echogram (24 May 1990).

with the height of the ground-based inversion layer observed on the echogram. The 'no-turbulence' zone on the sodar echogram, i.e., white patch between the ground-based layer and the elevated stable layer, is characterised by zero wind gradient (Figure 1). One more peak is also observed in the wind profile corresponding to the elevated stable layer on the echogram. Figures 2 and 3 show the night time contours of mean hourly wind for the months of July and August respectively, from 1900 hr to 0400 (hour 28 on the abscissa axis) hr. One can see the clusters of high winds at 400 m during the time period 2200–0300(27) hr. Thus taking the criterion that the low-level wind maximum coincides with the height of the nocturnal boundary layer (NBL), from Figure 2, the average height of the NBL may be taken as 350 m in July. Wind maxima at higher levels indicate the presence of elevated stable layers. Figure 3 shows the presence of high wind clusters at 300 m in August during the time period 2000–0100(25) hr. The average NBL height for the month of August is inferred to be about 300 m.

Mean wind profiles are shown in Figure 4 for the months of July from 1900 hr to 0400 hr. The low-level wind maximum in each profile is marked by an arrow. There is some uncertainty in the NBL height determined from the wind profile at 0300 hr as the lowest peak is not well defined. Similarly Figure 5 shows the mean

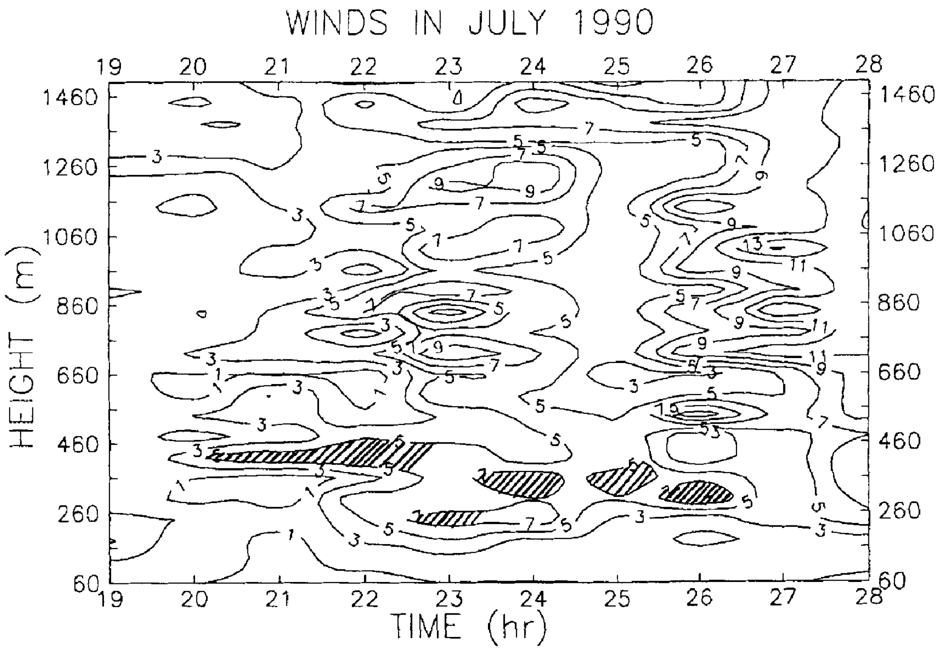

Figure 2. Time-height cross-section of monthly mean horizontal winds for the month of July 1990 (units of m s^{-1}).

