

Monthly Mean Sea Level Variations at Cochin, Southwest Coast of India

P.K. DINESH KUMAR

National Institute of Oceanography, Regional Centre, P.B. No. 1913, Cochin - 682014 (Kerala), India

(Email: dineshku@niokech.i.org)

ABSTRACT

This study focuses on the variations in monthly mean sea level at Cochin, southwest coast of India, over a period of 50 years (1949-1998). Analysis have shown that there are strong seasonal variations in the monthly mean sea level. Contrary to expectation, sea level values were found to be the lowest during the south west monsoon months, though this is the period of maximum discharge from rivers which debouch in the region. This is explained in relation to the geographic setting and associated upwelling in the region. It is also indicated that large fluctuations due to weather conditions do tend to balance through the years, and the periodic seasonal changes are mostly eliminated when annual averages are calculated.

Key Words : Mean Sea Level, Arabian sea, Tide gauge data, Seasonal variation.

INTRODUCTION

The notion that world climate is changing because of the release of carbon dioxide from fossil fuels and other 'greenhouse' gases is widespread (Dork et al. 1994, Houghton et al. 1996, Odd et al. 2000). Although the warming effect caused by the emission of greenhouse gases has some inherent uncertainties as in all other studies on climate, several observations indicated that the earth is warmer now than in the past century (Baes et al. 1981, Hansen et al. 1983, Kerr 1988, Ramathan 1988, Anonymous 1992, Wigley 1995, Hulme et al. 1999). Among the many consequences that may occur as a result of a gradual increase in mean global temperature is a rise in mean sea level (MSL) and recent analysis of water level records dating back almost 100 years indicate that global MSL has been rising at a rate of 1.0 to 1.2 mm/yr since 1890 with potentially dangerous consequences for the low lying coastal regions (Gornitz et al. 1982, Gornitz and Lebedeff 1987, Douglas 1991, Peltier and Tushingham 1991, Warrick et al. 1996, Gommers et al. 1997, Nicholls et al. 1999). A small rise in sea level may double the probability of damaging storm surges on coastal zones (Gornitz et al. 1982). Such a rise would also cause substantial beach erosion and the intrusion of sea water into low-lying areas. Flooding due to sea level rise would also threaten the habitat of a large proportion of the world's coastal population.

Mean sea level has thus received considerable attention on local and global scales due to its possible

sensitivity to climate changes (Warrick et al. 1994, Pugh 1987). Long-term sea level records are essential for the study of changes in sea level and its effects. The statistics of the extreme high waters obtained over a long period of time are the primary criteria in the design of structures and marine engineering along the coast and in the generation of flood evaluation maps and environmental impact statements.

The standard method of generating mean sea level data is by taking their average over a certain period of time. This process, however, is effective only in reducing the effects within the average period. For example, the monthly average is effective only in reducing all effects within a period of less than a month, but it will not be effective in removing seasonal or other long-term changes. Therefore, the monthly average will vary for different months.

The monthly mean sea level and the yearly mean sea level have been used in climate monitoring and in studies of coastal processes such as beach erosion, ocean circulation and detection of vertical crustal movement. The tide gauge data of various Indian tide gauge stations have been analysed using the stochastic modelling techniques (Das and Radhakrishna 1991) and also to identify trends (Das and Radhakrishna 1993). Emery and Aubrey (1989) determined the sea level trend for different tide gauge stations along the Indian coast. Shetye et al. (1990) have examined tide gauge records in order to study the vulnerability of the Indian coast to a possible rise in sea level. Fractal analysis of sea level variations in the coastal regions of

India has also been done (Indira et al. 1993). This study focuses on the variations in monthly mean sea level at Cochin along the southwest coast of India.

DATA AND METHOD OF ANALYSIS

Permanent Service for Mean Sea Level (PSMSL), located at Bidson observatory, U.K. has been responsible for the collection and distribution of sea level data from the global network of tide gauges and data obtained from PSMSL for the tidal station at Cochin have been used here to compute the mean monthly sea level and long term seasonal trends. Figure 1 shows the location of tide gauge station at Cochin.

