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TURBULENCE PARAMETERS FOR A DUSTY ATMOSPHERE

1. The thermodynamic properties of air-particle mixture are different. At high particle mass fractions the particle volume fraction may become sufficiently large so that it should not be neglected while analysing air flows. It is, therefore, of interest to investigate how the meteorological parameters are affected by the presence of a finite volume fraction of the particles. The presence of this particle cloud in the atmosphere may aggravate some aspects of pollution problems in localized areas by affecting important meteorological parameters. The effect on the thermal regime of coarser dust, which does not ascend above the lower layers of the troposphere, has yet been insufficiently studied. In this note we have discussed the effect of these coarser dust particles on the turbulence parameters like friction velocity U_* and friction temperature θ_*. These parameters are very important for air pollution modelling studies. The turbulence parameters are calculated using wind and temperature measurements in the surface layer, based on Monin-Obukhov similarity theory for different values of volume fraction of the particles.

2. The simplifying assumptions given below following Rudinger (1965) for air-particle mixture are assumed :

(*i*) The air-particle mixture is considered as continuum.

(*ii*) The pressure of the particles is neglected.

(*iii*) There is no direct interaction of particles with each other.

(*iv*) The velocity and temperature of the particles are equal to that of air.

(*v*) The air is assumed to be have as an ideal gas and specific heat at constant pressure, c_p, and the specific heat ratio γ are constant.

The potential temperature, θ, the surface sensible heat flux, H, and the potential temperature gradient, γ_p, for a dust laden atmosphere are reduced to the following form :

$$\theta = T\left(\frac{1000}{p}\right)^{\frac{(\gamma-1)}{\gamma(1+\eta\delta)}} \tag{1}$$

$$H = \frac{-\gamma_p(1-\epsilon)(\zeta-1)}{T(\gamma-1)}\, U_*\,\theta_* \tag{2}$$

$$\gamma_p = \left(\frac{dT}{dz}\right)_{\rm conv} - \left(\frac{dT}{dz}\right)_{\rm adia} \tag{3}$$

where, p, T, U_* and θ_* are pressure, temperature, friction velocity and friction temperature respectively. z is the vertical height in the PBL, and η, δ, ϵ, ζ, are the dust loading ratio, ratio of specific heat of the particles to specific heat of the air at constant pressure, volume fraction of the particles, and ratio of the material density of the particles to the material density of the air respectively, $(dT/dz)_{\rm adia}$, for dusty air is reduced to the following form :

$$\left(\frac{dT}{dz}\right)_{\rm adia} = \frac{-g}{c_p}(1-\epsilon)\left[\frac{1+\epsilon(\zeta-1)}{1+\epsilon(\zeta\delta-1)}\right] \tag{4}$$

The turbulence parameters are calculated following Berkhowicz and Prahm (1982). The mixing depth, z_i, is calculated with the method followed by Venkatram (1978).

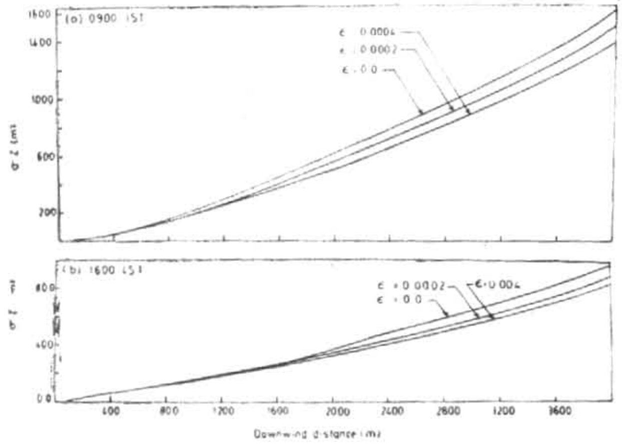

Fig. 1. Vertical dispersion parameter for different values of ϵ at at (a) 09 IST and (b) 16 IST for the month of March of the city of Delhi

3. The mean hourly data of net solar radiation surface wind speed, and surface air temperature is obtained from solar radiation data (Mani 1980). The net radiation is the difference between the total incoming short wave and long wave radiation and the outgoing short wave and long wave radiation. The data is based on careful measurements made over about 20 years, at radiation stations, operated and maintained by the India Meteorological Department.

4. Hourly variation of friction velocity, friction temperature, convective velocity scale, Monin-Obukhov length scale, mixing depth during day time for convective, boundary layer and stability parameter is shown Table 1 (a-f). These parameters are calculated for the month of March of the city of Delhi. These parameters are calculated for different values of volume friction of particles, ϵ, to show the sensitivity of these parameters to dust.

