Mausam, (1987), **38**, 4, 431-436

551.554:551.501.75

Wind profiles analysis near the ground

L. K. SADANI

Indian Institute of Tropical Meteorology, Pune

(*Received 2 August 1983*)

सार — प्रस्तुत अध्ययन में पुणे के ऊपर एक शीतकालीन महीने में पवन अनुप्रस्थकाट प्राचलों के मापन का वर्णन किया गया है। निम्नतम तीन मीटरों में दिन के विभिन्न घंटों के लिए घातांक 'a' का परिकलन किया गया है। घातांक का औसत मान 0.12 के बराबर पाया गया है। निष्क्रिय पवन अनुप्रस्थकाट के घर्षण वेग 'u_*' और अपरूपण प्रतिबल τ का परिकलन किया गया है।

क्षैतिज माध्यपवन रफ्तार भूमि के समीप एक सन्दर्भ ऊंचाई पर τ में वृद्धि प्रदर्शित करता है। शाम के समय (1900 – 2020 बजे) वायुमण्डलीय परतें स्थायी रूप से स्तरित पाई गई हैं।

ABSTRACT. The present study describes the measurement of wind profile parameters in a winter month at Pune. The power index "a" has been calculated for different hours of the day in the lowest 3 metres. The average value of power index is found to be equal to 0.12. The values of frictional velocity u_* and shear stress τ are calculated from neutral wind profile.

The horizontal mean wind speed shows increase in τ at a reference height near the ground. In the evening (1900 - 2020 hr) the atmospheric layers are found to be stably stratified.

1. Introduction

A number of studies have been made on shear stress and parameters of wind profiles for places other than those in Indian region. For this region not much attention appears to have been paid in this field, presumably because of lack of proper instrumentation support. The anemometer system of Thornthwaite Associates (1965) was mounted at Central Agro. Met. Observatory, Pune.

The wind observations were utilized to compute the power index a, frictional velocity u_* and shearing stress τ. The wind observations were taken at six different heights in the month of February 1977.

2. Data collection and utilization

The wind profile observations were taken at Central Agromet Observatory (18°32'N, 73°51'E), Pune from 11 to 18 February 1977. The anemometers height-interval on the mast were at doubling level to one another, starting from 10, 20, 40, 80 (check level) and 160 cm. The first cup sensor height is at 10 cm from the ground when the mast is fixed in the ground. The reason is that the vertical differences of wind speed $\triangle V$, tend to be same within lowest atmospheric levels if height difference $\triangle z$ increases upwards in the manner of a geometric series according to Lettau (Lettau 1966). The dates of data collection pertain to the period when the weather in and around Pune was clear.

Air temperatures were measured at standard heights of 0.0 (surface), 0.3 m (1 ft), .6 m (2 ft), 2.4 m (8 ft) and 3.6 m (12 ft) by using psychrometer at 0735 IST (7 LMT). The same method is adopted for routine microclimatic observations in the open at C.A.M.O. as per instructions in India Met.Dep. Agric. Tech. Circular No. 3. The psychrometer can record the difference of temp. up to 0.1°C, so the variation of temp. recorded in the observations come under the sensitivity limit of the psychrometer.

The soil temperature observations were also taken for the same hours with the help of soil thermometers installed up to a depth of 50 cm.

The observations were taken to see only the atmospheric condition during that time near the ground.

3. Instrumentation

The anemometers are designed for sensitive operation. The anemometer cups are of light weight plastics re-enforced with aluminium rings. The entire cup assembly weighs less than 7 gm. The shutter mounted on the other end of shaft of the anemometer makes and breaks a beam of light focussed on the photo cell mounted in the horizontal support of the anemometer one for every rotation of cup assembly. The photo cell current is transmitted by means of an amplifier. Input current to the amplifier varies below 30 microamps when dark condition and 150 microamps or more for light condition of photo cell.

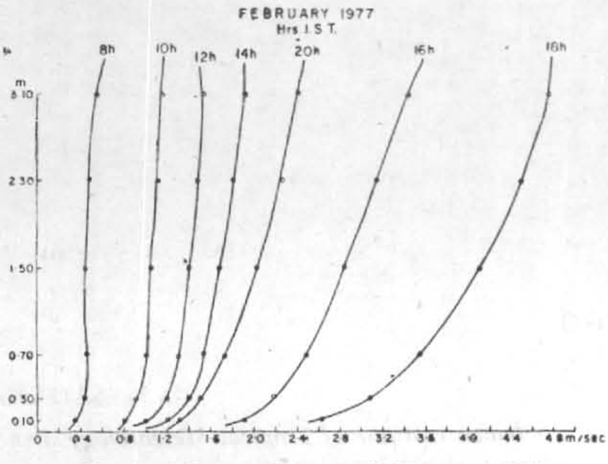

Fig. 1. Wind profiles of 13 February 1977

The output of the amplifier is connected to electromechanical counter.

