Environmental Implications of global climate change in Hong Kong

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ABSTRACT

There is growing concern that human activities are increasing the atmospheric concentrations of greenhouse gases, mainly carbon dioxide, methane, nitrous oxide and chlorofluorocarbons. This increase in greenhouse gases concentrations will intensify the greenhouse effect, leading to changes in regional and global climate. Comprehensive assessments of the climate change issue have been carried out by the Intergovernmental Panel on Climate Change (IPCC). The IPCC has developed a range of future greenhouse emissions scenarios. IS92a-f, based on assumptions concerning population and economic growth, land-use, technological changes, energy availability and emission control policies during the period 1990 to 2100. Through understanding of the global carbon cycle and of atmospheric chemistry, these scenarios can be used to project future atmospheric concentrations of greenhouse gases. Climate models can then be used to develop projections of future climate change. In Hong Kong, however, little literature exists in addressing the climate change issue and its impacts. The major objectives of this study are, therefore, to assess the potential impacts of climate change in Hong Kong and to suggest possible responses to climate change.

Keywords: Climate Change, General Circulation Models, China, Hong Kong, Hygrothermal, Intergovernmental Panel on Climate Change, Precipitation, Regional Climatology.

1. Introduction

There is growing concern that human activities are increasing the atmospheric concentrations of greenhouse gases, mainly carbon dioxide, methane, nitrous oxide and chlorofluorocarbons. This increase in greenhouse gas concentrations will enhance the greenhouse effect, leading to changes in regional and global climate (IPCC, 2007). At the international level, comprehensive assessments of climate change and its impacts have been carried out by the Intergovernmental Panel on Climate Change (IPCC). In Hong Kong, however, little literature exists in addressing the climate change issue and its impacts (Dickinson, 2006). The major objectives of this paper are, therefore, to assess the potential impacts of climate change in Hong Kong and to suggest possible responses to climate change. In this paper, results of selected regional General Circulation Models (GCMs) for East Asia are used and scenarios for climate change in the Hong Kong region are developed in Part 2. Based on these scenarios, the potential impacts of climate change in Hong Kong are assessed. Finally, possible responses to climate change in Hong Kong are suggested.

2. Scenarios of climate change for the Hong Kong

2.1 Changes in temperature and precipitation
Although it is certain that changes in climate will not occur uniformly around the world, there are uncertainties involved in modeling the changes in regional climate, particularly with regards to precipitation (Mitchell et al., 2000; Dickinson, 2006). Since the available predictions of climate change by GCMs at the regional scale are unreliable, scenarios must be developed for the purpose of climatic impact assessment. In order to develop regional scenarios of climate change for the East Asia region, results from six GCM models were chosen by the Chinese University of Hong Kong and Sun Yat-Sen University, and averaged to produce a “GCM composite” (Jiang et al., 2007). Based on the these results, a possible scenario for the Hong Kong region is that there would be an increase in the annual mean temperature of slightly more than 1°C by 2050, and 2°C towards the end of the century. Also there would be possible increase in summer precipitation and slight decrease in winter precipitation (Jiang et al., 2007). It must be emphasized that GCMs have a coarse resolution with typical grid size of a few hundred kilometers in width and Hong Kong is a very small place in comparison with a GCM grid. The above figures do not represent an exact climate state that may exist in future, but only a possible scenario indicating the general direction and magnitude of change.

2.2 Impacts of changes in regional climatology

2.2.1 Tropical cyclones

Tropical cyclones normally occur from May to November in Hong Kong. Each year, an average of 30 tropical cyclones forms over the northwest Pacific and the South China Sea. Of these, about one-sixth come close to the south China coast and pose a threat to Hong Kong (Hong Kong Observatory, 2004). It has been observed that tropical cyclones only develop over sea areas with sea surface temperatures higher than a critical value of 26.5°C (Anthes, 2002). Changes in climate would lead to increase in sea surface temperatures, and theoretically, the frequency and intensity of tropical cyclones might increase. However, whether such increase in sea surface temperature could have any effect in the frequency and intensity of tropical cyclones is uncertain at the moment (Anthes, 2002). The following are some of the reasons:

1. Although the area of sea having temperatures over the critical value will increase as the globe warms, the critical temperature itself may increase in a warmer world (Mitchell et al., 2000).
2. Climate models give no consistent indication whether tropical cyclones will increase or decrease in frequency or intensity as climate changes; neither is there any evidences that this has occurred over the past few decades (Mitchell, et al., 2000).
3. The occurrence region and movement of tropical cyclones are affected by ocean-atmospheric phenomena such as El Nino (Chan, 2005; Dong, 2008; Li, 2007).
4. Water has a large heat capacity and heats very slowly. The rate of rise in sea surface temperature would be slow due to this buffering effect (Chan, 2005).

