Suggested observational network for simulation of cloud processes during INDOEX

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The nature of precipitating cloud systems, their life cycles and vertical structure over the monsoon regime is poorly understood. Some of the results obtained from the single column model and a cloud ensemble model using the TOGA-COARE (Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment) data set are illustrated. The scope of comparing large-scale cloud fields such as cloud fractions, outgoing long-wave radiation, etc. from the global general circulation models are discussed.

DESPITE several international efforts such as the Global Atmospheric Research Programme (GARP), Global Atlantic Tropical Experiment (GATE), Monsoon Experiment (MONEX), Atlantic Stratocumulus Transition Experiment (ASTEX), TOGA-COARE etc., the nature of precipitating cloud systems, their life cycles and vertical structure over the monsoon regime continues to be poorly understood. There are no studies on cloud mergers, cloud draft structure, trace gas and pollution transports by the convective clouds, modeling of thunderstorms, Norwesters, orographic clouds, boundary layer clouds, the cloud top entrainment instability and the clouds associated with the western disturbances. Our knowledge of clouds over the Indian region is meagre and confined to their gross features. The importance of such studies in numerical weather prediction and climate modeling is well known. The basic question here is that given the information collected during INDOEX can we validate some of the results obtained from the state-of-art cumulus parametrization and prognostic cloud prediction schemes over the Indian Ocean region?

Unfortunately, the present set-up of the observational networks during INDOEX[1] may not provide sufficient information for modeling and simulations of cloud systems over the monsoon regime using single column models (SCM) or cloud ensemble models (CEM), unless additional observations are collected over a scale that is compatible with the cloud/mesoscale convective systems. The main thrust of INDOEX is to improve our knowledge of the cloud–chemistry–climate interactions. Cloud is therefore an important component of this project. Since we plan to collect massive observations to study aerosols, pollution transport and cloud–chemistry–climate interactions, it was considered worthwhile to collect additional observations for understanding and modeling of monsoon cloud systems. For example, to understand and simulate the cloud processes, observations were collected at three different scales representing synoptic systems, sub-synoptic systems and mesoscale convective systems during the TOGA-COARE[2,3]. Several studies[4,5] have earlier been conducted on the tropical cloud systems using this data set. The results obtained from SCM and CEM using the TOGA-COARE data set are described in the next section.

Simulation of cloud characteristics

One of the most promising methods to test physical parametrizations used in GCM is the use of field observations together with SCM and/or CEM[6]. SCM can be con-

