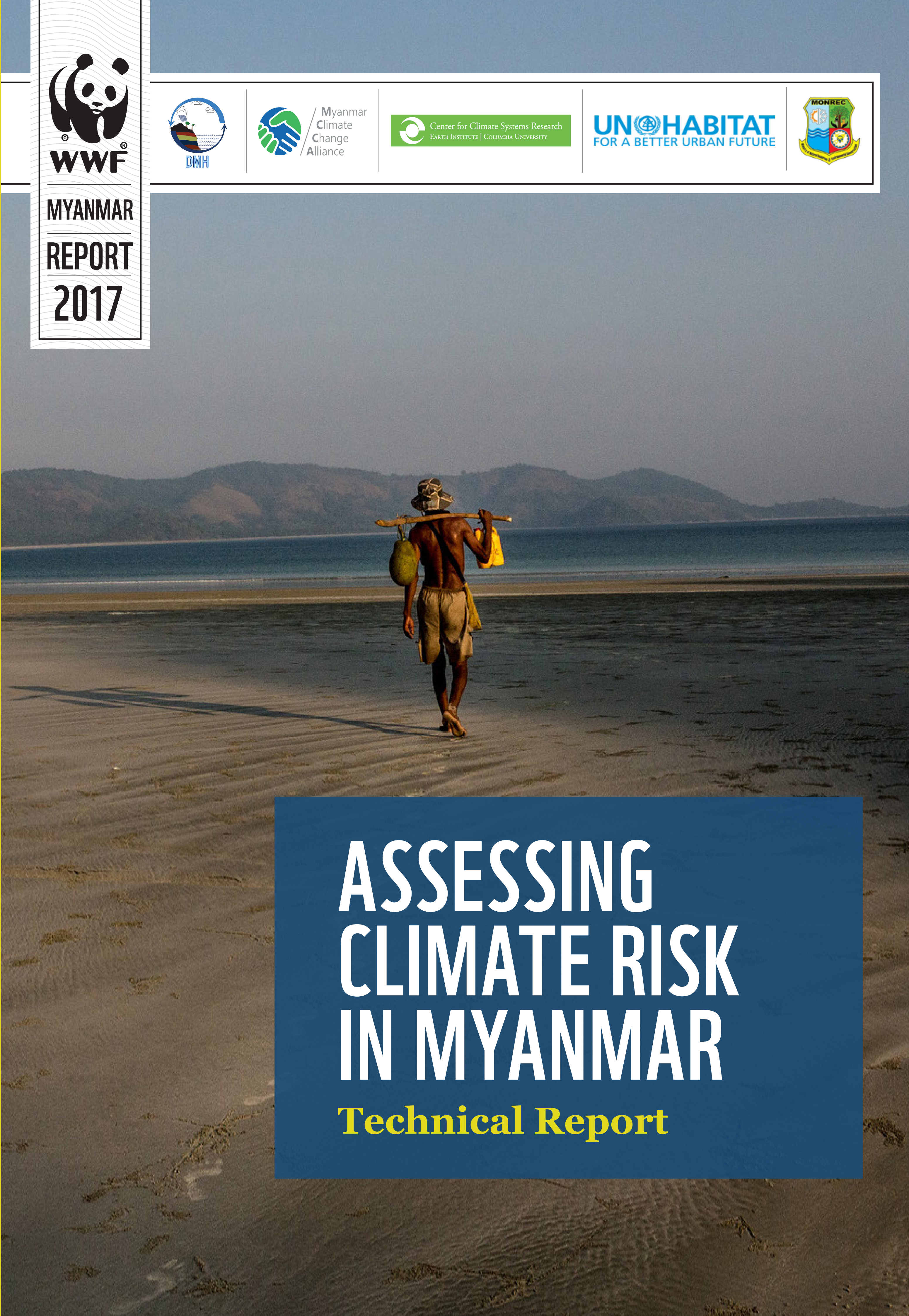

WWF

MYANMAR REPORT 2017

DMH

Myanmar Climate Change Alliance

Center for Climate Systems Research
Earth Institute | Columbia University

UN HABITAT
FOR A BETTER URBAN FUTURE

MONREC

ASSESSING CLIMATE RISK IN MYANMAR

Technical Report

ASSESSING CLIMATE RISK IN MYANMAR

A contribution to planning and decision-making in Myanmar

TECHNICAL REPORT

March 2017

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Acknowledgements

We would like to especially thank the Department of Meteorology and Hydrology (DMH) for graciously providing historical rainfall and temperature data from 19 stations across Myanmar for the historical analysis. This report would not have been possible without their support.

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Note: Like all future projections, climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some physical processes. In this Report, the levels of uncertainty are characterised using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations, and recent peer-reviewed literature. The projections are not true probabilities, and scenario-planning methods should be used to manage the risks inherent in future climate.

FOREWORD

With new temperature records being set regularly, the effects of climate change are already a stark reality throughout the world.

The agreement signed in Paris in 2015 is a sign of great hope that the world is collectively driven toward addressing climate change. However, as we have already seen around the world, even 1°C of warming is already having significant impacts.

This is especially the case for Myanmar, which, as recent events have shown – from severe flooding to extreme drought and exposure to strong coastal typhoons like the devastating Cyclone Nargis in 2008 – is highly vulnerable. As Myanmar develops its economy to bring millions out of poverty, it is critical that it does so in ways that ensure investments in infrastructure and human capital are resilient to these increasing extremes. One of the best ways to build resilience is to harness the power of ecosystems and the numerous benefits they provide to people; from forests, that help provide clean drinking water and reduce flooding downstream, to coastal mangroves that provide critical defences against coastal erosion and increasingly intense typhoons.

Our diverse group of partners has worked closely together to develop this report, outlining climate change impacts in different sectors and how these sectors can use climate risk information. Using best available data, including 30 years of weather station data generously provided by the Department of Meteorology and Hydrology and a new dataset from NASA that allows for higher resolution analysis than ever before, this report provides critically needed information on how climate change has already begun to affect Myanmar and is likely to continue into the future. We are pleased to collaborate in tackling such a critical issue, and believe this report serves as an important contribution for addressing important changes in Myanmar's future.

A. Christy williams   Cynthia Rosenzweig

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FOREWORD

We live in a world already affected by climate change. Global temperatures in 2015 were the hottest since record keeping began, and 15 out of the last 16 hottest years on global record have occurred since the year 2000.

At the same time, 2015 brought a glimmer of hope with the globally adopted Paris Agreement, in which over 190 countries committed to ensuring the average global temperature does not rise more than 1.5°C above pre-industrial levels. This agreement is of critical importance for Myanmar, one of the most vulnerable countries in the world to climate change.

Understanding and incorporating climate risk information today is crucial for building long-term resilience across various sectors in Myanmar. The population and economy are dependent upon agriculture, which relies on predictable seasonal cycles of water and temperature. Long-term investments in infrastructure must be built to withstand future climate conditions, to prevent future costs being incurred for repairs and upgrades as a result of extreme weather events. Myanmar is already exposed to natural hazards such as floods, droughts, cyclones and coastal storms – all of which are exacerbated by climate change. Myanmar's ecosystems provide crucial protection against these hazards. Mangroves and coastal habitats, for example, help to reduce the impact from coastal storms, while forests play a key role in regulating floods. As such, protecting these ecosystems will become even more important to building climate resilience.

We have an opportunity to ensure development activities are both sustainable and climate resilient. Using information about how our climate is likely to change in the coming decades will help to ensure a more sustainable, resilient economy while keeping our incredible ecosystems and biodiversity intact. In order to achieve a climate-resilient future, we need to work together – across ministries and sectors and with a wide range of stakeholders. I hope this report will contribute to better integration of climate science into decision making and planning, which will be essential if we are to adapt and build much needed resilience to climate change.

Dr. Hrin Nei Thiam,
Director-General
Department of Meteorology
and Hydrology
Ministry of Transport

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ABOUT THE INSTITUTIONS

Department of Meteorology and Hydrology

Department of meteorology and Hydrology (DMH) is under the Ministry of Transport and Communications. DMH responsibilities include taking precautionary measures against and minimize the effects of natural disasters. DMH also issue meteorological information, warning, news, alerts and special outlook to prevent natural disasters. They support public weather services, information, data, weather forecasts, advise and observations to decision makers, policy makers and different sectors.

Columbia Center for Climate Systems Research

The Center for Climate Systems Research (CCSR) is the home of the cooperative relationship between Columbia University and the NASA Goddard Institute for Space Studies (GISS) and a research center of The Earth Institute at Columbia University. CCSR was established with the objective of providing enhanced understanding of the Earth's climate and its impacts on key sectors and systems. CCSR also plays a large role in dissemination of climate change research and information to governments, local and international organizations, educational institutions, and stakeholders.

WWF

For more than 50 years, WWF has been protecting the future of nature. The world's leading conservation organization, WWF works in 100 countries and is supported by 1.1 million members in the United States and close to 5 million globally. WWF's unique way of working combines global reach with a foundation in science, involves action at every level from local to global, and ensures the delivery of innovative solutions that meet the needs of both people and nature.

Myanmar Climate Change Alliance

The MCCA programme is an initiative of the Myanmar's Ministry of Natural Resources and Environmental Conservation, implemented by the United Nations Human Settlements Programme (UN-Habitat) and the United Nations Environment Programme (UN-Environment) and funded by the European Union. It aims at mainstreaming climate change into Myanmar's development agenda by raising awareness of policy-makers and public opinion, formulating policies, strengthening coordination, building technical capacities and helping communities to adapt.

ADVANCE Partnership

ADVANCE is a partnership between World Wildlife Fund (WWF) and the Columbia University Center for Climate Systems Research (CCSR) at The Earth Institute. Launched in 2015, ADVANCE facilitates adaptation by providing new ways of generating and integrating climate risk information into conservation and development planning, policies, and practice. ADVANCE envisions a future where the world is using co-generated climate risk information based on the best-available science to guide conservation, development, and disaster risk reduction to benefit human well-being and ecosystem health.

ACRONYMS AND ABBREVIATIONS

CCSR – Center for Climate Systems Research

CMIP5 – Coupled Model Intercomparison Project Phase 5

DMH – Department of Meteorology (Myanmar)

EM-DAT – Emergency Events Database

ENSO – El Niño-Southern Oscillation

GCM – General Circulation Model

IPCC – Intergovernmental Panel on Climate Change

MCCA – Myanmar Climate Change Alliance

MoF – Matrix of Functions

MoNREC – Ministry of Natural Resources and Environmental Conservation (Myanmar)

NASA – National Aeronautics and Space Administration

NASA GISS – NASA Goddard Institute for Space Studies

NASA NEX-GDDP – NASA Earth Exchange Global Daily Downscaled Projections

NOAA –National Oceanic and Atmospheric Administration (United States)

RCP – Representative Concentration Pathway

UN-Environment – United Nations Environment Programme

UN-Habitat – United Nations Human Settlements Programme

VA – Vulnerability Assessment

WMO – World Meteorological Organization

WWF – World Wide Fund for Nature

EXECUTIVE SUMMARY

Myanmar's climate is projected to shift dramatically in the coming decades, having a lasting and significant impact on Myanmar's ecosystems and, in turn, on human health, agriculture, food security, infrastructure, local livelihoods and the larger economy. The climate risk information in this report, developed in collaboration with the Department of Meteorology (DMH) and in consultation with other key stakeholders, can aid adaptation and resilience planning across many sectors.

This report presents climate risk information including observed climate and future projections of temperature, rainfall, sea level rise and various extreme events, and outlines how this information can be used in decision-making. It also describes how climate change will affect biodiversity and ecosystem services, coastal zones, health, agriculture, infrastructure, water resources and urban areas. Finally, it documents how climate risk information is being used by the Myanmar Climate Change Alliance (MCCA) to support local ecosystem-based adaptation planning in the delta and Dry Zone towns of Labutta and Pakkoku. It should be seen as a contribution to the broader work on climate change and official projections on temperature and precipitation being carried out by DMH and the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) due to be released in the near future.

