香港天文台
HONG KONG OBSERVATORY

Reprint 1296

The Science of Climate Change and Its Relevance to Hong Kong

SHUN Chi-ming & LEE Sai-ming

Biennial Journal of Hong Kong Electrical Contractors' Association Limited, vol. 18, p.84-90

The Science of Climate Change and Its Relevance to Hong Kong

SHUN Chi-ming and LEE Sai-ming
Hong Kong Observatory

1. Global Climate Change

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) [1], the result of a collaborative effort of some 260 climate scientists from 39 countries in the world, re-affirmed in 2013 the unequivocal warming of the Earth's climate system and concluded that many changes observed since the 1950s were unprecedented over decades to millennia. AR5 also delivered a clear consensus reached by climate scientists worldwide that climate change was induced by human activities.

Since the Industrial Revolution, human activities have released more and more greenhouse gases into the atmosphere. The atmospheric concentration of carbon dioxide, the most important greenhouse gas as well as the main driver of global climate change in the last hundred years or so, has increased by over 40 per cent since pre-industrial times. The increase is primarily due to the burning of fossil fuels and secondarily due to deforestation. Present-day concentration of carbon dioxide is the highest in the last 800,000 years according to instrumental records and ice core analyses, and it keeps rising at a pace of 2 to 3 ppm per year.

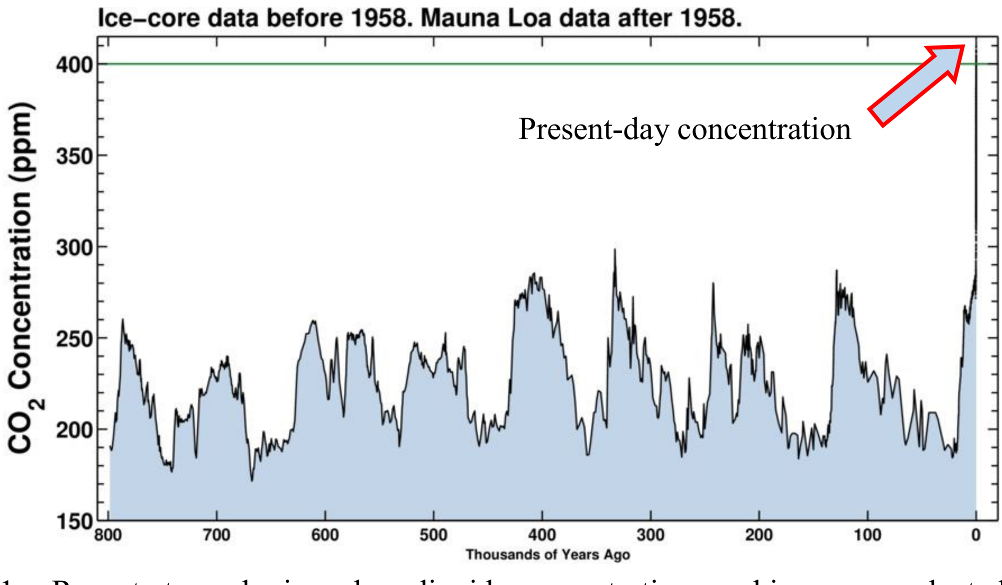

Figure 1 Recent atmospheric carbon dioxide concentration reaching unprecedented level in the past 800,000 years. (Source: Scripps Institution of Oceanography)

As a result of heat trapped by greenhouse gases, almost every corner of the globe has experienced a warming trend throughout the 20th century. The first decade of the 21st century has been the warmest since 1850, with the highest annual global temperature record broken for three consecutive years from 2014 to 2016, and with 16 of the 17 hottest years ever recorded falling into this century. A recent study pointed out that the chance of so many hot records clustering in the most recent couple of decades due to natural factors would be very low [2].

