Climate Change and Cities
First Assessment Report of the Urban Climate Change Research Network

Urban areas are home to over half of the world's people and are at the forefront of the climate change issue. Climate change exerts added stress on urban areas through increased numbers of heat waves threatening the health of the elderly, the infirm, and the very young; more frequent and intense droughts and inland floods compromising water supplies; and for coastal cities, enhanced sea level rise and storm surges affecting essential infrastructure, property, ecosystems, and inhabitants. At the same time, cities are responsible for no less than 40% of global greenhouse gas emissions, and given current demographic trends, this level will likely only increase over time. These challenges highlight the need for cities to rethink how assets and people are deployed and protected, how infrastructure investments are prioritized, and how climate will affect long-term growth and development plans.

Work on the *First Assessment Report on Climate Change and Cities* (ARC3) was launched by the Urban Climate Change Research Network (UCCRN) in November 2008 with the goal of building the scientific basis for city action on climate change. The authors include experts from cities in both the developing and developed world, representing a wide range of disciplines. The book focuses on how to use climate science and socio-economic research to map a city's vulnerability to climate hazards, and how cities can enhance their adaptive and mitigative capacity to deal with climate change over different timescales.

The volume is structured to communicate to a range of groups important for urban decision-making:

- The *Executive Summary* is invaluable for mayors, city officials, and policymakers;
- The *Urban Climate, Land Use*, and *Governance* chapters are of great interest to urban sustainability officers and urban planners;
- The *Sector* chapters are important for mid-level urban stakeholders in agencies charged with developing climate change mitigation and adaptation programs;
- The entire volume, including the framing *Urban Climate Change in Context* and the *Cities, Disasters, and Climate Risk* chapters, provides a broad spectrum of climate change knowledge to researchers, professors, and advanced students.

Cynthia Rosenzweig is a Senior Research Scientist at the NASA Goddard Institute for Space Studies where she heads the Climate Impacts Group. She recently co-chaired the New York City Panel on Climate Change, a body of experts convened by the Mayor to advise the city on adaptation for its critical infrastructure. She co-led the Metropolitan East Coast Regional Assessment of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, sponsored by the U.S. Global Change Research Program. She was a Coordinating Lead Author of the IPCC Working Group II Fourth Assessment Report, and served on the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis. A recipient of a Guggenheim Fellowship, she joins impact models with climate models to project future outcomes of both land-based and urban systems under altered climate conditions. She is a Professor at Barnard College and a Senior Research Scientist at the Earth Institute at Columbia University.

William D. Solecki is a Professor in the Department of Geography, Hunter College, City University of New York. He has led or co-led numerous projects on the process of urban environmental change and transformation. As Director of the CUNY Institute for Sustainable Cities, he has worked extensively on connecting cutting-edge urban environmental science to everyday practice and action in cities. He most recently served as Co-Chair of the New York City Panel on Climate Change, as Co-Principal Investigator of the Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State (ClimAID), and as Co-Leader of the Metropolitan East Coast Assessment of the US National Assessment of the Potential Consequences of Climate Variability and Change. He is a Lead Author of the IPCC Working Group II Fifth Assessment Report. He is also a member of the Scientific Steering Committee of the Urban and Global Environmental Change core project of the International Human Dimensions Programme.

Stephen A. Hammer is the President of Mesacosa LLC, a consultancy that conducts research on urban energy and climate issues in cities around the globe. He was formerly Executive Director of the Energy Smart Cities Initiative, a project of the Joint U.S.-China Collaboration on Clean Energy (JUCCCE), running energy and climate policy training and technical assistance programs for local governments in China. He is also the past director of the Urban Energy Program at Columbia University's Center for Energy, Marine Transportation and Public Policy. He has authored or co-authored dozens of policy studies and journal articles on urban sustainability planning, urban energy systems, distributed generation technology and the impacts of climate change on local and regional energy networks. He is an Adjunct Professor at Columbia University's School of International and Public Affairs, a member of New York City Mayor Bloomberg's Energy Policy Task Force, and a consultant to the OECD and the World Bank.

Shagun Mehrotra is Managing Director of Climate and Cities, an international policy advisory facility at Columbia University's Center for Climate Systems Research. As a Columbia University Faculty Fellow, he provides research and policy advice focusing on infrastructure economics and finance, development economics and poverty reduction in slums. He has developed a comprehensive framework for city climate risk assessment that combines hazards, vulnerabilities and agency. Previously, he was on the staff of the World Bank, leading infrastructure reform of state-owned utilities in Africa. Over the last decade, his advice has been sought by national and local governments in East Africa, South-East Asia, China and India, as well as the United Nations Human Development Report, the Bill and Melinda Gates Foundation, and the Columbia Earth Institute. His co-authored book, *Bankruptcy to Billions: How the Indian Railways Transformed*, was recently launched by the President of India.

From the Forewords to this book:

" … innovative and important. … I am convinced that this body of knowledge will be of direct benefit and inspiration to the cities which we are supporting to develop climate action plans."
Anna Tibaijuka, Former Under-Secretary General of the United Nations and Former Executive Director, UN-HABITAT

"I am highly appreciative of the work of the members of the UCCRN from developing and developed cities who are participating in the ARC3 activity. Policymakers, administrators, and researchers from cities around the world will benefit from the information provided in ARC3, helping them make more informed decisions about how climate change will affect public health, local infrastructure, and in turn, our economic vitality in the coming decades."
Rajendra Kumar Pachauri, Chair, Intergovernmental Panel on Climate Change and Director General, The Energy and Resources Institute, New Delhi, India

"The strategies explored in this text will not only help to guide individual local government efforts, but also help to tell the story of the critical importance of local action. The best scientific data tell us that it is long past time to address that challenge. And the best demographic data tells us that cities must lead the way. … The ARC3 project will help ensure that we not only create a greener, greater New York for future generations, but that we continue to learn from the lessons of our counterparts across the world, and that we share our progress and our story with our partners throughout government, academia, and the private sector."
Michael R. Bloomberg, *Mayor, New York City*

"[This] new volume … is a lifeline to sustainability. … The authors of this remarkable report … are at the cutting edge of global science and policy. … The work is a triumph, a must-read study for city planners, mayors, and managers around the world. The lead editors … merit our special thanks and admiration for taking on a challenge of such global significance, and for bringing the best of the world's scientific knowledge together in such a useful and comprehensive manner."
Jeffrey D. Sachs, Director of the Earth Institute at Columbia University and Special Advisor to UN Secretary General Ban Ki-Moon on the Millennium Development Goals

Other praise for this book:

"As the pioneer of a global movement of local climate actions since early 1990s, ICLEI - Local Governments for Sustainability welcomes ARC3. It provides key information that local governments need to develop effective plans and programs addressing climate change. UCCRN researchers synthesize knowledge and best practices for both mitigation and adaptation for crucial urban sectors and systems including water, energy, transportation, and public health. This valuable scientific compilation helps local decision makers and municipal officials play a vital leadership role in climate change action in their cities, regions, countries and beyond."
Konrad Otto-Zimmermann, *ICLEI (Local Governments for Sustainability) Secretary General*

"For the challenges that a city such as Mexico City must face, efforts like ARC3 are crucial to provide the much-needed scientific assessment to effectively address climate change."
Mayor Marcelo Ebrard of Mexico City

