21. White, T. J., Bruns, T., Lee, S. and Taylor, S., in *PCR Protocols: A Guide to Methods and Applications* (eds Innis, M. A., Gelfand, D. H. and Sninsky, J. J.), Academic Press, New York, 1990, pp. 315–322.

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Has the frequency of intense tropical cyclones increased in the north Indian Ocean?

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An effort has been made to settle the question whether the intense cyclones have become more frequent over the north Indian Ocean, posing a more serious threat to the vulnerable coastal population of the region. The results of the study, which has considered the entire existing data of 122 years of tropical cyclone frequency over the north Indian Ocean from 1877 to 1998, have shown that there is indeed a trend in the enhanced cyclogenesis during November and May. These months account for the maximum number of severe cyclones over the north Indian Ocean. The increasing trend in the cyclone frequency during these months has been primarily due to the significant positive trends over the Bay of Bengal, where the majority of north Indian Ocean cyclones develop. Thus the coastal regions of Bangladesh, India and Myanmar have indeed become more prone to the incidence of severe cyclones during November and May.

There has been a two-fold increase in the tropical cyclone frequency over the Bay of Bengal during November in the past 122 years. There has been a 17% increase in the intensification rate of cyclonic disturbances to the cyclone stage, and a 25% increase to severe cyclone stage over the north Indian Ocean during November, which accounts for highest monthly average of severe cyclone frequency. All these linear trends are statistically significant at 99% level. The increasing trend in the cyclone frequency during May is also highly significant but the intensification rates to cyclone and severe cyclone stages have registered only slight increasing tendencies. The cyclonic frequencies during transitional monsoon months, June and September, have diminished considerably. The detailed results have been presented for November and May only.

TROPICAL cyclones are among the most destructive natural disasters of the world. The north Indian Ocean accounts for 7% of global tropical cyclones[1]. More cyclones form in the Bay of Bengal than the Arabian Sea; the ratio of their respective frequencies is about 4:1 (ref. 2). There are two cyclone seasons in the north Indian Ocean, viz. pre-monsoon (especially May) and post-monsoon (especially October and November). A few cyclones form in transitional monsoon months June and September also. On an average about 5–6 tropical cyclones (maximum sustained wind of 34 knots or more) form in the Bay of Bengal and the Arabian Sea every year, of which 2–3 reach severe stage (maximum sustained wind of 48 knots or more). The total number of tropical cyclones in the Bay of Bengal and the Arabian Sea during May, June, September, October and November is given in Table 1.

The socio-economic impact of tropical cyclones is considerable[3]. The coasts of India, Bangladesh and Myanmar suffer enormous loss of life and property every year due to cyclones in the Bay of Bengal. Due to the high population density in the coastal regions, Bangladesh is most vulnerable to the hazards of tropical cyclones[4]. Therefore, any change in the tropical cyclone frequency in the Bay of Bengal would have far reaching consequences in the countries surrounding the Bay of Bengal rim.

The assessment of climate change effects on tropical cyclones is necessary, both in terms of occurrences and tracks. Cyclone activity may be affected by the changes in sea surface temperature (SST). For instance, El-Nino/Southern Oscillation is known to influence cyclone frequency in different ocean basins[5–7]. Therefore, the impacts of long-term SST trends on the cyclone frequency in each ocean basin needs to be documented. Some investigators have studied the changes in the

Table 1. Frequency of tropical cyclones in the Bay of Bengal and the Arabian Sea during the period 1877–1998

	Month				
	May	June	September	October	November
Bay of Bengal					
Cyclonic storms	59	35	40	89	114
Severe cyclonic storms	42	5	16	38	63
Arabian Sea					
Cyclonic storms	24	25	4	24	20
Severe cyclonic storms	19	17	2	11	15

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tropical cyclone frequency in the north Indian Ocean[8,9], but they have not been able to bring out significant changes due to the smoothing of frequencies on the annual time scale.