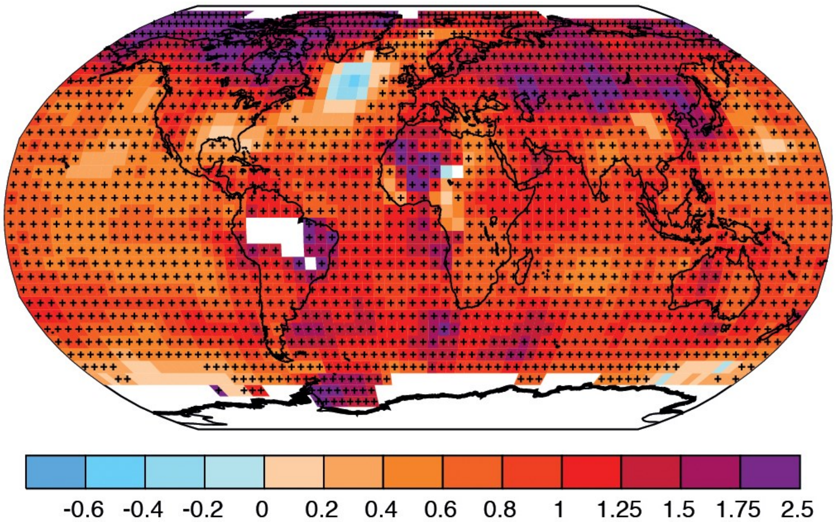

Figure 2 Warming trends during 1901-2012 in °C. (Source: IPCC, 2013 [1])

The cryosphere plays an important role in controlling the Earth's climate as the reduction of reflective surfaces of snow and ice will enhance warming through the climate-albedo feedback[1]. The meltdown of the cryosphere is the most conspicuous indicator of the warming climate. Hundreds of billions of tonnes of land-based glaciers are lost every year. Between 2011 and 2014, the Greenland Ice Sheet lost around one trillion tonnes of ice [3]. During the period of January 2016 – March 2017, the lowest monthly Arctic sea ice extent records were broken ten times, and April 2017 tied with April 2016 for the lowest for the month since the records based on satellite observations started in 1979. The decrease in Arctic sea ice has been most rapid in summer, with the summer retreat in the past three decades unprecedented in the last 1,450 years.

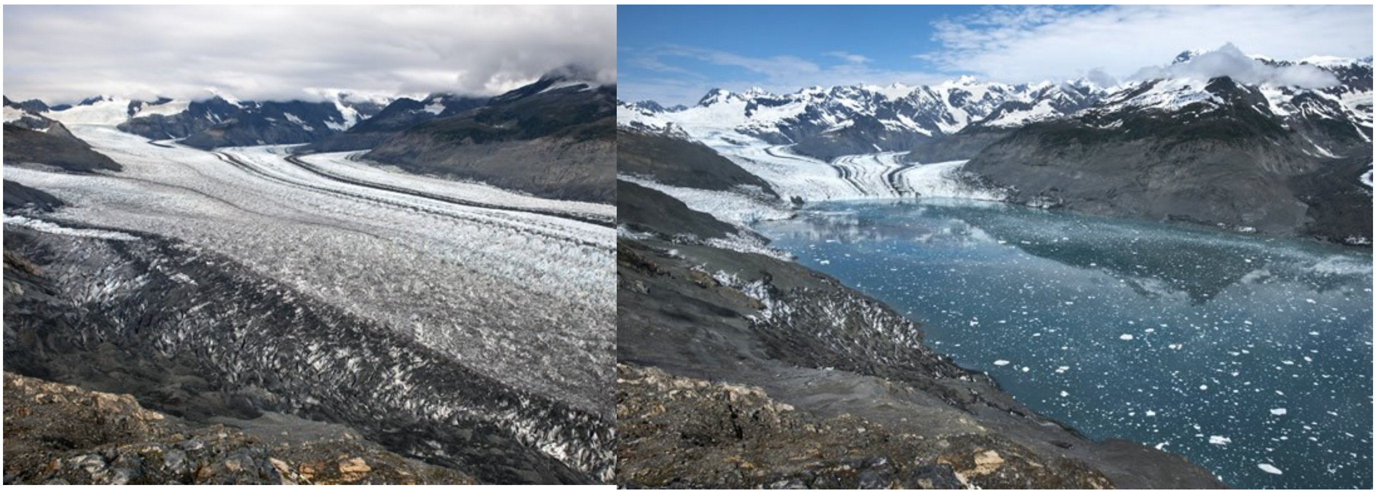

Figure 3 Columbia Glacier, Alaska in 2009 (left) and 2015 (right). (Source: The Geological Society of America)

[1] Albedo is the proportion of the incident light reflected by a surface, typically that of a planet. The climate-albedo feedback means that the albedo change caused by warming (cooling) of the planet will promote further warming (cooling).

