Study of the variability of convective heating and moistening using Simplified Arakawa–Schubert convection scheme during INDOEX IFP-99

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A single column model (SCM) is used to study the thermodynamic characteristics of atmosphere over Indian ocean in two cases during INDOEX-99 (*Sagar Kanya* cruise). The first case represents a convectively-active (cloudy) day (4 February) and another convectively-suppressed (fair-weather) day (8 February). The objective of this paper is to study the variability of convective heating and moistening in the above two cases using Simplified Arakawa–Schubert convection scheme incorporated in the single column model. Vertical profiles of temperature, specific humidity, wind (*u*, *v*, *w*), sensible and latent heat fluxes, temperature and moisture advective forcings were used for the initialiazation of the SCM. The first three inputs of the above variables were obtained from the analysed data of the T80 Global Circulation Model in which INDOEX data were used for the data assimilation. The large scale advective forcings were also taken from the T80 GCM over the INDOEX observation points. The SCM has been integrated with 15 min time step in a fully prognostic way to obtain the convective heating, moistening, convective rainfall and cloud base mass flux for the above two dates. The results showed that the convective heating and moistening were larger on the cloudy day than those on the fair-weather day. The distribution of hourly averaged values of convective heating and moistening showed the existence of multiple cloud types on the cloudy day.

INDIAN Ocean Experiment (INDOEX), an international research program, was conducted during January through March 1999 over the tropical Indian ocean in order to improve the knowledge of cloud–chemistry–climate interaction. The knowledge of cloud systems especially the impact of convective cloud on the thermodynamic characteristics over the tropical Indian ocean is poor. Several cumulus parameterization schemes[1–4] are available to study the role of cumulus convection in the evolution of large-scale fields.

The objective of the paper is to study the thermodynamic characteristics of the atmosphere over Indian Ocean using Simplified Arakawa–Schubert convection scheme[5] incorporated in a single column model (SCM) during INDOEX Intensive Field Program (IFP)-99. The study is based on the two dates – one representing the convectively-active (cloudy weather) day (4 February 1999) and another the convectively-suppressed (fair-weather) day (8 February 1999). Classification of cloudy and clear day for the present study is solely based on the INSAT pictures on both days. The thermodynamic characteristics, viz. convective heating, moistening, convective rainfall and cloud base mass flux were studied for the above two dates.

Overview of the single column model

A brief overview of the SCM is shown in Table 1. The SCM consists of Simplified Arakawa–Schubert convection scheme, which was used to study the thermodynamic

Table 1. A brief overview of the single column model used in the study

Model parameters	Components	Specifications
Grid	Vertical	18-sigma levels (s = 0.995, 0.981, 0.960, 0.920, 0.856, 0.777, 0.688, 0.594, 0.497, 0.425, 0.375, 0.325, 0.275, 0.225, 0.175, 0.124, 0.074, 0.021)
Dynamics	Prognostic variables	Temperature and mixing ratio
	Time differencing	Forward with time step 900 s
Physics	Boundary layer process	Monin–Obukhov similarity theory[6]
	Land surface process	Pan scheme[7]
	Radiation process	Harshavardhan scheme[8]
	Convection process	Simplified Arakawa–Schubert scheme[5]
	Air–sea interaction	Roughness length over ocean by Charnock's relation[9], bulk formulae for sensible and latent heat fluxes

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characteristics of the atmosphere over the Indian ocean. This scheme computes convective heating and moistening using a one cloud type Arakawa–Schubert convection scheme. It includes both updrafts and downdrafts and these are assumed to be saturated. The effect of moist downdraft is included in the equations of dynamic control and feedback processes. The static control includes entrainment and detrainment, and determines the updraft and downdraft properties. It defines the budgets of updraft and downdraft, and determines the convective rainfall. The calculation of rainfall requires the knowledge of cloud base mass flux, which is determined in the dynamic control. Dynamic control incorporates the closure assumptions of cloud work function and determines the modulation of the convection by the environment. Feedback process determines the modification of the environment by convection. These are simply the temperature and moisture differences between the cloud and the environment.

