Urban Development and Climate Change in China's Pearl River Delta

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Cities are both contributors to and victims of global climate change. Delta cities, in particular, have long been recognized as being extremely vulnerable because they are located where the stresses on natural systems coincide with intense human activity.

A number of climate change impacts may affect delta cities, including rising sea levels, infrastructure damage from extreme weather events, the public health implications of higher average temperatures, altered energy consumption patterns, stress on water resources, impacts on tourism and cultural heritage, decreased urban biodiversity, and ancillary effects on air pollution (IPCC 2007). Climate change also may affect physical assets used for economic production and services, as well as the costs of raw materials and inputs, which in turn will affect competitiveness, economic performance, and employment patterns.

China's remarkable economic growth since the beginning of the country's reform period in 1978 has concentrated a large share of population and wealth along the coast, especially in three megacity regions: Pearl River Delta, Yangtze River Delta, and Capital Region. While the potential implications of climate change pose a challenge for coastal communities around the world, this geographic concentration of population and economic activity seems disproportionate in China.

Among China's coastal and delta regions, the Pearl River Delta (PRD) in Guangdong province is an important economic center that includes the cities of Guangzhou, Shenzhen, and seven prefecture-level municipalities. Together with Hong Kong and Macao, the greater PRD area is one of the key megacity regions in the world, but its geography makes it highly vulnerable to sea level rise. Unprecedented economic and urban development, along with the major changes in land use and land cover accompanying that development over the past three decades, has released large emissions of CO_2, leading to higher temperatures and more intensive and extreme weather events (Tracy, Trumbull, and Loh 2006). Given the importance of this region to both China and the broader global economy, we take a closer look at the PRD's contribution to and risks from climate change.

Industrialization and Urbanization

With the establishment of the Shenzhen and Zhuhai Special Economic Zone in 1980, the PRD was among the earliest regions in China to begin to liberalize its economy. Its institutional advantages, combined with its proximity to Hong Kong and Macao, made the PRD the fastest growing region in the world during the past three decades. From 1979 to 2008, the PRD's GDP grew at 15.6 percent annually in constant prices, outpacing both the national rate of 9.77 percent and the provincial rate of 13.8 percent.

As a result, the delta's contribution to the share of GDP in China soared from 2.8 percent in 1979 to 9.5 percent in 2008. In terms of total fixed investment, foreign direct investment, exports, and energy consumption, the PRD was one of the most important and dynamic economic regions in China during this period (figure 1).

This rapid development resulted from the dual process of industrialization and urbanization. The region's secondary and tertiary industries have grown rapidly as primary industry has gradually decreased in relative economic importance, with its contribution to GDP declining from 26.9 percent in 1979 to 2.4 percent in 2008, while the tertiary service sector grew from 27.9 percent to 47.3 percent.

