Climate Change in the Asia/Pacific Region

A Consultancy Report Prepared for the Climate Change and Development Roundtable

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Climate Change Impacts and Risk
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EXECUTIVE SUMMARY

The 'Anthropocene Era'

The Earth currently finds itself in the midst of what some have termed the "Anthropocene Era" – a period during which human activities have become a dominate force affecting not only the planet's landscape, but also its atmosphere. Since the dawn of the industrial evolution of the mid-18th century, humans have contributed to substantial increases in the concentration of greenhouse gases in the atmosphere. Carbon dioxide has increased by 36%, methane by 17%, and nitrous oxide by 151%. These changes in the global atmosphere are directly linked to over two centuries of growth in the burning of fossil fuels by humans. The increase of these gases is warming the world. Temperatures have increased by approximately 0.8˚C since 1880, the global sea-level is rising, and Earth is already committed to additional global warming and climate change in the years ahead.

How much warming is likely to occur over the next century? More importantly, how much can the Earth system tolerate before critical thresholds are crossed and widespread, abrupt and/or irreversible consequences affect the global climate, environment, and human societies? A number of international assessments point to a threshold for 'dangerous' climate change of approximately 2°C above pre-industrial temperatures. Given historical warming, the current commitment to future warming as well as future growth in greenhouse gas emissions, remaining below such a threshold will necessitate global greenhouse gas emissions reductions on the order of 30-55% below 1990 levels. Under proposed burden sharing schemes, reductions for developed nations would likely be significantly higher. This is one component of the climate challenge facing human society. The other component is how the global environment – its oceans, rivers, forests and biodiversity – and human society will cope with the consequences of climate change. The implications of climate change will very significantly from one region of the world to another, but as this report demonstrates, the Asia/Pacific region is likely to experience significant adverse consequences.

The Asia/Pacific Region in Context

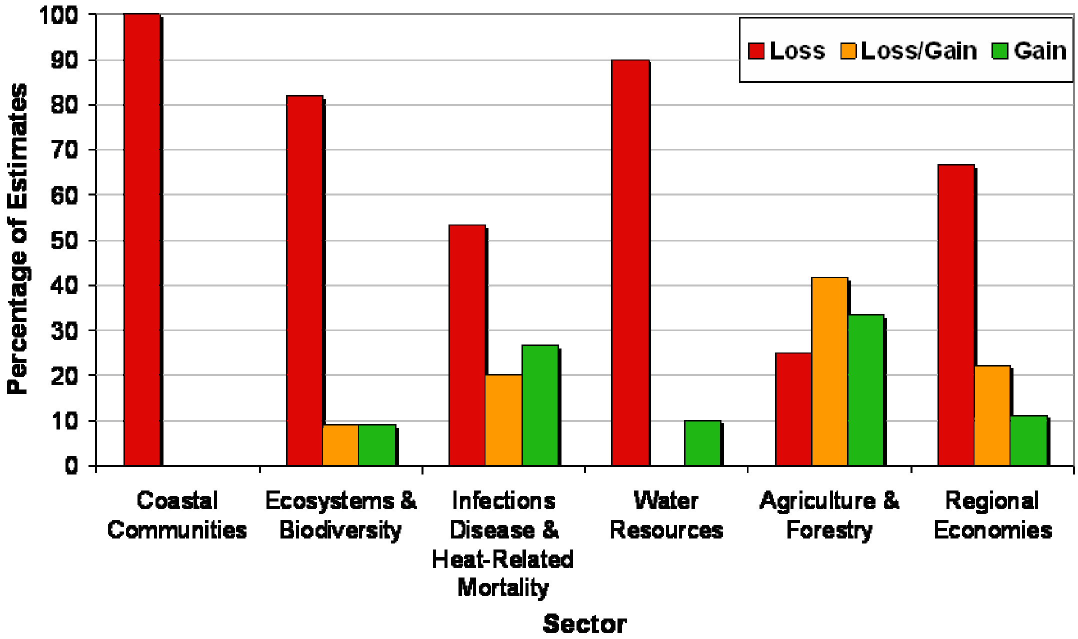
The Asia/Pacific region encompasses some of the planet's greatest cultural, economic, and ecological diversity. Approximately 60% of the world's population resides in the region, in communities ranging from major urban centres to remote rural communities. The collective economic activity of the region represents roughly 25% of the global domestic product. Rapid growth in large regional economies such as China and India has elevated human prosperity. However, unless ultimately decoupled from fossil fuel use, such growth also threatens to exacerbate the climate challenge. Furthermore, many of the countries within the Asia/Pacific region are developing nations, still struggling to tap into the global economic market and with little climate footprint. This means low performance in development indicators such as economic diversification, literacy, per capita income, and access to basic food and water security. Meanwhile, ongoing environmental degradation is eroding the valuable goods and services of the region's natural ecosystems. To combat these disadvantages, significant development assistance flows into the Asia/Pacific region on an annual basis. Australia contributed over $1 billion in aid to Asia/Pacific nations in 2004/05. These socioeconomic circumstances form the human and environmental context in which climate change and its consequences will be experienced.

The Changing Regional Climate

Climate modelling indicates temperature increases in the Asia/Pacific region on the order of 0.5–2°C by 2030 and 1–7°C by 2070. Temperatures are likely to warm more quickly in the arid areas of northern Pakistan and India and western China. In addition, models indicate increasing rainfall throughout much of the region in the decades ahead, including greater rainfall during the important summer monsoon. Yet the potential for changes in monsoon variability as well as for drying of monsoon rains from atmospheric aerosols leave the benefits of such rainfall changes in doubt. Furthermore, winter rainfall is projected to decline in South and Southeast Asia, suggesting increased aridity from the winter monsoon. The region will be affected by a rise in global sea level of approximately 3–16 cm by 2030 and 7–50 cm by 2070 in conjunction with regional sea level variability. Other modelling studies have also indicated the potential for more intense tropical cyclones and changes in important modes of climate variability such as the El Niño-Southern Oscillation.

Asia/Pacific Climate Vulnerability

Multiple factors indicate that the Asia/Pacific region possess a high degree of vulnerability to such climate changes. Many nations within the region already struggle to cope with the current climate variability to which they are exposed including tropical cyclones, rainfall extremes, frequent droughts, and extreme tides. The region is also highly sensitive to climate conditions. For example, widespread coral bleaching was observed in the Indian Ocean in response to anomalously warm conditions during the 1997/98 El Niño event, while cyclones, droughts and floods routinely affect thousands to tens of thousands of individuals each year, with costs measured in both dollars and lives. Meanwhile, the socioeconomic conditions in the region convey little in the way capacity to manage climate impacts.



Indicators of the vulnerability of several Asia/Pacific sectors to climate change. Individual estimates of climate change impacts are presented as a percentage of estimates that reflect losses from climate change, gains from climate change, or the potential for both gains and losses, depending upon study assumptions.

A review of 186 different regional and national estimates of the potential impacts of future climate change to various sectors within the Asia/Pacific region confirms that there is little room for optimism. At the regional scale, 62% of impact estimates indicated clear adverse consequences, and only 19% indicated clear benefits, with the remaining 20% suggesting the direction of impacts could lean either way. At the national scale, 58% of estimates indicated adverse effects, and only 14% indicated benefits. Furthermore, studies indicated that different sectors have different vulnerabilities to climate change.

- **Coastal Communities.** All of the studies, whether conducted at a regional or national level, indicated the region's coasts would experience climate damages in the decades ahead. These damages include coastal inundation and erosion from sea-level rise, the displacement of communities, increased coastal management and defence costs, and the potential for more intense tropical cyclones. Most at risk are the low-lying river deltas of Bangladesh, India, Vietnam, and China as well as the small island states.

- **Ecosystems and Biodiversity.** The natural ecosystems of the Asia/Pacific region will face increasing pressure from human activities and land use change. These factors will reduce the resilience of ecosystems to the effects of climate change. Coral reefs are likely to be damaged from increases in the frequency of bleaching events, while the region is likely to lose 1-13% of its mangrove wetlands – with much larger proportional losses for some individual nations. Changes in the high altitude biomes of the Tibetan Plateau may see desert and steppe systems give way to forests and grasslands. However, existing grasslands of Arid Asia and the boreal forests of China are projected to decline, while wildfires and dieback may affect some tropical forests.

- **Disease and Heat-Related Mortality.** Changing patterns of temperature and rainfall will likely cause shifts in the distribution of dengue and malaria-carrying mosquitoes. On a local basis, disease risk will increase for some and decrease for others, but region-wide, the net effect is projected to expose millions of additional individuals to such infectious diseases by the end of the century. Higher temperatures may reduce the risk of cold-weather mortality, but increase heat-related mortality, while increased flooding and intensification of tropical cyclones would increase climate-related injuries and deaths.

- **Water Resources.** Managing water resources to ensure a secure supply to growing populations is already a major challenge in many areas of the Asia/Pacific region. Climate change is likely to further alter the availability of water resources, driven by seasonal reductions in rainfall and runoff in South and Southeast Asia and increases in runoff in other areas, particularly the Pacific Islands. Some river basins may benefit from increasing runoff. Nevertheless, on a regional basis, water stress is likely to affect millions of people throughout the region, and the costs for managing water resources will rise. Furthermore, to the extent that rainfall increases manifest as extreme events, flood risk is also likely to increase.

- **Agriculture and Forestry.** Studies indicate a high degree of spatial variability in the vulnerability of Asia/Pacific agriculture to climate change. Although increases in summer rainfall alone may benefit crop production and commercial forestry, particularly in South Asia, crop stress from rising temperatures may offset such benefits, particularly for rice yields. Furthermore, areas currently in water crisis, such as northeast China and flood-prone river deltas of Bangladesh and Vietnam, are likely to experience significant land degradation and loss in a changing climate. For the least developed nations, such agriculture impacts may threaten not only food security, but also national economic productivity.

- **Regional Economies.** The net effect of climate change on regional and national economies is projected to be largely negative. Loss of agricultural revenue and additional costs for managing water resources, coastlines, and disease and other health risks will be a drag on economic activity. Given long-term, sustainable economic development and growth in per capita wealth, such economic impacts may comprise a declining portion of total economic welfare, and regional capacity to effectively manage climate risk is likely to rise. However, a number of Asia/Pacific nations currently have sluggish or stagnant economic growth that, in some instances, is projected to persist for the foreseeable future. Furthermore, even with growing regional prosperity, localised climate impacts, such as the collapse of a fishery or the inundation of core cropping land, could devastate local economies.

Existing challenges to human security in the Asia/Pacific region may be significantly exacerbated by the broad range of impacts that climate change may bring. Chronic food and water insecurity and epidemic disease may impede economic development in some nations, while degraded landscapes and inundation of populated areas by rising seas may ultimately displace millions of individuals forcing intra and inter-state migration. The implications of such challenges to human security are difficult to anticipate, but there is currently little awareness of the implications and regional management frameworks for addressing climate change-induced security and migration issues are lacking.

Reducing Climate Risk

Climate risk in the Asia/Pacific region may be ameliorated through two complementary strategies: greenhouse gas mitigation and adaptation. Mitigation will reduce the magnitude of climate change to which the region is exposed over the long-term, but will do little to address climate risk over the near-term, particularly in the least developed nations where climate vulnerability is substantial yet responsibility for global greenhouse gas emissions is quite small. Under the United Nations Framework Convention for Climate Change, the developed world has already agreed to take the lead in pursuance of greenhouse gas mitigation. Yet, as these efforts progress, investments must also be made in increasing the capacity of Asia/Pacific nations to adapt to climate variability and climate change. This may be most effectively achieved by mainstreaming climate change adaptation into development assistance that addresses developing world needs with respect to governance, education, health, technology, security, and disaster management.

Effective implementation of adaptation and capacity building projects is key to reducing future vulnerability of Asia/Pacific nations to climate change. This necessitates the development and maintenance of institutions and human capital that are knowledgeable regarding climate change and capable of effective decision-making, resource allocation, and risk management. At present, there are numerous examples of decision-making that will increase, rather than decrease, the future vulnerability of Asia/Pacific ecosystems and communities to climate change. Reigning in such behaviours and devising sustainable environmental management practices that harmonise economic development and wealth generation with natural resource management and vulnerability reduction is a core regional challenge.

1. International Context

1.1 Introduction to Global Climate Change

Over the past few centuries, the rate at which human beings have altered the Earth system and the various ecosystems of which it is comprised has grown exponentially. Species extinctions, deforestation, urbanisation and other changes to the landscape, along with the release of toxic substances to sea, land, and air have all been associated with rapid increases in the global population and economic activity.[1] Within the past several decades, it has become clear that the progressive growth of the human influence on the planet is now affecting the climate system itself.[2] As the climate is a major factor determining not only the spatial distribution of the world's plants and animals, but also the enterprises of human beings such as agriculture and forestry, such climate change is likely to have significant global consequences.

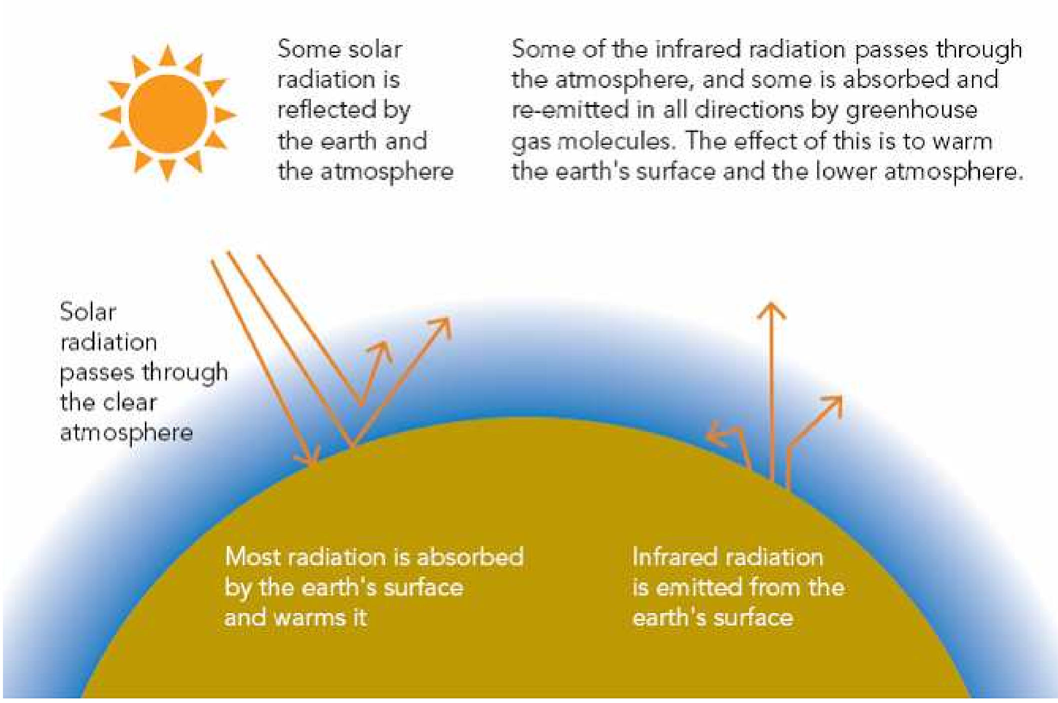


Figure 1.1. *The Greenhouse Effect*[3]

The source of this climatic change lies in the historical dependence of human beings upon fossil fuels as the primary source of the energy driving global mobility and commerce. To date, human consumption of fossil fuels has grown in step with the global population and economy, and the unintentional side-effect of their combustion has been a significant change in the composition of the Earth's atmosphere. The atmosphere has multiple components, several of which are naturally-occurring gases referred to as 'greenhouse gases,' due to their ability to trap heat. The primary greenhouse gas is water vapour, but others such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are also important. Energy from the sun passes through the atmosphere and warms the surface of the planet (Figure 1.1).[3] While most of this heat is simply radiated back into space, some is trapped by greenhouse gases. This has a warming effect on the atmosphere and ultimately keeps the planet at an average annual temperature of approximately 15°C. Without this process, the global average surface temperature would be closer to -18°C.

Centuries of human combustion of fossil fuels, along with land-clearing, have increased the flow of greenhouse gases to the atmosphere, increasing their concentration and subsequently magnifying the natural greenhouse effect. Carbon dioxide levels have increased by approximately 36% relative to their concentrations prior to the industrial revolution. At the end of 2005, the average atmospheric CO_2 concentration was 379 parts per million (ppm)[4] – higher than at any point over at least the past 650,000 years.[5] Meanwhile, other greenhouse gases such as N_2O and CH_4 have increased by 17% and 151%, respectively.[6]

The net effect of these changes to the atmosphere has been a warming of the planet. Since the mid-19th century, the average temperature at the Earth's surface has increased by approximately 0.8°C,[7] and according to the Intergovernmental Panel on Climate Change, a significant portion of this warming is attributed to human activities.[2] Such warming has also contributed to an acceleration in the rate of global sea-level rise.[8] Additional warming is projected over the 21st century and beyond in response to continued emissions of greenhouse gases. In 2001, the Intergovernmental Panel on Climate Change projected future increases in global mean temperature of 1.4–5.8°C by the year 2100, along with an increase in sea level of 9–88cm,[2] The actual magnitude of climate change that is ultimately realised will depend in large part upon future human emissions of greenhouse gases. Nevertheless, it is clear that humans, and the environment in which they live, are currently surrounded by a changing climate, and how we respond to this change over the next few decades will be central to achieving global economic and environmental sustainability.

1.2 International Perspectives on 'Dangerous' Climate Change

Are there limits to the rate and magnitude of climate change with which Earth's ecosystems and human enterprises can cope? This is a question that is central to international decision-making on climate change. Article II of the United Nations Framework Convention on Climate Change (1992), specifies the ultimate goal of international climate policy as follows:[9]

> **"*The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.*"**

Since the *Third Assessment Report* of the Intergovernmental Panel on Climate Change,[2] considerable attention has been devoted to identifying what magnitude of climate change comprises "dangerous anthropogenic interference" and, subsequently, assessing the risk of exceeding this temperature threshold under different scenarios of future growth in greenhouse gas emissions and/or efforts to reduce or mitigate those emissions.

Conducting such a risk assessment involves integrating estimates of the threshold for 'dangerous' climate change with the likelihood of different increases in future global temperatures. Various international estimates of the global threshold for 'dangerous' climate change were reviewed by Preston and Jones (2006).[10] The international community appears to have arrived at a consensus estimate of approximately 1.5°C above 1990 temperatures or approximately 2°C above pre-industrial temperatures. This represents a threshold beyond which there is a significant risk of damage or loss to unique or threatened systems (such as coral reefs), local to global economies, or large-scale and potentially irreversible changes in the climate system.[11]

Meanwhile, a number of attempts have been made to estimate the likelihood of different magnitudes of global mean temperature change over the 21st century if the global economy and its greenhouse gas emissions continue along their current trajectories.[12,13,14,15] These studies enable one to place the Intergovernmental Panel on Climate Change range (1.4-5.8°C) in some context and indicate that the likelihood of warming at either extreme of this range is relatively unlikely, relative to warming toward the middle of this range. What such studies also reveal, however, is that given 'business-as-usual' emissions, the likelihood of remaining below a 2°C threshold for average global temperature change is rather small (Figure 1.2). As a consequence, large-scale reductions in global greenhouse gas emissions on the order of 30-55% below 1990 levels are necessary over the 21st century if such a target is to be realised.[16,17] In order to achieve such targets, several developed nations, including the United Kingdom and Sweden, have adopted greenhouse gas mitigation goals of reducing emissions by approximately 60% from current levels by 2050, as have the Australian state governments of South Australia and New South Wales.[10,18,19] Such an emissions target was also recently recommended by the Australian Business Roundtable on Climate Change and the European Union's Environment Council.[20]

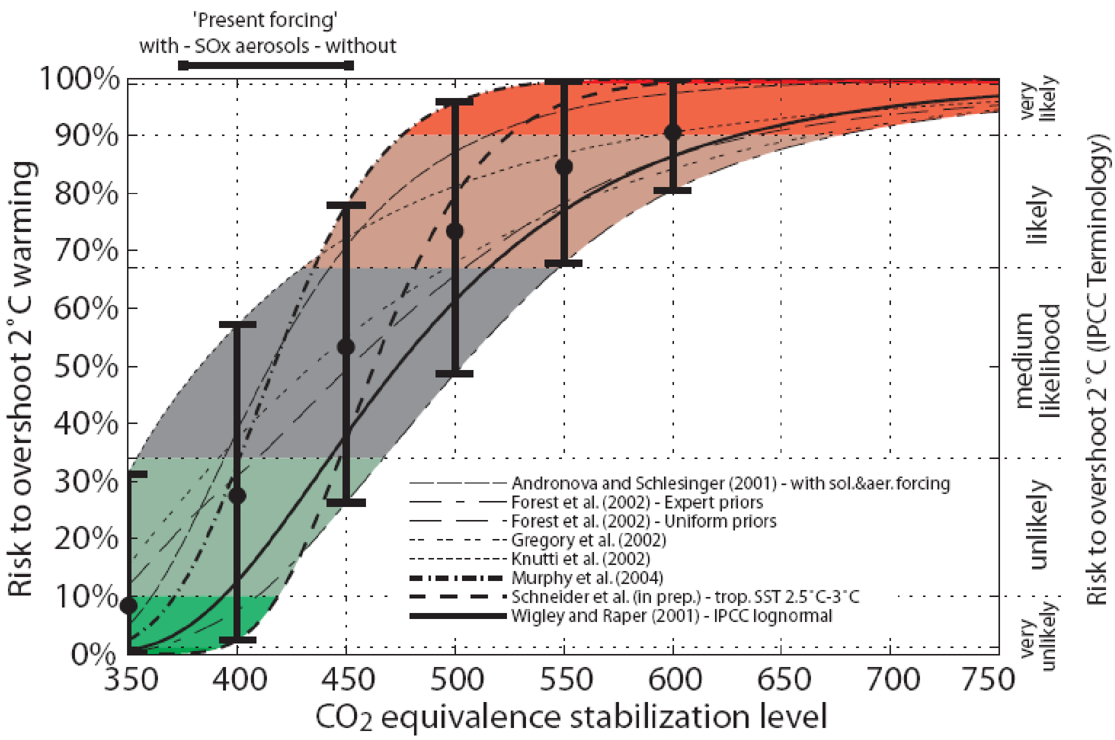


Figure 1.2. *Likelihood of exceeding a 2°C increase in global mean temperature under different assumptions regarding the stabilisation of greenhouse gases.*[21]

Achieving such a greenhouse gas concentration target is complicated by the inherent inertia of both the climate system as well as the global use of fossil fuels. For example, Hare and Meinshausen (2004) applied a simple climate model to estimate the commitment to warming.[21] They concluded that if greenhouse gas and aerosol emissions were held at current levels, CO_2 concentrations would increase to 531 ppm by 2100 and 929 ppm by 2400. These concentrations carried warming in the range of 1.4–2.7°C above pre-industrial temperatures by 2100 and 2.5–6.1°C by 2400. These results highlight the fact that emissions will have to be reduced to limit warming to 2°C. In fact, according to Hare and Meinshausen's (2004) analysis, even immediately ceasing emissions altogether, temperatures would continue to increase by up to 1.2°C above pre-industrial levels by 2400. Thus, assuming a 2°C threshold for global mean temperature change, the planet is already committed to covering half that distance without even considering the next century of population and economic growth, fossil fuel consumption, and greenhouse gas emissions.

What does the risk of 'dangerous' climate change at the global scale mean for individual nations or local communities and ecosystems? What constitutes 'dangerous' climate change for East Timor may be quite different from the Solomon Islands or a community in Bangladesh. Some areas already struggle to cope with existing climate variability, while others may have already taken advantage of the lessons learned in dealing with climate variability of the past and largely 'climate proofed' their communities, thereby buying greater coping capacity and resilience to future climate change. To understand future climate changes and impacts in the Asia/Pacific region, one must appreciate its socioeconomic, climatological, and environmental diversity.

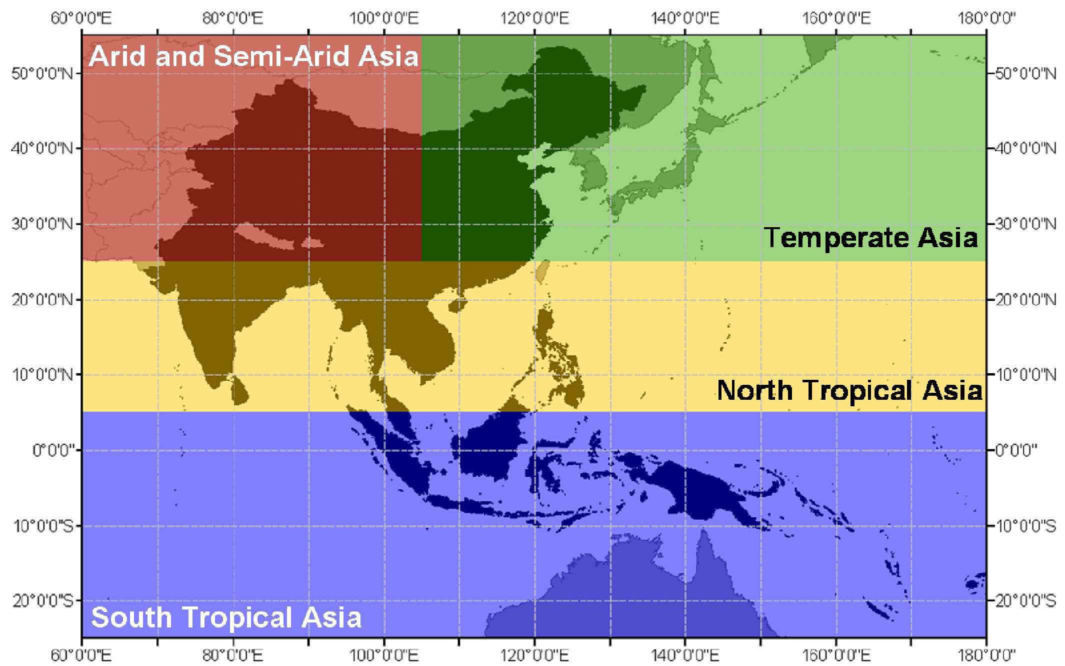


Figure 1.3. *Geographic extent of the Asia/Pacific region and various subregions as used in this report. The review of climate change impacts primarily addresses those nations coloured black.*

2. Regional Context

2.1 Economic Status and Trends of Asia/Pacific Nations

The Asia/Pacific region encompasses some of the planet's greatest cultural, economic, and ecological diversity. The region spans the eastern Indian to southwestern Pacific oceans including the Bay of Bengal and the South China, Philippine, and Coral Seas (Figure 1.3).[22] Approximately 60% of the world's population resides in the region, in communities ranging from major urban centres with 15+ million individuals to remote rural communities. The collective economic activity of the region represents roughly 25% of the global domestic product. In includes mature economic hubs such as Singapore, which are international waypoints and centres for commerce, as well as the native cultures of the Indian islands of Andaman and Nicobar, where small fragile communities live largely in isolation from the rest of the world and continue to engage in traditional subsistence and cultural practices.[23] The region's ecosystems are unique and represent several of Earth's major biodiversity hotspots, including the lowland rainforests of the Indo-Malayan archipelago and the mangroves and wetlands of Papua New Guinea, the Solomon Islands, and Vanuatu.[24]

Table 2.1. Vital Statistics for Selected Asia/Pacific Nations[a]

Nation	Pop. Growth Rate	GDP Per Capita[b]	Agriculture as a share of GDP	Pop. Access to Safe Water	Adult Literacy	P/capita CO_2 Emissions (tons)
Australia	1.1%	$23,249	3.5%	100%	-	17.3
Singapore	1.5%	$18,707	0.1%	100%	92.5%	13.1
Bangladesh	1.9%	$399	22.7%	75%	40.6%	0.2
China	0.6%	$799	15.4%	77%	82.8%	2.7
India	1.6%	$543	22.7%	86%	58.0%	1.0
Papua New Guinea	2.1%	$971	26.9%	29%	64.6%	0.5
Vanuatu	2.0%	$1,151	15.1%	60%	-	0.4
Vietnam	1.4%	$171	23.0%	73%	92.7%	0.7

Although the region has a profound economic, cultural, and environmental influence on the global community, much of the countries within the Asia/Pacific region are developing nations still in transition to mature market economies. This is readily demonstrated by comparing some vital statistics of Australia or a regional economic centre such as Singapore with those of the region's less developed nations (Table 2.1). Singapore, for example, is almost exclusively an urban nation devoted to an industrial and service economy. It has a high per capita gross domestic product (GDP), high rates of education and literacy among its population, and access to secure resources such as drinking water. In contrast, other Asia/Pacific nations, including Singapore's neighbours, have per capita GDPs an order of magnitude lower than that of Singapore, lower literacy rates, and lower access to safe water.

