香港天文台
HONG KONG OBSERVATORY

Reprint 556

Long Term Sea Level Change in Hong Kong

W.T. Wong, K.W. Li & K.H. Yeung

Hong Kong Meteorological Society Bulletin, Vol. 13, p. 24-40

Long Term Sea Level Change in Hong Kong

W.T. Wong, K.W. Li, K.H. Yeung
Hong Kong Observatory

1. Introduction

One of the consequences of global warming is the rise in sea level due to thermal expansion of the upper layer of the ocean and melting of polar ice caps and mountain glaciers. The rise of sea level has a potential impact on coastal regions, such as increased coastal erosion, more extensive coastal inundation, higher storm surge flooding, landward intrusion of seawater in estuaries and aquifers, and changes in surface water quality and groundwater characteristics. In the third assessment report of the Intergovernmental Panel on Climate Change (IPCC), it was estimated that the global mean sea level had risen by 1.0 to 2.0 millimetres per year in the 20th century and was projected to rise 0.09 to 0.88 metres from 1990 to 2100 (IPCC, 2001).

The sea level observed at a location is in a continuously changing state. It can be considered as the superposition of tide and meteorological residuals on the mean sea level (IOC, 1985). The principal tidal forcing is the gravitational pull by the Moon and the Sun. This is influenced by the rotation of the Earth, the relative motions among the Moon, the Sun and the Earth, the declination of the Moon's and Earth's orbital planes to the Earth's equatorial plane, and variable distances among these celestial bodies. These influences are manifested in the approximate semidiurnal, diurnal, half-monthly, monthly, semi-annual, annual, and 18.6 years periodicities of tidal height variations (Godin, 1988. Kantha *et al*, 2000).

Tides along coastal basins are strongly affected by geometry of the coastline, bathymetry and hydrology of estuaries. The eastern side of Hong Kong is open to influences of the coastal cold current that carries colder water from the East China Sea along the Taiwan Strait to the south China coast in winter, and the Kuro Shio current that transports warm water from the Pacific across the Luzon Strait into the South China Sea in springtime. During summer months, the Hainan current that carries warm water up to the northeastern coast of the South China Sea prevails. The western side of Hong Kong is at the Pearl River Estuary. Fresh water discharge via the Pearl River Estuary and sedimentation distribution at the Estuary exert an influence on the Hong Kong waters. This influence declines from west to east. The western part of Hong Kong waters is estuarine while the eastern part is predominantly oceanic; between the two is a region of mixing (Hong Kong Geological Survey, 2000).

The observed tides in open oceans have ranges of about 1.0 metre, which spread onto the shallow coastal shelves with higher tidal ranges. In Hong Kong, tides are mixed and mainly semi-diurnal, having two high tides and two low tides in a day for most days of a month. The tidal cycle begins in the southeast and propagates to the northwestern part of the Hong Kong waters. The mean delay in the tidal cycles between southeast and northwest is about one and a half hour. The mean tidal range between adjacent high and low waters is about 1.0 metre in the southeast and about 1.4 metres at the northwestern coast of Hong Kong. The mean differences between the higher high water and lower low water are about 1.5 and 2.1 metres for these areas respectively.

Meteorological residuals are the irregular non-tidal components due to the weather that remain after removing the tides by analysis. The major meteorological elements are atmospheric pressure and wind stress. A decrease of 1 hectopascal of the atmospheric pressure raises the sea level by about 1 centimetre. The drag of the wind on the sea surface increases approximately as the square of the wind speed which pushes the water up the shore when the wind blows in that direction, or pull the water down when wind is seaward. In extreme conditions such as storm surges during the passage of typhoons, the rise in sea level due to meteorological effects can be more than 3 metres above the tide level.

In this study, the annual mean sea levels measured at various tide gauge stations, including stations along the eastern and western coasts of Hong Kong, will be presented. The sea level trends will be compared to those in the open sea, the South China Sea. The long term sea level change in Hong Kong for the past 50 years will be determined.

2. Tidal Measurements

Since the 1950s, a number of automatic tide gauges were installed at sites along the coast of Hong Kong. Figure 1 shows the locations of these tide gauge stations. The periods of operation and data availability rates of these stations are given in Table 1.