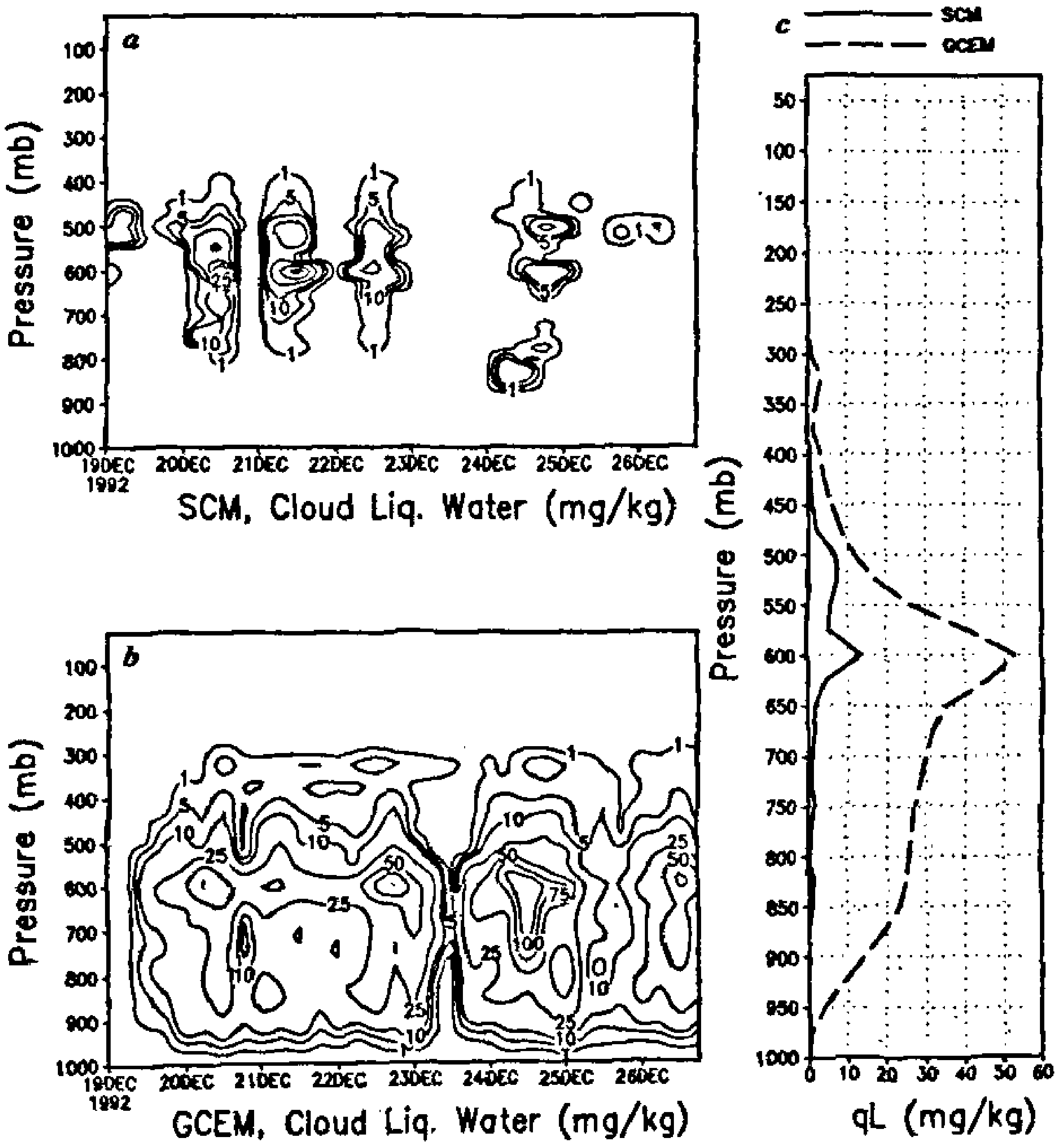

Figure 1. Time series of the vertical profiles of the cloud liquid water mixing ratio obtained from (*a*) SCM, (*b*) GCEM and (*c*) their time averaged vertical profiles.

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sidered as an isolated grid box of a climate model in which field observations may be used to test the parametrization of a physical process. Since the SCM do not interact with the neighbouring grid columns, the effects of surrounding grid boxes are specified in terms of large-scale advective forcings to run SCM. The advantage of testing a physical parametrization scheme using SCM is that errors from the remaining physical parametrizations of the model do not contaminate the results of the scheme being tested. CEM do not need cumulus parametrization scheme and can fairly resolve the evolution, structure and life cycles of individual clouds. CEM results although are not real, can be judiciously compared with SCM results to diagnose problems with the latter. Figures 1, 2 and 3 illustrate some of the results of simulations of TOGA-COARE convective systems[7] using SCM and the Goddard Cumulus Ensemble Model (GCEM)[8,9] of the National Aeronautics and Space Administration (NASA). For continuity, SCM and CEM are briefly summarized below.

SCM consists of the basic physics of the Goddard Earth Observing System (GEOS) model consisting of the Relaxed Arakawa-Schubert (RAS)[10] cumulus parametrization, downdraft[11], cloud microphysics[12,13], short and long-wave radiation[14,15], and the planetary boundary layer[16] having the turbulence level 2.5 order closure. GCEM includes solar and infrared radiative transfer processes and explicit cloud–radiation interaction processes. The cloud microphysics includes a parametrized Kesseler type two-category liquid water scheme (cloud water and rain). It has two parametrizations of a three-category ice phase scheme (cloud ice, snow, and hail/graupel). It includes subgrid-scale (turbulent) processes. The effects of both dry and moist processes on the generation of subgrid scale kinetic energy are incorporated in the model.

