Advances in Global Change Research 56

Michael Manton
Linda Anne Stevenson *Editors*

Climate in Asia and the Pacific

Security, Society and Sustainability

APN

Springer

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ADVANCES IN GLOBAL CHANGE RESEARCH

VOLUME 56

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ISSN 1574-0919
ISBN 978-94-007-7337-0 ISBN 978-94-007-7338-7 (eBook)
DOI 10.1007/978-94-007-7338-7
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2013945585

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

The 1992 Rio Declaration, emerging from the UN Conference on Environment and Development, stated that: "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature." Twenty years later, Heads of State and Government renewed their commitment to sustainable development at the Rio+20 UN Conference on Sustainable Development, with an outcome document titled *The Future We Want.* It noted that "to ensure the promotion of an economically, socially, and environmentally sustainable future for our planet, and for present and future generations" will require concrete and urgent action.

Advancing sustainable human development becomes very difficult as the world moves towards the edges of its planetary boundaries: the need for urgent action is real. This can be most clearly demonstrated with respect to climate change, where experts warn that the world must stay under a 2 °C increase in temperature threshold above pre-industrial levels – beyond which it is believed there would be catastrophic and irreversible change to our climate.

The impacts of global warming are already being felt through the depletion of natural resources; more frequent natural disasters, from flooding to heat waves and droughts; and changes in ecosystem dynamics.

The Executive Secretary of the UN Framework Convention on Climate Change, Christina Figueres, has said that "climate change has become the amplifier and multiplier of every crisis we are facing – be it human heath, population growth, the strain on water, food and other resources, or energy insecurity."

What is unfair is that the world's poorest countries, including Small Island Developing States, which have contributed little to greenhouse gas emissions, are among the most vulnerable to the consequences of climate change. Within countries, the poor rely disproportionately on natural resources for their livelihoods, and in urban settings often live in hazard-prone slums or remote locations. Their economic and overall well-being stands to be more directly impacted by the changing climate.

The costs of inaction on climate change are increasingly clear as extreme weather inflicts loss of life and livelihoods and the destruction of property and infrastructure around the world. The Asia-Pacific has suffered disproportionately in recent years, with 45 % of the world's natural disasters in the last three decades occurring in the region, leading to significant losses in human life and GDP.

Climate in Asia and the Pacific: Security, Society, and Sustainability, reviews the current understanding of trends around climate change in the Asia-Pacific, the impact on natural and human systems across the region, and strategies to mitigate and adapt to these impacts. It looks at the relationship between climate change and urbanization – highlighting the vulnerabilities of mega-cities and of unsustainable urbanisation practices. It explores the impact on human security, with a particular focus on food and water security; disaster risk; broader societal concerns – from human health to the needs of vulnerable remote communities; and looks at sustainable energy options for the region and future directions for climate research.

As the Asia-Pacific has not only many of the world's most climate-exposed territories, but also hosts more than half of the world's population, including nearly 900 million of those who are extremely poor, this report is relevant for all those interested in how our changing climate impacts on development.

UNDP's 2012 Asia-Pacific Human Development Report, *One Planet to Share: Sustaining Human Progress in a Changing Climate*, argued that while growth in Asia is important for the world economy and has contributed to poverty reduction in the region, the challenge now is to reduce the emissions intensity of that growth while simultaneously improving the lives of people – including through access to clean energy, and meeting unfinished development agendas.

This publication can provide valuable input into the discussion on how the region can follow a sustainable development path, which fulfils the urgent human needs of today while preserving a habitable planet for future generations. The diverse expertise of the various contributors and the broad scope of issues addressed are valuable for academic and practitioner communities alike.

The goal is clear: to reduce poverty while staying within the boundaries set by nature. To do that we need knowledge and evidence to support better policies, and we need political leadership willing to act.

United Nations Development Programme
New York, USA

Helen Clark

Foreword

Actionable Climate Information for Regional and Global Development

It is only in the last 10,000 years that we have moved to our modern society with its critical dependence on mechanized agriculture and exploitation of natural resources at an ever increasing rate using modern technology to improve the quality of humans' life on Earth. Every day climate and weather variability and changes shape the global commerce and development, including the natural environment and its biodiversity on which society depends for water, food and other ecosystem services for our comfort and well being.