Tides experienced in the region are of mixed semi-diurnal type with two high and two low waters, with unequal tidal amplitudes, occurring each day. Amplitudes of the principal tidal harmonic constituents at Cochin are: M_2 (22.2cm); S_2 (8.0cm); K_1 (18.0cm) and O_1 (9.4cm) (Defant 1961). The form number (Pugh 1987) given by $(K_1 + O_1)/(M_2 + S_2)$ is 0.91, also indicating that the tide is of mixed, but predominantly semi-diurnal type. Maximum tidal range is about one meter with highest known tide of 1.75 m. The highest and lowest water levels normally occur at spring tides. The high tides which occur during the months of November and December are found to be unusually high. Very often the highest high water (HHHW) levels exceeded 1.2 m. The maximum tidal ranges are also

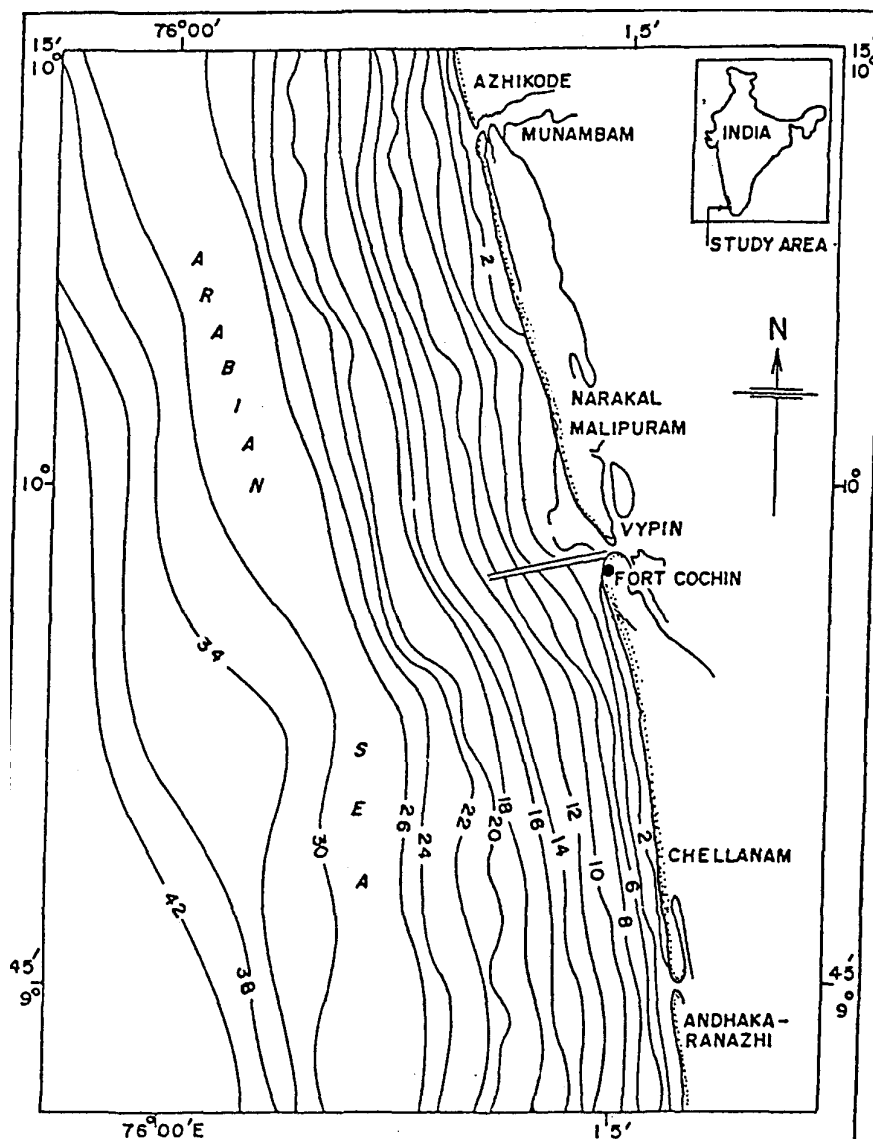
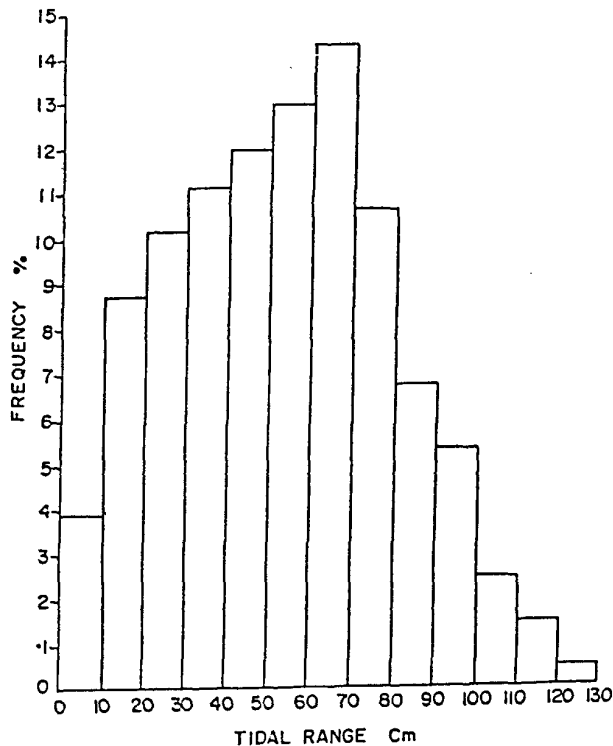