OBSERVED CLIMATE

Climate trends are based on observed weather data from 19 stations across Myanmar that were graciously provided by DMH. Between 1981 and 2010, average daily temperatures increased by about 0.25°C per decade and daily maximum temperatures by 0.4°C per decade between 1981 and 2010. The data indicates that the pace of warming has been faster in inland areas than in coastal areas, and that the rise in daily maximum temperatures has been greater than the daily average. A heat wave and drought in 2010 broke temperature records across the country and caused widespread damage to health and livelihoods (ReliefWeb, 2010). Based on the available weather station data, annual total precipitation rose slightly between 1981 and 2010, with a greater rate of increase in coastal areas than in inland ones. In coastal areas, the precipitation increases occurred throughout the year, while in inland areas the increases occurred mainly during the monsoon season. Research suggests that the summer monsoon season has become shorter by approximately one week on average (Lwin, 2002).

CLIMATE PROJECTIONS FOR MID-CENTURY

Outputs from 21 state-of-the-art climate models, downscaled to high spatial resolution, and two scenarios of future changes in greenhouse gases are used to project annual and seasonal temperature and precipitation projections for the early and mid-21st century. To project sea level rise, outputs from 24 climate models were integrated with other sources of information, including peer-reviewed literature.

In every region in Myanmar, temperatures are expected to increase by the middle of the century. Temperatures are projected to rise by 1.3°C to 2.7°C above historical levels, with the highest estimates associated with large increases in global greenhouse gas emissions. Warming varies by both season and region, with the cool (November-February) and hot (March-May) seasons seeing the most warming. Regional differences in mean warming manifest after 2040, as inland areas are projected to warm more than coastal ones. The Eastern and Northern Hilly Regions are likely to see the most dramatic warming among all regions of Myanmar, with hot season average temperatures rising by up to 3°C. An analysis was done on the frequency of hot days in the future. During 1981-2010, about one day of extreme heat per month was observed. By mid-21^{st} century, projections show that Myanmar could experience anywhere from four to 17 days of extreme heat each month.

Changes in rainfall patterns are projected to vary by region and season. Projections show that precipitation gains are most likely to occur during the monsoon season, whereas it is unclear whether precipitation will increase or decrease during the cool and hot seasons.

Sea level rise projections for the Myanmar coastline range from 20 to 41 centimeters by mid-century, depending on global greenhouse gas emission scenarios. Although projected changes in cyclone severity and frequency remain uncertain, coastal flooding during and independent of cyclones will worsen as sea levels rise.

APPLICATIONS OF CLIMATE RISK INFORMATION TO SECTORS

Climate projections can help decision-makers across several sectors incorporate climate change risks into planning and investment decisions. A flexible adaptation approach is a useful framework to not only address changes and impacts already underway, but also to accommodate future and, in some cases, more severe risks posed to ecosystems, livelihoods, infrastructure and economic growth. Since the climate projections account for the range of possible future climates in Myanmar, they are a key source of information for planning investments that build resilience at local and national levels.

Biodiversity and ecosystem services

Climate change will impact ecosystems and species in multiple ways. They will be particularly vulnerable to human responses to climate change, with efforts to increase human resilience potentially degrading ecosystems. These must be planned for alongside more direct effects, such as changes to phenology and migration patterns, as temperatures increase. Existing protected area management plans, alongside more general natural resource management and planning efforts, need to be reviewed in the light of a changing climate, along with improved monitoring of changes.

Coastal zones

Myanmar's extensive coastline will experience rising seas and increasingly frequent and extreme hazards, with the low-lying Ayeyarwaddy Delta likely to be most affected. Sea level rise alone will cause larger areas to be inundated during storm surges and coastal floods, even if the intensity of cyclones and coastal storms remain the same. It is essential that coastal-based development activities take these projections into account, along with precipitation changes, increasing temperatures and other changes such as saline intrusion and ocean acidification.

Health

Changing rainfall patterns, increasing temperatures and other extreme weather events pose major challenges to the health sector. The spread of pathogens and disease vectors, food scarcity and nutrition are health-related implications of climate change. Extreme heat events, especially when coupled with high humidity, can lead to heat-related death and severe health complications.

Agriculture

Agriculture is the main industry in Myanmar and the largest employer of the labour force. Climate change will significantly affect food security, nutrition and livelihoods as crops and livestock are sensitive to climate variables and extreme events. There are many existing options and technologies to build resilience in the agriculture sector, including changes in water use to improve water efficiency, best management practices to reduce soil loss and the cultivation of species with greater tolerance to extreme weather conditions.

Infrastructure

Critical infrastructure systems in Myanmar include energy, transportation, buildings, water supply and wastewater, and telecommunications. Any risks that climate change poses to these systems have knock-on effects on livelihoods. Planners can begin by taking a survey of current and future infrastructure vulnerabilities to highlight priority areas for adaptation. It will also be critical to evaluate the interdependencies between these various systems to prevent failures cascading from one system to another.

Water resources

With increasing rainfall variability and intensity of extreme weather events, steady, predictable seasonal water flows are unlikely to be maintained in the future, and year-to-year variation will continue to occur in the face of climate change. As the projections for future precipitation changes encompass a wide range of possible outcomes, there are measures that can be taken to manage this uncertainty when developing adaptation plans. Proper management of water resources is critical to prevent flooding of settlements and to cope with drought.

Urban areas

In urban areas, the intersection between energy, transportation and water infrastructure can have a domino effect during an extreme weather event, as an impact on one sector can, in turn, cascade onto other interdependent sectors. Managing these intersecting components in urban areas is critical to improving climate change resilience. By looking at a city's vulnerabilities today, and comparing them to how they might fare under future climate conditions, decision makers can implement adaptation measures to improve resilience in urban areas.

Potential interventions

Some interventions that can be deployed in Myanmar to prepare for climate change include:

- Maintaining forests and other ecosystems, which provide essential services such as clean drinking water and erosion control, while following forest management practices (e.g., planting native species resilient to projected climate conditions) that are adapted to changing climatic and environmental conditions;

- Reviewing and modifying conservation strategies to facilitate ecosystems and biodiversity to adapt to change (e.g., wildlife corridors to upland or inland areas) without major loss of ecosystem services;
- Changing practices in specific sectors (e.g., crop choices, planting patterns and improving water-use efficiency for agriculture);
- Strengthening infrastructure, including through the use of ecosystem-based adaptation approaches such as mangrove forests, to help communities withstand more frequent flooding events;
- Developing preparedness and response strategies to cope with increasing heat stresses, changes in the hydrological cycle and other climate hazards that pose risks to human health, wildlife and ecosystems.

Incorporating climate risk information in local planning

As an example of how the information in this report can be used, the observed climate trends and projections are contributing to vulnerability assessments and local adaptation planning in two populous and highly-vulnerable regions in Myanmar: Pakkoku township in the Central Dry Zone and Labutta township in the Ayeyarwaddy Delta. Recent projections were presented to communities and government departments to validate people's perceptions of changes already taking place and foster ownership of the adaptation process.

For example, in the Delta township of Labutta, projections of sea level rise in the 2050s have informed an assessment of which areas will suffer from increased freshwater scarcity due to saltwater intrusion and which areas may be inundated or exposed to storm-surges. Government and community leaders in Labutta can now target these communities for interventions to address increasing water scarcity in the Township Adaptation Plan. Adapting Labutta to climate change will require several areas of activity, in particular:

1. Maintaining and enhancing healthy ecosystems to support living standards, given the high dependency of people on ecosystem services;
2. Protecting and improving socioeconomic conditions by diversifying the economy and increasing skills and education to promote employability, as well as migration with dignity where necessary;
3. Ensuring that the people of Labutta have access to resilient housing and community infrastructure to protect them from hazards, and that the transport system continues to support people and the economy.

Achieving these will require addressing the climate risks in this report. For example, sea level rise projections will help to ensure that infrastructure development or reforestation is not implemented in areas that will be under water in 2050.

The Labutta Adaptation Plan is just one example of how local planning has been informed by the climate risks outlined in this report. As additional vulnerability assessments are undertaken and adaptation planning continues in towns and regions across Myanmar with support from MCCA, MoNREC, and DMH, this information can support additional interventions to increase resilience to climate risks.

INTRODUCTION

Myanmar ranked second out of 183 countries most affected by extreme weather events between 1995 and 2014 in the Global Climate Risk Index (Kreft *et al.,* 2016) Recent extreme weather events such as Cyclone Nargis in 2008, riverine flooding in 2015 and extreme heat waves in 2010 have had disastrous impacts on the society, ecology and economy of the country. Climate change threatens to compound the frequency and intensity of these events and, more importantly, to alter the conditions to which human and natural systems have adapted over millennia.

It is essential to understand and quantify the changes in climate already taking place in Myanmar, and those likely to occur over the coming century. This report describes the country's baseline climate and recent climate trends, and outlines how climate conditions are projected to change by the 2020s (defined as the time period from 2011-2040) and 2050s (defined as the time period from 2041-2070). It includes projected changes in temperature, precipitation and sea level. The report analyses extreme events, reviews key climate processes such as the monsoon, applies climate risk information to selected sectors and describes how local vulnerability assessments and adaptation planning activities are utilising climate risk information. The report contributes to the broader work on climate change and official precipitation and temperature projections being carried out by DMH and RIMES, which are due to be released in the near future.

For this report, temperature and precipitation projections were developed using the NASA Earth Exchange Global Daily Downscaled Projections (NASA NEX-GDDP) dataset released in 2015 (NASA, 2015). The NEX-GDDP dataset includes downscaled projections (0.25 degrees, ~25 kilometer resolution) from the 21 global climate models (GCMs), distributed under the Coupled Model Intercomparison Project Phase 5 (CMIP5) (NASA, 2015, CMIP5, 2016). The CMIP5 GCM simulations were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013). Sea level rise projections were developed using model outputs from the CMIP5 GCMs, along with other data sources and methods that account for land-based ice loss and changes in land water storage (Horton *et al.*, 2015a).

As the projections for future climate changes encompass a range of possible outcomes, there are measures that planners can take to manage this uncertainty while developing adaptation plans. For example, while projections in the cold and hot seasons span a range that suggests seasonal rainfall could either increase or decrease, all climate model outcomes presented in this report suggest at least some form of increase in precipitation for the wet season in every region by the mid-21st century. This is a starting point that stakeholders across Myanmar can use to begin planning for more summer monsoon rainfall in agriculture, hydropower, conservation areas, dams and flood management.

Year-to-year variation will still occur in the face of climate change, and not every future year or every location will always experience greater than average rainfall in the wet season. There may be years where rainfall is lower in the wet season, for example, and the climate models do not capture all possible futures. Still, the climate models, our best tools for long term projections, suggest that the long-term trend will be towards more rain as the century progresses.

Armed with this climate risk information, stakeholders are beginning to consider the long-term measures required to prepare for climate change, reduce vulnerability and improve resilience over the coming century. Further interactions between the research community and decision-makers are critical to developing climate risk information relevant to planning adaptation interventions that build resilience (Horton *et al.*, 2015b). This is an iterative process that does not stop with the projections and risk information presented here. Instead, this information serves as a contribution to continued analysis of climate change risks. This knowledge base will improve over time, through advancements in science and technology and through communication with relevant stakeholders as the 21st-century proceeds.

GLOBAL CLIMATE CHANGE

The global climate is changing (IPCC, 2013). Scientists from around the world have come to a consensus that global temperatures are rising, and that human activities which emit greenhouse gases into the atmosphere are causing many of these changes. The NASA Goddard Institute for Space Studies and the US National Oceanic and Atmospheric Administration (NASA, 2016; NOAA, 2016), the UK Met Office Hadley Center and the University of East Anglia's Climatic Research Unit (Met Office, 2016), as well as the World Meteorological Organization (WMO, 2016) have all found 2015 to be the hottest year since record-keeping began. Additionally, 15 out of the 16 warmest years have occurred since the year 2000 (NOAA, 2016). Changes in greenhouse gas concentrations not only increase global temperature, but also have far-reaching effects on climate. These effects are projected to include shifts in precipitation patterns, sea levels, heat extremes, storms, monsoon cycles, ocean currents, sea surface temperatures, land ice mass and river flows.

As we have already seen, natural and man-made systems alike will continue to be significantly affected by these changes. Species and ecosystems may experience climate conditions outside of those under which they have evolved to survive. Even if species are able to adjust and adapt to the direct climate changes, they may be affected by changes in synchronisation with important prey species. Human settlements and economies will be impacted across the globe: Farmers will face increasing droughts and floods and cities will have to respond to more frequent extreme events which will affect infrastructure and health. Coastal communities on every continent will face inundation from floodwaters reaching further inland as a result of sea level rise.

Local and regional decision-makers need to be aware of the changes that will directly affect the areas they govern. These changes can be met with measures that improve resiliency of human and natural systems to new climatic patterns and extreme events. By understanding local risks, action can be taken now to prevent the worst impacts of climate change in communities in Asia and around the globe.