Earth's climate and weather not only influence food and water supplies but they also have major impacts on human health, tourism, energy and transport, thus the global economy and society at large. While our increasing mastery of technology and exploitation of energy reserves has given us some ability to adapt to climate variations, the burgeoning global population, increasing urbanisation and the increasing demand on Earth's natural resources means that we are also becoming increasingly vulnerable to changes in climate/weather, particularly through extreme events such as floods, droughts, high heat waves, and other climate phenomena. These impacts are felt by all nations around the world, but the ability to respond to them and the resiliency to recover from their adverse impacts is very limited in most developing regions and nations. There is a growing demand by public and private sectors for timely access to reliable science-based information about climate variability and change, and their potential impacts on people, and natural and managed ecosystems.

The national and international global environmental research and development programmes established during the past several decades (e.g. Earth System Science Partnership, ESSP) have made great strides towards understanding the functioning of Earth's climate system, its natural variability, and human induced changes. Sustained observations of the atmosphere, oceans, terrestrial ecosystems and the polar regions together with development of computer-based models

have played a major role in these efforts. Indeed, the revolutionary progress in computation and telecommunication technologies during the recent decades have been instrumental in representing realistically the natural processes in the Earth system models, and to increase the resolution of smallest grid cells represented in these models while we have continued to improve the complexity of Earth's climate system for longer periods (multiple decades to centuries) into the future. Another major success during this period has been the establishment of coordinated international mechanisms for synthesis and translation of best available scientific knowledge about the state of Earth's climate system in a form that is useful to policy decision makers through the Intergovernmental Panel on Climate Change (IPCC) and other similar bodies for atmospheric ozone, biodiversity, water resources, energy, etc. In short, we have managed to make progress on advancing the science of climate change together with an effective approach to using the resulting knowledge for environmental policy decisions and a wide range of other applications around the world.

The need for climate information is now growing rapidly beyond the environmental policy domains by all sectors of the world economy that must consider both the risks and opportunities associated with climate change and variability on seasonal, decadal and longer time scales for day-to-day management activities (e.g. transport and tourism) and long-range planning (e.g. investments in infrastructure) for national, regional and global development. This implies a greater need for more sophisticated models that mimic realistically the behaviour of the entire Earth system at greater time and space resolutions, hence a demand for coordination of research activities across multiple scientific disciplines, more powerful computers, and greater capacity for translation and communication of the resulting information and knowledge to a wide range of users. The tasks of coordination, integration, synthesis of scientific information and effective communication of the results to managers and decision makers have to be carried out by entities at the national, regional and global level. Development and dissemination of "actionable" science-based climate information requires a symbiotic relationship between producers and users of this information. Such a partnership will ensure integration of users' need into the research agenda together with timely and effective access to the research results for decision makers. The international initiatives such as the Global Framework for Climate Services (GFCS) sponsored by the United Nations system and their partners and the Future Earth: Research for Global Development coordinated by the International Council for Science (ICSU) and its Alliance partners are intended to promote a more effective dialogue between providers and users of science-based climate/environment information. The regional organizations such as the Asia-Pacific Network for Global Change Research (APN), development banks and non-governmental organizations are expected to play a major role in implementation of these global initiatives, especially in the development of scientific and technical capabilities and networks that are essential for their success. The papers presented in this monograph describe excellent examples, case studies and projects on how to

forge such alliances between providers and users of science-based information for development purposes. Lessons learned from such efforts that are captured in these papers will be invaluable for successful implementation of the GFCS and Future Earth in the ensuing decades.

World Climate Research Program,
Geneva, Switzerland

Ghassem R. Asrar

Foreword

Climate in Asia and the Pacific: Security, Society and Sustainability provides a comprehensive description and discussion of the complex and interactive phenomena of climate related global change in the Asia Pacific region. Its chapters address the current state of knowledge from the fields of climate science, environmental science, sociology, technology development, public health, and security policy with an insightful look at issues of governance that are central to managing the impacts of climate change on human and national security. It draws upon these multiple fields of knowledge to consider strategies for mitigating and adapting to those impacts.

This phenomenon of climate related global change is unprecedented in human history in its complexity and in its potential threat to sustainable and secure living on planet Earth. Global warming and its impacts are interactive with other twenty-first century trends including population growth; urbanization; economic development and resource demands; and the generation of waste products and their release into the air, water, seas, and landscapes. Another layer of complexity is added by the political context, where developed and developing nations perceive different and sometimes conflicting interests in a dynamic regional security environment. The present volume does an excellent job of unfolding many of the layers of that complexity.