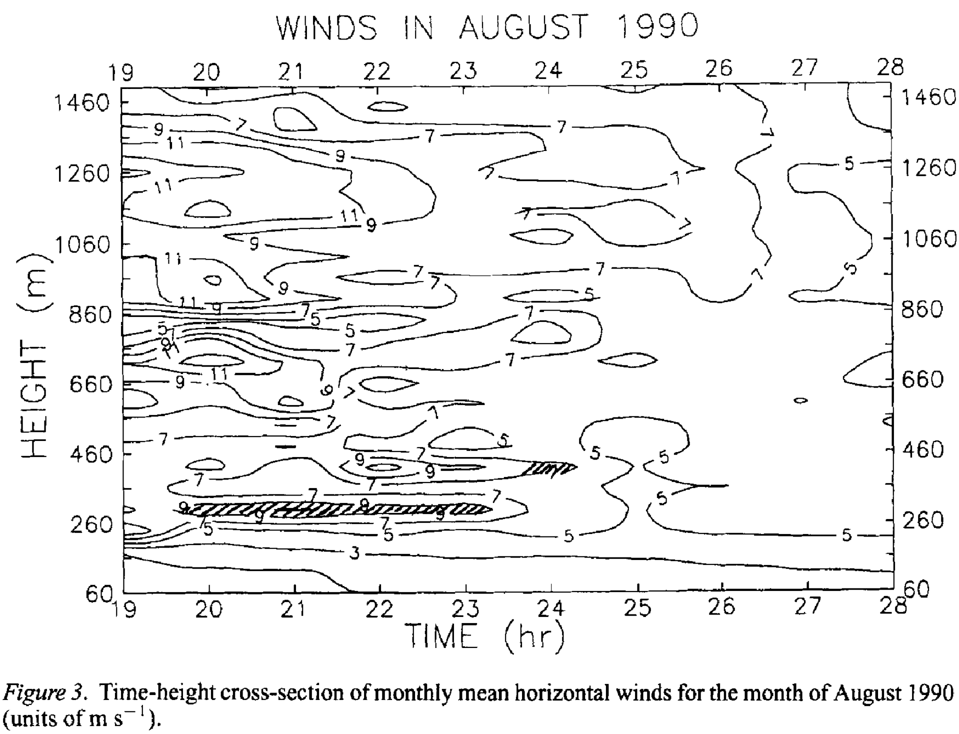

Figure 3. Time-height cross-section of monthly mean horizontal winds for the month of August 1990 (units of m s^{-1}).