UNCERTAINTY IN PROJECTING CLIMATE CHANGE

There is a degree of uncertainty associated with predicting future climate conditions as they have yet to occur (Horton *et al.*, 2015b), but this uncertainty should not be a reason for inaction or for not using projections to inform decision-making. One of the reasons for this uncertainty is that natural variability of the climate system is largely unpredictable. This includes randomness in ocean dynamics, storm events, solar cycles and atmospheric patterns that shift in an erratic manner over time. A second source of uncertainty is human behaviour. The effectiveness of international climate agreements to reduce greenhouse gas emissions, the development of new technologies and cultural and behavioural patterns will direct the trajectory of greenhouse gas emissions over time and determine the magnitude and rate of climate change.

A third source of uncertainty lies in the global climate models that project future climate patterns. Each of these mathematical models simulates the climate system, how that system will respond to increased greenhouse gas emissions and feedback loops from the interconnected systems that govern weather and climate. These models incorporate these various aspects in slightly different ways, resulting in different outputs for temperature, precipitation, sea level rise and other variables.

Due to these uncertainties, the climate projections in this report are presented as a range of possible outcomes, rather than a single number for a time period. This risk-based approach to decision-making is critical to appropriately account for uncertainty in adaptation planning across a range of sectors and applications. Detailed projection methods are described in Appendices B and C.

Interpreting climate projections

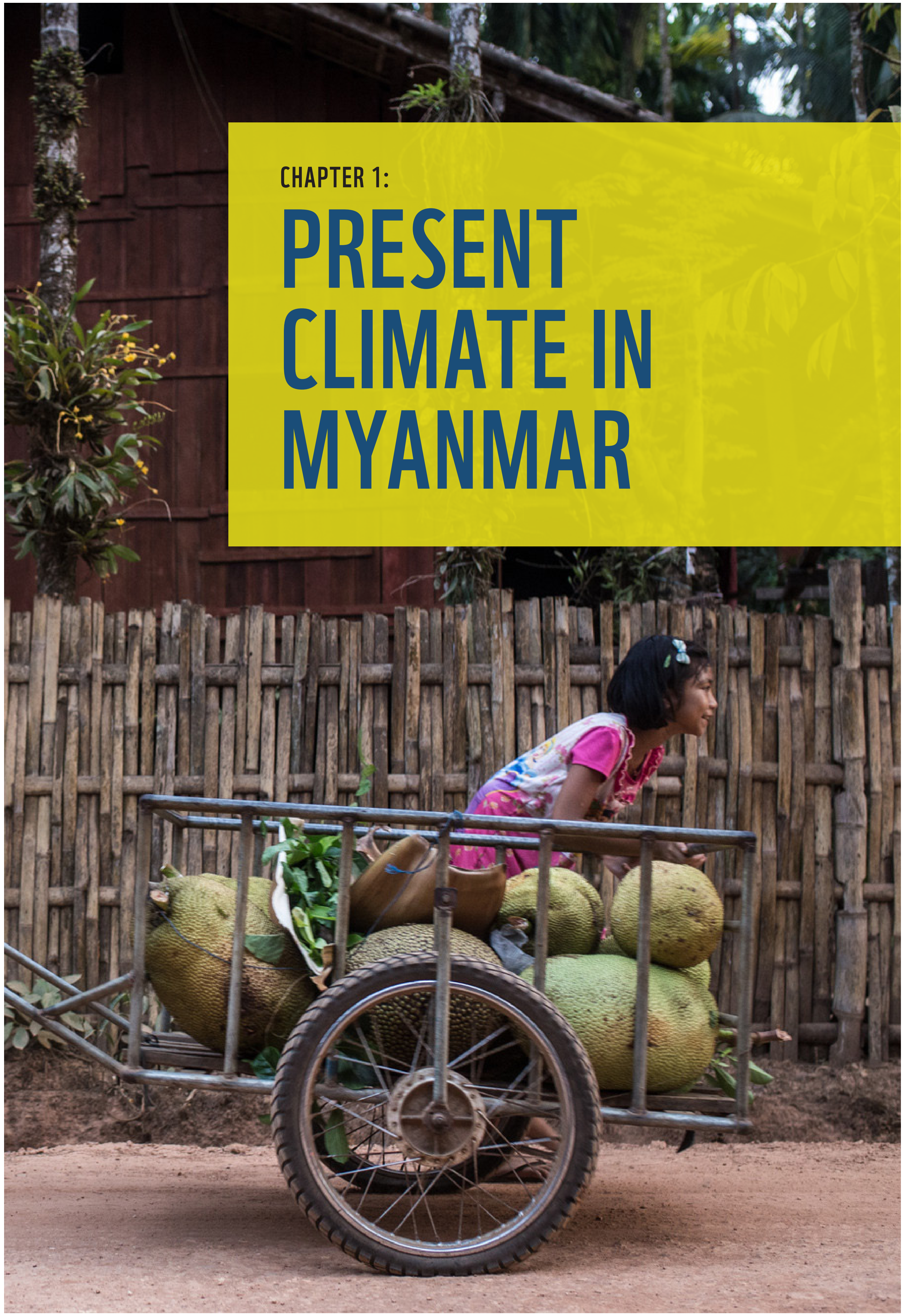
In this report, projections are presented as ranges. These estimates are based on a ranking (from most to least) of the outcomes of the 21 global climate models under two greenhouse gas emissions scenarios. We define the low estimate as the 25th percentile of the 21 global climate models under the RCP 4.5 emissions scenario. We define the high estimate as the 75th percentile of the 21 global climate models under the RCP 8.5 emissions scenario.

The 25th percentile, or low estimate, is defined as the value that 25 percent of the model outcomes (5 out of the 21 values) are the same or lower than, and 75 percent of the model outcomes (16 out of the 21 values) are the same or higher than. This 25th percentile value is the model outcome for which 75 percent of the model results reflect a larger increase (or, if the value is negative, a smaller decrease), and thus is considered the low estimate.

The 75th percentile, or high estimate, is defined as the value that 75 percent of the model outcomes (16 out of the 21 values) are the same or lower than, and 25 percent of the model outcomes (5 out of the 21 values) are the same or higher than. This 75th percentile value is the model outcome for which 25 percent of the model results reflect a larger increase (or, if the value is negative, a smaller decrease), and thus is considered the high estimate.

CHAPTER 1:

PRESENT CLIMATE IN MYANMAR



Currently, Myanmar experiences a tropical-monsoon climate with three dominant seasons: the March-to-May hot season, the June-to-October wet season and the November-to-February cool season.

Myanmar consists of eight major physiographic regions: The Ayeyarwaddy Delta, Central Dry Zone, Northern Hilly Region, Rakhine Coastal Region, Eastern Hilly Region, Southern Coastal Region, Yangon Deltaic Region, and Southern Interior Region (Figure 1.1). Climatology was generated using the NASA NEX-GDDP dataset, which is based on gridded datasets developed from a combination of observed weather station data and climate model results.

There are pronounced regional differences in climate (See Appendix A). The Central Dry Zone is a large inland swath of the country that is prone to extreme heat events and drought. The rainy coasts, such as the Rakhine, Southern Coastal and Yangon Deltaic areas, are slightly cooler in annual average temperature but are prone to flooding. Further inland are the cooler Northern and Eastern Hilly regions, which experience heat waves, droughts and floods (which can lead to landslides).

The Yangon Deltaic Region has the highest mean temperature. Because of its higher elevation, the Northern Hilly Region has the lowest mean and maximum annual temperature. This pattern remains consistent for seasonal temperature, such that the Yangon Deltaic has the highest mean and maximum annual temperatures for the hot, cool and wet seasons. The pattern for the Northern Hilly Region is similar, with the lowest mean and maximum annual temperature for the hot and cool seasons, with only one exception that the wet season has the same mean annual temperature as the Eastern Hilly Region. Figure 1.2 shows the baseline average annual temperature conditions across Myanmar.

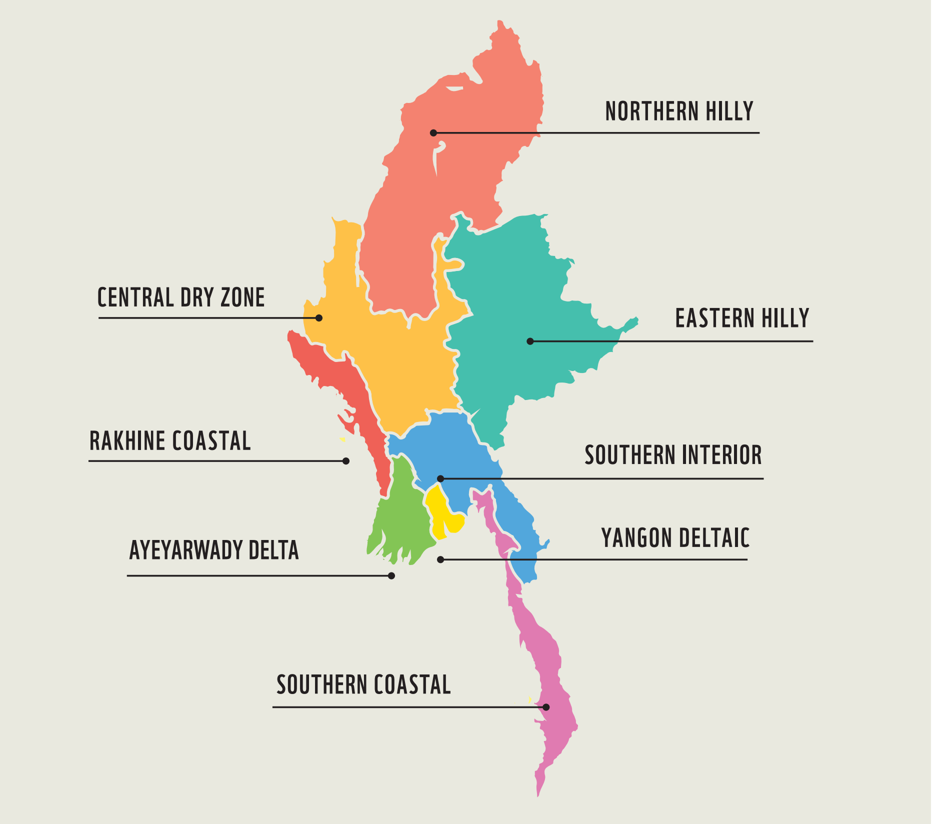


Figure 1.1. *Physiographic regions of Myanmar, as represented in this report.*

Myanmar receives most of its rainfall during the wet monsoon season. The hot and cool seasons bring little rainfall, with the cool season especially yielding very little rainfall for all regions. In the hot and cool seasons, the Southern Coastal Region receives the most rainfall, with the second-highest rainfall observed in the Northern Hilly Region (hot season) and Ayeyarwaddy Delta (cool season). The highest annual precipitation is observed in the Rakhine Coastal Region, followed by the Ayeyarwaddy Delta, with the same pattern being observed in the wet season.

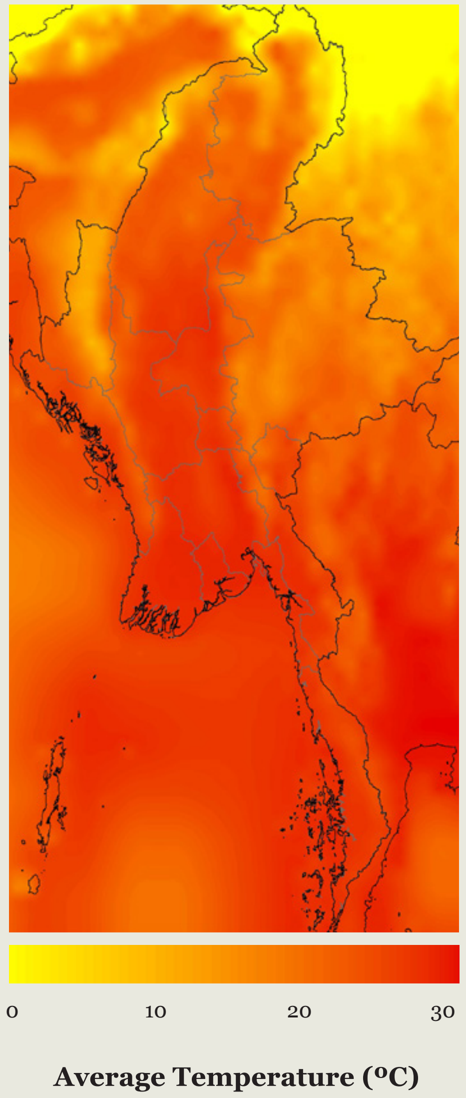
The lowest annual precipitation is observed in the Eastern Hilly Region, followed by the Northern Hilly Region. These regions also receive the lowest wet-season precipitation, with the Eastern Hilly Region receiving the lowest, followed by the Northern Hilly Region. The same pattern is observed during the wet season. In the hot season, the lowest precipitation is observed in the Eastern Hilly Region, followed by the Southern Interior Region. In the cool season, the Southern Interior Region receives the least rainfall, followed by the Yangon Deltaic Region.

