Sea-level change in Hong Kong's Victoria Harbour

The recently published UN Intergovernmental Panel on Climate Change (IPCC) Working Group II Sixth Assessment Report, titled *Climate Change 2022: Impacts, Adaptation and Vulnerability*, sets out the latest scientific findings for global governments and policymakers to aid them in taking action on climate change. It is the starkest warning yet of the dangers of failing to limit the global average temperature rise to within 1.5°C. But the horrific events of Putin's unprovoked war against Ukraine have overshadowed the warnings from the IPCC in both public and governmental attention.

For the first time, the report includes a detailed overview of the adverse impacts of climate change on mental health, and an emphasis on how misinformation has delayed climate action on an individual and collective level. Decisions to protect the most vulnerable, based on accurate science, are being impeded by deliberate misrepresentation of that science to protect vested interests.

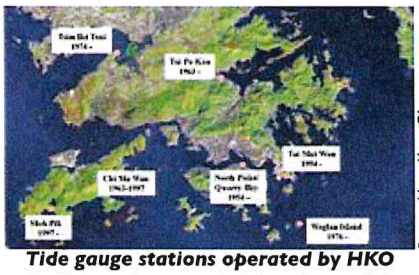
Here in the last of his articles offering a personal viewpoint of other factors that contribute to climate change, alongside anthropogenic activities, Wyss Yim considers historical tide gauge data from Hong Kong's Victoria Harbour.

Long records of temperature rise available from cities are uncorrected for the urban heat island effect resulting from land-use changes and population growth. Consequently, for verifying global warming a continuously rising sea level is an important supporting indicator of warming.

In the present study, an investigation of sea-level change in Hong Kong's Victoria Harbour is made using the record of tide gauges from 1954-2021. Victoria Harbour is located on the coast of the South China Sea adjacent to the mouth of the Pearl River Estuary and Delta. Two pauses in sea-level rise of 33 years (1959-1991) and 23 years (1999-2021) duration separated by 9 years of accelerated sea-level rise (1991-1999) can be interpreted. Contributing factors include uncertainties introduced by the relocation of tide gauge station from North Point to Quarry Bay in 1986; a 60-year cyclic sea-level changes; ground instability; and variability of precipitation and atmospheric pressure. Sea level overall is rising discontinuously despite a continuously rising level of carbon dioxide. Another fifty years of observations assisted by land motion measurements of tide gauge stations provided by interferometric synthetic aperture radar (INSAR) are needed to confirm the cyclical changes.

The continuously rising levels of carbon dioxide is the main cause of global warming resulting in turn in sea-level rise according to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). However, the rate of sea-level rise which is based on carbon dioxide scenarios is uncertain and since the first assessment report in 1990 has been repeatedly revised downwards.

Six automatic tide gauges installed since 1950s at sites along the coast of Hong Kong are currently in operation. The oldest, North Point Station which came into operation in 1954, is located in Victoria Harbour on reclaimed land prone to ground settlement. Although settlement corrections have been made, they were partial at best because the benchmark used for surveying the elevation of tide gauge was erroneously also located on reclaimed land instead of on the bedrock needed to rule out settlement completely. In the early 1980s, because of possible construction disturbance by the Eastern Corridor and the East Harbour Crossing, North Point Station was relocated to Quarry Bay on newly reclaimed land about 500m east. Since 1986 uncertainties of ground settlement corrections were removed using a new benchmark, on bedrock, in surveying. Subsequently the combined record of the North Point Station (1954-1985) and the Quarry Bay Station (1986-2021) was adopted by the Hong Kong Observatory (HKO) and the IPCC as the annual mean sea-level record for Victoria Harbour and Hong Kong.



Source: Hong Kong Observatory

Tide gauge stations operated by HKO

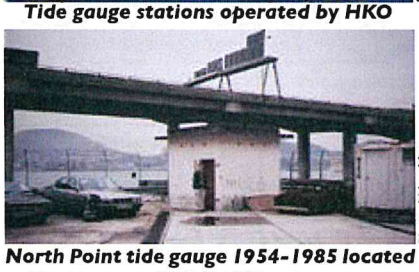


Photo: Wyss Yim

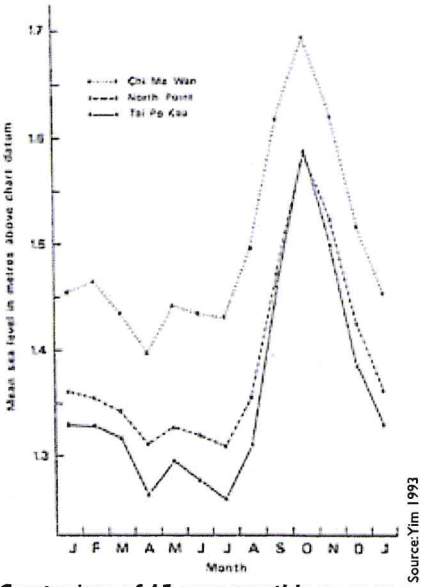
North Point tide gauge 1954-1985 located on reclaimed land

