Decadal variation of sea surface temperatures, cloudiness and monsoon depressions in the north Indian ocean

One of the prominent observed decadal variations of the ocean is a large variation of sea surface temperatures (SSTs) over the Pacific Ocean which occurred during the late 1970s to the early 1980s[1–4]. Tropical SST over the Pacific Ocean has increased since 1977 and the PNA-like pattern of the Northern Hemisphere geopotential height field in winter was strengthened during the same decade. Wang[5] showed a similar rapid transition from the cold to warm state of the Indian Ocean in the late 1970s. Such a warm state remained in the inter-decadal mode. This warm inter-decadal mode in SST would increase the likelihood of moist convection and cloudiness by adding moisture and reduce the atmospheric stability. Recently, the 1997–98 El Nino also caused unprecedented warm SSTs in the Indian Ocean[6–8], which might have further warmed up this inter-decadal mode. This recent warming of SST might have also contributed to more cloudiness, especially low clouds in the Indian Ocean. The unusually high NE monsoon rainfall during 1997 reported by De and Mukhopadhyay[9], may be one such indicator of warm SST impacts.

Here, we report the simultaneous increase in SST and cloudiness in the equatorial Indian Ocean and out of phase variation between SST and cloudiness over Bay of Bengal during the monsoon season (June to September) of recent four decades (1961 to 1998).

The source of SST data is the updated version of Meteorological Office Historical Sea Surface Temperature (MOHSST6) which contained only *in situ* SST measurements[10]. The data are in the form of anomalies (from the base period of 1961 to 1990) averaged in 5° × 5° lat./long. grids. The low and total cloud cover in the Indian Ocean are based on synoptic observations by Voluntary Observing Ships (VOS), which are reported according to the World Meteorological Organization (WMO) code. We have decoded these synoptic observations and low and total cloud cover were extracted and averaged in the same 5° × 5° lat./long. grids. In all, we have considered 35,13,563 observations during the period 1961 to 1998. The monthly cloud cover was further averaged for the monsoon season.

The linear trends of SST (°C/decade) and low cloud cover (%/decade) during the monsoon season of 1961 to 1998 are shown in Figure 1. The grids where the trends are statistically significant at 95% level are shaded. SSTs in the equatorial Indian Ocean have warmed up at the rate exceeding 0.15°C/decade. West Arabian Sea and some parts of Bay of Bengal also warmed up. The trends are relatively smaller over the west Indian Ocean off east Africa. Low cloud cover over these areas also increased significantly during this period. Maximum increase exceeding 2.5%/decade was observed over the equatorial Indian Ocean. It is observed that

