intensity of storms and storm surges is likely to worsen the city's flood risks. Since the local governments are very close to the people and the communities threatened by climate risks, there is the need to create the awareness at the local government level. There is an urgent need to empower them intellectually, technically and financially to identify, formulate and manage the climate-related emergencies and disasters, as well as longer-term risks more proactively.

4.4 New York

With 8.2 million people, a $1.1 trillion GDP (Bureau of Economic Analysis, 2008) and an operating budget of over $40 billion, New York City is the largest city in the United States both in population and economic productivity (The City of New York, 2007, 2009). The distribution of wealth within the City, however, has been described as an "hourglass economy" where there is a shrinking of the middle class and growth in both the upper and lower-income populations (Rosenzweig & Solecki, 2001).

New York City is an archipelago with five boroughs spread out over three islands—Long Island, Manhattan and Staten Island—and the mainland of the United States (see Figure 32). Once a major manufacturing center, New York is now one of the world's most important international financial hubs. As a coastal city, most of New York City sits at a relatively low elevation with approximately 1 percent of the city below 3 meters (10 feet) (Rosenzweig & Solecki, 2001). Much of Manhattan's very low-lying land is home to some of the most important economic infrastructure in the world. Lower Manhattan, including the Wall Street financial district, and portions of both LaGuardia and John F. Kennedy airports sit at this low elevation.

New York City has a temperate, continental climate characterized by hot and humid summers as well as cold winters and consistent precipitation year round. Tables 5, 9, and 11 show the historic, observed weather conditions for temperature, precipitation, and sea level in New York City for the period 1900–2005. Using a baseline period of 1971–2000, these records show an average temperature of 12.7°C with precipitation averaging 109 to 127 centimeters per year. Recent climate trends show an increase in average temperature of 1.4°C since 1900 and a slight increase in mean annual precipitation (New York City Panel on Climate Change [NPCC], 2009).

As with other cities, climate change risks in New York City are a function of the hazards that the city faces, the vulnerability of its population and infrastructure to those hazards, and the adaptive capacity of the city to address climate change mitigation and adaptation needs. Hazards come in the form of increasing incidence of heatwaves, droughts and floods, and sea-level rise and associated storm surges. Adaptive capacity in New York City has been bolstered by the high-level adoption at the Mayoral and the State levels of the need to develop climate change adaptation strategies. Agencies, departments and public authorities are now developing and being provided with the tools necessary to undertake climate change mitigation and adaptation strategies.

Hazards

Each year New York City is susceptible to mid-latitude cyclones and nor'easters, which peak from November to April. These storms contribute greatly to coastal erosion of vital wetlands that help defend areas of the city from coastal flooding. Tropical cyclones (hurricanes) also have the potential to reach New York City usually during the months of August to September. There is some indication that intense hurricanes will occur more frequently in the future, but this is an area of active scientific research.

Based on climate model projections and local conditions, sea level is expected to increase by 4 to 12 centimeters by the 2020s and 30 to 56 centimeters by the 2080s (see Figure 21); when the potential for rapid polar icemelt is taken into account based on current trends and paleoclimate studies, sea level rise projections increase to between 104 to 140 centimeters (NPCC, 2009). With some of the world's most valuable and important economic activity taking place on Wall Street, the economy of the City, the United States, and arguably the world is vulnerable to the effects of enhanced coastal flooding due to sea level rise. The New York Stock Exchange is the largest stock exchange in the world (NYSE Euronext, 2009) and sits at an elevation of less than three meters (Rosenzweig & Solecki, 2001). The possibility of inundation during coastal storms is greatly enhanced with the projected effects of sea level rise.

Another hazard to New York City as a result of climate change is rising mean temperature, along with the associated increase in heat waves. The annual mean temperature in New York City has increased nearly 2˚C since 1900 as seen in Figure 5 (NPCC, 2009). Climate models predict that the average temperature will increase between 1 to 1.5°C by 2020 and 2 to 4°C by the 2080s as seen in Figure 15 (NPCC, 2009). As defined by the New York Climate Change Task Force, a heat wave is any period of three straight days with a temperature over 32˚C. The frequency of heat waves is projected to increase as the number of days over 32˚C increases. These higher temperatures will also intensify the urban heat island in New York City, since urban materials absorb radiation throughout the daytime and release it during the night causing minimum temperatures to rise (Rosenzweig & Solecki, 2001; Kinney et al., 2008). These sustained, higher temperatures exacerbate the effects of heat on humans (Basu & Samet, 2002).