The source of data of tropical cyclone frequency in the north Indian Ocean for the period 1877–1979 is an India Meteorological Department publication (IMD)[10]. The domain of investigation is 5°N–35°N and 50°E–100°E and the same domain has been considered for all the years. The data for 1980–1998 have been obtained from different volumes of the quarterly journal *Mausam*. Pentad running totals of frequencies in different months have been obtained and the linear trends have been computed using the least squares method. The intensification rates of cyclonic disturbances (depressions and cyclonic storms) to cyclonic storm and severe cyclonic storm stages have been worked out for each month and year by computing the ratios of the number of cyclonic storms to the number of total cyclonic disturbances and the number of severe cyclonic storms to the number of total cyclonic disturbances, respectively. Pentad running averages of these intensification rates along with the trends have also been computed. In order to assess whether the changes in the north Indian Ocean have been primarily due to the changes in the Bay of Bengal or the Arabian Sea, the trends have been computed for the Bay of Bengal and the Arabian Sea separately. The criteria used in the classification of depression, cyclonic storm and severe cyclonic storm are as follows: depression–maximum sustained wind between 18 and 33 knots; cyclonic storm–maximum sustained wind between 34 and 47 knots; severe cyclonic storm–maximum sustained wind of 48 knots or more.

The trend coefficients of tropical frequency over the Bay of Bengal and the Arabian Sea along with levels of significance have been presented in Table 2. Pentad running total frequencies of cyclonic disturbances and the cyclonic storms over the north Indian Ocean for November and May have been presented in Figure 1 *a* and *b*, respectively. The intensification rates to cyclonic storm and severe cyclonic storm stages along with the trends have been presented in Figures 2 and 3. The pentad running total frequencies of cyclonic storms alone over the Bay of Bengal and the Arabian Sea separately have been given in Figure 4.

It is seen from Table 1 that the maximum number of severe cyclones in the north Indian Ocean is during November. On average, one severe cyclone is expected to form in November every year. November cyclones generally move westward to west-north-westward and strike the Andhra Pradesh or Tamil Nadu coasts of India. Occasionally, these cyclones move northward and recurve north-westward to strike the Bangladesh or Myanmar coast. November cyclones account for the highest number of natural-disaster deaths in India and Bangladesh. Therefore, any shift in their frequency is of paramount importance to India, Bangladesh, Myanmar and even to Sri Lanka. Considering the quantum of loss of life and property inflicted by these cyclones in South Asia due to various factors, even a slight increase in their frequency would be extremely hazardous. When we consider the number of occurrences of severe cyclones, it seems to be very small and insignificant. Therefore, when we talk of trends in these small numbers, they seem to be even more insignificant. The formation of 3 severe cyclones in 5 years is significantly different from the formation of 2 severe cyclones in 5 years. The vulnerable regions would be suffering from the losses of one more cyclone every 5 years. Numerically, this would mean a frequency increase of only 0.2 per year. Thus even a slight increase in the frequency of an extreme natural event needs careful assessment. Average losses per annum would be substantial even due to this insignificant increase in the number of occurrences of a natural event, which is capable of setting back social and economic advancement of a small developing nation by many years.

With this assessment background we now move to analyse and interpret the trend observed in the frequency of cyclones during November. As revealed by Figure 1 *a*, there has been an increasing secular trend in

Table 2. Results of trend analysis performed on the monthly frequencies of tropical cyclones over the Bay of Bengal and Arabian Sea for the period 1877–1998

	Bay of Bengal					Arabian Sea					North Indian Ocean
	May	June	September	October	November	May	June	September	October	November	Annual
Correlation coefficient	+0.168	–0.207	–0.157	–0.025	+0.244	–0.098	+0.009	+0.076	+0.11	+0.091	–0.112
Level of significance	0.90	0.975	0.90	NS	0.99	NS	NS	NS	NS	NS	NS
Trend per hundred years	+0.27	–0.31	–0.24	–0.05	+0.67	–0.11	+0.01	+0.04	+0.14	+0.11	–0.82