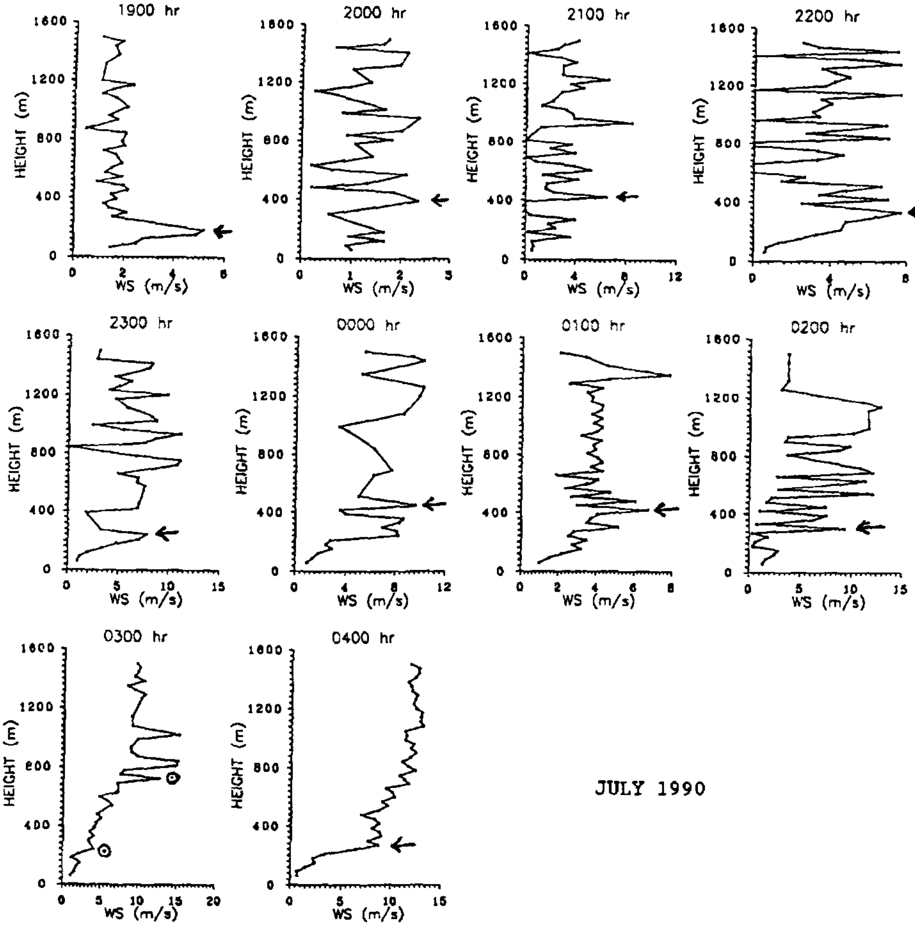

Figure 4. Solar measured mean wind profiles from 1900 hr to 0400 hr for the month of July 1990.

wind profiles for the month of August. Time variation of the NBL height is shown in Figure 6. The NBL in July is higher by approximately 100 m than that in August during the period 2000–0100. During the early morning hours, i.e., 0300–0400, the NBL for August is relatively high compared to July. On average the NBL height (324 m) during the active phase (July) is more than that (296 m) during less active phase (August). To see the effect of clouds on the NBL height during the monsoon season (active and less-active phases), rainfall recorded in the monsoon period over Kharagpur (at Alipore, near Calcutta, nearly 80 km from Kharagpur) is also considered. The total rainfall recorded at Kharagpur in the months of July (901 mm) and August (134 mm) was taken as an indicator of cloud amount during that month. It shows that July is associated with relatively more monsoonal clouds compared to that in August.

