A comparative analysis of the characteristics of the Marine Boundary Layer with GCM and 1-D PBL model simulations using INDOEX IFP-99 data

Swati Basu*, R. K. Paliwal*, A. N. V. Satyanarayana[†], U. C. Mohanty[†,§], V. N. Lykossov[‡] and N. V. Sam[†]

*National Centre for Medium Range Weather Forecasting, Mausam Bhavan Complex, Lodi Road, New Delhi 110 003, India
[†]Centre for Atmospheric Sciences, Indian Institute of Technology, New Delhi 110 016, India
[‡]Institute of Numerical Mathematics, Moscow, Russia

Glass-sonde observations consisting of wind, temperature and relative humidity at different pressure levels that were obtained on board ORV *Sagar Kanya* cruise #141 (INDOEX IFP-99), during winter monsoon of 1999 were used for the present study. An attempt has been made to compare the simulation of the evolution of the Marine Boundary Layer as obtained from the one-dimensional PBL model of IIT Delhi, having TKE-*e* closure scheme with that obtained from the GCM of NCMRWF having first order closure scheme. Simulation of various boundary layer characteristics including surface and upper air has been studied. The model simulations are compared with the available observations. Both the models simulated the vertical profiles reasonably well compared with the observations.

ANALYSIS of marine boundary layer structure and its interaction with sea surface are crucial and important in understanding the air–sea interaction processes, including genesis of lows and depressions. Bunker[1] had made a few marine boundary layer measurements. Pant[2] using the ISMEX data sets studied the vertical structure of the marine boundary layer in the West Indian Ocean. Holt and Raman[3] studied the mean and turbulence structure of the monsoon MBL over the Bay of Bengal during MONEX-79. It is important that the boundary layer structure be represented in a most realistic manner in the numerical models in order to obtain meaningful prediction of weather systems. INDOEX IFP-99 data provided an opportunity to evaluate the boundary layer structure as simulated by the operational global spectral model at National Centre for Medium Range Weather Forecasting (NCMRWF) having first order closure scheme for the boundary layer along with those obtained by the one-dimensional PBL model at Indian Institute of Technology (IIT) Delhi with TKE-*e* closure scheme. In the present article the vertical profiles of zonal and meridional wind components, potential temperature, specific humidity, fluxes of sensible and latent heat, drag coefficients of momentum (C_D) and heat (C_T) over Indian ocean using both NCMRWF–GCM and one-dimensional PBL model have been attempted including intercomparison. The evolution of turbulent kinetic energy using one-dimensional PBL model is also presented. This study provided not only an insight to the impact of different schemes of the boundary layer but also provided information about usage of a global and one-dimensional model in simulating certain features of the marine boundary layer.

Data

As part of the Indian component of INDOEX IFP-99 experiment, the upper air observations were obtained using glass sonde onboard ORV *Sagar Kanya* during 21 January–12 March 1999. The observations consist of zonal and meridional wind components, temperature, relative humidity at various pressure levels. The data made available for the present study were classified into two sets with different synoptic situations. The first set of data (6–7 February 1999, 20°S, ~ 73.14°–69.15°E, hereafter referred to as case-1) was in the vicinity of the convective zone and the second one (1–2 March 1999, ~ 12.12°–14.22°S, ~ 60.5°E, hereafter referred as case-2) featured calm conditions. For cruise track of ORV *Sagar Kanya* cruise #141 during the IFP-99 field campaign, please see figure 1 of Introductory Note.

Description of the schemes

PBL parameterization scheme of global spectral model

The description of the operational model at NCMRWF is given in Basu *et al*.[4]. The PBL parameterization uses first-

[§]For correspondence. (e-mail: mohanty@cas.iitd.ernet.in)

order closure approximation whereby the turbulent fluxes are correlated with the mean vertical gradients through the eddy diffusivities. These eddy diffusivities are stability dependent (depending upon the bulk Richardson number) and are determined through mixing length considerations. Details of the scheme are given in Basu *et al.*[4].

One-dimensional PBL model of IITD

The one-dimensional model used in the present study has 40 levels in the vertical and the top of the model domain was 2000 m. In this model TKE-*e* closure scheme is incorporated. For the surface layer, Monin–Obukhov similarity was utilized. The lower boundary conditions are provided using the observed surface synoptic observations consisting of pressure, sea surface temperature, wind and humidity. The initial conditions consist of the vertical profiles of zonal and meridional wind components, potential temperature and specific humidity. A detailed description of the model is given in Satyanarayana *et al.*[5].