These problems are often exacerbated by rapid rates of population growth that continually challenge government institutions to provide sufficient services to the public. The consequence is a lack of confidence among individuals in government and lack of resilience among populations and institutions in response to disturbance or disaster. For example, AusAid's *Pacfic 2020* report identified the Pacific Islands as performing poorly relative to the generally

[a] *For vital statistics for additional Asia/Pacific nations, see Section 8.*
[b] *In 1990 US$*

high rates of economic growth found across the region.[25] These challenges spill over to the environment. Developing nations of the Asia/Pacific region have high rates of environmental degradation from unsustainable resource extraction and use as individuals, communities, and enterprises seek the most immediately available opportunities to achieve economic needs and aspirations. This is perhaps best demonstrated by examining the region's progress toward the United Nations' Millennium Development Goals, which reveal that while progress is being made in other areas, environmental sustainability is perhaps the most recalcitrant problem in the region.[26]

Figure 2.1. *Global distribution of Australian development assistance.*[24]

To combat these disadvantages, significant development assistance flows into the Asia/Pacific region on an annual basis. The majority of Australia's global distribution of development assistance, for example, is concentrated in the Asia/Pacific region (Figure 2.1)[27] – the top ten recipients of Australian assistance during 2004/05 collectively received approximately $1.2 billion (Table 2.2–see also Section 9). This assistance has historically targeted the areas of health, education, governance, and infrastructure, but additional assistance has been provided recently to address disaster relief from the 2004 Indian Ocean Tsunami.27 As of 2003/04, Australia's investment in development assistance had increased by 35% relative to 1971/72.[28] However, the average annual increase in foreign assistance has only been 1.1% - lower than the average rate of economic growth. As a consequence, the proportion of aid relative to Australian gross national income has declined over the past 30 years from 0.48% to 0.25%.

The outlook for economic development across the Asia/Pacific region varies considerably. During the late 1990s, China and India, the region's largest economies, had annual rates of economic growth of approximately 8% and 6%, respectively (Section 8). Such rapid rates of growth are projected to continue in the decades ahead as these nations comprise a greater fraction of global economic activity, which, as an indirect consequence, will result in a greater contribution from these and other nations in the region to global greenhouse gas emissions, and thus the climate change challenge. A number of other Asia/Pacific nations such as Indonesia, Malaysia, the Philippines, Thailand and Vietnam also posted healthy rates of economic growth in 2005 of 5–8%.[29]

Table 2.2. Top-Ten Recipients of Australian Foreign Aid (2004/05)[27]

Nation	Assistance (millions AUS$)	Nation	Assistance (millions AUS$)
1) Papua New Guinea	$366.6	**6**) Philippines	$62.5
2) Indonesia	$270.3	**7**) China	$49.8
3) Solomon Islands	$171.5	**8**) Sri Lanka	$39.8
4) Vietnam	$74.4	**9**) Cambodia	$38.2
5) East Timor	$64.2	**10)** Bangladesh	$32.9

In contrast, the outlook for other nations in the region, at least economically, is not so optimistic. AusAid's *Pacfic 2020* report warned, for example, that the Pacific Islands will not be able to address current and future challenges without sustained economic growth.[30] Furthermore, although such growth is possible, it remains to be seen whether such growth will occur or whether economies will continue to struggle and stagnate. Some of the key factors inhibiting growth in the Pacific Islands include:

- **Weak Governance**
- **Poor and degraded infrastructure**
- **Limited cooperation politically and economically among nations**
- **Poor implementation of measures and policies to address soil and economic concerns**

It is important to note that these socioeconomic circumstances establish the context in which climate change and its impacts will be experienced by nations and communities in the Asia/Pacific region. Yet this context can shift considerably in coming decades in response to changes in economic condition and governance. To the extent that positive trends persist and negative trends are reversed, the region's future vulnerability to climate change may be significantly reduced (see Section 5).

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2.2 Asia/Pacific Climate and Trends

A broad range of climatological and geographic features exist within the Asia/Pacific region, from temperate areas with marked temperature differences from one season to another, to tropical areas with temperatures that are consistently relatively high throughout the year (Figure 2.2). For example for a nation such as China, which extends north of 30°N latitude, January temperatures may be at or below freezing, particularly in the high altitude areas around the Himalayas.[33] In contrast, the tropical areas south of 30°N, such as the Indian subcontinent, Southeast Asia, Indonesia, and the Pacific Islands, generally experience temperatures above 25°C throughout the year.

Similarly, there is significant spatial variability in seasonal precipitation (Figure 2.3). Regional rainfall, and subsequently temperature, are strongly influenced by the summer and winter monsoons. The summer monsoon (consisting of the Southwest Asian Monsoon and the East Asia Monsoon) influences the climate of this region from May to September and brings rains to South and Southeast Asia and east China. The northeast winter monsoon controls the climate from December to February and is characterised by dry winds out of the northeast which bring significant rainfall to parts of Southeast Asia, but leave much of South Asia dry, particularly central and northern India. The two inter-monsoon or transitional seasons comprise March to April and October to November. Strong inter-annual and intra-seasonal variations in climate of this region are caused by large and synoptic scale circulation patterns. Year-to-year monsoon variability and rainfall is strongly related to the El Niño-Southern Oscillation.[34] In general, below normal rainfall coincides with El Niño events, while above normal rainfall is associated with La Niña events.

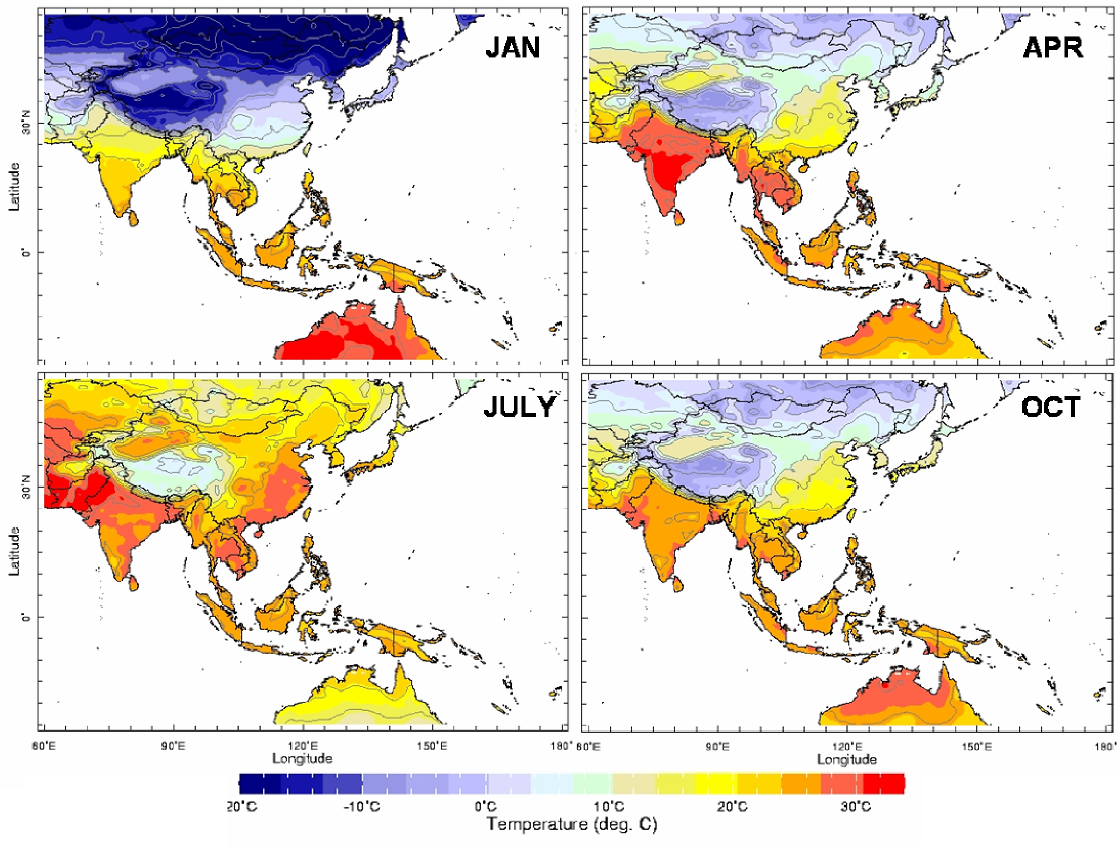

Figure 2.2. *Average seasonal temperatures across the Asia/Pacific region (1961-1990).*[24]

During the first six months of the year (January to May), continental Asia experiences moderate rainfall of less than 50 mm/month, whereas the equatorial areas further to the south receive intense rainfall of several hundred mm/month.[35] In contrast, during the latter half of the year, the precipitation band shifts north, bringing monsoon rains to South Asia, Southeast Asia, and southeast China. Some areas, such as northeast and western China as well as much of Pakistan receive relatively low precipitation throughout the year and tend to be more arid. These patterns of temperature and precipitation dictate not only the biological and ecological diversity throughout the region, but also the availability of natural resources such as water, and subsequently, the timing and productivity of agriculture.

For further detail on different areas, the region can be divided into four broad subregions, Arid and Semi-Arid Asia, Temperate Asia, North Tropical Asia and South Tropical Asia:[36] Each of these regions has its own distinctive climatological and ecological features that set the context for future climate change and impacts. Furthermore, future changes in climate will likely influence these four regions in different ways.

Generally, the Asia/Pacific region has experienced a warming trend in recent decades consistent with global temperature trends.[37] Trends in rainfall are more difficult to interpret, with some subregions experiencing declining rainfall, while others have experienced increases. For example, annual average rainfall has declined in the coastal margins and arid plains of Pakistan, the east coast of India, and in Indonesia.[37] Yet rainfall has increased in western and southeast coastal China, Bangladesh, and the Philippines.[37] In addition to such trends in average temperature and rainfall, there is some evidence that patterns of extreme weather in the Asia/Pacific region changed over the 20th century.[38] For example, significant changes in the frequency and intensity of tropical cyclones have been reported.[39] While the number of cyclones and the number of cyclone days have fallen, the intensity of cyclones in the region has increased over the past 35 years in association with increases in sea surface temperatures. A recent paper by Landsea et al. (2006) suggests this trend may be largely due to of inaccurate estimates of historical cyclone intensities rather than climate change.[40] However, global increases in ocean temperatures have been linked to human greenhouse gas emissions.[41]

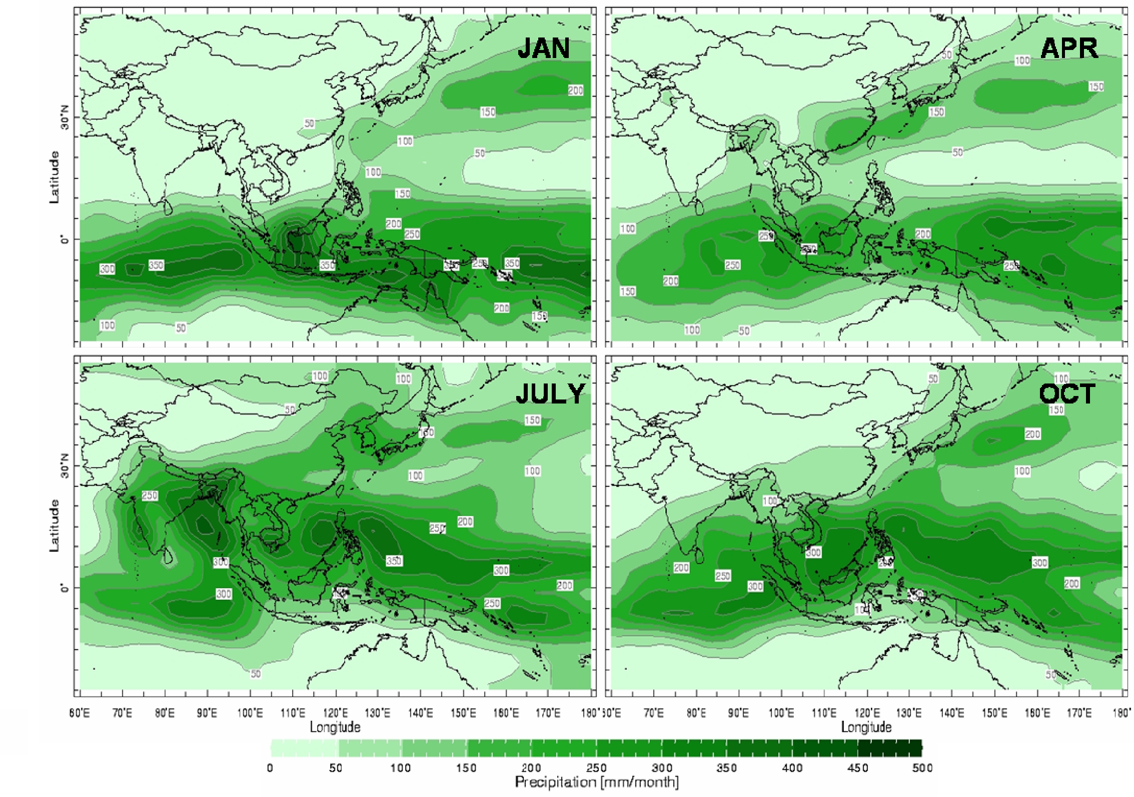

Figure 2.3 *Average seasonal precipitation across the Asia/Pacific region (1979-1995)*[25]

2.2.1 Arid and Semi-Arid Asia

Arid and Semi-Arid Asia is comprised of the northern extent of India and Pakistan as well as western China, and the landscape is represented by tropical savannah vegetation, grasslands, and desert. This subregion has a tropical climate with hot summers that can be either warm or wet. Rainfall is limited and can be highly variable during the year, with significant rainfall in some areas occurring in only a few months. This subregion has experienced warming over the 20th century. For example, Central Asia warmed by approximately 0.1–0.2°C per decade,[42] suggesting warming of 1–2°C over the past 100 years. Meanwhile, rainfall has increased by 22–33% in northwest China and most observing stations in Pakistan also record increases in rainfall.[43,44]

The subregion, particularly central Asia, is well-known for extremes of climate. Extreme temperatures occur in western arid lands during summer. In addition, localised storms are a frequent occurrence, and cyclones occasionally affect the region between January and March. However, these cyclones deliver little precipitation to the region because of its aridity. The frequency and severity of wildfires in grasslands and rangelands in Arid and Semi-Arid Asia have increased in recent decades.[45] Water resources and human settlements have been affected by increased melting of glaciers that appears to have increased the frequency of mudflows and avalanches.[46]

2.2.2 Temperate Asia

Temperate Asia is comprised of the Tibetan Plateau, eastern China, and the Korean Peninsula. The landscape has been significantly altered due to centuries of deforestation and agriculture. Temperatures in northeast China over the 20th century increased in winter but decreased in summer, while southeast China warmed by 1–2°C. [47,48] Higher rates of warming (0.16–0.32°C per decade) have been observed on the Tibetan Plateau.[49] Rainfall in temperate Asia is strongly influenced by the East Asian Monsoon, providing a large fraction of annual rainfall during the summer wet season.[37] Warm years tend to be associated with stronger monsoons and higher rainfall, while cooler years tend to be associated with drier conditions.[50] Nevertheless, in China, annual precipitation has been decreasing continuously since 1965,[51] although increases have been observed in southeast China,[52] and the northeast Tibetan Plateau.[53] Increases in extreme rainfall have been observed on the Korean Peninsula.[54]

Countries in temperate Asia have been frequented by many droughts in the 20th century, including major droughts in China in 1972, 1978, and 1997.[37] Severe flooding has also affected China, Korea, and Japan in recent years.[37,55] The occurrence of severe droughts and floods in temperate Asia also appears to be associated with the status of the El Niño-Southern Oscillation.[37]

2.2.3 Tropical Asia

Tropical Asia/Pacific can be divided into two subregions: North Tropical Asia is comprised of central and southern India, Sri Lanka, Bhutan, Bangladesh, and Southeast Asia (e.g., Myanmar, Vietnam, Laos, Cambodia, and Thailand); while South Tropical Asia consists of the island nations of the equatorial Indian Ocean (Maldives); western Pacific Ocean (Philippines, Malaysia, Papua New Guinea); the Maritime Continent (Indonesia, East Timor); and the islands of the southwest Pacific (Cook Islands, Solomon Islands, Fiji, Vanuatu, Tuvalu). These subregions are geographically diverse and contain a number of hotspots for terrestrial and marine biodiversity. Although the economies within these subregions are based largely upon rural agricultural systems, the region also contains some of the world’s largest, and most densely, populated cities.

For nations near the Equator, seasonal variability in temperature is small and increases as one moves toward higher latitudes. The dominating climatic feature in the region is the summer Southwest Asian Monsoon, which influences the climatology of the nations within the subregion to varying degrees and in diverse ways.[37] Observations indicate temperatures are increasing throughout much of the subregion. For example, warming in Vietnam of 0.32°C has been observed over the past three decades, consistent with other observations in Southeast Asia.[37] Meanwhile, temperatures in Sri Lanka and tropical India have increased by approximately 0.30°C and 0.68°C, respectively,[56,57] while coastal Pakistan warmed by 0.6–1.0°C over the 20th century.[58] There has been no consistent trend in rainfall throughout the North Tropical Asia subregion. For example, while northwest India has experienced increased extreme rainfall events, there are no clear signals of a long-term trend in annual rainfall.[59] In fact, the number of rain days along the east coast has declined in recent years.[58] A declining trend in annual rainfall has been observed in Thailand.[60] Elsewhere, including Sri Lanka and Bangladesh, there is little long-term trend, but rainfall is dominated by sequences of prolonged high rainfall years followed by low rainfall years.[37] Records also indicate that rainfall has decreased in the southwest Pacific.[37]

Tropical Asia is routinely affected by climate extremes, particularly floods, droughts, and cyclones. The number of reported disasters has increased steadily over the past 50 years, as has the number of affected individuals.[61] Vast areas of some Tropical Asia nations are prone to flooding including 3.1 million hectares of Bangladesh and 40 million hectares of India.[62] There are also reports of an increase in thunderstorms over the land regions of North Tropical Asia.[63] Yet in any given year, parts of Bangladesh and extensive areas of India are also prone to drought.[64] Monsoon failure and drought events in Tropical Asia appear to be associated with variability in the El Niño-Southern Oscillation, with drought more common in El Niño years.[65] Historical tide gauge data from small island states also reveal significant tidal variations associated with El Niño years.[37]

2.3 Regional Climate Vulnerability

What do the current socioeconomic statuses and climatological features found within the Asia/Pacific region suggest regarding vulnerability to climate change? The 2005 Australian Greenhouse Office report, *Climate Change Risk and Vulnerability*, outlined a conceptual model that defined vulnerability as a process integrating *exposure*, *sensitivity*, *potential impact*, and *adaptive capacity*.[66] This model implies that building a comprehensive understanding of climate change vulnerability requires considering the climatic drivers to which human and natural systems are exposed, the responsiveness of those systems to those drivers (i.e., the extent to which systems change with the climate), and the capacity of the system to adapt to climate change to reduce the likelihood of adverse consequences

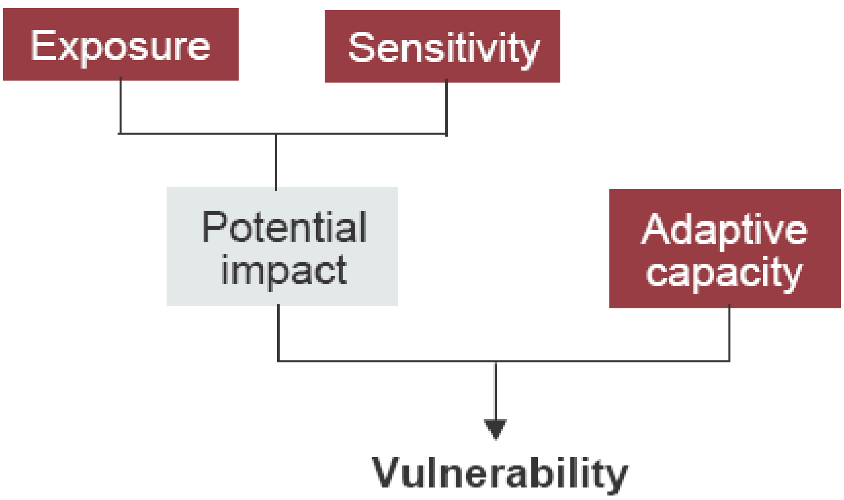

Figure 2.4. *Components of climate change vulnerability*[66]

If one considers the Asia/Pacific region in this context, it is possible to identify some of the key aspects of the region's exposure, sensitivity, and adaptive capacity that contribute to its net vulnerability to climate change:

1) **Exposure** – The Asia/Pacific region is exposed to a range of climate conditions and extreme events. In particular, some of the dominate features of the region's climate are

the influences of monsoons, the El Niño-Southern Oscillation, and cyclones on rainfall. Much of the region is adapted to, and thus dependent upon, the annual monsoon occurrence,[42] which leaves it vulnerable when the monsoon fails and rainfall is significantly curtailed. Meanwhile, variability associated with the El Niño-Southern Oscillation, and particularly El Niño events, contributes to periodic drought and extreme sea levels in the southwest Pacific. Finally, much of coastal Asia/Pacific is affected by tropical cyclones and their associated high winds, storm surge, and extreme rainfall. These climate challenges are permanent features of the Asia/Pacific region, but ones that may be significantly altered by anthropogenic climate change in the decades ahead.

2) **Sensitivity** – In addition to being exposed to various climate hazards, the vulnerability of the Asia/Pacific region is also affected by the sensitivity of different nations and sectors to these hazards when they occur. For example, with much of their subsistence and economic power dependent upon agriculture, the potential for widespread adverse impacts is enhanced in developing nations. Similarly, the development of existing water resources in many developing nations is limited as is, subsequently, access to safe drinking water and sanitation. In the event of drought or flood, the ability to safely and efficiently manage water storage, diversion, and delivery may be easily compromised. Settlements and infrastructure in developing Asia/Pacific tend to be more susceptible to the effects of climate extremes and more likely to be damaged. Low-lying coastal areas, including small island states, tend to be more sensitive to the effects of sea-level rise and storm surge and thus have potentially more to lose from climate change than land-locked nations. Statistics indicate that extreme events in the region are associated with significant financial losses as well as the loss of lives (Table 2.3), and disasters in the region have increased in recent decades.[61]

Table 2.3. Reported Natural Disasters in the Pacific Islands (1950-2004)[61]

Event	Number	Fatalities	Population Affected	Losses (millions 2004 US$)
Windstorms	157	1,380	2,496,808	5,903.90
Droughts	10	0	629,580	137.00
Floods	8	40	246,644	94.80
Earthquakes	17	53	22,254	330.60
Others	15	274	21,520+	60.00

3) **Adaptive Capacity** – The Asia/Pacific region's exposure and sensitivity to climate variability and climate change creates a large potential for adverse climate impacts, a fact that is readily evident from the toll that climate events take on the region at present. But in understanding the current and future vulnerability of the region to climate change, one must also give consideration to the capacity of its nations to adapt to climate change (see also Section 5). The aforementioned discussion of the socioeconomic state of affairs in the region provides room for both optimism and pessimism regarding adaptive capacity. On one hand, rapid structural change and growth in some national economies, such as China and India, suggests reduced future sensitivity to climate change, and the ability to leverage resources to reduce risk. On the other hand, some economies are currently stagnating and some nations, such as small island states, have limited options available to adapt in situ. Furthermore, continued rapid exploitation and degradation of natural resources and capital due to rapid urbanisation and economic development in a number of nations further reduces the resilience of some nations to climate variability and change. Rather than mustering the

resources to successfully address climate change impacts, some nations may find the changing climate to actually be a barrier to achieving a more prosperous future.

The net result is a region that is currently, on average, quite vulnerable to the effects of climate change, although vulnerabilities may vary significantly from one nation, or even one community, to another. Thus, the decisions made by nations in the region in the decades ahead, and their ability to access resources to plan for a changing climate, are likely to be critical issues affecting their response to climate change over the next century.

3. Climate Projections for the Asia/Pacific Region

3.1 Global Climate Model Selection

A new set of climate projections was developed for the Asia/Pacific region to provide up-to-date information regarding the spatial distribution and extent of future changes in regional temperature and rainfall. Climate models are the best available tools to simulate climate processes and their related spatial and temporal variations of temperature and rainfall. However, climate models divide the world into individual grid cells, which may be rather lage (e.g., about 200 400 km across). Therefore, small-scale meteorological phenomena, such as individual clouds or thunderstorms, are not adequately simulated. In addition, it should be noted that different climate model patterns produce different projections of both global and regional climate change, and thus multiple models must be utilised to assess the uncertainty associated with projections of future climate.