Hourly tidal records are available from the North Point tide gauge station for the period 1954 to 1985. The station was built on reclaimed land and the tide gauge was installed on a sea wall. Monitoring of land settlement was carried out by the Port Works Division of the Civil Engineering Department (Mott MacDonald, 1990). The height of the tide gauge benchmark was measured by precise levelling, a land surveying technique based on trigonometric calculations, against the Hong Kong survey benchmark[Note 1] to an accuracy of about 4 millimetres. In view of settlement of the sea wall and revaluation of the tide gauge benchmark, the gauge was reset in 1954, 1956 and 1958 (Watts, 1959).

In 1985, the tide gauge station was relocated to Quarry Bay, a new reclaimed site about 500 metres east of the original station at North Point. The Quarry Bay tide gauge station has been put into operation since 1986. Monitoring of settlement of the station was carried out by the Port Works Division of the Civil Engineering Department (Mott MacDonald, 1990).

The results of settlement measurement at the North Point tide gauge station are given in Figure 2(a). The rate of settlement was about 6 millimetres per year in the 1950s and decreased to about 2 millimetres per year in the 1980s. The results of settlement measurement at the Quarry Bay tide gauge station are given in Figure 2 (b). The rate of settlement was about 6 millimetres per year in the 1980s and decreased to about 2 millimetres per year near the turn of the century.

Ip *et al* compared the tidal records at North Point and Quarry Bay and found no noticeable difference (Ip *et al*, 1990). Hence, the tide gauge data from these two stations are regarded as belonging to the same series. The North Point/Quarry Bay (NPQB) tide gauge station provides the longest tidal records in Hong Kong.

In contrast to NPQB, other tide gauge stations were not built on reclaimed land. Regular settlement measurements for these stations have been carried out since December 1991. The measurements showed that the tide gauge benchmarks fluctuated within a vertical range of about 2 to 10 millimetres and no significant trends were observed during the observation periods.

Due to telecommunication problems, data availability for some tide gauge stations was not satisfactory particularly in the earlier years. In this study, only tidal records from NPQB, Tai Po Kau, Lok On Pai and Shek Pik tide gauge stations where the data availability exceeds 80% are presented.

NPQB and Tai Po Kau are located on the eastern coast of Hong Kong and more

---

[Note 1] The datum of Hong Kong survey benchmark is called the Principal Datum (PD), which is about 0.88 metre below the Yellow Sea Datum. Tide heights are measured in metres above the Chart Datum, which is 0.146 metre below the Principal Datum.

affected by the northeast monsoon in winter, the oceanic currents from the east, and storm surges for typhoons that pass the south of Hong Kong, i.e. oceanic effects play an important role in affecting the hydrology at these locations. Lok On Pai and Shek Pik are close to the Pearl River Estuary. Fresh water discharge and sedimentation from the Pearl River affect the sea levels at these sites and shallow water effects on the tide are also more important. The maximum storm surges above tide level at NPQB, Tai Po Kau, Lok On Pai and Shek Pik are given in Table 2.

3. Data Analysis

Daily mean sea levels are computed from hourly tidal records using a sea level data processing software package developed by the University of Hawaii Sea Level Centre (Caldwell, 1998). Short data gaps less than or equal to 24 hours are filled with linear interpolation via the predicted tide data. A two-step filtering is applied to remove the periodic changes associated with tides. First, the dominant diurnal and semi-diurnal tidal components are removed from the hourly tidal records. Secondly, a 119-point convolution filter centred on noon is used to remove the remaining high frequency energy. Monthly means are computed from the daily mean sea levels if not more than 7 days of data are missing in the month.

Monthly mean sea levels at North Point between 1954 and 1957 are corrected for the error due to reset of the tide gauge based on the correction table from Watts (Watts, 1959). It was assumed that the error in the gauge was constant from one reset to the next and the amount of error was the difference between the mean of the recorded tides and the mean of the predicted tides over the period between resets.

Settlement correction based on Figures 2(a) and 2(b) is applied to the monthly mean sea levels at NPQB between 1958 and 2003. Data in Figure 2(a) and 2(b) are fitted by second order polynomials. No correction for settlement is applied to the monthly mean sea levels at Tai Po Kau, Lok On Pai and Shek Pik as settlement has been found to be insignificant.

Annual mean sea levels are computed from the monthly means if at least 10 months of monthly mean sea levels are available. The trend of long term annual mean sea level is obtained using a least squares linear fit.