2. What the Future Holds

AR5 presented projections under various scenarios/pathways (in terms of low, medium-low, medium-high, and high greenhouse gas concentration) corresponding to a range of options we have in responding to the climate change challenges. The world moved along the trajectory of the high greenhouse concentration pathway in the past decade. Although implementation of the emission reduction pledges in the Paris Agreement could steer the world away from the worst scenario, it is evident that based on the climate projections by AR5, much more effort will be required from now on if we aim to reach the goal of the Paris Agreement of keeping global temperature rise below 2°C (relative to pre-industrial levels) by the end of this century. Based on those pledges, the world could still be heading towards a temperature rise of around 3°C (relative to pre-industrial levels) by the end of this century [4].

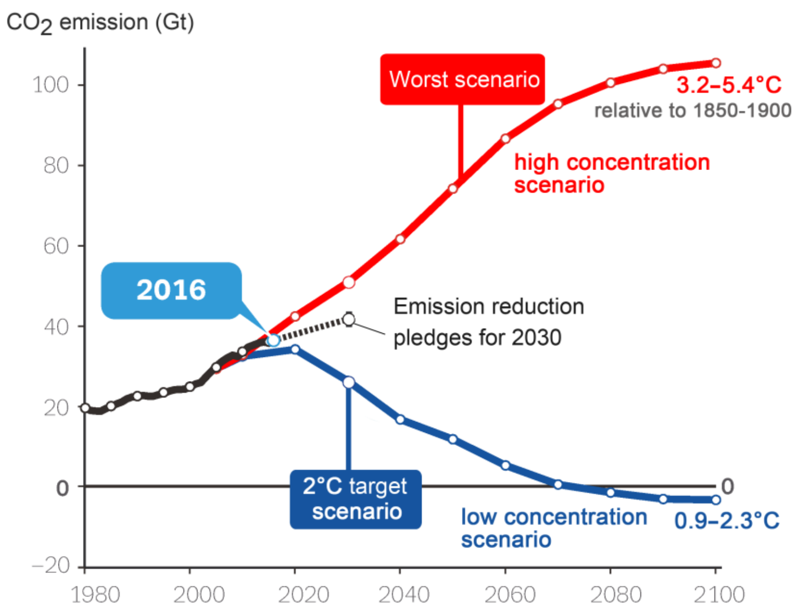

Figure 4 Carbon dioxide emissions associated with different greenhouse gas concentration scenarios shown in coloured lines. Observations are plotted in black. (Source: Global Carbon Project)

More than just an increase in the average temperature, a warming climate has a number of serious consequences. As the climate normal shifts to the warm side, the odds for extreme heat will correspondingly increase. Studies showed that the risk of heat waves in recent decades, such as the 2003 European heat wave that killed 70,000 people [5], had been enhanced by human-induced warming [6]. More recent examples were the 2015 deadly heat waves in India and Pakistan [7]. It is virtually certain that there will be more hot temperature extremes and fewer cold temperature extremes over most land areas as global mean temperature increases. Heat waves will occur with a higher frequency and duration despite the occasional episodes of cold winter extremes.

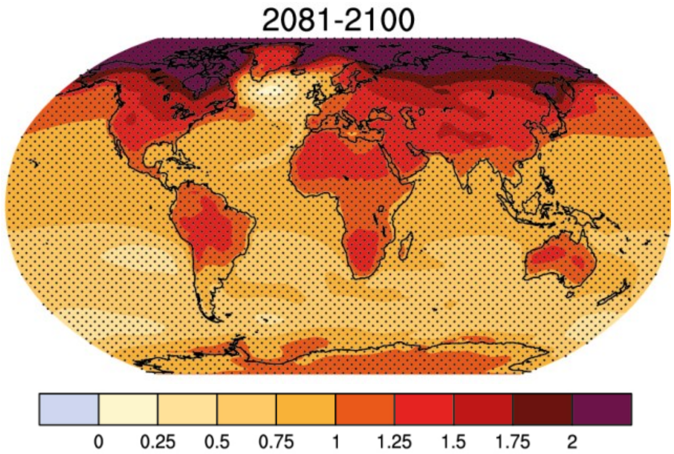

Figure 5 Projected regional temperature change (°C) for 2081-2100 per unit global average temperature increase (relative to 1986-2005). (Source: IPCC, 2013 [1])

Ocean warming leads to more evaporation of sea water and releases more water vapour into the atmosphere. A warmer atmosphere has the capacity to hold more water vapour and, combined with an over-heated land surface, will enhance the likelihood of heavy rain. More land areas have experienced an increase in heavy precipitation since the mid-20th century. Extreme rainfall events have become more frequent in a warmer climate. For example, attribution studies estimated that greenhouse gas emissions had increased the chance of record-breaking rainfall in southern England in 2014 and in southern Louisiana in 2016 by more than 40% [8, 9]. In a warmer world, extreme precipitation events will very likely become more intense and more frequent over most of the mid-latitude land masses and over the wet tropical regions by the end of this century, though the risk of drought remains in many parts of the world.