Initial conditions

Two sets of data as stated earlier were utilized in the two schemes. For case-1, the one-dimensional model is integrated for 31 h with an initial condition of 05 UTC on 6 February 1999. In case-2, 16 h of integration were obtained with an initial condition of 08 UTC on 1 March 1999. The global model on the other hand was run for 72 h, with initial condition of 00 UTC of 6 February 1999 and 1 March 1999.

The simulated vertical profiles of zonal and meridional wind components, potential temperature and specific humidity obtained from NCMRWF-GCM were extracted at the nearest grid points to the actual glass sonde observations from onboard ORV *Sagar Kanya*. These simulated profiles were compared with the actual observations. The one-dimensional model, on the other hand, was run at the specific location of the observations and the profiles were compared after different hours of integration. In all, there were about 28 profiles that were compared with the observations.

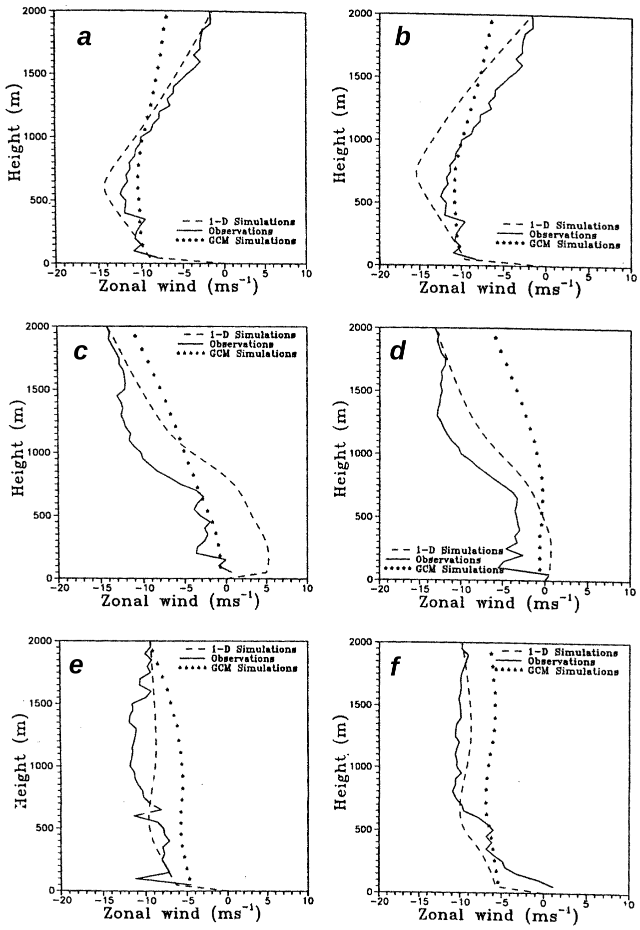

Figure 1. Simulated vertical profiles of zonal wind (ms^{-1}) on (***a***) 7–2–1999 at 09 UTC, (***b***) 7–2–1999 at 12 UTC, (***c***) 1–3–1999 at 10 UTC, (***d***) 1–3–1999 at 12 UTC, (***e***) 1–3–1999 at 20 UTC and (***f***) 2–3–1999 at 00 UTC along with the observations.