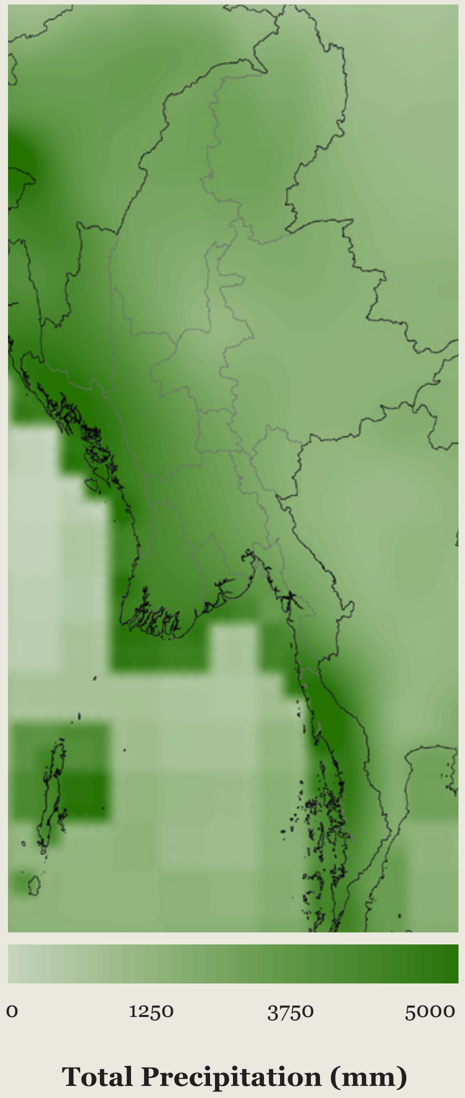
The current baseline conditions for rainfall, shown in Figure 1.3, show that the coastal regions experience much greater amounts of annual rainfall than inland areas.

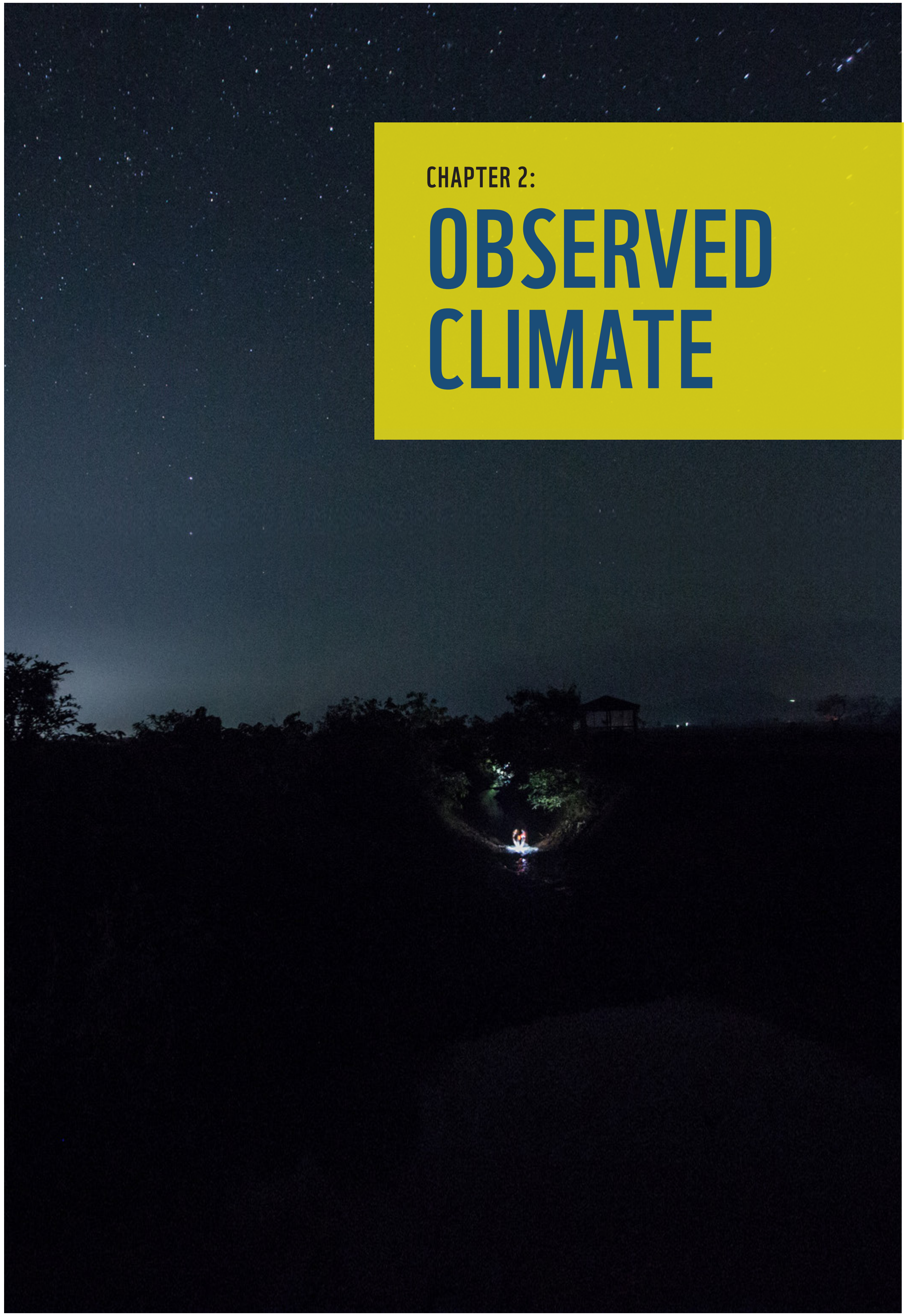
Figure 1.2. _(Left) Baseline annual average temperature climatology across Myanmar (1980-2005) from climate model outputs._

Figure 1.3. _(Right) Baseline annual precipitation climatology across Myanmar (1980-2005) from climate model outputs._

Source data: NASA NEX GDDP, 2015

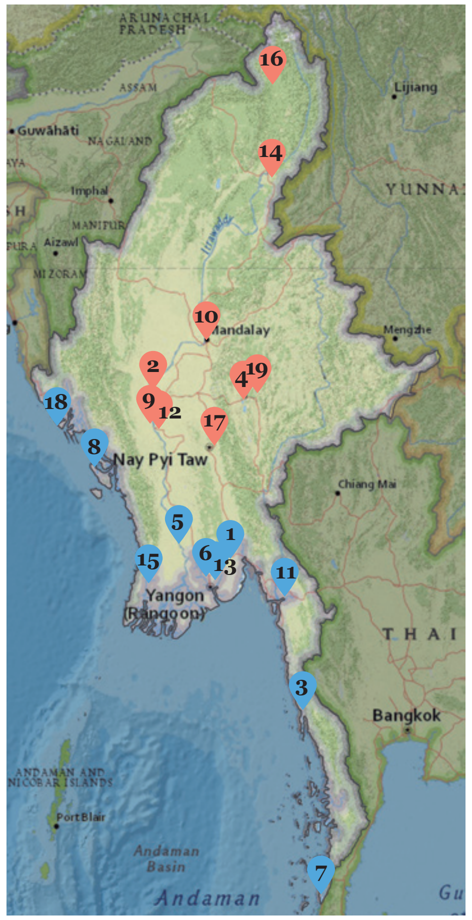






CHAPTER 2:

OBSERVED CLIMATE



Myanmar has already experienced climate change over recent decades. Although climate change trends that span only a few decades are often statistically weak at individual weather stations, a robust signal emerges when considering many weather stations at once.

National average daily temperatures based on 19 weather stations across Myanmar increased by about 0.25°C per decade during the period 1981-2010, and daily maximum temperatures have risen at a slightly faster rate of 0.4°C per decade over the same period. These rates are similar to global averages for the same time period (IPCC 2014).

To investigate the differences in observed climate change between coastal and inland areas, the set of 19 weather stations was split into 10 coastal and 9 inland stations and the groups were evaluated separately for trends from 1981 to 2010 (Figure 2.1). Inland regions warmed faster than coastal ones, both in terms of average temperature (0.35°C per decade increase in inland regions versus 0.14°C per decade coastally) and maximum temperature (0.57°C increase per decade inland versus 0.23°C increase per decade along the coasts, Figure 2.2). Similar to national trends, maximum temperatures rose slightly faster than daily average temperatures in both coastal and inland areas.

Figure 2.1. *Weather stations used to evaluate observed climate trends in Myanmar. Blue markers represent stations in the coastal region, and red markers represent stations in the inland region. Weather station data provided by DMH (2015).*

1. Bago
2. Chauk
3. Dawei
4. Heho
5. Henzada
6. Kabaaye
7. Kawthong
8. Kyaukphyu
9. Magway
10. Mandalay
11. Mawlamyine
12. Minbu
13. Mingaladon
14. Myitkyina
15. Pathein
16. Putao
17. Pyinmana
18. Sittwe
19. Taunggyi

As in most places, precipitation trends over 1981-2010 are more ambiguous than temperature trends (Figure 2.3), due to a combination of large natural variability and small trend relative to baseline average amounts. Coastal areas have experienced an increase of 157mm (4.5%) per decade in annual total rainfall, driven by gains in rainfall during the November-to-May dry season (85mm per decade or 17% per decade) compared to gains during June-to-October monsoon months (72mm per decade or 2.5% per decade). Compared to coastal areas, increases in inland annual precipitation have been more moderate at 37mm (2.5%) per decade. Since no trend was detected during the dry season, we conclude that these small gains are driven by slightly wetter monsoon months. Globally, increased monsoonal rains are attributed largely to the increase in atmospheric moisture content (Christensen *et al.*, 2014)

While total annual rainfall has increased in recent decades, when and how it falls – its distribution – is important. Consistent rainfall tends to be more beneficial for farmers, while short, highly-intense rainfall is likely to be more damaging due to damage to crops and livestock from floods. While there has been no statistically meaningful trend in the number of rainy days (defined as days with rainfall >1mm) per year over 1981-2010, annual precipitation totals have increased, implying that rainfall events have become more intense. Intense rainfall events are often less useful as they are concentrated during a short time, with the potential to cause floods and limiting use (e.g. rain-fed agriculture, excess water in dams etc.).