4. Results and Discussion

The annual mean sea levels at NPQB, Tai Po Kau, Lok On Pai and Shek Pik are given in Figures 3(a) to (d).

During the 50 years period from 1954 to 2003, the annual mean sea level at NPQB has risen at a rate of 2.3 ± 0.6[Note 2] millimetres per year. This is similar to the rate of sea level rise of 2.3 millimetres per year at an island station Zhapo in the South China Sea in the past 50 years (State Oceanic Administration, 2004). These rates are slightly higher than the global mean sea level rise of 1.0 to 2.0 millimetres per year for the 20th century (IPCC, 2001).

From 1954 to 1987, the annual mean sea levels at NPQB show a general falling trend at a rate of 2.0 ± 0.5 millimetres per year. From 1987 to 1999, the annual mean sea levels rose rapidly at a rate of 22.1 ± 2.3 millimetres per year. From 1999 to 2003, the annual mean sea levels fell sharply at a rate of 21.0 ± 5.1 millimetres per year. Since the amplitude of the 18.6 years cycle for tides in Hong Kong is about 20 millimetres (Ding *et al*, 2001), the rate of rise or fall in the annual mean sea level due to this astronomical component is of the order of 2 millimetres per year, which is an order of magnitude smaller than the observed trends since 1987.

At Tai Po Kau, the annual mean sea level has risen at a rate of 3.0 ± 0.7 millimetres per year from 1963 to 2003. The corresponding annual mean sea level at NPQB has risen at a rate of 4.2 ± 0.8 millimetres per year during the same period. Similar to NPQB, there was a steep rising trend since the late 1980s and it became a falling trend from 2001 to 2003.

The annual mean sea level at Lok On Pai shows no significant trend from 1982 to 1998.

The length of the record of mean sea level at Shek Pik (from 1998 to 2003) is too short for any meaningful long term trend to be evaluated. Similar to NPQB and Tai Po Kau, the annual mean sea level declined from 2001 to 2003.

The trends of sea level change observed at NPQB and Tai Po Kau since the 1990s are remarkably similar to the sea level trends over the South China Sea from 1993

[Note 2] All error terms quoted in this report are given in one standard deviation.

to 2003, when satellite altimetry measurements of the oceans are available.

The TOPEX/Poseidon (T/P) satellite is a joint venture of France and the United States to measure the global sea level with respect to the centre of the Earth. An altimeter onboard the satellite sends radar pulses to the ocean surface and measures the time taken for bounced off pulses to return to the satellite. The T/P mission provides sea level data from 1993 to 2001 with an accuracy of 4 to 5 centimetres. Jason-1 is successor to the T/P mission and provides sea level data since 2002.

Figure 4 shows the average annual mean sea level over the South China Sea for the period 1993 to 2003 from the T/P and Jason-1 satellites published by the University of Colorado (http://sealevel.colorado.edu/). The annual mean sea level has risen rapidly from 1993 to 2001 and fell sharply from 2001 to 2003, with an overall rising rate of 7.4 ± 2.4 millimetres per year. The rising rate is considerably higher than the global mean sea level rise of 2.8 millimetres per year for the period 1993 to 2003. The sea level rise over the South China Sea was partly offset by a fall in the sea level in some other parts of the world.

From 1993 to 2003, the annual mean sea levels at NPQB and Tai Po Kau rose at a rate of 7.6 ± 3.8 and 3.4 ± 3.1 millimetres per year respectively. Notwithstanding the fact that these sea levels were referenced to the local tide gauge benchmarks instead of the centre of the Earth and hence did not take account of any local or regional crustal movements, the rates agree with the rate of sea level rise over the South China Sea within the error limits, i.e. the waters near NPQB and Tai Po Kau have responded to oceanic changes in the sea level. It therefore appears likely that the long term sea level change in the eastern waters of Hong Kong is driven by the sea level change in the South China Sea. Coastal effects including influences due to geometry of the coastline, bathymetry and large scale coastal projects would have affected the tidal currents and contributed to the differences.

Since the availability of T/P and Jason-1 satellite observations in 1993, a similar rising trend was not observable at Lok On Pai and Shek Pik on the western coast of Hong Kong though the annual mean sea level at Shek Pik also shows a declining trend since 2001. Apart from the geometry of coastline and bathymetry, fresh water discharge and sedimentation from the Pearl River might have influenced the response to the progress of oceanic currents in the western waters of Hong Kong. Extensive hydrographical measurements and modelling would be required to better understand the influence from various sources to the sea level at these locations, and are beyond the scope of this study.