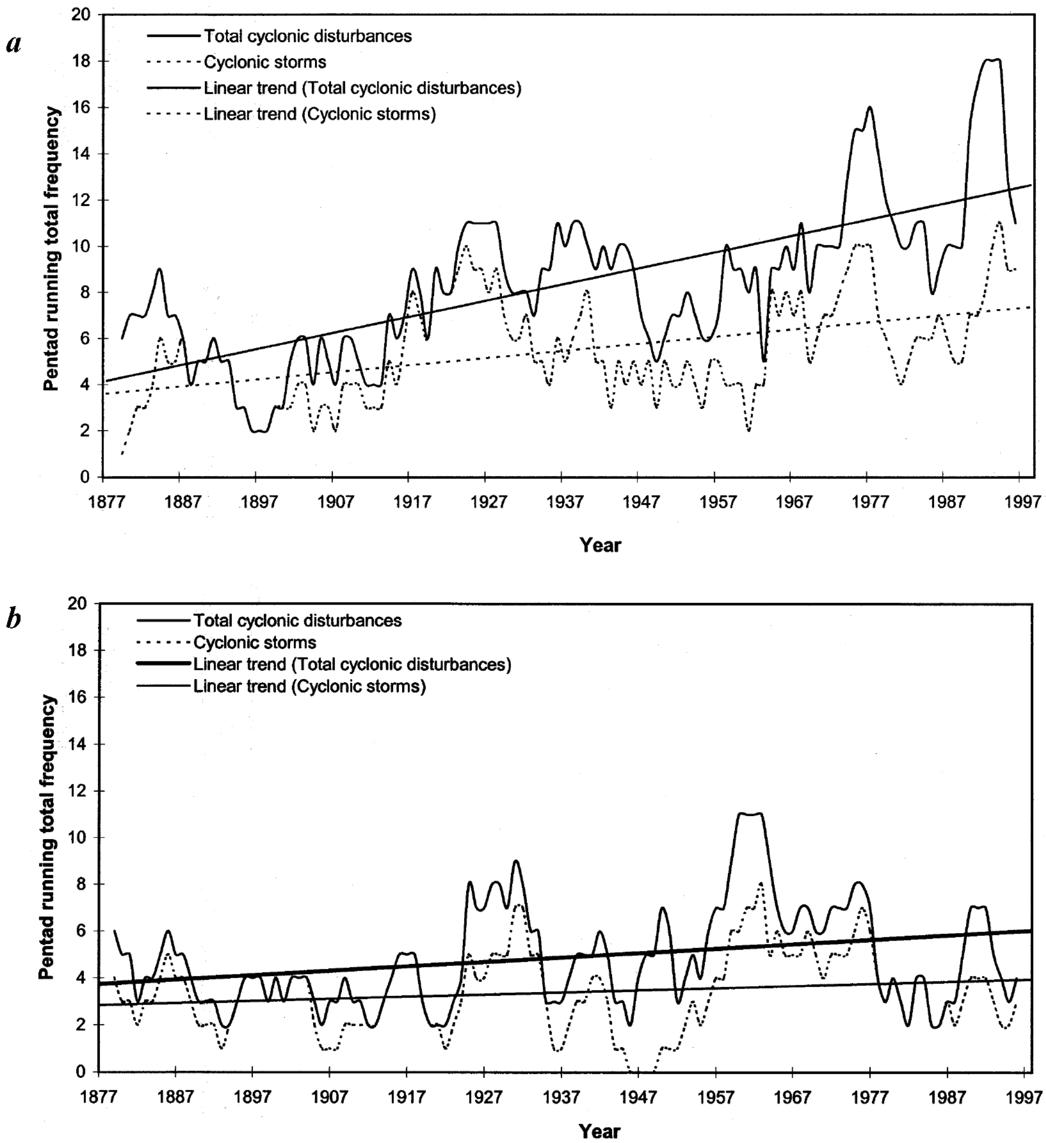


Figure 1. Pentad running total frequencies of total cyclonic disturbances and cyclonic storms over north Indian Ocean for (*a*) November and (*b*) May (1877–1998).

the tropical cyclone frequency over the north Indian Ocean during this month. The frequency of total cyclonic disturbances also has registered an increasing trend. Table 2 shows that the trend in the November cyclone frequency over the Bay of Bengal has been + 0.67 per hundred years, implying that about 3 more cyclones are forming in every 4-year period in the Bay of Bengal during the month, compared to the corresponding frequency 122 years ago. This trend is significant at 99% level, but the practical significance is even more important.

Figure 2 *a* shows that more cyclonic disturbances are now intensifying into tropical cyclones during November. Most importantly more disturbances are now reaching severe cyclone stage (Figure 2 *b*). This implies that the frequency of severe cyclones has increased at a faster rate compared to the total frequency of cyclones. The intensification rate to severe cyclone stage shows an increasing trend of 20% per hundred years. The trend coefficient is significant at 99% level.