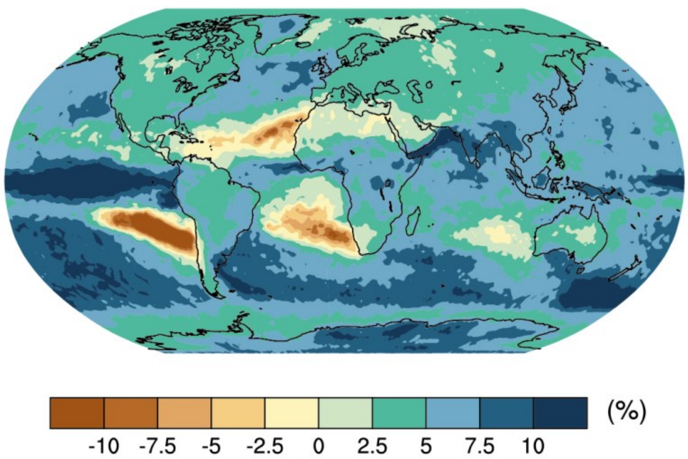

Figure 6 Projected percentage change in 20-year return values of annual maximum daily precipitation for 2081-2100 (relative to 1986-2005) per unit local temperature increase (°C). (Source: IPCC, 2013 [1])

More than 90% of the heat trapped by greenhouse gases goes to heating up the ocean. Thermal expansion of sea water and melting of land-based ice and snow will lead to a global sea level rise. The rate of sea level rise since the mid-19th century has apparently accelerated when compared to the mean rate in the previous two millennia. The global mean sea level in 2016 was the highest in the satellite altimeter record since 1993.

In a warmer world, most of the coastline will be affected by sea level rise. Even for the medium-low and medium-high greenhouse gas concentration scenarios, which are the more likely scenarios under the Paris Agreement, the impact of sea level rise to coastal communities will still be significant. Post-AR5 studies considering the instabilities of the Antarctic Ice Sheet showed that contribution to sea level rise from the ice sheet might have been underestimated [10, 11].