Table 3.1. Models Used for Generating Asia/Pacific Climate Scenarios

Climate Modelling Group and Nation	Model Symbols	Horizontal resolution (km)
Bjerknes Centre for Climate Research, Norway	BCCR	~200
Canadian Climate Centre, Canada	CCMA T47	~300
Canadian Climate Centre , Canada	CCMA T63	~200
Meteo-France, France	CNRM	~200
CSIRO, Australia	CSIRO-MARK3	~200
Geophysical Fluid Dynamics Lab, USA	GFDL 2.0	~300
Geophysical Fluid Dynamics Lab, USA	GFDL 2.1	~300
NASA/Goddard Institute for Space Studies, USA	GISS-AOM	~300
LASG/Institute of Atmospheric Physics. China	IAP	~300
Institute of Numerical Mathematics, Russia	INMCM	~400
Centre for Climate Research, Japan	MIROC-M	~300
Meteorological Research Institute , Japan	MRI	~300
Max Planck Institute for meteorology DKRZ, Germany	MPI-ECHAM5	~200
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	MIUB	~400
National Center for Atmospheric Research, USA	NCAR-CCSM	~150
Hadley Centre, UK	HADGEM1	~125

Simulations with 23 different climate models have been undertaken for the *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change. These model simulations were acquired from the Program for Climate Model Diagnosis and Intercomparison and used to generate climate change projections for the Asia/Pacific region.[67] A prerequisite for the inclusion of a model in climate projections is that it adequately simulates present-day climate conditions. Therefore, statistical methods were used to test the fidelity with which individual models simulate observed climate conditions over the Asia/Pacific region. Results from these validation tests are discussed in Section 10. Based upon these tests, a set of 16 climate models were selected for use in generating climate projections for the Asia/Pacific region (Table 3.1).

3.2 Generation of Climate Change Projections

Climate change projections are often based on time-slices within a given climate simulation, such as a thirty year period centered on 2020, or 2050 or 2080. A disadvantage with this approach is that large portions of the simulation are not used and the chosen intervals are strongly affected by decadal variability, particularly for rainfall. An alternative that avoids this disadvantage is to calculate the rate at which local (i.e., individual grid cell) average seasonal temperature or rainfall changes with increases in average global temperature over multiple decades. The grid cell values can then be mapped to obtain a spatial pattern of model response per degree of global warming. These patterns can then be multiplied by estimates of global warming for any desired year. This ‘pattern scaling’ method has been used by CSIRO since 2001 and is considered robust.[68,69]

Pattern scaling techniques were therefore used to develop annual and seasonal ‘patterns of change’ per degree of global warming for each of the 16 climate models listed in Table 3.1 at a common resolution of 4 decimal degrees (approximately 400 km) per grid cell. Estimates of global warming in 2030 or 2070 were then applied to these patterns to obtain projections of temperature or rainfall change. Estimates of global warming were based upon climate modelling from the Intergovernmental Panel on Climate Change’s *Third Assessment Report*.[2] For both 2030 and 2070, low, central, and high estimates of global warming were applied to climate model patterns.[70] These global temperature changes were 0.54, 0.85, and 1.24°C in 2030 and 1.17, 2.28, and 3.77°C in 2070.[71] It should be noted that additional global warming is projected beyond 2070.

Combining the various estimates for global mean temperature change with the different per degree climate model patterns resulted in a series of regional maps depicting the spatial patterns of projected changes in temperature and rainfall over the Asia/Pacific region in 2030 and 2070 that reflect different assumptions about future greenhouse gas emissions, climate sensitivity, and regional climate responses. These maps formed the basis of the climate projections provided below. In addition, projections were averaged over the four subregions discussed in Section 0 to generate summary tables highlighting some of the geographic differences in projected climate changes for the Asia/Pacific region.

Table 3.2. Projected temperature changes for Asia/Pacific subregions[c]

	2030 (°C)				
Subregion	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
Arid and Semi-Arid Asia	1.2 (0.6–2.3)	1.3 (0.6–2.7)	1.2 (0.5–2.4)	1.2 (0.5–2.3)	1.2 (0.6–2.2)
Temperate Asia	0.9 (0.4–1.9)	1.0 (0.4–2.5)	0.8 (0.3–1.3)	0.8 (0.4–1.7)	0.9 (0.4–1.8)
North Tropical Asia	0.8 (0.4–1.3)	0.8 (0.4–1.4)	0.8 (0.4–1.4)	0.8 (0.4–1.4)	0.8 (0.4–1.3)
South Tropical Asia	0.8 (0.4–1.3)	0.8 (0.4–1.3)	0.8 (0.4–1.4)	0.8 (0.4–1.3)	0.8 (0.4–1.3)
	2070 (°C)				
Arid and Semi-Arid Asia	3.2 (1.3–7.1)	3.4 (1.3–8.3)	3.2 (1.0–7.3)	3.1(1.1–7.1)	3.1 (1.2–6.8)
Temperate Asia	2.4 (0.9–5.7)	2.8 (0.9–7.7)	2.3 (0.8–5.5)	2.2(0.8–5.3)	2.4 (0.9–5.6)
North Tropical Asia	2.1 (0.9–4.0)	2.1(0.8–4.1)	2.1 (0.9–4.2)	2.0(0.8–4.1)	2.0 (0.8–4.0)
South Tropical Asia	2.1 (0.9–4.0)	2.0 (0.9–4.1)	2.1(0.9–4.2)	2.1(0.8–4.1)	2.1(0.8–4.1)

3.3 Projected Asia/Pacific Temperature Changes

Based upon the analysis of results from different climate models, temperatures throughout the Asia/Pacific region are projected to increase over the 21st century (Figure 3.1; Table 3.2). Generally, climate models indicate higher rates of warming for central Asia, particularly the Arid and Semi-Arid areas of western China, with a central estimate of annual temperature change by 2030 and 2070 of 1.2 and 3.2°C, respectively. However, there is considerable uncertainty in these changes, with low and high warming scenarios for 2030 and 2070 ranging from 0.6–2.3°C and 1.3–7.1°C, respectively. More moderate warming is projected for the other three subregions, with central estimates of warming of just under 1°C by 2030 and just over 2.0°C by 2070. Meanwhile, low and high scenarios of warming for the other subregions range from approximately 0.5°C to 2.0°C by 2030 and 1.0 to 6.0°C by 2070.

Projected warming in individual seasons is generally consistent with annual averages (Figure 3.1; Table 3.2). However, in Arid and Semi-Arid Asia as well as Temperate Asia, higher rates of warming are projected in the northern hemisphere winter (DJF) than the other seasons. In contrast, the tropical subregions, which lie closer to the equator, are projected to have fairly uniform warming throughout the year.

[c] *Annual refers to average annual temperatures. DJF refers to average temperatures over December, January, and February; while MAM refers to temperatures from March to May; JJA from June to August, and SON from September to November.*

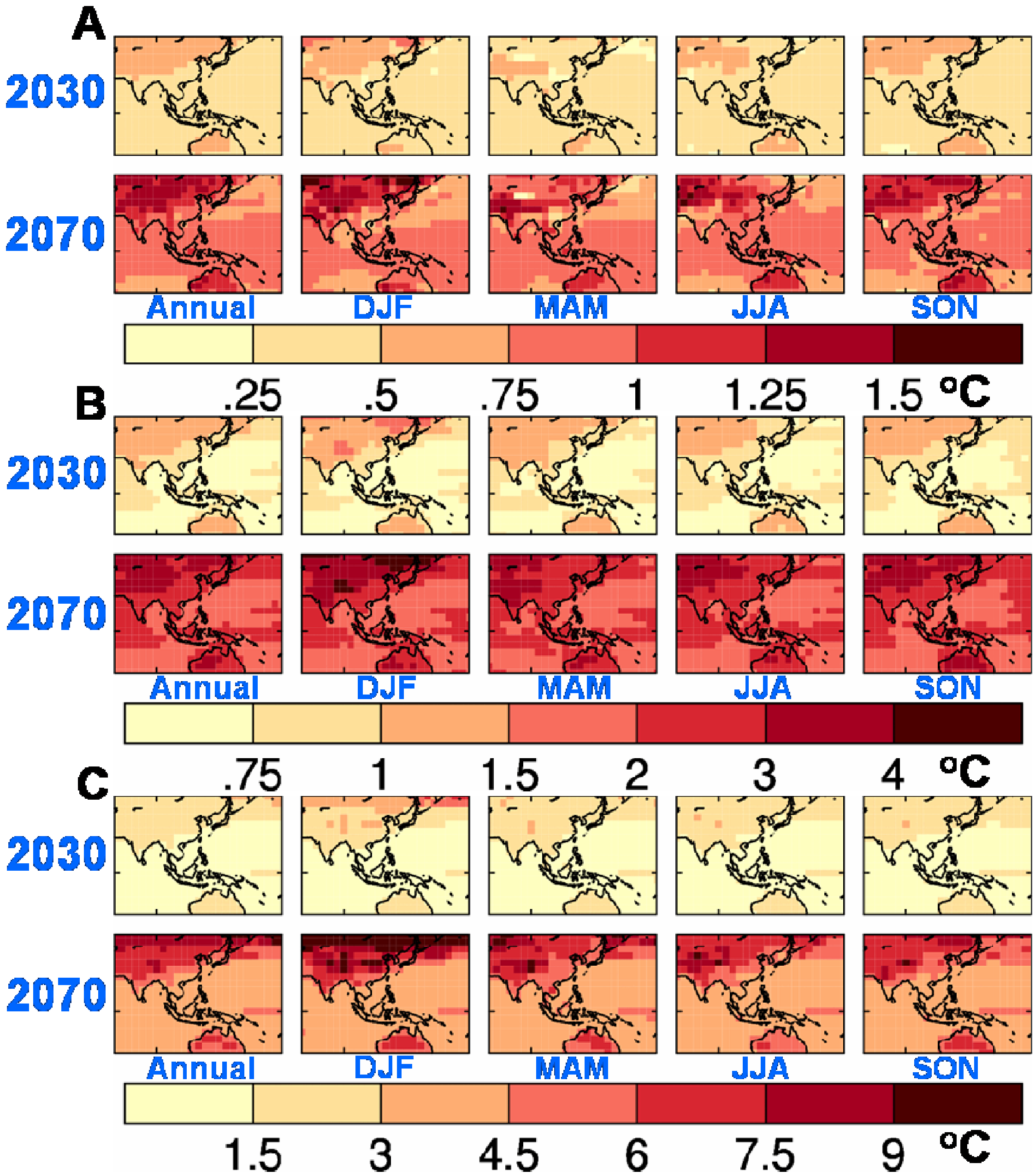

Figure 3.1. *Projections of annual and seasonal temperature increases in the Asia/Pacific region in 2030 and 2070 relative to 1990. A) Minimum temperature changes from the 16 climate models given a low global warming scenario; B) Central temperature changes given a central global warming scenario; and C) Maximum temperature changes given a high global warming scenario.*[d]

3.4 Projected Asia/Pacific Rainfall Changes

Climate change is also projected to cause significant changes in rainfall throughout the Asia/Pacific region over the next century (Figure 3.2b; Table 3.2). However, as a general rule, there is more uncertainty regarding the direction and magnitude of future rainfall changes as different climate models yield different results. A central estimate of rainfall changes in 2030 and 2070 from the different climate models suggests annual increases in rainfall of less than

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[d] *Annual refers to average annual temperatures. DJF refers to average temperatures over December, January, and February; while MAM refers to temperatures from March to May; JJA from June to August, and SON from September to November.*

10% throughout much of the Asia/Pacific region. This is generally consistent with the expectation of a more vigorous hydrologic cycle as a result of atmospheric warming.[2] However, reductions in rainfall of less than 10% are projected over Pakistan and parts of Indonesia over the next 30 years.

The projected changes in rainfall vary significantly from one region to another. A central estimate indicates reductions in winter (DJF) rainfall of less than 10% by 2030 for southern Asia, extending from Pakistan across India, Southeast Asia, and southeast China. These reductions in rainfall increase to approximately 20-30% in southern India and Southeast Asia by 2070, and generally suggest increased winter aridity associated with the northeast winter (DJF) monsoon (Box 3.1). This pattern of rainfall reductions persists through spring (MAM). In contrast, patterns of rainfall change in summer (JJA) and fall (SON) resemble the annual pattern, with increasing rainfall throughout much of the region, consistent with increased rainfall from the summer monsoon (Box 3.1). The exceptions to this pattern include west Arid and Semi-Arid Asia, east Temperate Asia, and Indonesia.

Table 3.3. Projected Rainfall Changes for Asia/Pacific Subregions[e]

	2030 (%)				
Subregion	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
Arid and Semi-Arid Asia	+2	+5	+2	0	+4
Temperate Asia	+1	+2	+1	+2	+1
North Tropical Asia	+2	-1	0	+3	+2
South Tropical Asia	+1	+2	+2	+1	0
	2070 (%)				
Temperate Asia	+7	+13	+5	+1	+10
North Tropical Asia	+4	+6	+4	+6	+2
South Tropical Asia	+4	-3	-1	+7	+6
Arid and Semi-Arid Asia	+4	+4	+5	+2	0

These central estimates of future rainfall changes do not necessarily reflect the uncertainty associated with different climate models or assumptions about greenhouse gases. Future global warming may be higher or lower than central estimates (see Section 3.2), and even for a given estimate of global warming, projected rainfall patterns among different climate models vary significantly. As a result, two tests were conducted on projected rainfall in an attempt to identify where different climate models agree about the direction of rainfall change (i.e., positive or negative) in different areas of the Asia/Pacific region as well as the likelihood of ’large’ changes, such as an increase or decrease greater than 10%.

First, model agreement in the direction of rainfall changes across the Asia/Pacific region was assessed by calculating the percentage of model simulations that yield increases in rainfall in response to low, central, or high estimates of global warming. Values of 0% indicate *none* of the simulations project increasing rainfall for a given area (or alternatively, all of the models project decreases in rainfall); while values of 100% mean *all* of the simulations project increases in rainfall (or alternatively, none of the models project decreases). Values between 40 and 60% suggest there is little agreement among models regarding the direction of change for a given area. The results from this analysis indicate that different climate models agree regarding increasing rainfall throughout North and South Tropical Asia (Figure 3.2b). There is also high

[e] *Annual refers to average annual temperatures. DJF refers to average temperatures over December, January, and February; while MAM refers to temperatures from March to May; JJA from June to August, and SON from September to November.*

model agreement regarding reductions in rainfall throughout the year in the west South Tropical Asia. Similarly, models agree regarding reductions in rainfall in Arid and Semi-Arid Asia and South and Southeast Asia from December through May; and high model agreement regarding reductions in rainfall over parts of Indonesia from June through November.

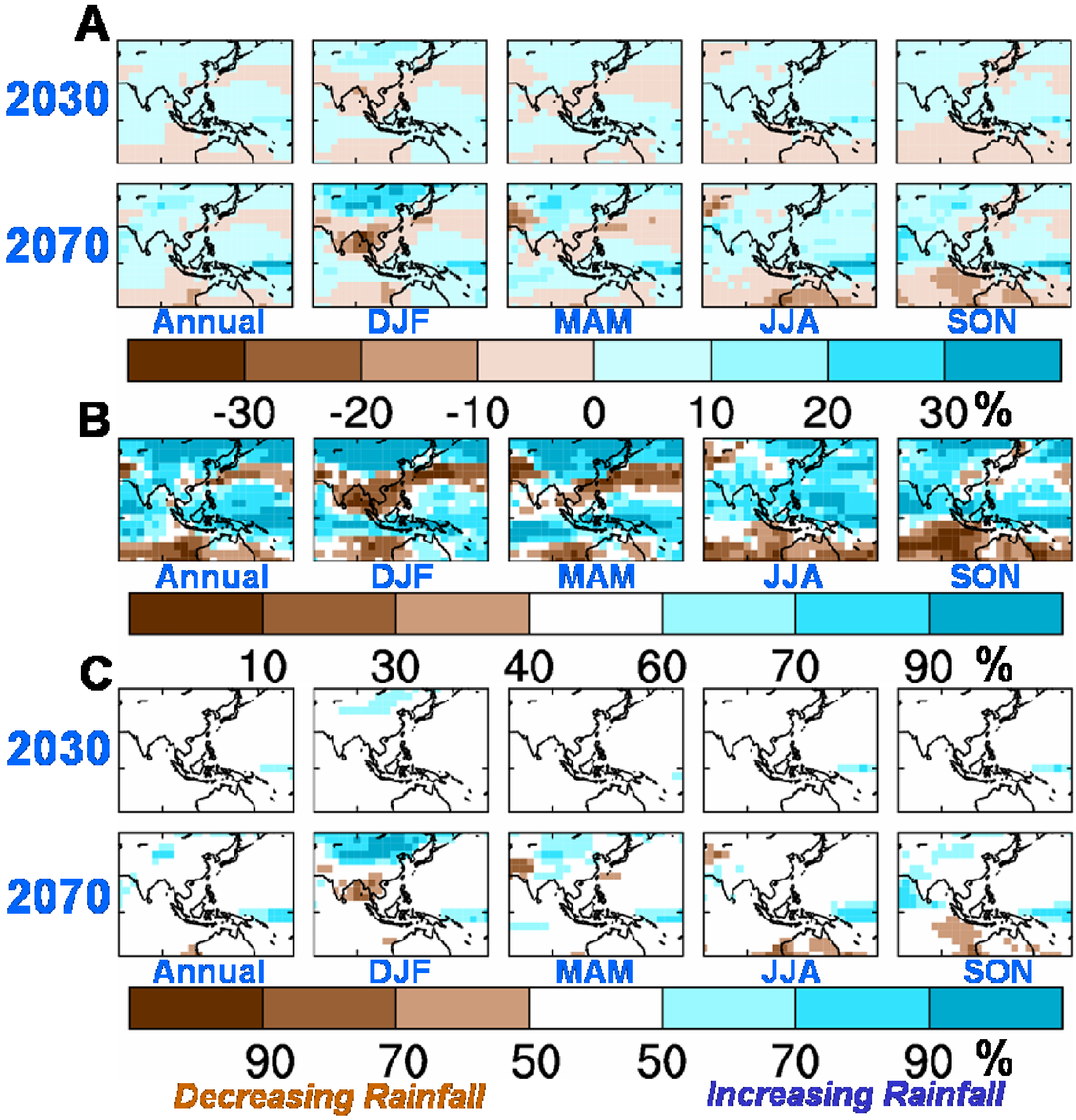

Figure 3.2. *Projections of annual and seasonal rainfall changes in the Asia/Pacific region in 2030 and 2070. In all figures, brown colours indicate decreasing rainfall while blue colours indicate increasing rainfall. A) central rainfall changes (as a percentage change from 1990 rainfall) from the 16 climate models given a central global warming scenario; B) Percentage of the 16 climate models projecting increases in rainfall in 2030 and 2070 in response to low, medium, and high global warming scenarios. Values greater than 60% indicate the majority of models project increases in rainfall while values less than 40% indicate the majority of models project decreases in rainfall. C) Percentage of the 16 climate models projecting changes in rainfall in 2030 and 2070 greater than ±10% in response to low, central, and high global warming scenarios. Blue colours indicate the proportion of models that agree regarding rainfall increases greater than 10%. Brown colours indicate the proportion of models that agree regarding rainfall decreases greater than 10%. Unshaded areas are those where less than 50% of model simulations indicate rainfall changes greater than ±10%.*[f]

[f] *Annual refers to average annual temperatures. DJF refers to average temperatures over December, January, and February; while MAM refers to temperatures from March to May; JJA from June to August, and SON from September to November.*

The aforementioned analysis provides information regarding where models agree about the *direction* of rainfall change, but not necessarily the *magnitude*. Therefore a second test was conducted by calculating the percentage of model simulations that yield increases or decreases in rainfall greater than 10% in response to low, central, or high estimates of global warming in 2030 and 2070. Values of 50, 70, or 90% indicate an increasingly higher proportion, respectively, of model simulations agree regarding rainfall changes greater than ±10% in a given area.

This analysis indicates that there are few areas within the Asia/Pacific region where large changes (i.e., changes of ± 10%) in rainfall can be projected with confidence (i.e., greater than 50/50 chance), particularly by 2030 (Figure 3.2c). On an annual basis, the only areas where rainfall increases greater than 10% are projected by 2030 and 2070 are the Pacific Islands east of Papua New Guinea (e.g., Solomon Islands, Kiribati, and Tuvalu) and, by 2070, a small area in central China. However, for individual seasons, there are strong signals of large changes in rainfall, particularly in winter (DJF). By 2070, most of the models agree regarding winter (DJF) rainfall increases greater than 10% in northern Temperate Asia and the Pacific Islands, and rainfall decreases greater than 10% in Arid and Semi-Arid Asia, South Asia, and Southeast Asia. In spring (MAM), models agree regarding large rainfall increases in northern and central China and the Pacific Islands, and large rainfall decreases in Arid and Semi-Arid Asia (e.g., Pakistan). In summer (JJA), models agree regarding large increases in rainfall in the Pacific Islands and large declines in Arid and Semi-Arid Asia. In fall (SON), models agree regarding large increases in rainfall in central China, northwest India, and the Arabian Sea.

Box 3.1. Climate Change and the Asian Monsoons

The climate, and subsequently agricultural productivity and water resources, of South and Southeast Asia are strongly influenced by summer and winter monsoons, which are responsible for bringing significant rainfall to India, Southeast Asia, and east China during the wet seasons from approximately May through September and December to February. Crop plantings and yields are closely related to the onset of the summer monsoon and the magnitude of monsoon rains. Monsoon failures have been associated with drought and food shortages, although improvements in drought management and technology have been increasingly effective in preventing widespread famine.[72] Runoff from monsoon rains also increases stream and river flows affecting water availability for environmental and human uses. Yet, during times of extreme monsoon years, excessive rainfall contributes to flooding and crop damage. Thus, much of the Asia/Pacific's food and water security in a changing climate is likely to be influenced by the effects of global climate change on the monsoon.

The climate scenarios generated for this report generally indicate increasing rainfall during the summer monsoon. This is consistent with a number of other recent studies where global climate models have been used to investigate the relationship between climate change and the Asian monsoons.[73,74,75] Nevertheless, other research has shown that the effects of climate change on the monsoon are not uniformly distributed. For example, Bhaskaran and Mitchell (1998) found that while monsoon rains increased throughout much of South and East Asia, northwest India experienced declines in rainfall, which is consistent with the projections generated for this report.[76]

In general, an increase in regional water availability would be beneficial for crop production and water availability in a region where scarcity is a common problem. However, two issues prevent one from having confidence in such an optimistic outlook. Although future summer monsoons *may bring more rainfall to Asia on average in the future, there is also evidence that climate change will increase the variability of monsoon rains from one year to another.*[77] *This would increase the likelihood of receiving suboptimal or excessive rainfall in any given year, which could reduce the benefits associated with an average increase. Monsoon variability is also tied to the El Niño Southern Oscillation,*[78] *with drought risk increasing during El Niño events,*[79] *yet there is little agreement among climate models with respect to how future climate change may alter the frequency or intensity of El Niño events.*[80]

In addition, recent work examining the effects of aerosol particles (e.g., black carbon and organic carbon from incomplete combustion as well as dust) on South Asia climate indicates such aerosols may significantly reduce regional rainfall.[81,82] *Declines in monsoon rains in India in recent decades, for example, may be related to the presence of such aerosols. To date, these aerosols have generally not been included in global climate model projections of future climate change. When they are, the models indicate weakening of the monsoon, and hence, reduced rainfall. Clearly further research is required to understand the implications of such aerosols on regional climate, as well as future emissions of these aerosols. Given significant efforts to control pollution and improve regional air quality in the decades ahead, it may be possible to significantly reduce aerosol loads over Asia. However, some researchers caution that because black carbon aerosols also have a cooling effect on the regional climate, efforts to reduce aerosol air pollution without simultaneous efforts to reduce greenhouse gas emissions could result in more rapid warming.*[81]

3.5 Sea-level Rise and Variability

Global climate change is anticipated to increase global sea-levels over the 21st century and beyond, as a consequence of thermal expansion of the oceans from rising global temperatures and increased melting of glaciers and ice caps over land. Estimates of global sea-level changes from the Intergovernmental Panel on Climate Change's *Fourth Assessment Report* model simulations were not available at the time this report was published. As such, estimates of sea-level rise were derived from model simulations associated with the *Third Assessment Report*, and, specifically, the MAGICC simple climate model (v. 4.2).[2] MAGICC was used to simulate sea-level rise from seven global climate models, spanning a range of climate sensitivities (1.7–4.2°C) and seven emissions scenarios (the six illustrative scenarios from the Intergovernmental Panel on Climate Change's *Special Report on Emissions Scenarios*.[83] Simulations were conducted assuming low, medium, and high rates of ice melt in response to global warming. There is significant overlap in projected sea-level rise among climate models, emissions scenarios, and ice melt parameterisations. The results from these simulations are presented in Figure 3.3. Simulations suggest increases in global sea level of 3–16 (central estimate of 7) cm by 2030 and 7–50 (central estimate of 37) cm by 2070. However, it should be noted that these estimates are likely to be updated by the Intergovernmental Panel on Climate Change's *Fourth Assessment Report* (to be released in 2007). In addition, these estimates do not account for potential contributions from the ice sheets of West Antarctica or Greenland (see Section 3.6), which, if they were to melt, would contribute to sea-level rise of approximately 5 and 7 metres, respectively, over the coming centuries. A recent study suggests that the rate of melting of the Greenland ice sheet has doubled within the past decade.[84]

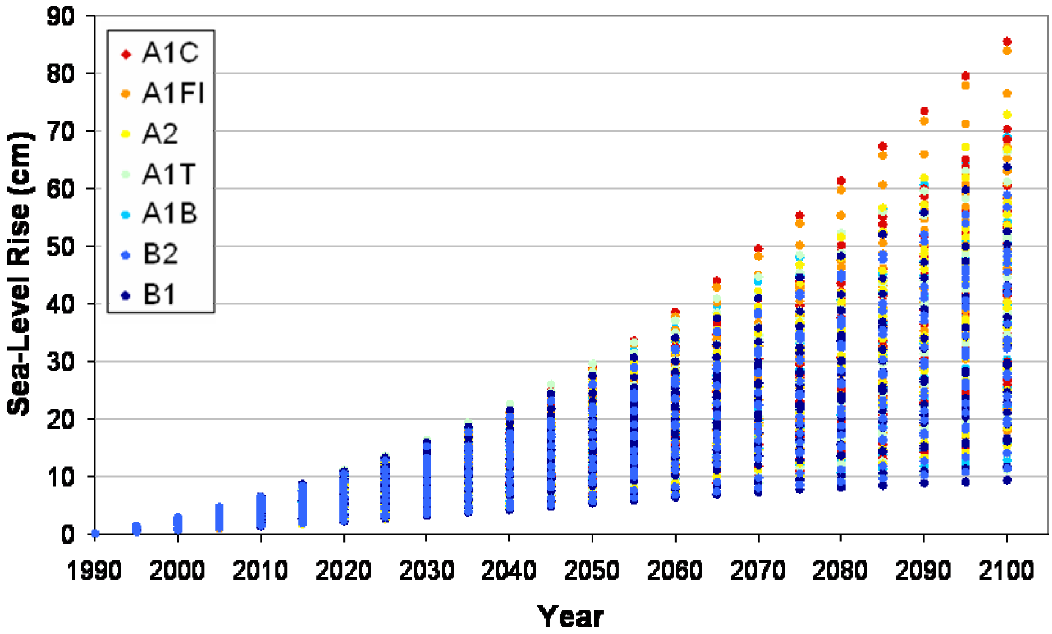

Figure 3.3. *Sea-level rise projections as simulated by the MAGICC simple climate model. Each point represents one model simulation based upon a range of assumptions about climate sensitivity, the rate of global ice melt, and greenhouse gas emissions scenarios (see legend).*

Table 3.4. Recent Trends in Sea-Level Rise in Pacific Island Nations[85]

Nation	Year of Gauge Installation	Trend (mm/year)
Cook Islands	1993	+2.5
Fiji	1992	+2.5
Federated States of Micronesia	2001	+21.4
Kiribati	1992	+5.7
Marshall Islands	1993	+5.2
Nauru	1993	+7.1
Papua New Guinea	1994	+8.1
Samoa	1993	+6.9
Solomon Islands	1994	+6.8
Tonga	1993	+8.0
Tuvalu	1993	+6.4
Vanuatu	1993	+3.1

Climate change-induced sea-level rise will exacerbate natural variability in sea level and local tides to affect coastal communities and ecosystems in the Asia/Pacific region. Sea level at any given point is a function of local pressure, temperature, and salinity conditions, as well as local land subsidence and regimes. For example, a coordinated sea level monitoring effort has been under way in the Pacific Islands since the early 1990s (Table 3.4). Data through June 2006 reflect highly variable trends in sea levels throughout the Pacific Islands, with rates as low as 2.5 mm/year around the Cook Islands or as high as 21.4 mm/year in the Federated States of Micronesia. Short-term variability in lunar tides, storm activity, as well as the effects of the El Niño Southern Oscillation (e.g., El Niño and La Niña events) may contribute to anomalously high or low tides in various regions. For example, during February of 2005, King Tides were responsible for damage to Pacific Islands such as Kiribati. Meanwhile the strong 1997/98 El Niño event contributed to anomalously low sea levels throughout the Pacific Islands.[85] Furthermore, storm surges associated with storm events and tropical cyclones clearly contribute to short-term extreme sea levels that routinely cause significant damage and loss of life in the Asia/Pacific region.