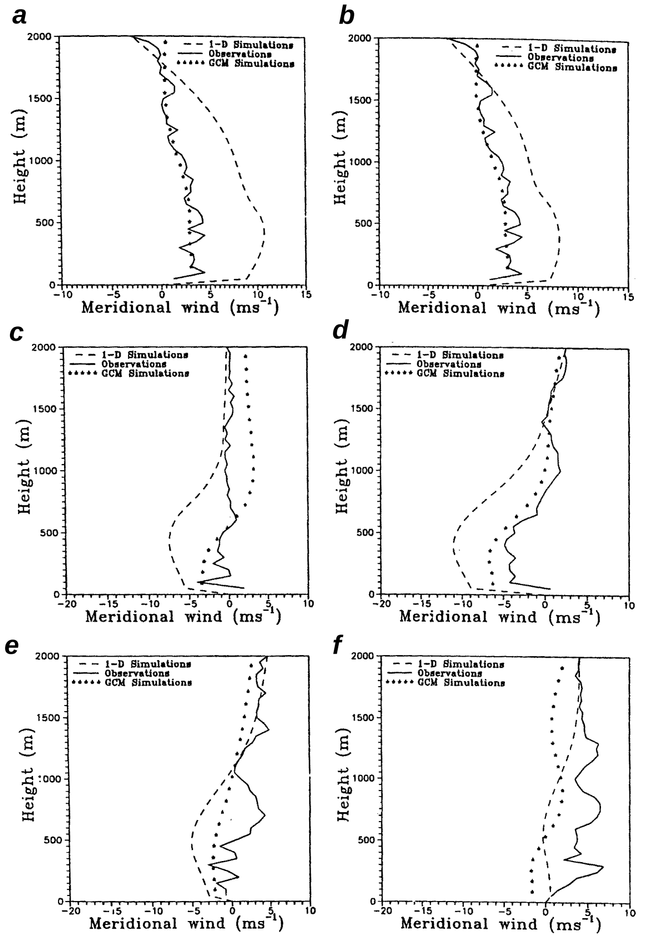

Figure 2. Simulated vertical profiles of meridional wind (ms^{-1}) on (***a***) 7–2–1999 at 09 UTC, (***b***) 7–2–1999 at 12 UTC, (***c***) 1–3–1999 at 10 UTC, (***d***) 1–3–1999 at 12 UTC, (***e***) 1–3–1999 at 20 UTC and (***f***) 2–3–1999 at 00 UTC along with the observations.

NCMRWF-GCM simulated surface parameters such as sensible heat flux, latent heat flux, C_D and C_T were compared with those of one-dimensional PBL model simulations.

Results and discussion

Figure 1 *a–f* shows the simulations of the zonal winds as obtained from the NCMRWF-GCM (hereafter referred to as GCM) and one-dimensional models (hereafter referred to as 1-D) along with the observations for the specific time intervals as indicated. Figure 1 *a–b* represents case-1 and Figure 1 *c–f* represents case-2. It is seen that GCM in general has a tendency to underestimate the magnitude and does not show variations in the profile pattern. 1-D on the other hand, shows a reasonably good profile pattern especially for the profiles of case-1.

The simulated meridional wind profiles obtained from GCM and 1-D along with the observations are shown in Figure 2 *a–f*. The simulations of case-1 and case-2 are presented in Figure 2 *a*, *b* and Figure 2 *c–f*, respectively. Close examination of the results reveal that the meridional wind profiles obtained from GCM is closer to the observations both in respect of magnitude as well as the variations compared to 1-D.

Figure 3 *a–f* shows simulated potential temperature profiles of GCM and 1-D along with the observations. As before, case-1 and case-2 are presented in Figure 3 *a*, *b* and Figure 3 *c–f*, respectively. From these figures one can see clearly that both GCM and 1-D compare well with the observations. The extent of the neutrally stable atmosphere as obtained from both the models compares well with the observations, especially for case-2. Figure 4 *a–f* shows the simulated specific humidity profiles using both GCM and 1-D. GCM is seen to underestimate the humidity (~ 2 g kg^{-1}) at the lower levels and overestimate the same at the higher levels. In contrast, it shows a reverse trend for case-2. 1-D on the other hand overestimates the humidity in case-2 and compares fairly well in case-1. However, by and large, both the models compare fairly well with the observations.

Figure 5 *a–d* and 5 *e–h* show the diurnal variation of surface fields, viz. sensible heat flux, latent heat flux, C_D