Description of data

The surface and upper air observations of on-board ORV *Sagar Kanya* taken during IFP-99 were used in the study. The SCM required data up to 10 mb for its 18 sigma levels (Table 1). Unfortunately, the wind data were completely missing at all levels on the cloudy day (4 February). The soundings were available up to 116 mb and then from 54 mb to 25 mb on fair-weather day (8 February). Hence, the available observations at 06 : 45 UTC (18.83°S, 76.99°E) and at 11 : 50 UTC (19.04°S, 76.91°E) on 4 February, and at 11 : 42 UTC (19.99°S, 65.60°E) and at 18 : 35 UTC (20.01°S, 64.45°E) on 8 February were assimilated by the Data Assimilation System of the NCMRWF T80 General Circulation Model (GCM). The assimilated data over the INDOEX observation points were then used as inputs for the SCM.

Initial and boundary conditions

The initial conditions are based on the sounding profiles of temperature, specific humidity and wind velocity (u, v, w), sensible and latent heat fluxes, large scale advective forcings of temperature and moisture. The present observations during ORV *Sagar Kanya* cruise IFP-99 do not include vertical velocity and large scale forcings. These were derived at 6-h interval from the simulation carried out by T80 GCM of NCMRWF (Figures 1 and 2). The input time series distribution of vertical velocity (cm/day) indicated considerable upward motion (17 cm/day) at and around 06 UTC (Figure 1 *a*) on 4 February when clouds were also observed. Both upward and downward motions were observed at around 4th and 12th sigma levels respectively at 18 UTC on this day. The advective forcings of temperature (K/day) were positive mainly in the few lowest sigma levels (Figure 1 *b*) at all hours (with larger value more than 12 K/day around 18 UTC). The advective forcings of moisture were of high values (6 g/kg/day) at and around 06 UTC below the sigma level 6 (Figure 1 *c*). Figure 2 *a* shows strong downward motion at and around 06 UTC on 8 February. On this day, the advective forcings of temperature is high

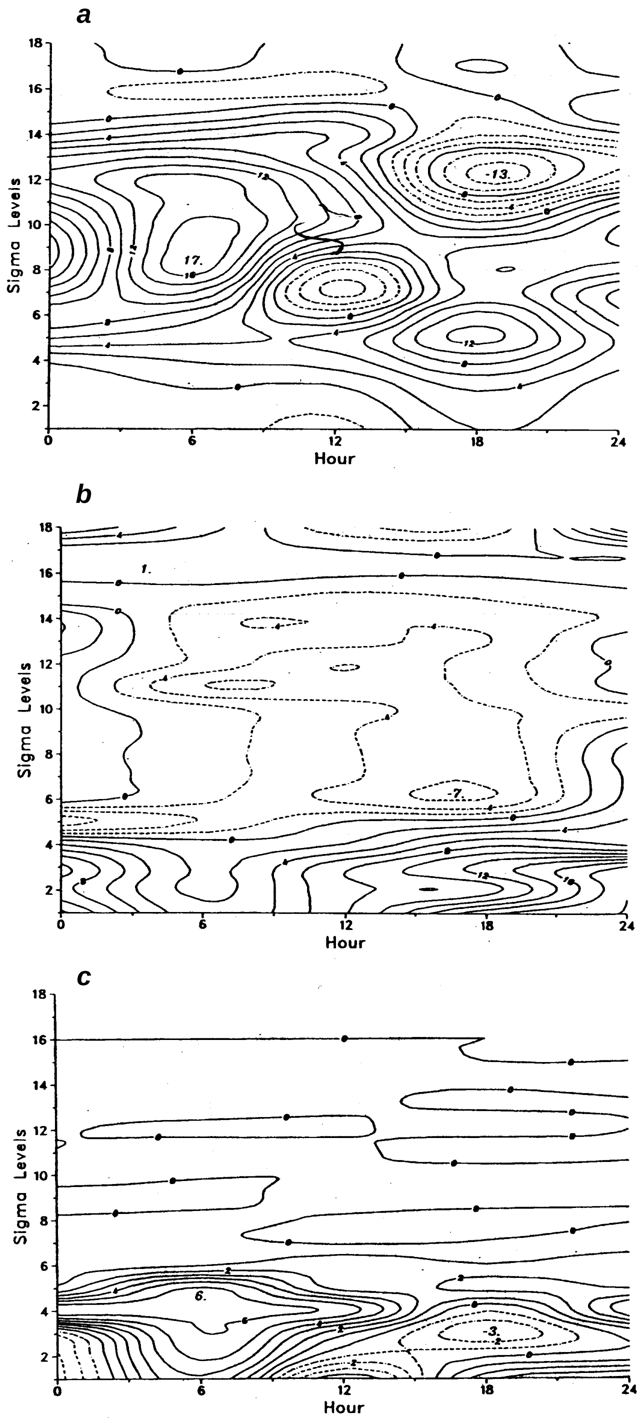

Figure 1. Time series distribution of the input (***a***) vertical velocity (cm/day); (***b***) advective forcings of temperature (K/day) and (***c***) advective forcings of moisture (g/kg/day) on the day (4 February 1999).