"Cities need increasingly sound scientific knowledge to take decisions related to combating climate change. We therefore welcome initiatives like the ARC3 and hope that cities all over the world can benefit from its findings."
Mayor Gilberto Kassab of São Paulo

"The *First Assessment Report on Climate Change and Cities* is a critical piece in helping cities to develop sound, science-based policies to address the climate change mitigation and adaptation challenges they face."
Governor Babatunde Raji Fashola of Lagos State

"Cities are leaders in taking action to fight climate change. ARC3 is a must read for city leaders who want to incorporate the most current understanding of climate change science in cities into their decision-making."
David Miller, former Mayor of Toronto and former Chair of the C40 Cities Climate Leadership Group

"ARC3 fills a critical gap in addressing climate change issues in Indonesia's vulnerable and diverse urban areas such as Jakarta, Palangkaraya, and Samarinda city."
Senator Hambdani and Senator Bambang Susilo, Indonesia

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Foreword - *Anna Tibaijuka*

The world rapidly urbanizing, and a majority of the global population will experience climate change in cities. Climate change will exacerbate the existing urban environmental management challenges in cities – in most cases making existing problems much worse. Additionally, it is the urban poor, who often are forced to live in flood- and landslide-prone areas and who face other vulnerabilities, who will bear a disproportionate share of the effects of climate change. Though cities are vulnerable to the effects of climate change, they are also uniquely positioned to take a global leadership role in both mitigating and adapting to it.

As cities begin to develop climate change action plans there is great need for a mechanism by which research and expert knowledge may contribute to the development and implementation of effective urban climate change policies and programs. Since responding to the complex challenges of climate change mitigation and adaptation requires a knowledge-based approach, the First UCCRN Assessment Report on Climate Change and Cities (ARC3) provides a tool for policymakers as they "mainstream" responses to climate change in urban areas.

The ARC3, a project of the Urban Climate Change Research Network (UCCRN), is innovative and important. It supports the work of local government officials and local researchers and complements the work of the already-existing body of knowledge developed by the Intergovernmental Panel on Climate Change (IPCC) by addressing the needs of cities. ARC3 provides the scientific base needed for sound mitigation and adaptation decision-making on a sector-by-sector basis, mirroring the administrative structure of a city.

The UCCRN's goal of turning the ARC3 process into an on-going initiative is also critical. Climate science is ever-evolving and cities are constantly reacting to and proactively addressing their unique climate change challenges. With the support of the research community, cities around the world will now have access to the latest information and the most robust understanding of climate change available.

I therefore applaud the work of groups such as UCCRN and the many researchers from both developing and developed cities contributing to this important research initiative and creating a mechanism to help cities further empower themselves. We will promote the use of the information compiled in ARC3 through our Cities and Climate Change Initiative and through our collaboration frameworks with other organizations, including the Joint Work Programme between the World Bank, UN-HABITAT and UNEP, supported by the Cities Alliance.

I am convinced that this body of knowledge will be of direct benefit and inspiration to the cities which we are supporting to develop climate action plans. It will help cities make more informed decisions about how climate change will affect public health, local infrastructure, and in turn, their own economic vitality in the coming decades.

Anna Tibaijuka
Former Under-Secretary General of the United Nations
Former Executive Director, UN-HABITAT

Foreword - *Rajendra Kumar Pachauri*

Clearly, cities are playing an increasing role in responding to climate challenges and are therefore in need of knowledge to aid in their policy development. The First Assessment Report on Climate Change in Cities (ARC3), a project of the Urban Climate Change Research Network (UCCRN), is particularly useful in this regard. The ARC3 provides a scientific assessment of climate change in cities, presenting the information necessary for sound mitigation and adaptation decision-making on a sector-by-sector basis. By specifically addressing climate change in cities, the ARC3 supports the work of local governments, officials and researchers, and complements the work of the Intergovernmental Panel on Climate Change (IPCC).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provided the global community with up-to-date knowledge about the impacts of climate change. It projected that climate change will lead to a number of consequences for urban areas, including declining air quality, an increased number and severity of heat waves in cities in which heat waves already occur, increased pressure on infrastructure, and augmented stress on water resources. Furthermore, the Fourth Assessment Report noted that residents of some cities in the world, including some in Europe and the USA, have experienced high levels of mortality due to the impacts of extreme climate events. The 2003 European heat-related deaths and the deaths of over 1,000 people in New Orleans due to Hurricane Katrina are two examples of this. The IPCC Fifth Assessment, now underway, will continue to address these important issues, building on the work of the ARC3.

Due to the evolving nature of climate science, developing the ARC3 process into one that issues reports for cities on a regular basis is important. The UCCRN researchers will thus provide crucial information to urban decision-makers in a timely way as scientific understanding progresses.

I am highly appreciative of the work of the members of the UCCRN from developing and developed cities who are participating in the ARC3 activity. Policymakers, administrators, and researchers from cities around the world will benefit from the information provided in ARC3, enabling them to develop effective programs for mitigating and adapting to climate change.

Rajendra Kumar Pachauri
Chair, Intergovernmental Panel on Climate Change

Foreword - *Michael R. Bloomberg*

Cities are the vanguard in the battle against climate change. We are the source of approximately 80 percent of global greenhouse gas emissions. And densely populated urban areas, particularly coastal cities, will disproportionately feel the impacts of climate change. Those of us in local government recognize the importance of national and international leadership on climate change. But we also are not waiting for others to act first.

Through *PlaNYC*, New York City's comprehensive sustainability plan that we released in April 2007, we are working to create a greener, greater New York. Many of the 127 initiatives in the plan focus on reducing our greenhouse gas emissions. These initiatives, including the Greener, Greater Buildings Plan, which will increase the energy efficiency of existing buildings, will help us meet our goal of reducing the city's carbon emissions by 30 percent by 2030.

Four years after launching *PlaNYC*, we are seeing the benefits of our efforts. Our greenhouse gas emissions are down by over 12 percent from 2005 levels, and we've developed the City's first official climate change projections. We are now in the process of updating *PlaNYC*, and also doing more to draw on the creativity of New Yorkers in every borough. At the same time, we are learning from our colleagues across the world who are undertaking ambitious climate change mitigation and adaptation programs.

Five years ago, 18 of the world's great cities came together, to share best practices and make common cause in the effort to reduce greenhouse gas emissions. This group of 18 eventually grew into what is now the C40 Climate Leadership Group, a network of 40 of the largest cities in the world.

The Urban Climate Change Research Network recognizes the potential and responsibility of cities to enact change, and highlights the strategies employed by cities across the globe who are leading the way towards a sustainable future. The strategies explored in this text will not only help to guide individual local government efforts, but also help to tell the story of the critical importance of local action. The best scientific data tell us that it is long past time to address that challenge. And the best demographic data tell us that cities must lead the way.

Cities have demonstrated that we are prepared to boldly confront climate change. As mayors, we know that we don't have the luxury of simply talking about change without delivering it. The ARC3 project will help ensure that we not only create a greener, greater New York for future generations, that we continue to learn from the lessons of our counterparts across the world, and that we share our progress and our story with our partners throughout government, academia, and the private sector.