One count is registered for every rotation of cup assembly. From the No. of counts/minute, wind speed in m/s were computed from tables provided for this purpose by the manufacturer. The accuracy of (Thornthwaite associate 1965) wind speed measurement is $\pm$ 0.55 m/s. This system works on a power supply of 12 V and draws a current of about 1 amp.

4. Theory

The simplest relation between wind speed u and height z can be expressed by a power law:

$$u = u_1 z^a \text{ or } \log u - \log u_1 = a \log z \qquad (1)$$

in which u_0 is the wind speed at a reference height arbitrarily taken as 0.1 m and exponent a is the constant.

For neutral or adiabatic equilibrium we have Prandtl (1957) law :

$$u = \frac{u_*}{K} \ln\left(\frac{z}{z_0}\right) \qquad (2)$$

where u_* is the velocity of shear, an indicative of the amount of turbulence and is independent of height for a given wind profile. K is the Von Karman constant and z_0 is the roughness parameter. The constant K has been evaluated in various ways and was found to be approximately equal to 0.4 (a dimensionless number for the layer of air close to the ground).

The relation (2) can be expressed as follows :

$$u = c \log (z/z_0) \qquad (3)$$

where, $c = u_*/K$

According to Deacon (1953), the simplest relation between wind speed and height is :

$$\frac{du}{dz} = c.z^{-\beta} \qquad (4)$$

where the factor β is called stability factor, depends on the temperature structure. In the neutral stability conditions $\beta = 1$ and the Eqn. (4) reduces to the Prandtl's equation as given in Eqn. (3). When the atmosphere is stable, wind strength increases with height, *i.e.*, the shear is greater than of neutral stablility condition. In such case β is less than 1.

TABLE 1

Average values of power index "a"

Time of the day (IST)	Average value of "a"
0800	0.0879
1000	0.1197
1200	0.122
1400	0.1454
1600	0.1722
1800	0.1587
2000	0.129

The shearing stress τ is found to be proportional to the square of the wind velocity at some arbitrary reference height.

Thus, with the introduction of u_* for which the square law holds exactly, we get

$$u_*^2 = \tau/\rho \qquad (5)$$

where ρ is the density of air. Evaluating u_* from the slope of the st. line of Eqn. (3) above. Then Eqn. (5) can be used to compute τ .

5. Analysis

(*i*) *Computation of power index*

The day of 13 February is arbitrarily chosen because there is good separation between hourly wind profiles during the day time (Fig. 1) in comparison to other dates.

Fig. 1 suggests that profiles obey power law as given in Eqn. (1) above. The data for the period from 11 to 18 February have been used in calculating the power index a and its values are shown in Table 1 for different hours of a day.

To determine a the wind profiles were plotted on a double logarithmic graph, and are shown in Fig. 2. The angle of inclination of the line with log z axis was determined. The tangent of this angle gave a value of a on account of Eqn. (1).

The average derived value of the constant a is 0.12 while the earlier reported value 0.28 is based on the measurement made in linder by Hening (1957). It is seen that the value of a increases with the time of the day reaching a peak at 1600 hr and falling subsequently. Similar variations of a have been reported by Rudolf Geiger (1975).

(*ii*) *Shape of the profiles*

Wind variation with height under neutral stability condition has been found to be accurately described by Eqn. (3). The wind observations are plotted on the