It is evident from Figure 4 *a* that the increasing trend in the tropical cyclone frequency over the north Indian Ocean during November has been due to the increasing trend in the Bay of Bengal. If the peak in pentad frequency during 1990s is removed, then there would not be any secular trend over the Arabian Sea. Therefore, the frequency of severe cyclones in the Bay of Bengal during November, which has substantial socio-economic impact in the coastal regions of India, Bangladesh, Myanmar and Sri Lanka, has registered an increasing trend during past 122 years. At present we would not like to go into the probable causes, but would

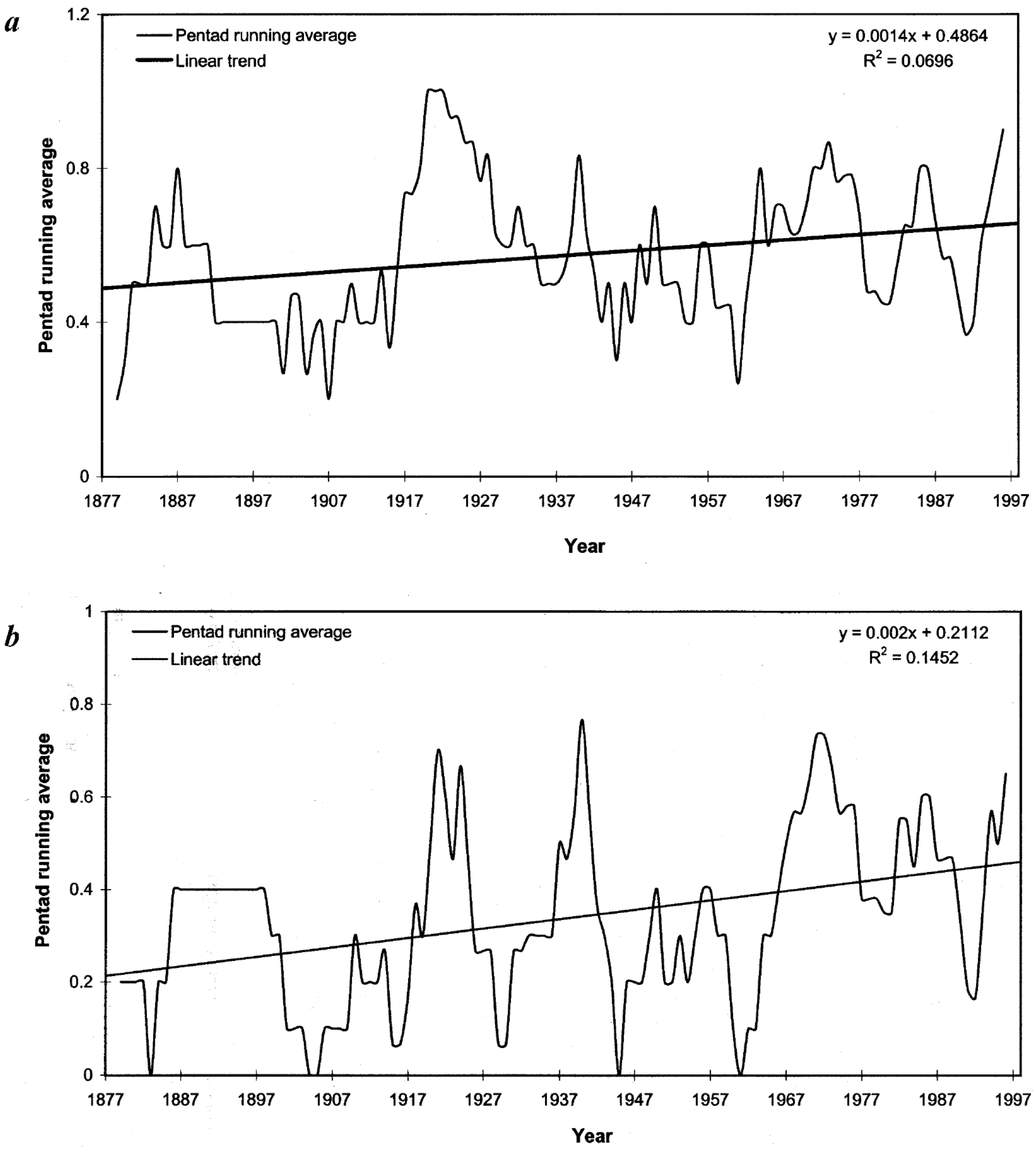


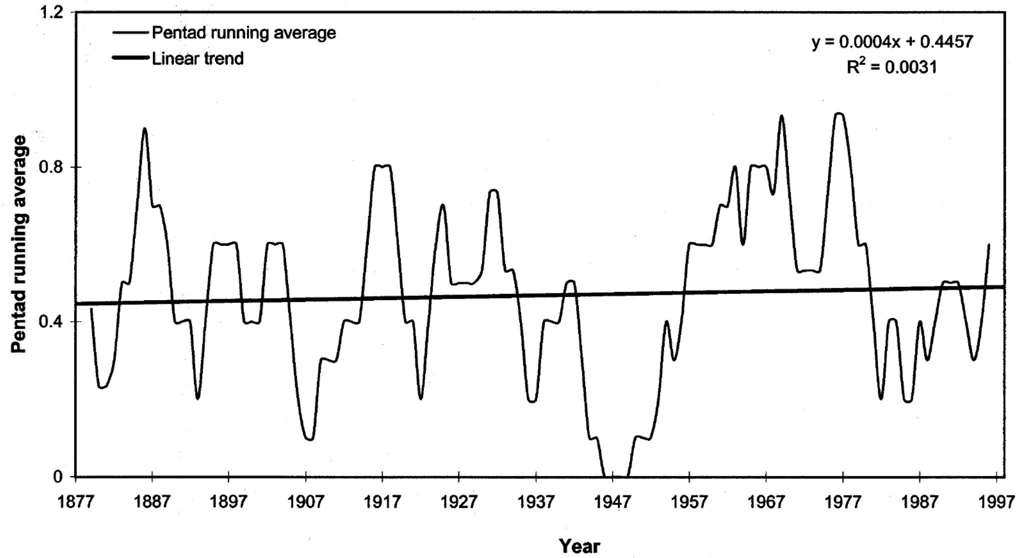
Figure 2. Five-year running average of intensification rate to (*a*) cyclonic storm stage and (*b*) severe cyclonic storm stage over the north Indian Ocean for November.

like to remark that it would not be correct to link the increasing trend to satellite monitoring or advancement in instrumental techniques, as the positive trend has been very consistent. Further, as revealed by Table 2, the tropical cyclone frequencies during June and September have shown significant decreasing trends. Thus the trends cannot be attributed to advancement of monitoring techniques.