Inland floods and droughts are two more hazards that confront New York City. Climate models indicate that precipitation in New York City is likely to increase up to 5 percent by the 2020s and between 5 and 10 percent by the 2080s as seen in Figure 19 (NPCC, 2009). These increases are projected to come in the form of more intense rain events. This means more days without precipitation between larger and more intense storms. As extreme rain events are expected to increase in intensity while decreasing in frequency, many of the rivers and tributaries that flow through New York City and feed into the bodies of water that surround the city may breech their banks more frequently as they will likely be unable to handle the volume of water flowing into them as runoff.

Droughts may also prove to be a hazard as a result of climate change if the period between rain events increases. A major concern is the New York City water supply, which is drawn from up to 100 miles north of the City. The higher levels of precipitation associated with climate change are expected to be offset by the greater rates of evaporation associated with temperature increase, thus increasing the likelihood of drought (NPCC, 2009).

Vulnerability

The impacts of these climate hazards are interconnected and affect many systems in New York City differently but simultaneously. Roadways and subways, as well as ferry ports, industries located along the coast, and wastewater treatment facilities are susceptible to inundation. More hot days will increase electricity demand to run cooling systems, thereby increasing CO_2 emissions. The erosion of natural defenses like coastal wetlands increases the likelihood of flooding of nearby neighborhoods and industries.

Different populations are more vulnerable than others and these vulnerabilities are frequently differentiated along the lines of inland vs. proximity to coast, young vs. old, and rich vs. poor. One key climate change vulnerability is related to air quality and human health, since degradation of air quality is linked with warmer temperatures. The production of ozone (O_3) and particulate matter with diameters below 2.5 micrometers ($PM_{2.5}$) in the atmosphere is highly dependent on temperature (Rosenzweig & Solecki, 2001). Therefore, increased temperatures are likely to make managing these pollutants more difficult. Both of these pollutants affect lung functioning with higher ozone levels being associated with increased hospital admissions for asthma (Figure 33). Further, the elderly and those suffering from heart and lung-related diseases have been shown to be more susceptible to the effects of heat, often resulting in death from heat stroke and heat -related causes (Knowlton et al., 2007).

New York City is vulnerable to heat waves and, as an archipelago, is particularly vulnerable to the effects of storm surge as a result of sea level rise. Projected sea level rise of 30 to 58 centimeters—or 104 to 140 centimeters, if rapid polar icemelt is considered—is not expected to inundate the city extensively; rather, the problem emerges when larger storms such as the 1-in-100 year storm, which are expected to become more frequent, produce a greater storm surge that will likely cause damaging floods (NPCC, 2009).

Certain populations are more vulnerable to the effects of heat and higher sea levels. Approximately 967,022 people in New York City are 65 or older and of those it is estimated that 43 percent are living with some sort of disability (US Census Bureau, 2008). These two factors contribute to the extreme vulnerability to heat of the elderly (Basu & Samet, 2002). According to the Department of Health for the City of New York, during the heatwave of 2006 over half of those who died in New York City were over age 65 and all but five people were known to have suffered from some type of medical condition (Department of Health and Mental Hygiene [DOHMH], 2006).

New York City is a densely city with approximately 10,380 people in each of its 305 square miles or 790 square kilometers (Department of City Planning, 2009). Within this area there are clear pockets of wealth and poverty. The majority of high per capita income households are concentrated along the eastern border of Central Park with other areas of high per capita income households located along the western edge of the Park and the western shore along the southern part of Manhattan (see Figure 34). The shore areas are primarily vulnerable to coastal flooding caused by the storm surge associated with the combined effects of an increased sea level and an extreme rain event.

The areas of low per capita income are in northern Manhattan, above Central Park, the borough of the Bronx and parts of Brooklyn. Sea level rise and coastal flooding are concerns for certain parts of these areas including Coney Island, Brighton Beach, and Jamaica Bay. One of the more recurring vulnerabilities for these populations is extreme heat and the diminished air quality that accompanies the heating trend that New York City has seen over the last 100 years and that is projected to continue. The US Census Bureau has estimated that for the period 2005–2007 about twenty percent of those in New York City were living below the poverty line as established by the US Government (US Census Bureau, 2008). During the heat wave of 2006, thirty-eight of those who died of heat stroke did not have a functioning air conditioning in their apartment (DOHMH, 2006).