Photo: Wyss Yim

Quarry Bay tide gauge 1986-present located on reclaimed land

After ground settlement correction, a rate of future sea-level rise of 3.1cm/decade in the Harbour was projected by the Hong Kong Observatory. Under the *intermediate* and *very high* greenhouse gas emissions scenarios of the IPCC, the projected annual mean sea level in 2100 is likely to rise by 37-82cm and 57-108cm respectively relative to the average of 1995-2014 (1.45m above Hong Kong Chart Datum).

A comparative study of 1970-1984 monthly sea level at three tide gauge stations in Hong Kong (published in 1993 by the author) has revealed that major differences in sea-level elevation exist under the strong easterly monsoonal wind during winter and spring. Out of the three stations, Chi Ma Wan Station abandoned in 1997 with maximum wind forcing has the highest mean monthly sea level followed by North Point Station with intermediate wind forcing and Tai Po Kau Station with minimum wind forcing. Monthly mean sea level at North Point Station is on average between 8-15cm lower than Chi Ma Wan Station while Tai Po Kau Station is on average between 2-5cm lower than North Point Station. Such a comparative study of sea-level variability is possible only when multiple stations are available like Hong Kong. North Point/Quarry Bay Station with the longest record and intermediate level of wind forcing make it the most suitable station for sea-level change study out of the three.



Source: Yim 1993

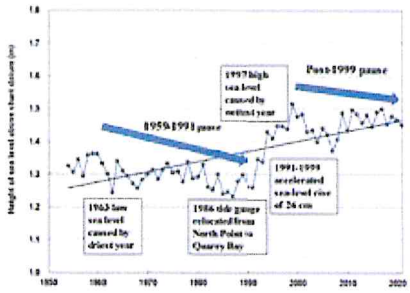
Comparison of 15-year monthly mean sea level during 1970-1984 at the North Point, Tai Po Kau and Chi Ma Wan Stations

Source: Hong Kong Observatory

Annual mean sea level in Victoria Harbour based on the combined records of the North Point/Quarry Bay Station

The changes in annual mean sea level found in the combined record of the North Point / Quarry Bay Station during 1954-2021 include:

1. Sea-level rise of 4cm from 1954-1959.
2. Pause in sea-level rise of 33 years duration from 1959-1991.
3. Accelerated sea-level rise of 9 years duration by up to 26cm from 1991-1999.
4. Pause in sea-level rise of 23 years duration from 1999-2021.



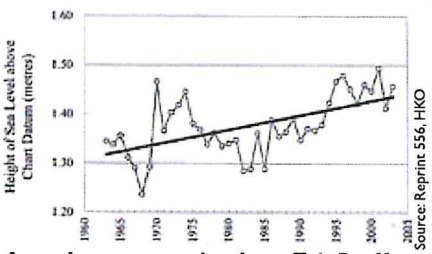
Changes in annual mean sea level found in the combined record of the North Point/ Quarry Bay Station

An improved understanding of the changes can be obtained by a comparison between the North Point / Quarry Bay Station record and the Tai Po Kau Station record. The three advantages of the Tai Po Kau record are:

1. Lowest monthly sea-level change in comparison to Chi Ma Wan Station and North Point / Quarry Bay Station as pointed out earlier.
2. The tide gauge is located on a pier with piled foundation less prone to ground settlement.
3. Unlike North Point / Quarry Bay Station a continuous record without interruption from the same location is available.

Differences found in a comparison between the North Point / Quarry Bay and Tai Po Kau records during 1963-2003 include:

1. No agreement in the years with minimum and maximum annual mean sea level.
2. Absence of the two pauses of sea-level rise interpreted from the North Point / Quarry Bay Station record. In the Tai Po Kau Station record, only one pause of sea-level rise 25 years in duration is present from 1970-1994.
3. The wettest year on record in 1997 coincided better with an anomaly in annual mean sea level peak than in the North Point/Quarry Bay Station.
4. An accelerated rise in sea level of up to 13cm is observed during 1990-1996 in the Tai Po Kau Station record. The potential sea-level rise is 13cm lower than the potential sea-level rise of 26cm found in the North Point / Quarry Bay Station during 1991-1999.