Climate change is an issue of the global commons because the green house gases, which are the anthropogenic contribution to global warming spread across the atmosphere and the oceans, whatever their point of origin. It is a regional issue because its environmental impacts on water and food supplies, on coastal infrastructure, or on biodiversity are not contained by national boundaries. It is a national issue because mitigation and adaptation must be managed by the executive agencies of sovereign nations, and it is a local issue because its impacts are felt locally.

Because our institutions for governance are the product of our past experience, they are often better reflections of past needs for managing human affairs than of emerging needs. Complex problems are by their nature unpredictable, subject to unexpected consequences and possible tipping points. As Stewart Brand is reported to have said, "Dealing with climate change…involves a level of global cooperation that has never happened, and the mechanisms for that are not in sight" (Achenbach 2012).

Climate change is a slow motion crisis. First recognized by the climate science and meteorological communities about 50 years ago, awareness of the emerging problem slowly spread among environmental research and policy communities, until the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) brought a shared Nobel Peace Prize for "*for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change*"

Those measures are the domain of governance, and the goal of good governance must be a secure and sustainable society for peoples and nations across the Asia Pacific region and around the globe. Climate change is a challenge – perhaps an existential challenge – to the people of our region. But it also represents an opportunity to work together across scientific and traditional knowledge communities, across government agencies, across public and private sectors, and through regional organizations for security and for economic development. It represents an opportunity to share knowledge and to collaborate across all of these groups and perspectives to manage the complex problems of climate related global change, to ensure a secure and sustainable environment for our children and posterity. The authors of this book have provided us with a good platform to work from.

Asia Pacific Center for Security Studies J. Scott Hauger
Honolulu, USA

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Preface

Following a mandate from its governing body, the Intergovernmental Meeting (IGM), the Asia-Pacific Network for Global Change Research (APN) produced a synthesis report of all of the activities it had conducted under one of its four broad themes of global environmental change - climate change and climate variability. The Synthesis Report – *Climate in Asia and the Pacific: A Synthesis of APN Activities,* summarised more than 55 regional research and capacity building projects that the APN had conducted under this theme since 1998.

Positive feedback following wide distribution of the synthesis report prompted the need, and decision, to complement the report with a book explaining the current status of climate change and climate variability in the Asia-Pacific region; future directions in the area and overarching issues. It was agreed among the authors that the foci of the book be security (food, water and energy); society (urban and remote communities; human health and governance) and sustainability (low carbon development and ecosystem services).

The first chapter of the book addresses a number of key questions that relate to our current understanding of the interactions between climate, natural ecosystems and human communities across Asia and the Pacific. The analysis presented in subsequent chapters addresses these questions and provides recommendations for a number of future directions in research needed to better understand and manage the risks associated with climate change and variability in the region. The final chapter summarises the findings presented in the book and provides an overall picture of future needs for climate research in Asia and the Pacific. Finally, we suggest a number of overarching issues that should be taken into account in future considerations of climate interactions across the region.

Immediately following the publication of the Synthesis Report, an authors' workshop for the present book convened in October 2011 kick-starting a gathering and 16-month coordination of the work of 31 authors from broad backgrounds in global environmental change.

We are immensely grateful to the contributing authors, who are not only leaders in their field but most are contributing authors to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change (IPCC AR5). We also acknowledge and appreciate comments by Francisco Werner in the preparation of the manuscript. Finally, there are four people that deserve special acknowledgement and who worked particularly hard in the background to realise the timely publication of the book. I would like to thank Ratisya Radzi, my right arm through the entire process, as well as fellow Editor, Michael J. Manton; Lead Author, Michael James Salinger; and APN Communications & Development Officer, Xiaojun Deng. All of you went above and beyond the call of duty in your work towards this book and the fruits of your labour, I am sure, will not go unnoticed.

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Chapter 1
Introduction

Michael J. Manton

Abstract Variations in climate in the Asia-Pacific region play a major role in the development of natural ecosystems and of human societies. Furthermore, human activities place additional stresses on natural and societal systems and climate change is now considered a significant factor in these increases. The book documents the climate of the region and interactions of the climate with both the environment and societies in the region. The book emphasizes the impacts of climate change as well as strategies to mitigate and adapt to those impacts. A number of aspects of climate in the region that capture interactions between climate and natural and human systems are considered and include climate variability and change, climate and urbanization, climate and security, climate and society, and climate and sustainability.