2.2.2 Precipitation

The wet season in Hong Kong is normally between April and September. Rain can be particularly heavy during May and June. Heavy rain can cause flooding and landslides. Flooding occurs when the rainfall rate is so large that natural or artificial drainage is insufficient to drain away the fast accumulated water on the ground. During heavy and prolonged rain, natural slopes may fail and therefore pose considerable threat to people living
on these hills. The occurrence of landslides in Hong Kong is closely related to the amount and intensity of rainfall (Brand et al., 2004).

Lam and Leung (2004) analyzed the rainfall data at the Hong Kong Observatory during the periods 1884-1939, 1947-2000 and developed return periods for extreme rainfall. It was found that rainfall amounts of over 200 mm in a day are not uncommon. Climate change might lead to increase in summer precipitation over the southern China region. In a warmer climate, there is a tendency for convective motions to penetrate higher (Wetherald and Manabe, 2008), and this may imply an increase in the intensity of local rainstorms. In Hong Kong, a scenario of increased summer rainfall amount and intensity would lead to elevated flood and landslide hazards.

2.3 Impacts of changes in the hygrothermal environment

Global warming might also lead to changes in the hygrothermal environment for human comfort. In this study, an index of human thermal comfort, the Relative Strain Index (RSI) is calculated for present and possible future climatic scenarios in Hong Kong. The index is the ratio of the amount of sweat evaporation needed for comfort, to the amount of evaporation possible in the given ambient conditions. The RSI is given by the following expression:

\[ \text{RSI} = \frac{(T-21)}{(58-e)} \]

Where T is the air temperature (°C) and e is the vapor pressure of the air (hPa). It is found in practice that values of RSI above 0.3 represents thermal discomfort. The RSI has been used in Australia for evaluating the number of days per year on which thermal discomfort is experienced (Linacre and Hobbs, 2006), and has also been used in the western tropical Pacific and Hong Kong for the assessment of possible changes in the hygrothermal thermal environment for human comfort (McGregor, 2002).

A limitation of the RSI is that it does not take account of the effect of air motion on human comfort which would facilitate a greater rate of sweat evaporation. The effect of solar radiation is also not accounted for by the RSI. The reference person for which the index applies is a motionless man dressed in a business suit. The levels of discomfort therefore refer to conditions in which there is negligible air motion and no marked radiation load imposed on the body. The meteorological conditions are similar to indoor or sheltered outdoor environment (McGregor, 2002). In the present study, mean hourly air temperature and vapor pressure data by month for the 10-year period 1993-2002 measured at the Hong Kong Observatory are used for the calculation of the RSI (Hong Kong Observatory, 1993-2002). From the 24 individual hourly records, values at 3 hour intervals were selected started at 0000 hours so as to assess both the diurnal and seasonal variation of the RSI.

Scenarios of 1°C and 2°C rise in air temperature are assumed for the calculation of possible future RSI values. Due to enhanced radiative heating at the surface, global mean rates of evaporation should increase (Manabe, 2003). Increasing temperature by 1°C increases the saturation vapor pressure by 6-7 % and it is expected that the atmospheric water vapor content will increase with temperature (Mitchell, 2007). In this study, it is assumed that the vapor pressure would increase by 2 % above the present value for each degree rise in temperature. This assumption is justified since it is unlikely that actual vapor pressure increases will match potential increases of saturation vapor pressure of 6-7 % per 1°C of warming (McGregor, 2002). It is seen that at present, hygrothermal discomfort is experienced in Hong Kong in the months of late June to August centered around 1500 hour. This matches
the common perception of human climates in Hong Kong which are known to be least tolerable at this time of the year during these hours. With a 1°C rise in temperature and a 2% increase in vapor pressure in the hygrothermal environment, a change to the magnitude and temporal distribution of the RSI occurs. On a monthly basis, the period of thermal discomfort now extends from June to early September. While diurnally, thermal discomfort would be experienced from late morning to late evening in July and August.