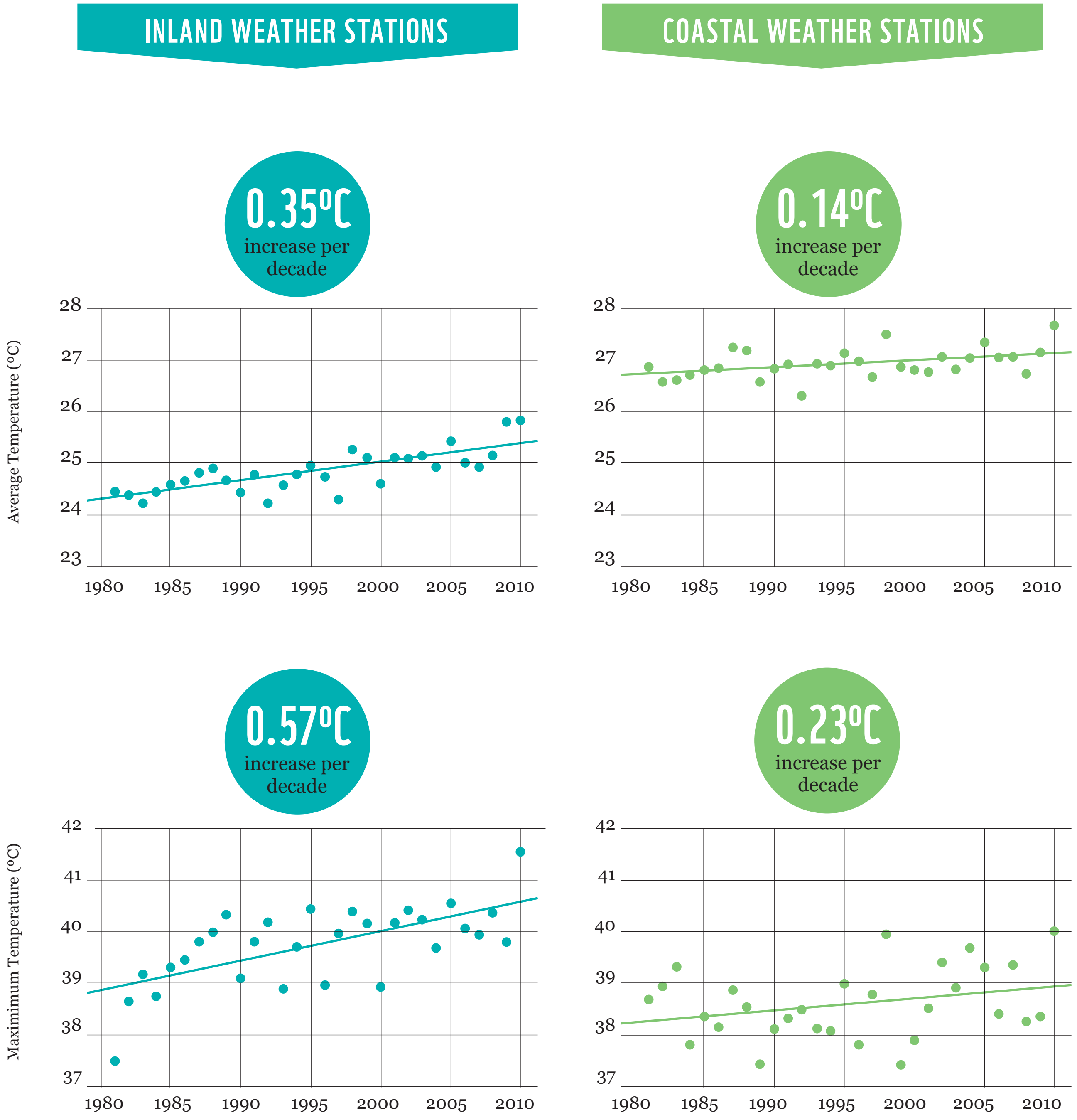
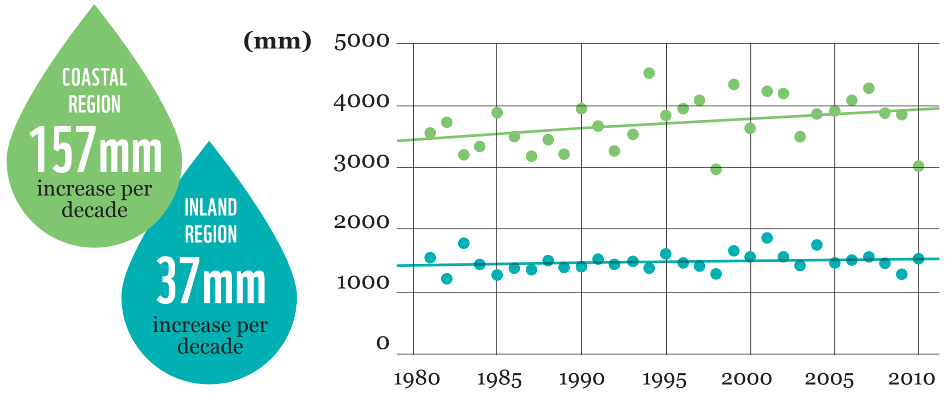


Figure 2.2. *Trends in daily average (top row) and daily maximum (bottom row) temperatures on average across nine inland (blue) and 10 coastal (green) weather stations, 1981-2010.*
Weather station data provided by DMH (2015).

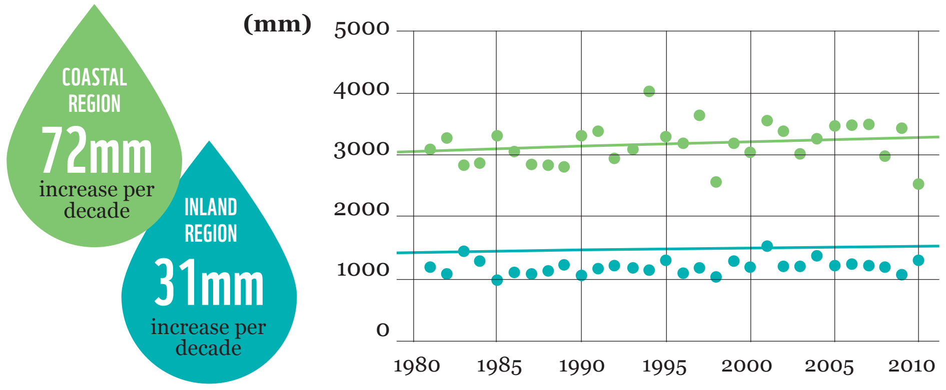
> WE'VE NOTICED IT HAS BEEN GETTING HOTTER, AND THERE IS LESS WATER IN THE RIVERS THAN THERE USED TO BE. IT MUST BE BECAUSE OF DEFORESTATION. WE HAVE A SAYING, THAT WEATHER AND CLIMATE DEPEND ON THE FOREST. I BELIEVE IT IS TRUE.
>
> U MYO WIN, PHAUNG TAW VILLAGE, BANCHAUNG VALLEY

Figure 2.3. *Trends in total annual [top], wet season (June to October) [center], and dry season (November to May) [bottom] precipitation for 10 coastal (green) and nine inland (blue) weather stations, 1981-2010.*
Weather station data provided by DMH (2015).

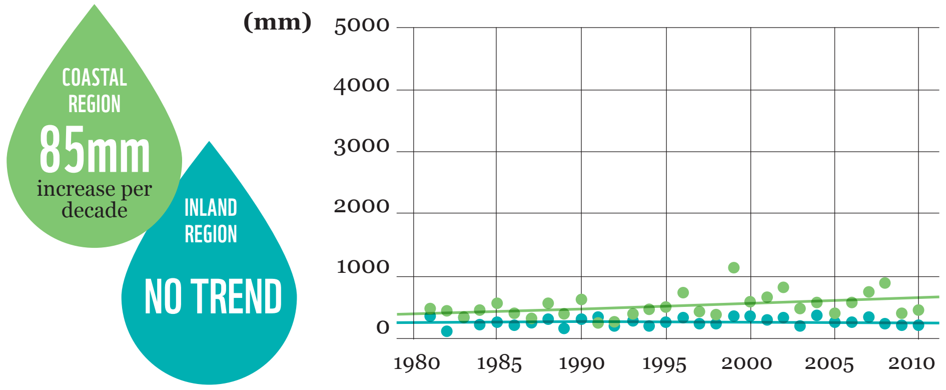
ANNUAL TOTAL PRECIPITATION



WET SEASON TOTAL PRECIPITATION



DRY SEASON TOTAL PRECIPITATION



CHAPTER 3:

TEMPERATURE PROJECTIONS

The average annual temperature in Myanmar is expected to rise over the coming century as a result of climate change, though the magnitude of warming varies by region and season (see Appendix B for methods and Appendix C for detailed projections for regions and seasons).

During the 2011-2040 period, national annual average temperatures are projected to rise by 0.7-1.1°C compared with the 1980-2005 base period, while warming trends may accelerate beyond 2040, raising average temperatures by 1.3-2.7°C (Table 3.1 and Figure 3.1). These change factors are associated with an increase in mean temperature, meaning that some areas will experience more warming than described here.

Table 3.1. *Projections for mean annual and seasonal temperature change above the baseline across Myanmar.*
Source data: NASA NEX GDDP, 2015

	Model baseline* (1980 to 2006)	Warming by 2011-2040	Warming by 2041-2070
Annual	23.6 °C	0.7-1.1°C	1.3-2.7°C
Hot Season	25.1°C	0.8-1.2°C	1.4-2.9°C
Wet Season	25.1°C	0.6-1.1°C	1.1-2.4°C
Cool Season	20.5°C	0.7-1.2°C	1.3-2.8°C

* The NASA NEX baseline data reflects model values averaged over a .25 degree (25km). For this and other reasons, the actual observed station temperatures may differ from the model baseline shown here.

While the cool (November-February) and hot seasons (March-May) are most likely to warm at a similar rate to the annual average, wet season temperature changes are projected to be smaller. By 2041-2070, wet season (June to October) mean temperatures are projected to increase by 1.1°C to 2.4°C, which is 0.3-0.5°C less than the projected warming during the remainder of the year.

Regional differences in mean warming manifest after 2040; by 2041-2070 temperatures in inland areas are projected to warm 0.3-0.4°C more than coastal ones. The Eastern and Northern Hilly Regions are likely to see the most dramatic warming among all regions of Myanmar, with hot season average temperatures rising by up to 3°C. Daily maximum temperatures changes through 2070 are projected to largely mirror the seasonal and regional changes in mean temperatures.

Uncertainty in these temperature projections increases into the future. The range of temperature projections presented (i.e., the difference between the high and low estimates) spans 0.3-0.4°C for 2011-2040, increasing to 1.0-1.5°C by 2041-2070. The uncertainty range is generally consistent across regions and seasons.