Michael R. Bloomberg
Mayor, New York City

Foreword - *Jeffrey D. Sachs*

The twenty-first century will be the age of sustainable development - or the age of ruin. Worldwide economic growth over the past two centuries has brought remarkable progress but also remarkable risk. By mobilizing fossil fuels, humanity lifted itself from the ancient scourges of hunger, disease, and early death. Living standards and income levels in many parts of the world soared beyond the wildest of expectations. Yet these gains are now bringing new and grave threats as well. Humanity has inadvertently pushed against the planet's safe boundaries regarding greenhouse gas emissions, land use changes, pollution, and human-induced threats to biodiversity and public health. In the coming decades, the core challenge of societies around the world will be to refashion our ways of life – living patterns, technologies, and economic systems – so that we can combine the benefits of economic development with sustainable management of the Earth's ecosystems.

Cities will be at the center of this unique and unprecedented challenge. During the past decade, humanity reached the decisive halfway point on the path to urbanization. From time immemorial until the Industrial Revolution two centuries ago, almost all of humanity lived as subsistence farmers in the rural areas. Starting two centuries ago, with the mobilization of new energy resources and technologies, including in food production, humanity began a long-term transition to urban living. As farmers became more productive, a declining share of the population could feed the rest. For generations now, the children of farm families have been heading to the cities for a new urban life. Today, the UN tells us that a little more than 50 percent of the world now lives in cities, and that by 2050 the proportion is likely to rise to nearly 70 percent.

How cities are structured – in the patterns of residential settlements, commercial and industrial land use, energy systems, transport networks, water and sewerage infrastructure, public health management, and more – will not only determine the quality of life of the majority of the world's population, but also whether humanity, at long last, is able to live sustainably with nature. To learn to do so is vital. Our livelihoods and very lives will depend on it. But it will not be easy by any means. The scale, scope, and complexity of the challenge will rival any that humanity has faced in recent centuries.

The new volume produced by the scientists of the Urban Climate Change Research Network (UCCRN) is a lifeline to sustainability. We should be grateful that leading scientists from around the world have taken up the challenge of sustainable urbanization, with a specific focus on the interrelationship of city life and human-induced climate change. The authors of this remarkable report, the First Assessment Report of the UCCRN, are at the cutting edge of global science and policy. Every essay emphasizes the complexity of the challenges ahead, and how we are just at the start of reshaping our cities for sustainability.

As this report makes amply clear, climate change will be a vital entry point for achieving sustainable development in the world's cities. While climate change is just one of several environmental challenges facing the world, it is the largest, most complex, and most urgent. There can be no answers to other challenges of sustainable development – safe water, clean and abundant energy, and urban public health – unless they are also answers to the climate-change conundrum.

As this volume explains, there are two interrelated aspects of the climate change puzzle. The first is adaptation. Human-induced climate change is already underway and will intensify in the coming decades. The cities will be threatened in several major ways, and every city must plan ahead to confront, manage, and where possible, fully head off the growing risks. Heat waves will threaten lives of vulnerable populations such as the elderly. Droughts, floods, and other natural hazards will become more frequent, though the vulnerability of specific cities will vary widely depending on their physical geography, climatology, level of economic development, the quality of governance, social cohesion, and the financial capacity to adjust. Rising sea levels may play havoc with coastal cities, submerging some areas, and making others far more vulnerable to storm surges, or adversely impacting key infrastructure.

The other major challenge is climate change mitigation: reducing humanity's greenhouse gas emissions in order to slow and eventually to stop or even reverse the human impacts on the climate. Mitigation is every bit as complex as adaptation, and often the two are closely intertwined. Green buildings can both reduce energy use and also increase resilience to heat waves and other climate hazards. Mitigation will require major long-term changes to energy systems, the design of buildings, transport networks, and urban spatial patterns and zoning. Changing these fundamental attributes of cities will often involve making deep changes in the fabric of city life and its underlying economics. Yet the task of mitigation, essentially moving to a low-carbon society, will have to be carried out in thousands of cities around the world. The process will require decades of persistent and creative policymaking to achieve. There is no better place to start charting that transition than with this pioneering report.

Humanity is in uncharted territory. We must steer future technologies and urban development in a directed and coherent manner, consistent with the best science, social fairness, and economic efficiency. This book is a remarkable, cutting-edge, how-to manual at the start of a decades-long process. The authors don't claim to have all of the answers. Indeed, they constantly emphasize the uncertainties around climate forecasts, technological options, and social best practices. Yet the tools described here are the best around for getting started.

The volume is extraordinary on several counts. First, it is comprehensive, in that it considers every major dimension of adaptation and mitigation that cities will confront. Second, it is remarkably broad ranging in its case studies of dozens of cities around the world. These cases are enormously interesting and enormously instructive. Third, it draws on the very best current knowledge by recognized leaders in their respective fields. Fourth, and impressively, it is very clearly written. This is not a theoretical tome. This is a volume that can guide policymakers in cities and national governments around the world to launch their own climate assessments, and to begin developing meaningful climate solutions for their cities. By complementing the work of the already existing body of knowledge developed by the Intergovernmental Panel on Climate Change (IPCC), this First Assessment Report on Climate Change and Cities (ARC3) provides a rigorous set of analytical tools for effective mitigation and adaptation decision-making, and in a sector-by-sector approach that is likely to be of practical benefit for city planners, managers, businesses, and non-governmental organizations.

Over one hundred scholars around the world, representing a diverse group of developing and developed country cities, have collaborated on the ARC3. The work is a triumph, a must-read study for city planners, mayors, and managers around the world. The lead editors, Cynthia Rosenzweig, William D. Solecki, Stephen A. Hammer, and

Shagun Mehrotra, merit our special thanks and admiration for taking on a challenge of such global significance, and for bringing the best of the world's scientific knowledge together in such a useful and comprehensive manner.

Jeffrey D. Sachs
Director of the Earth Institute at Columbia University
Special Advisor to UN Secretary General Ban Ki-Moon on the Millennium Development Goals

Preface

This volume is the Urban Climate Change Research Network's First Assessment Report on Climate Change and Cities (ARC3). It contains an Executive Summary and the four sections of the report.

This report would not be possible without the tremendous support of the Cities Alliance, UN-HABITAT, United Nations Environment Programme (UNEP), and the World Bank. We especially thank William Cobbett and his team at Cities Alliance, Jean Christophe, Ricardo Jimenez, Sid Henderson, Neelam Tutej, Kevin Milroy, Viorica Revutch, Phyllis Kibui, and Madhavan Balachandra.

At UN-HABITAT, we are thankful to Anna Tibaijuka and Joan Clos, the outgoing and incoming Executive Directors, and their team led by Rafael Tuts with Robert Kehew and Bernhard Barth, as well as others who provided useful reviews of ARC3.

At the World Bank, we thank Inger Andersen, Vice President, Sustainable Development Department, and her team at the Urban Anchor led by Abha Joshi Ghani; Dan Hoornweg and Anthony Bigio of the Urban Anchor have been unfailingly supportive. At UNEP we would like to thank Soraya Smaoun.

We would also like to thank the Sector Managers and Directors at the World Bank and the leaders of the UNFCCC and the IPCC who have supported the need for ARC3. The Global Facility for Disaster Reduction and Recovery (GFDRR) and the U.S. Geological Survey also provided much-appreciated support for the ARC3 initiating workshop, through the enthusiastic leadership of Saroj Jha and DeWayne Cecil, respectively. They are all exemplary international public servants committed to the development of effective ways for cities to confront climate change challenges and to identify opportunities in resolving them.