The change in the monthly and diurnal distribution of the RSI is more significant for a 2°C rise in temperature. On a monthly basis, the period of discomfort would cover the months from June to September. Diurnally, thermal discomfort would be experienced throughout the day and night from June to September. It should be noted that the level of human thermal comfort will not suddenly change as a result of climate change. There will be a gradual transition to the more hygrothermally stressful conditions in the summer months. As the transition to a more stressful hygrothermal environment will be gradual, the opportunity exists for the development of physiologically compensating mechanisms in humans in response to changes in atmospheric conditions (McGregor, 2002). The body can adapt to changing ambient conditions by the process of acclimatization. This may take several weeks for young adults, and the ability to acclimatize decreases with age (Linacre and Hobbs, 2006).

Changes in the hygrothermal environment hold a number of implications (McGregor, 2002):

1. A warmer environment will lead to an increase in demand in the level of air conditioning in buildings, which will place further demands on electricity and energy supply.
2. With increase in magnitude and duration of periods of discomfort, outdoor work will become more stressful in the summer months. This may cause a lower level of worker productivity.
3. There might be an increase in the incidence of heat exhaustion, dehydration and heatstroke, especially in the very young, aged and the unhealthy during extreme hygrothermal events.

2.4 Impact of climate change on energy demand

In summer, when the outdoor air temperature is higher than the temperature inside a building, heat will be conducted through the external surfaces into the building, and consequently cooling will be required to maintain indoor building temperature at a comfortable level. Electricity consumed in buildings accounts for about half of the total energy consumption in Hong Kong. Much of the electricity is used for lighting and air-conditioning in buildings, particularly during the hot summer months. Electricity consumption peaks during the summer months, because of the high demand for air-conditioning. (Census and Statistics Department, 2001-2004)

A warmer climate will obviously lead to higher demands of air-conditioning and hence electricity consumption. The implications of temperature rise scenarios of 1°C and 2°C on energy demand for space cooling and heating will now be examined.

2.4.1 Assessment of changes in energy demand for temperature rise scenarios

A parameter called the Cooling Degree Days (CDD) is used to indicate how often and to what extent cooling will be required during a particular period (Maunder, 2002). It is
calculated by summing the difference between the mean daily outdoor temperature and the indoor temperature required during the same period. The CDD thus gives an indication of the energy requirement for space cooling. The larger the value of CDD, the more energy is required for space cooling.

**Figure 1:** Mean monthly cooling degree days assuming a base temperature of 24 degrees Celsius
In the present study, it has been assumed that whenever the mean daily outdoor temperature is greater than 24.0°C (called the base temperature), cooling will be required. The mean monthly CDD calculated from temperature data measured at the Hong Kong Observatory for the 10-year period from 1996 to 2005 are shown in Figure 1.0 (Hong Kong Observatory, 1996-2005). As expected, CDD peaks during the hot summer months. Figure 1.0 also shows how monthly CDD might change under temperature rise scenarios of 1°C and 2°C respectively. The CDD would increase by 30 % for a 1°C rise in temperature, and would increase by 63 % for a 2°C rise. This implies an increase in energy required for space cooling.

Similarly, the Heating Degree Days (HDD) can be used to indicate how often and to what extent heating will be required during a particular period (Maunder, 2002). It is calculated by summing the difference between the indoor temperature required and the mean daily outdoor temperature during the same period. The HDD gives an indication of the energy requirement for space heating. The larger the value of HDD, the more energy is required for space heating.

In this case, the base temperature for calculating the HDD has been assumed to be 17°C (i.e. whenever the mean daily outdoor temperature is lower than 17°C, heating will be required). The mean monthly HDD for the 10-year period from 1996 to 2005 are shown in Figure 2.0. It can be seen that heating is required only in the cooler winter months. Also, the values of HDD are much smaller than those of CDD, since cooling is more important than heating in subtropical Hong Kong.

The monthly HDD under temperature rise scenarios of 1°C and 2°C are also shown in Figure 2.0. It was found that the HDD would decrease by 38 % for a 1°C rise in temperature, and would decrease by 63 % for a 2°C rise. This implies a decrease in energy required for space heating. The results of the preceding analysis indicate the magnitude of the change in space cooling and heating requirement due to temperature rise. It was found that under a temperature rise scenario of 1°C, Hong Kong would experience a 30 % increase in CDD, and a 38 % reduction in HDD; while for a temperature rise scenario of 2°C, Hong Kong would experience a 63 % increase in CDD, and also a 63 % reduction in HDD. Since the energy required for space cooling in summer is much larger than the energy required for space heating in winter, the overall annual energy demand will increase for both scenarios.