How much global warming had contributed to the observed long term sea level rise in Hong Kong is difficult to determine. While the global mean sea level rise due to global warming depends mainly on the thermal expansion of the upper sea layer and the amount of melting of polar ice caps and mountain glaciers, regional variations in the sea level are additionally dependent on variations in the regional weather pattern and oceanic circulation which are affected by global warming. This is a complex problem which requires extensive monitoring and modelling of atmospheric and oceanic circulations to shed light on, and is outside the scope of the current study.

It is however worth noting that the large fluctuation in the annual mean sea level at NPQB since the mid-1980s, i.e. a rapid rise from 1987 to 1999 and an equally rapid fall from 1999 to 2003, coincided with the rapid rise in global mean surface temperature during the same period (IPCC, 2001), suggesting that the two phenomena might be related.

It should also be noted that the observed sea levels at the tide gauge stations in Hong Kong are referenced to the local tide gauge benchmarks. As pointed out by Yim, movement of the local earth crust would affect the observed sea level (Yim, 1992). Techniques based on differential Global Positioning System (GPS) are now available (IOC, 1994) to determine the vertical ground movement of the tide gauge stations with respect to the centre of the Earth to an accuracy at the centimetre level. The Hong Kong Observatory has embarked on a project to measure the long term vertical ground movement at Quarry Bay, Tai Po Kau and Shek Pik by GPS techniques starting 2004. In time, the effect of local crustal movement on sea level measurement can be determined and taken into account.

5. Conclusion

During the 50 years from 1954 to 2003, the annual mean sea level at NPQB has risen at a rate of 2.3 millimetres per year. This is similar to the rate of sea level rise of 2.3 millimetres per year in the South China Sea in the past 50 years as reported by State Oceanic Administration of China and slightly higher than the global mean sea level rise of 1.0 to 2.0 millimetres per year for the 20th century as reported by IPCC.

Since satellite altimetry measurements of the oceans became available in 1993, the annual mean sea level at the South China Sea rose rapidly at a rate of about 7 millimetres per year and the sea levels at NPQB and Tai Po Kau responded accordingly. It appears that the long term sea level change in the eastern waters of Hong Kong is driven by the sea level change of the South China Sea.

The large fluctuation in the mean sea level at NPQB since the mid-1980s coincided with the rapid rise in global mean surface temperature. It hints that the contribution of global warming to long term changes to the local sea level is probable. But this requires further study.

To determine the absolute change in local sea level requires information on local crustal movement. A Hong Kong Observatory project has commenced whereby vertical ground movement at selected tide gauge stations in Hong Kong will be regularly monitored by GPS measurement of the ground level.

Acknowledgement

The authors would like to thank colleagues Mess. C.F. Wong and K.L. Kwan for their assistance in data analysis and preparation of figures.

References

1. Caldwell, P. (1998) *Sea Level Data Processing On IBM-PC Compatible Computers Version 3.0*. Joint Archive for Sea Level of the National Oceanographic Data Center and University of Hawaii Sea Level Center.

2. Ding, X., Zheng, D., Chen, Y., Chao, J., and Li., Z. (2001) Sea Level Change in Hong Kong from Tide Gauge Measurements of 1954-1999. *Journal of Geodesy*, **74**, 683-689.

3. Godin, G. (1988) *Tides*. Anadyomene Edition.

4. Hong Kong Geological Survey (2000) *The Quaternary Geology of Hong Kong*. Civil Engineering Department.

5. Intergovernmental Oceanographic Commission (IOC) (1985) *Manual on Sea Level Measurement and Interpretation Volume I*. United Nations Educational, Scientific and Cultural Organization (UNESCO).

6. Intergovernmental Oceanographic Commission (IOC) (1994) *Manual on Sea Level Measurement and Interpretation Volume II*. United Nations Educational, Scientific and Cultural Organization (UNESCO).

7. Intergovernmental Panel on Climate Change (IPCC) (2001) *Climate Change 2001: The Scientific Basis*.

8. Ip, S.F. & Wai, H.G. (1990) *An application of harmonic method to tidal analysis and prediction in Hong Kong*. Technical Notes (Local) No. 55. Royal Observatory.