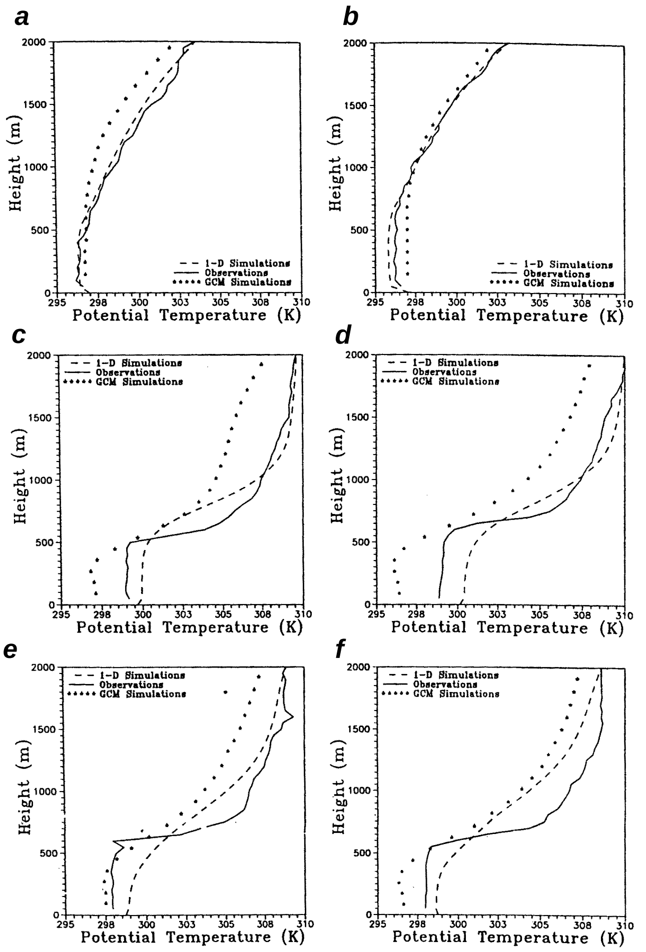

Figure 3. Simulated vertical profiles of potential temperature (K) on (***a***) 7–2–1999 at 09 UTC, (***b***) 7–2–1999 at 12 UTC, (***c***) 1–3–1999 at 10 UTC, (***d***) 1–3–1999 at 12 UTC, (***e***) 1–3–1999 at 20 UTC and (***f***) 2–3–1999 at 00 UTC along with the observations.

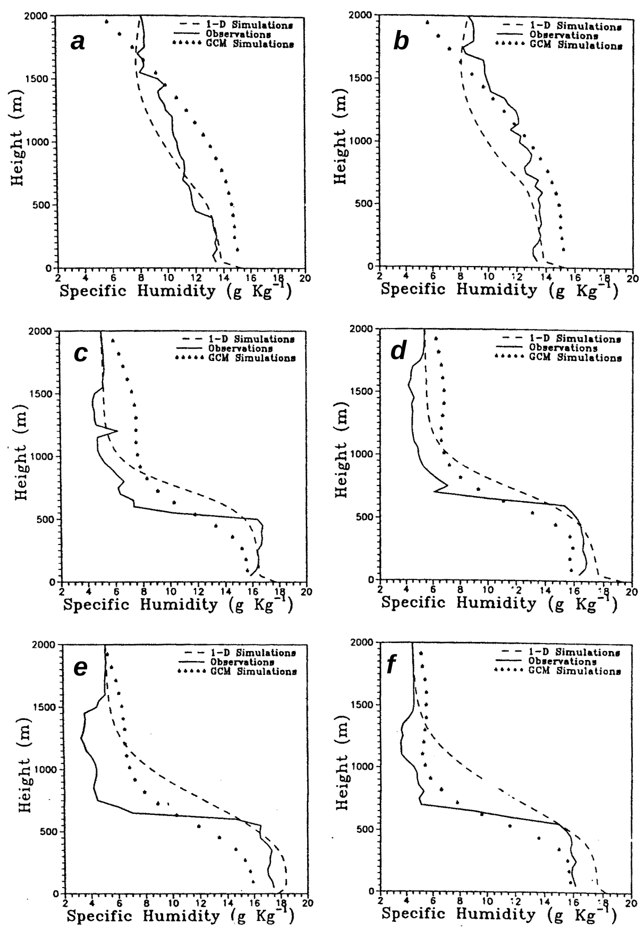

Figure 4. Simulated vertical profiles of specific humidity (g kg^{-1}) on (***a***) 7–2–1999 at 09 UTC, (***b***) 7–2–1999 at 12 UTC, (***c***) 1–3–1999 at 10 UTC, (***d***) 1–3–1999 at 12 UTC, (***e***) 1–3–1999 at 20 UTC and (***f***) 2–3–1999 at 00 UTC along with the observations.