A close examination of Figure 1 *a* would reveal that the increasing linear trend in the tropical cyclone frequency during November has been very consistent and systematic right from the beginning of the 20th century. There is no abrupt change since the advent of the satellite era of observation since mid 1960s. Time-series of cyclone frequency shows that the current rising leg has started from late 1950s, much before the satellite era. Similarly, 1920s have witnessed another spurt in the cyclone frequency. Thus it could be safely stated that the rising linear trend in the cyclone frequency is not due to the changes in the observational techniques. This point has been thoroughly investigated by the authors during the course of the present and other associated studies.

May is another month when devastating tropical cyclones form in the north Indian Ocean. Most of these cyclones develop in the Bay of Bengal and strike the Bangladesh or Myanmar coast. Statistically, May accounts for the second highest number of severe cyclones after November. Cyclonic disturbances that develop during May have a high probability of reaching a severe cyclonic stage. Therefore, any change in the frequency of tropical cyclones in the Bay of Bengal during May is also important for the affected regions.

a



b

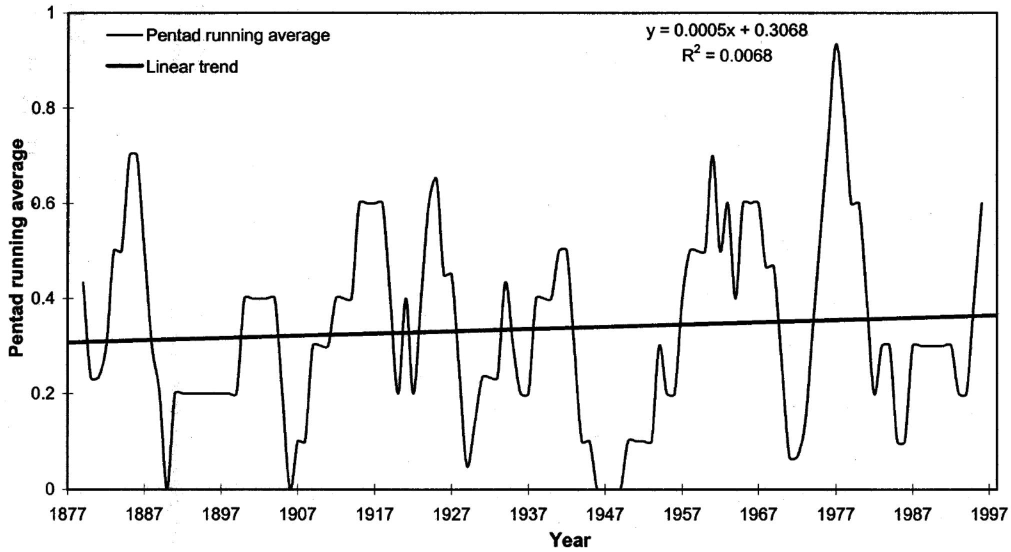


Figure 3. Five-year running average of intensification rate to (*a*) cyclonic storm stage and (*b*) severe cyclonic storm stage over the north Indian Ocean for May.