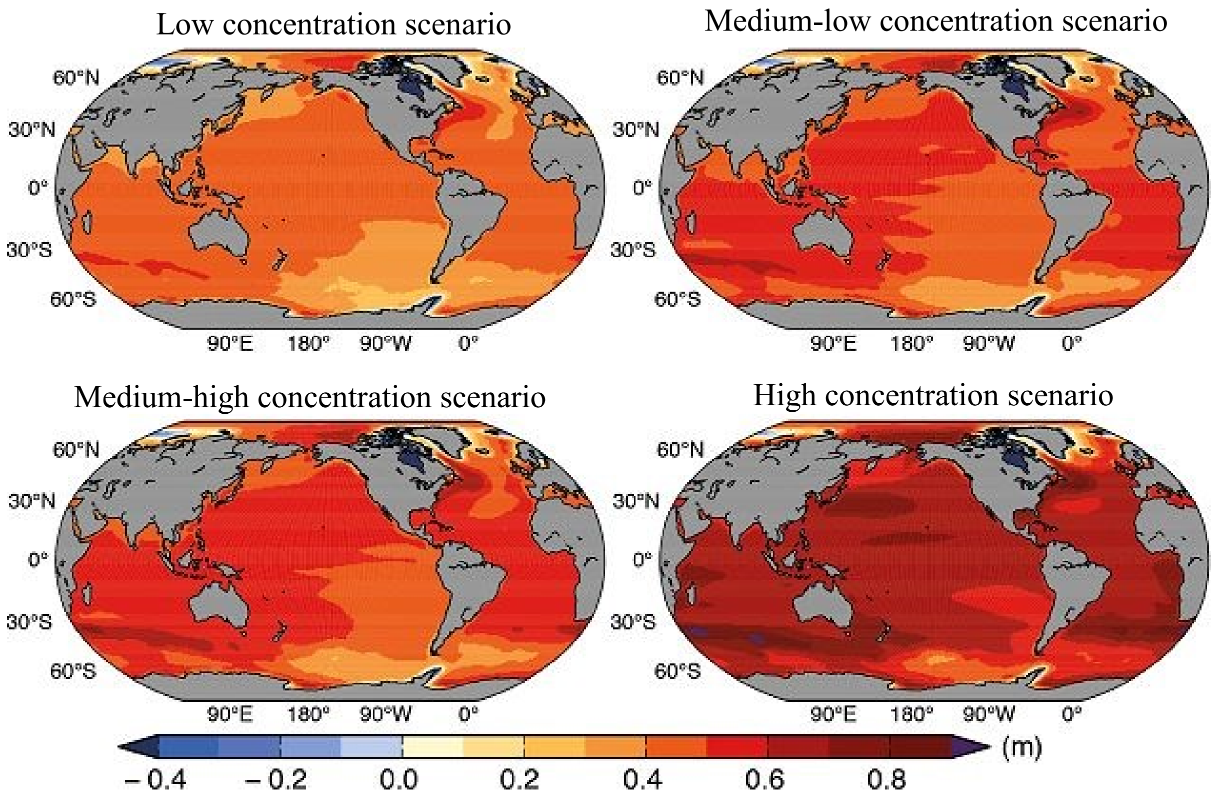

Figure 7 Projected regional mean sea level rise for 2081-2100 (relative to 1986-2005) under different greenhouse gas concentration scenarios. (Source: IPCC, 2013 [1])

Rising sea level will increase not only the chance of coastal flooding but also accentuate the threat of storm surges brought by cyclones. Unusually high water levels will become a real threat with potential catastrophic consequences when high tides coincide with storm surges.

Figure 8 Devastating storm surge associated with Hurricane Sandy in New Jersey, US, in 2012. (Source: Mark C. Olsen, US Air Force)

3. Past Trends in Hong Kong

Analysis of the century-long temperature records kept by the Hong Kong Observatory shows that Hong Kong has experienced a significant long-term warming trend. As Hong Kong has become a densely populated city over the past century, the effects of urbanization also play a role in warming up the city and the contribution is estimated to be up to 50% of the warming according to studies conducted by the Observatory [12]. In line with the global warming trend, the numbers of hot nights (daily minimum temperature at or above 28°C) and very hot days (daily maximum temperature at or above 33°C) in Hong Kong have increased while the number of cold days (daily minimum temperature at or below 12°C) has decreased.

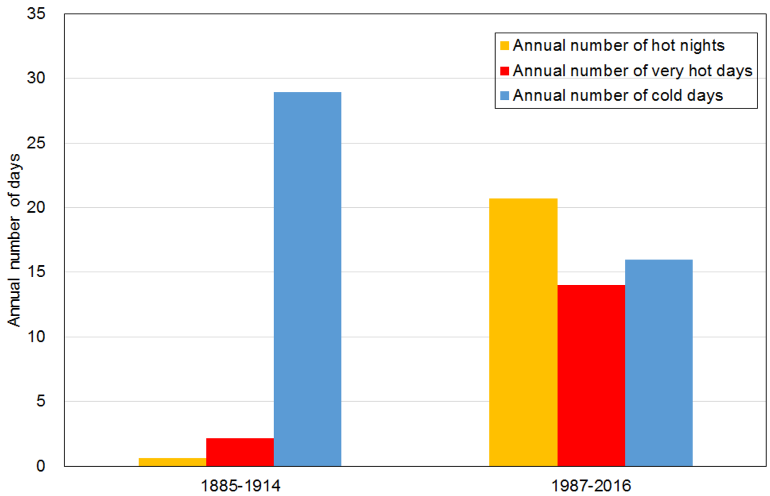

Figure 9 Changes in the annual number of hot nights, very hot days and cold days in Hong Kong.

Extreme precipitation events have become more frequent. While it used to take several decades to break the record in the past, the hourly rainfall record at the Hong Kong Observatory headquarters was broken quite a few times in the past several decades, and the latest by a significant margin. A more sophisticated analysis of the rainfall data shows that the chance of hourly rainfall of 100 mm or more has doubled over the past century [13].