Note that the above analysis has the following assumptions and limitations:

1. It has been assumed that, on average, there is a uniform increase in temperature throughout the year. But, clearly, any future rise in temperature will not spread evenly throughout the year.

2. Demand for space cooling and heating is dependent on a number of climatic factors other than temperature, notably amount of solar radiation, relative humidity and wind speed.

3. The effect of climate change on energy demand for space cooling and heating would occur slowly. There would be changes in socio-economic and technological conditions which could lead to different patterns of energy demand over the next several decades (e.g. technological advance in building design).

2.5 Impacts of climate change on water resources
Over the southern China region, the scenario for precipitation change by 2050 would be an increase in precipitation in summer and a slight decrease in winter. Besides affecting regional precipitation patterns, climate change would probably alter evaporation rates as well (Chan, 2005). In general, higher temperature would increase the rate of evaporation. Changes in precipitation and evaporation patterns would have effects on the regional water balance, which holds implications for water resource planning. Precipitation will affect reservoir storage directly.

Table 1: The rainfall amount and yield from catchment areas in Hong Kong from 2000 to 2004 (Source: Government Information Services, 2005b)

| Year (from 1 April to 31 March) | 2000-01 | 2001-02 | 2002-03 | 2003-04 |
|--------------------------------|---------|---------|---------|---------|
| Rainfall recorded at the Hong Kong Observatory (in mm) | 1862.2  | 1975.9  | 2337.1  | 2337.3  |
| Yield from catchment areas (in million cubic meters) | 202.40  | 205.90  | 336.31  | 366.13  |

Table 1.0 show the annual rainfall recorded at the Hong Kong Observatory and the yield from catchment areas from 2000 to 2004 (Government Information Services, 2005b). It seems that there maybe a correlation between the yield from catchment areas and the rainfall records, and this could assist the long-term forecasting of availability of water supply. However, quite frequently, the overall catchment rainfall can be considerably less than that recorded at the Hong Kong Observatory. This is because the rainfall may not be evenly distributed over the catchment areas, and dry ground can absorb a significant portion of the first rains. This means that no direct relationship can be drawn from the rainfall data and increase in reservoir storage over the same period. Moreover, these rainfall figures are not necessarily representative of the rainfall in the catchment areas in the short term. Thus, in any particular year, the distribution of rainfall can be quite variable (Water Supplies Department, 2003). It can only be concluded that the yield increases in proportion to rainfall in most cases. Assuming a scenario that there would be an increase in precipitation in summer and a decrease in precipitation in winter, the following are some possible impacts of climate change on water resources in Hong Kong:

1. Higher temperatures may lead to increased water demand for cooling purposes in the summer months.
2. Higher temperatures will lead to increased evaporation rate, which would reduce water storage.
3. On the other hand, increased precipitation in the summer might increase yield from catchment areas and hence reservoir storage.
4. Although the annual water balance may not change drastically, the distribution of precipitation between the months may become exaggerated and the chance of drought in the dry winter months may increase (McGregor, 2002).

It must be emphasized that there is a high uncertainty in the prediction of regional precipitation change due to global warming. Furthermore, there will be natural variability in the annual rainfall amount. Meanwhile, it is unknown whether increased precipitation would be counteracted by higher evaporation rates in affecting water storage. Although it has been
suggested that future water balance scenarios can be assessed by response surface analysis using hydrological models (Fowler and de Freitas, 2009), the complicated interactions between climatic factors and water balance make it difficult to do so and this is outside the scope of the present paper.

3. Possible responses to climate change in Hong Kong

3.1 Responses to changes in regional climatology

Change in regional climatology would produce change in the frequency and magnitude of extreme events like rainstorms, tropical cyclones and storm surges. This has implications for civil engineering design such as drainage services and formation level of reclamation. Increase in the frequency and magnitude of these extremes would reduce their return periods on which engineering designs are currently based. Engineering designs should therefore incorporate possible future changes in climatic factor in their planning.