Figure 1. Location of sampling station at Cochin

high during this period and often vary between 1 and 1.2 m. The tidal ranges during the neap periods are usually low, very often less than 50 cm. The mean spring tidal range is 60.4 cm and the mean neap range is 28.4 cm. In general, the range and duration of the flood tide during the spring were greater. Neap tides, however, did not show any conspicuous variations in tidal ranges during flood and ebb tides as in the case of spring tides.

Frequency analysis of the tidal ranges (Figure 2) showed that the maximum frequency of 14.4% was in the range of 60 to 70 cm and the lowest frequency, 0.5% was in the range of 120 to 130 cm. There was one or two rare instances when the values were below the datum level. With every tide changing the direction, there was a period of no horizontal movement, called the slack period. Normally duration of the slack period was around 20 to 25 minutes.



Daily mean sea level is computed from the daily average of hourly data extracted from the tidal records. This averaging will eliminate significantly the influence of diurnal, semi-diurnal and shorter tidal components in the data (Roden 1966). The monthly and yearly means are then computed from the daily means.

Regression technique was used for the determination of trend equation (Spiegel 1981)

$$y = a_0 + a_1x$$

$$a_0 = \frac{(\sum Y) (\sum X^2) (\sum X) (\sum XY)}{N \sum X^2 - (\sum X)^2}$$

$$a_1 = \frac{N \sum XY - (\sum X) (\sum Y)}{N \sum X^2 - (\sum X)^2}$$

$$r = \frac{N \sum XY - (\sum X) (\sum Y)}{\sqrt{[N \sum X^2 - (\sum X)^2][N \sum Y^2 - (\sum Y)^2]}}$$

where r = correlation coefficient

a₁ = slope of the straight line

a₀ = Y intercept

The percentage of variance accounted by the seasonal signal in the monthly mean sea level time series is given by Sultan et al. (1995) which is,

$$100 [I - \text{var}(\text{res})/\text{var}(\text{org})]$$

where, var(org) is the variance of the monthly observed series, and var(res) is the variance of the monthly anomaly series.

DISCUSSION

Monthly and Annual Mean Sea Level Variations

Figure 3 shows mean monthly values of sea level at Cochin for the 50 year period, 1949-1998. The climatological seasonal cycle derived from the data has a range of nearly 19 cm, the increase from the lowest to highest occurring from September to December (3 months). The sea level is lowest during the southwest monsoon season, even though the rainfall and river discharges are maximum during that period. This can be explained in relation to the prevailing monsoonal forcings and associated upwelling in the region. In addition to its dynamical importance, the density of sea water has a considerable influence on the variations of sea level (Sultan et al. 1995) and the effect of water density upon sea level was recognized long ago (Pattullo et al. 1955). The south west monsoon is the time of an equatorward current along the west coast and upwelling occurs (Shetye et al. 1990). During monsoon months the coastal region off Cochin too experiences upwelling by which denser sea water is brought to the surface. The seasonal cycle is dominated by a strong annual cycle, followed by a weak semi-annual cycle. The seasonal cycle is similar to that presented by Bansal (1968). Sharma (1979) and Longhurst and Yvooster (1990).