9. Kantha L.H. & Clayson C.A. (2000) *Numerical Models of Oceans and Oceanic Processes*. Academic Press.

10. Mott MacDonald Hong Kong Ltd. (1990) *Territorial Land Drainage and Flood Control Strategy Study Phase 1 Task 2 Report*. Drainage Services Department.

11. State Oceanic Administration of China (2004) *China Sea Level Public Notice 2003* (in Chinese).

12. Watts, I.E.M. (1959) *The effect of meteorological conditions on tide height at Hong Kong*. Technical Memoirs No. 8. Royal Observatory.

13. Yim, W.W.S. (1992) Future Sea-level Rise and Coastal Land Reclamations for Urbanization in Hong Kong. *HKMetS Bulletin*, **2(2)**, 3-10.

Station Name	***Latitude and Longitude***	***Operation Period***	***Data Availability***
Chi Ma Wan	22°14’N 114°00’E	1963 - 1997	67%
Ko Lau Wan	22°28’N 114°22’E	1974 –1995	58%
Lok On Pai	22°22’N 114°00’E	1981 –1999	87%
North Point/ Quarry Bay	22°18’N 114°12’E/ 22°17’N 114°13’E	1954 – 1985/ 1986 – 2003	98%
Shek Pik	22°13’N 113°54’E	1997 – 2003	89%
Tai Miu Wan	22°16’N 114°17’E	1994 – 2003	71%
Tai O	22°15’N 113°51’E	1985 – 1997	48%
Tai Po Kau	22°27’N 114°11’E	1963 –2003	94%
Tamar	22°17’N 114°10’E	1984 –1990	56%
Tsim Bei Tsui	22°29’N 114°01’E	1974 –2003	75%
Waglan Island	22°11’N 114°18’E	1976 –2003	45%

Table 1 Tide Gauge Stations in Hong Kong,
Their Operation Periods and Data Availability Rates

Location	*Maximum Storm Surge above Tide Level (metres)*	*Name of Tropical Cyclone and Time of Occurrence*
North Point/Quarry Bay	1.77	Wanda, September 1962
Tai Po Kau	3.23	Hope, August 1979
Lok On Pai	1.34	Koryn, June 1993
Shek Pik	1.09	Imbudo, July 2003

Table 2 Maximum Storm Surges above Tide Level Recorded at North Point/Quarry Bay, Tai Po Kau, Lok On Pai and Shek Pik