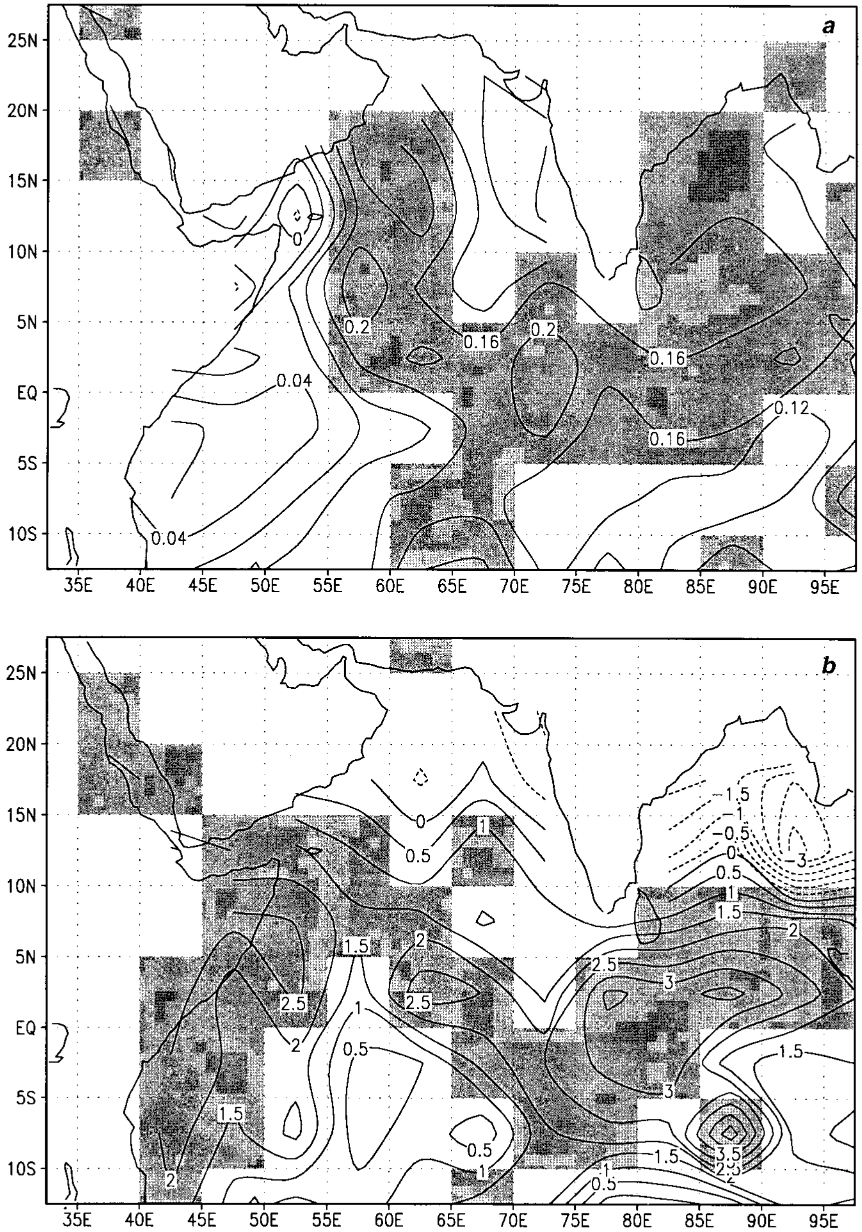

Figure 1. Linear trends of (*a*) SST (°C/decade) and (*b*) low cloud amount (%/decade) over the Indian Ocean during the period 1961 to 1998. The grids where the trends are statistically significant at 95% level are shaded. Contour interval – SST, 0.04°C; Cloud cover, 0.5%. Negative values are shown as dotted lines.

low cloud cover over Bay of Bengal north of 10°N decreased at the rate of 1 to 1.5%/decade in spite of moderate increase in SSTs in this region. Total cloud cover also showed similar type of trends even though the magnitudes are smaller.

Composite SST and low cloud cover anomalies averaged for two periods, 1961 to 1980 and 1981 to 1998 were then calculated. SST anomalies over the north Indian Ocean averaged during the period 1981 to 1998 were more than the SST anomalies averaged during the period 1961 to 1980 by about 0.3°C. Low cloud cover over the equatorial Indian ocean between 10°N and 10°S was more by 4 to 6% during the later period. However, the low cloud cover over Bay of Bengal north of 10°N was less by 4 to 6% during the later period, which is consistent with the negative or decreasing trends of low cloud cover shown in Figure 1. Thus, while over the equatorial Indian Ocean, low cloud cover increased in association with the increase in SST, over Bay of Bengal, low cloud cover decreased in spite of moderate increase in SST.