We appreciate the advice provided by the members of the UCCRN Steering Group – Albert Bressand, Richenda Connell, Peter Droege, Alice Grimm, Saleemul Huq, Eva Ligeti, Claudia Natenzon, Ademola Omojola, Roberto Sanchez, and Niels Schulz – whose wisdom has guided the establishment of the network and the development of the ARC3 process.

We gratefully acknowledge the discussions and feedback during sessions with Mayors, their advisors, leaders of major institutions, urban policymakers, and scholars. In particular, we thank everyone who participated in ARC3 consultations: scholars at NCCARF 2010 Climate Adaptation Futures Conference in Australia; Konrad Otto-Zimmermann, Monica Zimmermann, Yunus Arikan, and participants at ICLEI's Resilient Cities Adaptation Summit in Bonn; scholars and practitioners at UGEC's Global Summit in Phoenix, Arizona; Mayors and city leaders at the C40 Large City Climate Change Summits in New York, Seoul, and Hong Kong; and at the Mayors Summit held during the COP15 in Copenhagen and the World Council of Mayors Summit held in Mexico City before COP16 in Cancun. At the UN-HABITAT's World Urban Forum in Rio de Janeiro we benefited from the interaction with a broad array of urban stakeholders who shared their thoughts on how to maximize the effectiveness of the ARC3 process. We extend special gratitude to the urban leaders who represent a diverse group of cities, who have commended UCCRN and ARC3. We also give a special thanks to the many students at Columbia University (New York), The Daly College (Indore), and Tec de Monterry (Mexico City) for their keen interest in the emerging field of urban climate change, which helped push the ideas for this volume forward.

This report is the product of the work of the over 100 dedicated members of the UCCRN ARC3 writing team representing more than 50 cities in developing and developed countries. We express our sincere thanks to each of them for their sustained and sustaining contributions, and to their institutions for supporting their participation. We especially thank Shobhakar Dhakal (Tsukuba), Toshiaki Ichinose (Tokyo), Haluk Gerçek (Istanbul), Claudia Natenzon (Buenos Aires), Martha Barata (Rio de Janeiro), and Ademola Omojola (Lagos) for their efforts on behalf of the UCCRN in Asia, the Middle East, Latin America, and Africa regions.

We profoundly appreciate Joseph Gilbride and Somayya Ali for their tremendous work as the UCCRN ARC3 Project Managers, without whom the ARC3 could not have been completed in such a comprehensive and timely way. We also acknowledge the exceptional commitment of the ARC3 research assistants and interns, Jeanene Mitchell, Shailly Kedia, Young-Jin Kang, Masahiko Haraguchi, Steve Solecki, Casey Jung, Irune Echevarria, Lumari Pardo-Rodriguez and Kimberly Peng. At the Goddard Institute for Space Studies, we thank Daniel Bader, José Mendoza, Richard Goldberg and Adam Greeley for their technical expertise, and George Ropes, of www.climateyou.org, for his superb editing.

We recognize with great esteem the expert reviewers of the ARC3 without whom the independent provision of sound science for climate change mitigation and adaptation in cities cannot proceed.

It is a great honor that the ARC3 is being published by Cambridge University Press. We would especially like to thank Matt Lloyd, Editorial Director, Science, Technology and Medicine, Americas; Laura Clark, Assistant Editor; Abigail Jones, Production Editor; and their staff for their expert partnership in the publication of this volume.

Finally, we are deeply grateful to the Columbia University Earth Institute and its Director Jeffrey Sachs for their support for the UCCRN ARC3 process from its inception.

Cynthia Rosenzweig, William D. Solecki, Stephen A. Hammer, and Shagun Mehrotra,
Editors
First UCCRN Assessment Report on Climate Change and Cities

Climate Change and Cities

First Assessment Report of the Urban Climate Change Research Network

Executive Summary

Executive Summary

Cities[1] are home to over half of the world's people and are at the forefront of the climate change issue. Climate change exerts added stress on urban areas through increased numbers of heat waves threatening the health of the elderly, the infirm, and the very young; more frequent and intense droughts and inland floods compromising water supplies; and for coastal cities, enhanced sea level rise and storm surges affecting inhabitants and essential infrastructure, property, and ecosystems. At the same time, cities are responsible for no less than 40% of global greenhouse gas emissions, and given current demographic trends, this level will likely only increase over time. These challenges highlight the need for cities to rethink how assets are deployed and people protected, how infrastructure investments are prioritized, and how climate will affect long-term growth and development plans.

Work on the *First Assessment Report on Climate Change and Cities* (ARC3) was launched by the Urban Climate Change Research Network (UCCRN) in November 2008 at a major workshop in New York City with the goal of building the scientific basis for city action on climate change. Eventually more than 100 lead and contributing authors from over 50 cities around the world contributed to the report, including experts from cities in both the developing and developed world, representing a wide range of disciplines. The book focuses on how to use climate science and socio-economic research to map a city's vulnerability to climate hazards, and how cities can enhance their adaptive and mitigative capacity to deal with climate change over different timescales.

Key findings

Defining the risk framework

A new vulnerability and risk management paradigm is emerging as a useful framework for city decision-makers to analyze how their city should seek to adapt to the anticipated impacts of climate change. The UCCRN climate change vulnerability and risk assessment framework (Figure 1) is composed of three sets of indicators:

- *Climate hazards* facing the city, such as more frequent and longer duration heat waves, greater incidence of heavy downpours, and increased and expanded coastal or riverine flooding;
- *Vulnerabilities* due to a city's social, economic, or physical attributes such as its population size and density, topography, the percentage of its population in poverty, and the percentage of national GDP that it generates;
- *Adaptive capacity aspects*, factors that relate to the ability of a city to act, such as availability of climate change information, resources to apply to mitigation and adaptation efforts, and the presence of effective institutions, governance, and change agents.

In most cities, readily available data exist about climate hazards (trends and projections), population and geographic features, and institutional capacity that can serve as a foundation for adaptation planning efforts. In other cities that are still in the early stages of efforts to assess local vulnerabilities and climate risks, work can nonetheless begin by using generalized climate risks and information from similar urban areas as a starting point for local climate planning efforts.

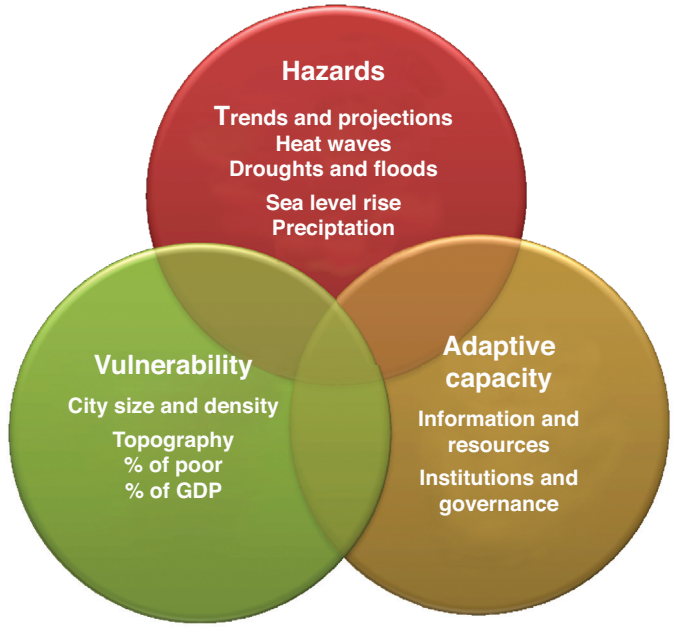

Figure 1: *Urban climate change vulnerability and risk assessment framework.*

Source: Mehrotra et al. (2009).