3.6 Climate Extremes and Surprises

The aforementioned climate scenarios do not account for changes in climate variability or extremes. Yet the potential effects of climate change on the frequency and intensity of extreme events is a key cross-cutting issue that will affect the frequency and severity of a wide variety of climate impacts. Extreme events tend to inflict large environmental and economic costs, which is exacerbated by the fact that they can be difficult to adequately manage through adaptive processes. Globally, the World Meteorological Organisation has reported that extreme events are on the rise as a result of anthropogenic perturbation of the climate system,[86] and climate models indicate the potential for increases in extremes of temperature, precipitation, droughts, storms, and floods.[37] For example, modelling for Pohnpei, the Federated States of Micronesia and Rarotonga, Cook Islands suggests a shortening of return periods for extreme winds and rainfall as the world warms.[87] Furthermore, modelling studies consistently find that tropical cyclone intensities increase in response to higher sea surface temperatures, meaning the potential for long-term increases in average cyclone intensities in the Asia/pacific region in the decades ahead.[88] Nevertheless, specific knowledge regarding the magnitude or frequency of climate extremes remains limited.

In addition to the consequences of climate variability, so called 'large-scale singularities' – major and potentially abrupt changes in the climate system – could cause a broad range of direct and indirect consequences to many regions of the world, including the Asia/Pacific. Although the likelihoods of such event are uncertain, the consequences would be large and global. As such, much of the interest in defining 'dangerous' climate change has emphasised the importance of mitigating greenhouse gas emissions to ensure such events are avoided. The climate thresholds for some of these events may be quite low.

For example, historical and paleological data provide ample evidence that singularities and abrupt changes in the climate system have occurred repeatedly in the past. Perhaps the event of most immediate relevance to the Asia/Pacific region is the collapse of the ice sheets of Greenland and/or West Antarctica. For a number of years, scientists have expressed concern about the potential for climate change to destabilise these ice sheets.[89] Hansen (2005) recently suggested that the threshold for an irreversible loss of the Greenland ice sheet may be as low as 1^{o}C.[90] Vast quantities of water are locked away in the ice sheets of West Antarctica and Greenland, collectively equivalent to approximately 12 metres of sea-level rise. Destabilisation or collapse of these ice sheets would lead to centuries of irreversible sea-level rise and coastal inundation around the world. Global warming as well as the melting of glaciers and ice sheets (which increases the delivery of freshwater to the oceans), could destabilise the global ocean thermohaline circulation. Climate models indicate circulation begins to show signs of moderate weakening for warming of just 1–2^{o}C, and beyond 4^{o}C, some studies suggest the potential for ocean circulation to be pushed to the point of collapse.[10] Such destabilisation could cause regional climate shifts with significant environmental and economic consequences.[91,92]

Melting of the world's great ice sheets as well as the retreat of Arctic sea ice also acts as a positive feedback on global warming – as ice retreats, less solar energy is reflected causing the Earth to absorb more solar energy.[93] Other such feedbacks are also believed to have the potential to enhance climate change. For example, carbon cycle modelling has suggested that forest dieback in tropical regions could ultimately transform the terrestrial biosphere from a sink for carbon to a source – increasing the net concentration of CO_2 in the atmosphere.[94] Recent work in the United Kingdom indicates that climate change is causing carbon to be released from soils at a rate equivalent to almost 10% of the United Kingdom's annual industrial CO_2 emissions – potentially offsetting reductions in human emissions.[95] Paleological data indicate that abrupt climate shifts have occurred in the past as a result of the catastrophic release of greenhouse gases, primarily methane, from methane hydrates in the ocean's sediments. There has been some investigation of the causes of this release,[96] and speculation regarding the potential for anthropogenic climate change to once again destabilise this reservoir.

4. Climate change Impacts in the Asia/Pacific Region

Over the next century and beyond, climate change will result in a broad range of consequences for most regions of the world including the Asia/Pacific.[3] Although climate change impact assessment has been an active area of research for over two decades, this research has intensified in recent years as a result of growing evidence of a human influence on the climate system, direct observations of climate impacts, and increasing concern about the nature of future impacts. Some of these impacts will be large, others small, and some surprises will likely occur.

As is clear from the climate scenarios presented in Section 3, there are significant uncertainties associated with projecting future changes in the climate system and, subsequently, environmental responses to that change. Often one cannot offer specific predictions regarding impacts, their rate of occurrence, magnitude, and likelihood. Instead, impacts are estimated based upon different "if. . . then" scenarios of future changes in temperature and precipitation and how systems may subsequently respond.

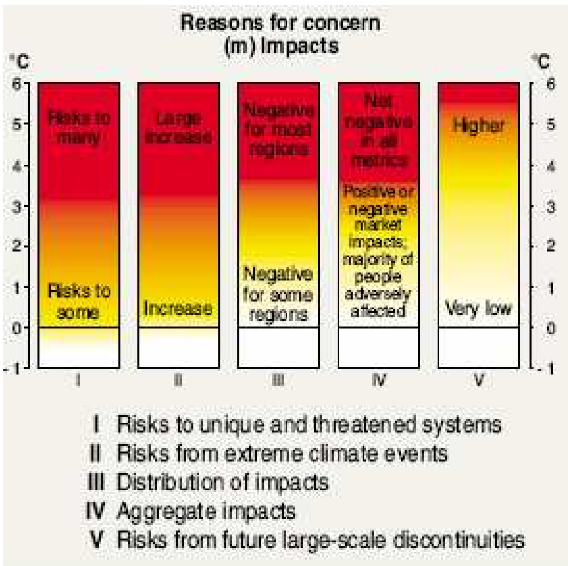

Figure 4.1. *Intergovernmental Panel on Climate Change's "reasons for concern," reflecting the differential vulnerability among systems to climate change and the tendency for impacts to increase with temperature.*

Regardless of a system's vulnerability, impacts will increase with increases in the magnitude or rate of climate change.[37] As suggested by Figure 4.1, the vulnerability of systems to climate change has largely been expressed relative to average global temperature. Yet, other climate changes, and particularly the variability in future climate conditions, are often more important. Impacts to water resources, for example, clearly depend upon changes in precipitation and evaporation. Similarly, in the coastal zone, sea-level rise and storm surge may be more critical drivers than temperature alone. In some situations, climate variables may be highly interactive, meaning the magnitude of change in one variable affects the response of the system to the other. For example, the impacts associated with a large temperature increase may be quite high if precipitation declines, but more modest if precipitation keeps pace with temperature. In communicating the risks of climate change, it is important to acknowledge these complex interactions.

This section summarises a range of climate change impacts, divided into five core sectors: Coastal communities; ecosystems and biodiversity; infectious disease and heat-related mortality; water resources; agriculture and commercial forestry; and regional economies. The general factors that affect the vulnerability of these sectors are discussed, and understanding of the relative vulnerability of individual sectors is informed by reviewing a number of sectoral impact estimates which appear in the scientific literature. A total of 186 estimates were considered (81 at regional scales and 105 at national scales). Individual impact estimates appear in Section 11 as a series of tables indicating impacts across a gradient of temperature increases of <2°C, 2–4°C, and >4°C. Each impact estimate was scored based upon whether it suggests losses or damages to a particular sector, benefits, or spans a range from losses to benefits. A 'weight-of-evidence' approach was then used to assess vulnerability by examining what the balance of impact estimates suggest about future impacts, and these analyses are presented for each sector in the following subsections. In addition, the implications of these impacts for regional human and national security are also discussed.

It should be noted that different impact assessment studies employ different methodological approaches and climate scenarios, and may address impacts at various scales, from regional aggregations to subnational areas. As a consequence, estimates of climate change consequences may vary significantly from one study to another. The results from any one study should not be interpreted as specific predictions of future impacts; rather they represent different estimates of the sensitivity of a particular sector or system to a set of assumptions about a changing climate. Furthermore, because of such variability in potential responses to climate change, no likelihoods are attached to any of the individual impacts estimates that are discussed. Nevertheless, to the extent that multiple estimates consistently indicate adverse consequences for a particular region or sector, this can be taken as robust evidence of significant climate vulnerability.

4.1 Coastal Communities

The coastlines of Asia/Pacific nations are generally highly vulnerable to the effects of climate change, particularly sea-level rise caused by rising global temperatures (see Section 3.5). This vulnerability stems from a number of factors including the geology and geography of some of the region's coastal areas, the growing density of population and infrastructure in the coastal zone, and of course the limited adaptive capacity of much of the region's population. Vast areas of the Asia/Pacific are low-lying (Figure 4.2),[97] particularly the small-island states as well as the large river deltas found in India and Bangladesh, Southeast Asia, and China.[98] Furthermore, large tidal variations, tropical cyclones, and extreme rainfall events are common throughout the region, resulting in frequent coastal and inland flooding. The expectation of stronger tropical cyclones in coming decades, combined with the potential for significant increases in regional rainfall, suggest the potential for increased coastal hazard.

Much of the research conducted on the impacts of climate change on coastal communities is based upon modelling of shoreline inundation or retreat in response to varying magnitudes of sea-level rise and the subsequent implications for exposed populations and economies. Scenarios for sea-level rise are often based upon arbitrary estimates such as an increase in sea-level of 50 or 100 cm. As such, there is a paucity of information available regarding impacts for lower magnitudes of sea-level rise, despite the fact that the effects of sea-level rise are often magnified 100-fold due to coastal erosion.[99] For this report, a number of such studies were reviewed and grouped under three different ranges of sea-level rise: <30 cm, 30–50 cm, and >50 cm. These ranges generally correspond with estimated sea-level rise by 2100 from global warming of less than 2°C, 2–4°C, and greater than 4°C, and are thus consistent with the impacts reported to other sectors in this report.

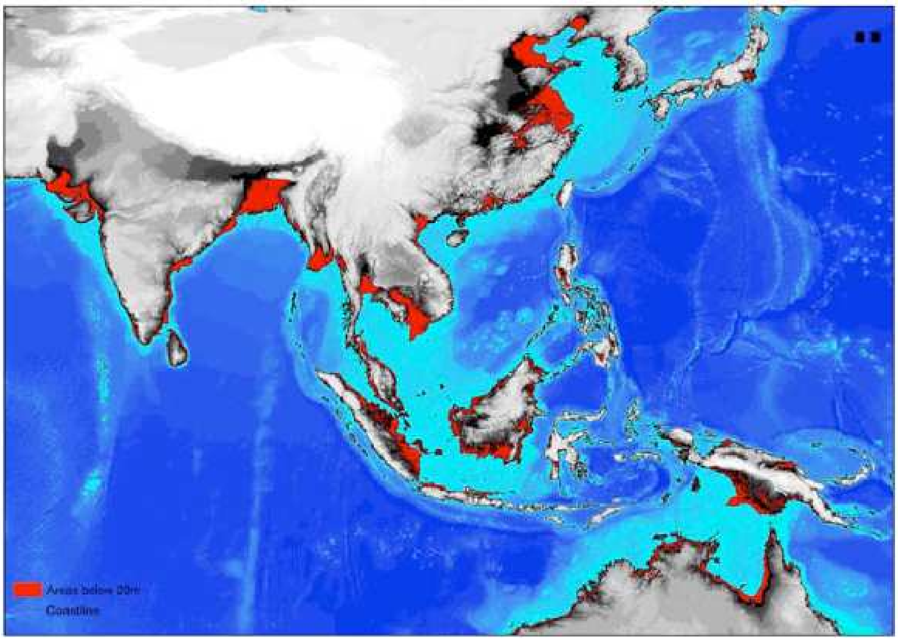

Figure 4.2. *Vulnerability of the Asia/Pacific region to sea-level rise. Land areas in red are below 20 metres in elevation, highlighting the most low-lying areas.*[97]

Table 4.1. Summary of Impact Estimates to Asia/Pacific Coastal Communities[g]

	Regional				National			
	<30cm	**30-50cm**	**>50cm**	**Sum**	**<30cm**	**30-50cm**	**>50cm**	**Sum**
●Loss	0	5	7	**12**	4	7	15	**26**
●Loss/Gain	0	0	0	**0**	0	0	0	**0**
●Gain	0	0	0	**0**	0	0	0	**0**
Total				**12**				**26**

The estimates of Asia/Pacific impacts from sea-level rise are unambiguous in indicating adverse consequences for the regions (Table 4.1). For less than 30 cm of sea-level rise, the island states of Fiji and Kiribati already experience significant losses of land area and subsequent economic consequences (Table 11.1). Similarly, a large area of coastal land is affected in the deltas of Pakistan. However, the modelling conducted for this study indicates that sea-level rise of more than 30cm is not likely to occur until the latter half of the 21st century (e.g., ~2070). With 30-50 cm of sea-level rise, the economic costs in the Asia/Pacific region rise to the hundreds of

[g] *Values in table refer to the number of impact estimates for each sea-level rise category that indicate sectoral losses; losses to gains; or gains in response to climate change. See Section 11 for a list of individual studies and impacts*

millions to billions of dollars per year, and over 100,000 km of coastline experiences the effects. Tens of thousands of square kilometres of land in Bangladesh is lost, displacing tens of millions of individuals. Additional land area is lost in Fiji, Kiribati, and Indonesia, and China faces billions of dollars in costs associated with flooding in the Pearl Delta region. As sea-level rise exceeds half a metre, the area affected in the Asia/Pacific region rises to over half a million square kilometres, affecting hundreds of millions of people. The total costs for protecting Southeast Asia alone are on the order of $300 billion. Large areas of Bangladesh, India, and Vietnam are inundated, and Kiribati, Fiji, and the Maldives are reduced to just a small fraction of their current land area. Modelling suggests these magnitudes of global sea-level rise are not likely to be realised until the end of the 21st century (e.g., 2070-2100).

Box 4.1. Vulnerability of Bangladesh to Sea-Level Rise

Bangladesh is one of the most commonly-cited examples of a nation with a high degree of vulnerability to sea-level rise. Although the northern regions of the nation are associated with steep elevation gradients secure from sea-level rise, extensive areas of the nation along the Bay of Bengal are comprised of low-lying lands at or below 1 metre above mean sea-level. As a consequence, much of this land is thought to be susceptible to inundation as a result of future climate change and the associated sea-level rise. Estimates of the effects of a 1 metre rise in sea-level on Bangladesh indicate the loss of approximately 30,000 km^2 of land area to permanent inundation.[100] Meanwhile, severe tropical cyclones have the potential to cause a storm surge of 3-6 metres.[101]Subsequent erosion of the remaining coastline from sea-level rise and extreme events would contribute to further land loss. The resulting consequences would include:

- ***Displacement of people***
- ***Loss of high-value agricultural land***
- ***Intrusion of saline waters into surface and groundwater***
- ***Increased risk of backwater effects that exacerbate flood risk***
- ***Loss of coastal vegetation and forests***

This vulnerability is exacerbated by the fact that Bangladesh is one of the world's most densely populated nations, with much of that population residing in the vulnerable delta regions. Furthermore, the flood-prone deltas also represent core areas of agricultural production. Sixty-five percent of Bangladesh's land is dedicated to agriculture, which also comprises approximately 23% of the nation's annual GDP (Table 2.1). This large allocation of both land and economic activity to climate-sensitive agricultural enterprises highlights the nation's vulnerability to climate change. Nevertheless, Bangladesh is still not self-sufficient in food resources and has high rates of population growth and low-per capita income, suggesting even more individuals will be vulnerable to climate change in the future. The nation is experiencing relatively rapid economic growth which may enhance the capacity of Bangladesh to cope and adapt to climatic variability and change, including sea-level rise, in the decades ahead.[173] The critical question is whether such resources can be acquired and leveraged on time-scales relevant to offset the rate at which climate change encroaches on the nation's coast.

4.2 Ecosystems and Biodiversity

The ecosystems within the Asia/Pacific region, as well as the rich plant and animal diversity of which they are comprised, represent an invaluable asset at local, regional, and global scales. They contribute directly to regional economies by providing food and water that sustain human life as well as natural resources such as timber and fisheries that support commercial enterprises. The natural amenities provided by Asia/Pacific ecosystems are also increasingly drawing tourism to the region, creating economic opportunity as well as environmental pressures. However, ecosystems also provide a range of indirect services that are often not fully appreciated or valued. Vegetation cover helps purify water as it runs off the land into streams and rivers. Coral reefs and coastal wetlands provide flood defence and buffers to coastal communities as well as nursery area for marine species. Many communities within the Asia/Pacific region are dependent upon such ecosystems goods and services, particularly in the region's least developed countries. Furthermore, the region's environment may have strong cultural significance to its people. Therefore, degradation and loss of species and ecosystems poses a threat to not only the economic, but also the social and cultural stability of the region.

The natural ecosystems and biodiversity of the Asia/Pacific region are considered highly vulnerable to the effects of climate change due to a number of factors. First, various locations within the region, including high altitude ecosystems of the Himalayas and the landscapes of small islands contain a disproportionately high percentage of endemic species that are dependent upon these core habitats. In addition, climate change is likely to affect Asia/Pacific ecosystems as one of a number of important drivers that will have cumulative effects in the decades ahead. Despite rapid growth in conservation and protected areas within the region over the last few decades,[102] land-use change and degradation, overexploitation of water resources and biodiversity, and contamination of inland and coastal waters already threatens many species. For example, in Indonesia, hundreds of mammal and bird species have been declared threatened.[103] In India, up to 1,256 plant species are threatened.[104] The Pacific Islands within Oceania contain the largest number of documented extinctions and are home to more threatened species than any other region in the world.[105]

Projected changes in climate will have diverse ecological implications.[106] Species within ecosystems have an inherent capacity (behavioral, physiological, and genetic) to cope with some degree of climate variability and change, provided it is maintained within a certain range. Yet this coping range can be relatively narrow for many species and may be exceeded by short-term changes in climate extremes or long-term changes in average climate conditions. Habitat for some species will expand, contract, and/or shift with the changing climate, resulting in habitat losses or gains, which could prove challenging, particularly for species that are already threatened or endangered. Research indicates that species exchange among islands is quite high, and climate change may accelerate this process, but the consequences are largely unknown.[107] Changes in habitat (e.g., fragmentation) and the distribution of species also creates opportunities for invasive nuisance species that may be able to capitalise on climate change, disrupting local ecosystems.[108,109]

Recent studies indicate that globally, natural ecosystems are already responding to climate change.[110] For some species, these responses appear to part of coping strategies, for others adverse effects including localised population extinctions have been observed.[111] Observations also indicate that the productivity of the Asia/Pacific landscape has increased over the past 20 years,[112]except in Arid and Semi-Arid Asia and Southeast Asia, where significant declines in productivity have been observed. Increases in productivity must also be considered in the context of trends toward increasing wildfires around the globe.[113] For example, wildfires associated with 1997/98 El Niño event released approximately 2.1 billion tons of carbon to the atmosphere, with 60% coming from Southeast Asia.[114]

Despite the well-known biodiversity of the Asia/Pacific region as well as the chronic challenges associated with environmental management, there is a paucity of specific information regarding the implications of climate change. There is much awareness of the mechanisms by which climate change may affect natural ecosystems and resources in the Asia/Pacific region,[115] but there are limited quantitative estimates of potential impacts under specific climate change scenarios. This stems from a number of factors, including limited assessment capacity within Asia/Pacific nations to conduct such work as well as a disproportionate, but not necessarily misplaced, emphasis in regional impact assessments on natural disasters and issues related to human security (e.g., impacts to food, water, and coastlines) and infrastructure.

In the context of climate change, impact assessment studies have focused on four key ecological aspects of the Asia/Pacific region: coral reef communities, mangrove wetlands, tropical and temperate forests, and high altitude montane species. Each of these is discussed further below, but one should note that ecological impacts from climate change will by no means be limited to these few examples. Furthermore, the studies that exist, though perhaps limited, are generally consistent in finding that climate change will pose adverse consequences to Asia/Pacific ecosystems (Table 4.2; Table 11.2).

Table 4.2. Summary of Impact Estimates to Asia/Pacific Ecosystems and Biodiversity[h]

	Regional				National			
	<2℃	**2-4℃**	**>4℃**	**Sum**	**<2℃**	**2-4℃**	**>4℃**	**Sum**
●Loss	3	3	3	**9**	1	2	0	**3**
●Loss/Gain	0	1	0	**1**	0	2	0	**2**
●Gain	0	1	0	**1**	0	0	0	**0**
Total				**11**				**5**

The Pacific Islands of the Asia/Pacific region contain the largest collection of coral communities in the world, which are relied upon for local populations for beach defence, fisheries, and as an attraction for tourism. The sensitivity of the world's coral reefs to temperature is well-documented. Estimates of the coping capacity of corals suggests that prolonged temperature increases of just 1–2°C above average are sufficient to induce bleaching (Table 11.2).[116] The 1997/98 El Niño event caused widespread bleaching of coral reefs in the Asia/Pacific region including India, the Maldives, Indonesia, Thailand, Cambodia, Malaysia, and India. Modelling studies from the Great Barrier Reef suggest temperature increases may become sufficiently frequent within just a few decades to overwhelm corals recovery mechanisms.[117] A study from Fiji suggests that coral reef impacts from warming of less than 2°C would also cause economic losses to fisheries. Temperature projections indicate warming in the Asia/Pacific region of 1–2°C is possible as early as 2030 and virtually certain by 2070 (Figure 3.1). In addition, ocean acidification from higher atmospheric CO_2 concentrations has been shown to reduce the ability for corals and other organisms to build their calcium carbonate skeletons,[118] although it remains unclear how this effect may interact with temperature changes.[119]

[h] *Values in table refer to the number of impact estimates for each temperature category that indicate sectoral losses; losses to gains; or gains in response to climate change.See Appendix IV for a list of individual studies and impacts.*

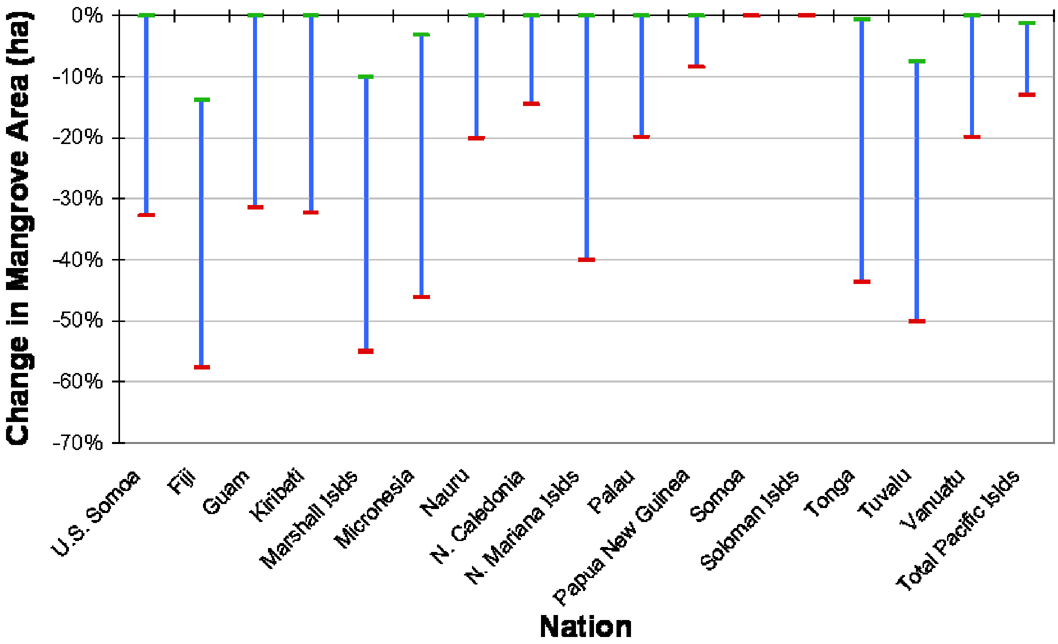

Figure 4.3. *Projected changes in mangrove area in various Pacific Island nations by 2100. Horizontal green bars represent minimum impacts based upon extrapolation of historical sea-level rise. Red horizontal bars represents upper limit of mangrove loss based upon Intergovernmental Panel on Climate Change's upper range of 21st century sea-level rise.*

The Pacific Islands also contain just under 1% of the world's mangrove ecosystems.[120] A recent report by the United Nation's Environment Programme concluded that sea-level rise is likely to adversely affect mangroves throughout the region.[121] Across the Pacific Islands, total impacts range from a loss of 1% of mangrove area, given conservative estimates of future sea-level rise, to a 13% loss (Table 11.2), assuming the Intergovernmental Panel on Climate Change's (2001) upper range for 21st century sea-level rise.[2] However, the impacts to specific locations may be much more significant, with losses of up to 50% or more projected for some island nations (Figure 4.3). Mangrove communities are found throughout the coastal margins of the Asia/Pacific region, and thus such impacts from sea-level rise are likely to be felt quite broadly. The distribution of mangroves in coastal margins can also be affected by rainfall patterns and runoff that alters the flow of freshwater to the coastal zone, and, subsequently, the distribution of appropriate saline habitat for mangroves. Like coral reefs, mangroves provide critical habitat for the Asia/Pacific's coastal biodiversity, shoreline protection, and are valuable resources for human populations. Furthermore, the loss of mangroves to sea-level rise is just one symptom of a larger pattern of regional coastal wetland loss due to climate change, which could reach into the tens of thousands of square kilometres given high magnitudes of global warming.