The decadal variation of SST and low cloud cover averaged over the equatorial Indian ocean (10°N–10°S, 55°E–95°E) and Bay of Bengal (10°N–25°N, 80°E–100°E) is extracted by making the 11-year running means of SST anomalies and low cloud cover standardized anomalies. The results are shown in Figure 2. Over Bay of Bengal, beginning in early 1980s, low cloud cover showed declining trends in spite of increasing SST. During the last 20 years or so, reduced low cloud cover was observed in spite of very warm sea surface temperatures. On the other hand, over the equatorial Indian Ocean, till the early 1980s, SSTs and low cloud cover have exhibited little decadal variations. However during the early 1980s, SSTs and low cloud cover have shown a sharp increase which continued steadily thereafter. Thus on decadal time scale, SSTs and low cloud cover had shown systematic simultaneous variations in the equatorial Indian Ocean. This is consistent with the results of Chu and Wang[11] on decreasing trends of Outgoing Long-Wave Radiation (OLR) over the equatorial Indian Ocean, which indicates increased convection. A similar type of decadal variation is observed over the Arabian Sea. Total clouds also display a similar type of variation (not shown).

During the monsoon season, cloudiness over north Bay of Bengal is mainly caused due to the activity of monsoon trough on the surface and formation of monsoon depressions and storms on it. On an average, 7 to 8 monsoon depressions form during the monsoon season. The frequency of storm (depressions and above) during the monsoon season is reported to be decreasing at the rate of about 1 storm per decade[12], which might have contributed to the observed reduced low cloud cover over north Bay of Bengal. It is to be noted that frequency of monsoon depression activity decreased in spite of increasing SSTs. In order to understand the relationship between SST and frequency of storms, we have further examined the variation of SST and frequency of storm over north Bay of Bengal (north of 10°N) using a longer period of data, 1901 to 1998. Figure 3 shows the 11-year running means of area averaged SST and frequency of monsoon storms during the monsoon season from 1901 to 1998, which reveals very interesting results. Till early 1980s, both SST and storm frequency had shown similar decadal variations. During the period 1921 to 1960, both SST and storm frequency were more than normal and during the next 25 years or so, both SST and storm frequency were close to normal without much decadal variations. However, since mid-1980s, SST and storm frequency have behaved very differently and have