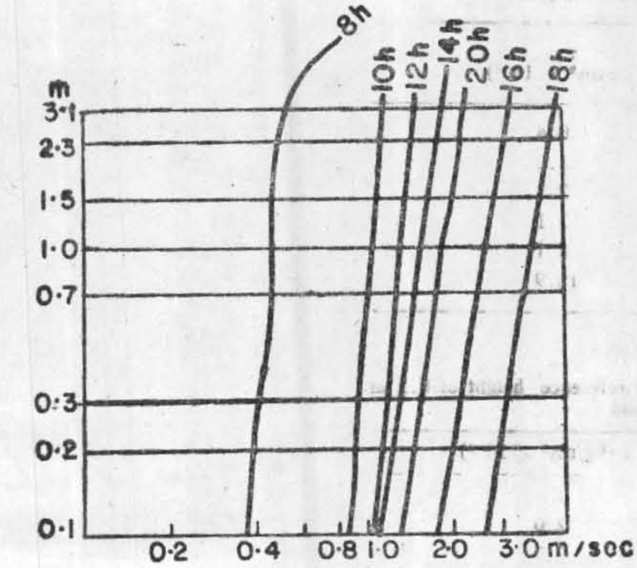

Fig. 2. Wind profiles on double logarithmic graph of 13 February 1977

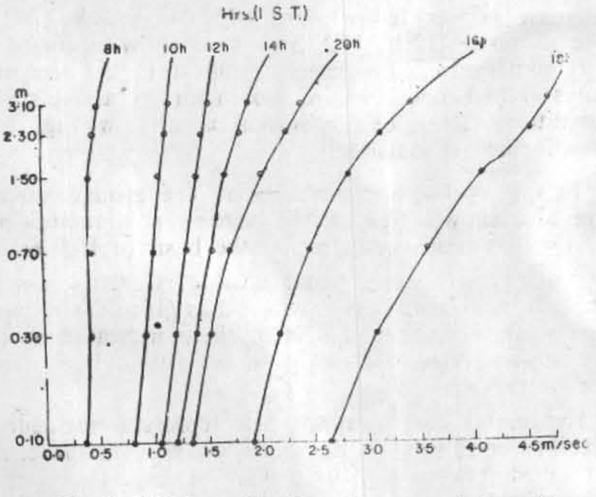

Fig. 3. Wind profiles (*e.g.*, Ln z *vs.* wind speed) according to logarithmic law of 13 February 1977

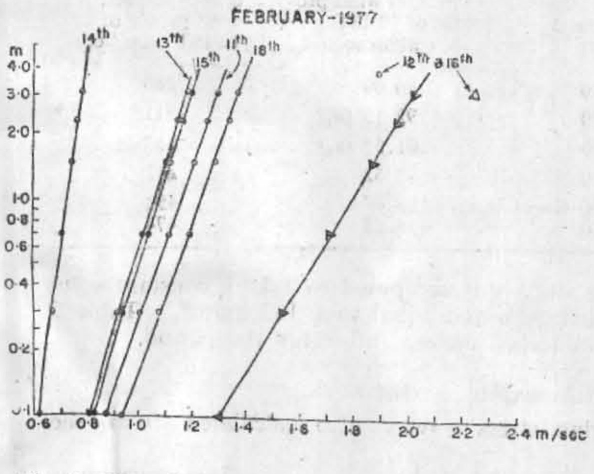

Fig. 4. Neutral stability wind profiles of 10 IST

graph, with natural logarithmic of the height (ln z) as the ordinate and wind speed as the abscissae. The Fig. 3 shows one such wind profiles plot of 13 Feb at an interval of every 2 hr from 8 to 18 IST. It is seen in Fig. 4 that the wind profiles are concave towards u axis.

According to Rudolf (1975) the curvature in wind profiles is due to the temperature structure and is lowest in the 2 metres layer from the ground but in our studies (Fig. 3) the wind profiles start curving at height 0.7 m instead of 2 m from the ground.

(iii) Computation of u_* and τ

It is seen from Fig. 4 that the wind profile of 10 IST is st. line in nature, which is due to neutral stability condition of the atmosphere as per Eqn. (3). To ascertain the st. line nature of wind profiles of 10 IST of other days, the 10 IST profiles of the period from 11 to 18 Feburary are given in Fig. 4.

The frictional velocity u_* was computed from the slope of these st. lines, taking value of constant K equal to 0.4. Using u_* values in Eqn. (5), the term

TABLE 2

Values of u_* and τ from neutral wind profiles

u_* (m sec^{-1})	τ (kg/ms^2 $\times$ 10^{-3})
0.019	0.4
0.03	1.0
0.043	2.1
0.05	2.1
0.08	8.1
0.1	12.9

TABLE 3

Wind speed $\bar{u}$ *vs.* shear stress τ at the reference height of 0.1 m from the ground

$\bar{u}$ (m/s)	τ (kg/ms^2 $\times$ 10^{-3})
0.68	1.1
0.8	2.0
0.82	2.2
1.06	3.0
1.31	7.0
1.61	12.9

TABLE 4

Neutral and stabily layered wind profile of 13 February 1977

z height from the ground (cm)	Neutral wind profile of 10 IST u(cm/sec)	Stabily layered wind profile of 18 IST u(cm/sec)
10	80.09	266
30	92.19 (u_1)	311
70	101.52 (u_2)	357
150	107.52	412
230 (check level)	113.47	452
310	116.25	474

shearing stress was computed by taking constant value of air density ρ and equal to 1.183 kg/m^3. Table 2 shows values of the u_* and τ for the period.