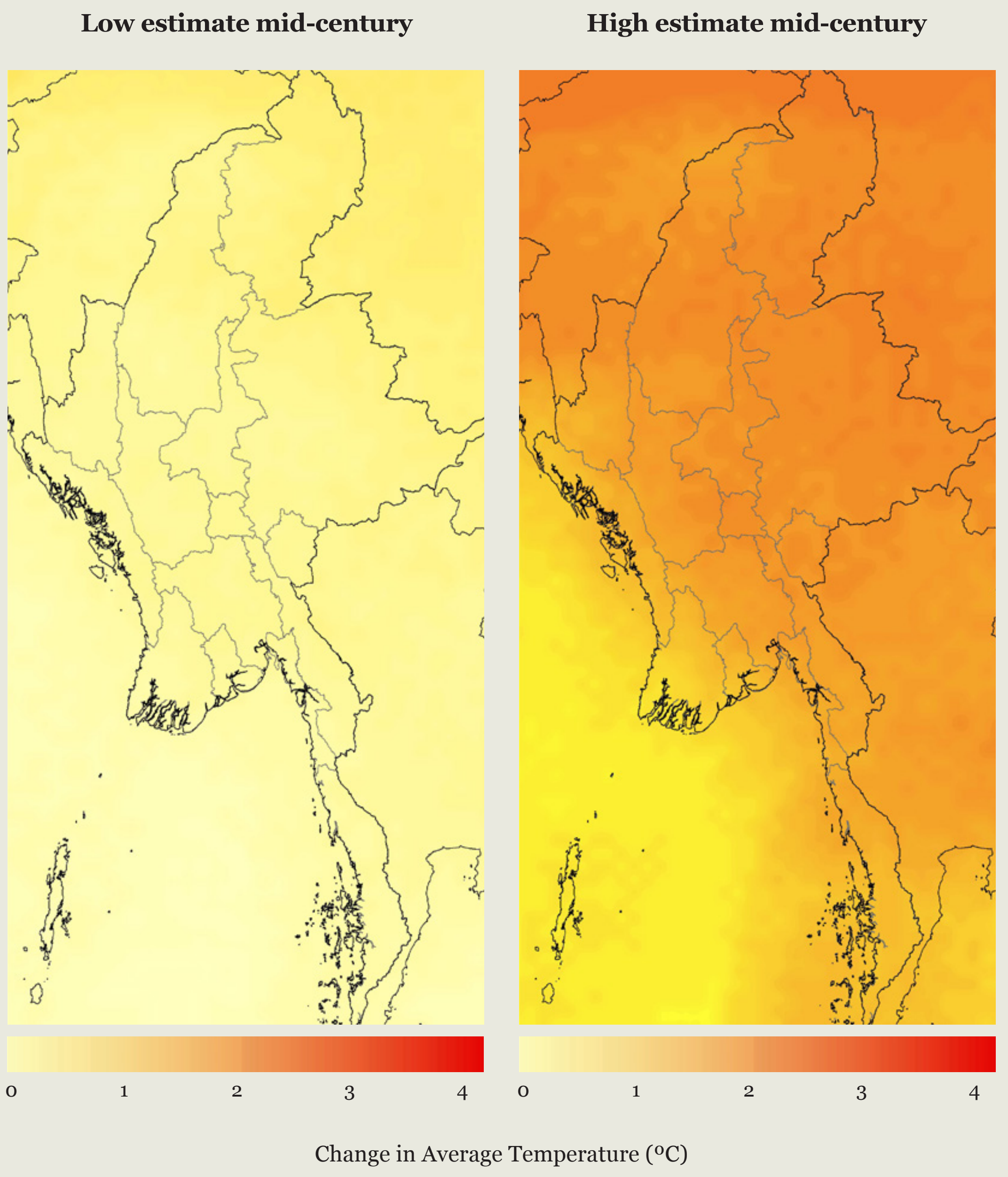
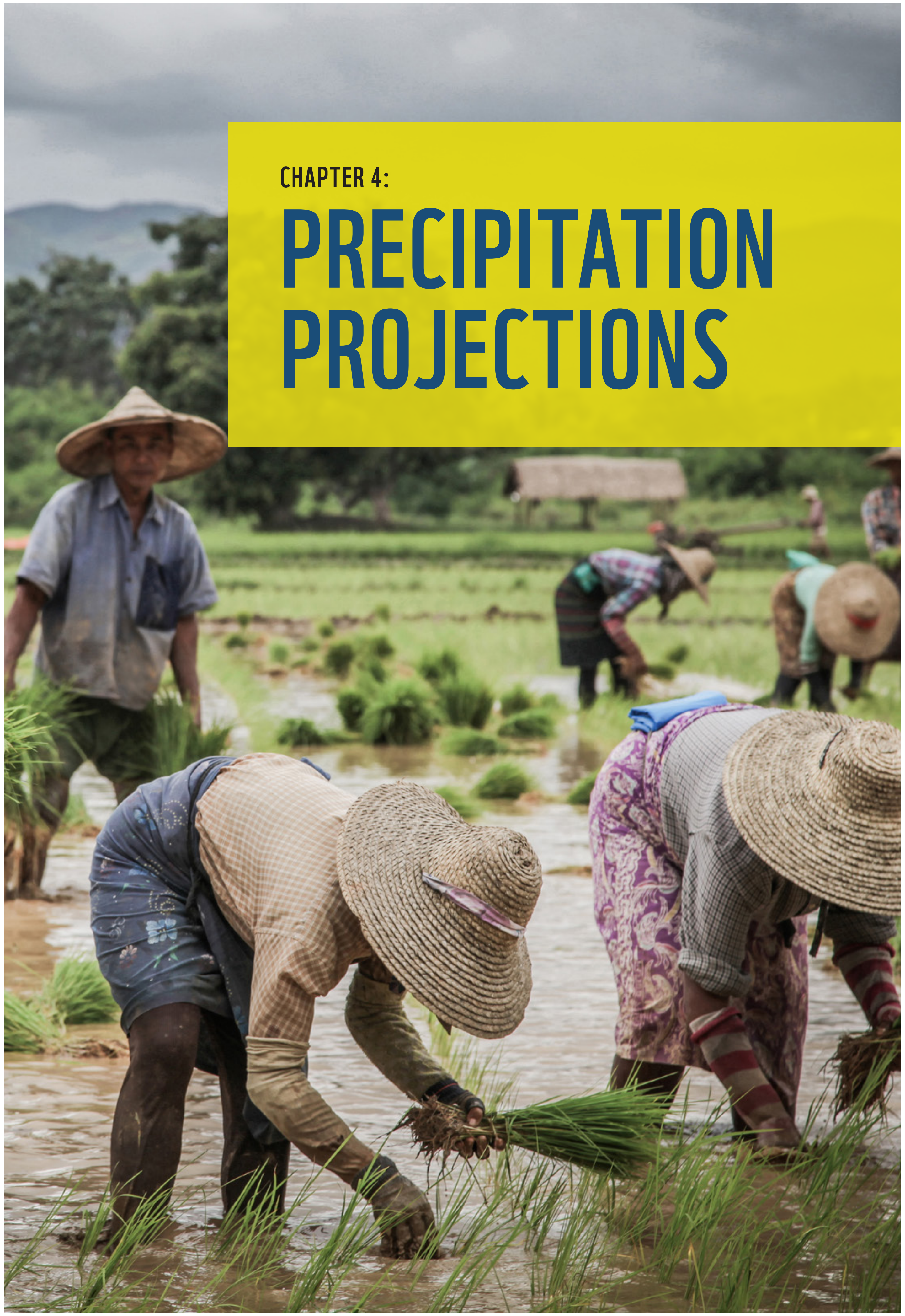


Figure 3.1. *Average annual temperature change in mid-century relative to the 1980-2005 base period under low emissions (left) and high emissions (right) scenarios*

Note: Data source for temperature projections is NASA Earth Exchange Global Daily Downscaled Projections (NASA NEX GDDP).

CHAPTER 4:

PRECIPITATION PROJECTIONS



Precipitation patterns across Myanmar are projected to change over the coming century (Figure 4.1). However, because precipitation processes are more complex and less well- understood than those governing mean temperatures, spatial and seasonal patterns in precipitation projections are often less clear than those for temperature.”

The IPCC Fifth Assessment Report emphasises the high uncertainty and spatial variation in projected precipitation shifts under climate change compared to temperature projections, which are generally more spatially uniform and less uncertain. As a result, the uncertainty ranges presented for precipitation change are higher than for temperature and this should be accounted for in planning.

Although the uncertainty range is relatively large, overall the current wet season months (June to October) are projected to see more rainfall. Wet season total precipitation is projected to increase in both the near and long term relative to the 1980-2005 baseline. These changes are expected to raise the national average wet season total precipitation after 2040, and could exacerbate wet season flooding in some regions (Table 4.1). (See Appendix B for methods and Appendix D for detailed projections for regions and seasons).

Table 4.1. *Projections for mean annual and seasonal precipitation change from the baseline across Myanmar.*
Source data: NASA NEX GDDP, 2015

	Model baseline* (1980 to 2006)	**Precipitation range 2011-2040**	**Precipitation range 2041-2070**
Annual	2000 mm	+1% to +11%	+6% to +23%
Hot Season	300 mm	-11% to +12%	-7% to +19%
Wet Season	1700 mm	+2% to +12%	+6% to +27%
Cool Season	100 mm	-23% to +11%	-12% to +11%

* The NASA NEX baseline data reflects model values averaged over a .25 degree (25km). For this and other reasons, the actual observed station temperatures may differ from the model baseline shown here.

In contrast, it is uncertain whether cool (November-February) and hot season (March-May) precipitation will increase or decrease. By 2041-2070, precipitation projections during the hot season are more likely to increase than decrease, and the cold season is equally likely to decrease or increase (Table 4.1). The percentage changes presented offer one way of considering shifts in seasonal precipitation. However, a large percent change in a dry region can result in a smaller absolute change in a wet region.

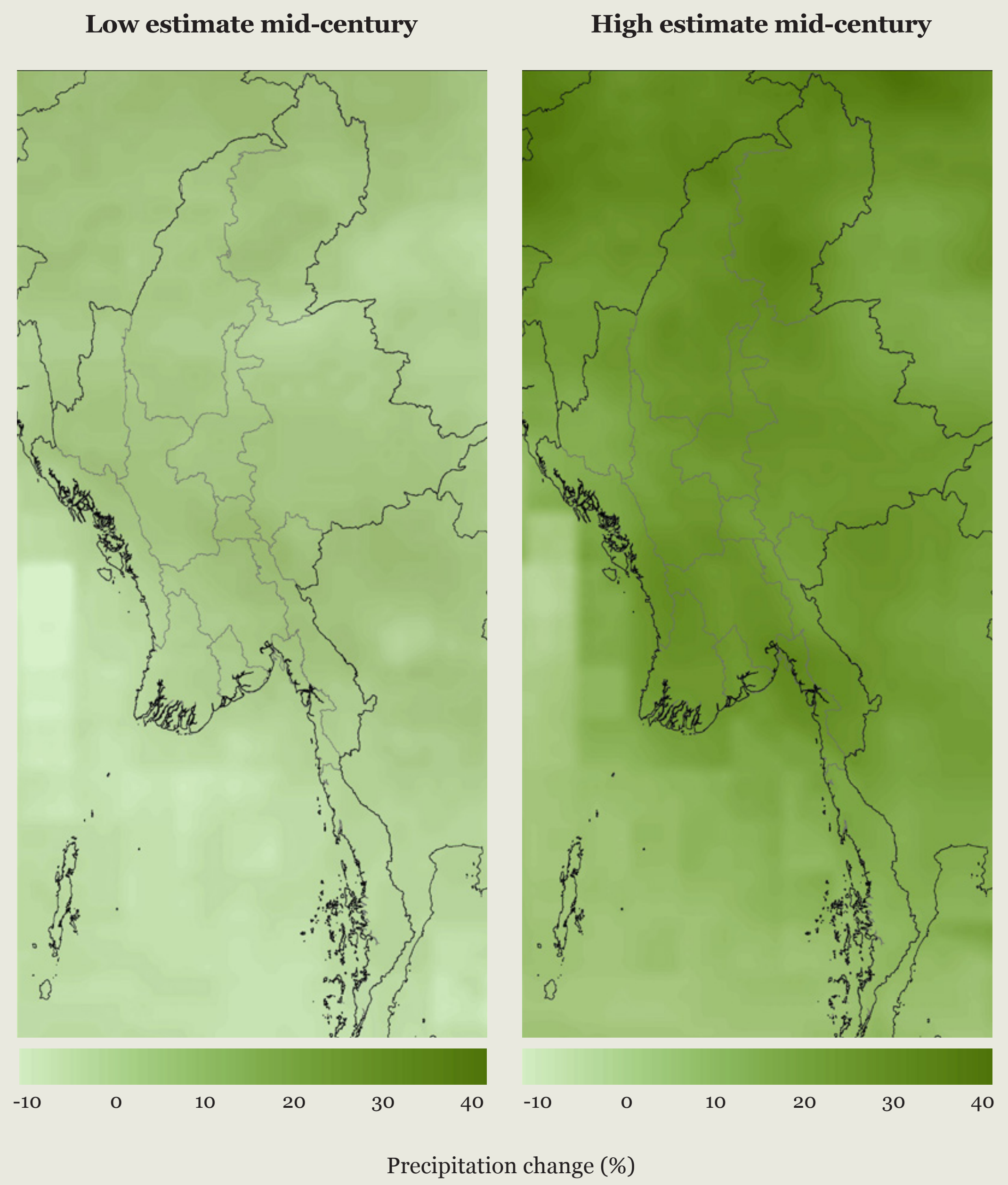
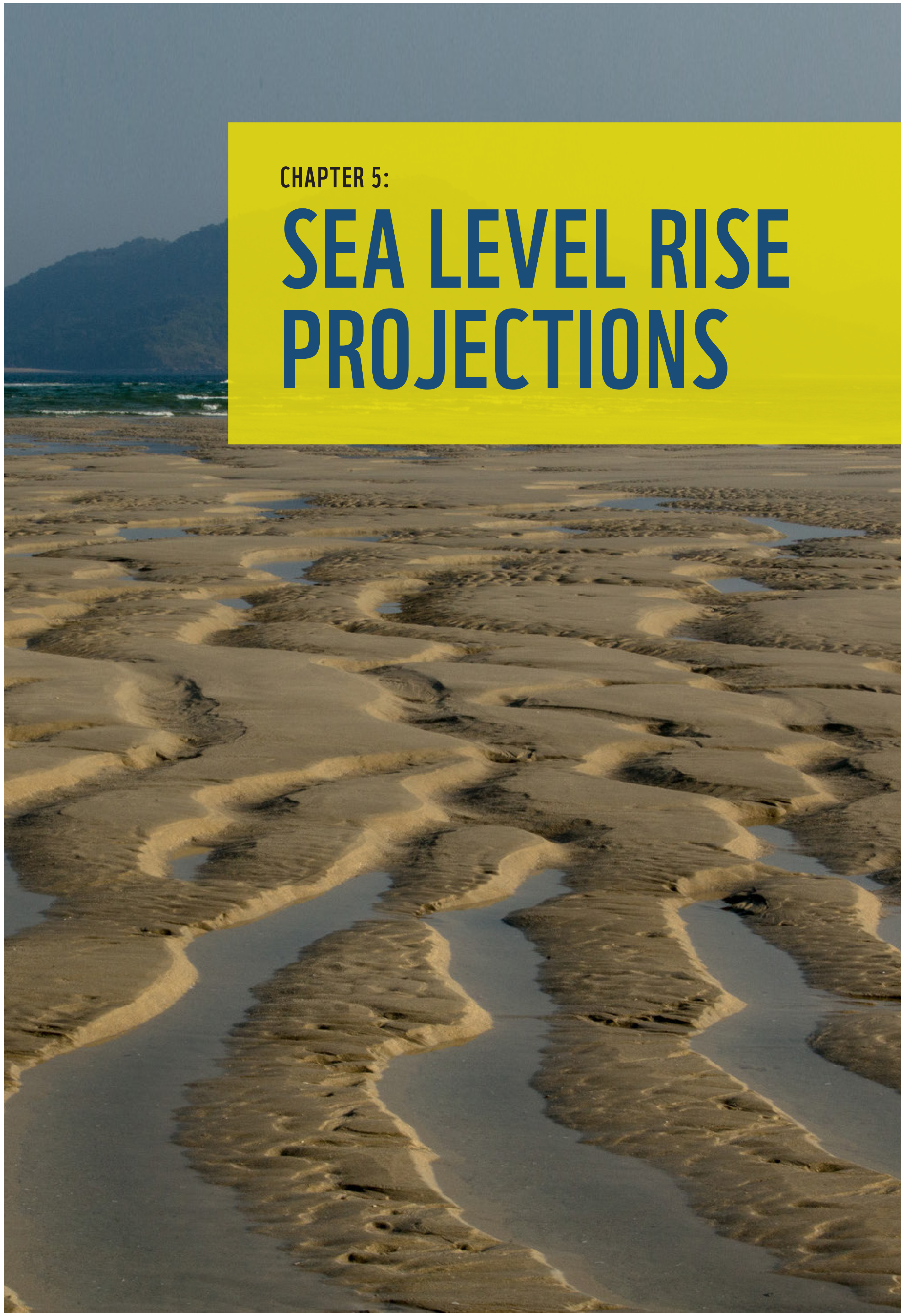