For example, in Sorsogon City in the Philippines, the city government developed its local vulnerability assumptions using climate change projections and risk assessments from national government agencies and private research institutions.

Urban climate: processes, trends, and projections

Cities already face special climatic conditions that must be accounted for when preparing long-term climate change adaptation plans. These include:

- *Urban heat island.* Cities already tend to be hotter than surrounding suburban and rural areas due to the absorption of heat by concrete and other building materials and the removal of vegetation and loss of permeable surfaces, both of which provide evaporative cooling.
- *Air pollution.* The concentration of residential, commercial, industrial, electricity-generating, and transportation activities (including automobiles, railroads, etc.) contributes to air pollution, leading to acute and chronic health hazards for urban residents.
- *Climate extremes.* Major variability systems such as the El Niño-Southern Oscillation, the North Atlantic Oscillation, and

1 Cities are defined here in the broad sense to be urban areas, including metropolitan and suburban regions.

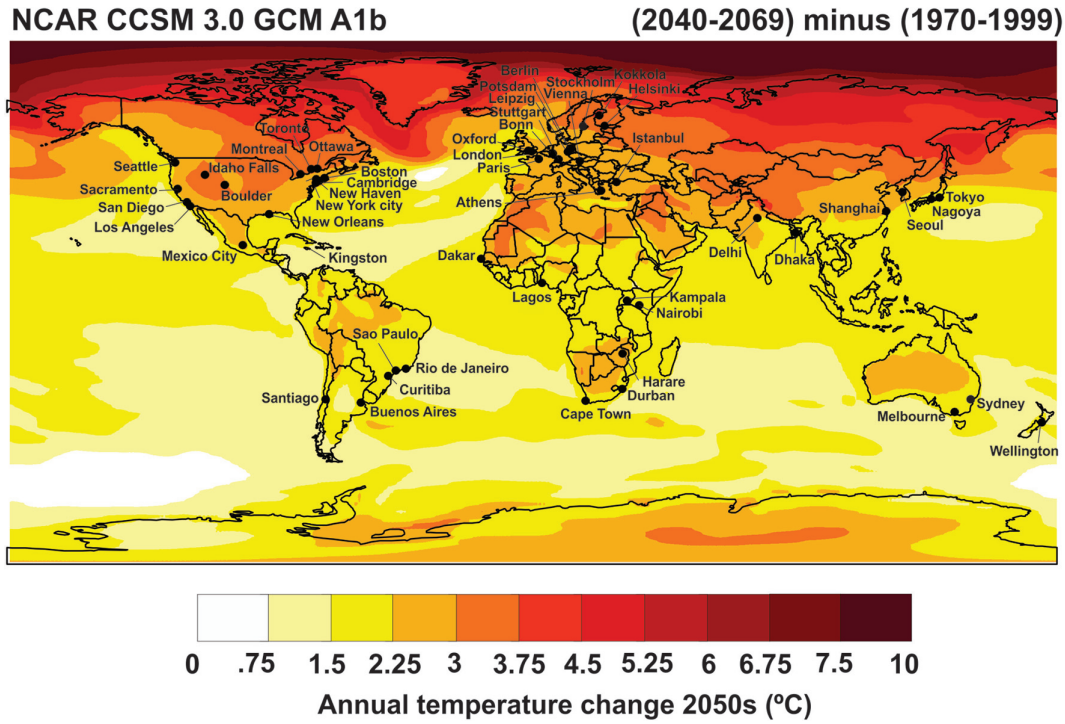

Figure 2: *Cities represented in ARC3 and 2050s temperature projections for the NCAR CCSM 3.0 GCM with greenhouse gas emissions scenario A1b.*

Source: NCAR CCSM 3.0 – Collins et al. (2006); Emissions Scenario A1b – Nakicenovic et al. (2000).

oceanic cyclonic storms (e.g., hurricanes and typhoons) affect climate extremes in cities. How these systems will interact with anthropogenic climate change is uncertain, but awareness of their effects can help urban areas to improve climate resilience.

Existing city-specific climate data and downscaled projections from global climate models can provide the scientific foundation for planning efforts by city decision-makers and other stakeholder groups (Figure 2). In twelve cities analyzed in depth in this report (Athens, Dakar, Delhi, Harare, Kingston, London, Melbourne, New York, São Paulo, Shanghai, Tokyo, and Toronto), average temperatures are projected to increase by between 1 °C and 4 °C by the 2050s. Most cities can expect more frequent, longer, and hotter heat waves than they have experienced in the past. Additionally, variations in precipitation are projected to cause more floods as the intensity of rainfall is expected to increase. In many cities, droughts are expected to become more frequent, more severe, and of longer duration.

Coastal cities should expect to experience more frequent and more damaging flooding related to storm events in the future due to sea level rise. In Buenos Aires, for example, damage to real estate from flooding is projected to total US$80 million per year by 2030, and US$300 million per year by 2050. This figure does not account for lost productivity by those displaced or injured by the flooding, meaning total economic losses could be significantly higher.

Sector-specific impacts, adaptation, and mitigation

Climate change is expected to have significant impacts on four sectors in most cities – the local energy system; water supply, demand, and wastewater treatment; transportation; and public health. It is critical that policymakers focus their attention on understanding the nature and scale of the impacts on each sector, developing adaptation and mitigation strategies, and determining policy alternatives.

Climate change and urban energy systems

Cities around the world have prioritized efforts to reduce energy consumption and the associated carbon emissions. This has been done both for localized efficiency reasons – to reduce the effects of high energy costs on household budgets, for example – as well as to respond to concerns that activities in cities are responsible for a large share of global greenhouse gas emissions. Emphasis is now being placed on urban energy system adaptation, as well, because climate change impacts such as the loss of key supply sources or transmission and distribution assets can jeopardize public health and the economic vitality of a city. For example, in New York City, power plants were historically sited on the waterfront to facilitate fuel supply delivery and to provide access to cooling waters. The majority of these facilities are at an elevation of less than 5m, making them susceptible to increased coastal flooding due to sea level rise (Figure 3).

Increases in the incidence or duration of summertime heat waves may result in higher rates of power system breakdown or failure, particularly if sustained high demand – driven by high rates of air conditioning use – stresses transmission and distribution assets beyond their rated design capacity. In Chinese cities, the number of households with air conditioners has increased dramatically in the past 15 years (Figure 4), although the extent to which usage is nearing a point where system vulnerabilities are heightened is still unclear. In cities heavily reliant on hydropower, changing precipitation patterns resulting from climate change may be problematic, if availability is reduced during summertime periods when demand is greatest.