Figure 1 *b* shows that both cyclonic disturbances as well as cyclonic storms have registered increasing tendencies during May. Table 2 reveals that the increasing trend in the cyclone frequency over the Bay of Bengal during May has been + 0.27 per hundred years. Keeping in view the average frequency of one cyclone every two years in May, this trend is highly significant. Statistically, the trend is significant at 90% level.

Figure 3 *a* and *b* show that the intensification rates to cyclone and severe cyclone stages have registered slight increasing trends during May. It may be seen from Figure 4 *b* and Table 2 that the positive trend has been only over the Bay of Bengal. The trend over the Arabian Sea is slightly negative, which is not statistically significant.

When we consider the trend in the annual frequency of tropical cyclones over the north Indian Ocean, it is – 0.82 per hundred years. This amounts to a decrease of about 15% in the annual cyclone frequency. This trend is not statistically significant.

The decreasing trends during June and September have been highly significant. The decline in the annual cyclone frequency has been primarily because of diminishing frequency during the monsoon season.

The study has brought out the following results.

(i) The frequency of tropical cyclones in the north Indian Ocean has registered increasing trends during November and May, which account for maximum number of intense cyclones. The increasing trend has been primarily due to the positive trend in the Bay of Bengal. (ii) The intensification rate of cyclonic disturbances to severe cyclone stage has shown an increase of 20% per hundred years during the month of November. (iii) The tropical cyclone frequency in the north Indian Ocean