Figures 1 and 2 show the time series of cloud liquid water and ice mixing ratios simulated by SCM and GCEM and indicate the existence of four episodes of maximum cloud liquid water and ice contents associated with the convective activities. Cloud liquid water is generally confined below 400 mb in SCM while ice dominates in the upper levels. Comparison between SCM and GCEM indicates that the former underestimates maximum cloud water by about four times. The maximum ice contents however, are slightly overestimated by SCM as compared to GCEM. The time series of vertical profile of cloud mass fraction obtained from SCM and GCEM are shown in Figure 3. Maximum cloudiness associated with the four episodes of convective activities are clearly evident from the simulation by SCM. Both SCM and GCEM produced maximum cloudiness in upper levels between 100 and 300 mb, but the maximum cloudiness values in GCEM are simulated about 50 mb above those in SCM. The distribution of cloudiness by SCM shows deeper clouds extending from 800 mb to 150 mb, while GCEM shows most clouds only in the upper levels above 350 mb. CEM can provide insights into the cloud processes which are not described here for brevity. Such simulations can be done for the monsoon cloud systems if we have proper network of observations for this study.

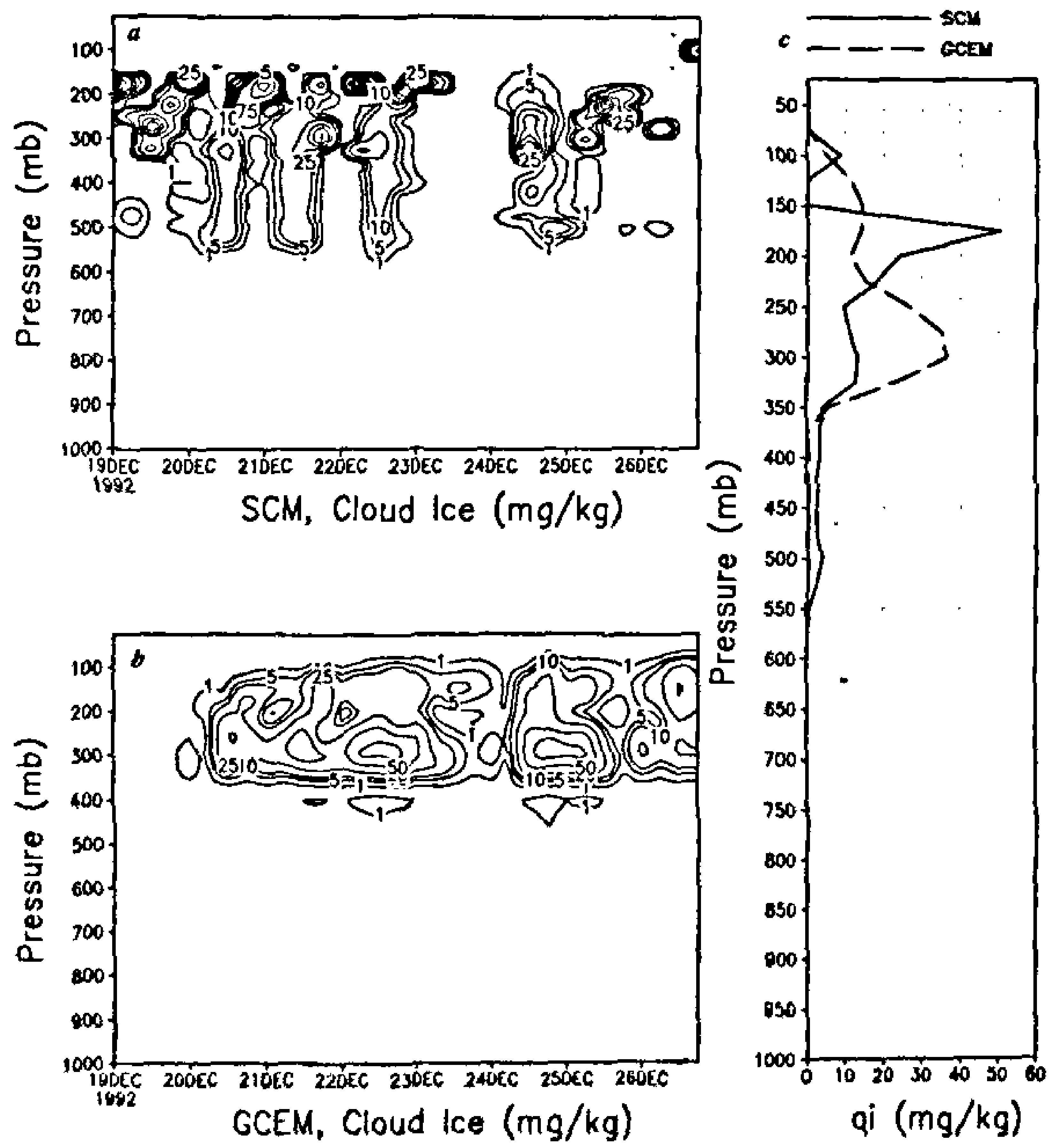

Figure 2. As in Figure 1 but for the cloud ice mixing ratio.