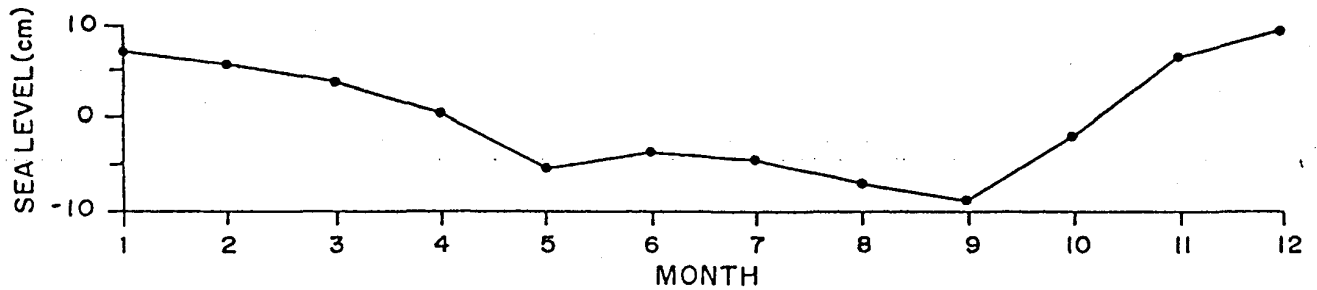


Figure 3. Mean seasonal cycle of sea level at Cochin (1949-1998).

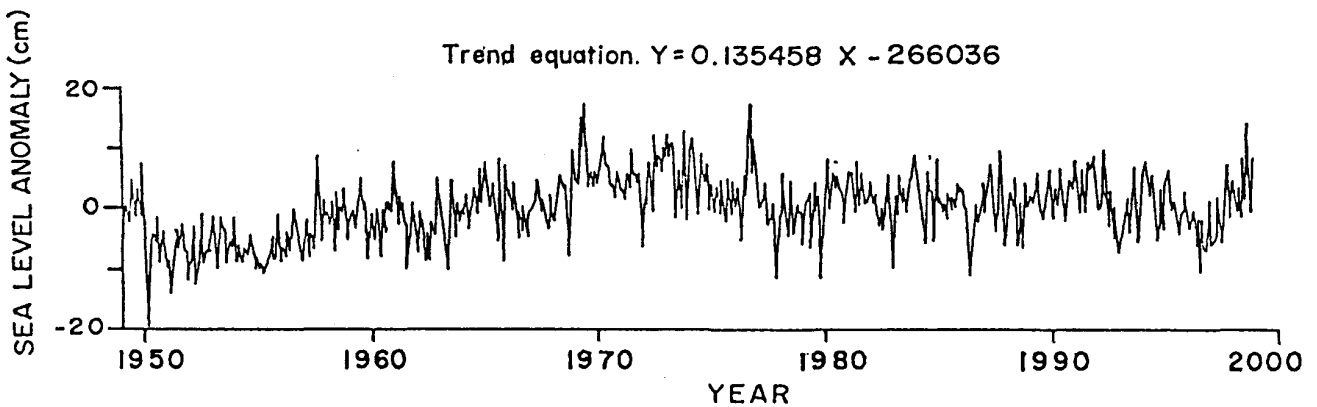


Figure 4. Long-term trend based on monthly mean sea level anomalies for the period 1949-1998 at Cochin.

The observed monthly mean sea level series for 1949-1998 period had a variance of 65.29 cm^2 and that of the anomalies from the mean seasonal cycle, 29.16 cm^2 . The seasonal signal, thus, accounts for 55% of the variance in the entire series and 45% of sea level variance is by other signals.

Large fluctuations due to weather conditions tend to balance through the years and the periodic seasonal changes are mostly eliminated when annual averages are calculated as shown in Figure 4. The trend is significant and accounts for nearly 13% of the variance of the series.