(> 12 K/day) at 12 UTC (Figure 2 *b*), whereas the advective forcings of moisture were positive only at 06 UTC (Figure 2 *c*).

The sensible and latent heat fluxes (Figure 3 *a*, *b*) were calculated using bulk formulae. The sensible heat fluxes for cloudy day were more than those for fair-weather day only in the first six hours (Figure 3 *a*). On cloudy day, the latent heat flux was more than that on the fair-weather day in the first few hours and after 12 UTC.

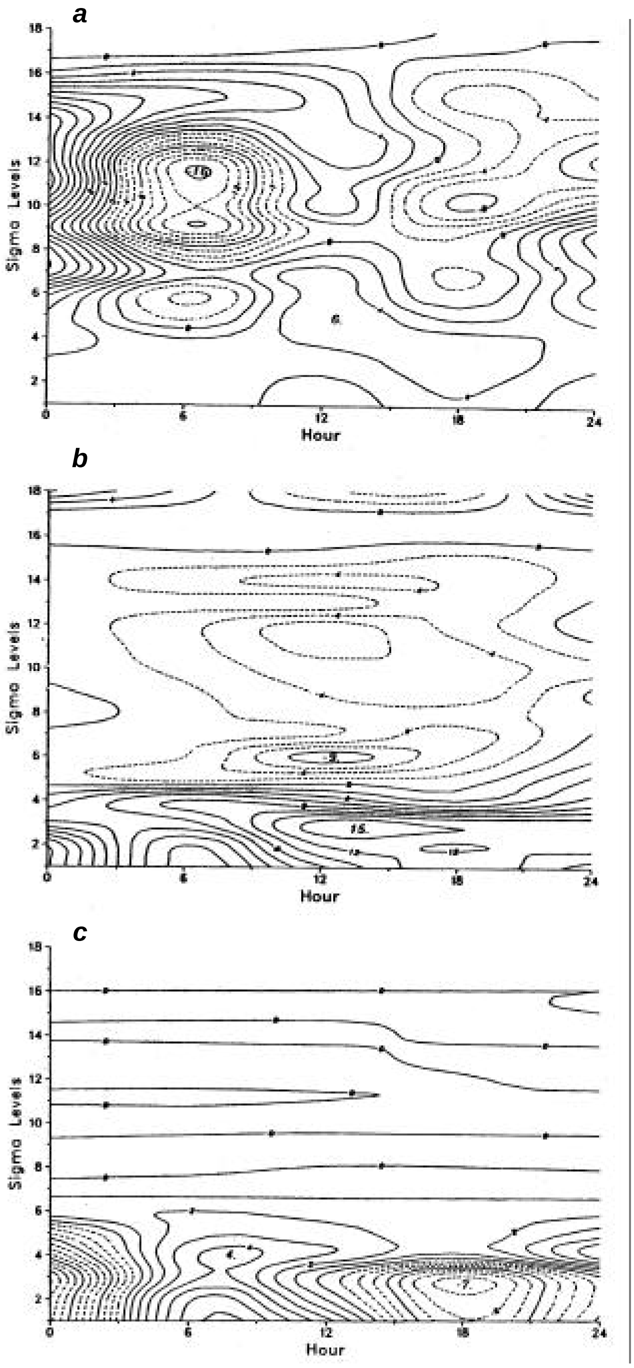

Figure 2. Same as Figure 1 except on the fair-weather day (8 February 1999).