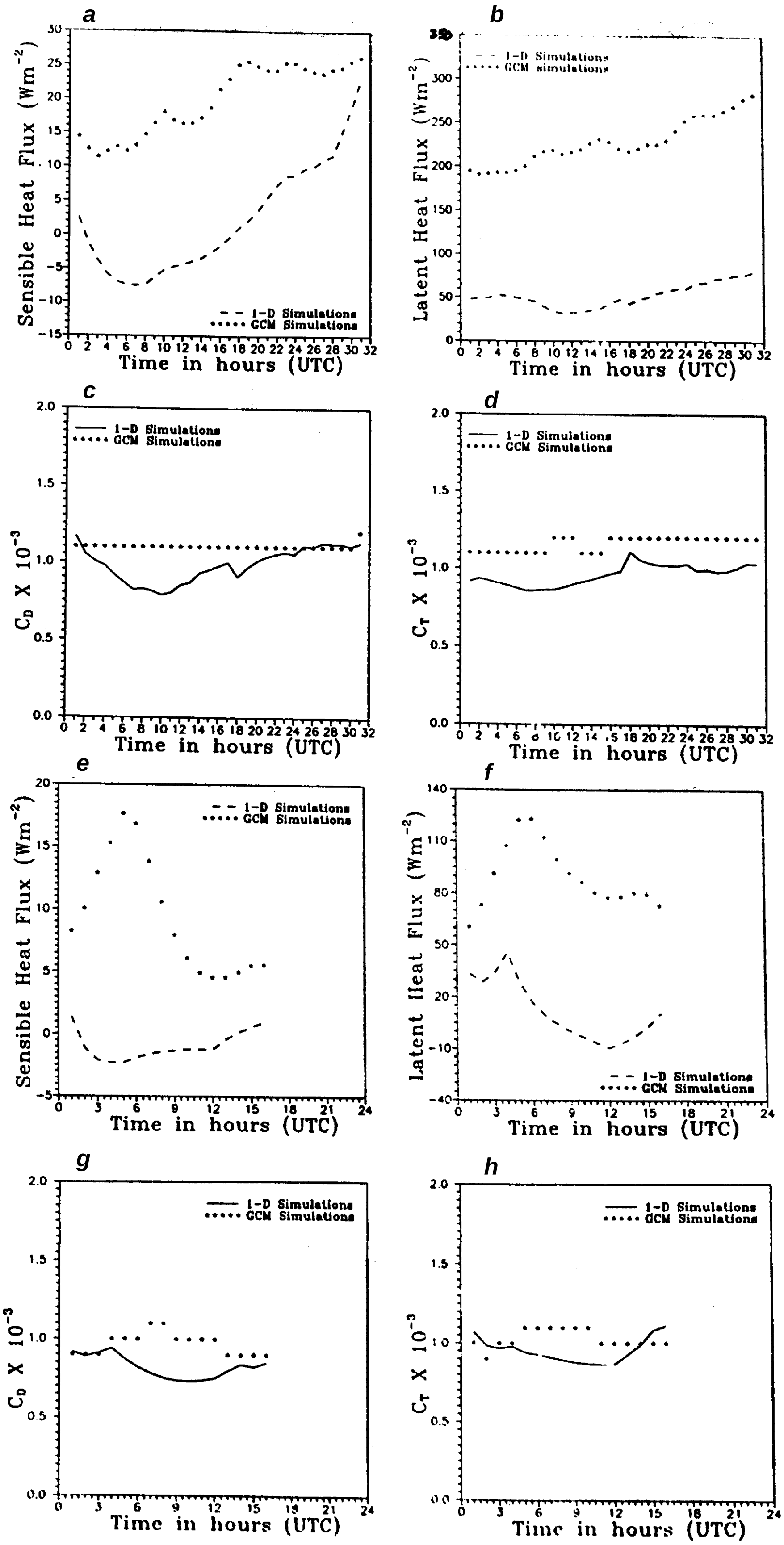

Figure 5. Diurnal variation of (***a***) sensible heat flux (Wm^{-2}), (***b***) latent heat flux (Wm^{-2}), (***c***) C_D, (***d***) C_T during 6–7 February 1999, (***e***) sensible heat flux (Wm^{-2}), (***f***) latent heat flux (Wm^{-2}), (***g***) C_D and (***h***) C_T during 1–2 March 1999.

