Tropical cyclones in a warmer world

About 80 tropical cyclones (with wind speeds equal to or greater than 35 knots) form in the world's waters every year[1]. Of these about 6.5% develop in the Bay of Bengal and Arabian Sea[2]. Since the frequency of cyclones in the Bay of Bengal is about 5 to 6 times the frequency of those in the Arabian Sea, the Bay of Bengal's share comes out to be about 5.5%. The tropical cyclones forming in the Bay of Bengal hit the coast of India (particularly the states of Andhra Pradesh, Orissa and West Bengal) every year, causing heavy loss of life and property.

Two tropical cyclones crossed Orissa in the month of October 1999 (17 and 29 October). The tropical cyclone of 29 October (Friday) hit the coast of Orissa with wind speed of 135 knots (about 260 kmph) and heavy rains causing severe floods. Surges with more than 8 m height were associated with this cyclone. The cyclone was more or less stationary (with slight southward drift) over the region after making landfall and this led to destruction of the existing infrastructure. More than 10,000 human lives were lost and over a million were rendered homeless by this 'super cyclone'.

Some of the pronounced year-to-year variabilities in climate features and the extreme weather events (such as cyclones) in many parts of Asia have been linked to El Niño – Southern Oscillation (ENSO). The analysis of data generated in new coupled atmosphere–ocean global climate model (A–O GCM) experiments indicates that as global temperature increases, the Pacific climate will tend to resemble an El Niño-like state[3–6]. Collins[7] finds an increased frequency of ENSO events and a shift in their seasonal cycle in a warmer atmosphere, so that the maximum occurs between August and October rather than around January, as currently observed. Meehl and Washington[3] indicate that future seasonal precipitation extremes associated with a given ENSO event are likely to be more intense in tropical Indian Ocean region; anomalously wet areas could become wetter and anomalously dry areas become drier during future ENSO events. Changes in frequency and intensity of tropical cyclones could also result from changes in sea surface temperature (SST) linked to characteristics of ENSO events. During ENSO, a cyclone in tropical oceans has more than 40% chance of being a severe one[8].

The role of SST in the genesis and intensification of tropical cyclones has been well demonstrated, for example, by Gray[9], Emanuel[10] and Saunders and Harris[11]. One of the necessary (but not sufficient) conditions for tropical cyclone formation in the north Indian Ocean is that the sea surface should have a minimum temperature of about 28°C. Analysis of SST in the Bay of Bengal during the period 1951–1999 suggests that the SSTs have been increasing here since 1951.

Recent observations suggest that there is no appreciable long-term variation in the total number of tropical cyclones observed in the north Indian, south-west Indian and south-west Pacific oceans east of 160°E (refs 2, 12). For the north-west subtropical Pacific basin, Chan and Shi[13] found that the frequency of typhoons and the total number of tropical storms and typhoons have been more variable since about 1980. Observational records suggest that, while there has been a rising trend in all-India mean surface air temperature, the number of monsoon depressions and tropical cyclones forming over the Bay of Bengal and Arabian Sea exhibits declining trend since 1970 (Figure 1). There have been a number of studies that have considered likely changes in tropical cyclones in a warmer atmosphere[14–17]. Some recent global climate model experiments suggest a future decline in tropical cyclone frequency[16,18]. Jones *et al.*[18] performed an analysis of tropical cyclones from a 140-year simulation with regional climate model (RCM) nested in A–O GCM. This analysis indicated that there was a small decrease in tropical cyclone formation, although this result is considered preliminary. The pattern of cyclones