Adaptive Capacity

The environment in which New York City makes climate change adaptation and mitigation decisions is highly complex. Due to shared regional transportation, water, and energy systems, the stakeholders in any decision include numerous local governments, multiple state governments, businesses and public authorities.

The foundation for tackling the challenges of climate change in New York City began in the mid-90s when the New York Academies of Science published, "*The Baked Apple? Metropolitan New York in the Greenhouse*" in 1996. Shortly thereafter, The Earth Institute at Columbia University, through the Center for Climate Systems Research (CCSR) released "*Climate Change and a Global City: The Potential Consequences of Climate Variability and Change*", (Rosenzweig & Solecki, 2001). This report covered the Metro-East Coast Region and served as the first assessment of climate change and cities in the United States. In 2008, CCSR worked with the New York City Department of Environmental Protection to develop a sector specific climate assessment and action plan for New York City's water system (New York City Department of Environmental Protection, 2008).

The New York City administration through its Office of Long-Term Planning and Sustainability created the NYC Climate Change Adaptation Task Force in 2008, which is now working with local experts, city departments and stakeholders to develop a comprehensive, integrated climate change risk assessment and adaptation plan for the critical infrastructure of the metropolitan region. The NYC Climate Change Adaptation Task Force is made up of representatives from over 30 city and regional departments and industries. The City administration also convened the New York Panel on Climate Change (NPCC) to provide expert information about climate change risks and adaptation. The NPCC is made up of climate change scientists, and experts from the legal field, insurance, telecommunications and transportation, and has provided the climate risk information needed to create actionable guidelines and plans for adapting the city's critical infrastructure for the projected effects of climate change (NPCC, 2009). The NPCC has also worked with the NYC Climate Change Adaptation Task Force to develop a common set of definitions for adaptation assessment.

The next step is to begin planning and making specific adaptation investments across the city. In the past in New York City, this has tended to be on a project basis and so has been less coordinated across sectors. Having brought decision-makers from all key departments in the city and from numerous sectors, the New York City climate change adaptation process is helping to facilitate more open avenues of communication and coordination within and among departments.

4.5 Across-City Findings

As the various scholars applied the risk framework to their cities, a combination of local factors revealed very specific climate risks confronting each city; however, there are some common threads as well (see Table 22). This summary table also provides the basis for developing a city climate risk assessment index. First, a multidimensional approach to risk assessment is essential as was observed in all four cities. Second, despite lack of data, climate risks can be articulated as especially demonstrated by the cases of Lagos and Delhi. Third, there are substantial mismatches between needs and responses—who mitigates, how much adaptation, and why, remain serious concerns. For instance Delhi, despite its extremely high risk due to its large vulnerable population is now focusing primarily on mitigation, as does Buenos Aires. Fourth, as observed in all cities vertical and horizontal fragmentation of urban governance is a challenge. As in the case of Delhi, however, such distributed jurisdictions may offers an opportunity. In Delhi, the Environment Ministry is an early adopter of pro-active climate change responses and is thus providing an entry point for systemic change. Finally, there are the oft-noted challenges for the climate scientists to provide credible downscaled risk information on regionally-crucial climate dynamics such as potential changes in the Indian Monsoon. We also found, however, that effective adaptation planning can start with the climate risk information available now. For a programmatic approach for risk assessment and adaptation planning where an institutional structure is articulated see Annex 4 (Mehrotra, 2009).

5.0 LESSONS FOR DEVELOPING COUNTRIES AND KNOWLEDGE GAPS

Three initial lessons are summarized. ***First, a multidimensional approach to risk assessment is a prerequisite to effective urban development programs that incorporate climate change responses.*** At present most climate risk assessment is dominated by an over-emphasis on climate hazards. The application of the climate risk framework developed in this paper provides more nuanced and more actionable insights into the differential risks depending on the exposure to hazards on the spectrum of vulnerabilities of urban households, neighborhoods, and firms—for instance, from the most vulnerable slums in flood plains where infrastructure is lacking—and the adaptive capacity of local governments. However, a critical issue that requires further research is identifying when strategic retreat may be more cost-effective than adaptation and under what socio-economic conditions is it desirable and feasible.