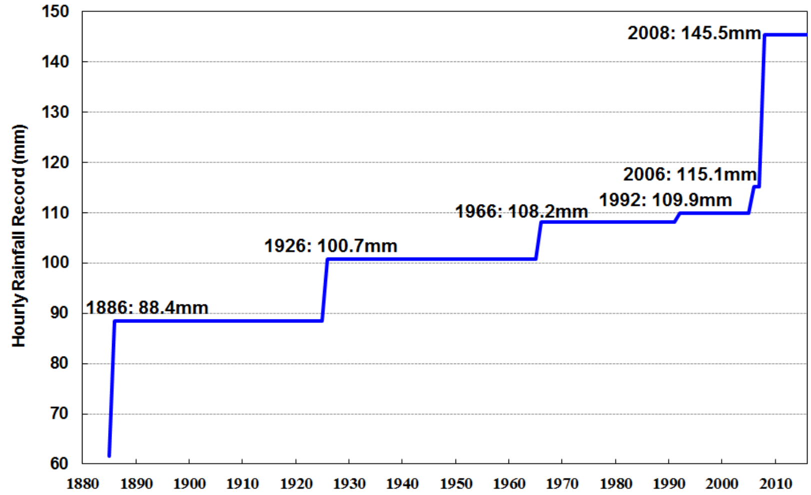

Figure 10 Record-breaking hourly rainfall events at the Hong Kong Observatory headquarters (1885 – 2016).

Tide gauge records in the Victoria Harbour since 1954 show an unambiguous rise of mean sea level during this period. The rising trend was consistent with satellite observations and tide gauge records at other coastal stations in the region.

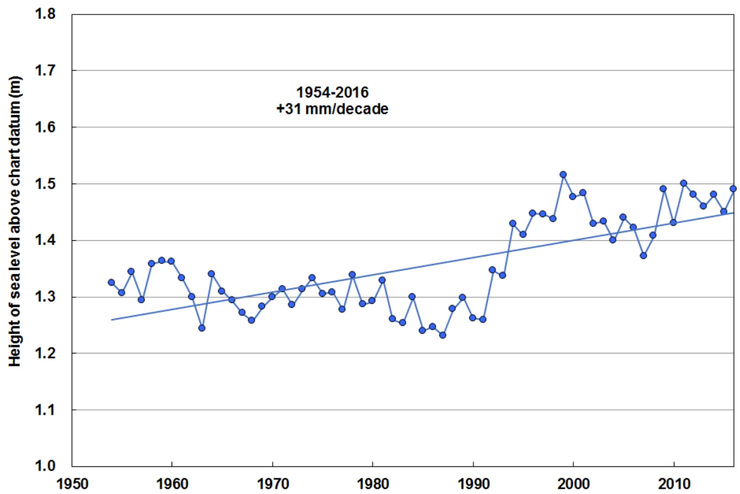

Figure 11 Annual mean sea levels at the Victoria Harbour (1954-2016).

4. Future Hong Kong in a Warming World

If the emission reduction targets in the Paris Agreement materialize, the medium-low to medium-high greenhouse gas concentration scenarios would be more likely than the other two scenarios. In such cases, a rise of 1.5 to 3.5°C (relative to 1986-2005) in the decade of 2091-2100 is expected. Even under the medium-low and medium-high greenhouse gas concentration scenarios, the annual numbers of hot nights and very hot days are expected to continue rising significantly in the 21st century, while the annual number of cold days is expected to drop.

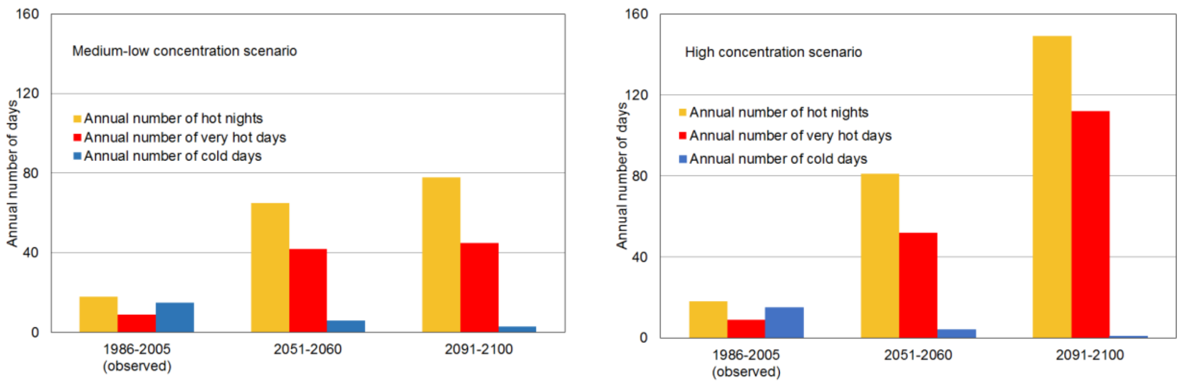

Figure 12 Projected annual number of hot nights, very hot days and cold days in Hong Kong under the medium-low (left) and high (right) greenhouse gas concentration scenarios.