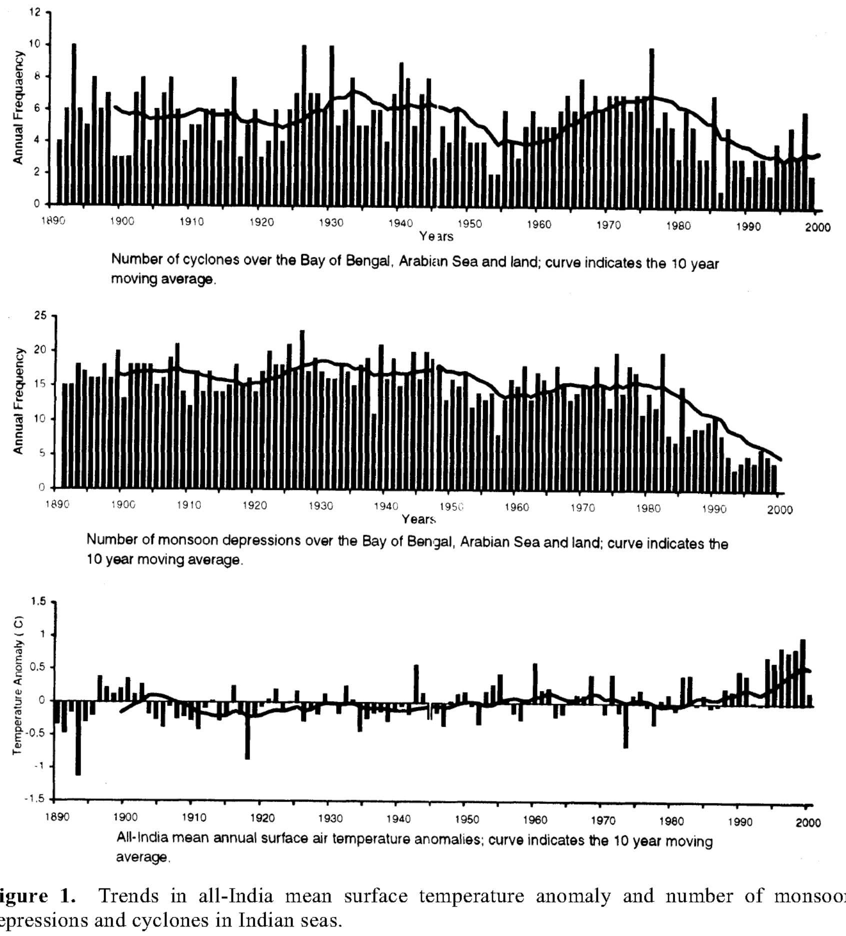

Figure 1. Trends in all-India mean surface temperature anomaly and number of monsoon depressions and cyclones in Indian seas.

during phases of ENSO was unchanged, suggesting that the current relationship between cyclone distribution and ENSO may continue. This study, however, reconfirmed an increase in cyclone intensity (10–20%) with CO_2-induced warming as estimated by Tonkin *et al.*[19] and Holland[20] as being likely.

Although no consensus has emerged as yet on the behaviour of tropical cyclones in a warmer world based on modelling studies, it is almost certain that an increase in SST will be accompanied by a corresponding increase in cyclone intensity (wind speed). The relationship between cyclone intensity (maximum sustained wind speed) and SST is well discussed in literature[21,22]. A possible increase in cyclone intensity of 10–20% for a rise in SST of 2 to 4°C relative to the threshold temperature of 28°C is very likely. Thus, while it is not yet certain that tropical cyclone frequency may change, the available data strongly suggest that an increase in its intensity is most probable.

Storm surges are generated by the winds and the atmospheric pressure changes associated with cyclones. At low latitude land-locked locations such as the Bay of Bengal, the tropical cyclones are the major cause of storm surges. Any increase in SST is likely to cause greater convective activity, leading to an increase in wind speed. The stress exerted by wind on water underneath is proportional to the square of the wind velocity. Amplification in storm surge heights should result from the occurrence of stronger winds and low pressures associated with tropical storms. Thus, an increase in SST due to climate change should lead to higher storm surges and an enhanced risk of coastal disasters along the east coast of India.

Cyclones have the best predictability among all the disaster phenomena. They can be detected as soon as they form over oceans and can be kept under continuous watch through meteorological satellites and radars. The magnitude of the accompanying hazard of storm surge is also predictable through techniques which take into account the parameters of the approaching cyclone as well as the physical and oceanographic characteristics of the coast in the area of anticipated landfall. The existing forecasting and warning system will have to be made more effective to cope with the potential threat from intense cyclones. Apart from large-scale expansion of the disaster warning service (DWS) by installing more DWS receiving stations across the Indian coastline, a system of aircraft reconnaissance flights will be very helpful. Such a cyclone-probing aircraft flight facility will be able to give the most reliable data on the exact location of the eye (centre) of the cyclone, the central pressure and the wind field in the cyclone. These precise measurements will also enable better modelling of cyclone dynamics and thereby more accurate regular (hours to day) forecast of cyclone track.