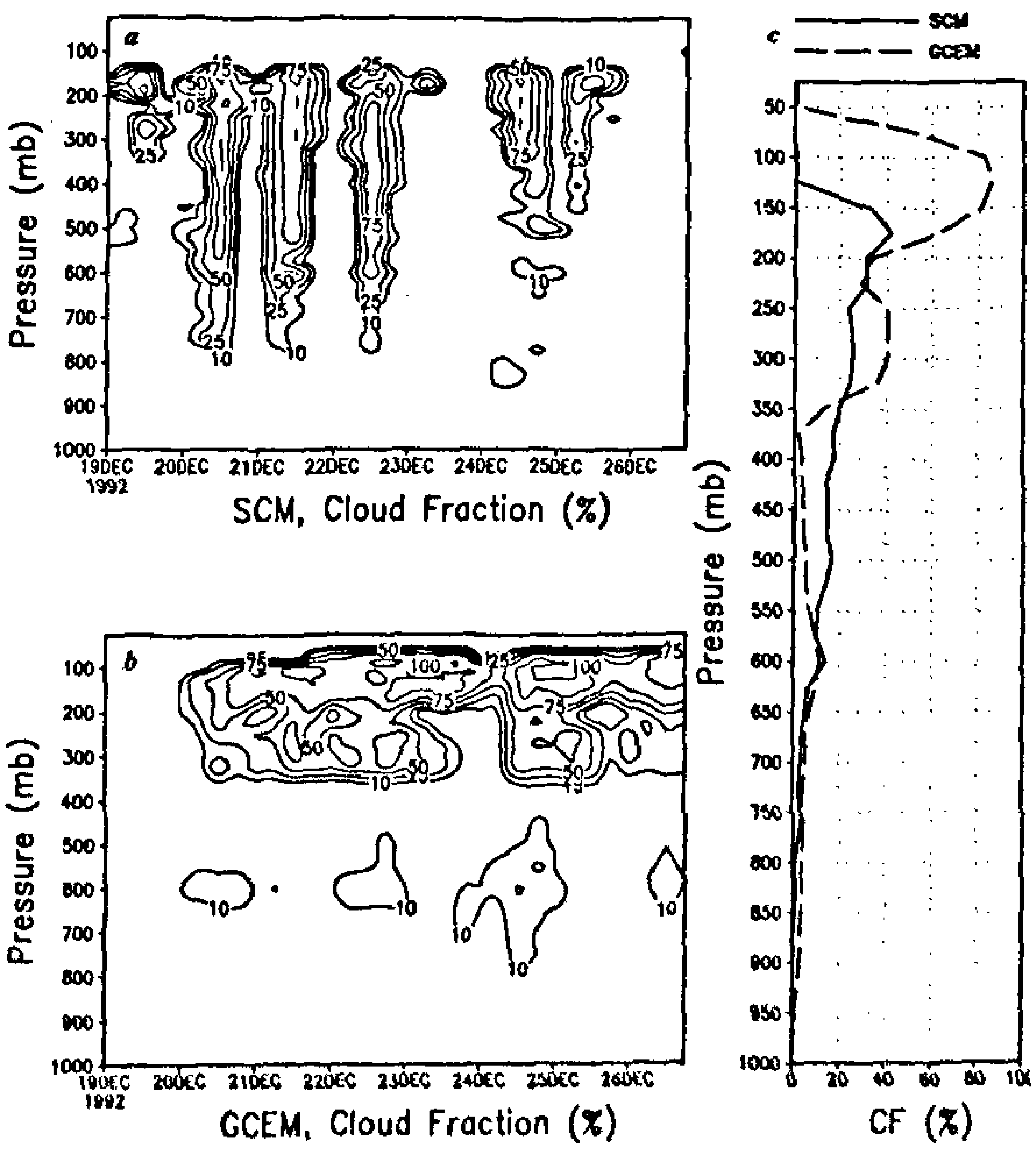

Figure 3. As in Figure 1 but for the cloud mass fraction.

Proposed observational network for simulation of cloud processes

Clearly, the present set-up of the observational networks during INDOEX will not be able to provide sufficient information for modeling and simulations of cloud systems over the monsoon regime using SCM or CEM. It is therefore suggested that observations may be collected over a scale that is compatible with the cloud/mesoscale convective systems similar to those in the TOGA-COARE. The observations should be organized such that they cover a period of formation, growth, dissipation and passage of several convective episodes over the Indian Ocean prior to the onset of monsoon. The observational platforms should consist of dense sounding networks, strategically placed Doppler RADARS, geosynchronous satellite, microphysical instruments, radiometers, aircraft, wind profilers, omega-sondes, drop-sondes and LIDARS. These instruments would measure the vertical profiles of wind, temperature, moisture, surface fluxes, cloud base, top water/ice content, particle size and distributions, precipitation, cloud fraction, OLR, cloud top temperature, radiative fluxes, etc. All these observations can then be used to simulate the structure and properties of clouds using SCM and CEM and validate the state-of-art cumulus parametrization and prognostic cloud prediction schemes for large-scale models over the monsoon regime. This observational network can be extended subsequently to study the Norwesters and pre-monsoon thunderstorms over the land area as well. Such experiments are being conducted by the GEWEX Cloud System Study (GCSS)[17] team to compare results from different CEM and SCM around the world.

Verification of the large scale cloud fields

In the absence of measurements of cloud characteristics over a cloud scale or a mesoscale area, only the broad