Lisitzin (1974), Pugh (1987) and Emery and Thompson (1998) concluded that changes in sea level take place over a wide range of temporal and spatial scales. Patullo et al. (1955) gave a global description of the seasonal variation of the mean sea level. Determination of the change in sea level is based not only on a long series of observations, but also on the accuracy of the data. The averaging processes used in the computation of mean sea level can only remove short-term fluctuations caused by tides and seasonal

climatological changes; it cannot effectively remove other factors caused by long-term changes in meteorologic, hydrographic, oceanographic, eustatic, astronomic and technical (water level recorder) conditions. It is very difficult to separate the effects of these long-term changes from the true changes in the sea level, and such study requires other data which are more difficult to obtain than sea level.

Therefore, the most important consideration in collecting data for the study of the mean sea level is to minimize the effect of all other possible long-term changes in the data. The tide gauge at Cochin was very old and of simple design and is well to have several operational problems. However, recently a modern tide gauge has been installed. This modern electronic tide gauge has the capability of transmitting data in real time which will (1) aid more accurate prediction of times and heights of coastal tides (2) provide accurate and sustainable data for the establishment of mean sea level (3) help in developing the immediate living zones along the coast (4) enable scientists to better understand the associated coastal processes and (5) further improve

safety of navigation. Further it is reported that climate is changing as a consequence of global warming due to industrial, agricultural and other human activities. The major effects of global warming are changes in the hydrological cycle and rise in sea level. Cochin is vulnerable to the effects of climate change and sea level rise due to the low elevation of the land areas, the low gradient of rivers and exposure to the sea. Hence comprehensive and systematic generation of sea level data will provide possible solutions to adapt to short and long-term changes.

ACKNOWLEDGEMENT

I am grateful to Dr. E. Desa, Director, National Institute of Oceanography (NIO) and Dr. K.K.C. Nair, Scientist-in-Charge, Regional Centre, NIO, Kochi, for the facilities and support provided.

REFERENCES

- Anonymous. 1992. Documenting and explaining recent global mean temperature changes. Final Report to NERC, U.K., Contract GR: 3/6565, Climate Research Unit, Norwich.
- Baes, C.F. Jr., Goeller, H.E., Olson, J.S. and Rotty, R.M. 1981. Carbon dioxide and climate: The uncontrolled experiment, pages 86-96, In: Skinner, B.J., (Editor) *Climates, Past and Present* W. Kaufmann, Inc., California, USA..
- Banse, K. 1965. Hydrography of the Arabian sea shelf of India and Pakistan and effects on demersal fishes. *Deep Sea Research* 15: 45-79.
- Das, P. K. and Radhakrishna, M. 1991. Analysis of Indian tide gauge records. *Proceedings Indian Academy of Sciences (Earth Planetary Sciences)* 100:177-194.
- Das, P. K. and Radhakrishna, M. 1993. Trends and the pole tide in Indian tide gauge records. *Proceedings Indian Academy of Sciences (Earth Planetary Sciences)* 102:175-183.
- Dorland, L.S., Frank, W.S. and David, K.J. 1994. Direct anthropogenic contributions to sea level rise in the twentieth century. *Nature* 17: 54-56.
- Defant, A. 1961. *Physical Oceanography*, Pergamon Press, Oxford. 595 pages.
- Douglas, B.C. 1991. Global sea level rise. *Journal of Geophysical Research* 96(C4): 6981-6992.
- Emery, K. O. and Aubrey, D. G. 1989. Tide gauges of India, *Journal of Coastal Research* 5: 489-500.
- Emery, W.J. and Thomson, R.E. 1998. *Data Analysis Methods in Physical Oceanography*. Pergamon, Kent, U.K. 634 pages'
- Gommes, R., Duerny J., Nachtergaele, F. and Brinkman, R. 1997. Potential Impacts of Sea Level Rise on Populations and Agriculture. Food and Agriculture Organisation of the United Nations, Rome.
- Gornitz, V. and Lebedeff. S. 1987. Global sea level changes during the past century. Pages 3-16, In: Nummedal.D., Pilkey, O.H., and Howard, J.D. (Editors) *Sea Level Fluctuations and Coastal Evolution*. Special Publication, 41, SEPM, Tulsa, Oklahoma, USA..
- Gornitz, V., Lebedeff, S. and Hansen, H. 1982. Global sea level trend in the past century. *Science* 215: 1612.
- Hansen, J., Lacis, A. and Rind, D. 1983. Climate trends due to increasing greenhouse gases. Pages 2796-2810, In: Magoon, O.T and Converse.H. (Editors) *Coastal Zone '83*, Proceedings Third Symposium on Coastal and Ocean Management. American Society of Civil Engineers, New York.
- Houghton, L.G., Meira Filho, L.G. and Callander, B.A. 1996. *The Science of Climate Change*. Cambridge University Press, Cambridge. 405 pages.
- Hulme, M., Mitchell, J., Ingram, W., Johns, T., New, M., Viner, D. 1999. Climate change scenarios for global impact studies. *Global Environmental Change* 9: S3-S19.
- Indira, N.K., Singh, R.N. and Yagnik, K.S. 1996. Fractal analysis of sea level variations in coastal regions of India. *Current Science* 70: 719-723
- Kerr, R.A., 1988. Is the greenhouse here? *Science* 239: 559-561.
- Lisitzin, E. 1974. *Sea Level Changes*. Oxford, New York. 286 pages.
- Longhurst, A.R. and Wooster, W.S. 1990. Abundance of oil sardine (*Sardinella longiceps*) and upwelling in the southwest coast of India. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2407-2419.
- Nicholls, R.J., Hoozemans, F.M.J., and Marchand, M., 1999. Increasing flood risk and wetland losses due to global sea level rise: Regional and global analyses. *Global Environmental Change* 9: S69-S87.
- Odd, G., Linda, S., Jan, S.F. and Terge, B. 2000. Estimates of future climate based on SRES emission scenarios. Working paper 2000:4. Centre for International Climate and Environmental Research, Oslo. 28 pages.
- Patullo, J., Munk, W., Revelle, R. and Strong E. 1955. The seasonal oscillation in sea level. *Journal of Marine Research* 14: 88-156.
- Peltier, W.R. and Tushingham, A.M. 1991. Influence of glacial isostatic adjustment on tide gauge measurements of secular sea level change. *Journal of Geophysical Research* 96 (B4):6779-6796.
- Pugh, D.T. 1987. *Tides, Surges and Mean Sea Level*. John Wiley, New York. 472 pages.
- Ramanathan, V. 1988. The radiative and climatic consequences of the changing atmospheric composition of trace gases. Pages 49-84, In: Rowland and Isaken, I.S.A. (Editors) *The Changing Atmosphere*. John Wiley, Chichester, U.K.