The book draws on published results in the scientific literature and the analysis presented highlights key climate-related issues for Asia and the Pacific. Subsequent chapters of the book include important issues such as: C*limate variability and change* – large-scale climate systems, trends in mean climate, trends in extreme climate events across Asia and the Pacific, challenges and opportunities for modeling the climate, current projections for future climate under climate change; *Society and urbanization* – trends in urbanization, interactions between urban areas and climate, climate hazards and vulnerabilities for urban areas, climate change mitigation and adaptation strategies for urban areas; *Food, water and energy security* – meeting future needs for rice and wheat across Asia, food from fisheries, water security, and balancing energy demands with reduced GHG emissions; *Governance and sustainability* – institutional arrangements to address the impacts of climate change, prospects for remote communities under climate change, effects of climate change on human health, low carbon development pathways, and ecosystem services to enhance the adaptive capacity of communities.

Keywords Asia-Pacific • Climate change and variability • Climate research • Sustainability

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M.J. Manton and L.A. Stevenson (eds.), *Climate in Asia and the Pacific: Security, Society and Sustainability*, Advances in Global Change Research 56,
DOI 10.1007/978-94-007-7338-7_1,

1.1 Climate in Asia and the Pacific

Asia and the Pacific is the major region of the world for rapid economic and social development in the twenty-first century. For this development to be sustainable, the growth needs to account for the effects of climate variability and change, as well as various socio-economic factors. This book aims to review the current understanding of the climate of Asia and the Pacific, its impact on natural and human systems across the region, and strategies adopted to mitigate and adapt to these impacts. From this analysis, we are able to identify significant research and development issues that need to be considered in the future. This book complements the report 'Climate in Asia and the Pacific: A Synthesis of APN Activities' (Manton et al. 2011) prepared by the Asia-Pacific Network for Global Change Research (APN), which draws together the climate-related work supported by the APN over the last 15 years.

The region of interest is focused on monsoon Asia and the western Pacific Ocean (Fig. 1.1). It extends from Pakistan in the west to Hawaii and French Polynesia in the east. The latitudinal extent is broadly defined by the influence of the Asian-Australian monsoon, but some issues extend into the more temperate areas of northern Asia. The topographical features of the region vary from the mountains of the Himalayas to the small islands of the Pacific. The variation in climate regime across the region is correspondingly vast, with tropical climates in the Pacific and deserts in continental Asia. The local climate has a significant impact on human and natural systems of each region. For example, both natural ecosystems and human communities have adapted to the seasonal cycle of the monsoon across much of Asia. Similarly the sea-surface temperature (SST) patterns of the Pacific, associated with the El Niño – Southern Oscillation (ENSO), lead to interannual climate variations that affect the lives of many communities, especially in Pacific islands. Other SST patterns in the Indian Ocean, associated with the Indian Ocean Dipole (IOD), impact the climates of Asia.

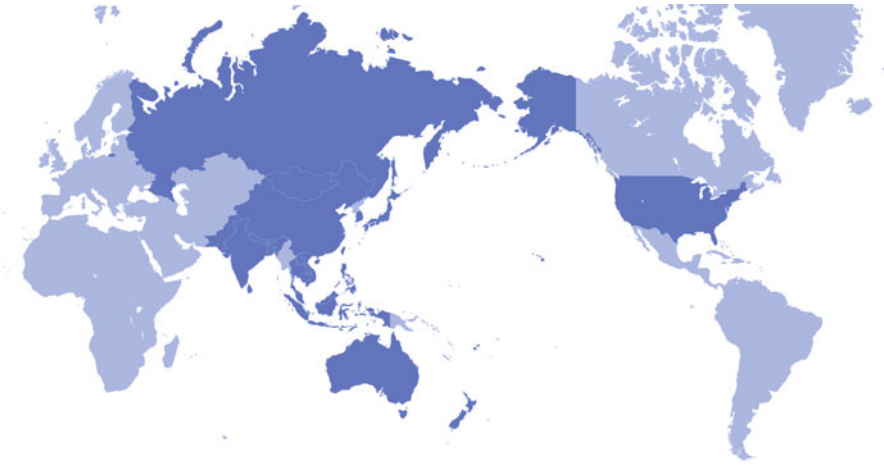

Fig. 1.1 World map highlighting member countries of the APN (Source: APN)

In addition to the large geographical variations across Asia and the Pacific, there are major differences in the cultures and socio-economic features of the communities of the region. The communities of monsoon Asia include remote mountain groups and mega-cities. All these communities have vulnerabilities to climate variability and change. While many communities have adapted over centuries to the natural variations of climate, the phenomenon of global climate change often brings new hazards about which we have limited knowledge. The time scale for mitigating and adapting to these hazards is short, and so new policy frameworks are being developed to understand and manage the associated risks.