(*iv*) *Relationship $\bar{u}$ and τ*

Shearing stress τ was also calculated from the equation $\tau = K^2 z^2 \left(\frac{\Delta \bar{u}}{\Delta z} \right)^2$. This equation is valid for neutral wind profile (Oke 1978), where $\bar{u}$ is an average wind speed at some reference height above the ground. Table 3 shows computed values of τ and $\bar{u}$ at reference height of 0.1 m from the ground.

The graph of τ *vs.* $\bar{u}$ is shown in Fig. 5.

It is seen from Fig. 5 that relationship between these two is exponential in nature.

(*v*) *The temperature effect*

The condition pre-supposed in formulating the wind law in Eqn. (3) must be of neutral condition of the atmosphere. The pattern corresponding to neutral condition or more closely prevail in the morning hours, when the night inversion has broken down nd before *diurnal heating* has set in.

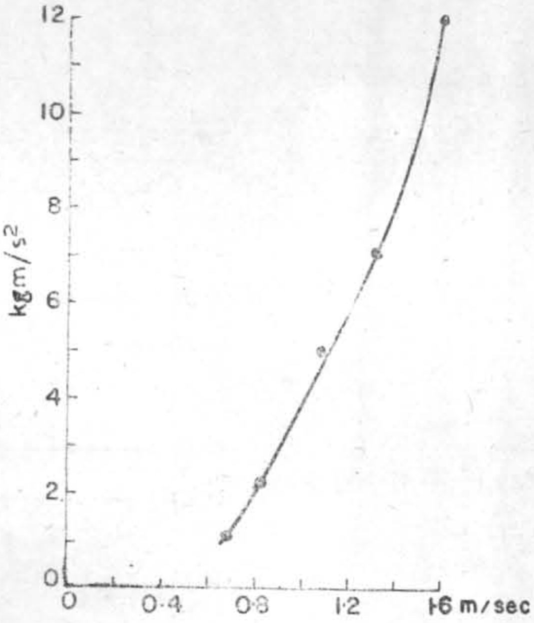

Fig. 5. Shear τ *versus* average velocity

To observe neutral wind profile near the ground, the temperature profiles of 0735 IST were examined in the light of above condition. Fig. 6(a) gives a graph of such temperature profiles for the observed period. The profiles of 11, 12, 16, 17 and 18 February show increase of air temperature with the height. While the graph of 13th, 14th and 15th show decrease of air temperature with height. Arbitrarily, the temperatures of 13 February were chosen for the above stated conditions. The plot is shown separately in Fig. 6(b) for further discussion.

In Fig. 6(b) temperatures below the ground surface are also shown. The dotted portion is simulated one and it has been simulated on the basis of Fig. 6(a).

The beginning of diurnal heating is clearly seen in the soil by flow of heat downward as far as 2 cm depth and weak indication of it, is in air as indicated by the temperature decrease with height (solid line) from the dotted line.

Hence, this state of atmosphere represents the neutral stability condition as described above. Therefore, the straight line wind plot of 10 IST of Fig. 4 is further ascertained for neutral wind profile.

The factor β of Eqn. (4) depends on the temperature structure. For neutral condition of atmosphere $\beta = 1$ and the 1st and 2nd columns of Table 4 show such a plot of wind profile for the above example.

(*vi*) *Stable case of wind profiles*

In the case of stable atmosphere the increase of wind strength with height is greater than of neutral stability and so β becomes less than 1. A comparison has been made of neutral wind profile (of 10 IST) and to that of stable condition (at 18 IST). This is given at 2nd and 3rd columns of Table 4 for 13 February 1977. It is evident from the table that wind under stable conditions far exceeds those under neutral stability conditions.

Wind profiles at 1800 IST for a period from 11 to 17 February 1977 have been shown in Fig. 7.