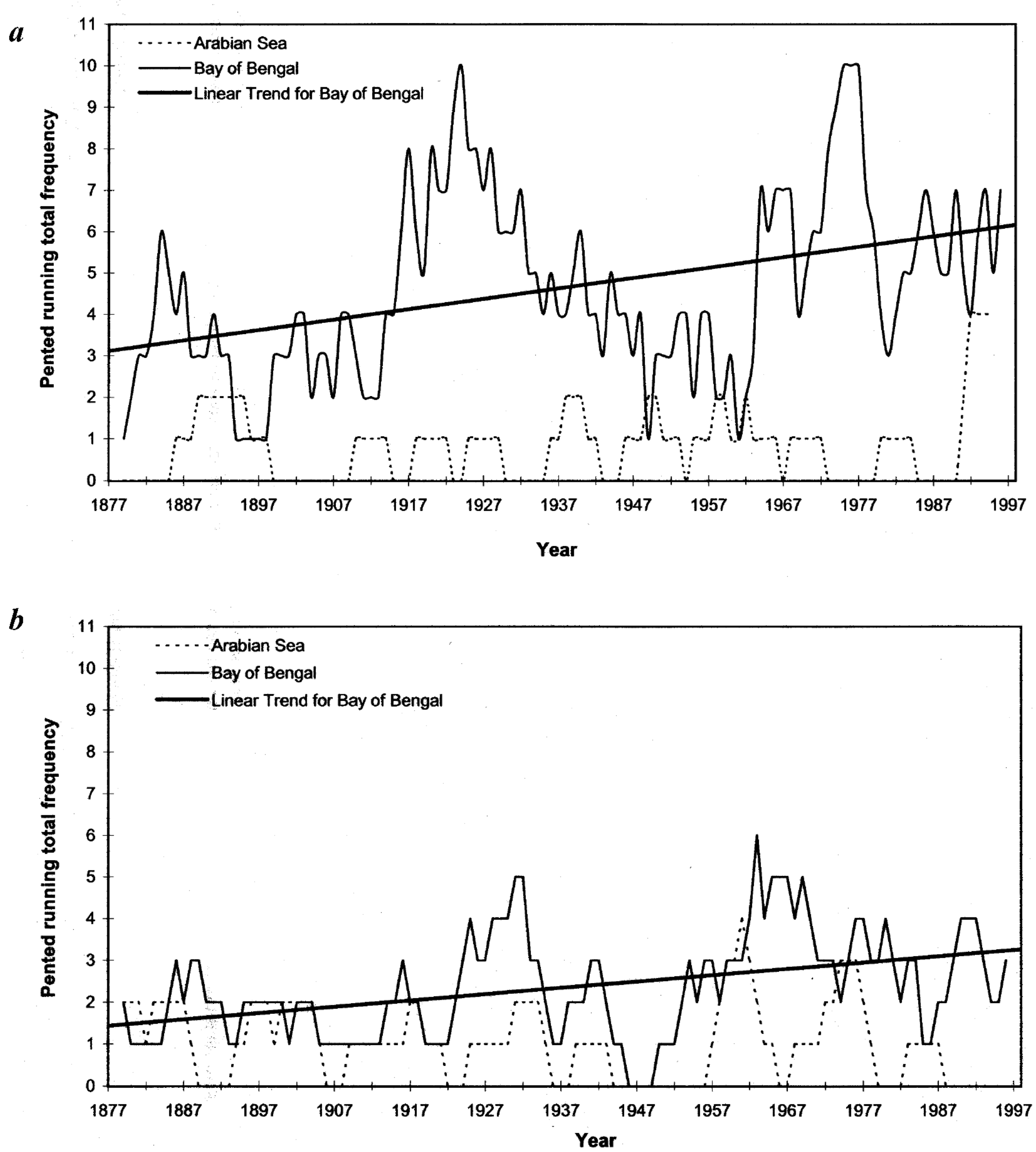


Figure 4. Pentad running total frequencies of cyclonic storms over the Bay of Bengal and the Arabian Sea for (*a*) November and (*b*) May.

has diminished considerably during June and September. (iv) During October, another important cyclone month, the cyclone frequency has not changed much. (v) The annual frequency of tropical cyclones in the north Indian Ocean has registered a decreasing trend of about 15% per hundred years.

1. Gray, W. M., Technical Document WMO/TD No. 72, WMO, Geneva, Switzerland, 1985, vol. I, pp. 3–19.
2. Dube, S. K., Rao, A. D., Sinha, P. C., Murty, T. S. and Bahulayan, N., *Mausam*, 1977, **48**, 283–304.
3. Obasi, G. O. P., *Mausam*, 1997, **48**, 103–112.
4. Ali, A. and Chowdhury, J. U., *Mausam*, 1997, **48**, 305–322.
5. Chan, J. C. L., *Mon. Weather Rev*., 1985, **110**, 1354–1374.
6. Gray, W. M. and Sheafer, J. D., *Teleconnections Linking Worldwide Climate Anomalies* (eds Glantz, M. H., Katz, M. W. and Nichols, N.), Cambridge University Press, 1991, pp. 257–284.
7. Singh, O. P., Ali Khan, T. M. and Rahman, S., *Mausam*, 1999 (to appear).
8. Ali, A., Paper presented in the workshop on Global Climate Change and Tropical Cyclones, Dhaka, Bangladesh, 18–21 December, 1995.
9. Joseph, P. V., Paper presented in the workshop on Global Climate Change and Tropical Cyclones, Dhaka, Bangladesh, 18–21 December, 1995.
10. Atlas, India Meteorological Department, New Delhi, India, 1979.

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It is our usual practice to publish only a single review of a book. In this case, in view of current interest in the topic, we have chosen to print two reviews which provide completely different perspectives.

– Editors

The Vedic People: Their History and Geography. Rajesh Kochhar. Orient Longman, Hyderabad, India. 2000. 259 pp. Price: Rs 425.00.

1st review

Rajesh Kochhar is a theoretical astrophysicist, but in this engaging book on the history and geography of the Vedic people, he has transcended the barriers of specialities and has attempted to synthesize data from varied sources to get a broader understanding of the prehistoric India. His book is a valiant effort to interpret the historical and geographical content of the *Vedas* and *Puranas*, using evidence from archaeology, natural history, etymology, geomorphology and astronomy. Besides building up a chronology and context of origin and interaction of Vedic people and Harappans, he tries to find out the location and period of *Vedas*, *Ramayana*, *Mahabharata* and their social milieu. His search compels him to question the conventional wisdom on the above subjects. Core of his thesis is built on the extra-Indian origin of the early Indo-Aryans.