High-altitude and mountain ecosystems represent another key ecosystem of concern within the Asia/Pacific region. Like small islands, the ecosystems of mountains possess a high proportion of endemic species, which tend to be isolated due to steep gradients in temperature and vegetation along mountain slopes. Snowpack and glaciers are often core characteristics of high-altitude environments, and rising temperatures will alter the timing of snowfall as well as runoff from melting snow and glaciers. A general estimate is that the snowline of mountains will rise 150 m for every 1°C increase in temperature. Warming of 1°C is likely by 2030, and warming in the Himalayas of up to 6–8°C by 2070 suggests substantial changes in mountain ecosystems over the 21st century. Observations from Irian Jaya, West Papua as well as the Himalayas suggest rising temperatures have already affected glaciers in the Asia/Pacific region.[2] Declining snowpacks will have downstream consequences for water resources. It is also assumed that as temperatures increase, cool habitat for plant and animal species will contract upward, potentially resulting in the loss of the coolest habitat. Species will have to migrate to higher altitudes to accommodate the shift in thermal habitat, but the extent to which montane species are capable of such migrations is largely untested. Modelling of biome changes on the arid, high-altitude Tibetan Plateau indicates steppe and desert biomes (temperate and alpine) as well as ice desert biomes will contract as temperatures on the plateau increase (Table 11.2).

Climate change studies suggest that some Asia/Pacific forests and vegetation have the potential to experience some beneficial effects from climate change and enhanced atmospheric CO_2 concentrations (Table 11.2). For example, the decline of steppe and desert biomes on the Tibetan Plateau may be accompanied by an expansion of conifer, broad-leaved, and evergreen forests and shrubland. In addition, studies suggest significant shifts in tree species in China in response to warming of 2–4°C, including the migration of forest communities into non-forest areas of east China. Similarly, vegetation growth is projected to increase throughout most of central China and the Pacific Islands. However, not all studies reflect optimism. It’s been estimated, for example, that climate change will reduce the extent of China’s boreal forests by 70%, and grassland productivity in Arid and Semi-Arid Asia is projected to decline by 40-90%. Vegetation modelling also indicates significant dieback of tropical forests in parts of Southeast Asia. Meanwhile, global studies suggest the potential for significant extinction of plant and animal species in temperate and tropical forests such as those found in the Asia/Pacific region. In addition, climate change is likely to alter disturbance regimes within forest communities, affecting the frequency and intensity of pest outbreaks and wildfire. For example, fire risk is project to increase throughout much of central Asia.

4.3 Infectious Disease and Heat-Related Mortality

Improving the standard of public health in the Asia/Pacific region is a fundamental development goal, and one which necessitates consideration of a range of issues from food security and nutrition, to water resources, to extreme weather events.[122] Climate change is likely to pose a number of challenges for the region’s public health, in both direct and indirect ways. In fact, work by the World Health Organisation suggests that climate change has already taken a human toll in the region, largely due to the effects of climate change on infectious disease.[123]

The direct effects of climate change on human health in the Asia/Pacific tend to be obvious, as they are often associated with extreme weather events and natural disasters. As temperatures increase, for example, the frequency, severity, and duration of extreme heat events is likely to increase. Such events can have significant health consequences, and even in developed countries, represent some of the most lethal forms of extreme weather. In May 2002, temperatures in the Indian state of Andhra Pradesh reached 49°C, resulting in over 1,000 deaths.[124] Tropical cyclones are also a routine danger in the Asia/Pacific region. In 1991, a cyclone struck Bangladesh, killing approximately 139,000 people. While the extent to which climate change is currently affecting cyclone intensities remain unclear, modelling studies consistently project increases in cyclone intensity in a warmer world.[2,125]

Over the long-term, the indirect effects of climate change on human health, though perhaps less dramatic, may prove just as important and costly. In addition to fundamental health considerations such as food and water security, changing climate patterns are projected to alter the distribution of infectious diseases such as malaria, dengue, and schistosomiasis; increase the risk of water-borne disease; and exacerbate air quality. With the exception of east central China and the highlands of west China, much of the Asia/Pacific region is exposed to (or has the potential to be exposed to) malaria and dengue. Modelling studies suggest the region will continue to be a hotspot for both of these diseases in the decades ahead, with some isolated regions becoming more prone to epidemics and others less (Figure 4.4).[126,127] Meanwhile, changing patterns of rainfall, particularly increases in intense rain events, may increase the risk of surface and drinking water contamination and water-borne illness.[128] Work from the United States suggests increases in temperature will exacerbate air quality problems in urban areas, increasing mortality.[129] Such studies are quite relevant to some of the Asia/Pacific's megacities where air quality currently poses a significant health challenge.[130]

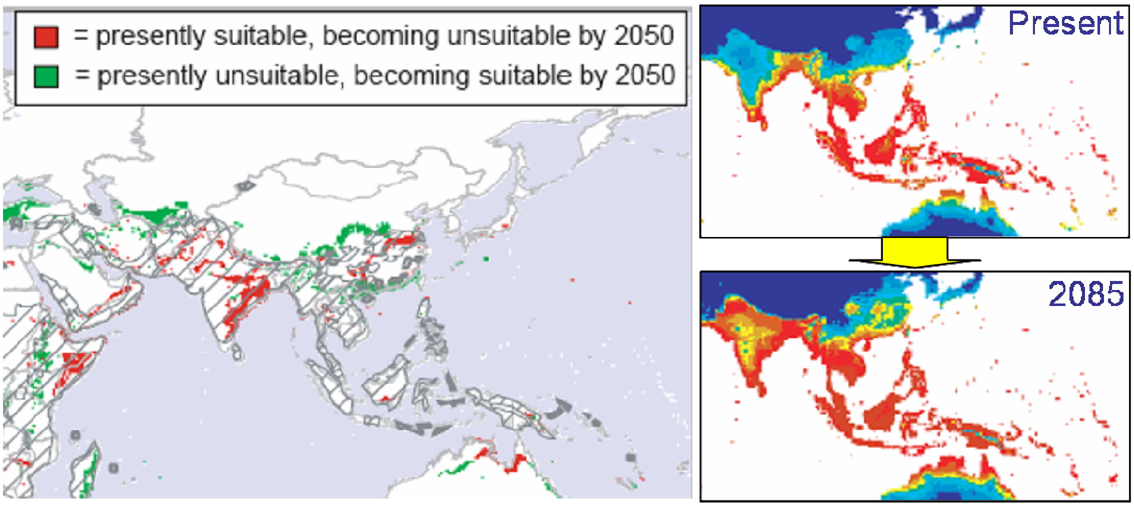

Figure 4.4. *Effects of climate change on malaria (left) and dengue (right) risk in the Asia/Pacific region.[126,127] For malaria, areas in red represent locations where climate change is projected to reduce malaria risk, while areas in green represent locations where risk will increase. For dengue, red areas are those projected to be at high risk, followed by moderate risk (orange to yellow), and low risk (green to blue).*

Table 4.3. Summary of Impact Estimates to Asia/Pacific Infectious Disease and Heat-Related Mortality[i]

	Regional				National			
	<2°C	2-4°C	>4°C	Sum	<2°C	2-4°C	>4°C	Sum
●Loss	5	2	1	**8**	4	6	0	**10**
●Loss/Gain	1	2	0	**3**	0	0	0	**0**
●Gain	2	2	0	**4**	0	0	0	**0**
Total				**15**				**10**

Climate projections indicate the Asia/Pacific region as a whole is likely to become warmer and wetter in the decades ahead, creating conditions more conducive to heat-related illness and death as well as disease vectors such as mosquitoes. Looking across estimates of the effects of climate change on health in the Asia/Pacific, various studies indicate that adverse health effects are likely at relatively low to modest warming of less than 2°C (Table 4.3; Table 11.3). Impacts for this magnitude of warming include additional deaths from malaria and dengue and more intense tropical cyclones, which will increase the risk of injury and death. However, mortality from

[i] *Values in table refer to the number of impact estimates for each temperature category that indicate sectoral losses; losses to gains; or gains in response to climate change.See Appendix IV for a list of individual studies and impacts.*

schistosomiasis is projected to decline. For warming of 2–4°C, the impacts are similar, but more severe, with larger numbers of individuals exposed to or affected by infectious disease as well as rising costs associated with their treatment. While tropical cyclone intensities increase, some high-resolution modelling suggests that the frequency of cyclones will decline. There are few available studies that test the regional or national health response of the Asia/Pacific region to warming greater than 4^{o}C, but at least one reflects a continued upward mortality toll from higher levels of regional warming, with deaths in the hundreds of thousands.

It is important to note that many of the potential health impacts of climate change are closely tied to socioeconomic conditions. Malaria, for example, were once widely distributed throughout North America, Europe, northern Asia, and northern Australia but was largely eradicated through prevention efforts and other socioeconomic changes that reduced human exposure.[131] Therefore, while climatic conditions may dictate the potential range of disease vectors, socioeconomic conditions often dictate the actual prevalence and incidence of disease within human populations. Similarly, water-borne illnesses are another symptom of economic development associated with lack of access to secure drinking water and sanitation while injury and death during extreme events is a function of emergency management and the uptake and use of risk management strategies such as building codes, zoning, or air conditioning. This means that interpreting the future implications of climate change for the health impacts of disease or extreme events must be conducted within the context of current and future social and economic change in the Asia/Pacific region that may enhance or reduce vulnerability.

4.4 Water Resources

Water resources are increasingly a core issue for both the developed and, particularly, the developing world due to limited resources and a growing global population. Water resources supply a broad range of goods and services, including drinking water, waste management, hydroelectric generation, irrigation, recreation and tourism opportunities, and habitat for wildlife. As such, maintaining the security of water resources is a priority for any population, and climate change impacts to water resources may have a broad array of subsequent adverse consequences. Both past and present challenges to water management have demonstrated the powerful influence of climate variability and change. A particular challenge for water resources management are extreme events, such as prolonged droughts which undermine food security, or extreme rainfall events, which increase the risk of flooding.

Water resources management is already a pressing issue for a number of areas in the Asia/Pacific region. Northern China, for example, has been in a water crisis for a number or years, as a result of population growth and water use as well as climate change. The main course of the lower Yellow River often runs dry during summer months,[132] and reduced reliability of other water resources due to land degradation and use is problematic as well. Glacier retreat in the Himalayas as raised concerns about long-term impacts to catchments dependent upon glacier run-off as well as short-term consequences from glacier flood outburst events, which can cause downstream flooding, injury, and death.[133] Meanwhile, water security is also problematic in small-island states, which are often dependent upon limited groundwater, rainfall collection, and to some extent, desalination (e.g. Nauru).[37] Such limited resources and infrastructure must meet all demands – domestic, industrial, and agricultural – making water management and sanitation during periods of water deficit or surplus particularly challenging. For example, El Niño events tend to bring warm and dry conditions to South and Southeast Asia and much of the Pacific Islands, with the exception of Kiribati, Tuvalu, Christmas Island, and the northern Cook Islands, where rainfall increases.[134] Challenges to water resources management may be exacerbated by sea-level rise which contributes to salt-water intrusion into available freshwater resources.

Table 4.4. Summary of Impact Estimates to Asia/Pacific Water Resources[j]

	Regional				National			
	<2℃	2-4℃	>4℃	Sum	<2℃	2-4℃	>4℃	Sum
●Loss	1	6	2	**9**	1	3	0	**4**
●Loss/Gain	0	0	0	**0**	1	3	0	**4**
●Gain	0	1	0	**1**	1	4	0	**5**
Total				**10**				**13**

Impacts assessments examining water resources suggest changing patterns of runoff and river flows in the Asia/Pacific region in the decades ahead, along with increases in water management costs and increases in the number of people experiencing water stress. Temperature projections indicate warming of ~1–2°C across the Asia/Pacific region by 2030 and 1–7°C by 2070. In response to such changes, the regional-scale studies are, on balance, pessimistic, with the majority indicating adverse consequences to water resources (Table 4.4; Table 11.4). Studies looking at temperature increases of less than 2°C, for example, suggest economic losses in South and Southeast Asia. For 2–4°C of warming, millions more individuals are exposed to water stress throughout the Asia/Pacific region. Meanwhile, the costs of water resources management may be positive or negative in Asia, but Oceania experiences economic losses. The two regional studies that explore temperature scenarios beyond 4°C both suggest economic damages in Asia and Oceania. Rainfall projections suggest increasing rainfall throughout much of the Asia/Pacific region, which may ameliorate some of these projected impacts. However, rising temperatures may offset increases in rainfall through evaporative processes, and thus greater rainfall is not necessarily an indicator of greater water security, particularly in the context of growing populations and demands on water resources.

Studies from select nations suggest the potential for both gains and losses (Table 4.4; Table 11.4), largely due to projections of increased runoff in some river basins in response to increasing rainfall. For warming of less than 2°C, melting and runoff from Himalayan glaciers increase while costs for water resources management on the small island state of Kiribati rise to address salt-water intrusion and desalination (Table 11.4). China experiences increases or decreases in runoff among different river systems. For warming of 2–4°C, runoff from Himalayan glaciers continues to rise, although because such runoff occurs at the cost of waning glaciers, such increases in availability are likely not sustainable over the long-term and declines are inevitable. Runoff also increases in Bangladesh but so does the risk of flooding. China experiences increases or decreases in runoff among different river systems, although the nation's interior generally experiences reductions. Water stress in the Mekong Delta rises, and water storages in the Philippines may rise or fall.

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[j] *Values in table refer to the number of impact estimates for each temperature category that indicate sectoral losses; losses to gains; or gains in response to climate change.See Appendix IV for a list of individual studies and impacts.*

4.5 Agriculture and Commercial Forestry

Global agricultural production has been growing at a rate of 2–3% per year for the past four decades, fuelled in particular by growth in developing nations.[135] Nevertheless, there are a number of countries that continue to have high rates of under-nourishment. For example, Bangladesh has low levels of food consumption and has made little progress in reversing this situation over the past several decades.[135] Pakistan and India, though slightly better off, have also experienced sluggish growth in per capita consumption. The Food and Agricultural Organisation projects that growth in global production will slow to just 1% per year over the next several decades, although above-average growth is projected to continue in developing nations.

Despite slowing growth, the net increase in production that is projected is quite substantial. For example, by 2050 global cereal production is projected to increase by 50% relative to 2005.[135] If realised, such growth would significantly reduce the prevalence of under-nourishment in developing nations. For example, the percentages of the population experiencing under-nourishment in East Asia and South Asia are projected to decline from 12 and 22%, respectively, at present to just 3% and 4% by 2050. The composition of food consumption is likely to change as well, particularly as developing nations acquire wealth and access to greater food diversity.[135] Meanwhile, as discussed in Section 4.2, climate change is likely to have important implications for forest ecosystems, and therefore, commercial forestry. Studies indicate that globally, climate change will contribute to increased global timber production, despite (and in many instances because of) shifts in species distributions and forest dieback.

These projections of future global food and timber production and availability remain uncertain and are dependent upon assumptions about socioeconomic trends such as economic and population growth, particularly in developing nations. To what extent might this relatively optimistic outlook be altered by climate change, particularly given current constraints on global water resources and quality crop land? The productivity of crop agriculture, livestock, and commercial forestry is directly influenced by climatic conditions, particularly seasonal patterns of temperature, rainfall, and evaporation.. These variables affect the length of the growing season, the availability of soil moisture for vegetation growth, and under extreme conditions, contribute to heat waves, droughts, and floods that damage crops and livestock and reduce productivity.

In addition, extensive research has identified a CO_2-fertilisation effect, which improves water use efficiency in vegetation, enhancing productivity.[136] The magnitude of this effect varies considerably among plant species, and it remains uncertain to what extent experimental results from one region of the world hold up in other regions. Furthermore, recent research suggests the effects of CO_2-fertilisation may not be as beneficial as originally thought, as other factors such as nutrients and soil quality may also limit growth.[137] Yet consideration of this effect in assessing the potential consequences of climate change to agriculture is essential. Where climate change is likely to benefit crop production, this benefit may be enhanced by CO_2-fertilisation. Meanwhile, where climate change alone is harmful to production, in some instances the effects of CO_2-fertilisation may be sufficient to offset adverse impacts.

It is also important to note that climate change may affect the agricultural sector in a number of ways (Table 4.5). For example, irrigation systems will be affected by changes in rainfall and runoff, and subsequently, water quality and supply. Yet water resources in many nations of the Asia/Pacific region are already stretched thin or challenged in a number of ways, and future climatic change effects on regional rainfall will therefore have both direct and indirect effects on agriculture. In addition, the most productive agricultural areas for a number of Asia/Pacific nations, particularly Bangladesh, Vietnam, and small island states, lie in low-lying coastal margins and river deltas that are prone to flooding. Sea-level rise and storm activity will inundate prime agricultural land and potentially increase periodic crop damage.

Although highly exposed to the weather and climate, agriculture and forestry are managed enterprises, and operations can be potentially upgraded and optimised to reduce vulnerability to climate change. The greater the investments made in agricultural production, however, the greater the consequence of crop failures during extreme years. Nevertheless, agricultural practices throughout the Asia/Pacific region have emerged through generations of experience with climate variability, and coping capacities and resilience of these systems has expanded as technology and knowledge have been built-up and traded with other nations. In addition, agricultural practices such as irrigation and pest control further expand the resilience of these sectors to climate conditions. The extent to which such management tools can be deployed to reduce future vulnerability, however, is arguable and will be closely tied to regional economic development.

Table 4.5. Vulnerability of Asian Sectors Related to Agriculture to Climate Change[138]

Regions	Food and Fibre	Water Resources	Coastal Ecosystems
Arid and semi-arid Asia			
Central Asia	Highly vulnerable	Highly vulnerable	Moderately vulnerable
Tibetan Plateau	Slightly or not vulnerable	Moderately vulnerable	Not applicable
Temperate Asia	Highly vulnerable	Highly vulnerable	Highly vulnerable
Tropical Asia and Small Island States			
South Asia	Highly vulnerable	Highly vulnerable	Highly vulnerable
Southeast Asia	Highly vulnerable	Highly vulnerable	Highly vulnerable

Climate change will likely pose a broad and complex array of consequences for agriculture and commercial forestry in the Asia/Pacific region, with regional winners and losers (even within individual nations), and differential responses among different types of crops (Table 4.7; Table 11.5). Agriculture in China is perhaps a useful demonstration of this complexity and diversity of responses, as climate change will interact with existing land degradation and water scarcity to adversely affect agriculture in some areas, but perhaps enhance agriculture in others (Box 4.2). Both regional and national-scale studies suggest a wide range of potential outcomes to Asia/Pacific agriculture, including both declines in yields as well as increases. Such apparent ambiguity is largely a function of different assumptions within agricultural studies regarding future changes in temperature and, in particular, rainfall, but also the benefits of CO_2-fertilisation and trends in land degradation.

Box 4.2. Climate Change and Agriculture in China

China represents one of the most-well studied nations in the Asia/Pacific region with respect to the impacts of climate change on agriculture. This stems from the size of the country (both in area and population) and its rapidly changing economy and environment. As with other studies of Asia/Pacific agriculture, uncertainty in future climate change makes identifying clear responses difficult (Table 4.6; Table 11.6). Up to approximately 2℃, studies suggest benefits for rice, maize, and wheat, although one study finds modest reductions in agricultural revenue. For 2–4℃ of warming, some studies suggest rice, maize, and wheat yields will increase, although the gains tend to be larger for dryland cropping due to a greater benefit from the CO_2-fertilisation effect relative to irrigated crops. Yet, results for maize and rice are not consistent across studies, as the majority of studies suggest sizeable reductions in yields are possible. Similarly, some studies also suggest reductions in net agricultural production and the potential for declines in agricultural revenue. Beyond 4℃, studies are generally negative, indicating declining rice yields and revenue, and the sustainability of certain crops under more extreme scenarios of climate change is questionable. This is particularly problematic for China, which is projected to experience some of the most significant warming in the Asia/Pacific region, with central estimates of 2–3℃ by 2070 in central and northeast China, and the potential for approximately twice this magnitude under a worst-case warming scenario (Figure 3.1).

Table 4.6. Summary of Impact Estimates to Agriculture in China[k]

	<2℃	2-4℃	>4℃	Sum
●Loss	1	1	1	**3**
●Loss/Gain	0	10	1	**11**
●Gain	3	2	0	**5**
Total				**19**

Crop modelling studies also indicate a high degree of spatial variability with respect to climate change impacts in China. Crop yields in northeast China appear to be more vulnerable, with studies suggesting declines in yield in response to climate change, while the southeast appears to be a region of relatively lower vulnerability and the potential to realise some benefits.[218,139,140] Two of the critical factors affecting agriculture in China are the fate of the nation's water resources in response to climate change, which is dependent upon seasonal rainfall patterns, and CO_2-fertilisation. Northeast China is currently in the midst of a water crisis, and planning is underway for large-scale diversion projects to bring water from more southern areas to the troubled northeast.[141] Modelling of China's water cycle in response to climate change has suggested increased rainfall and soil water in southeast China, but decreases in the northeast, consistent with modelling of agricultural yields.[139] However, the projections generated for this report, which draw upon a wider range of models, reflect a different picture – one of increasing rainfall in northeast China throughout much of the year, but declining winter rainfall in southeast China (Figure 3.2). Therefore, water stress in northern China may be alleviated by climate change, though human water demands will continue to drain resources. Meanwhile, studies also suggest that the fate of China's agriculture is highly dependent upon the strength of the CO_2-fertilisation effect. When excluded, impacts are negative across all major crops, while

[k] *Values in table refer to the number of impact estimates for each temperature category that indicate sectoral losses; losses to gains; or gains in response to climate change.See Appendix IV for a list of individual studies and impacts.*

inclusion of the effect offsets losses and generally yields benefits.[218] It is clear that much of the estimates of China's agriculture under a changing climate hinge heavily upon assumed CO_2-fertilisation effects, and uncertainty persists as the extent of the benefits that can be realised. Therefore, should current estimates of the benefits of CO_2-fertilisation prove overly optimistic, the effects of climate change on China's agriculture may shift more decisively toward more pessimistic outcomes.

Studies which take a regional view generally lean toward damages to agricultural production for warming of less than 2°C, although one study suggests that rice yields across Asia will increase. For warming of 2–4°C, the majority of studies suggest the potential for both gains and losses, depending on the region under consideration and assumptions about climate change. Yet studies of cereal and rice production in South Asia indicate declining yields while crop quantities increase in Southeast Asia and East Asia. Asia/Pacific commercial forestry is also projected to benefit. Above 4°C, the majority of studies again indicate the potential for both gains and losses. Those studies that are less ambiguous project benefits in Southeast Asia and East Asia, but a number of studies project net economic damages to the agriculture and forestry sectors in Asia as whole, and Southeast Asia and Oceania, specifically.

Table 4.7. Summary of Impact Estimates to Asia/Pacific Agriculture and Commercial Forestry[l]

	Regional				National			
	<2℃	2-4℃	>4℃	Sum	<2℃	2-4℃	>4℃	Sum
●Loss	1	2	3	7	3	5	5	13
●Loss/Gain	2	6	2	9	0	21	2	23
●Gain	1	5	2	8	3	4	2	9
Total				23				45

At the national level, studies suggest that some nations will gain from climate change while others will lose. For less than 2°C, for example, rice yields in one state of India increase, but agricultural losses are experienced in the Philippines and Fiji. The outlook for 2–4°C of warming is mixed – rice and wheat yields in Bangladesh tend to decline, and some studies suggest declining yields in cultivable land as well as net economic losses in India. Meanwhile, rice yields in Indonesia and Malaysia are projected to increase. The majority of studies, however, indicate that the fate of agriculture in a number of nations is tied to assumptions about climate change. For warming greater than 4°C, national studies suggest declining rice yields in Bangladesh, India, the Philippines and Thailand, but increases in Indonesia and Malaysia.

Looking across the various regional and national studies, it remains difficult to develop a robust picture of the effects of climate change on regional agriculture and forestry. There do appear to be some clear regional losers, such as Bangladesh and small island states within Oceania. These represent nations within highly vulnerable agricultural systems that are exposed not only to the effects of temperature and rainfall changes, but also sea-level rise. The reliance of these nations upon subsistence agriculture suggests the potential for significant adverse consequences from climate change-induced reductions in crop yields. Multiple studies indicate that climate change

[l] *Values in table refer to the number of impact estimates for each temperature category that indicate sectoral losses; losses to gains; or gains in response to climate change.See Appendix IV for a list of individual studies and impacts.*

has the potential to inflict similar damages throughout the rest of the region, depending upon how regional climate changes manifest.

The climate projections generated for this report generally indicate increasing rainfall throughout much of the region, including during the critical summer monsoon season, which may bode well for agricultural production. Nevertheless, changing monsoon variability and the dynamics of extremes may offset the benefits. Rainfall is projected to decline in Arid Asia, India, and Southeast Asia during the winter monsoon. The implications of this for regional agriculture merit closer examination. Any benefits of climate change to regional agriculture may prove transient and be reversed as the magnitude of climate change grows. For example, recent work by Mendelsohn (2005) indicates agriculture benefits throughout Southeast Asia nations given moderate magnitudes of warming and increasing rainfall, but significant adverse impacts from larger magnitudes of warming and/or significant reductions in rainfall.[205] Even with rainfall increases, rising temperatures may pose a challenge to agriculture, stressing crops and reducing yields. Central estimates of climate change suggest relatively large increases in temperatures of 2–3°C by 2070, with the potential for warming in excess of 5°C for continental Asia.

Unfortunately, specific studies of climate effects on agriculture in a number of nations, particularly small island states, in the Asia/Pacific region are lacking. Those that do exist often generate highly uncertain results that are not always consistent, in part due to dissimilar assumptions about future climate changes (e.g., changes in rainfall). It is also important to note that the fate of food security in the Asia/Pacific region will likely be driven largely by socioeconomic trends that affect production, supply, and demand. To the extent that nations are able to develop high-yield, sustainable agriculture and mature their economies, their ability to cope with climate change is likely to grow as well. Where persistent or emergent problems lie with food security, economic growth, and governance, however, is where climate change impacts may be more critical.