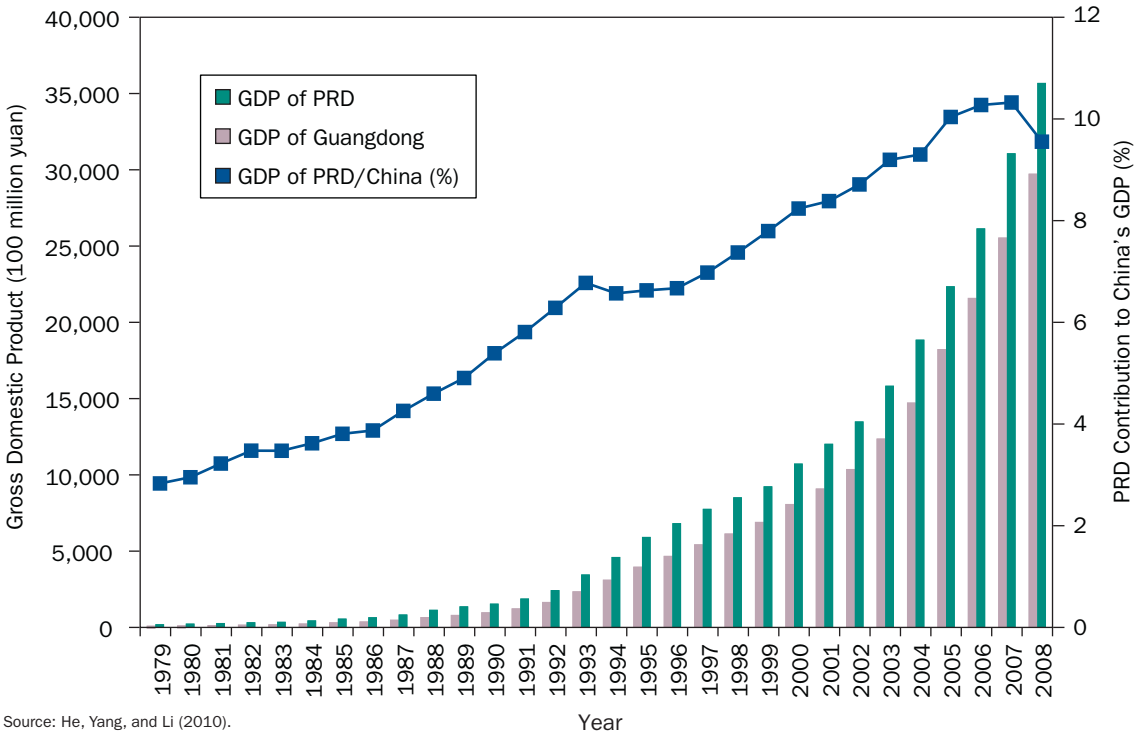
Over the same time, the population increased from 17.97 to 47.71 million residents, reaching an urbanization rate of 82.2 percent in 2008. In terms of land use, areas designated for manufacturing, residential, and commercial uses grew by 8.47 percent annually, increasing from 1,068.7 square kilometers (k^2) in 1979 to 4,617.16 k^2 in 2008 (figure 2).

Climate Changes

Given these dramatic land use changes and the region's increased emissions of greenhouse gases, it is not surprising that the PRD has experienced noticeable regional climate changes. The Guangdong Meteorological Administration (2007) reported that the average temperature increase in Guangdong province over the past five decades has been 0.21 °C every 10 years, which is similar to the rate of warming seen nationally in China. Guangdong's coastal region, especially the highly urbanized PRD, witnessed even greater temperature increases, averaging 0.3 °C every 10 years. The cities of Shenzhen, Dongguan, Zhongshan, and Foshan warmed more than 0.4 °C every 10 years.

After compiling data from 21 meteorological stations in the PRD region, we calculated the average annual and seasonal temperatures during the 1971–2008 period and compared them with the annual temperatures in Guangdong. Our research showed the PRD has experienced significant warming and has been hotter than the entire Guangdong province during the observed period. Since the 1970s, the PRD has seen its average temperature

FIGURE 1
Importance of GDP in the PRD Region, Guangdong, and China, 1979-2008



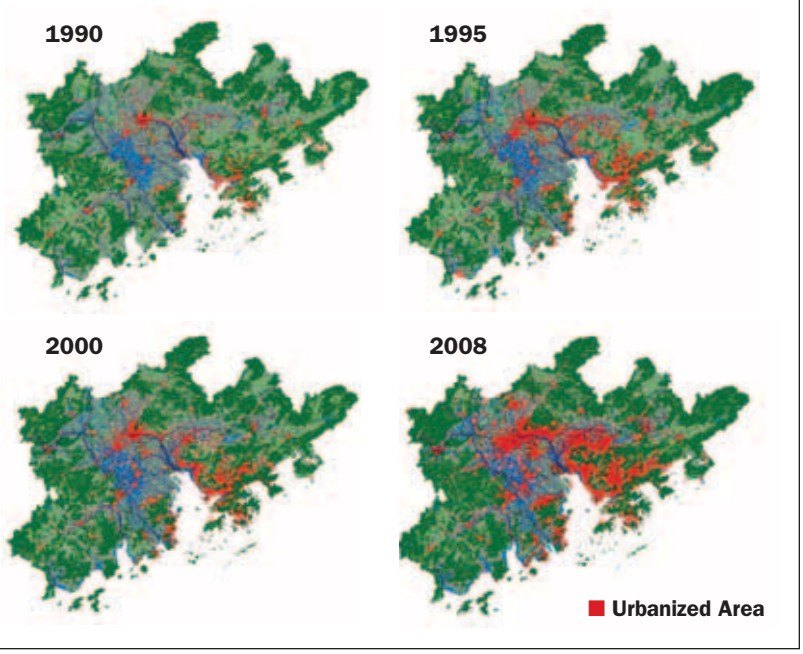
Source: He, Yang, and Li (2010).