Figure 4.1. *Average annual rainfall percentage change in the mid-century relative to the 1980-2005 base period under low emissions (left) and high emissions (right) scenarios.*
Note: Data source for precipitation projections is NASA Earth Exchange Global Daily Downscaled Projections (NASA NEX GDDP).

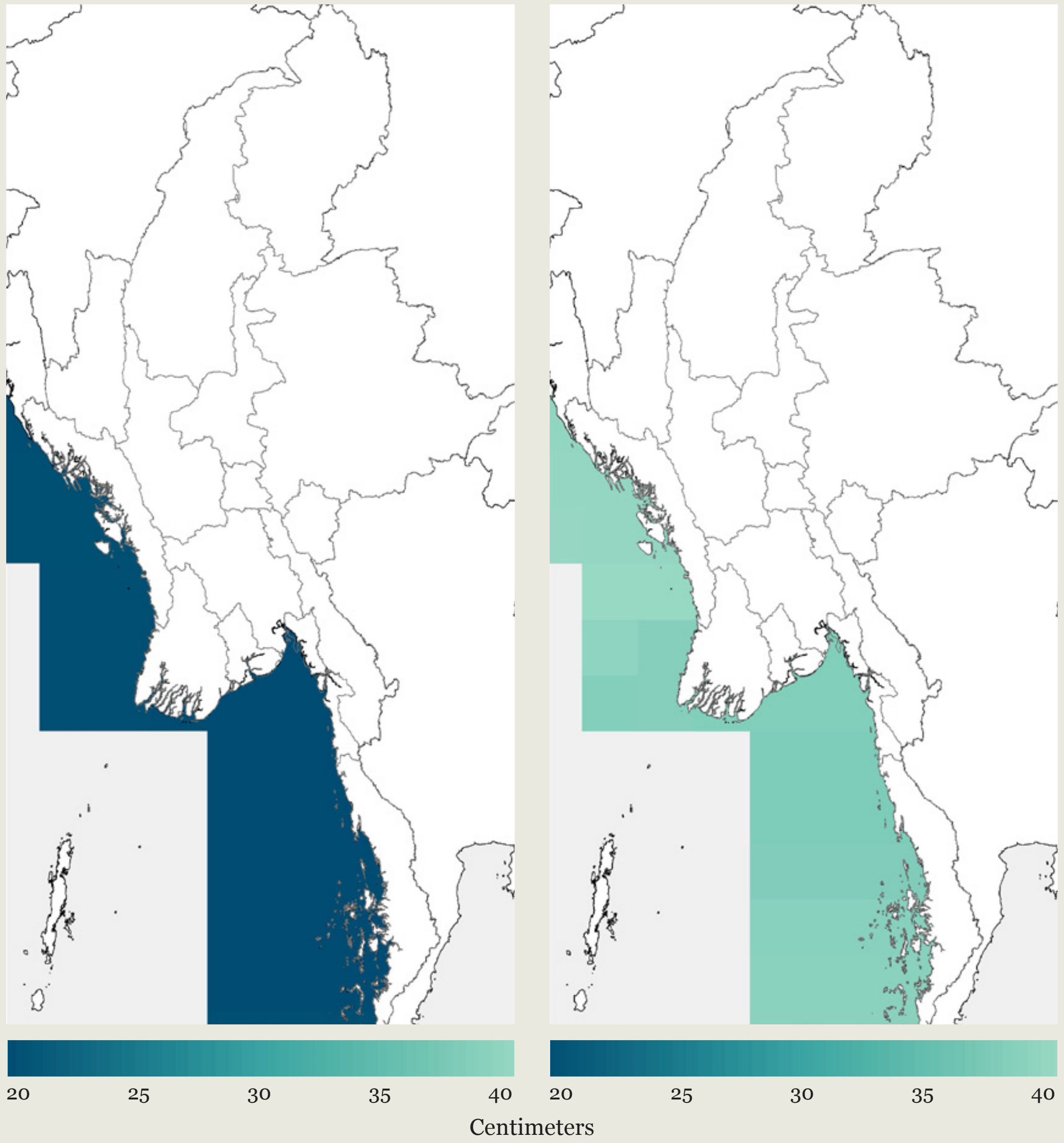


CHAPTER 5:

SEA LEVEL RISE PROJECTIONS

Sea level rise projections were developed for the entire coastline of Myanmar (Table 5.1). These projections take into account global and regional components that contribute to changes in sea level.

These include thermal expansion and local ocean height (ocean component), loss of land ice, and global land water storage. The results do not take into account local land subsidence. While local land subsidence is negligible along much of the coast, in some regions, including populous delta regions it can lead to effective sea level rise rates that are larger than those shown here.



Low estimate
25th percentile for sea level rise in Myanmar in the 2050.

High estimate
75th percentile for sea level rise in Myanmar in the 2050s.

Figure 5.1. *Projected sea level rise along the coast of Myanmar in the 2050s relative to the 2000-2004 base period.*

Table 5.1 *Middle range projections of sea level rise above 2000-2004 base period levels in Myanmar (cm).*

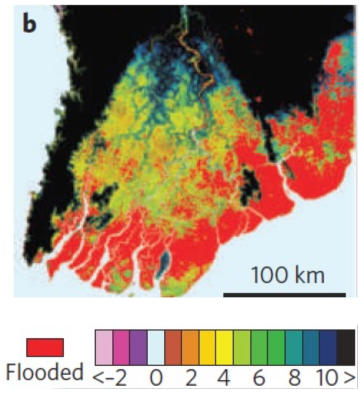
Timeslice	Middle range of future sea level rise
2020s	5 cm to 13 cm
2050s	20 cm to 41cm
2080s	37 cm to 83 cm

Note: The middle range refers to the 25th to 75th percentile of model-based outcomes for sea level rise projections.

When looking at the results for the entire coastal area of Myanmar, middle range sea level rise estimates for 2020-2029 time period are 5 centimeters to 13 centimeters above the baseline level. By the 2050-2059 time period, sea level may rise 20 centimeters to 41 centimeters above the baseline. In the 2080-2089 time period, the middle range of projections estimate sea level to be between 37 centimeters to 83 centimeters above the baseline, with the potential for up to 122 centimeters in the highest range[1] of projections for this time period. These results are visualised in Figure 5.1. See Appendix E for detailed sea level rise projections.

Given that Myanmar's coastline consists of large low-lying areas, including the Ayeyarwaddy Delta, these sea level rise projections would mean large increases in permanently flooded areas and in the frequency and magnitude of flooding for those coastal areas not permanently inundated. As was evidenced by the devastating effects of Cyclone Nargis on the densely-populated Delta Region in 2008, Myanmar is already highly vulnerable to coastal flooding (Figure 5.2). This projected increase in sea levels would carry such flooding further inland in the future, resulting in even greater impacts. For example, it has been estimated that a 0.5 meter rise in sea levels could lead to a retreat of the coastline by approximately 10 kilometers in Myanmar's lowest lying areas (Ministry of Environmental Conservation and Forestry and Department of Meteorology and Hydrology, 2012).

Figure 5.2. *Coastal surge from Cyclone Nargis on 5 May 2008. Flood waters, shown in red, superimposed on SRTM altimetry.*
Source: Syvitski *et al.*, 2009.



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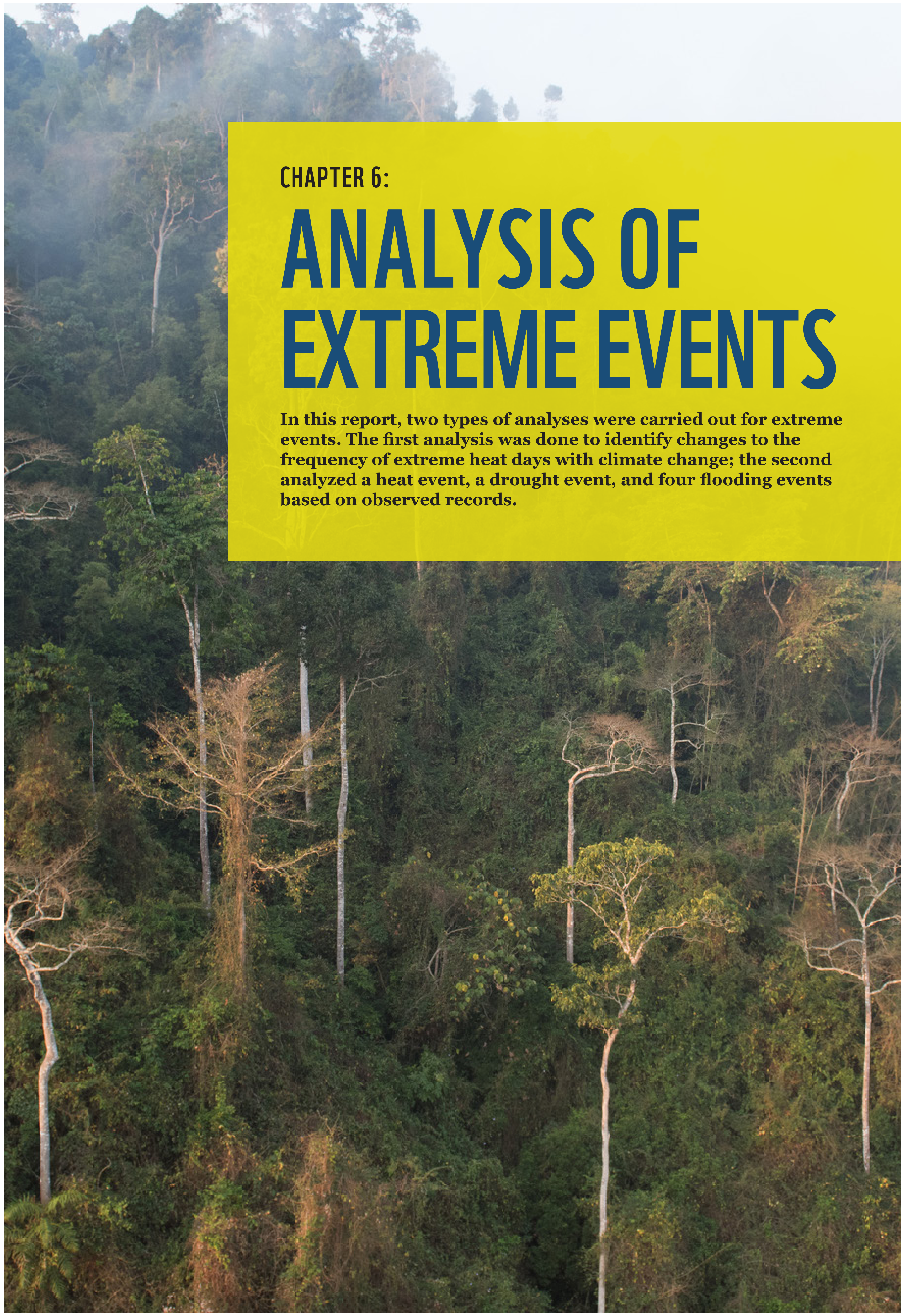
[1] The highest range refers to the 90th percentile of model-based outcomes for sea level rise projections. See Appendix E for full results.