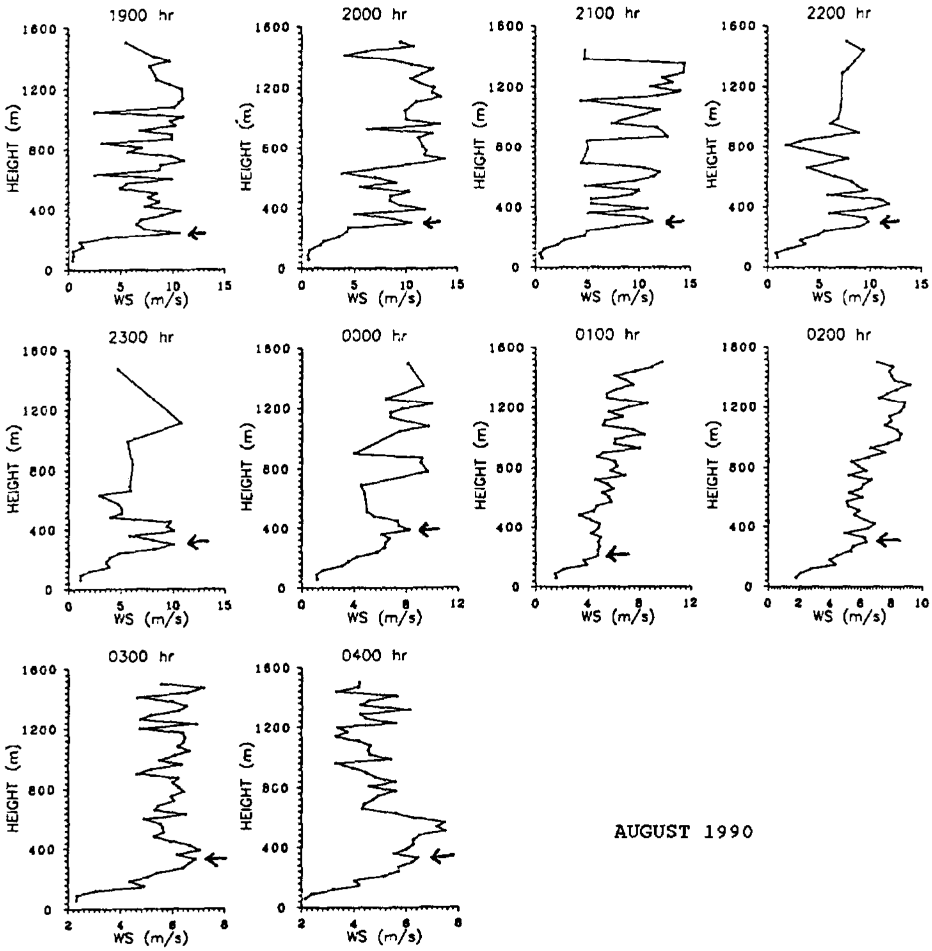

Figure 5. Sodar measured mean wind profiles from 1900 hr to 0400 hr for the month of August 1990.

For a given geostrophic wind speed, the NBL height is much influenced by radiative cooling of the surface, and hence cloud cover. Daytime generated turbulence is suppressed by the radiative cooling of the air during night time and the height of NBL, defined in terms of turbulence activity, is less under clear sky conditions. During the active monsoon phase (July) turbulence is less suppressed by radiative cooling because the sky was almost continuously overcast. So during the active phase, there is less tendency for the atmosphere to become stably stratified and for turbulence to reduce after sunset. Thus during the active phase turbulence is less suppressed during the night time and the height of the NBL is relatively high compared to that during the weak (less cloudy) phase of the monsoon. It indicates that clouds can play a very important role in determining the NBL height during the monsoon season.

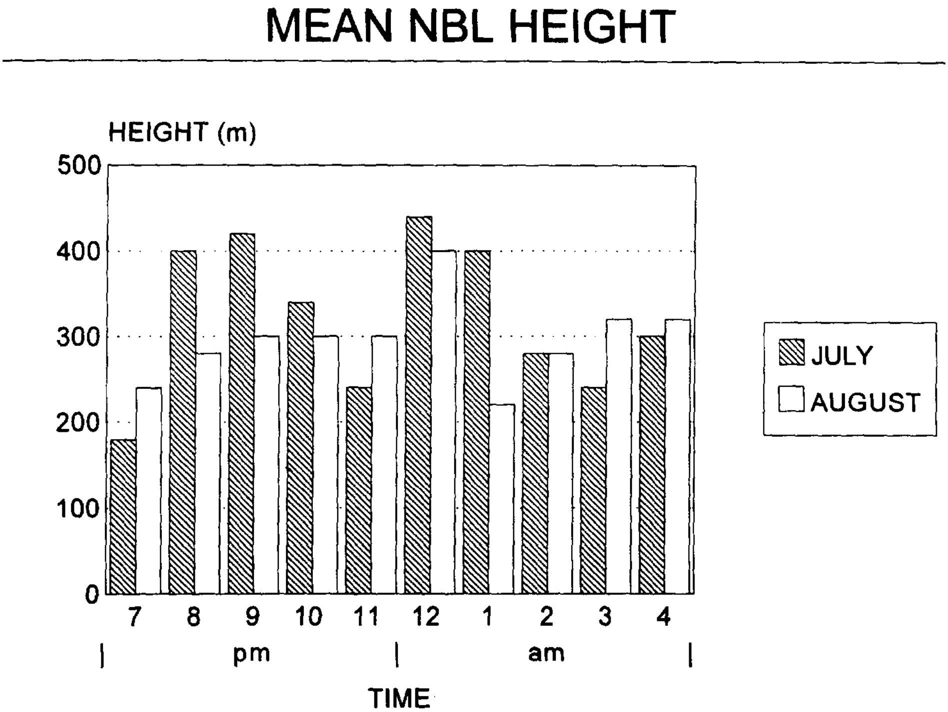

Figure 6. Time variation of NBL height for the months of July and August 1990.

5. Summary

The mean NBL height over Kharagpur for the months of July and August 1990 have been determined using the sodar-measured hourly wind profiles, using the criterion of 'low-level wind maximum'. The mean NBL height for the month of July is relatively high compared to that for the month of August. This may be due to the high cloud cover, high precipitation (July) and less radiative cooling of the surface during the active phase (July) of the monsoon.

Acknowledgments

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