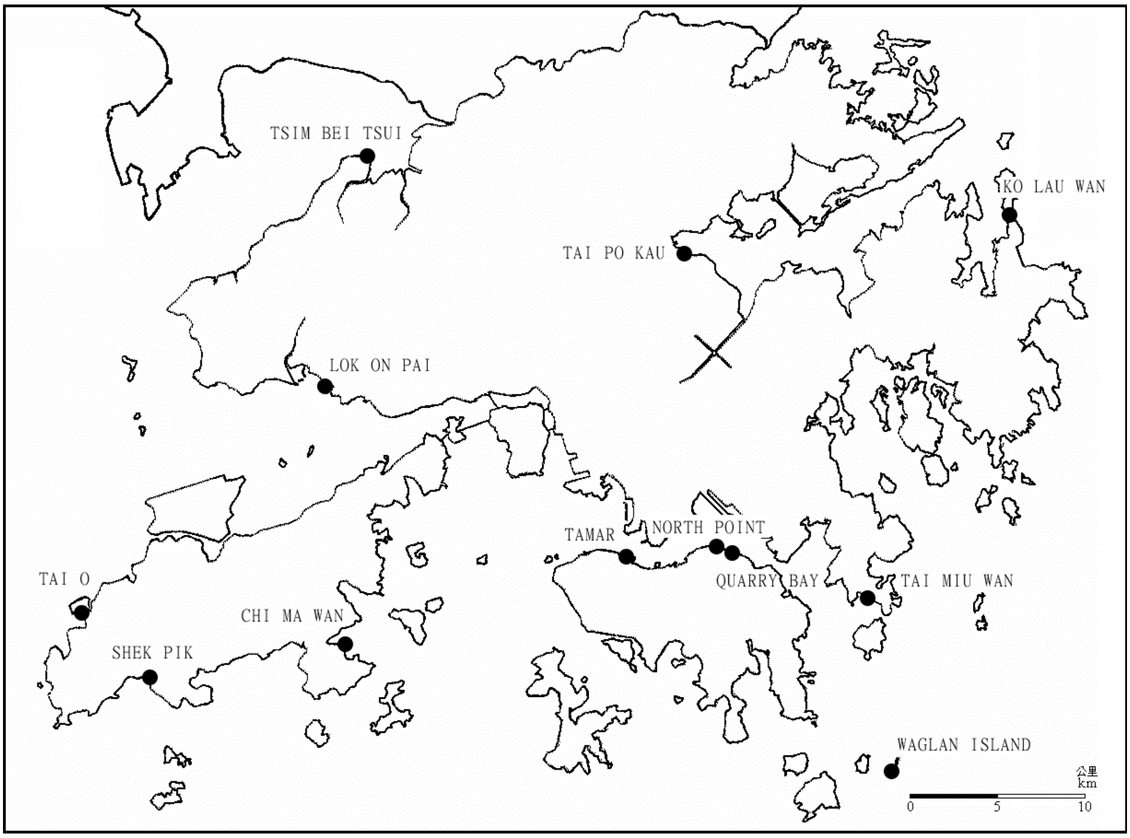

Figure 1 Locations of Tide Gauge Stations in Hong Kong

Figure 2(b) Land Settlement at Quarry Bay Tide Gauge Station
(1986 - 2003)

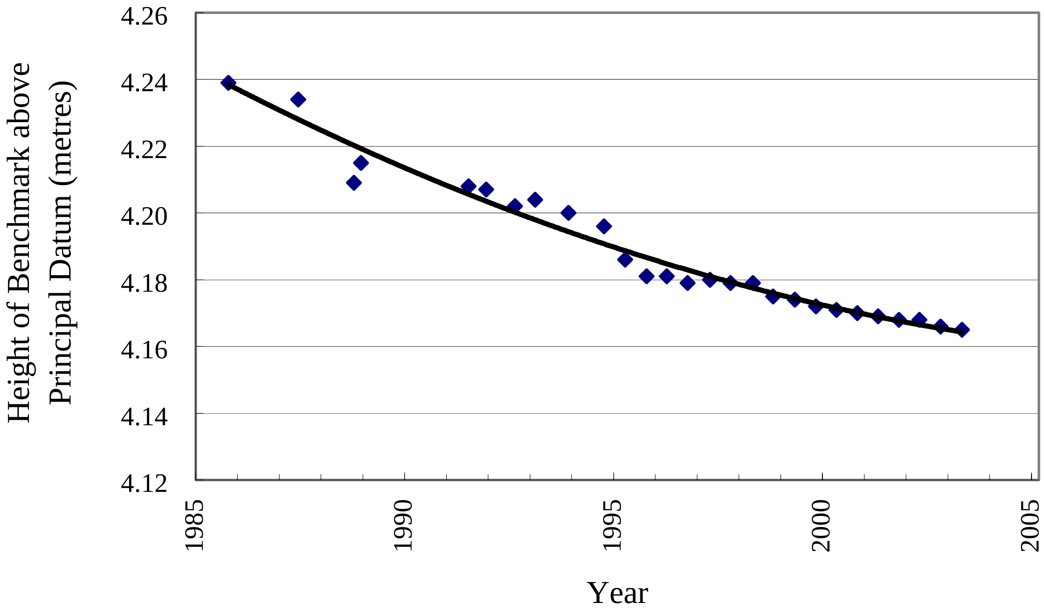

Figure 2(a) Land Settlement at North Point Tide Gauge Station
(1955-1989)