Except for the low greenhouse gas concentration scenario, the annual rainfall is expected to generally increase towards the end of this century. Of even more interest is the remarkable increase in extremely wet years (annual rainfall > 3168 mm) in 2006-2100 for all the scenarios while the number of extremely dry years (annual rainfall < 1289 mm) is expected to remain about the same. The year-to-year and decade-to-decade variations of rainfall will remain large. As temperature continues to increase in the 21st century, extreme rainfall is also expected to increase.

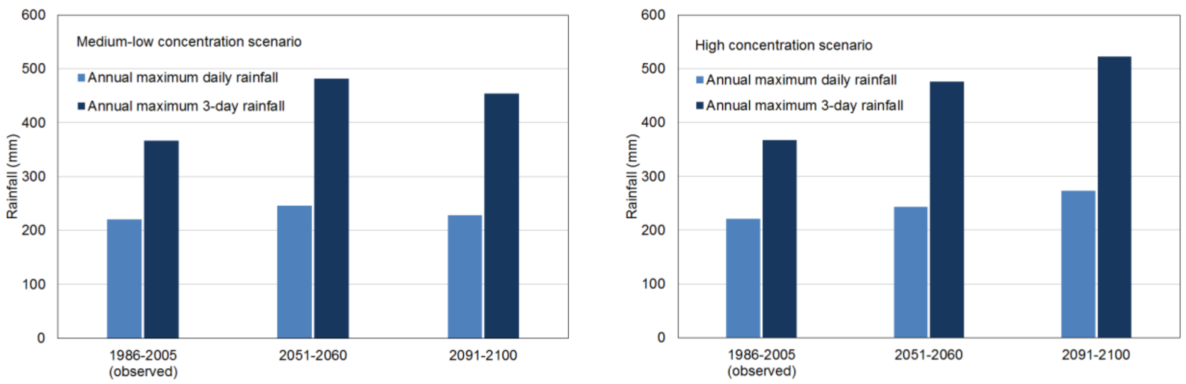

Figure 13 Projected annual maximum daily rainfall (mm) and annual maximum 3-day rainfall (mm) in Hong Kong under the medium-low (left) and high (right) greenhouse gas concentration scenarios.

Regardless of the greenhouse gas concentration scenario, the mean sea level in Hong Kong and its adjacent waters is expected to rise further in the 21st century [14], and the threat of storm surges brought by tropical cyclones will correspondingly increase. A sea level of 3.5 m that can cause serious flooding in certain low-lying areas in Hong Kong, such as the one brought by Typhoon Hagupit in 2008, is a 1-in-50 year event today. It would however become a 1-in-5 year to 1-in-10 year event by 2021-2040 and an annual event by the end of the 21st century if the high end of the sea level rise projections materializes.

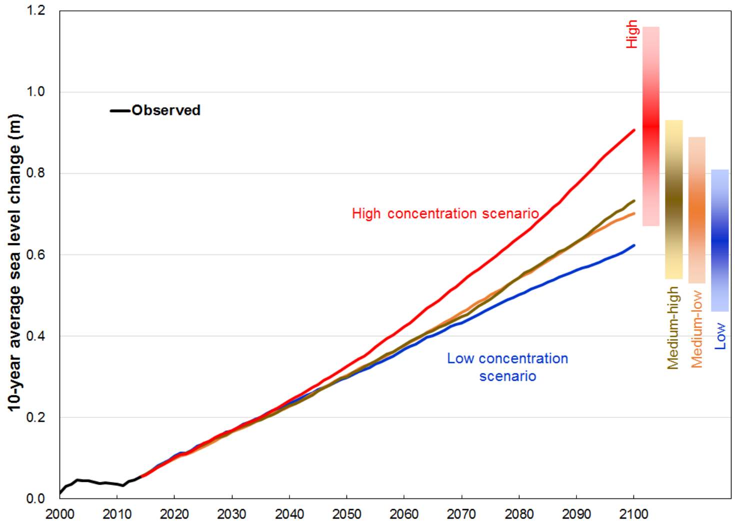

Figure 14 Projected changes in the mean sea level in Hong Kong and its adjacent waters (relative to 1986-2005) under different greenhouse gas concentration scenarios (thick line plots the 10-year average value while shaded area shows the likely range for 2091-2100).