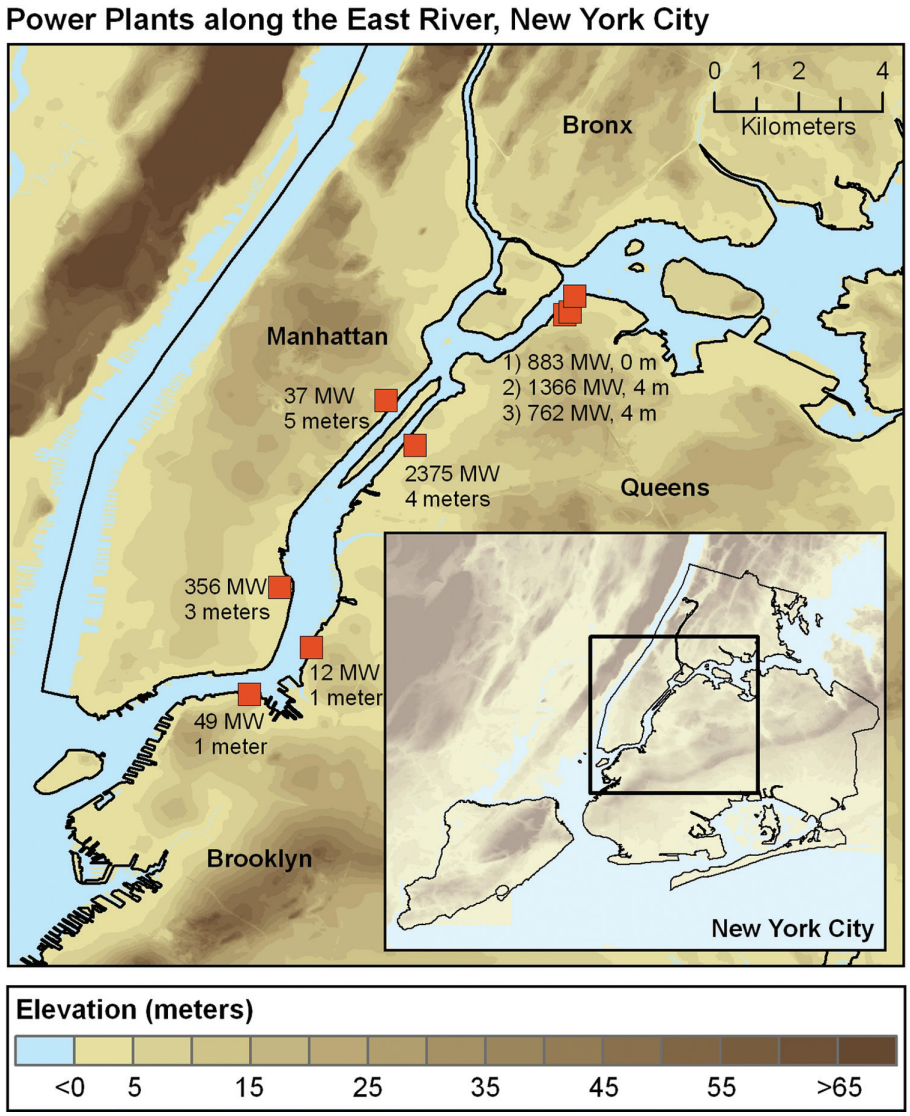

Figure 3: *Location and elevation of power plants along the East River in New York City.*

Source: Power plant data for 2000 from eGRID (US EPA, 2002) to reflect with recently retired plants deleted. New York City digital elevation model is from the USGS (1999), which has a vertical error of approximately +/–4 feet.

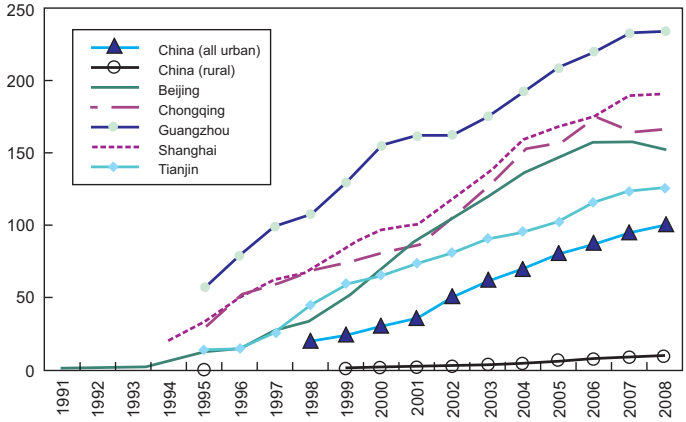

Figure 4: *Number of air conditioners per 100 households in selected Chinese cities.*

Source: CEIC (2010).

For any given city, local analyses are necessary to determine the overall impact of climate change on energy demand, as it may increase *or* decrease depending on which of the seasonal effects of climate change (i.e., reduction in energy demand in cooler seasons and increased demand in warmer seasons) are most significant.

Cities can take robust steps to reduce their energy demand and thus their carbon emissions, and it is increasingly clear that many of these steps also provide significant adaptation benefits. These steps include:

- Develop demand management programs to cut peak load, reducing carbon emission levels and simultaneously lessening stress on the system during times of heightened vulnerability.
- Capitalize on the natural replacement cycle to update power plants and energy networks to reduce their carbon intensity and simultaneously increase their resilience to flooding, storm, and temperature-related risks.

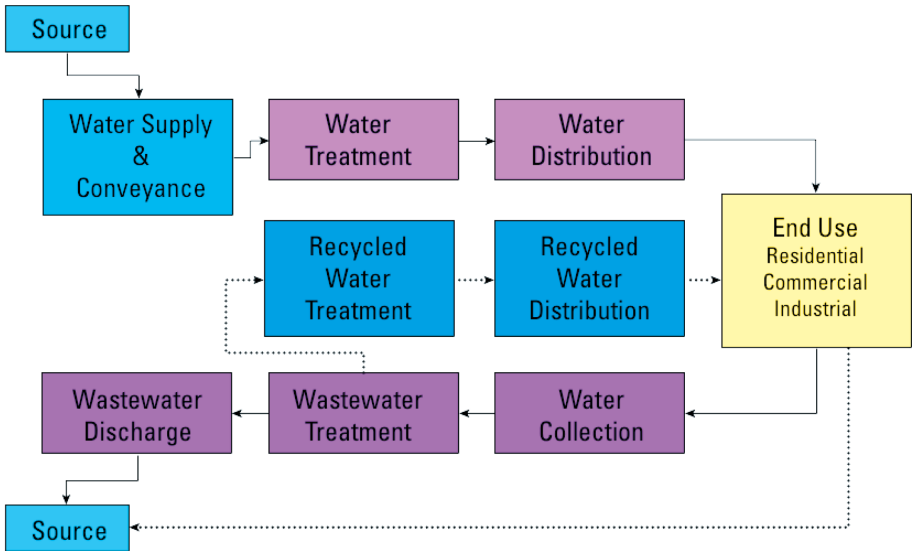

Figure 5: *Typical water-use cycle for cities and other developed supplies; dotted arrows indicate pathways that sometimes occur.*

Source: Modified from Klein et al. (2005).

- Diversify local power supply sources to increase the share of renewables, thereby enhancing system resiliency and reducing carbon emissions.

Climate change, water, and wastewater in cities

Urban water systems include water supply sources, conveyance, distribution, reuse, treatment, and disposal elements, all of which may be vulnerable to a changing climate (Figure 5).