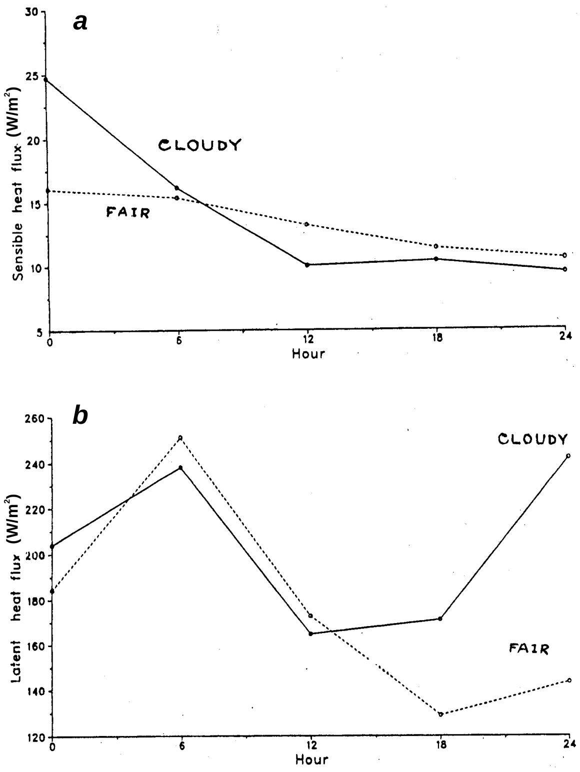

Figure 3. Time series distribution of the input (***a***) sensible heat fluxes (W/m^2) and (***b***) latent heat fluxes (W/m^2) on the cloudy and fair-weather day.

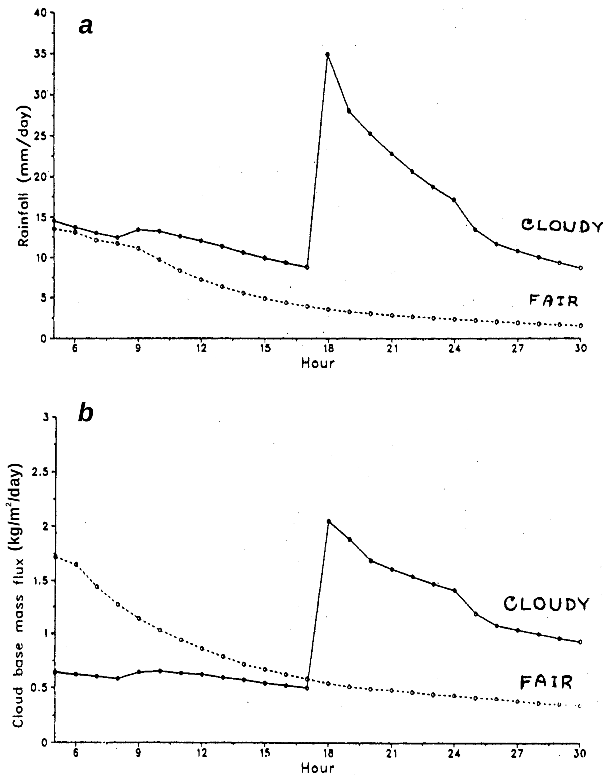

Figure 4. Time series distribution of hourly averaged (***a***) convective rainfall (mm/day) and (***b***) cloud base mass flux (kg/m^2/day) on the cloudy and fair-weather day.

Results

The SCM were integrated with 15 min (900 s) time steps in a fully prognostic way for 30 h starting at 00 UTC on both 4 February and 8 February. The convective rainfall, cloud base mass flux, convective heating and moistening were studied on the cloudy and the fair-weather days. Because of the spin-up problem, the results of the first four hours were not presented.

Figure 4 *a* shows the time series distribution of hourly averaged convective rainfall on both cloudy and fair-weather days. It indicates a considerable amount of rainfall (14.8 mm/day) at and around 05 UTC on cloudy day. It also shows a sharp rise (35 mm/day) at 18 UTC, which may not be realistic. After 18 UTC there was decreasing trend. On the fair-weather day (dashed curve), though the rainfall was of large amount (13.5 mm/day) at 05 UTC, there was a gradual decreasing trend as the time progressed, indicating the absence of cloud systems. The INSAT pictures at 12 and 18 UTC indicated clear skies over the respective ship locations.

Figure 4 *b* shows the time series distribution of hourly averaged cloud base mass flux on both dates. The patterns for the distribution of cloud base mass fluxes followed the respective rainfall distribution on both the dates.

Figure 5 *a* shows the time series distribution of hourly average vertical profiles of convective heating (TCV) (K/day) on the cloudy day. It was seen (Figure 5 *a*) that high values of TCV were present between the sigma levels 8 and 16 on this day. It also showed the highest values of TCV (27 K/day) around 18 UTC, which is consistent with the high convective cloud base mass flux and rainfall as seen in Figure 4. On the fair-weather day (Figure 5 *b*), the high values of TCV were confined between the sigma levels 11 and 17. Convective drying was observed at all hours between the sigma levels 8 and 16 on the cloudy day (Figure 5 *c*). On the fair-weather day (Figure 5 *d*) convective drying was mainly confined at 05 UTC.