4.6 Regional Economic Impacts

Several attempts have been made at estimating the net economic costs that climate change might inflict upon the world or specific regions. Such analyses are potentially quite relevant, given the close connection between the status of Asia/Pacific economies and their vulnerability and capacity to cope with the effects of climate change. However, a number of limitations of such studies leave them vulnerable to underestimating the net economic impacts as well as the human and ecological toll of climate change. Studies tend to focus on direct market costs of a few sectors (e.g., agriculture, tourism, water, forestry, fisheries, and energy), but overlook non-market costs that are difficult to quantify in economic terms such as health and ecosystem goods and services.

Furthermore, economic assessments often aggregate economic impacts across broad geographic areas. This invariably masks significant consequences to local economies. An assessment of economic impacts on the entire economy of the Asia/Pacific region would, for example, aggregate the large economies of China and India with the much smaller economies of some of the Pacific Islands, precluding the examination of the geographic diversity in economic consequences. An example from the Intergovernmental Panel on Climate Change's *Third Assessment Report* demonstrates some of the potential pitfalls in such quantifications. Assuming climate change causes environmental and economic damage in Bangladesh equivalent to 80% of its GDP, this loss would amount to only 0.1% of global GDP and would slow the rate of global economic growth by less than three weeks.[42] Thus catastrophes at the local scale may be relatively innocuous at the global scale when viewed through a strict economic lens, thereby neglecting the real human and environmental toll. Therefore, the results from economic studies should be cautiously interpreted. Nevertheless, the fate of Asia/Pacific economies in response to climate change is likely to be of interest to regional decision-makers.

The few estimates of impacts to Asia/Pacific economies from climate change that are available generally indicate climate change will pose net economic damages to the region (Table 4.8; Table 11.7). The majority of regional scale studies indicate economic losses to South and Southeast Asia as well as Oceania, although one study indicates the potential for net economic gains for Asia as a whole. Similarly, the majority of national scale studies also indicate economic damages are likely. For example, one study indicates the potential for annual GDP impacts of 2.4% on Sri Lanka for less than 2°C of warming. In comparison, the Indian Ocean Tsunami in 2004 caused direct damages equivalent to 4.5% of Sri Lanka's GDP, with an additional 7.5% of GDP required in financing relief and reconstruction efforts.[142] For 2–4°C of warming, studies indicate economic losses in India, Bangladesh, Indonesia, and Thailand, while one study suggests the potential for modest economic benefits in China. Given central estimates of temperature increases in the Asia/Pacific region by 2070 are on the order of 2–3°C, these economic impacts are, unfortunately, well within reach. It should be noted that the distribution of economic damages and benefits may be highly variable, even within individual nations. For example, rural areas dependent upon subsistence agriculture are likely more vulnerable to potential climate consequences than urbanised areas with more diverse economies including manufacturing and service sectors.

Table 4.8. Summary of Impact Estimates to Asia/Pacific Economies[m]

	Regional				National			
	<2°C	2-4°C	>4°C	Sum	<2°C	2-4°C	>4°C	Sum
●Loss	1	3	2	**6**	1	4	0	**5**
●Loss/Gain	1	1	0	**2**	0	0	0	**0**
●Gain	0	1	0	**1**	0	1	0	**1**
Total				**9**				**6**

Although these studies indicate that climate change will have real consequences for the economies of the Asia/Pacific region, the impacts must be viewed in the context of continued regional economic growth. On one hand, in the face of continued economic development, the annual damages from climate change may represent a declining fraction of the economy. As such, the average long-term economic impacts in any given year may have little influence on national to regional prosperity. On the other hand, an analysis by the reinsurance company Munich Re highlights the fact that economic damages from natural disasters have grown over time in conjunction with economic growth.[143] Therefore, the relevant economic implications of climate change may be the potential for increased climate variability and extreme events (e.g., cyclones, droughts, and floods) that cause significant loss of life and economic damage, often shattering local economies and requiring significant foreign assistance to aid in relief and reconstruction efforts.

[m] *Values in table refer to the number of impact estimates for each temperature category that indicate sectoral losses; losses to gains; or gains in response to climate change.See Appendix IV for a list of individual studies and impacts.*

4.7 Cross-Sectoral Synthesis

The review of climate change impact assessment studies from the Asia/Pacific region enables one to draw some general conclusions regarding its vulnerability. Of the 186 impact estimates reviewed for this report, the majority provided a clear indication of adverse impacts. Sixty-two percent of regional and 58% of national estimates indicated adverse impacts, while only 19% and 14%, respectively, indicated benefits Figure 4.5). However, 20–28% of estimates suggested the potential for either adverse or beneficial consequences from climate change, depending on assumptions.

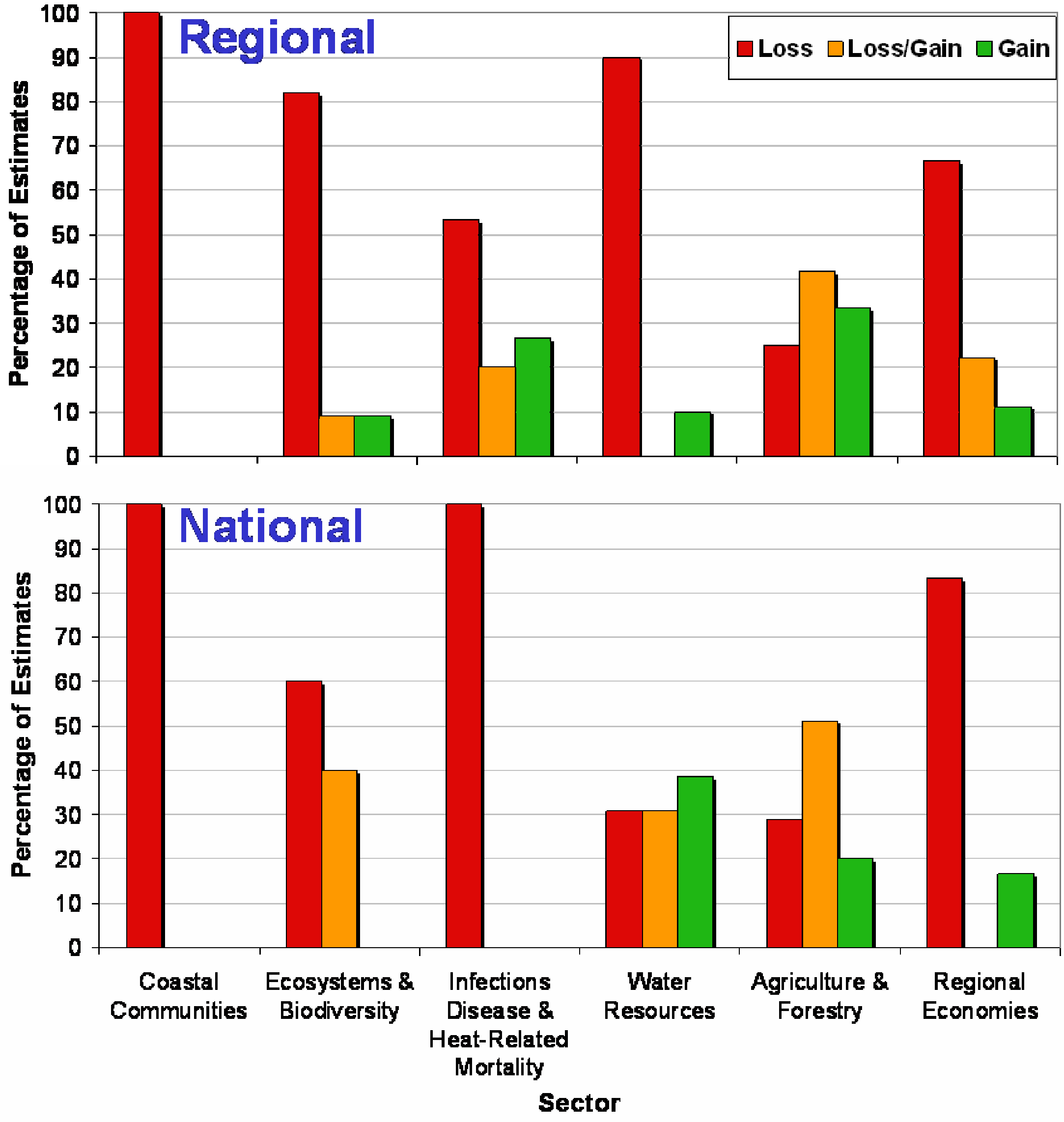

Figure 4.5. *Indicators of the vulnerability of several Asia/Pacific sectors to climate change. Individual estimates (n=186) of climate change impacts are presented as a percentage of sectoral estimates that reflect losses from climate change, gains from climate change, or the potential for both gains and losses, depending upon study assumptions.*

The vulnerability of different sectors varied significantly. One hundred percent of the regional and national estimates of the impacts to coastal communities indicate adverse physical and economic consequences in the region, which grow progressively worse with higher magnitudes of sea-level rise. Results for the regions' ecosystems and water resources are similarly pessimistic, although national-scale ecosystem impacts may prove beneficial for some species and biomes while negative for others. Despite some potential for reductions in schistosomiasis and localised reductions in malaria risk in the Asia/Pacific region, the majority of studies also indicate the implications of climate change will be largely adverse for infectious disease and other health threats. At the regional scale, impacts to water resources are decisively negative, although at smaller geographic scales, individual nations or subregions may experience increased water availability due to higher rainfall amounts and subsequent runoff. Uncertainty in future regional rainfall regimes means that crop agriculture and commercial forestry at both regional and national scales could experience benefits or losses, although some nations appear to be clear losers, such as Bangladesh and the Pacific Islands. Finally, the majority of studies indicate climate change will damage Asia/Pacific economies, although the potential for economic benefits in some subregions does appear in the literature.

It is important to note, however, that the impacts of climate change will not be isolated within individual sectors. In reality, the individual sectors identified above function as inter-connected units. Agriculture, water resources, and economic growth cannot truly be separated from the health of human populations and communities, and rising sea-levels and coastal erosion degrade coastal wetland ecosystems and habitat as readily as they undermine human settlements and enterprises. While is it possible to identify glimmers of hope for individual sectors in individual regions, when viewed collectively, the body of impact estimates reviewed for this report indicate a high degree of vulnerability and potential for significant adverse consequences. While communities may have the capacity to cope with individual sources of stress, managing multiple risks is a substantially more challenging undertaking. Yet it is quite likely that some nations and communities will indeed face climate challenges from multiple directions, and it is such cumulative effects that may prove most threatening to regional prosperity and sustainability.

One must also be mindful of the fact that such environmental challenges will manifest within the context of Asia/Pacific's ongoing social, economic, and environmental changes. Many areas within the region are already marginal for water availability and agricultural productivity. The water crisis and growing desertification in China is a case in point. Ecosystem degradation through resource exploitation and land-use change is a pervasive problem. Malaria and dengue are endemic in some areas. Variable economic performance suggests the potential for growing opportunity and capacity to manage future climate risk in some nations while others continue to struggle to simply cope with current climate variability. As a consequence, seemingly small changes in climate and marginally more challenging environmental conditions may be sufficient to exceed the coping ability of some communities or ecosystems. Alternatively, rapidly changing economies and dynamics of global trade may significantly reduce the sensitivity of human populations to climate change. For example, the tourism trade is currently transforming the economies of some small island nations, such as Vanuatu and Fiji. If pursued in a sustainable and equitable manner, such developments may help insulate some areas and populations from the adverse effects of climate change. Such competing assumptions about future socioeconomic change and adaptive capacity are often excluded from impact assessments, but will certainly have important implications for the fate of the Asia/Pacific region in a changing climate.

4.8 Climate Impacts and Human and Regional Security

The potential implications of climate change are increasingly being viewed within the larger context of human security. A recent report on the status and trends of conflict around the world "red-flagged" six nations in the Asia/Pacific region and "yellow-flagged" twelve due to security concerns stemming from a range of issues including armed conflict, human security, effectiveness of governments, and social capacity.[144] Generally, the Asia/Pacific region experiences a relatively high number of ethnopolitical and armed conflicts compared to other regions of the world.[145] How might future climate change interact with these existing regional security challenges?

Failures in food and water security, natural disasters, and progressive degradation of ecosystem goods and services are all factors that can act to undermine human security and threaten the health and sustainability of communities and entire nations. As a consequence, the aforementioned impacts of climate change on the Asia/Pacific region pose a challenge to human security across a range of geopolitical scales. According to Dupont and Pearman (2006),

> ***"The reality is that climate change on the order of time frames predicted by climate scientists poses fundamental questions of human security, survival and the stability of nation states which necessitates judgments about political and strategic risk as well as economic cost."***[146]

Dupont and Pearman (2006), go on to identify a range of potential mechanisms by which climate change may jeopardise human security:

- **Adverse effects on food, water and energy**
- **Unregulated migrations within the Asia/Pacific region**
- **Natural disasters**
- **Enduring health issues associated with poverty, food and water-borne illness and infectious disease**
- **Reductions in local and national carrying capacities, undermining legitimacy and confidence in government**
- **Climate surprises such as collapse of the global oceanic thermohaline circulation system or a collapse of ice sheets of Greenland and/or West Antarctica**

The greater the extent to which societies are dependent on climate-sensitive enterprises, the greater the risk of threats to human security. Yet, climate change will not threaten human security in isolation. Undoubtedly, current socioeconomic conditions, environmental status, and geopolitical relationships within the region are critical factors affecting human vulnerability. Although climate change is quite likely to interact with such factors, the implications remain speculative and are likely to vary considerably from one location to another. Nevertheless, uncertainty regarding the rate and magnitude of future climate change as well as the potential for large-scale consequences suggests the need for a precautionary approach to the issue and careful consideration of how interactions among climate change and human and national security may play out in the future.[146]

One of the central issues with respect to climate change and security is that of human displacement and migration. Archaeological evidence indicates that human populations have been migrating within Pakistan and India for the past 10,000 years in response to changing dynamics of the summer monsoon.[147] Some may view such migrations as voluntary, adaptive processes. Yet, it has been hypothesised that unregulated migration in response to climate change-induced displacement may contribute to security issues as migrants move to new regions without social support mechanisms or sufficient resources to assimilate or establish stable communities. This may be particularly problematic if migration causes conflicts between migrant and native groups as a result of ethnic, cultural, or economic grievances.

Environmental displacements of human populations may result from three basic causes a) short-term events such as natural disasters; b) long-term environmental change that induces individuals to move away from degraded environments that can no longer sustain the population; and c) development of new infrastructure for environmental management (e.g. dams). Nicholls (1995) estimated approximately 150 million individuals would be affected in various countries in the Asia/Pacific region by 1 metre of sea-level rise, [148] and Myers (1993) estimated 75 million individuals would be displaced by climate change in Bangladesh, China, and India by 2050.[149] More recently, Tol (2002) estimated approximately 2.3 million migrants from South and Southeast Asia as a result of 1 metre of sea-level rise.[150] Meanwhile, damming of waterways in India and China has historically forced the displacement of millions of individuals – a consequence of environmental management efforts to provide drinking water, irrigation, and flood control. It is estimated that the recently completed Three Gorges Dam in China, for example, will ultimately displace 1.2 million people.[151] Attempts to engineer the environment to compensate for future climate impacts could also drive future displacement of communities.

Although it is likely that climate change will ultimately force the displacement of some populations within the Asia/Pacific region, considerable uncertainty persists regarding the number of individuals that will be displaced, whether those displacements will drive internal or external migration, the extent to which human adaptation can reduce displacement, and the extent to which migration will jeopardise human security. Furthermore, very little is known regarding how climate change will interact with existing migration pressures and incentives emerging from economic globalisation and other forms of environmental degradation. Experience with prior natural disasters in different regions of the world demonstrates that various factors including access to information, assistance, and transport as well as social and cultural ties to land affect mobility and the capacity to migrate. Compare and contrast the natural disasters of hurricane Katrina which made landfall in New Orleans, USA in August, 2005 with the Indian Ocean Tsunami which devastated Indonesia, Thailand, and Sri Lanka in December of 2004. Whereas the survivors in Aceh, Indonesia remained in place, rebuilding and recovering with foreign assistance to the best of their ability, tens of thousands of displaced residents of New Orleans have relocated to other cities within the United States.

One likely outcome over the next few decades will be a growing build-up in the number of individuals within the Asia/Pacific region seeking regulated migration opportunities. For example, citizens of Samoa, Fiji, Tonga, Kiribati and Tuvalu are eligible to apply for New Zealand residence under the Samoa Quota and Pacific Access Category immigration policies.

During 2005 and 2006, approximately 17,000 applications were filed for residency under these programs, compared with just 4,000 in 2003.[152] Although such interest in migration stems from a range of issues, not the least of which is economic opportunity, it is rather easy to see how climate change could contribute to similar interest and demand for migration options within nations where climate change exacerbates other issues to limit economic development and human security.

Growth in demand for migration, however, does not necessarily mean that opportunities for migration will be available or expand accordingly. This raises a number of challenging questions, particularly for small-island states where the long-term sustainability of some islands and communities is in doubt. At present, there is no legal or logistical framework within the region for addressing migration under these circumstances. Furthermore, given one-way flow of migrants out of trouble areas, it is difficult to foresee how conditions and opportunities for those that remain behind may be affected, particularly given that migration opportunities will likely fall preferentially to those with economic resources, education, and skills. Hence, increasing globalisation, mobility, and pressures including climate change within the Asia/Pacific region will likely require careful management to ensure equitable development continues despite shifting preferences and opportunities among the region's residents.

It has also been postulated that climate change impacts on human security could potentially become sufficiently severe as to induce, or at least contribute to, violence that threatens to elevate human security concerns to national and regional security issues.[153] Some of the commonly cited causes of violence and armed conflict include chronic poverty, sudden contraction of livelihoods, failed states, and involuntary relocation. Nevertheless, states with high rates of poverty and underperforming governments do not necessarily deteriorate into violence. Recent indicators suggest a general decline in armed conflict around the world over the past two decades, including developing nations affected by chronic poverty.[144] Barnett and Adger (2005) emphasise the importance of human agency in the development of violence, or, put simply, people choose to engage in violent behaviour.[154] Put in this light, the question becomes one of how might climate change increase the propensity for individuals to engage in violence. Unfortunately, there is currently little analysis that can aid in answering this question. Studies of violent conflict, however, suggest that violence emerges as a means of obtaining resources that are perceived to be otherwise unobtainable.[154] This economic rationality argument agrees well with the correlation between poverty and violent conflict in developing nations, although it does overlook other important considerations such as leadership, grievances, and group identities.

Barnett and Adger (2005) also emphasise the roll of the state in security, noting that the existence of a strong, effective liberal-democratic state reduces the risk of violent conflict.[154] Weak or failed states that are poor performers at providing security, equity, and opportunity for their citizenry are more likely to be rejected and challenged by the populace, contributing to an erosion of authority. Therefore,

> ***"understanding the way climate change may increase the risk of violent conflict therefore also requires understanding the way it may weaken (or strengthen) the capacity of States to provide or deny opportunities for people, and manage globalisation."***[154]

Many of the impacts of climate change affect systems and sectors that are traditionally public goods or state sponsored (or at least state regulated) enterprises: ecosystem goods and services, water resources, public health, infrastructure and land-use planning, and emergency management. As such, adverse climate impacts may be perceived by the public as failures in governance, lowering confidence in state institutions, particularly if climate change impacts occur in a larger context of weak statehood where there are existing grievances among the public. Although much of current thinking about climate change and security remains speculative, this points to a general path forward for the management of climate change – namely, continued economic development in conjunction with the maturation of strong, democratic governments that have the capacity to provide for basic human security and equality while managing the risks of climate change.

5. Regional Adaptation and Capacity-Building

5.1 Climate Adaptation: Terms and Definitions

Adaptation is a risk-reduction strategy for ameliorating the adverse effects of climate change on human and ecological communities and for capitalising upon potential opportunities. Specifically, adaptation refers to actions, policies, and measures that increase the coping capacity and resilience of systems to climate variability and climate change (see Box 5.1).[155] Whereas greenhouse gas mitigation ameliorates risk by reducing the magnitude and rate of climate change (see Section 1.2), adaptation reduces the residual risk between what is achieved via mitigation and that degree of climate change to which the Earth is already committed.

Box 5.1. Coping Capacity, Resilience and Adaptation to Climate Change

To better understand the benefits of adaptation for reducing adverse consequences of climate change, it is useful to consider the concepts of ***coping range*** *and* ***resilience range****. Coping ranges represent the magnitude or rate of disturbance communities, enterprises, or ecosystems can tolerate without significant adverse impacts or the crossing of critical thresholds.[156] For example, flood defences are designed to cope with water levels up to a certain magnitude, often those estimated to be of an infrequent return period (e.g., 1 in 50 or 1 in 100 year flood levels). When water levels exceed this coping range, the network of flood protections fail as a viable means of defence and damages occur.*

The ***resilience range*** *is the magnitude of damage a system can tolerate and still autonomously return to its original state.[157] Qualities that convey resilience include the ability to mobilise equipment, personnel, and financial resources; the availability and effectiveness of emergency management efforts; and the ability to rebuild, recover, and restore affected systems to their original level of production or service delivery. Returning to the example of flood, once the coping capacity is exceeded, societal and environmental damage will occur, and the resilience range represents the magnitude of the flood from which systems can recover. To the extent that flood damages are minor and/or covered by insurance, individual property owners may be able to recover relatively quickly and resume prior activities. Once that resilience range is exceeded, however, a community may not be able to recover independently, and external intervention is required.*

The goal of adaptation is to expand both the coping and resilience ranges of systems that are vulnerable to climate change. Expansion of the coping capacity increases the ability of systems to tolerate variability in the climate system without adverse effects, while expanding the resilience range enhances the capacity of systems to recover in the event that coping ranges *are exceeded and damages occur. Bolstering coping and resilience ranges is particularly important for developing nations such as those common within the Asia/Pacific region. Climate events of relatively moderate magnitude or frequency are sufficient to exceed coping ranges and cause damage, and when damages occur, the ability of nations to recover is also limited, slowing the rate of return and increasing the chance of persistent social, environmental, and economic harm. Recent experiences with natural disasters in the Asia/Pacific region including the 2004 Indian Ocean Tsunami and the 2005 Kashmir earthquake in Pakistan, though not related to climate change, demonstrate that developing nations have limited capacities to independently marshal aid to recover from disaster and significant external assistance was required to augment national resilience to put affected nations on the, sometimes lengthy, path to recovery.*

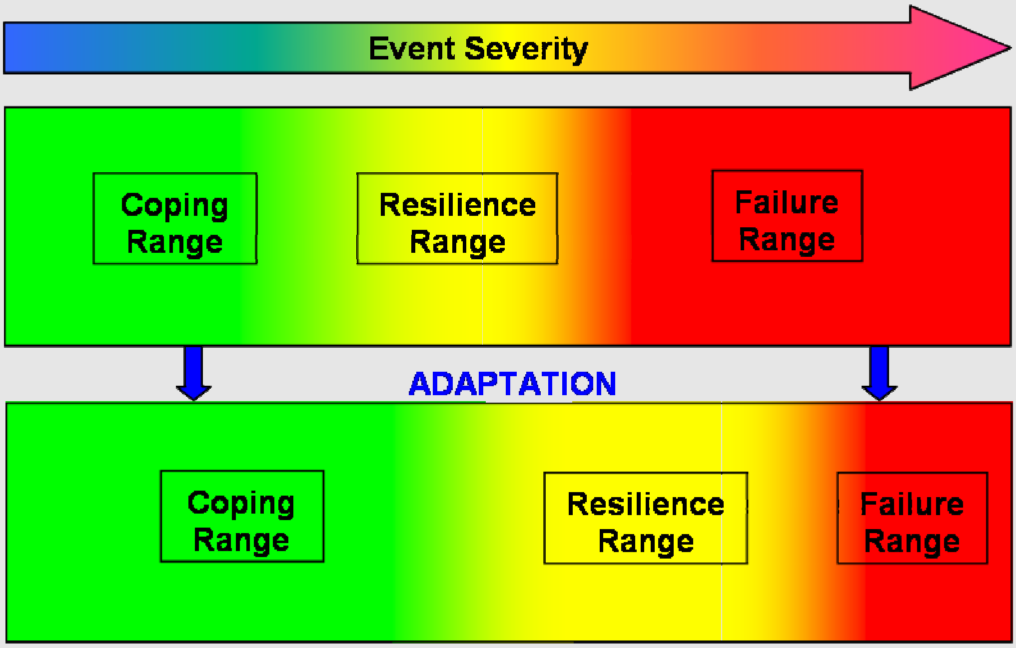

Figure 5.1. *Relationship between adaptation, coping ranges, and resilience.*

Adaptation is implemented along two fundamental pathways.[158] *Autonomous* adaptation represents those actions that are taken as individual institutions, enterprises, and communities independently adjust to their perceptions about climate risk. Such autonomous actions may be short-term adjustments achieved via internal decision-making and are often considered to be reactive processes that occur from the bottom-up. In contrast, *anticipatory* adaptation represents more proactive decision-making, where expectations of long-term changes in the climate system are incorporated into present decision-making to prepare systems to cope with climate change well in advance of the those changes. Such anticipatory adaptation would likely progress form the top-down, through regulations, standards, and investment schemes. Such anticipatory thinking is particularly critical for decisions that have long-term implications, such as the design and citing of long-lived infrastructure.

The extent to which adaptation actions can be implemented to increase coping capacity and resilience is referred to as *adaptive capacity*. One of the central issues at play in adaptation is the fact that adaptive capacity varies considerably from one nation, or even one community, to another. Such variability in adaptive capacity is a function of differential capabilities within nations and communities with respect to financial resources, technology, expertise, and economic diversification that are often called upon to implement adaptation actions. For example, low literacy rates, corruption, and stagnate economic growth are all recognised as indicators of low adaptive capacity that limit the ability of nations to recognise and prioritise climate change impacts, as well as plan, design and implement adaptation actions. As such, the issue of adaptive capacity is perhaps one of the most important considerations in preparing the Asia/Pacific region for climate change (see Section 5.3).

5.2 Summary of Adaptation Strategies

There are a wide-variety of specific adaptation strategies that may be effective in increasing the coping capacity and resilience of communities, nations, and ecosystems of the Asia/Pacific region (Table 5.1). The appropriateness of a particular strategy is likely to be highly place and time-dependent, as climate vulnerability varies considerably from one location to another, and climate risk may change over time. In addition, different communities and cultures may place greater or lesser value on different consequences and thus may have strong preferences for different types of adaptation measures.