- Roden, G.I. 1966. Low frequency sea level oscillations along the Pacific coast of North America. *Journal of Geophysical Research* 71: 4755.
- Sharma, G, S. 1978. Upwelling off the southwest coast of India. *Indian Journal of Marine Sciences* 7: 209-218.
- Shelve. S.R., Gouveia, A.D. and Pathak, M.C. 1990. Vulnerability of Indian coastal region to damage from sea level rise. *Current Science* 59:152-156.
- Shetye, S.R., Gouveia, A.D, Shenoi, S.S.C., Sundar, D., Michael, G.S., Almeida, A.M. and Santanam, K. 1990. Hydrography and circulation off the west coast of India during the south west monsoon 1987. *Journal of Marine Research* 48: 359-378.
- Spiegel, M.R. 1981. *Theory and Problems of Statistics*. McGraw-Hill International, Singapore. 359 pages.
- Sultan, S.A.R., Ahmad, F., Elghribi, N.M. and Al. Subhi, A.M. 1995. An analysis of Arabian Gulf monthly mean sea level. *Continental Shelf Research* 15(11/12): 1471-1482.
- Warrick, R.A., Oerlemans, J., Woodworth, P.L., Meier, M.F., le Provost, C. 1996. Changes in sea level. Pages 395-405, In: Houghton, J.T., Meira Filho, L.G. and Callander, B.A. (Editors) *Climate Change 1995: The Science of Climate Change*. Cambridge University Press, Cambridge.
- Warrick, R.A, Barrom, E.M and Wigley, T.M.L. 1994. *Climate and sea level change: Observations, projections and implications*. Cambridge University Press, Cambridge. 424 pages.
- Wigley, T.M.L. 1995. Global mean temperature and sea level consequences of greenhouse gas stabilization. *Geophysical Research Letters* 22: 45-48.