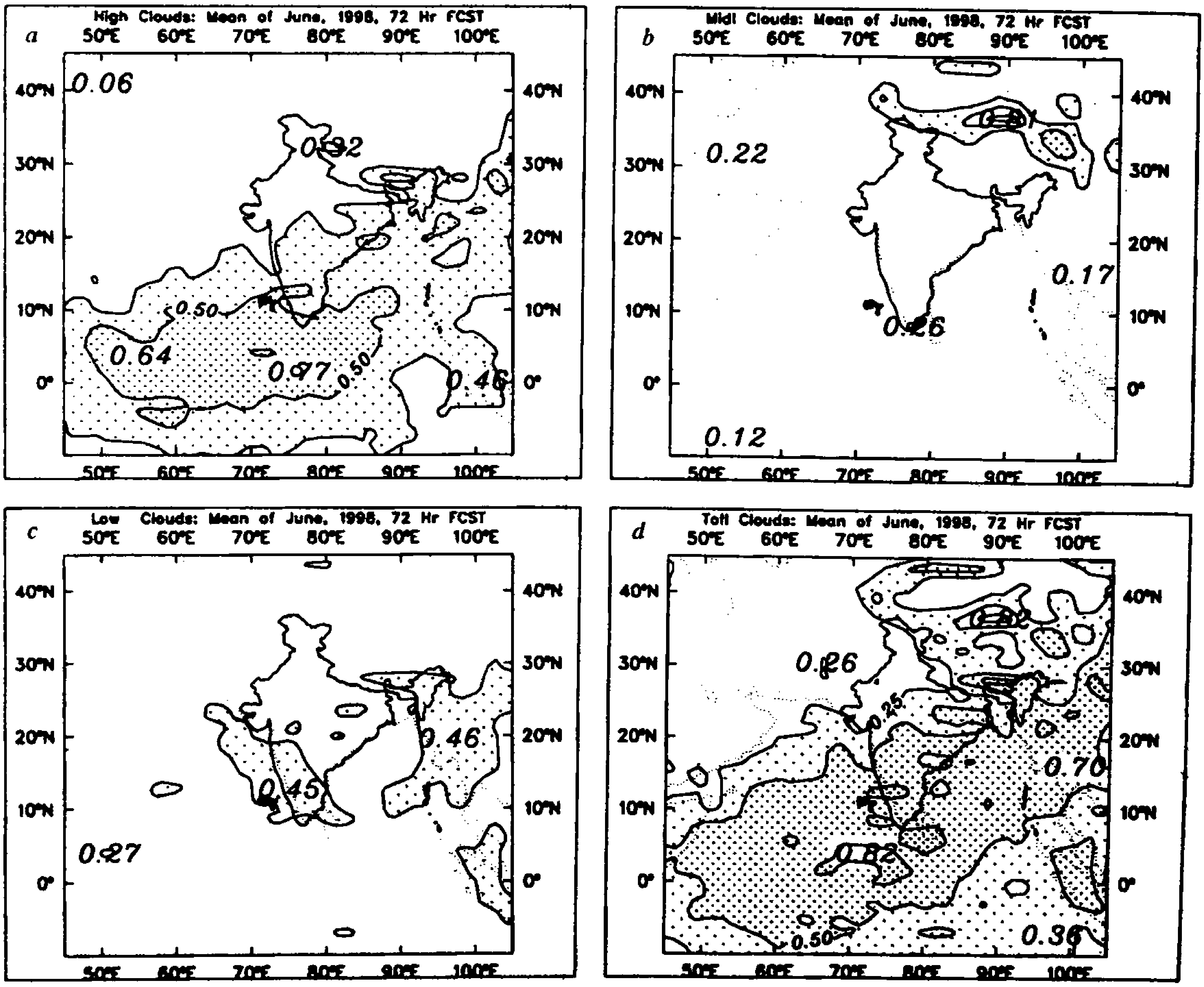

Figure 4. Mean cloud fraction for June 1998 obtained from the NCMRWF model for (*a*) High clouds, (*b*) Middle clouds, (*c*) Low clouds and (*d*) Total clouds.