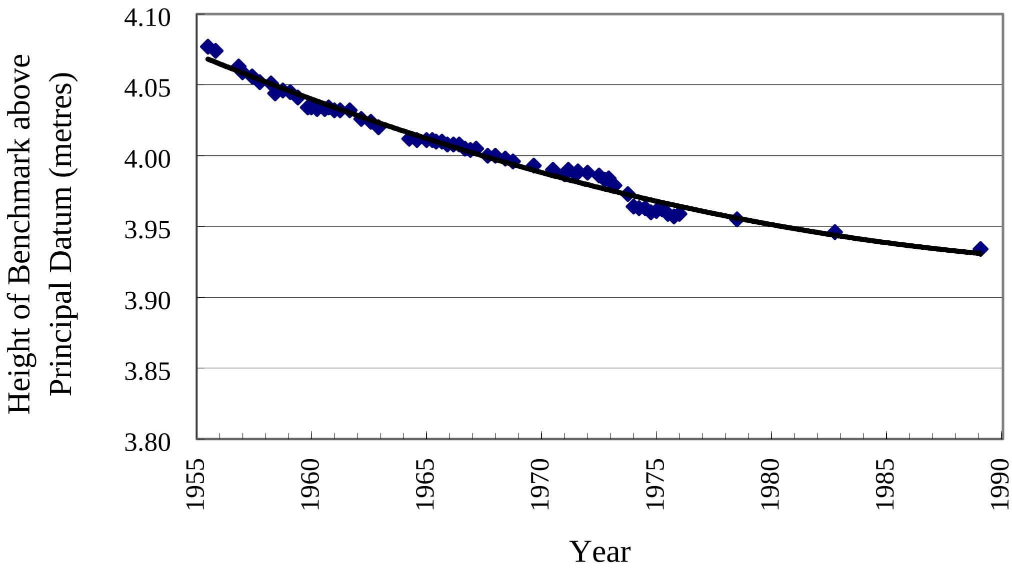

Figure 3(a) Annual Mean Sea Level at North Point/Quarry Bay (1954-2003)

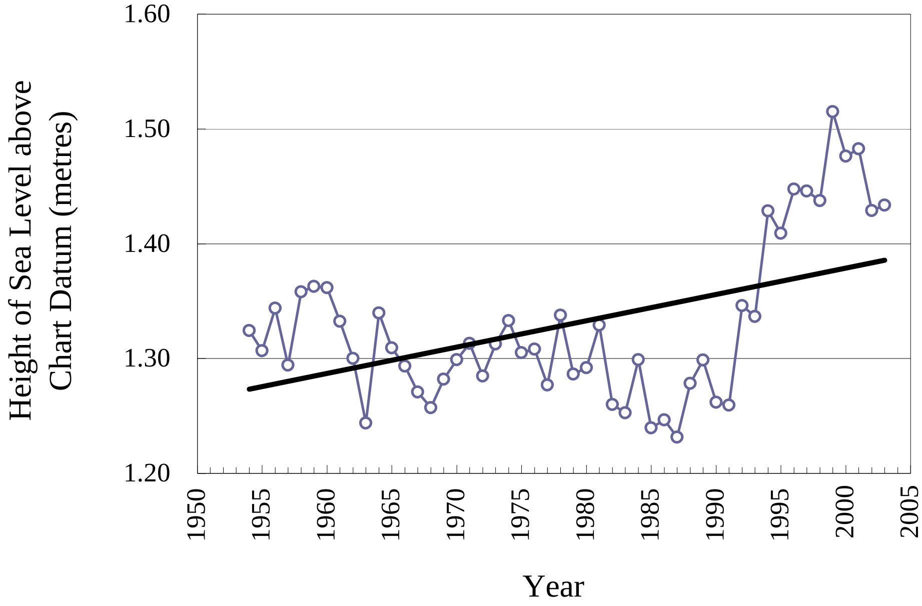

Figure 3(b) Annual Mean Sea Level at Tai Po Kau (1963-2003)

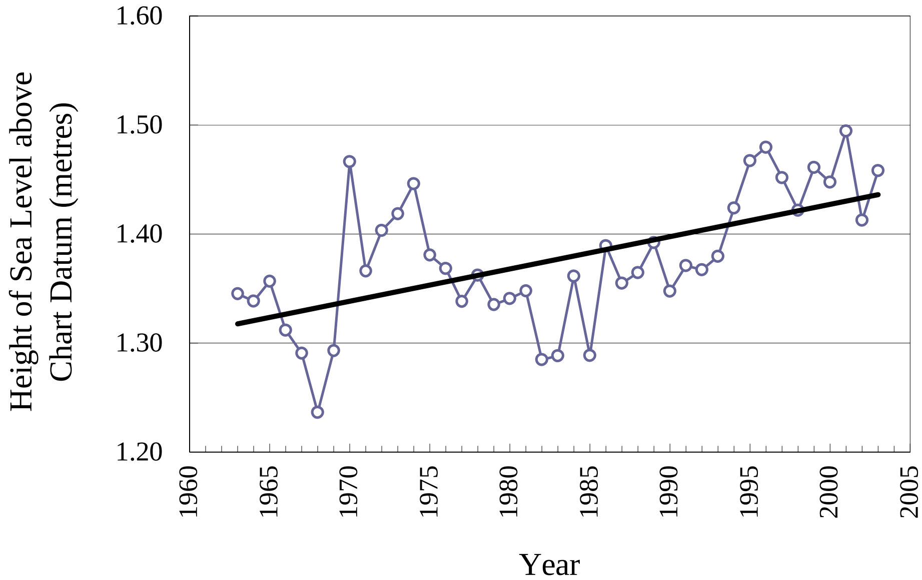

Figure 3(c) Annual Mean Sea Level at Lok On Pai
(1982-1998)