rise by approximately 1.19 °C to 22.89 °C in the most recent decade, with annual average temperatures remaining above the region's 30-year average temperature of 22.1 °C since 1994 (figure 3).

The winter and autumn seasons saw the most considerable temperature increases, with averages of 24.1 °C in the autumn and 15.2 °C in the winter between 1994 and 2007. These temperatures are significantly higher than their respective 40-year averages of 23.5 °C and 14.6 °C. While not as significant, average spring and summer temperatures in the PRD during the 1997–2007 period were also greater than their 40-year average temperatures of 22 °C and 28.2 °C. This regional warming phenomenon is also seen to a lesser degree in Guangzhou, a populous and characteristic metropolis in the PRD, where average temperatures have risen like those in the greater delta region.

As the PRD's climate has warmed more quickly than that in the rest of the province, the rapid industrialization and urbanization has generated enormous energy demand from manufacturing industries, transportation, and residential consumers, resulting in greater emissions of CO_2 and other greenhouse gases that are contributing to global climate change. The increased concentration of greenhouse gases, both regionally and globally, represents a large latent source of future warming and additional changes.

FIGURE 2
Urban Expansion in the Greater Pearl River Delta

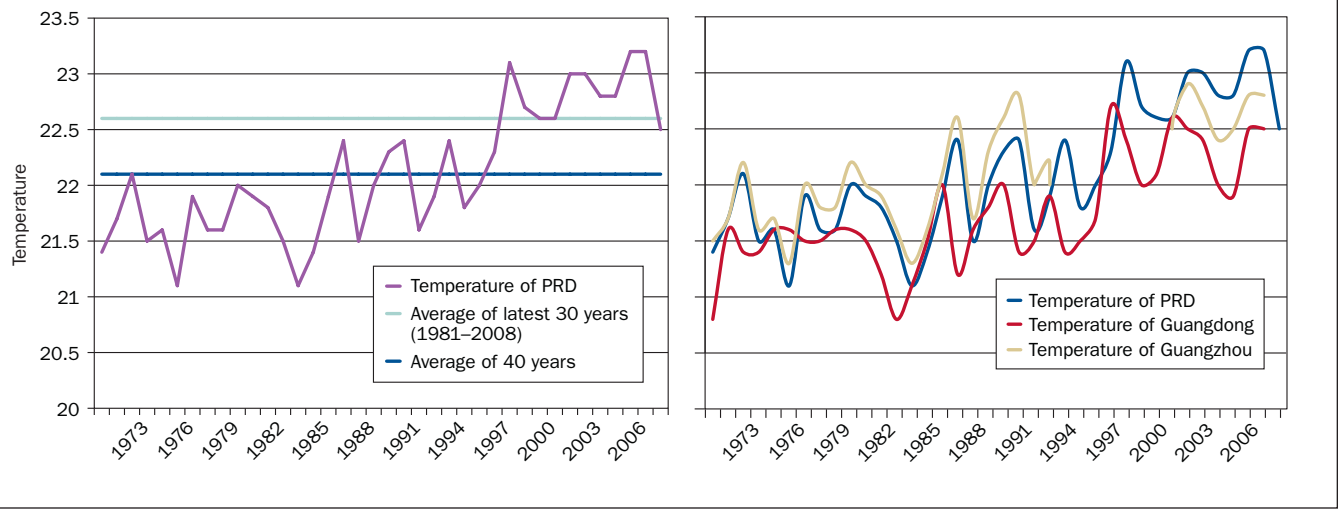


Source: He, Yang, and Li (2010).