1.2 Scope of Analysis

In this book we consider five broad aspects of climate in Asia and the Pacific that capture the interactions between climate and both natural and human systems. These are:

- Climate variability and change
- Climate and urbanization
- Climate and security
- Climate and society
- Climate and sustainability.

To focus the analysis, which draws on published results in the scientific literature, we first highlight some of the key climate-related issues for Asia and the Pacific. More detailed discussions of each of these issues are presented in the subsequent chapters of the book.

1.2.1 Large-Scale Climate Systems of Asia and the Pacific

The Asian-Australian monsoon influences the lives of about 60 % of the world's population through its major seasonal variations. The movement of the monsoon is essentially a result of the seasonal migration of the sun and the temperature contrast between the oceans and continental land masses. These interactions lead not only to large spatial variations in the monsoon across Asia but also to substantial temporal variability on scales from sub-seasonal to decadal. Indeed, the natural variability of the monsoon makes it difficult to detect significant trends in its characteristics.

The onset of the Indian monsoon is characterized by the transition of the zone of high precipitation (inter-tropical convergence zone – ICTZ) from the equator to about 15 °N at the end of May. This transition is followed by a more gradual progression north, with subsequent return southward in September. The initial onset of the East Asian monsoon is characterized by the establishment of the Meiyu-Baiu-Changma front in May, with further development in June (Goswami et al. 2006).

Since the early studies of (Walker 1924), it has been recognized that the behavior of the monsoon is affected by the east–west circulation across the Pacific of the Walker cell, which is in turn associated with the ENSO phenomenon. This relationship leads to inter-annual and longer-term variability in the monsoon.

The climate of the Pacific is dominated by the easterly trade winds that are driven by the meridional Hadley cell. The upward arm of the Hadley cell is delineated by the rain clouds of the ICTZ. These clouds form as the warm moist air in the Hadley cell is lifted before flowing in the upper troposphere to higher latitudes and subsequently sinking in the dry belts of the sub-tropics. In the South Pacific, the rising arm of the Hadley cell is also apparent from the clouds of the South Pacific Convergence Zone (SPCZ), which is associated with the interaction between the trade winds and mid-latitude disturbances in the prevailing westerly winds.

The seasonal variations in the ICTZ and SPCZ generate the annual cycle of the climate of the Pacific. Inter-annual variability in the climate is greatly affected by the interaction of the Walker cell with the upper ocean that produces the ENSO phenomenon. In the Indian Ocean, some distinct patterns in the sea-surface temperature are known as the Indian Ocean Dipole (IOD), which is correlated with inter-annual variations in climate in parts of Asia and Australia. Correlations are also found between inter-decadal variations in climate of the region and a sea-surface temperature pattern of the Pacific Ocean known as the Inter-decadal Pacific Oscillation (IPO). The IPO is also known as the Decadal Pacific Oscillation, or DPO.

In Sect. 2.1, we investigate the nature of the climate of Asia and the Pacific in more detail, and identify some evidence of longer-term variability and change in these large-scale features of the climate. A particular question is whether identified changes can be attributed to human activities, and there is continuing research to clarify this issue.

1.2.2 Trends in the Mean Climate Across Asia and the Pacific

Analysis of the surface climate records from around the world has clearly established that the world is warming, with similar trends in the sea-surface temperature and in the land temperature. Identifying trends in precipitation is much more difficult, partly because its natural variability is high and its spatial and temporal coherence is low. The basic measurement of precipitation over the Indian and Pacific Oceans is limited by the lack of *in situ* observations, and so there is great dependence on indirect satellite-based instruments.

The Himalayas and Tibetan Plateau (HTP) are of particular interest because the region includes a large number of glaciers. The mass balance of a glacier is determined by the combined impacts of precipitation and temperature, which can vary locally. Nonetheless, it is found that in Asia (and globally) glaciers have been retreating for some decades. The remoteness of the HTP region together with the large number of small glaciers means that comprehensive monitoring is very difficult (Sect. 2.1).