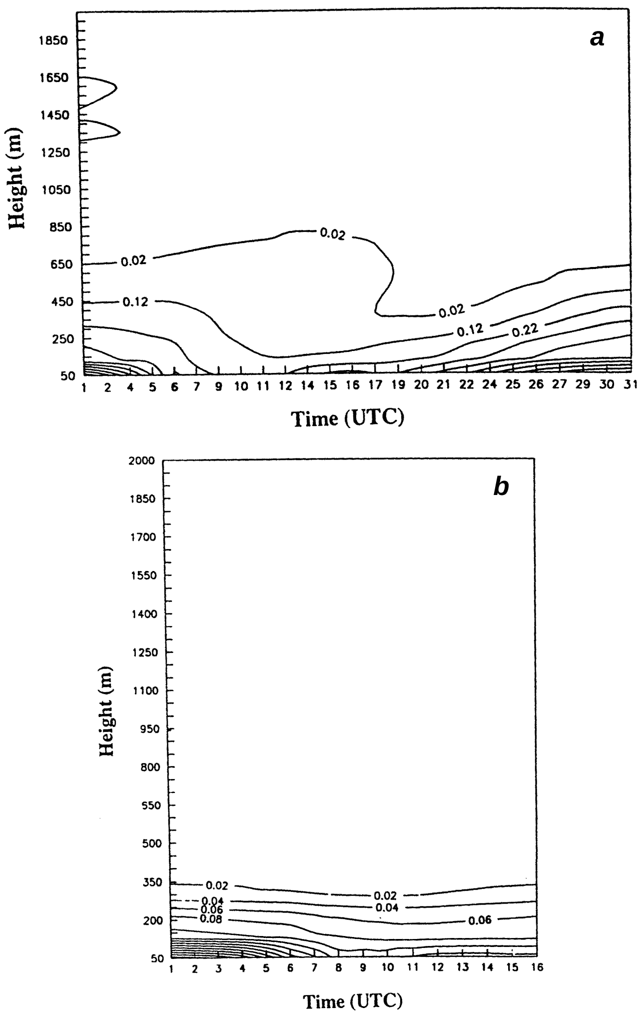

Figure 6. Time evolution of TKE (m^2s^{-2}) during (***a***) 6–7 February 1999 and (***b***) 1–2 March 1999.

and C_T for case-1 and case-2 respectively. It is seen that for both the cases, GCM simulated higher values of sensible and latent heat fluxes compared to 1-D. As far as the drag coefficients are concerned, GCM and 1-D values are found to be in good agreement[6]. Figure 6 *a*, *b* shows the TKE evolution for case-1 and case-2 using 1-D. As expected, during the case-1 when there was relatively more convective activity, the TKE generation was more and was seen to a higher vertical extent than that of case-2 when calm conditions prevailed.

Conclusions

The comparison of 1-D and GCM with INDOEX IFP-99 data shows that although different parameterization schemes for the boundary layer exist in both the models, nonetheless, the performance of the models as far as the marine boundary layer structure is concerned, is comparable with each other. The simple 1-D has a relatively sophisticated closure scheme for the PBL and the GCM has a fairly simple first-order closure approximation for the PBL. However in the latter case, there are other parameterization schemes for different physical processes, which do not exist in the 1-D. By and large, both of them compare reasonably well with the observations. However, there are some differences in the surface layer characteristics which exist in the form of fluxes, which have to be compared in detail with the estimated values when more observations are available.

1. Bunker, A., Proc. Symp. IIOE, Mumbai, 1965, pp. 3–16.
2. Pant, M. C., *Indian. J. Met. Hydrol. Geophys*., 1978, **29**, p. 88.
3. Holt, T. and Sethu Raman, *Mon. Wea. Rev*., 1986, **114**, 2176–2190.
4. Swati Basu, Raman, Sethu, Mohanty, U. C. and Rajagopal, E. N., *Pure Appl. Geophys*., 1999, **155**, 33–55.
5. Satyanarayana, A. N. V., Mohanty, U. C. and Sam, N. V., 1999, *Curr. Sci.*, **76**, 890–897.
6. Stull, R., *Introduction to Planetary Boundary Layer*, Kluwer Publishers, Dordrecht, 1988.

ACKNOWLEDGEMENTS. We are grateful to the CSIR, DOS, DST, New Delhi; the INDOEX India Programme Directorate and the Office of Naval Research, Washington, DC, USA for providing the necessary funds, and required facilities for the completion of this work.