Impacts of Climate Change

Given its coastal geography and population density, Guangdong is among the most vulnerable of China's coastal provinces to the sort of meteorological disasters that are expected to increase with global warming. In 2008, Guangdong experienced

FIGURE 3
Temperature Change in the Pearl River Delta, 1971–2008



Source: He, Yang, and Li (2010).

TABLE 1
Climate Change Impacts on China's Coastal Provinces, 2008

Province	Marine hazards			Sea level above the average of 1975–1993 (mm)	Estimated sea level rise, 2008–2038 (mm)
	Direct economic loss (100 million yuan)	Deaths	Erosion (km)		
Liaoning	0.24	27	142	50	78~120
Hebei	0.26		280	45	66~110
Tianjin			34	47	76~150
Shandong	12.89		1211	69	89~140
Jiangsu	0.38	6	225	76	77~130
Shanghai	0.02	2	75	47	98~150
Zhejiang	0.97	8	54	39	96~140
Fujian	17.52	11	90	54	68~110
Guangdong	**154.29**	**73**	**602**	**75**	**78~150**
Guangxi	15.82	2	168	60	70~110
Hainan	3.66	23	827	86	80~130
Total	206.05	152	3708		

Sources: China Meteorological Administration (2009a; 2009b).

direct economic losses of 15.43 billion yuan and 73 deaths, accounting for 75 percent and 48 percent of national totals, respectively, as well as the loss of 602 kilometers (km) of land to coastal erosion (table 1). With sea levels in the province having risen by 75 millimeters (mm) during the 1975–1993 period, the China Meteorological Administration's (2009b) prediction that sea levels will rise a further 78–150 mm between 2008 and 2038 represents a serious threat to coastal infrastructure and communities in the PRD.

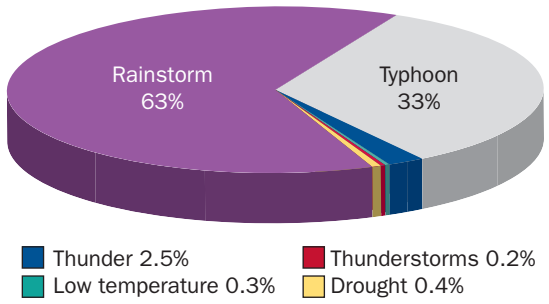
Guangdong has long been impacted by marine hazards such as rainstorms, cyclones, and storm surges that have killed hundreds of people, caused serious damage to housing and transportation infrastructure, and impacted farming in the province. In the 1950s, the annual average farming area affected by marine hazards was about 200,000 hectares (ha), which grew to 440,000 ha in the 1960s and 500,000 ha in the 1970s, before jumping to 1,411,000 ha in the 1990s.

In addition to more frequent extreme storm events, instances of drought also have been increasing in the PRD. In the 1950s, the average farming area affected by droughts in Guangdong was 104,000 ha, which grew steadily to reach 201,500 ha in the 1980s, 282,500 ha in the 1990s, and 426,400 ha in the 2000s. Given the expected increases in the frequency of extreme weather events, as well as rising temperatures and sea levels, agricultural and mariculture activities in the PRD will be increasingly vulnerable to future climate change.

Cities in the PRD are particularly susceptible to natural disasters and climate change as they concentrate infrastructure, nonagricultural activities, and population, severely impacting economic activities and daily life. Rainstorms and typhoons occur frequently in the region and typically entail serious damage and huge economic losses. During the 2000–2007 period, for instance, rainstorms and typhoons in Shenzhen caused cumulative direct economic losses of 525 and 277 million yuan respectively, accounting for approximately for 63 and 33 percent of total direct economic losses associated with all meteorological hazards in the city (figure 4).