The costs and benefits of a particular strategy may vary considerably and be difficult to quantify. Large-scale infrastructure such as new dams or coastal defences can be quite costly and require significant lead-up times for design and construction. In contrast, educating the public about climate change or the establishment of early warning systems may be relatively low-cost options that can be implemented rapidly. Examples of potential adaptation costs from Samoa sum to approximately 1.4 million US$ per year, not including fixed investments in infrastructure updates.[188] While costing individual projects may be a rather straightforward process, estimating project benefits is a more difficult challenge. Over the near-term, distinguishing climate variability from anthropogenic climate change will continue to be quite difficult, and thus determining the return on an adaptation investment is likely to be somewhat speculative. Nevertheless, assessments of the economics of 'climate proofing' communities in the Cook Islands and the Federated States of Micronesia indicate that the benefits of investments in adaptation outweigh the costs, as they reduce damages from both current climate variability and extremes as well as future climate change.[87]

Box 5.2. Six Reasons to Adapt Now[159]

1) *Climate change cannot be totally avoided.*
2) *Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting.*
3) *Climate change may be more rapid and more pronounced than current estimates suggest. Unexpected events are possible.*
4) *Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events.*
5) *Immediate benefits also can be gained by removing maladaptive policies and practices.*
6) *Climate change brings opportunities as well as threats. Future benefits can result from climate change.*

In light of such uncertainties, one potential path forward for adaptation is to identify 'no regrets' actions that reduce vulnerability to climate change but are low-risk in themselves in that they are not sensitive to future assumptions about the rate and magnitude of future climate change. Two types of approaches to 'no regrets' adaptation include:

Actions that reduce existing vulnerability – The most straightforward example of a 'no-regrets' adaptation strategy is one that reduces an existing climate vulnerability and therefore is likely to yield benefits regardless of future climate change. For example, early warning systems for heat waves will reduce current heat-related illness and death and continue to pay dividends as temperatures rise in the future. Such activities have a high probability of generating a positive return on the investment.

Mainstreaming climate change into existing activities – Many decisions that will affect future vulnerability to climate change are currently being made without necessarily explicit consideration of climate change. This is perhaps particularly true for some of the more rapidly growing economies in the Asia/Pacific region where major infrastructure and land-use decisions are being made at an ever-faster pace, and where international assistance routinely supports development projects. In many instances, it may be possible to reduce the vulnerability of a planning decision or project to climate change through small adjustments that are low-cost relative to the overall project, particularly if climate change may increase the risk of failure or premature renovation and/or retirement of assets.

The ability of adaptation to offset adverse impacts of climate change will depend upon the efficiency of implementation, the region and sector under consideration, and the rate and magnitude of future climate change. For example, agricultural and plantation forestry systems can be directly manipulated through management practices (nutrients, irrigation, planting times and distributions) that can increase their capacity to cope with climate change. However, natural ecosystems often lack such management levers to increase coping capacity, and thus human attempts to adapt such systems must rely largely upon increasing resilience of ecosystems so that they can recover from climate-related stress and disturbance.

Table 5.1. Adaptation Strategies for Climate Change
Coastal Communities
• Identify vulnerable areas, communities, and infrastructure
• Channel future development around "high" "moderate" and "low growth" areas
• Develop coastal zone management plans
• Construct new, or modify existing, coastal defences
• Design infrastructure to accommodate sea-level rise
• Manage progressive retreat from the coastline
Public Health
• Develop early warning systems for extreme weather events (e.g., flood, cyclones, heat waves)
• Establishment or bolstering of public health institutions
• Research and development regarding disease transmission and prevention
• Improving access of individuals and communities to medical and public health agencies
• Education in disease prevention
Ecosystems and Biodiversity
• Establish conservation areas and networks
• Invest in natural resource management plans
• Manage land-use to reduce environmental harm
• Identify at-risk ecosystems and species
• Development of aquaculture and plantation forestry over exploitation of native resources

Water Resources
• Develop new water resources and storages (where possible)
• Invest in climate and catchment monitoring and research
• Rehabilitate existing water supply and transport systems
• Implement demand management measures
• Increase recycling and reuse of waste water
• Invest in water saving technologies/methods
Agriculture
• Change farming practices
• Change timing of farm operations
• Use different crop varieties
• Review governmental and institutional policies and programs
• Research new practices and technologies (e.g., land-use planning, biotechnology)
• Development drought management and relief protocols
Disasters and Emergency Management
• Diversify economic activity to reduce reliance upon climate sensitive sectors
• Develop emergency management plans for climate hazards
• Develop early warning systems for extreme weather events (e.g., flood, cyclones, heat waves)
• Expand availability and use of risk-spreading institutions (e.g., insurance, government assistance)
• Identify critical activities and infrastructure for protection (e.g., health services, energy, transport, communication)
Public Awareness and Education
• Facilitate public awareness about climate change and its potential impacts
• Communicate with public and stakeholders regarding risk management decisions and programs
• Identify pathways for individuals to be active participants in the sustainable management of the environment and its natural resources

The faster the rate at which the climate changes or the greater the change in climate extremes, the more difficult and costly it will be for both human and natural systems to adapt. Invariably there are limits to the ability of some systems to adapt. For example, major species extinction events are anticipated as climate-induced changes in species habitat occur more quickly than species can adapt.[160] Similarly, natural disasters are by definition events that overwhelm the coping capacity of communities and nations, and it is difficult to imagine adaptation actions expanding the capacity of communities to simply cope with a major cyclone or flood event. Hence, adaptation actions which also expand resilience are an important second line-of-defence necessary for preparing communities and nations of the Asia/Pacific for the coming era of enhanced variability and extremes associated with climate change.

5.3 Adaptation in the Context of Sustainable Development

Perhaps the most significant challenge for implementing adaptation strategies in developing nations such as those of the Asia/Pacific region is not so much identifying vulnerable systems or potential adaptation actions and measures. Rather, the limiting step is establishing and growing the capacity for nations to undertake adaptation, or, in other words, focusing attention on the adaptive capacity component of vulnerability (see Section 5.1). As stated by Ribot et al. (1996),

> ***"It is not that the risk is unknown, not that the methods for coping do not exist…rather inability to cope is due to lack of—or systematic alienation from—resources needed to guard against these events."[161]***

When presented in such a manner, the issue of adaptation becomes closely aligned with that of sustainable development. In fact, in the absence of significant gains in sustainable economic development it is difficult to envision many of the developing nations within the region successfully managing the risks future climate change will bring. Quite clearly, many nations require assistance and resources simply to cope with, and bolster resilience to, existing climate challenges. Without significant boosts in their capacity, these nations will be struggling to manage greater threats with potentially diminished resources.

What determines a nation's capacity to adapt? There is in fact no fixed set of characteristics that dictate adaptive capacity. A number of broad indicators have been developed that suggest a greater or lesser capacity to adapt, although a variety of more proximal measures may be used in the actual quantification of adaptive capacity (Table 5.2).[162] Clearly, improving adaptive capacity involves much more than simply executing a particular adaptation project, such as flood defences, designed to reduce climate risk. Instead, it is fundamentally a process of building working institutions that have knowledge and ability to manage the process of climate adaptation as well as generating the resources (human, technical, and financial) to implement adaptation actions. Hence improving the adaptive capacity of Asia/Pacific nations requires continued economic development that leads to the establishment of robust institutions, infrastructure, and the growth of human and financial capital. Rather than adaptation to climate change being a separate venture pursued in isolation, ideally it should one that is 'mainstreamed' into existing development activities and decision-making.

Table 5.2. Indicators of Adaptive Capacity[162]

Ultimate Indicator	Proximal Indicator
A stable and prosperous economy	• National and per capita GDP • GDP growth rates • Degree of economic diversification
Access to technology	• Internet access and usage • Level of technology education among the public • Investments in technology research and development • Efficiency of deployed technologies
Clearly define institutional responsibilities with respect to adaptation decision-making and implementation	• Institutional authorities on climate change • Extent of political corruption • Checks and balances on political decision-making
Access to information on climate change impacts and mechanisms for adaptation	• Investments in impacts and adaptation research • Number of scientific institutions • Number of publications
Equitable distribution of resources and decision-making powers	• Democratic institutions • Gender equity in economic and political affairs
Maintenance of existing adaptive capacity within systems	• Robustness of emergency management protocols • Presence of disaster relief and risk-spreading mechanisms • Robustness of public health services • Experience managing climate variability

In fact, because failure to consider climate risk in other decision-making activities, such as the design of infrastructure, can increase vulnerability to climate change, climate change adaptation is increasingly recognised as a fundamental issue at play in the pursuit of sustainable development. The World Bank, for example, recently produced a report regarding pathways for enhancing climate risk management in its economic development investments.[163] However, as with any other decision-making event, care must be taken to ensure successful outcomes – poor implementation of adaptation projects at best leads to limited reduction in climate risk and at worst may waste considerable resources and time. Furthermore, some adaptation actions may actually be maladaptive in that they reduce vulnerability over the short-term but increase vulnerability over the long-term, or, alternatively, reduce vulnerability in one area or sector only to increase the vulnerability of others. For example, large-scale structural engineering to climate change that alters the natural landscape may reduce the resilience of natural ecosystems to climate change or threaten the livelihoods of those who live on the land.

5.4 Balancing Mitigation and Adaptation

Multiple studies of future greenhouse gas emissions and the resulting climate change indicate that global emissions reductions on the order of 30–55% below 1990 levels are needed over the next century to avoid 'dangerous' climate change.[10,17] Yet another set of literature emphasises the importance of adaptation in the assessment of climate impacts and its role in reducing vulnerability and future climate risk. Where do linkages between adaptation and mitigation lie?

While originally presented as 'either-or' options for addressing climate change (with advocates aligning on either side), recent years have seen much greater acknowledgement of the need for both mitigation and adaptation in the portfolio of policy responses. The existing commitment to climate change, and the adverse impacts that will result, necessitates adaptation actions to reduce vulnerability and risk. Nevertheless, greenhouse gas mitigation is necessary if the rate and magnitude of climate change is to be reduced, and for systems, such as coral reefs, with critical climate thresholds than cannot be readily expanded via adaptation, mitigation may be the only option for preventing system collapse.

Table 5.3. Historical Responsibility for Global CO_2 Emissions (1850-2000)[164]

Top-10		***Bottom-10***	
Nation	**Responsibility (%)**	**Nation**	**Responsibility (%)**
United States	29.64	Seychelles	<0.01
European Union[n]	27.06	Bhutan	<0.01
Russian Federation	8.23	Solomon Islands	<0.01
China	7.24	Maldives	<0.01
Canada	2.14	Nauru	<0.01
India	2.07	Samoa	<0.01
Australia	1.05	Vanuatu	<0.01
Indonesia	0.48	Tonga	<0.01
Thailand	0.24	Kiribati	<0.01
Pakistan	0.18	Cook Islands	<0.01

Recent work indicates that there are trade-offs between adaptation and mitigation. Some adaptation actions, such as desalination to augment water supplies or increased air conditioning to reduce heat-related risks, are energy-intensive and thus may be at odds with mitigation efforts. On the other hand, afforestation, reforestation and forest conservation initiatives may help mitigate emissions while improving the resilience of ecological systems to climate change. There is growing interest within the international community in the facilitation of adaptation in the developing world. This creates the potential for competition between investments in mitigation (e.g., through the United Nations Framework Convention on Climate Change's Clean Development Mechanism) and adaptation in the form of development assistance.[165] Whereas both strategies are designed to fundamentally reduce the risks associated with climate change, mitigation and adaptation have different costs and benefits in different regions of the world. For

[n] *Individual nations within the European Union also carry a relatively high responsibility for historical emissions, but are represented here as a collective unit.*

example, assuming a finite supply of financial resources for international efforts to address climate change, Tol (2006) has recently suggested that the balance of costs and benefits to the world's least developed nations may favour international investments in adaptation via development assistance. This assumes that the costs incurred by the developed world for achieving emissions reductions will reduce public and private investment in the least developed nations, constricting economic growth. These impacts, at least in economic terms, may be greater than those realised from the impacts of climate change. Of course, the legitimacy of this argument is dependent upon assumptions regarding the costs of mitigation as well as the market consequences of climate impacts in different global regions. It also overlooks the potential for local critical thresholds that, if exceeded, could devastate local economies independent of external market drivers. Nevertheless, it identifies the need for clear articulation of goals and careful planning in the pursuit of mitigation and adaptation.

The picture becomes somewhat clearer when one considers investments by individual nations. At present, most of the nations within the Asia/Pacific region, with the exception of China and India, are relatively minor contributors to global greenhouse gas emissions due to low per capita emissions (Section 8), and historically, all of the Asia/Pacific nations bear a relatively minor responsibility for climate change (Table 5.3). While the United States, the European Union, and the Russian Federation collectively account for approximately 65% of historical CO_2 emissions; India and China account for just over 9%; Australia for 1%; and the remaining nations in the Asia/Pacific region for much less than 1% each. As such, particularly for small greenhouse gas emitters, investing in mitigation yields little in the way of direct benefits, as the effect on global emissions and climate change will be small to negligible. Meanwhile, investments in economic development and adaptation which target capacity building and expansion of coping capacity and resilience are more likely to generate direct and immediate returns.

The above generalisations do not necessarily hold for the Asia/Pacific's largest economies, China and India. Despite modest historical responsibility, these nations are currently among the world's largest greenhouse gas emitters (accounting for approximately 20% of 2002 emissions) and are projected to exceed the United States in the near future.[164,166] The relatively large contribution of such nations to global emissions suggests that the benefits (both local and global) of national investments in mitigation are relatively larger for these compared to other Asia/Pacific nations. Nevertheless, despite large economies and associated emissions, the vulnerability of these nations remains high, as reflected in their low per capita GDPs, and thus there are still significant benefits to be realised from adaptation and capacity building in these nations.

Rather than such analyses forcing a decision between adaptation and mitigation, they highlight the importance of having either a) clearly delineated and separate responsibilities for greenhouse gas mitigation and adaptation among financing institutions; or b) strategic coordination between mitigation and adaptation efforts to maximise benefits. In addition, efforts should be taken to ensure that actions to reduce greenhouse gas emissions in either developed or developing nations are not paid for by reducing development assistance. The latest report on the United Nation's Millennium Development Goals indicates significant progress must still be realised within the Asia/Pacific region in areas of reducing poverty and hunger, infant mortality, combating disease, and environmental sustainability.[26] In some instances, progress has stagnated or is even deteriorating. Development assistance that builds adaptive capacity will therefore continue to be an important tool for reducing climate risk in the region.

6. Knowledge Gaps

This review of potential climate change and environmental impacts in the Asia/Pacific region highlights a number of knowledge gaps that should be targeted by future research and assessment work.

1) **Climate Change, Monsoons, and ENSO** – While existing climate models enable one to predict with confidence that average temperatures in the Asia/Pacific region will increase over the 21st century, the implications of climate change for rainfall are less certain. Some consistent patterns of potential rainfall change emerged from the current study, particularly reductions in winter rainfall in South and Southeast Asia, with general increases in rainfall in other areas and seasons. These rainfall patterns are consistent with changes in the dynamics of the Asia/Pacific monsoons. However, basic research and applied climate modelling of the effects of climate change on monsoons and the potential effects of regional atmospheric aerosols continues to develop. Furthermore, climate model simulations do not agree regarding important modes of climate variability, such as the El Niño-Southern Oscillation (ENSO) and the frequency and/or intensity of El Niño events, which will influence the occurrence of extreme heat, droughts, rainfall, and sea-levels in the Asia/Pacific region.

2) **Risk of Ice Sheet Loss** – Sea-level rise emerges from the current study as a key concern throughout much of the Asia/Pacific region. While sea-level rise estimates span a wide range, like temperature, climate models indicate that increases in global sea level are certain. Yet to date, most projections of sea-level rise (including those included in this study) do not account for the potential irreversible loss of the large ice sheets of Greenland or West Antarctica. Recent evidence from Greenland suggests an acceleration of the melt rate, which, if sustained, would have implications for Asia/Pacific nations and coastlines, raising expectations of 21st century sea level rise. In addition, such concerns highlight the fact that climate change impacts in other parts of the world may nevertheless have significant consequences for the Asia/Pacific region.

3) **Impact Assessment** – Knowledge of climate change impacts throughout the Asia/Pacific region is not evenly distributed. Limited information is available for a number of nations, assessments are not routinely updated, and estimates of impacts may be available for a relatively small number of sectors or ecosystems. Such gaps in information regarding regional impacts of climate change are a symptom of the limited capacity that exists with the region for simply understanding climate risk, much less coping with climate variability and climate change or implementing strategies to effectively reduce risk. Greater investment in impact assessment, and particularly, risk analysis that can elucidate the likelihoods of different regional climate impacts would be of great benefit.

4) **Socioeconomic Change –** The Asia/Pacific region is currently experiencing significant change in a range of areas: social, cultural, economic, and political. Some of these changes have been beneficial, increasing economic opportunity, education, and standards of living for many individuals. Others have been more problematic, degrading environmental assets and natural resources, stifling economic growth, and undermining human security. The effects of climate and environmental change, both now and in the future, are inextricably linked to these processes of economic and social change. There is much uncertainty regarding how current trends will progress in the decades ahead. Yet, success or failure in the development of prosperous, democratic, sustainable communities and nations within the region may be one of the most critical determinants of future vulnerability to climate change.

7. Conclusions

Undoubtedly, there are many considerations in the regional implications of climate change that merit more detailed analysis. Nevertheless, a number of key conclusions can be drawn from the preceding discussion. These conclusions are discussed further below and are organised around five central themes:

1) **The Asia/Pacific region has a high degree of vulnerability to climate change, resulting from pre-existing socioeconomic conditions, exposure to a range of climate hazards, and potentially significant changes in future climate conditions over the next century.** Climate modelling indicates temperature increases in the Asia/Pacific region on the order of 0.5–2°C by 2030 and 1–7°C by 2070. In addition, models generally indicate increasing rainfall throughout much of the region in the decades ahead, including greater rainfall during the important summer monsoon season. However, winter rainfall is projected to decline in South and Southeast Asia, suggesting increased aridity associated with the winter monsoon. The region will be affected by a rise in global sea level of approximately 3–16 cm by 2030 and 7–50 cm by 2070 in conjunction with regional sea level variability. Other modelling studies have also indicated the potential for more intense tropical cyclones and changes in important modes of climate variability such as the El Niño-Southern Oscillation.

2) **A review of studies estimating how various environmental and economic sectors of the Asia/Pacific region respond to climate change indicates that adverse impacts will dominate.** Perhaps the region's greatest vulnerability is to sea-level rise, which all studies indicate will erode and inundate coastlines and wetlands and displace communities. The natural ecosystems of the Asia/Pacific region will face increasing pressure from human activities and land use change, reducing the resilience of mangroves, coral reefs, tropical forests, and montane communities to rising temperatures and sea levels and changes in rainfall. Shifts in the vectors for dengue and malaria may expose millions of additional individuals to disease, while increased climate variability and intensification of tropical cyclones may increase the risk of injury and death. Changes in the availability of water resources are anticipated, driven by regional population growth and winter reductions in runoff in South and Southeast Asia and increases in runoff in other seasons and areas, particularly the Pacific Islands. Impacts on agricultural yields will be highly variable from one location to another, but reductions are likely in Bangladesh and the Pacific Islands. The net effect of climate change on regional and national economies is projected to be largely negative as agricultural revenue declines and other funds are channelled to address water resource and coastal management issues.

3) **Existing challenges to human security in the Asia/Pacific region may be significantly exacerbated by the broad range of impacts that climate change may bring.** Chronic food and water insecurity and epidemic disease may impede economic development in some nations, while degraded landscapes and inundation of populated areas by rising seas may ultimately displace communities and millions of individuals forcing intra and inter-state migration. The implications of such challenges to human security are difficult to anticipate, but there is currently little

awareness of the implications and regional management frameworks for addressing climate change-induced security and migration issues are lacking.

4) **Climate risk in the Asia/Pacific region may be ameliorated through two complementary strategies: greenhouse gas mitigation and adaptation.** Mitigation will reduce the magnitude of climate change to which the region is exposed over the long-term, but will do little to address climate risk over the near-term, particularly in the least developed nations where climate vulnerability is substantial yet historical responsibility for global greenhouse gas emissions is quite small. Therefore, while global mitigation efforts progress, investments must be made in increasing the capacity of Asia/Pacific nations to adapt to climate variability and climate change. This may be most effectively achieved by mainstreaming climate change adaptation into development assistance that addresses developing world needs with respect to governance, education, health, technology, security, and disaster management.

5) **Effective implementation of adaptation and capacity building projects is key to reducing future vulnerability of Asia/Pacific nations to climate change.** This necessitates the development and maintenance of institutions and human capital that are knowledgeable regarding climate change and capable of effective decision-making, resource allocation, and risk management. At present, there are numerous examples of decision-making that will increase, rather than decrease, the future vulnerability of Asia/Pacific ecosystems and communities to climate change. Reigning in such behaviours and devising sustainable environmental management practices that harmonise economic development and wealth generation with natural resource management and vulnerability reduction are core regional challenges.

8. Appendix I. Vital Statistics for Asia/Pacific Nations

Table 8.1. Vital Statistics for Nations in the Asia/Pacific Region[167]

Nation	Population in thousands (% Growth Rate)	% Urban Population	GDP in millions US$ (% Growth Rate)	GDP Per Capita in US$ (% Growth Rate)	Agriculture as a % of GDP	% Access to Safe Water	% Adult Literacy	% Land Area as Crops	P/Capita Emissions CO_2 (tons)
Australia	20,155 (1.1)	92.7	443,397 (3.9)	23,249 (2.7%)	3.5	100	-	6.6	17.3
Bangladesh	141,822(1.9)	25	51,380 (5.1)	399 (3.1%)	22.7	75	40.6%	65.2	0.2
Bhutan	2,163(2.2)	9.1	511 (6.4)	264 (4.2%)	33.9	62	-	3.5	0.6
Brunei Darussalam	374 (2.3)	77.6	4,453 (2.6)	13,352 (0.2%)	-	-	91.6%	1.3	-
Cambodia	14,071 (2.0)	19.7	3,024 (5.0)	237 (2.7%)	35.6	34	68.7%	21.6	0.0
China	1,315,844 (0.6)	40.5	1,308,310 (7.9)	799 (7.0%)	15.4	77	82.8%	16.6	2.7
Fiji	848 (0.9)	53.2	1,717(2.3)	2,118 (1.2%)	16.2	-	93.2%	15.6	1.5
French Polynesia	257 (1.7)	51.9	3,932 (1.5)	16,653 (-0.3%)	-	-	-	6.3	-
India	1,103,371 (1.6)	28.7	554,475 (5.7)	543 (3.9%)	22.7	86	58.0%	57.1	1.0
Indonesia	222,781 (1.3)	47.9	172,180 (0.6)	823 (-0.7%)	17.5	78	87.3%	18.5	1.4

Nation	Population in thousands (% Growth Rate)	% Urban Population	GDP in millions US$ (% Growth Rate)	GDP Per Capita in US$ (% Growth Rate)	Agriculture as a % of GDP	% Access to Safe Water	% Adult Literacy	% Land Area as Crops	P/Capita Emissions CO_2 (tons)
Laos	5,924 (2.3)	21.6	1,594 (6.0)	302 (3.6%)	52.8	43	65.6	4.2	0.2
Malaysia	25,347 (1.9)	65.1	84,944 (4.0)	3,694 (1.6)	9.0	95	87.9	23.1	5.2
Maldives	329 (2.5)	29.7	394 (5.4)	1,359 (2.5)	-	84	97.0	30.2	1.8
Mauritius	1,245 (1.0)	43.8	4,307 (5.4)	3,633 (4.4)	7.0	100	84.8	52.2	2.4
Micronesia	110 (0.6)	30.0	175 (-1.0)	1,633 (-0.9)	-	94	-	-	-
Myanmar	50,519 (1.1)	30.6	23,947 (5.5)	690 (4.1)	57.2	80	85.0	16.2	0.2
New Caledonia	237 (1.9)	61.6	2,941(0.5)	13,661 (-1.6)	3.5	-	-	0.7	-
Papua New Guinea	5,887 (2.1)	13.2	5,145 (0.4)	971 (-2.1)	26.9	39	64.6	1.9	0.5
Philippines	83,054 (1.8)	62.6	58,735 (3.4)	775 (1.4)	14.7	85	95.1	35.7	1.0
Samoa	185 (0.8)	22.5	245 (3.9)	1,382 (2.8)	-	88	98.7	45.6	0.8
Singapore	4,326 (1.5)	100.0	75,154 (5.6)	18,707 (2.7)	0.1	100	92.5	1.6	13.1
Solomon Islands	478 (2.6)	17.1	271 (-1.9)	648 (-4.7%)	-	70	-	2.6	0.4
Sri Lanka	20,743 (0.9)	21.0	13,018 (4.5)	656 (3.5)	20.1	78	91.9	29.6	0.5
Thailand	64,233 (0.9)	32.5	130,715 (0.4)	2,128 (-0.6)	9.4	85	95.7	35.8	2.9
Vanuatu	211 (2.0)	23.7	220 (1.0)	1,151 (-1.1)	15.1	60	-	9.8	0.4
Vietnam	84,238 (1.4)	26.7	13,452 (6.7)	171 (5.3)	23.0	73	92.7	25.9	0.7

9. APPENDIX II. 2004/2005 AUSTRALIAN DEVELOPMENT ASSISTANCE TO ASIA/PACIFIC NATIONS

Table 9.1. Development Assistance Provided by Australia to Asia/Pacific Nations (2004/2005)[27]

Nation	Assistance (millions AUS$)	Nation	Assistance (millions AUS$)	Nation	Assistance (millions AUS$)
Bangladesh	32.9	Mongolia	3.0	Thailand	13.4
Burma	11.3	Nauru	18.2	Tonga	12.8
Cambodia	38.2	Nepal	4.8	Tuvalu	4.5
China	49.8	Other Pacific Islands[a]	4.0	Vanuatu	28.7
East Timor	64.2	Pakistan	5.2	Vietnam	74.4
Fiji	28.0	Papua New Guinea	366.6		
India	17.2	Philippines	62.5		
Indonesia	270.3	Samoa	18.6		
Kiribati	10.9	Solomon Islands	171.5		
Laos	19.4	Sri Lanka	39.8		

[a] Includes Federated States of Micronesia, Marshall Islands, Palau, Niue, Tokelau and the Cook Islands.

10. APPENDIX III. MODEL SELECTION CRITERIA

Twenty-three different climate model simulations were undertaken for the *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change. These model simulations were acquired from the Program for Climate Model Diagnosis and Intercomparison and used to generate climate change projections for the Asia/Pacific region.[67] These model simulations were individually evaluated with respect to their abilities to faithfully reproduce observed seasonal patterns of mean sea-level pressure, temperature, and rainfall over the Asia/Pacific (60–180ºE, 55ºN–25ºS) region for a 30-year period (1961-1990).

Table 10.1.Twenty-Three Climate Models Available for Generating Climate Change Projections for the Asia/Pacific Region. The Sixteen Models Selected After Applying Reliability Criteria are Shown in Bold.