1.2.3 Trends in Extreme Climate Events Across Asia and the Pacific

While there is interest in identifying trends in the mean climate, many natural ecosystems (as well as humans) respond dramatically to extremes in temperature and rainfall. For example, heat waves where the over-night minimum temperature does not fall below about 24 °C can lead to substantial increases in human mortality in Melbourne, Australia (Nicholls et al. 2008b). Several studies have been carried out in the Asia-Pacific region to prepare systematic analyses of current trends in climate extremes (for example, Choi et al. 2009). Given the range in orography across the region from the HTP to small islands in the Pacific, it is useful to consider whether trends are different in the high mountain areas, but analysis of temperatures across South Asia suggests that trends at high altitudes are often affected by local features (Revadekar et al. 2012).

As with mean climate trends, we expect trends in precipitation extremes to be more difficult to detect. In Sect. 2.1, we report on the findings from recent studies of temperature and precipitation extremes across Asia and the Pacific. In general, the indicators are based on percentiles so that meaningful comparisons can be made across different climate regimes.

1.2.4 Challenges and Opportunities for Modeling the Climate of Asia and the Pacific

Climate modeling involves the use of computers to solve the complex equations that describe the physical basis of variations in the atmosphere and ocean; these models also take into account the interactions between the atmosphere and the land surface. Indeed, modeling provides an effective means to assimilate observations to improve our understanding of climate variations on a range of time and space scales. Together modeling and monitoring of climate provide the foundation for analysis of the interactions between climate, natural ecosystems and human socio-economic systems.

In recent decades there has been much use of global climate models (GCMs) to provide projections of future climate under the effects of enhanced emissions of greenhouse gases (GHGs). Similar models are also used routinely for weather forecasting and for seasonal outlooks of climate variability. While global climate models generally provide information on scales of 100 km or so, regional climate models (RCMs) are used to give details at much finer scales. Statistical methods can also be used to relate the output of climate models to local-scale features, such as the temperature and rainfall at a specific location.

Climate modeling for the Asia and the Pacific has particular challenges because of the complexities in the topography. Over the Pacific there are many small islands with extensive coastlines that generate small-scale weather features such as sea

breezes. Over Asia the steep and rugged orography of the HTP region is difficult to resolve in most numerical climate models. Progress in modeling for Asia and the Pacific is discussed in Sect. 2.2.

1.2.5 Current Projections for the Future Climate Across Asia and the Pacific Under Climate Change

Projections of future climate in Asia are dependent upon the ability of climate models to represent the Asia monsoon, which dominates the seasonal variability of the region. Tropical cyclones, which are relatively small-scale features to be represented in climate models, also have significant impacts on the climate of Asia and the Pacific. Nonetheless, a number of studies have been carried out to assess the likely variations in the monsoon under climate change scenarios developed through the international Climate Model Intercomparison Project Phase 3 (CMIP3). There are also some early results from the more recent CMIP5, which uses updated emission scenarios and climate models.

In Sect. 2.2, we also consider the results of studies carried out using regional climate models, focused on specific subregions of Asia and the Pacific. The Regional Model Intercomparison Project (RMIP) is a collaborative study by about ten groups from the region aimed at providing climate projections to support the impact and adaptation community (Fu et al. 2005) across Asia. The Pacific Climate Change Science Program (PCCSP) provides detailed projections for 15 island states in the Pacific (Power et al. 2011) to support impact and adaptation studies. The World Climate Research Programme (WCRP) has established a new programme, the Coordinated Regional Downscaling Experiment (CORDEX), to produce climate information at regional scales across the globe (Giorgi et al. 2009), and there are CORDEX projects focused on South Asia, East Asia and Southeast Asia. These projects are collaborating to generate consistent and useful projections across monsoon Asia.

1.2.6 Climate: Society, Security and Sustainability

The climate of the Asia-Pacific region clearly plays an essential role in the functioning of the environments and societies across the region. Chapters 3, 4, 5 and 6 of the book consider the complex interactions between these features of the region, with an emphasis on the impacts of climate variability and change and on the responses of human and environmental systems to climate. Chapter 3 considers the interactions between urbanization and climate, while Chap. 4 discusses the relationships between climate and the security of societies for food, water and energy, as well as the need for the management of climate-related natural disasters. In Chap. 5 we consider societal issues of governance, remote communities, and human health in

relation to climate variability and change. The interactions between climate and sustainability are discussed in Chap. 6, with a focus on integrated assessments and the management of natural ecosystems.