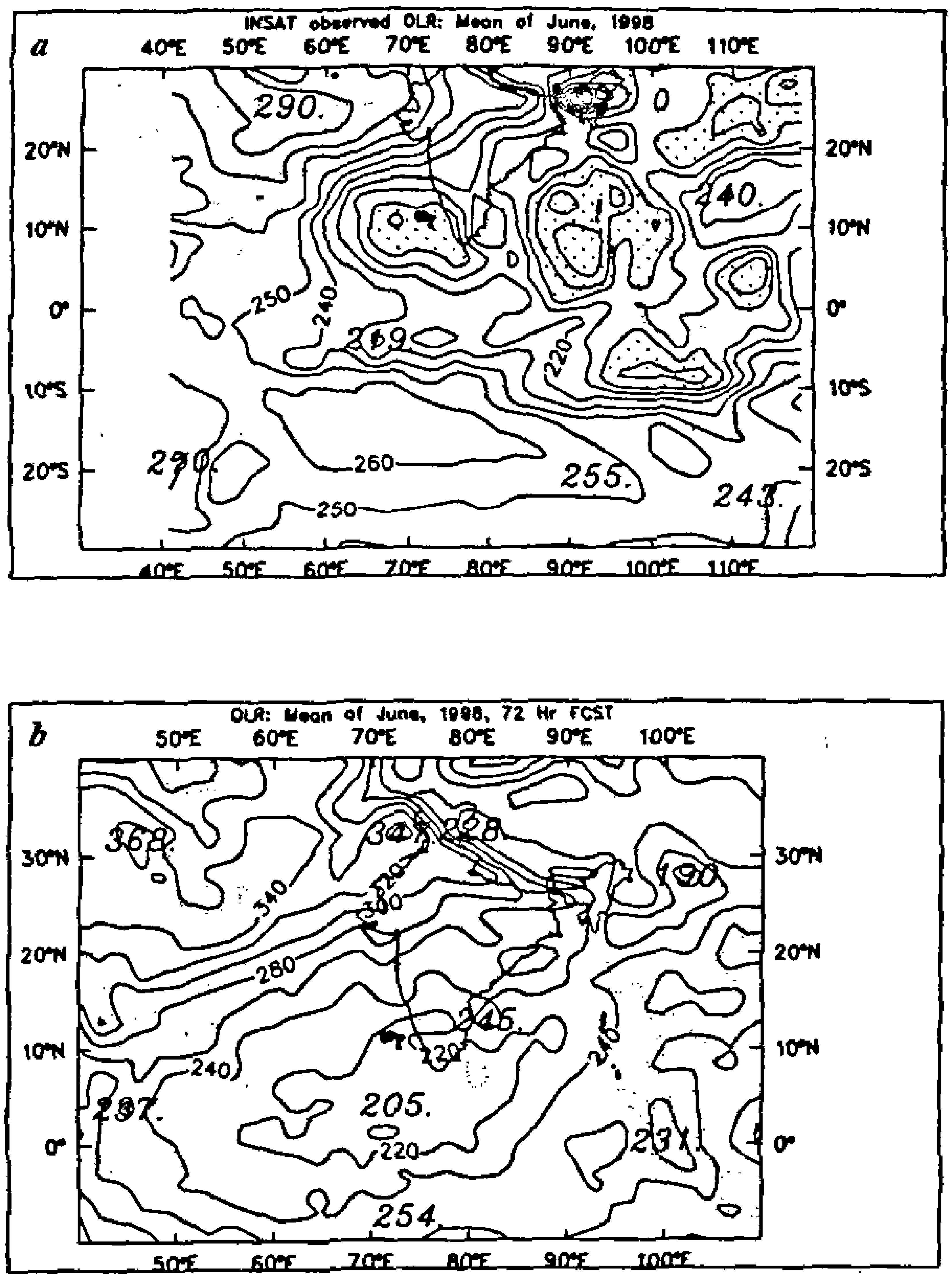

Figure 5. Mean OLR for June 1998 obtained from (*a*) INSAT and (*b*) NCMRWF model forecasts.

features and indirect verifications of cloud properties can be studied using GCM. Cloud fields that can be verified using GCM are for example, cloud radiative forcing, OLR, optical thickness, cloud liquid water and ice contents, cloud fraction and precipitation rates after proper assimilation with global models. For illustration, Figures 4 and 5 show the mean of 72 h forecasts of the high, medium, low and total cloud fractions and the outgoing longwave radiation (OLR) during June 1998. These values have been obtained from the NCMRWF[18] global T80, 18 levels model. The diagrams indicate that the north Indian Ocean including the southern tip of India is covered by 60 to 70% high clouds during June 1998. These high clouds result from the deep cumulus convection during the onset of monsoon over this region. The medium clouds are confined to the Himalayas and the Tibetan region. The low clouds (25 to 50%) are confined to the west coast of India, eastern Bay of Bengal, Assam and the adjoining region. Unfortunately, the observed distributions of the high, medium and low clouds are not available for comparison at present but they can be compared with INSAT and METEOSAT data from INDOEX.

Figure 5 illustrates the simulated and observed OLR from INSAT during June 1998. Observations show that OLR values are minimum over the southwest coast of India and the Bay of Bengal, indicating the zone of maximum convection and cloudiness during this time. Values $< 200\ \mathrm{Wm}^{-2}$ are shaded in the diagram. The simulated fields show that the minimum OLR values are located over the north Indian Ocean and parts of the southern tip of India during June. The values are however 20 to 30 Wm^{-2} higher than the observations from INSAT. Larger differences (50 to 60 Wm^{-2}) are noted over the northwest parts of India and the adjoining Pakistan, Afghanistan and the Saudi Arabian regions. The OLR values may be resolved better by the METEOSAT over this region.

Summary

The present set-up of INDOEX can provide data only for verifications of large-scale GCM outputs after proper assimilation with global models. Cloud fields that can be verified from this project, are for example, cloud radiative forcing, OLR, optical thickness, cloud liquid water and ice contents, cloud fraction and precipitation.

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ACKNOWLEDGEMENT. Results described in Figures 1, 2, 3 were obtained at the NASA/Goddard Space Flight Center under a fellowship administered by the Universities Space Research Association (USRA).