Second, mismatches between needs and responses are occurring in regard to who should mitigate, how much to adapt, and why. Cities need climate change risk assessment in order to decide for themselves what is the right mix between mitigation and adaptation. Climate change risk frameworks, such as those described in this paper, can help cities to address the issue of mismatches, that is, the difference between the city's response to climate change as opposed to the actual needs. For example, it appears that some developing countries may be over-focusing on mitigation when they could be focusing more on adaptation due to the presence of critical climate risks in the near-term as well as in future decades. The seventeen largest economies account for most of the greenhouse gas emissions, the root cause of climate change (US Department of State, 2009). And while many cities within these major economies have a significant role in mitigation, it may be prudent for cities in low-income countries with large populations of poor households to incorporate climate risk into ongoing and planned investments as a first step (Mehrotra, 2009). However, since cities play an important role in greenhouse gas emissions in both developed and developing countries, there is also motivation for cities to lead on mitigation activities as well. Emissions from cities everywhere burden the environment, which is a global public good, and thus can be regulated through a combination of market and non-market incentives at the urban scale.

Third, the vertically and horizontally fragmented structure of urban governance is as much an opportunity as an obstacle to introducing responses to climate change. While much has been researched about the need for an integrated and coordinated approach, the fragmented governance structure of cities is unlikely to change in the short term and offers the opportunity to have multiple agents of change. Examples in the case study cities show that early adopters on climate change solutions play an important role. The broad spectrum of governmental, civil society, and private sector actors in cities encourages a broader ownership of climate change adaptation programs.

Further, gaps and future research for scaled-down regional and local climate models were identified. In addition to the difficulties global climate models have with simulating the climate at regional scales, especially for locations with distinct elevational or land-sea contrasts, they also continue to have difficulty simulating monsoonal climates. Such is this case for climate projections for some of the case study cities in this paper, especially related to projected changes in precipitation. This is because simulation of seasonal periods of precipitation is challenging in terms of both timing and amount; in some cases the baseline values used for the projection of future changes are extreme—either too high or too low. Therefore, the percentage change calculated, vary greatly and can, on occasions, have distorted values. Especially for precipitation projections, the future trends may appear to be inconsistent compared to observed data, because the averages from the baseline period to which the projected changes were added onto are inaccurate, either due to a lack of data or extreme values within the time period that are skewing the averages. The inability of the global models to simulate the climate of individual cities raises the need for further research on regional climate modeling.

However, what is important to focus on in these future climate projections is the general trends of the projected changes and their ranges of uncertainty. These refers to attributes such as increasing, decreasing, or stable trends, and information about the uncertainty of projections in particular due to climate sensitivity or greenhouse gas emission pathways through time. Information on climate model projections regarding the extreme values and the central ranges both provide useful information to city decision-makers.

5.1 Other Concerns, What Next

Even as climate risk assessment frameworks as described in this paper are developed and implemented, a multitude of further concerns and questions immediately arise regarding climate change challenges for cities, pointing the way towards further research and policy development. These include:

- Ethical questions about what levels of government and what combination of stakeholders should (and in practice will) prioritize the actions on climate-related concerns where uncertainty at the local level remains high and the awareness among the poor and vulnerable sub-groups is low. How can cities address the specific needs of the most vulnerable sections of its inhabitants—the urban poor? Especially, as these sub-groups lack access to basic services and live in vulnerable shelters, and on disaster prone land—flood plains and the like—further environmental stress can be catastrophic for the slum dwellers.

- How can mega-cities in developing countries do a holistic assessment of the potential risk due to climate-change, plan complementary mitigation strategies and adaptive resilience that do not remain mere recommendations in reports but lead to action? The lack of a climate-change strategy for the city increases the risk of the already vulnerable urban poor—how can this neglect of the poor be addressed in the broader climate and city debate? As Delhi has introduced CNG-fueled public transportation as a mitigation measure, what are the strategic interventions—short-gestation, low-cost, high-impact—that facilitate large-scale adaptation to reduce the economic, social, and environmental risk to cities, particularly the poor?
- How can city infrastructure—public transport, water, electricity—and social institutions for public health or disaster management be retrofitted to adapt to climate change? How can a city craft a flexible and calibrated approach towards adaptive resilience?
- How can cities develop an institutional response to climate change with complementary strategies for mitigation and adaptation that result in action on the ground? What strategies work for vertical coordination among national, regional, and local policy efforts? Moreover, how can horizontal co-operation be fostered resulting in collaborative action across stakeholders and between departments and agencies at the city level, and across cities nationally and internationally?