1.2.7 Trends in Urbanization Across Asia and the Pacific

The move of rural populations to towns and cities has been the basis of economic progress for thousands of years around the world. In Sect. 3.2, trends in urbanization since 1950 across Asia and the Pacific are documented and the expected trends to 2050 are discussed. The fraction of urban population in Asia increased from about 15 % in 1950 to 30 % by 1990, and to 40 % by 2010. The rapid increase in urbanization has been accompanied with significant economic growth across the region.

A noticeable trend in Asia has been the growth of mega-cities, which have populations greater than ten million. Urbanization is expected to continue in the coming decades with about three billion people in urban areas by 2050. However, while the number of mega-cities will continue to increase, the majority of urban residents (about 60 % of the total urban population) will live in cities of less than one million people. The increase in urbanization has profound implications on the interactions between climate, land and energy use on scales varying from global to local. The expected concentration of people in smaller urban areas means that there should be greater focus on mitigation and adaptation planning for these areas.

1.2.8 Interactions Between Urban Areas and Climate

The urban heat island effect is a well-known feature of a significant impact of cities on climate (Oke 1973), and the effect has been documented in the cities of Asia. Once a heat island effect is established, there is evidence that the urban trends in temperature become similar to those in neighboring rural areas, so that the effect is not seen in hemispheric or global temperature trends (Peterson 2003).

In Sect. 3.3 we also consider the impacts of urban areas on precipitation and air quality. While it is clear that the land-use change associated with urban areas affects local precipitation patterns, the details can vary from place to place and from season to season. On the other hand urban activity, especially those associated with fossil fuels, leads to reductions in air quality in urban areas. Aerosols emitted from the burning of fossil fuel are a major problem for human health and for their impacts on local and regional climate across Asia.

Urban areas are the main source of greenhouse gases (GHGs) associated with global warming. Indeed, the provision of food, water and energy for cities is the main driver of the increasing emissions of GHGs in Asia and the world. The handling of waste from urban areas is also a significant source of GHGs. Recognizing that some of these functions (especially the production of energy and food) tend to take

place in the areas around rather than within cities, it is important to include the peri-urban areas when considering the total impact of cities on GHG emissions.

While the largest cities are the highest emitters of GHGs across Asia, the per capita emission rate depends upon a range of factors, such as local climate, community wealth and population density. Higher emission rates per capita tend to be in lower density cities in colder climates and with greater wealth. There is evidence that low density urban areas (and rural areas) are less energy efficient than areas with higher population densities (Marcotullio et al. 2012). Such observations imply that mitigation policies should not unintentionally promote anti-urban outcomes.

1.2.9 Climate Hazards and Vulnerabilities for Urban Areas

Climate change is manifested through changes in local features such as temperature, sea level (storm surges), air quality, precipitation and hydrology. All these features are impacting on urban communities across Asia, often resulting in weather-related disasters. In Sect. 3.4, it is noted that about 40 % of the reported flooding events across the globe from 2000 to 2009 occurred in Asia, with cities of China, India and Thailand seen as most vulnerable to future coastal flooding (Nicholls et al. 2008a).

Urban infrastructure is vulnerable to climate variability and change in Asia and the Pacific. Vulnerabilities are seen in transportation, water supply and sanitation, food production and distribution, energy production and distribution, and manufacturing industries. Within communities, there are sections with higher vulnerability to the hazards of climate because of their lower capacity for adaptation: these groups include the poor, the elderly and the very young.

1.2.10 Climate Change Mitigation and Adaptation Strategies for Urban Areas

The significance of climate variability and change is recognized in most regions of Asia and the Pacific and Sect. 3.5 describes a range of mitigation and adaptation strategies that are being developed and implemented. The wide variation in the nature of urban areas across the region means that different strategies are being applied. Cities are generally encouraged to use their local knowledge in developing optimal strategies, taking into account their local biophysical and socio-economic conditions.

The policy emphasis in Asia tends to be on mitigation rather than adaptation strategies at present (Satterthwaite et al. 2007). However, some mitigation policies, such as those to reduce GHG emissions from transportation, also assist the process of adaptation to climate change through, for example, improved air quality. Urban design is a key area for innovative strategies to both reduce GHG emissions and adapt to climate variability and change. For example, the reclaimed Cheonggyecheon

River in the middle of Seoul has provided benefits for tourism, recreation and reductions in heat island effects (Cho 2010). The development of acceptable and effective policies for mitigation and adaptation will require enhanced understanding of urban governance, particularly of the power relationships that influence outcomes at the local level.