3.2 Responses to changes in hygrothermal environment

For outside workers experiencing elevated levels of hygrothermal stress, a possible response would be a change in the working hours so that workers may start work during the less stressful hours of the day. For built up urban areas, which tend to generate their own microclimate and are warmer than the surrounding non-urban environments, the provision of greater amounts of vegetated and water covered space as energy sinks within the urban framework is a possible response for managing a more thermally stressful urban environment (McGregor, 2002).

3.3 Responses to changes in energy demand

Climate change may have a perceptible effect on the energy demand over the next century. Both government and energy suppliers should consider taking explicit account of climatic effects in carrying out long-term projections of energy supply and demand. It is worthwhile to consider more energy efficient design of buildings and building services systems such that the demand for space cooling and heating could be reduced. In some countries, building regulations require designs and building materials to meet specified thermal standards. For example, Singapore has saved 17% on its energy bill since introducing energy conservation measures in buildings in 1979 (Litton, 2009). In Hong Kong, following a government study which concluded that the energy efficiency of buildings could be improved by limiting thermal transmittance through the building material, statutory controls on the Overall Thermal Transfer Values (OTTV) of new commercial buildings and hotels were proposed in 2003 (Planning, Environment and Lands branch, 2004).

3.4 Responses to changes in water balance

The potential change in precipitation pattern and evaporation rates might affect the water balance in Hong Kong. Although the degree of such effects is uncertain at the moment, additional water resources are still required to secure a full supply in future. Some of the prospects for meeting future water demand in Hong Kong are discussed below:

1. The total water gathering grounds now comprise about one third of the land area of Hong Kong. The development of further areas as water gathering grounds is limited both by high cost of collecting water from the gathering grounds and by the lack of...
suitable sites for additional impounding reservoirs (Water Supplies Department, 2003).

2. Desalinization of sea water has been attempted in Hong Kong. The trial was technically successful at the Lok On Pai Desalting Plant. However, the high energy cost made the operation hardly economically viable. The plant had not been put into use since 1982 and was eventually demolished in 1991 (Hong Kong Government, 1992).

3. Studies have also been undertaken on the feasibility of treating used waters, but the cost of large scale operation was found to be unattractive while its contribution would be far from significant (Water Supplies Department, 2003).

4. At present, the supply of sea water for flushing is limited to the urban areas and the new towns. This sea water flushing system can be expanded to reduce the usage of fresh water.

5. Further development of water supply from China seems to be the major long term solution for meeting Hong Kong's future water demand.

6. Other steps would be to educate residence regarding the problems of water wastage and to introduce policies that would encourage minimization of water usage.

### 4. Conclusion

Climate change would have a perceptible effect on the environment of Hong Kong in the next century. Apart from a warmer hygrothermal environment and increase in energy demand, the most severe impacts arise from flooding due to rainstorms and increased damage caused by storm surges associated with sea level rise. Although the potential impacts of climate change in Hong Kong are not fully understood, the negative effects could be minimized by formulating appropriate response strategies. Limitation and adaptation strategies are the two approaches in response to climate change. Although abating greenhouse gases emission in Hong Kong would have minimal effect on the global greenhouse gases concentration, this could help mitigate the local air pollution problem. Adaptation strategies are best considered at the planning stage. Uncertainty does not mean that a community cannot position itself better to cope with the broad range of possible climate changes or protect against potentially costly future outcomes. Delaying such measures may leave a community poorly-prepared to deal with the adverse changes and may increase the possibility of irreversible or costly consequences. The costs and benefits of a response measure to climate change should be carefully evaluated. In Hong Kong, the possible impacts of climate change on engineering designs should be considered at an early stage. Provided that the cost of taking into account future change in climatic factors is small, or if a high degree of security is required, it is worthwhile to make allowance for climate change in engineering designs. In conclusion, the following recommendations are suggested in response to climate change in Hong Kong:

1. Long-term engineering projects such as storm water drains and reclamations should fully take into account of future variability in climatic factors.

2. An integrated long-term program of sea level monitoring, programs should be established which will provide data of controlled quality.

3. Further research should be carried out to study the potential impacts of sea level rise on Hong Kong’s Mai Po wetlands.
4. D. The potential impacts of climate change in the planning of any long-term energy supply projects should be considered. Further energy saving measures and incentives should be introduced by the government.

5. Since the generation of electricity by burning fossil fuel results in the release of large quantities of carbon dioxide into the atmosphere, the use of natural gas instead of coal in power stations can reduce carbon dioxide emissions.

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