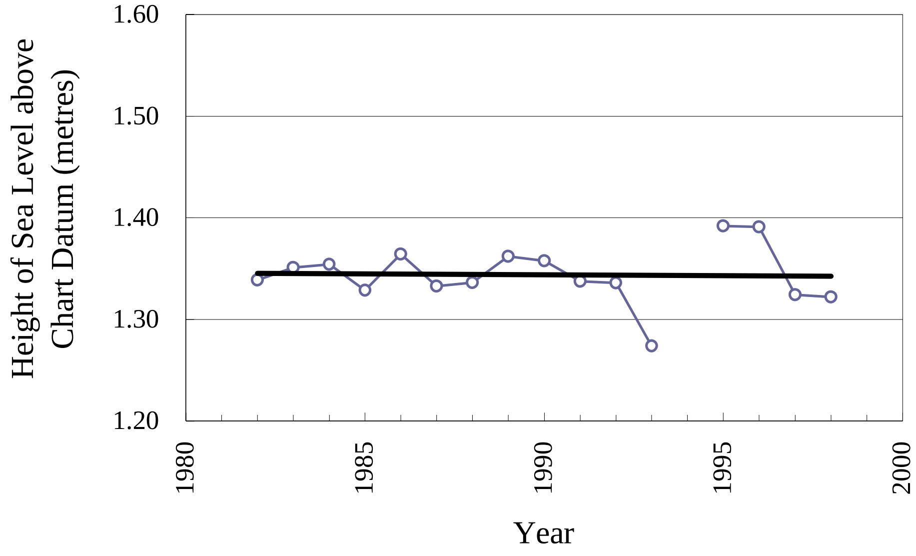

Figure 3(d) Annual Mean Sea Level at Shek Pik
(1998-2003)

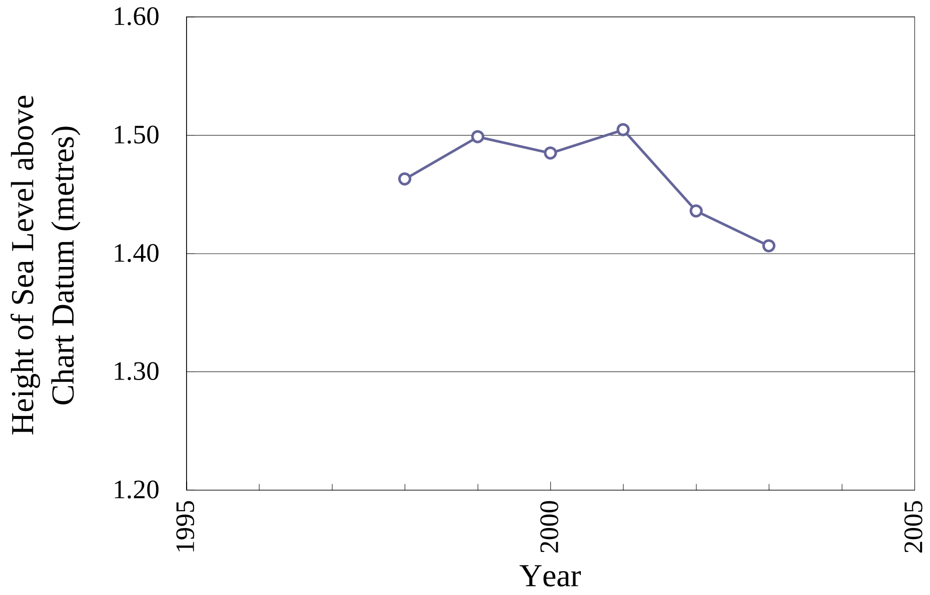

Figure 4 Mean Sea Level Anomaly for the South China Sea
Measured by TOPEX/Poseidon and Jason-1 Satellites (1993-2003)