1. McBride, J. L., Report, WMO/TD-No. 693, No. TCP-38, WMO, Geneva, 1995, pp. 65–103.
2. Neumann, C. J., *Global Guide to Tropical Cyclone Forecasting*, WMO, Geneva, 1993.
3. Meehl, G. A. and Washington, W. M., *Nature*, 1996, **382**, 56–60.
4. Knutson, T. R. and Manabe, S., *J. Climate*, 1998, 2273–2296.
5. Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M. and Roeckner, E., *Nature*, 1999, **398**, 694–696.
6. Boer, G. J., Flato, G., Reader, C. and Ramscen, D., *Climate Dyn.*, 1999, **16**, 405–425.
7. Collins, M., *J. Climate*, 1999, **13**, 1299–1312.
8. Lander, M., *Mon. Weather Rev.*, 1994, **122**, 636–651.
9. Gray, W. M., in *Meteorology Over Tropical Oceans* (ed. Shaw, D. B.), *R. Meteorol. Soc.*, Bracknell, 1979, pp. 155–218.
10. Emanuel, K. A., *Am. Sci.*, 1988, **76**, 371–379.
11. Saunders, M. A. and Harris, A. R., *Geophys. Res. Lett.*, 1997, **24**, 1255–1258.
12. Lander, M. A. and Guard, C. P., *Mon. Weather Rev.*, 1998, **126**, 1163–1173.
13. Chan, J. C. L. and Shi, J., *Geophys. Res. Lett.*, 1996, **23**, 2765–2767.
14. Knutson, T. R., Tuleya, R. E. and Kurihara, Y., *Science*, 1998, **279**, 1018–1020.
15. Henderson-Sellers, A. *et al.*, *Bull. Am. Meteorol. Soc.*, 1998, **79**, 19–38.
16. Royer, J.-F., Chauvin, F., Timbal, B., Araspin, P. and Grimal, D., *Climatic Change*, 1998, **38**, 307–343.
17. Krishnamurti, T. N., Correa-Torres, R., Latif, M. and Daughenbaugh, G., *Tellus A*, 1998, **50**, 186–210.
18. Jones, R. N., Hennessy, K. J., Page, C. M., Pittock, A. B., Suppiah, R., Walsh, K. J. E. and Whetton, P. H., CSIRO Atmospheric Research Report to the South Pacific Regional Environment Programme, 1999, p. 69.
19. Tonkin, H., Landsea, C., Holland, G. J. and Li, S., in *Assessing Climate Change Results from the Model Evaluation Consortium for Climate Assessment* (eds Howe, W. and Henderson-Sellers, A.), Gordon and Breach, 1997, pp. 327–360.
20. Holland, G. J., *J. Atmos. Sci.*, 1997, **54**, 2519–2541.
21. Emanuel, K. A., *Nature*, 1987, **329**, 483–485.
22. Emanuel, K. A., *Nature*, 1999, **401**, 665.

Received 3 November 2000; revised accepted 22 January 2001

M. LAL

Centre for Atmospheric Sciences,
Indian Institute of Technology,
Hauz Khas,
New Delhi 110 016, India
e-mail: mlal@cas.iitd.ernet.in

Microbial fouling of an anion exchange resin

Water used in power plants and other industries needs moderate to severe treatment, depending on its quality[1]. Generally, three basic ion-exchange techniques are employed for the high water purity demanded by most industries. Firstly water softening, i.e. the removal of hardness (calcium and magnesium). Secondly, dealkalization, i.e. removal of alkalinity (bicarbonates and carbonates) together with hardness. Thirdly deionization or demineralization, i.e. removal of cations and anions from the raw water[1,2]. Depending on the water quality, ion exchange resins may get fouled in different ways, resulting in loss of resin efficiency to deliver pure water. Resin fouling comprises adsorption of foreign matter, resulting in impairment of resin performance. Common forms include corrosion products, organic acids, bacteria, iron, turbi-