Within cities, impervious surfaces and increased precipitation intensity can overwhelm current drainage systems. In Mexico City, the city's 27 treatment facilities currently handle only a fraction of the total sewage generated citywide, and as the local population increases, the ability of the system to accommodate runoff has become compromised, raising the risk of flooding around the city.

In many cities, the quantity and quality of the water supply will be significantly affected by the projected increases in both flooding and droughts, amplifying the need for cities to focus on upgrading their supply networks to maximize the availability of existing supplies. For example, in developed country cities, leakage from the supply distribution system can be severe, resulting in system losses of between approximately 5% and more than 30%. In developing country cities, the supply problem is often different, as significant numbers of people rely on informal water supply systems. In Lagos, for instance, 60% of the population uses informal distribution systems (Figure 6), which are far more vulnerable to drought-induced stoppages.

A range of adaptation measures will be required to ensure water supplies of adequate quantity and quality, especially in coastal regions where water sources and infrastructure are subject to the impacts of rising sea level, higher storm surge, salt-water intrusion, and land subsidence. Cities are pursuing a range of strategies to address these water and wastewater challenges, including:

- Reduce non-revenue water, which constitutes a significant fraction of supply in many urban areas, through leak detection and repair and reduction in unauthorized withdrawals;
- Review and modify surface water and groundwater sources, storage facilities, and intakes where appropriate to make supplies less vulnerable to climate-induced risks such as floods and droughts;
- Implement innovative local supply augmentations where feasible through techniques such as rainwater harvesting and water reuse, as well as through improved water accounting from better observation networks and holistic modeling;
- Practice demand management through appropriate pricing (including social, environmental and economic objectives), public education on water use and conservation, improved toilet and shower codes, updated drought management plans, and targeted land-use strategies; and
- Encourage the use of water-efficient processes in domestic, industrial, and agricultural uses.

Figure 6: *Informal urban water supply: a water vendor's cart in Lagos.*

Photo by Ademola Omojola.

Climate change and urban transportation systems

Globally, according to the IPCC 2007 report, the transport sector accounted for 23% of the world's greenhouse gas emissions related to energy in 2004, although in some cities, the percentage is much higher, a reflection of local land use and mobility patterns. Cities are adopting a range of strategies to reduce transport-related emissions, including promoting transit-oriented development, reclaiming roadways to provide more space for bicycles and pedestrian walkways, and increasing the amount of mass transit systems available around the city.

Regulatory and pricing instruments are also increasingly being deployed to reduce the volume, timing, or location of private vehicle use, often with significant impact. In London, a congestion pricing program resulted in a 12% decrease in traffic levels in the congestion pricing zone, while in Stockholm, there was a 22% reduction in vehicle passages in the congestion zone. Beijing, Bogota, and Mexico City have all pursued limits on the number of days vehicles can be driven, but this approach may penalize households in locations where public transportation is inadequate. Other cities have focused on promoting more efficient fuels and technology as a means of reducing transport-related carbon emissions. In Delhi, for instance, all public transport buses were converted to compressed natural gas (CNG)-operated systems, in response to public action and right-to-clean-air campaigns that brought the issue to the attention of the Supreme Court of India. The Court subsequently issued a series of judgments regulating public transport and air quality. A key lesson from this experience is that leadership for change in cities can arise from diverse stakeholders – be it citizen groups, the private sector, or the judiciary – as well as from city government itself (Figure. 7).

Some of these mitigation strategies will bring climate change adaptation co-benefits, such as new energy-efficient fuel technologies that provide better temperature control for passengers, but others are being undertaken specifically to maintain the integrity of essential transportation infrastructure assets under changing climate conditions, such as improved engineering and management. Maputo is one of four cities benefiting from a UN HABITAT-supported initiative focused on climate planning, with a specific goal of identifying the hard approaches (sea walls, engineered levees, pump stations) and soft, ecosystem-based approaches (wetlands, parks, and planted levees) designed to protect local transportation system assets from coastal flooding. Mitigation and adaptation strategies for city transportation systems include:

- Integrate land use and transportation planning to increase the density of the urbanized portion of developed land, plan for mixed-use development, and enhance the proximity of travelers to transit and/or to their destinations to reduce vehicle miles of travel;
- Construct transport systems with materials that are more resilient to higher temperatures and the potentially corrosive effects of increased exposure to sea water due to sea level rise and coastal flooding;
- Consider the appropriateness of rezoning as an adaptation solution, retreating from the shoreline, and building new transportation facilities farther inland on higher ground;
- Protect transport systems from increased precipitation and flash flooding through the use of larger culverts and catch basins, and replacement of impermeable road surfaces with permeable material and impermeable roof surfaces with green roofs; and
- Introduce operational measures, including traffic closures during extreme weather events; moving rolling stock to flood-protected and/or wind-protected locations; closing traffic on tall bridges during high winds; and using media to indicate hazardous road conditions and safer alternate transportation routes and modes.

Figure 7: *Compressed natural gas public bus, Delhi. Photo by Shagun Mehrotra.*

Climate change and human health in cities

Cities are subject to unique health risks since larger populations and higher population density amplify the potential for negative outcomes. Climate change is likely to exacerbate existing health risks in cities and to create new ones. Specific impacts include:

- Direct physical injuries and deaths from extreme weather events such as tropical cyclones, storm surges, intense rainfall that leads to flooding, or ice storms that damage trees and overhead structures and produce dangerous transport conditions;
- Illnesses resulting from the aftermath of extreme weather events that destroy housing, disrupt access to clean water and food, and increase exposure to biological and chemical contaminants;
- Water-borne diseases following extended or intense periods of rainfall, ground saturation and floods, and saline intrusion due to sea level rise; all of which compound existing deficiencies in local water services (Figure 8);
- Food-borne diseases resulting from bacterial growth in foods exposed to higher temperatures;
- Illnesses and deaths from an expanded range of vector-borne infectious diseases;
- Respiratory illnesses due to worsening air quality related to changes in temperature;
- Morbidity and mortality, especially among the elderly, small children, and people whose health is already compromised, as a result of stress from hotter and longer heat waves.

City health agencies can contribute to improvement of knowledge of the health effects of climate change on urban populations and work together with other responsible agencies to reduce the vulnerability of city dwellers to climate variability. Adaptation strategies, many linked to other sectors, land use planning, and governance, include:

Figure 8: *Potential health hazards in Kibera related to sanitation and water systems. Photo by Shagun Mehrotra.*

- Expand health surveillance and early warning systems utilizing both technology and social networks, especially for the elderly, very young, and the poor;
- Reduce the size of the urban heat island effect through passive approaches such as tree planting, green and reflective roofs, and permeable pavements, thereby minimizing heat stress on all citizens.
- Emphasize water and energy system climate resilience strategies, because of the key role they play in protecting the public during and after extreme weather events; and
- Regulate settlement in flood plains to minimize exposure to coastal storms and inland flooding.

Cross-cutting issues

A city's land use and governance practices are integrally bound up in the climate change issue. Past zoning and land use decisions are key factors because they create the essential circumstances from which climate-related vulnerabilities may arise. Local powers and the larger governance environment will influence what can actually be done, and at what pace. Progress in addressing climate change requires strategic management, science-based policies, efficient financing, jurisdictional coordination, and citizen participation.