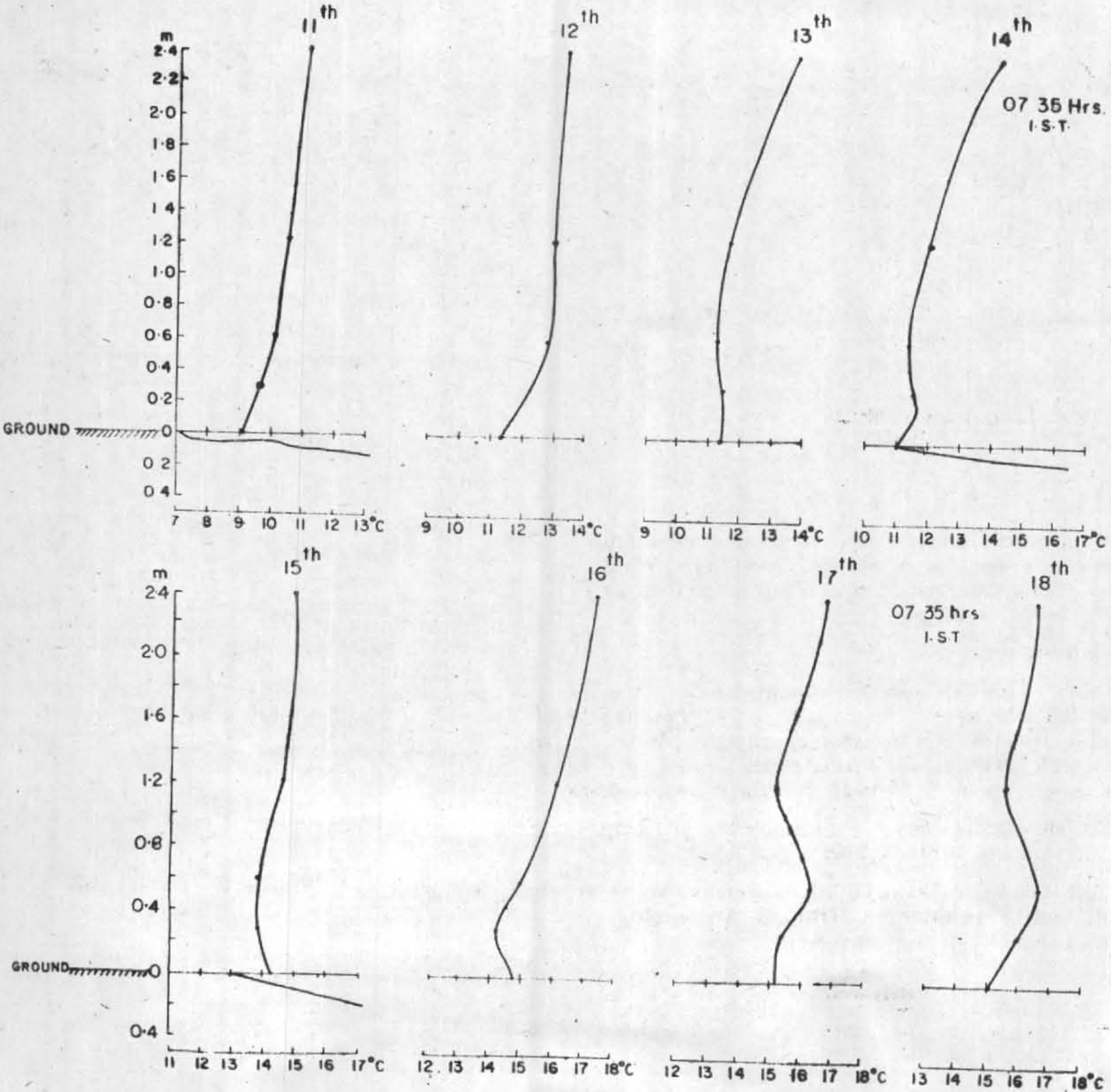

Fig. 6(a). Temperature profiles from 11 to 16 February 1977

Under the stable conditions the wind law $u = c \log z$ develops a concave-curvature toward u axis.

(*vii*) *Computation of neutral wind profile*

The value of β is computed for the height of 0.5 m. Computation of β from Eqn. (4) is :

$$c = \frac{u_*}{K} = \frac{0.0445}{0.4} = 0.1125$$

$$z = \frac{0 \cdot 3_{(u_1)} + \cdot 7_{(u_2)}}{2.0} = 0 \cdot 5 \text{ m}$$

$$dz = 0.7\,(u_2) \;-\; 0.3(u_1)$$

$$du = 9.33 \text{ m/s}$$

$$\frac{du}{dz} = 0.23325$$

Putting the value of c, z and du/dz in the equation $du/dz = cz^{-\beta}$, we get :

$$\beta = 1.06807$$

Thus, the neutral stability conditions (*i.e.*, $\beta = 1$) is apparently borne out from the above calculations as is the case in the above equation where $\beta \simeq 1$.