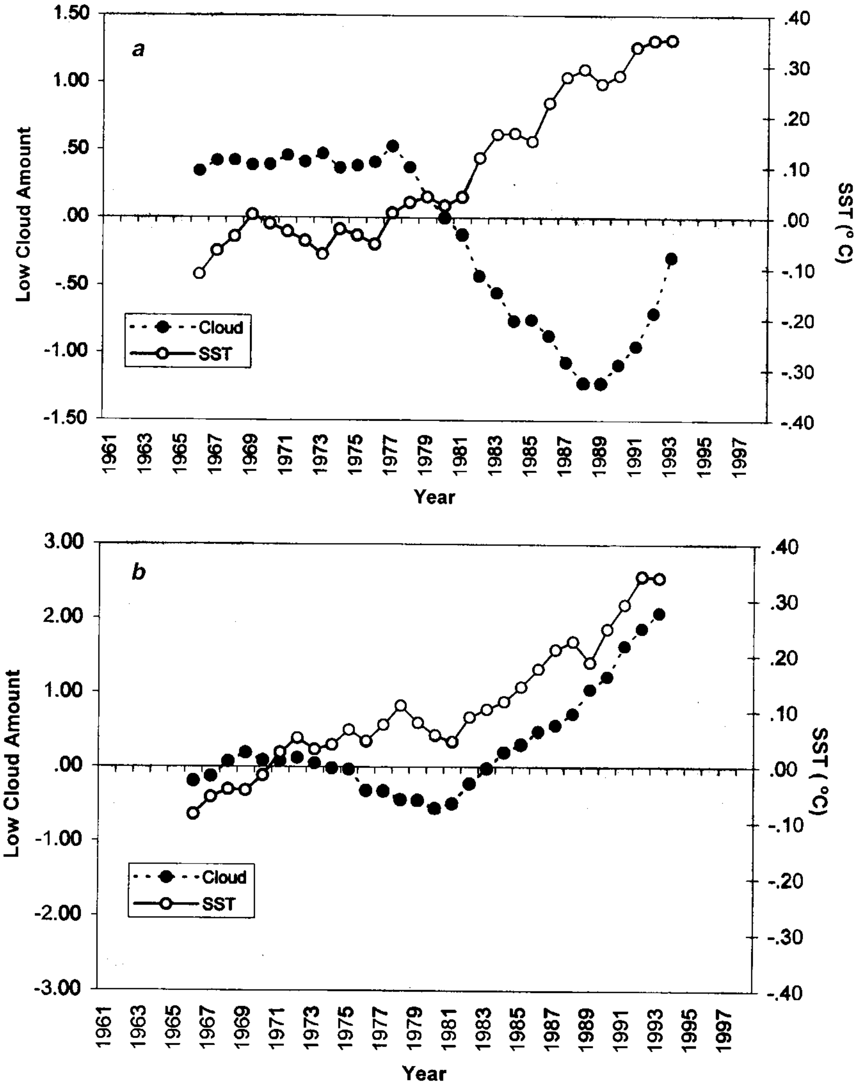

Figure 2. Eleven-year running means of standardized low cloud cover anomalies (dashed line) and SST anomalies (continous line) over (*a*) north Bay of Bengal (10°N–25°N, 80°E–100°E) and (*b*) equatorial Indian Ocean (10°S–10°N, 55°E–95°E).

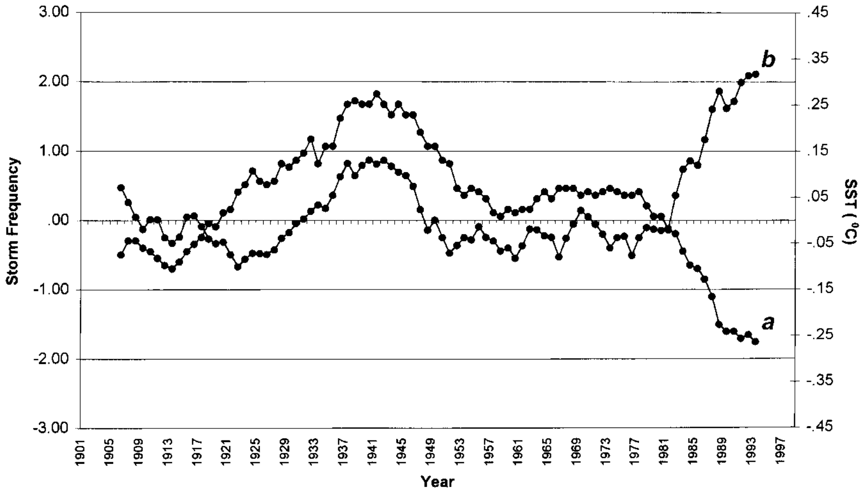

Figure 3. Eleven-year running means of Bay of Bengal (10°N–25°N, 80°E–100°E) storm frequency (standardized anomalies; ***a***) and SST anomalies (***b***) during the period 1901 to 1998.

Table 1. Horizontal and vertical wind shear over Bay of Bengal during the monsoon seasons of 1997 and 1998. Data Source: NCEP/NCAR reanalysis

Year	Number of monsoon systems	850 hPa south–north wind shear (m/s)	Vertical (850–200 hPa) wind shear (m/s)
1997	6	6.6	13.8
1998	1	2.0	22.2

shown a out-of-phase relationship. Storm frequency has shown declining trends on decadal scale in spite of increasing SST, which ultimately might have led to reduced low cloud cover over this area.