The role of urban land in climate change

The built environment or structural aspects of cities, streets, buildings, and infrastructure systems contribute significantly to the emission of greenhouse gases, and can also amplify climate change impacts. The structure, orientation, and conditions of buildings and streetscapes can increase the need for cooling and heating buildings, which are associated with the level of energy use and greenhouse gas emissions in a city. Swaths of impervious surfaces can intensify flooding and are direct determinants of the heat island effect. The presence or lack of street trees and parks, and the extent of wastewater and drainage systems can either impede or enhance the natural processes of evapotranspiration, in addition to amplifying flooding and drought effects.

A city's natural setting, its urban form and built environments are relatively static factors, but they are subject to future modification through urban planning and management. For example, Shanghai has sought to increase the level of vegetation around the urban core to mitigate the urban heat island; since 1990, urban greenery per capita has increased from 1.0 m^2 to 12.5 m^2, resulting in decreasing temperatures. In Tokyo, the municipal government has similarly expanded its expenditures on tree planting, park development, and the use of paved surfaces that block heat and absorb moisture.

Stockholm is engaged in a long-term planning initiative to both mitigate and adapt to climate change. The Stockholm Royal Seaport is a new development district with strict environmental requirements on buildings. All buildings will be placed 2.5 m above the average sea level; building materials will be required to resist high humidity; and other requirements call for greenery on roofs, walls, and yards.

These examples represent a starting point for initiatives that local authorities can use to respond to climate change. These initiatives can be pursued through legal and political systems, planning departments, zoning regulations, infrastructure and urban services, real estate markets, and fiscal arrangements. Other specific adaptation and mitigation initiatives related to urban land use include:

- Reduce sprawl by increasing population and building densities, mixing land uses to reduce automobile traffic, and more frequent use of public transit;
- Change building codes to reduce energy use for heating and cooling;
- Restrict land use in areas subject to climate change impacts such as sea level rise and riverine flooding;

- Change building codes and land regulations to reduce damage from climate change hazards, e.g., elevating buildings in flood-prone areas;

- Increase urban tree coverage and vegetation to reduce the heat island effect;

Cities and climate change: The challenges for governance

Local governments face many challenges in their efforts to mitigate and adapt to climate change. For any city, climate is but one of many issues on the local agenda. Governments are also faced with the trade-offs between current priorities and long-term risks, a situation compounded by the uncertainties that may surround the timing and severity of climate-related impacts in a city.

Most cities undertaking climate plans find themselves constrained by fiscal and policymaking limitations. Jurisdictional conflicts over who can or must take action on a specific mitigation or adaptation initiative can make progress challenging. For example, in Mexico City, administrative boundaries do not align with the city's geographic boundaries and carbon-relevant functioning. Similar issues exist in Paris, where the *Plan Climat de Paris* is focused on the 105 km^2 area under the direct control of the *Mairie de Paris*, a fraction of the Paris metropolitan region which totals 700 km^2 and is under the jurisdiction of three other *départements*. In Durban, local officials are seeking to ensure that climate change does not get pigeonholed as simply an environmental issue, but instead is more appropriately seen as a development-related challenge.

Despite these difficulties, cities around the world are committing to action on climate change, entering into dialogues with state, provincial, and national governments to discuss their climate policy agendas. Cities are also increasingly focused on data gathering, both to improve internal management practices and to allow for comparison with other cities around the world.

In examining how cities are delivering effective action on climate change adaptation and mitigation, four key factors emerge:

- *Effective leadership* is critical for overcoming fragmentation across neighborhoods and sectors when building consensus on the climate change agenda in cities;

- *Efficient financing* is a core requirement for empowered governance in cities; success to date with efforts to confront climate change challenges has been hampered due to deficient financing;

- *Jurisdictional coordination* across city, state, and national governments is one of the most pressing challenges common to cities worldwide; and,

- *Citizen participation* can help in development of inclusive local government decision-making on climate change.

Cities act

Cities around the world are highly vulnerable to climate change, but have great potential to lead on both adaptation and mitigation efforts. Despite the economic and political constraints that many cities face, they are serving as important laboratories for climate change action.

These efforts have produced much helpful climate risk and response information. In order to effectively address the challenges presented by climate change, cities need to incorporate climate science, adaptation strategies, and mitigation actions into daily decision-making and long-term plans and investments. Many cities in both developing and developed country cities are also centers for research and house extensive research communities that are able and willing to help develop plans for assessing and acting on climate change.

Many cities are developing both near- and long-term climate action plans–but many more need to bring climate adaptation and mitigation into their everyday operations as well as their longer-term planning process. The *First Assessment Report on Climate Change and Cities* (ARC3) of the Urban Climate Change Research Network (UCCRN) provides knowledge to urban policy-makers for science-based city climate actions through an on-going information collection, review, and sharing process.

About the *First Assessment Report on Climate Change and Cities* (ARC3)

The First Assessment Report on Climate Change and Cities (ARC3) presents a comprehensive assessment of the most significant issues for cities as they face the climate change challenge. It was launched by the Urban Climate Change Research Network (UCCRN) in November 2008, with the goal of providing the scientific basis for city action in the mitigation of and adaptation to climate change. The ARC3 seeks to synthesize our current state of knowledge about how cities will be affected by climate change and the steps being taken to address climate change at the local level. It is specifically intended both to identify and to fill data gaps in the existing climate change literature, the majority of which has been compiled to analyze the information at a global, national, or regional scale.

To ensure that the information provided would be of use to urban decision-makers, UCCRN first conducted a needs assessment via a survey of city leaders in both developed and developing countries around the world. The content and structure of ARC3 reflects feedback received from respondents to this survey.

The report encompasses nine chapters which are divided into four sections: **Introduction** (Urban climate change in context), **Defining the risk framework** (Cities, disasters, and climate risk; and Urban climate: processes, trends, and projections), **Urban sectors** (Climate change and urban energy systems; Climate change, water, and wastewater in cities; Climate change and urban transportation systems; and Climate change and human health in cities), and **Cross-cutting issues** (The role of urban land in climate change; and Cities and climate change: The challenges for governance). The report represents the work of more than 100 lead and contributing authors from over 50 cities around the world. ARC3 authors are experts in climate change adaptation and mitigation, and include physical scientists, geographers, planners, engineers, social scientists, and policy experts. Each chapter of ARC3 has gone through a multi-stage expert review process.

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References

CEIC (2010). *Webceic Data manager* (on-line database), China Premium Database, New York, USA: ISI Emerging Markets.

Collins, W. D., *et al.* (2006). The Community Climate System Model Version 3 (CCSM3). *Journal of Climate*, **19**, 2122-2143, doi: 10.1175/JCLI3761.1

Klein, G., M. Krebs, V. Hall, T. O'Brien, and B.B. Blevins (2005). *California's Water-Energy Relationship*. California Energy Commission Final Staff Report CEC-700-2005-011-SF.

Mehotra, S., C. E. Natenzon, A. Omojola, *et al.* (2009). *Framework for City Climate Risk Assessment*. Commissioned research, World Bank Fifth Urban Research Symposium, Marseille, France.

Nakicenovic, N., *et al.* (2000). *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

US EPA (2002). eGRID 2002 Archive. Available at www.epa.gov/cleanenergy/energy-resources/egrid/archive.html, accessed September 2008.

USGS (1999) *New York City Area Digital Elevation Model, 1/3 Arc Second,* US Geological Survey, EROS Data Center.