Meteorological hazards also lead to disruptive impacts on facilities, infrastructure, and transportation. Rainstorms and typhoons impose challenges on urban sewage systems and flood control facilities, while prolonged periods of high or low temperatures exert pressure on urban power supply infrastructure.

FIGURE 4
Direct Economic Loss Caused by Meteorological Hazards in Shenzhen, 2000–2007



Source: Wu and Li (2009).

In May 2009, Shenzhen experienced an unprecedented rainstorm, with some parts of the city receiving daily precipitation in excess of 208 mm. The storm flooded 40 areas of the city and left 11 areas under at least one meter of water. Two years before, in April 2007, rainstorms flooded the Qinghuhe River in Shenzhen, damaging embankments and toppling power lines. On the other end of the spectrum, in July 2004 Guangzhou suffered a prolonged heat wave that created tremendous demand for electricity. Usage eventually peaked at 8.45 million kilowatts and forced many enterprises to stop production to help conserve power.

Transportation is the lifeline of urban activity and economic production. As two of China's major population and economic centers, Shenzhen and Guangzhou are particularly important national transportation hubs, and any disruptions from extreme weather events such as rainstorms, typhoons, and flooding have far-reaching effects across the country.

When tropical storm *Fengshen* landed in Shenzhen on June 24, 2008, the city's Yantian seaport was forced to close and hundreds of vessels were stuck in port, resulting in huge economic losses. During 2008, four tropical storms and one rainstorm resulted in the cancellation of 249 flights and the delay of 386 other flights at the Shenzhen International Airport, stranding more than 20,000 passengers. In 2009, three major weather events caused the cancellation of 176 flights and the delay of 326 flights, while 4,151 ships were forced to take shelter in Yantian port. As Chinese travelers become more affluent and air travel grows more rapidly, the vulnerability of these cities to disruption by severe weather events is set to increase.

Disruptive Effects of Sea Level Rise

The China Meteorological Administration (2009b) has identified the PRD as one of the country's areas most at risk from rising sea levels due to its low mean sea level. Previous studies concur that sea levels in the PRD are rising and will continue to do so in the foreseeable future. Figure 5 illustrates the changes in sea level recorded at three tidal gauges (Hong Kong, Zha Po, and Shan Tou) during the 1958–2001 period. Hong Kong recorded a sea level rise of 0.24 centimeters per year (cm/year) during the period, while Zha Po and Shan Tou saw sea levels rise by 0.21cm/year and 0.13cm/year, respectively. Tidal records from six different gauges in the Pearl River estuary show that sea levels have risen at an accelerating rate over the last 40 years.

With the melting of glaciers globally due to climate change, these recent rises in sea level are expected to continue and potentially even accelerate. Li and Zeng (1998) offered three forecasts for sea level rise in the PRD, with 100 cm (high), 65 cm (middle), and 35 cm (low) forecasts by 2100. These predictions have been echoed by similar projections from the Chinese Academy of Sciences (1994), which indicate that sea levels in the PRD would rise by 40 to 60 cm by 2050.

The physical geography and urban development of the delta render it extremely vulnerable to the effects of sea level rise, and many lowland areas are likely to be inundated (Yang 1996). According to calculations by China's National Marine Data and Information Service, a sea level rise of 30 cm could inundate an area of 1,154 k^2 of coast and islands at high tide, with Guangzhou, Doumen County, and Foshan at particular risk (Guangdong Meteorological Administration 2007).