1.2.11 Meeting Future Needs for Rice and Wheat Across Asia

It is anticipated that global food production will need to double by 2050 to feed a world population of 9.2 billion. There are now 450 million small-farm holders largely across Asia whose livelihoods are vulnerable to climate variability and change. Increasingly, food producers are also susceptible to market forces at regional or even global scales, as the interactions between markets become more complex. Section 4.1 considers the interactions between the range of hazards and vulnerabilities for farmers in Asia and the Pacific.

Rice is the dominant staple food across most of Asia. Indeed, it feeds about half the world population, and about 750 million of the poorest people depend on rice. Rice is therefore the focus of Sect. 4.1. The production of a kilogram of rice requires 2,500 l of water. The production of rice is clearly susceptible to the availability of water and land and to the impacts of climate change. The impacts of climate change are compounded with the continuing impacts of inter-annual climate variability, generally driven by the El Niño phenomenon. In parts of Asia there are additional pressures on food production from the competitive generation of biofuels, based on uncertain attempts at the mitigation of GHG emissions.

Wheat is also an important crop in parts of Asia, especially in India, Pakistan and China. The issues associated with the production of wheat are similar to those of rice. Strategies are being developed in Asia for both the mitigation of climate change and the adaptation to its impacts. Because of the continuing challenges of seasonal to inter-annual climate variability, many strategies are based on the management of these issues.

1.2.12 Meeting Future Needs for Food from Fisheries Across Asia and the Pacific

The fisheries of the Pacific and Indian Oceans are an essential source of food for Asia and the Pacific. These fisheries are under stress not only from climate change and variability, but also from direct human activities such as pollution from industries along coastal areas and increased fishing due to population growth. In Sect. 4.1 we consider the impacts of these pressures, which have led to significant changes in the diversity and biomass of marine ecosystems (Fig. 1.2).

Fig. 1.2 Local fisheries in Ha Long Bay, Viet Nam (Source: APN)

While the concentration of GHGs has increased in the atmosphere leading to global warming, the oceans have absorbed about 40 % of the carbon dioxide emitted from anthropogenic activities and 80 % of the heat associated with global warming. These additional loadings have caused the acidity of the ocean to increase by about 30 % and the temperature of the upper ocean to increase by a fraction of a degree. Changes in evaporation and precipitation lead to changes in salinity near the surface. Marine ecosystems are susceptible to all these changes; for example, (Takasuka et al. 2004) suggests that shifts in the 'warm' and 'cool' anchovy regimes in the North Pacific Ocean are due to temperature variations in the ocean.

Fisheries management for the future needs to be built on an ecosystems approach, where marine, climate and human influences are taken into account. The life span of marine species varies considerably, and so management measures should be developed and implemented early in order to account for the time lags in the growth of stocks to sustainable levels.

1.2.13 Future Prospects for Water Security Across Asia and the Pacific

For many countries of Asia and the Pacific, water security is a critical issue due to growing populations and economies matched against the finite availability of water in any one nation. Climate change intensifies the issue with its enhanced uncertainties in the annual cycle of rainfall in many regions. These issues are discussed in Sect. 4.2.

Fig. 1.3 Himalayas from Kathmandu Valley (Source: APN)

The "water tower" for Asia is the HTP region, which covers about seven million square kilometers and includes the largest and highest glaciers in the world (see Fig. 1.3). This region provides water for about 20 % of the world population, principally through the annual melting of snow and ice into the major rivers that then flow through several countries to the sea. Trans-border issues are therefore special challenges that require multi-national agreements to ensure water security for all countries along each river.

The HTP region is especially sensitive to climate change, with higher temperatures promoting increased melting of glaciers. The rate of glacier retreat is, however, a complex function of local conditions (Fujita and Nuimura 2011). The relationship between glacier melt and river stream flow is further complicated by the varying hydrology along each river. Glacier melt not only provides vital water resources for downstream communities and natural ecosystems, but they also bring the threat of natural disasters such as glacier lake outburst floods (GLOF).

The rivers of the HTP provide hydro-electric power at an increasing number of locations. There are plans to build a further 100 dams to generate about 150 gigawatts of power across the region. The local and regional impacts of the infrastructure associated with these generators are not fully understood at this time. Their construction does emphasize the need for multi-national agreements on flows along the relevant river systems.

Water security for Pacific Islands tends to be a national issue. The supply of fresh water and the disposal of waste are critical for many island communities, owing to both natural and human factors. Population growth and climate change exacerbate