5. Summary

The comprehensive assessment made in IPCC AR5 re-affirmed the unequivocal warming of the Earth's climate. Some of the changes observed in the climate system were unprecedented on time scales from decades to millennia. With the abrupt rise in atmospheric greenhouse gas concentration, the scientific consensus on the anthropogenic cause of the warming is overwhelming.

Laws of physics tell us that a warming climate could lead to serious consequences, e.g. more extreme heat, enhanced water cycle bringing more extreme rainfall by and large but also more droughts to certain regions, rising seas bringing more coastal flooding and enhancing storm surge threats. Such effects have been emerging in recent decades, and Hong Kong is not immune to the clear and present danger brought by climate change as well as its long-term impact in the future.

While science-based climate information and services are indispensable in dealing with climate change, collaboration among different sectors would also be crucial in achieving sustainable results, e.g. climate information and projections in support of informed decisions on the long-term planning and adaptation for the future in critical aspects such as water resource management, design standards for infrastructure development, and disaster risk reduction, making Hong Kong a city more resilient to climate change. In a highly sophisticated city like Hong Kong where power and electricity consumption is indispensable in meeting the requirements and expectations of lifestyle, as well as maintaining a certain standard of reliable operation, energy-efficient and environment-friendly designs of facilities and appliances will play an important role in the ongoing effort to combat the impacts of climate change, particularly through a change in the behavioural patterns of users and consumers. The Hong Kong Observatory stands ready to work with all stakeholders and the community in taking forward actions for mitigation, adaptation and resilience to climate change.

References

[1] IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[2] Mann, M. E. *et al*., 2016: The likelihood of recent record warmth. *Sci. Rep.* **6**, 19831.

[3] McMillan, M., *et al*., 2016: A high-resolution record of Greenland mass balance, *Geophys. Res. Lett.*, **43**, 7002–7010.

[4] UNEP 2016: The Emissions Gap Report 2016. United Nations Environment Programme (UNEP), Nairobi.

[5] Robine, J.-M. *et al*., 2008: Death toll exceeded 70,000 in Europe during the summer of 2003. *C. R. Biologies,* **331**.

[6] Stott, P. A., D. A. Stone & M. R. Allen, 2004: Human contribution to the European heatwave of 2003. *Nature,* **432**, 610-614.

[7] Herring, S. C., A. Hoell, M. P. Hoerling, J. P. Kossin, C. J. Schreck III, and P. A. Stott, Eds., 2016: Explaining Extreme Events of 2015 from a Climate Perspective. *Bull. Amer. Meteor. Soc*., **97 (12)**, S1–S145.

[8] Schaller, N., *et al*., 2016: Human influence on climate in the 2014 southern England winter floods and their impacts. *Nat. Clim. Change,* **6**, 627–34.

[9] Wiel, K., *et al*., 2017: Rapid attribution of the August 2016 flood-inducing extreme precipitation in south Louisiana to climate change. *Hydrol. Earth Syst. Sci.*, **21**, 897-921, 2017.

[10] Rignot, E., *et al*., 2014: Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011. *Geophys. Res. Lett.*, **41**, 3502 – 3509.

[11] DeConto, R. M., D. Pollard, 2016: Contribution of Antarctica to past and future sea-level rise. *Nature* **531**, 591-597.

[12] Chan, H. S., M. H. Kok and T. C. Lee, 2012: Temperature trends in Hong Kong from a seasonal perspective. *Clim. Res.*, **55**, 53-63, 2012.

[13] Wong, M. C., H. Y. Mok and T. C. Lee, 2011: Observed changes in extreme weather indices in Hong Kong. *Int. J. Climatol.*, **31**, 2300-2311.

[14] He, Y. H., H. Y. Mok and Edwin S. T. Lai, 2016: Projections of sea-level change in the vicinity of Hong Kong in the 21^{st} century. *Int. J. Climatol.*, **36**, 3237-3244.