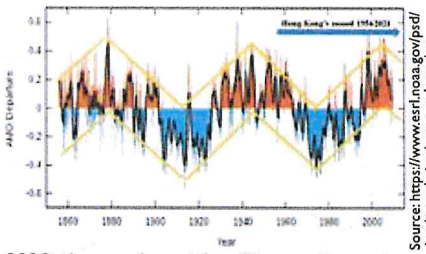


Source: Reprint 556, HKO

Annual mean sea level at Tai Po Kau Station during 1963-2003

Because continuous sea-level rise is not supported by the record of tide gauges, other local and regional controlling factors including astronomy, tectonics, climate and man-made are examined. A summary table of these factors and their explanation is provided below.

The pauses in sea-level rise may be explained by astronomically-driven multidecadal cyclic changes. Out of these changes, the 60-year cycle originally identified and introduced into the Chinese Calendar around 2637 BCE, which appears in phase with the Atlantic Multidecadal Oscillation (AMO), is particularly easy to observe. Significant surface temperature maxima accompanied by accelerated sea-level rise occurred in 1880-1881, 1940-1941, and 2000-2001. These warmer periods coincided with times when orbital positions of Jupiter and Saturn were relatively close to the Sun and Earth.



Source: https://www.esrl.noaa.gov/psd/data/correlation/amon.us.long.data

AMO time series with a 12-month moving average (black) 1856-2013. The pattern of sea-level change found in the 1954-2021 record in Hong Kong's Victoria Harbour is in general agreement.

Uncertainties are highlighted in this investigation using the record of tide gauges in Hong Kong's Victoria Harbour from 1954-2021. The conclusions drawn are:

1. Tide gauge stations located on bedrock in areas unaffected by human activities are essential to rule out ground settlement and reduction on the influence of man-made crustal loading and unloading.
2. Uncertainties in the record are caused by the relocation of the North Point Station to Quarry Bay.
3. Tide gauges adjacent to mouth of estuary and delta are influenced by changes in sedimentation-related crustal loading, river discharges and atmospheric pressure.
4. Sea-level rise projections based on a single tide gauge station can be misleading. It is desirable to perform a comparative study of tide gauge stations in an area in order to select the most suitable tide gauge station least affected by prevailing wind forcing for analysis of sea-level change.
5. Land motion measurements by Interferometric Synthetic Aperture Radar should be carried out to determine elevation changes of tide gauges located on both reclaimed land and bedrock.
6. Another fifty years of observations are needed to confirm the 60-year cyclical changes.
7. Carbon dioxide driven continuous sea-level rise is not addressed in this study.

Type	Feature	Explanation
Astronomy	Cyclic change in sea level	Cycle length approximately 60 years tracking the Atlantic Multidecadal Oscillation
Tectonics	Crustal instability through loading and unloading	Tectonic movement, erosion and deposition including mass movement and sedimentation
Climate	Lowest uncorrected mean sea level of 1.28m above Chart Datum in 1963	Driest year since record began at Hong Kong Observatory's Headquarters Station; high local/ regional pressure and low Pearl River discharge
	Highest uncorrected mean sea level of 1.51m above Chart Datum in 1999	Possible influence by the wettest year since record began at Hong Kong Observatory's Headquarters Station in 1997; low local/regional pressure and high Pearl River discharge
	Accelerated sea-level rise of up to 26cm 1991-1999	Partially explained by cyclic climate changes
Man-made	Low relative sea level 1985-1987	Uncertainty introduced by the relocation of the North Point Station to Quarry Bay including ground settlement
	Isostasy-related sea-level change	Human activities including coastal reclamation, construction loading, landfills, quarrying, mining and dredging
	Fossil fuel driven sea-level rise	Not addressed in the present study

Summary table of local and regional controlling factors for annual mean sea level in Hong Kong's Victoria Harbour

Professor Wyss Yim DSc PhD DIC FGS was at Imperial College in the Department of Geology from 1971-1974. After that he spent 35 years until retirement at the University of Hong Kong where he taught civil engineering, geosciences and environmental management students, and helped found the Department of Earth Sciences. He was awarded the DSc by the University of London in 1997. Wyss served as President of the *Western Pacific Sub-commission on Quaternary Shorelines* (1995-1999), President of the *Shelf Carbon Group* (1999-2003) and President of the *Sub-commission on Continental Shelves* (2003-2007), all bodies of the *International Union for Quaternary Research*.