Figure 6 *a* shows the variation of hourly averaged values of convective heating with sigma levels on the cloudy and the fair-weather days. The presence of two

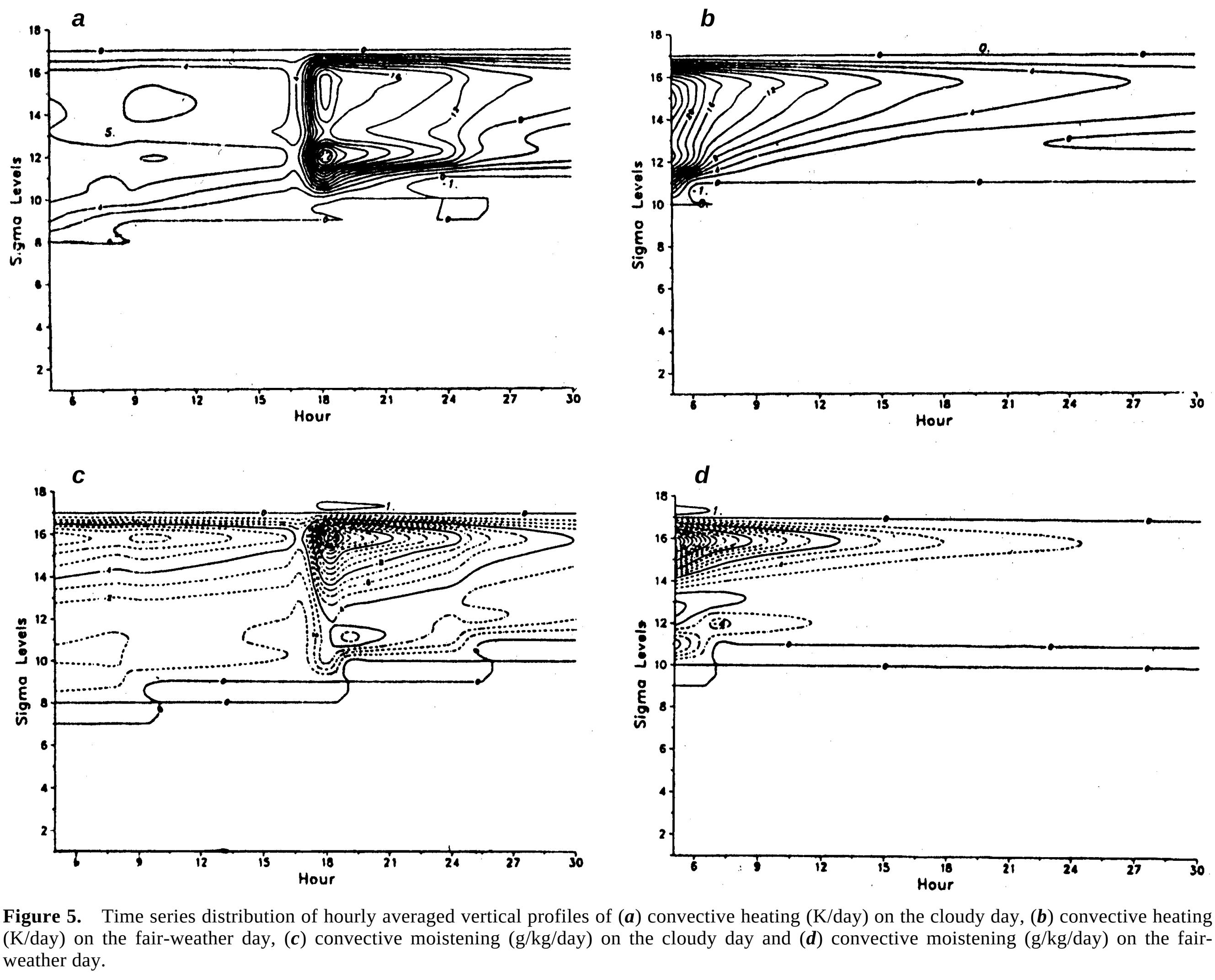

Figure 5. Time series distribution of hourly averaged vertical profiles of (***a***) convective heating (K/day) on the cloudy day, (***b***) convective heating (K/day) on the fair-weather day, (***c***) convective moistening (g/kg/day) on the cloudy day and (***d***) convective moistening (g/kg/day) on the fair-weather day.