The low cloud cover in this study was not separated between the convective and stratiform clouds. It may be worth investigating the relationship with SST separately for convective and stratiform clouds as these clouds may be coupled with SST differently. However, the coupling between convective clouds and SST in the Indian Ocean is too complex[13–15]. Similarly, the physical mechanisms for the decrease of storm frequency during the recent years are also to be examined thoroughly. Warm SSTs alone are not sufficient for the genesis and intensification of monsoon depressions. In addition, favourable environmental conditions like low level convergence and small vertical wind shear are also required. Probably, in association with the unprecedented warming of the Indian Ocean during the period 1991 to 1998, atmospheric circulation patterns (like vertical wind shear) over Bay of Bengal might have altered, which ultimately suppressed the formation and intensification of monsoon depressions. For example, in recent years, six monsoon systems formed during the monsoon season of 1997, while in 1998 only one depression formed. We have found that the south–north wind-shear at 850 hPa over Bay of Bengal in 1997 monsoon season (6.6 m/s) was more than the 1998 monsoon season (2.0 m/s; Table 1). However the vertical wind shear (difference of zonal wind of 850 and 200 hPa) over north Bay of Bengal (20°N–25°N, 82.5°E–95°E) was more in 1998 (22.2 m/s) than in 1997 (13.8 m/s). These results suggest that larger horizontal shear at lower tropospheric level and smaller vertical wind shear may help more depressions to form on a seasonal time scale. The decadal time scale variation in wind shear and other dynamical forcings may be examined using a longer time series of NCEP/NCAR or ECMWF reanalyses data. However, this is beyond the scope of the present study.

1. Nitta, T. and Yamada, S., *J. Meterol. Soc. Jpn*, 1989, **67**, 375–382.
2. Zhang, Y., Wallace, J. M. and Battisti, D. S., *J. Climate*, 1997, **10**, 1004–1020.
3. Torrence, C. and Webster, P. J., *ibid*, 1999, **12**, 2679–2690.
4. Kachi, M. and Nitta, T., *J. Meteorol. Soc. Jpn*, 1997, **75**, 657–675.
5. Wang, B., *J. Climate*, 1995, **8**, 267–285.
6. Webster, P. J., Moore, A. M., Loscnigg, J. P. and Leben, R. R., *Nature*, 1999, **401**, 356–360.
7. Yu, L. and Rienecker, M. M., *Geophys. Res. Lett.*, 1999, **26**, 735–738.
8. Medha Khole, *Curr. Sci.*, 1999, **77**, 1241–1245.
9. De, U. S. and Mukhopadhyay, R. K., *Mausam*, 1999, **50** (in press).
10. Parker, D. E., Folland, C. K. and Jackson, M., *Clim. Change*, 1995, **31**, 559–600.
11. Chu, P. and Wang, J. B., *J. Climate*, 1997, **10**, 636–646.
12. Rajeevan, M., Medha Khole and De, U. S., Paper presented at the Tropmet 2000 Symposium on Oceans and Atmosphere, Cochin, 1–4 February 2000.
13. Gadgil, S., *Curr. Sci.*, 2000, **78**, 309–322.
14. Srinivasan, J., *J. Indian Inst. Sci.*, 1997, **77**, 237–255.
15. Pai, D. S. and Rajeevan, M., *Curr. Sci.*, 1998, **75**, 372–381.

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Detection of bacteriocinogenic strains of *Cicer–Rhizobium* by modified simultaneous antagonism method