Unravelling the prehistoric India, defined by two major traditions, namely Harappan and Aryan, is a painful exercise. The Harappan culture provides ample archaeological evidence, but no literary tradition. Converse is true for the Vedic culture. The problem is compounded by the fact that the Vedic texts are poor documents of human history, which are full of allusions and invocations and do not provide any direct reference to ancient geography and social life. Using the constraints from natural history, namely Aryan's affinity to horses and Soma plant (alkaloidal Ephedra), Kochhar lends credence to the idea of a West Asian ancestry to Indo-Aryans. Another crucial point he makes is that the earlier parts of the *Rigveda* were composed outside the geographical boundaries of the Indian subcontinent, most probably when these people lived around River Helmand in Afghanistan, on their way to India. Kochhar points out that the initial hymns of *Rigveda* are replete with allusions to geographical entities of Afghanistan, rather than geography of north-west India. For example, the Zoroastrian sacred book, *Avesta*, mentions about River Helmand in Afghanistan which resembles the description of River Saraswati in *Rigveda*. This river is called Harahvaiti in *Avesta*, phonetically the same as Saraswati. The Vedic people during their migration eastward to India carried with them their poetry, religious beliefs and also place and river names and reused them while settling in India.

Harappans were the earlier settlers and belonged to the Greater Indus Valley Civilization that shows a cultural continuity extending from 7000 to 2000 BC, and was spread over a wide area around the Indus River, Rann of Kutch (Dholavira), Saurashtra, along the Ghaggar–Hakra channel, parts of Baluchistan (Mehrgarh) and the Makhran Coast. It was during the late Harappan phase (2000 BC) that the Rigvedic people entered the Indian subcontinent. Harappan culture had a slow death, and was ascribed to increasing aridity of the land. Kochhar, however, rules out an Aryan invasion story. As renowned archaeologist Dales would call it, Harappans met their end not with an Aryan bang, but with an Indus expatriate's whimper, a figure of speech he borrowed from T. S. Eliot. Environmental degradation, such as increasing salinity was also said to be the cause of the decline of another great civilization in Mesopotamia. The late Harappan culture finally made way for the Painted Grey Ware (PGW) culture, developed elsewhere in north India and was active between 850 and 400 BC. PGW marks the Iron Age in India, which helped the people to clear the jungle and use the Ganga plain to its fullest potential. PGW period was succeeded by Northern Black Polished Ware (NBPW) period, which is assigned the time bracket of 600–100 BC. This period is considered to herald the Indian historical era. The PGW and NBPW eras saw the amalgamation of Harappan and Aryan traditions.

PGW represented by wheel-made and well-fired pottery with painted designs was excavated from Ahichhatra, Hastinapur, Purana Qila (Indraprastha) and some other places known to be associated with the epic *Mahabharata*. What is intriguing here is that the pottery from these sites is younger than the date assigned to the Bharata battle (around 900 BC). Such pottery was also excavated from Sringaverapura in the Allahabad district, a location associated with the *Ramayana*. The oldest settlement in these areas is dated to be 1050–1000 BC, which is pre-Aryan. Younger pottery, defined by a lustrous surface which gives a metallic ring, called NBPW excavated from Ayodhya, another site mentioned in the *Ramayana*, suggests that this site is younger than the Sringaverapura. This is perplexing because Ayodhya is believed to be founded by Iksvaku clan, 60 generations before Rama. It is clear that the archaeological findings from these sites do not match the perceived period during which the epics were formulated. In fact archaeology comes up with a curious fact that the *Mahabharata* site is older (PGW) than the *Ramayana* site (NBPW), although *Ramayana* (1600 BC) is considered to be an older epic. Kochhar argues that excavated sites do not represent the actual sites referred in the epics, even though they bear the same names. For example, he suggests that Rama's capital Ayodhya should be searched for along the banks of River Haroyu in south Afghanistan whose present name is Harirud, which he has equated with Rigvedic Sarayu. Regarding *Mahabharata* sites, he suggests that they must be near the Indus River, west of Yamuna. In view of the low-level technology (presumably Copper Age) available at that time, Bharata war itself might not have been a major one-time event, but rather a long lasting skirmish.

Kochhar's complex narrative darts back and forth in time and space. A substantial part of the book is devoted to make the point that River Saraswati, alluded in *Rigveda*, is not the Ghaggar–Hakra channel which may have been more watery than present, but certainly not a giant river, as interpreted to be on the basis of Vedic literature. Kochhar argues that Ghaggar–Hakra, as a river sustained by the waters from Sutlej and