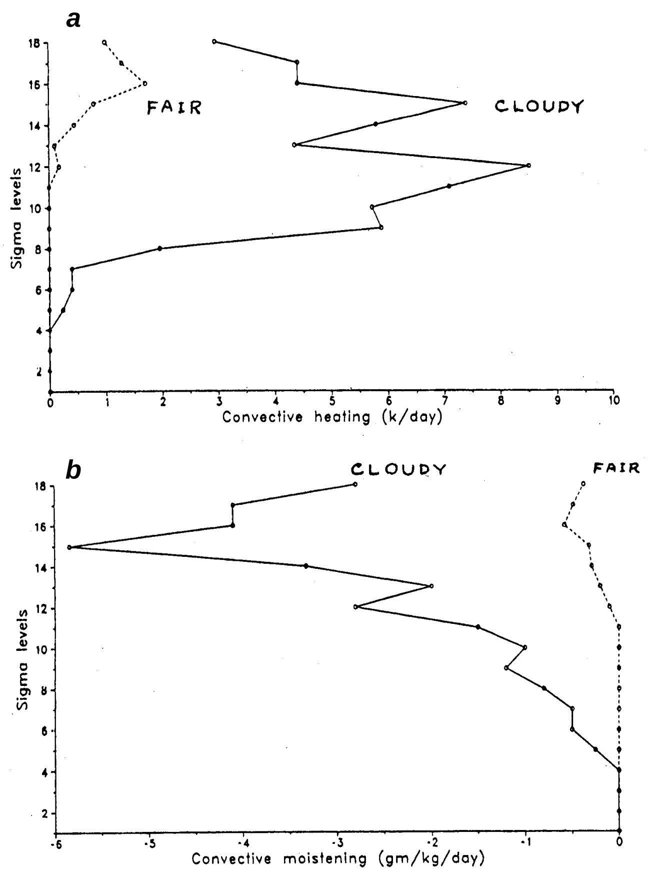

Figure 6. Vertical profiles of averaged values of (***a***) convecting heating on the cloudy and fair-weather day and (***b***) convective moistening (g/kg/day) on the cloudy and fair-weather day.

maxima in the convective heating profile indicates the existence of multiple cloud types on the convectively-active day. It was seen that the average value of TCV was more than 4 K/day above the sigma level 8 (~ 600 mb) on this day. It also shows that the average value of TCV on the fair-weather day (dashed curve) was zero between the sigma levels 1 and 10 and the maximum value was 1.7 K/day at level 15 (~ 125 mb). The distribution of average values of convective moistening (QCV) on the cloudy day (continuous curve) also shows the presence of multi-layer clouds (Figure 6 *b*). It showed complete drying above the sigma level 4 and the maximum value of QCV was 5.8 g/kg/day. On the fair-weather day (dashed curve), the average value of QCV was zero between sigma levels 1 and 11 and the maximum value was 0.5 g/kg/day.

Conclusion

The thermodynamic characteristics, viz. convective heating and moistening, convective rainfall and cloud base mass fluxes over the Indian Ocean during IFP-99 were computed using Simplified Arakawa–Schubert convection scheme incorporated in a single column model. The study was confined on the two dates; one convectively-active day and another convectively-suppressed day. The results showed that the convective heating and moistening/drying were larger on cloudy days than those observed on the fair-weather day. The distribution of hourly averaged values of TCV showed the existence of multiple cloud types on the cloudy day. The distribution of convective rainfall and cloud base mass flux followed similar trend on the respective days. The time series distribution of TCV and QCV also followed the pattern of convective rainfall and cloud base mass flux. However, the results could be improved by taking sufficient numbers of cloudy and fair-weather days. Also, the present set-up of the observational network during ORV *Sagar Kanya* cruise does not provide sufficient informations to study the detailed role of convective cloud systems on the large scale environment.

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ACKNOWLEDGEMENTS. We thank Dr E. N. Rajagopal and Dr Swati Basu for providing the SCM with land surface and boundary layer schemes. We also thank Dr K. S. Zalpuri (NPL) and Mrs Mun-Mun Dasgupta of NCMRWF for giving raw and assimilated data respectively. A.K.P. thanks CSIR INDOEX for providing financial grant to carry out this work.