Many strains of bacteria, including rhizobia, are known to produce bacteriocins. Of the various methods described for detecting freely produced bacteriocins[1], the most commonly used methods are those developed by Gratia and Fredricq. In all these methods, the antagonism is performed on solid media and involves detection of inhibition of growth of an indicator (sensitive) strain by a test (producer) strain. These methods are based either on simultaneous (direct) or deferred antagonistic activity[2]. Excepting few studies[3], mostly the deferred antagonism procedures have been employed for studying bacteriocinogeny among strains of rhizobia[4,5]. There are two procedures of studying deferred antagonism. One is to grow both the producer and indicator strains on the same surface of a gel, where the growth of the producer strain is removed and the surface is sterilized by fumigation with chloroform, before cross-streaking the indicator strains. The other procedure is based on the fact that diffusion of bacteriocin is tri-dimensional[6]. The producer strain is strip-inoculated at the centre of the surface of agar medium. After the full growth, the gel is inverted onto the lid of the petri dish and the indicator strain is cross-streaked over the sterile reverse surface of the gel. In this laboratory, while working with *Cajanus*-rhizobia, chloroform was found to inactivate the bacteriocinogenic property of the cultures, while the method of Kekessy and Piguet[6] was successfully used to screen out bacteriocin-producing strains[7–9]. We further successfully identified bacteriocin-producing strains of *Cicer*-rhizobia using this deferred antagonism procedure on a medium containing D-xylose. However, the method was found highly prodigious in terms of time, particularly to screen out bacteriocin negative mutants from a collection of several thousand transconjugants generated after Tn5 mutagenesis[10]. Therefore we used the simultaneous procedure involving double layers, and modified it to further improve the clear visibility of the inhibition zone.

The indicator (sensitive) strain was grown in yeast extract D-xylose (YEDX) broth for 3 days, and 0.5 ml of it was mixed with 9.5 ml of molten YEDXA containing 1.0% agar. The inoculated medium was over-layered on a 3 mm gel of YEDXA containing 2% agar in a plate. After solidification of the soft agar, the test strains were gently spotted. Observation for antagonism was taken from 3 to 7 day of inoculation.

It was interesting to observe that there was no inhibition of the growth of the sensitive culture around the growth spot of the producer strain. However, a very weak halo zone was visible under the growth. This was more sharply visible as a well, when the growth was gently swabbed off. Though we have no clear explanation for the lack of inhibition in the horizontal direction, probably the entrapment of antagonistic substance in diffusing exopolysaccharides over the surface of the gel limits the horizontal diffusion, while under the cell growth most of the antagonistic substance diffuse down into the soft agar rapidly. The results by this simultaneous antagonism method and those obtained with deferred antagonism were totally identical.

In order to observe inhibition around the growth spot, we made further attempts by modifying the composition of the media, particularly the solidifying agent, the agar. Four different media containing agar from three different sources were used (Table 1). Again the inhibition as a well-like halo zone under the growth was

Table 1. Detection of antagonism on different media varying in the source by simultaneous antagonism (double layer) method

	Source of agar		Halo zone produced by test strains (PR2042c, PR2015b, PR2109a, PR2303)	
Medium	Bottom layer	Top layer	Indicator strain PR2005b	Indicator strain 2007a
YEDXA	Qualigens 2%	Qualigens 1%	+	+
	Qualigens 0.5% + Difco 1.5%	Qualigens 0.5% + Difco 0.5%	++	++
	Sisco 1.5%	Sisco 1%	±	±
YEMA	Qualigens 2%	Qualigens 1%	+	+
	Qualigens 0.5% + Difco 1.5%	Qualigens 0.5% + Difco 0.5%	++	++
	Sisco 1.5%	Sisco 1%	±	±
Defined medium	Qualigens 2%	Qualigens 1%	+	+
	Qualigens 0.5% + Difco 1.5%	Qualigens 0.5% + Difco 0.5%	++	++
	Sisco 1.5%	Sisco 1%	±	±
SEYA	Qualigens 2%	Qualigens 1%	+	+
	Qualigens 0.5% + Difco 1.5%	Qualigens 0.5% + Difco 0.5%	++	++
	Sisco 1.5%	Sisco 1%	±	±

++, Very clear; +, clear; ±, weakly clear.

Qualigens, Glaxo India Ltd; Difco, Detroit, Michigan; Sisco, Sisco Research Laboratory, Mumbai, India.

Defined medium: According to Bergersen[11] but D-xylose as the carbon source.

YEMA, Yeast extract mannitol agar[12]; YEDXA, Yeast extract D-xylose agar (YEMA-mannitol + 0.5% D-xylose); SEYA, Soil yeast extract agar[13] except that no glucose but 0.4% yeast extract was incorporated.