Table 1 shows that as the volume fraction of particles increases there is a decrease in the values of friction velocity, friction temperature, convective velocity scale, mixing depth and stability parameter, and an increase in the value of Monin-Obukhov length scale. The decrease in the mixing depth in the dusty atmosphere is due to the fact that the equivalent potential temperature gradient for dusty atmosphere increases with dust loading. A decrease in the stability parameter z_i/L with an increase in volume fraction of particles shows that the decrease in z_i is more pronounce than the increase in L with an increase in volume fraction of particles. Weil and Brower (1982) have classified convective neutral stabilities on the basis of convective velocity scale W_* as follows :

$\frac{U}{W_*} < 3.5$ extremely unstable condition

$3.5 < \frac{U}{W_*} < 6$ moderately unstable condition

TABLE 1

Hourly variation of the (a) friction velocity, (b) friction temp, (c) convective velocity, (d) Monin-Obukhov length, (e) mixing depth and (f) stability for different values of ϵ for the month of March of the city of Delhi

ϵ	Time hours (IST)							
	9	10	11	12	13	14	15	16
(a) Friction velocity [U_* (m s^{-1})]								
0.0000	0.581	0.590	0.634	0.667	0.679	0.692	0.682	0.671
0.0001	0.526	0.584	0.628	0.661	0.673	0.687	0.678	0.668
0.0002	0.522	0.579	0.623	0.656	0.668	0.682	0.673	0.665
0.0003	0.518	0.575	0.618	0.651	0.663	0.678	0.670	0.663
0.0004	0.515	0.571	0.614	0.647	0.659	0.674	0.666	0.660
(b) Friction temperature [θ_* ( )]								
0.0000	0.143	0.213	0.247	0.255	0.251	0.214	0.164	0.096
0.0001	0.136	0.195	0.226	0.235	0.230	0.196	0.150	0.088
0.0002	0.125	0.181	0.209	0.217	0.212	0.181	0.138	0.081
0.0003	0.116	0.168	0.195	0.202	0.198	0.168	0.128	0.075
0.0004	0.109	0.157	0.182	0.189	0.185	0.157	0.120	0.069
(c) Convective velocity scale								
0.0000	1.43	1.71	1.86	1.93	1.94	1.85	1.68	1.39
0.0001	1.35	1.61	1.75	1.87	1.83	1.75	1.59	1.81
0.0002	1.28	1.53	1.67	1.78	1.74	1.66	1.51	1.25
0.0003	1.23	1.47	1.60	1.66	1.67	1.60	1.45	1.20
0.0004	1.19	1.42	1.54	1.60	1.61	1.54	1.40	0.16
(d) Monin-Obukhov length scale, L(m)								
0.0000	143.4	124.1	124.6	133.6	141.7	173.3	219.5	361.9
0.0001	153.5	132.5	133.1	142.9	151.6	185.9	236.4	392.0
0.0002	163.4	140.9	141.5	152.0	161.4	198.5	253.1	422.1
0.0003	173.3	149.1	149.7	161.0	171.1	210.9	269.7	452.1
0.0004	183.0	157.2	157.9	169.9	180.7	223.3	286.2	482.0
(e) Mixing depth, z_i (m)								
0.0	1128	1200	1257	1298	1323	1332	1323	1298
0.0001	1039	1105	1158	1196	1219	1227	1219	1196
0.0002	979	1042	1091	1127	1149	1156	1149	1127
0.0003	936	995	1043	1077	1098	1105	1098	1077
0.0004	903	960	1006	1039	1059	1066	1066	1059
(f) Stability parameter, (z_i/L)								
0.0	7.86	9.67	10.0	9.72	9.34	7.69	6.03	3.59
0.0001	6.77	8.34	8.70	8.37	8.04	6.60	5.16	3.05
0.0002	5.99	7.40	7.71	7.42	7.12	5.83	4.54	2.67
0.0003	5.40	6.68	6.97	6.69	6.42	5.24	4.07	2.38
0.0004	4.93	6.11	6.37	6.12	5.86	4.78	3.70	2.16

We found that the ratio U/W_* for $\epsilon = 0.0$ and $\epsilon = 0.0004$ at 16 IST is 3.3 and 4.04 respectively. Hence, volume fraction of particles equal to 0.0004 transforms an extremely unstable PBL to a moderately unstable PBL. Fig. 1 shows the vertical dispersion parameter at 9 IST and 16 IST respectively. The figures illustrate that the vertical dispersion parameter decreases with an increase in the volume fraction of particles.

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