6. Conclusion

In this study, it is found that the average power index, $a = 0.12$, while Henning (1957) cites average value of $a = 0.28$. It reaches peak value equal to 0.1722 at 16 IST.

The dependence of wind increase on the temperature is lowest up to 0.7 m level from the ground but other researchers cite the lowest limit of 2 m from the ground.

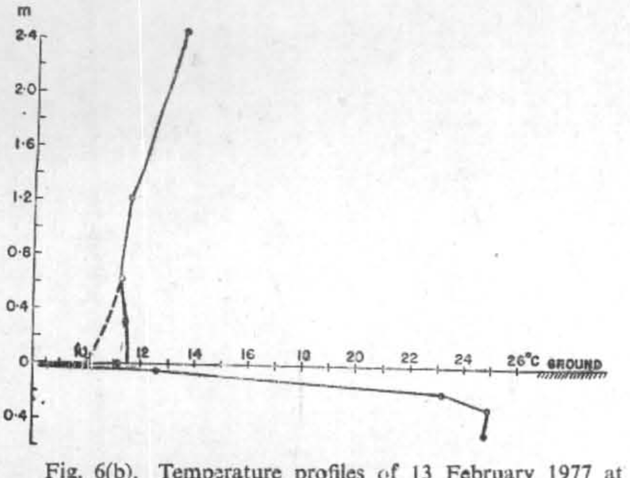

Fig. 6(b). Temperature profiles of 13 February 1977 at 1735 IST (7 LMT)

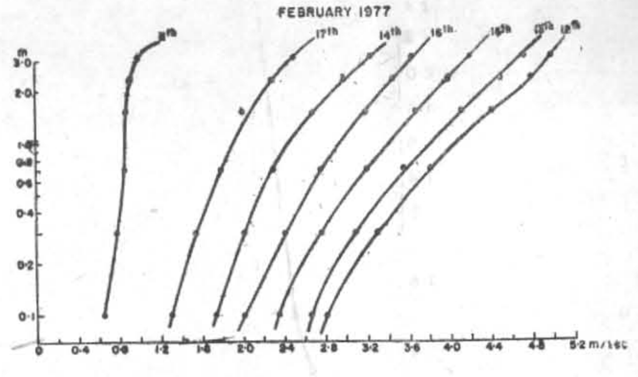

Fig. 7. Stable case wind profiles of 18 IST

The wind speeds under stable conditions are more than those of under neutral stability conditions. Wind speeds in stable case are 3 to 4 times more than of neutral stability conditions.

Acknowledgements

The author wishes to express his thanks to Shri A.B. Sathe for the collection of data and Shri T.D. Pradhan and staff of Central Agrometeorological Observatory, Pune for their co-operation during experiment. Useful discussions with Shri A.B. Chowdhary are acknowledged.

Thanks are due to Shri U.P. Raibole for his help in the preparation of the paper.

The author wishes to thank Dr. Bh. V. Ramana Murty, Director, Indian Institute of Tropical Meteorology, for permission to publish this work.

References

C.W. Thornthwaite Associates, 1965, *Operating instructions for wind profile register system.*

Deacon, E.L., 1953, Vertical profiles of mean wind in the surface layers of the atmosphere. *Geophys. Mem.*, **11**, Nr. 91, London.

Henning, H., Pico, 1957, Aerologische unter suchungen uher temperature and wind verhaltmiss d badmahan luftschichtleis, 10 m Hohe in Lindeu berg abh Met D DDR6, Nr 42, 1-166.

Lettau, H.H., 1966, *Problems of micrometeorological measurements. The collection and processing of field data—a CSIRO Symposium,* Inter Science Publishers, a division of John Wiley & Sons, New York.

Oke, T.R., 1978, *Boundary layer climates*, Methuen & Co. Ltd., London.

Prandtl, L., 1957, Fuhrer durch die stromugslehre, 5 aufl Fr Viewg Braunschweg.

Rudolf Geiger, 1975, *The climate near ground,* Harward University Press, Cambridge, Massachusetts, London, England.

Sutton, O.G., 1932, Note on the variation of the wind with height, *Quart. J.*, **58**, 74-76.