Climate Modelling Group & Country	Model Symbols	Horizontal resolution (km)
Beijing Climate Center, China	BCC	~200-
Bjerknes Centre for Climate Research, Norway	**BCCR**	~200
Canadian Climate Centre, Canada	**CCMA T47**	~300
Canadian Climate Centre , Canada	**CCMA T63**	~200
Meteo-France, France	**CNRM**	~200
CSIRO, Australia	**CSIRO-MARK3**	~200
Geophysical Fluid Dynamics Lab, USA	**GFDL 2.0**	~300
Geophysical Fluid Dynamics Lab, USA	**GFDL 2.1**	~300
NASA/Goddard Institute for Space Studies, USA	**GISS-AOM**	~300
NASA/Goddard Institute for Space Studies, USA	GISS-E-H	~400
NASA/Goddard Institute for Space Studies, USA	GISS-E-R	~400
LASG/Institute of Atmospheric Physics. China	**IAP**	~300
Institute of Numerical Mathematics, Russia	**INMCM**	~400
Institut Pierre Simon Laplace, France	IPSL	~300
Centre for Climate Research, Japan	MIROC-H	~125
Centre for Climate Research, Japan	**MIROC-M**	~300
Meteorological Research Institute, Japan	**MRI**	~300
Max Planck Institute for meteorology DKRZ, Germany	**MPI-ECHAM5**	~200
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	**MIUB**	~400
National Center for Atmospheric Research, USA	**NCAR-CCSM**	~150
National Center for Atmospheric Research, USA	NCAR-PCM	~300
Hadley Centre, UK	HADCM3	~300
Hadley Centre, UK	**HADGEM1**	~125

Two statistical metrics, pattern correlation and root mean square error, were used to measure model performance. A pattern correlation coefficient of 1.0 indicates a perfect match between the observed and simulated spatial pattern, and a root mean square error of 0.0 indicates a perfect match between the observed and simulated magnitudes. Since the selected area is large with strong spatial variations, root mean square errors for temperature and rainfall among the different models were relatively large. Similarly, for rainfall, pattern correlations for most of the climate models were less than 0.8. Therefore, only the pattern correlations were used to select a set of models. Models corresponding with pattern correlations greater than 0.8 for mean sea level pressure and temperature, and greater than 0.6 for rainfall were selected, resulting in a set of 16 models (Table 10.1). Simulations of these models were used to construct temperature and rainfall projections for the Asia/Pacific region using pattern scaling techniques (Section 3). Additional information regarding model performance with respect to each of these criteria is provided below.

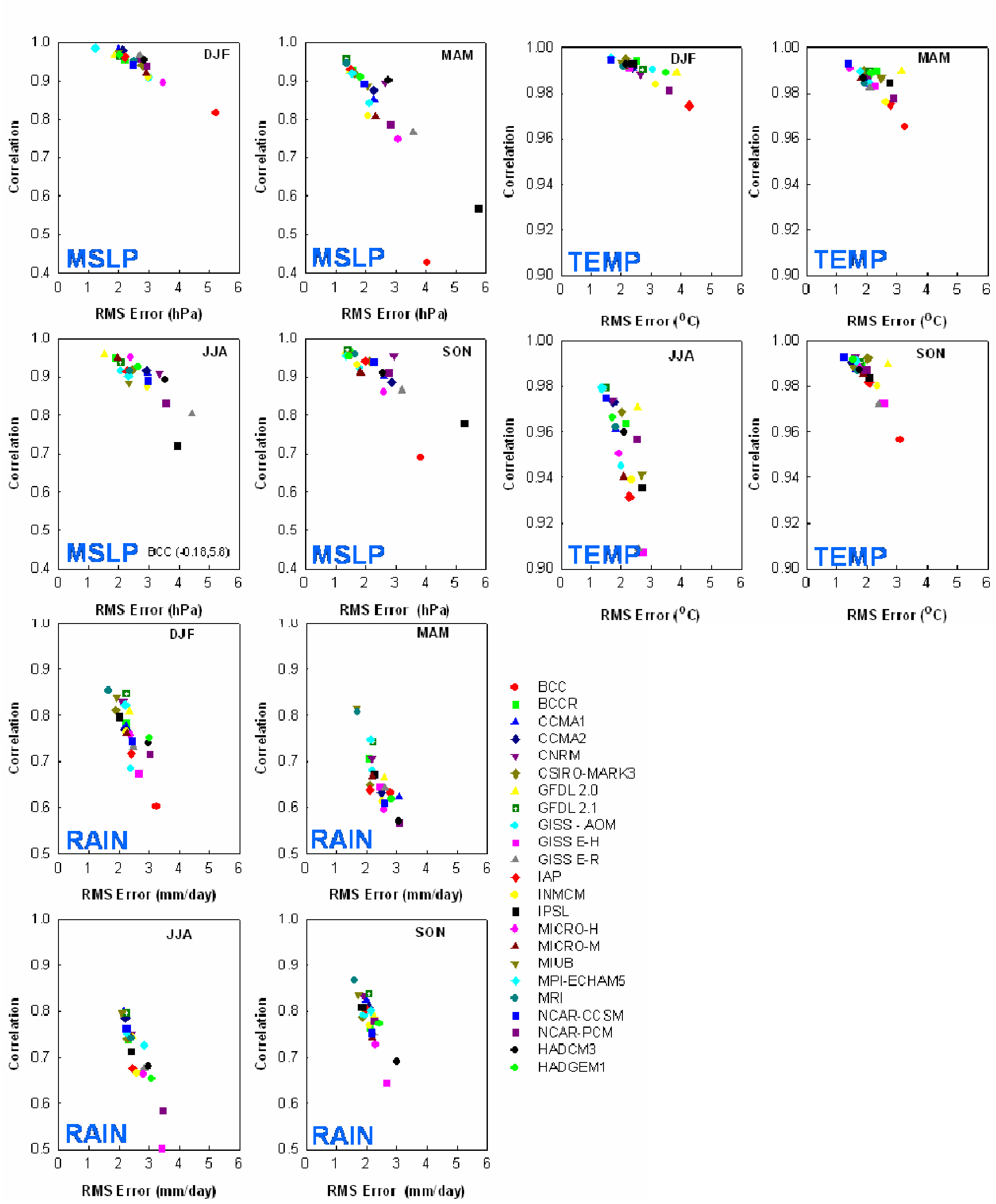

Figure 10.1. *Pattern correlation and root mean square errors for observed versus model seasonal mean sea level pressure, temperature, and rainfall for the Asia/Pacific region. Details of models are given in Table 1. In these diagrams, values in the top-left indicate better performance, while values in the bottom-right indicate poorer performance.*

Realistic simulations of mean sea level pressure patterns are important as they are implicitly linked to atmospheric circulation (i.e. wind, moisture, etc) patterns. Figure 10.1 shows pattern correlations and root mean square errors for the Asia/Pacific region for December to February

(DJF), March to May (MAM), June to August (JJA) and September to November (SON). The closer a model result lies to the top left corner, the better its performance, with strong pattern correlations and small root mean square errors, while models in the bottom right corner are poorer performers. Strong correlations, greater than 0.8, between observed and simulated patterns suggest that most of the models capture large-scale circulation features of this region. However, models such as BCC, GISS E-R and IPSL show poor performance in most cases.

Pattern correlations and root mean square errors for seasonal temperature are shown in Figure 10.1. This figure shows that most of the models capture the observed spatial pattern of temperature over the Asia Pacific region very well, yielding a pattern correlation of at least 0.9 for all seasons. However, the root mean square error exceeds 3°C for some models in DJF. In JJA, there is a considerable spread in the pattern correlation among different models that could be related to the influence of the summer monsoon and the topography of this region. Other seasons show small variations.

Rainfall simulations are more complex than the simulations of mean sea level pressure and temperature as rainfall is strongly influenced by dynamical and topographical characteristics of the region. Temporal and spatial patterns of rainfall during JJA are influenced by the summer monsoon, and rainfall patterns during DJF are influenced by the winter monsoon. Rainfall associated with convective systems dominate MAM, and in SON, rainfall is received from thunderstorms and tropical cyclones. Figure 10.1 depicts the pattern correlations and root mean square errors for observed and simulated rainfall. Pattern correlations are relatively high in all seasons, greater than 0.6 for most of the models.

11. APPENDIX IV. SECTORAL IMPACTS OF CLIMATE CHANGE

The following tables present individual estimates of climate change impacts to a range of sectors in the Asia/Pacific region. A separate table is presented for each sector, and each table is organised around three categories of increasing temperature or sea-level rise, with subdivisions indicating whether an estimate applies to an individual nation or a regional aggregation of nations. Each estimate is also accompanied by a colour-coded circle which represents the following:

● – Climate change impact is adverse, causing damages or losses to the indicated sector.

● – Climate change impact may be beneficial or adverse, depending upon assumptions about climatic change and system responses.

● – Climate change impact is beneficial, causing gains or opportunities to the indicated sector.

11.1 Coastal Communities

Table 11.1. Estimated Impacts of Sea-Level Rise on Asia/Pacific Coastal Communities

<30 cm	*National Studies*	● 370 ha of land inundated in Viti Levu, **Fiji** worth 0.3 million US$/year[188]
		● 18% of land area affected on Buariki, **Kiribati** and 0% of land affected on Bikenibeu[188]
		● 1,700 km^2 of land area in **Pakistan** affected[37]
		● 69 – 91% of land area in Mekong Delta, **Vietnam** affected by sea-level rise during flood season[168]
30-50 cm	*Regional Studies*	● 0.2 – 4.0 billion US$/year in economic losses in **Asia**[206,217]
		● 27,768 km of shoreline affected in **East Asia** with direct costs of 781 million US$/year[169]
		● 29,808 km of shoreline affected in **Southeast Asia** with direct costs of 226 million US$/year[169]
		● 77,018 km of shoreline affected in **Oceania** with direct costs of 1,419 million US$/year[169]
		● Less than 1 billion US$/year in economic losses in **Oceania**[206,217]
	National Studies	● 15,568 km^2 of land area lost in **Bangladesh** affecting 12.1 million people[170]
		● 13.6 – 19.0 billion US$ in total costs from sea-level rise in Pearl Delta region, **China**[171]
		● 3,530 ha of land area inundated in Viti Levu, **Fiji** worth 0.5 million US$/year[188]

		● 34,000 km^2 of land area lost in **Indonesia** affecting 3.1 million people[170]
		● 30% of land area affected on Buariki, **Kiribati** and 3% of land area affected on Bikenibeu[188]
		● 6.6 – 12.4 million US$/year in losses in Tarawa, **Kiribati** (158 – 374.6 million US$ during 1:14 year storm)[188]
		● 86 – 100% of land area in Mekong Delta, **Vietnam** affected by sea-level rise during flood season[168]
>50 cm	***Regional Studies***	● 618,000 – 858,000 km^2 of land area inundated in the **Asia/Pacific** region affecting 200 – 450 million people[172]
		● 150 million people displaced from various nations across the **Asia/Pacific** region[148]
		● 2.4 million emigrants from **Central Asia**[150]
		● 1.8 billion US$/year in costs to **Central Asia** from sea-level rise[150]
		● 305 billion US$ in total sea-level rise protection costs in **South and Southeast Asia**
		● 2.3 million emigrants from **South and Southeast Asia**[150]
		● 3.3 billion US$/year in costs to **South and Southeast Asia** from sea-level rise[150]
	National Studies	● 10% of dry land lost in **Bangladesh** and 5% of GDP[173]
		● 29,846 km^2 of land area lost in **Bangladesh** affecting 32.8 million people[170]
		● 38.9 – 67.1 billion US$ in total costs from sea-level rise in Pearl Delta region, **China**[171]
		● 5,763 km^2 of land area lost in **India** affecting 12.7 million people[170]
		● 80 – 85% of land area affected on Buariki, **Kiribati** and 54 – 80% of land affected on Bikenibeu[188]
		● 69.7 million US$/year in losses in Tarawa, **Kiribati** (497.3 during 1:14 year storm)[188]
		● 18% of dry land lost in **Macau** and 10% of GDP[173]
		● 7,000 km^2 of land area lost in **Malaysia** affecting ~500,000 people[37]
		● 77% of dry land lost in the **Maldives** and 122% of GDP[173]
		● 65 ha of land area inundated in Majuro Atoll, **Marshall Islands**[174]
		● 9 – 96 metres of shoreline retreat in Yap Island, **Micronesia**[175]
		● 21% of dry land lost in **Micronesia** and 12% of GDP[173]

		● 10.3 – 37.3 km^2 of land area inundated in Tongatapu island, **Tonga**[176]
		● 40,000 km^2 of land area lost in **Vietnam** affecting 26.9 million people[170]
		● 15% of dry land lost in **Vietnam** and 8% of GDP[173]

11.2 Ecosystems and Biodiversity

Table 11.2. Impacts to Asia/Pacific Ecosystems and Biodiversity

+<2℃	***Regional Studies***	● Threshold for large-scale damages to coral reef ecosystems in the **Asia/Pacific** region exceeded[116]
		● Risk of local extinction of coral reefs between 10°–15°S in the **Indian Ocean**[177]
		● Mangrove area in **Pacific Island** nations declines by 1%[121]
	National Studies	● 15 – 40% of forest and wetland area lost to sea-level rise in Sundarbans, **Bangladesh**[177]
+2-4℃	***Regional Studies***	● Grassland productivity declines by 40 – 90% in **Arid and Semi-Arid Asia**[178]
		● High probability of increase in wildfire risk in **Central Asia**[179]
		● Vegetation biomass in **Central Asia** and the **Pacific Islands** increases, but decreases in northeast **India** and southern **Southeast Asia**[180]
		● 4 – 8% of species extinct in tropical woodlands and forests (global estimate); 19 – 24% of species extinct in temperate forests[181]
		● 40% increase in net coral calcification rate (global estimate)[182]
	National Studies	● 75 – 100% of forest and wetland area lost to sea-level rise in Sundarbans, **Bangladesh**[177]
		● Broad-leaved forests in **East China** may shift northward by approximately 3° of latitude (~300+ km)[183]
		● Significant expansion of forest and shrubland biomes and contraction of temperate and alpine steppe and desert biomes in the **Tibetan Plateau**[184]
		● 0.6 – 1.0 million US$/year in damages to subsistence and commercial fisheries in Viti Levu, **Fiji**[188]
+>4℃	***Regional Studies***	● 15,600 km^2 of wetland area lost in **Central Asia**[150]
		● Mangrove area in **Pacific Island** nations declines by 13%[121]
		● 54,900 km^2 of wetland area lost in **South and Southeast Asia**[150]

11.3 *Infectious Disease and Heat-Related Mortality*

Table 11.3. Impacts to Asia/Pacific Health

+<2℃	***Regional Studies***	8,218 additional deaths from malaria in **South and Southeast Asia**[185]
		116 fewer deaths due to schistosomiasis in **South and Southeast Asia**[185]
		6,745 additional deaths from Dengue fever in **South and Southeast Asia**[185]
		0 – 219,000 additional net deaths from all climate-change related causes in **South and Southeast Asia**[150]
		Eastern **India**, parts of northeastern and central **China** become unsuitable for malaria transmission[126]
		Coastal southeastern **Asia** becomes suitable for malaria transmission[126]
		Epidemic potential for malaria, schistosomiasis, and dengue in **Southeast Asia** changes by +7 – +45%, -10 – -11%, and +24 – +47%, respectively.[186]
		Tropical cyclone intensities in the **NW Pacific** increase by 12 –15% and average rainfall increases by 12 – 28%[187]
	National Studies	Risk of dengue epidemic in **Kiribati** increases by 11 – 33%[188]
		Incidence of Ciguatera poisoning in **Kiribati** increases from 35 – 70 per 1000 individuals to 160 – 430 per 1000[188]
		Number of annual cases of dengue in Viti Levu, **Fiji** increases by 10 – 30%[188]
		Economic impacts to the public health sector of Viti Levu, **Fiji** of 0.5 – 6.1 million US$/year[188]
+2-4℃	***Regional Studies***	219,000 – 438,000 additional net deaths from all climate-change related causes in **South and Southeast Asia**[150]
		Population at risk for malaria in **Southeast Asia** declines by 1 million[189]
		Population at risk for malaria in **South Asia** changes by -104 – +102 million[189]
		Population at risk for malaria in **East Asia** increases by 7 – 143 million[189]
		Tropical cyclone intensities increase by 8 – 17% in the south **Indian Ocean**, but decline in other basins[88]
		Tropical cyclone frequencies in the **Asia/Pacific** region decline by approximately 30%[88]

	National Studies	● $64.5 billion US$ in cumulative health costs associated with treatment of infectious disease in **Indonesia**[190]
		● Increased risk of malaria in southwest and northeast **India**[191]
		● Risk of dengue epidemic in **Kiribati** increases by 37 – 100%[188]
		● Incidence of ciguatera poisoning in **Kiribati** increases from 35 – 70 per 1000 individuals to 245 – 1,010 per 1000[188]
		● Number of annual cases of dengue in Viti Levu, **Fiji** increases by 40 – 100%[188]
		● Economic impacts to the public health sector of Viti Levu, **Fiji** of 1.3 – 18.1 million US$/year[188]
+>4℃	*Regional Studies*	● >438,000 additional net deaths from all climate-change related causes in **South and Southeast Asia**[150]

11.4 Water Resources

Table 11.4. Impacts to Water Resources in the Asia/Pacific Region		
+<2℃	*Regional Studies*	● Loss of 1.7 billion US$ in total costs in the water resources sector of **South and Southeast Asia**[150]
	National Studies	● -12 – +10 % change in runoff for **China**[192]
		● 14 – 18% increase in runoff from Bhagirathi River basin, **Himalayas**[193]
		● 0.7 – 2.7 million US$/year in additional costs in Tarawa, **Kiribati** due to salt-water intrusion and desalination[188]
+2-4℃	*Regional Studies*	● 7.9 – 15.9 billion US$/year in damages to water resources in **Asia**[217]
		● 18 billion US$ in benefits to water resources in **Asia**[206]
		● Number of people experiencing increase in water stress in **Central Asia** increases by 0 – 137 million[194]
		● 0.3 – 0.5 billion US$ in damages to water resources in **Oceania**[217]
		● 1 billion US$ in damages to water resources in **Oceania**[206]
		● Number of people experiencing increase in water stress in **South Asia** increases by 7 – 924 million[194]
		● Number of people experiencing increase in water stress in

		Southeast Asia increases by 0 – 10 million[194]
	National Studies	2 – 42% increase in discharge of the Ganges River, **Bangladesh**[195]
		Rapid shift in the extent and depth of flooding in **Bangladesh**[196]
		0 – 13% increase in discharge of the Brahamaputra River, **Bangladesh**[195]
		Runoff changes of -16 – +17 across seven river basins in **China**[197]
		Reductions in runoff likely for the interior of **China**[179]
		Number of people experiencing increase in water stress in **Greater Mekong** increases by 0 – 105 million[194]
		Increase in snowmelt runoff and stream flow in the Spiti River, **Himalayas** of 4 – 18% and 6 – 12%, respectively[198]
		25 – 46% increase in runoff from Bhagirathi River basin, **Himalayas**[193]
		Change in runoff of -12 – +7 in Lake Lanao Reservoir and -12 – +32 in Angat Reservoir, **Philippines**[199]
		Little change in annual river flows in Mekong Delta, **Vietnam**[200]
+>4℃	Regional Studies	11.0 – 21.9 billion US$/year in damages to water resources in **Asia**[217]
		0.4 – 0.8 billion US$/year in damages to water resources in **Oceania**[217]

11.5 Agriculture

Table 11.5. Impacts to Agriculture and Commercial Forestry in Asia/Pacific for Different Magnitudes of Temperature Change[15]

+<2℃	Regional Results	Change in rice yields in **Asia** of -7 – +26%[201]
		Limited impacts to commercial forestry in **Central Asia**[150]
		Wheat yields in **South Asia** decline by 0.45 ton/ha[196]
		140 million US$/year in benefits to commercial forestry in **Southeast Asia**[150]

[15] See Box 4.2 for China-specific impacts

	National Results	Agricultural damages to Viti Levu, **Fiji** of approximately 14 million US$/year (70 million US$ during an extreme event)[188]
		Average rice yields in Kerala State, **India** increase by 12%[202]
		Reduction in rice yields of 20 – 40% in the **Philippines**[203]
+2-4°C	*Regional Results*	Change in rice yields in **Asia** of -31 – +7%[201]
		3 – 4 billion US$/year increase in economic benefits from commercial forestry in **Asia**[206]
		Present value of climate benefits to commercial forestry in developing nations of **Asia/Pacific** of 15.1 – 18.7 billion US$[204]
		Rice yields in **South Asia** decline by 0.75 tons/ha[196]
		Wheat yields in **South Asia** change by -34 – +5%[196]
		Economic impacts to agriculture sector in **Southeast Asia** of -61.6 – +35.8 billion US$/year[205]
		Increase in agricultural welfare of 37 – 80 billion US$/year in **Asia/Mid East**[206]
		Change in production of cereals in **Central Asia** of -0.8 – +4.3% (all crops -5.8 – +5.7)[207]
		Limited impacts to commercial forestry in **Oceania**[217]
		Change in production of cereals in **South Asia** of -13.5 – -7.4% (all crops -10.7 – +0.2%)[207]
		Crop quantities in **Southeast Asia** increase by 0 – 1.1% (prices increase by 0.6 – 2.0%)[208]
		Crop quantities in **East Asia** increase by 1.9 – 2.3% (prices decline by 2.1 – 2.7%)[208]
		Change in agricultural welfare of -8 – +4 billion US$/year in **Oceania**[206]
	National Results	10 – 17% reduction in rice yields in **Bangladesh**[209]
		20 – 61% reduction in wheat yields in **Bangladesh**[209]
		Changes in rice yields in **Bangladesh** of -10.2 – +14.2[210]

		Rice and wheat production in **Bangladesh** changes by -28 – +32% and -68 – +9%, respectively[211]
		Rice yields in **Indonesia** increase by 9.0 – 23.3%[210]
		Rice yields in **India** increase by 6.0 – 33.8% among different areas[212]
		Rice yields among different areas of **India** change by -36.9 – +10.5[210]
		Net income in **India** changes by -20 – +19%[213]
		Net income in **India** changes by -6 – +8%[214]
		Reduction in total net agricultural revenue of **India** of 8.4%[215]
		Most cultivated land in **India** experiences decreased cereal productivity[207]
		Rice yields in **Malaysia** increase by 12.0 – 24.6%[210]
		Rice yields in **Myanmar** change by -13.8 – +21.5%[210]
		Rice yields in the **Philippines** change by -13 – +9[216]
		Wheat yields in the **Philippines** change by -14 – +8[216]
		Rice yields in the **Philippines** change by -13.7 – +14.1%[210]
		Rice yields in **Thailand** change by -11.6 – +9.3%[210]
+>4℃	***Regional Results***	Agricultural welfare in **Asia** declines by 15 – 296 billion US$/year[217]
		Economic impacts to the commercial forestry sector of **Asia** of -4.2 – +1.8 billion/year [217]
		Economic damages to agriculture sector of **Southeast Asia** of 9.9 – 218.8 billion US$[205]
		Crop quantities in **East Asia** increase by 1.4 – 2.1% (prices decline by 2.0 – 2.6%)[207]
		-1 – 0 billion US$/year in damages to commercial forestry in **Oceania**[217]

		Change in annual agricultural welfare of -19.1 – +1.2 billion US$/year in **Oceania**[217]
		Crop quantities in **Southeast Asia** increase by 0.1 – 0.9% (prices change by -0.29 – +1.6%)[207]
	National Results	Rice yields in **Bangladesh** decline by 2.8 – 9.0%[210]
		Rice yields among multiple sites in **India** decline by 1.3 – 92.4%[210]
		Rice yields in **Indonesia** increase by 5.9 – 23.3%[210]
		Rice yields in **Malaysia** increase by 14.7 – 26.8%[210]
		Rice yields in **Myanmar** change by -4.9 – +1.2%[210]
		Rice yields in the **Philippines** decline by 4.7– 5.4%[210]
		Rice yields in **Thailand** decline by 0.9 – 7.3%[210]

Table 11.6. Impacts to Agriculture in China for Different Magnitudes of Temperature Change	
+<2℃	Changes in rice yields (Irrigated -0.4 – +3.8%; Dryland +0.2 – +2.1%)[218]
	Changes in maize yields (Irrigated -0.6 – -0.1%; Dryland +1.1 – +9.8%)[218]
	Changes in wheat yields (Irrigated +11 – +13.3%; Dryland +4.5 – +15.4%)[218]
	Agricultural revenue declines by 11.95%[219]
+2-4℃	Changes in rice yields (Irrigated -4.9 – +7.8%; Dryland -2.5 – +4.3)[218]
	Changes in maize yields (Irrigated -2.8 – +1.3%; Dryland +18.5 – +20.3)[218]
	Changes in wheat yields (Irrigated+14.2 – +40.3%; Dryland +6.6 – +23.6)[218]
	Agricultural revenue changes by -68.09 – +28.31%[219]
	Changes in rice yields of -21 – +7%[197]
	Changes in rice yields of -20 – +20%[196]
	Changes in maize yields of -9 – +5%[197]
	Changes in maize yields of -19 – +5%[220]
	Changes in wheat yields of -6 – +42% [197]
	Increase in cotton yields of 21 – 53%[197]
	Agriculture production declines by 3 – 6%[220]

	Most cultivated land experiences increased cereal productivity[207]
	Changes in rice yields of -30.7 – +9.7%[221]
+>4℃	Agricultural revenue declines by 69%[219]
	Changes in rice yields among different sites of -27.6 – +3.1%[210]

11.6 Regional Economies

Table 11.7. Impacts to the Asia/Pacific Economy

+<2℃	*Regional Studies*	Limited economic impacts in **South and Southeast Asia**[185]
		Loss of $14 billion annually in **South and Southeast Asia[150]**
	National Studies	Economic damages equivalent to 2.4% of GDP in **Sri Lanka**[190]
+2-4℃	*Regional Studies*	Economic impacts of -12 – +4 billion US$/year in **Oceania[206]**
		Economic benefits of 20 – 90 billion US$/year in **Asia[206]**
		Economic losses equivalent to 0.5% of GDP in **South and Southeast Asia**[185]
		Economic losses equivalent to 8.6% of regional GDP in **South and Southeast Asia[222]**
		Total climate change losses equivalent to 70 billion US$ in **Asia**[223]
	National Studies	0.2 – 0.4% increase in **China's** GDP[224]
		0.9 – 5.5% decline in **India's** GDP[224]
		Economic losses equivalent to a 5% reduction in GDP in **Bangladesh**[190]
		Total climate change losses equivalent to 766 billion US$ in **Indonesia**[190]
		1.1 – 3.5% decline in **Thailand's** GDP[224]
+>4℃	*Regional Studies*	Economic losses of 0.53 – 0.6 billion US$/year in **Asia[217]**
		Economic impacts of -0.89 – +0.09 billion US$/year in **Oceania[217]**

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