Coastal and river flooding in the PRD is influenced by several factors: rainfall, high tides, high winds, and typhoons and storm surges. The combination of weather and tidal factors that causes water levels to rise by upwards of three meters during tidal cycles is already well known in parts of the Pearl River Estuary (Tracy, Trumbull, and Loh 2006). According to Huang, Zong, and Zhang (2004), the current maximum tidal range increases as one travels up the estuary, from a low of 2.34

meters near Hong Kong to 3.31 meters at Zhewan, before reaching 3.35 meters at Nansha.

Rising sea levels would magnify the effect of storm surges, which already can be dramatic when weather and tidal factors coincide. Analyzing records from 54 tidal gauges across the PRD, Huang, Zong, and Zhang (2004) created predictions for water level rises in different parts of the delta under a number of different flood scenarios. According to the lowest freshwater discharge scenario (2000 m^2/s), their simulations show that a 30 cm sea level rise will affect the northwest part of the region most severely and the majority of the area significantly. These researchers also simulated the impacts of a 30 cm sea level rise on the distribution of flood damage based on four freshwater discharge scenarios, showing that as floods increase in severity the size of the areas affected also increases.

Summary and Discussion

Delta cities enjoy locational advantages that make them attractive to both residents and businesses, and thereby lead many delta regions to develop into vital economic cores in many countries. Delta cities, however, are particularly vulnerable to meteorological hazards and are more at risk than inland cities to the existing and anticipated effects of climate change. The Pearl River Delta has witnessed substantial increases in both sea levels and temperatures, greater variation in rainfall, more frequent extreme weather events, and increasing losses from marine hazards.

More frequent meteorological hazards such as flooding from tropical storms and rainfalls have indeed caused disruptive impacts in the PRD: disrupting agricultural and mariculture production, damaging coastal defenses and embankments, destroying houses and facilities, shutting down transportation, and causing the loss of life. Sea level rise resulting from global warming represents a further threat and challenge in many parts of the region. The cumulative impact of these interrelated weather and climate phenomena have increased the costs of development in the PRD substantially. Fortunately, provincial and municipal governments have realized the importance of climate mitigation and adaptation, and are looking to the experiences of other delta cities around the world for valuable lessons about how best to strengthen urban sustainability and resiliency.

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REFERENCES

China Meteorological Administration. 2009a. *China marine hazards report 2008*. Beijing.

———. 2009b. *China sea level report 2008*. Beijing.

Chinese Academy of Sciences. 1994. The impact of sea level rise on economic development of the Pearl River Delta. In *The impacts of sea level rise on China's delta regions*. Beijing: Science Press.

Du, Yao-dong, Li-li Song, Hui-qing Mao, Hai-yan Tang, and An-gao Xu. 2004. Climate warming in Guangdong province and its influences on agriculture and counter measures. *Journal of Tropical Meteorology* 10(2): 150–159.

Guangdong Meteorological Administration. 2007. Assessment report on climate change in Guangdong. *www.gdemo.gov.cn*

He, Canfei, Lei Yang, and Guicai Li. 2010. Urban development and climate change in the Pearl River Delta. Working Paper. Cambridge, MA: Lincoln Institute of Land Policy.

Huang, Z., Y. Zong, and W. Zhang. 2004. Coastal inundation due to sea level rise in the Pearl River Delta, China. *Natural Hazards* 33: 247–264.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge, UK: Cambridge University Press.

Li, P., and Z. Zeng. 1998. On the climatic and environmental changes in the Pearl River Delta during the last 500 years. *Quaternary Sciences* 1: 65–70.

Tracy, A., K. Trumbull, and C. Loh. 2006. The impacts of climate change in Hong Kong and the Pearl River Delta. Hong Kong: Civic Exchange.

Wu, Y. and Li, H. 2009. Meteorological disasters and hazard evaluations in Shenzhen since 2000. *Guangdong Meteorology.* 31(3): 43-45 (in Chinese).

Yang, H. 1996. Potential effects of sea-level rise in the Pearl River Delta area: Preliminary study results and a comprehensive adaptation strategy. In *Adapting to climate change: An international perspective,* J. N. Smith, et al., eds. New York: Springer-Verlag.