CHAPTER 6:

ANALYSIS OF EXTREME EVENTS

In this report, two types of analyses were carried out for extreme events. The first analysis was done to identify changes to the frequency of extreme heat days with climate change; the second analyzed a heat event, a drought event, and four flooding events based on observed records.

6.1 FUTURE HEAT EXTREMES

In addition to changes in the seasonal average of daily average and maximum temperatures, it is important to understand how the frequency of very hot days might shift in the future. Extreme heat can cause severe damage to human health, ecosystems, crops and infrastructure. Furthermore, small changes in average temperature can result in disproportionate increases in very hot days.

To project changes in the incidence of extreme heat into the future, we first defined "extreme heat days" as those with a maximum temperature exceeding a threshold corresponding to the 95th percentile of daily maximum temperatures by month from the historical period (1981-2010) using weather station data provided by DMH. This definition corresponds approximately to the historical hottest day of the month. Using this hottest day as a baseline temperature that signifies an extreme heat day, projections were developed for the increase in the frequency of these extreme heat days per month (using the NASA NEX GDDP database). Figure 6.1 provides a conceptual illustration of the analysis performed to understand the changes in these heat extremes.

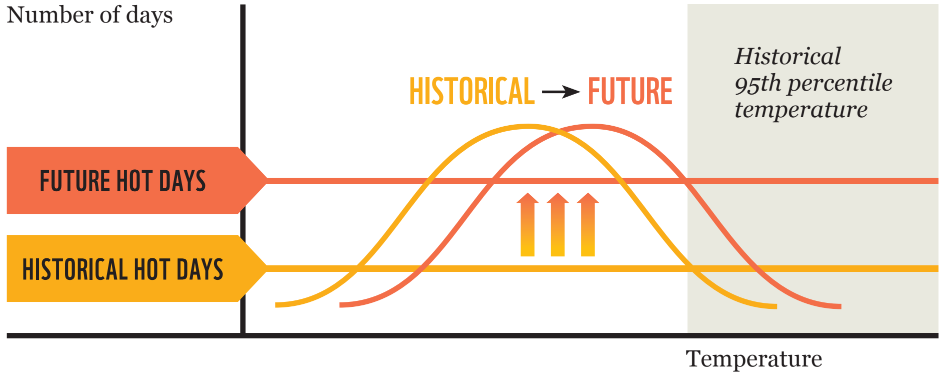


Figure 6.1. *Shifting distribution of future heat extremes in Myanmar.*

Table 6.1 shows the threshold temperature for each hot season month (March to May), as well as the observed (1981-2010) and projected (2011-2040 and 2041-2070) number of days per month exceeding the baseline threshold temperature. These projections were developed separately for inland and coastal weather stations.

During 1981-2010, about one extreme heat day per month was observed in the maximum temperature data (Figure 6.2). By 2011-2040, the incidence of extreme heat days during March to May rises substantially to two to six days per month and to four to seventeen days per month by 2041-2070. The month of April has experienced the most severe extreme heat days historically (threshold temperature of roughly 38-39°C), and is expected to see the greatest increase in the incidence of such extreme heat days in the future. Meanwhile, May is projected to experience a smaller increase in the number of extreme heat days compared to other months. There are no consistent differences between high temperature projections for inland versus coastal areas.

Impacts of high temperatures on key sectors

An increase in heat extremes, especially at the high end of the projections, would have significant impacts across sectors in Myanmar. Crop productivity could decline, as some crops are especially vulnerable to temperature increases. Drought incidence would likely increase, affecting agriculture, livestock, hydropower production, wildlife and communities alike that struggle with declining water availability resulting from increased evaporation. The elderly and young are most at risk, as hot days exacerbate heat-stress. Managing these risks will require significant planning across ministries and departments, with special attention paid to public health to address these vulnerable populations.

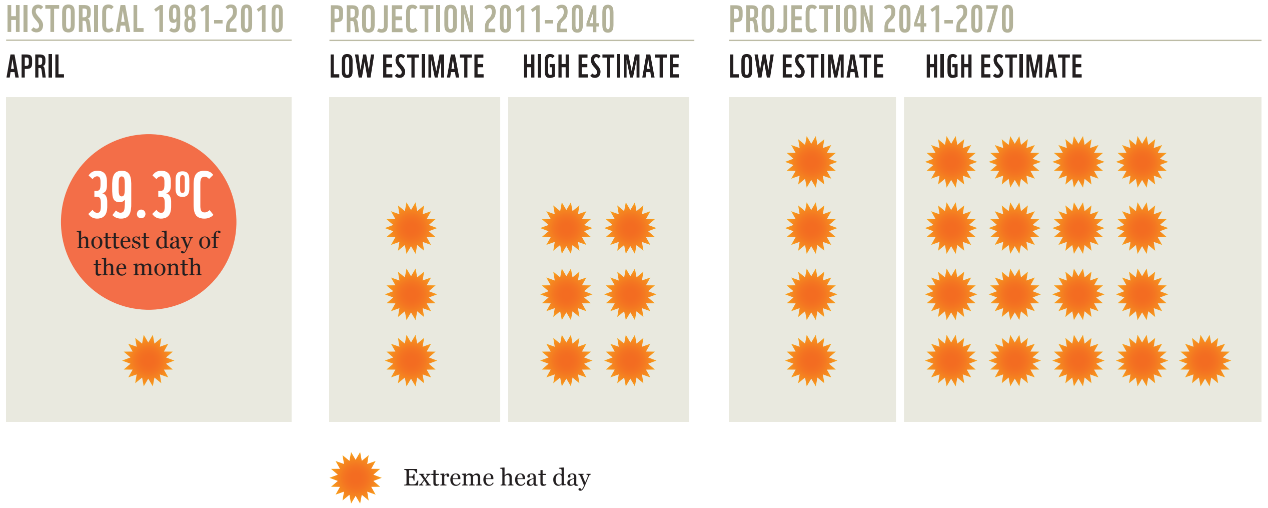
Table 6.1. *Projected 2011-2040 and 2041-2070 frequency of occurrence of the historical (1981-2010) daily 95th percentile temperatures in a month (i.e., extreme heat days).*

Month	Region*	Extreme heat day temperature 1981-2010	Historical frequency 1981-2010	Projected number of days per month hotter than historical extreme heat days from 1981-2010			
				2011-2040		2041-2070	
				Low estimate	High estimate	Low estimate	High estimate
April	Coastal	38.3°C	1 day	4 days	6 days	8 days	17 days
	Inland	39.3°C	1 day	3 days	6 days	7 days	14 days

*See Figure 2.1 for map of coastal and inland stations.

Note: Weather station data provided by DMH (2015). Projections reflect the NASA NEX GDDP dataset. See Appendix F for detailed results.

Figure 6.2. *Projected 2011-2040 and 2041-2070 frequency of occurrence of the historical (1981-2010) daily 95th percentile temperatures in April (i.e., extreme heat days) for inland regions in Myanmar.*



Note: Weather station data provided by DMH (2015). Projections reflect the NASA NEX GDDP dataset.

6.2 HISTORICAL EXTREMES

Examining the relationship between reported extreme weather events that had significant impacts on communities and their corresponding weather data can yield insights for decision-makers into how extreme weather impacts people and nature. This provides a ground-up approach to studying extreme events and their impacts, providing information about the vulnerability and resilience of communities, ecosystems and local economies that may be affected by future climate extremes. It allows a closer examination of the most extreme historical events which, by definition, are rare and therefore often do not emerge from an analysis of historical climate trends (see Section 2). This additional knowledge can help to guide policies and adaptation actions to prepare for these types of events in the future.

Weather data corresponding to several prominently-reported extreme weather events from the past 20 years are examined. A heat event, a drought event, and four flooding events were selected from the International Disaster Database (EM-DAT) (www.emdat.be) and ReliefWeb (www.reliefweb.int) database, based on sufficient geographic breadth and duration to be analysable.

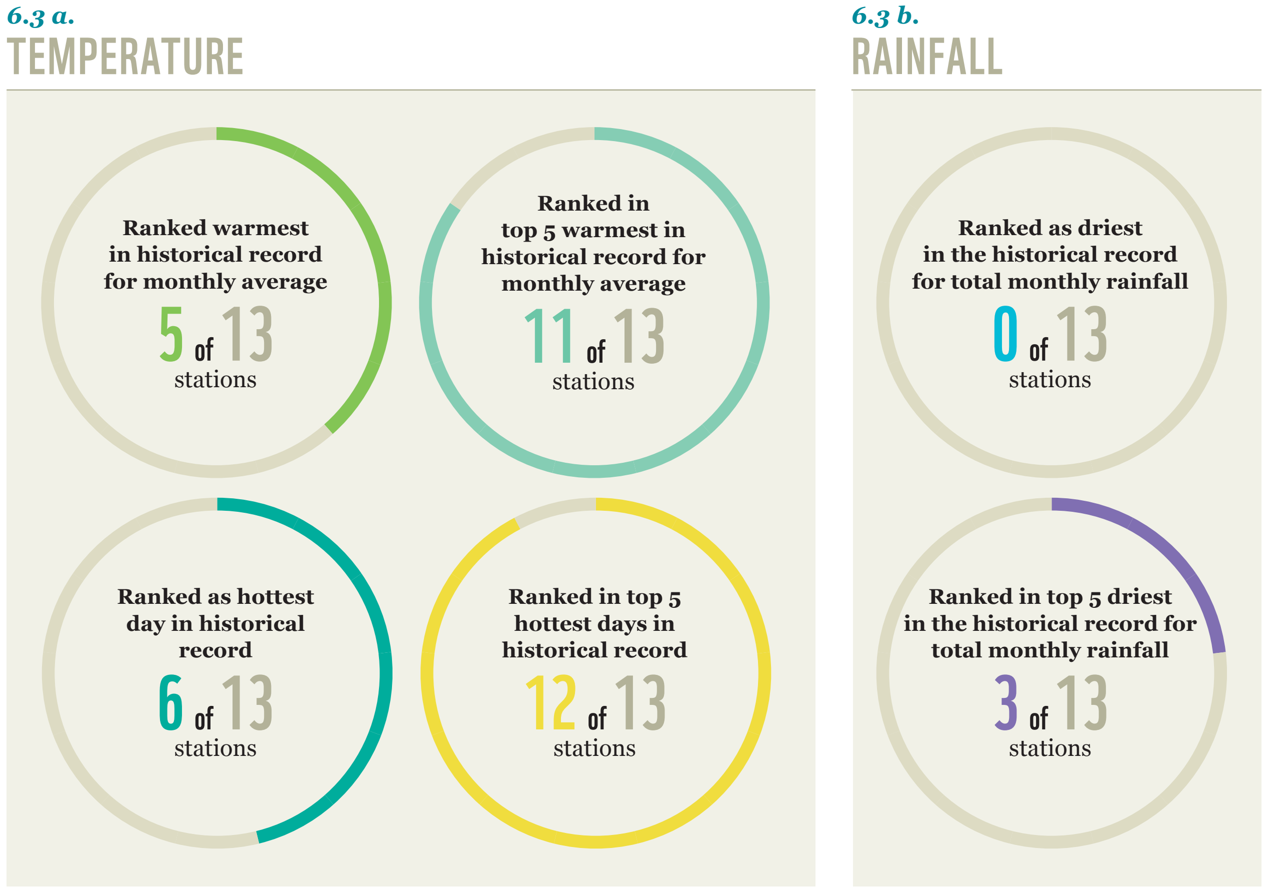
May 2010 was widely reported as a month of extreme heat and drought across most of Myanmar including the coastal, central and eastern areas (ReliefWeb, EM-DAT). Monthly average and maximum temperatures broke 1981-2010 records at many weather stations and were on average 2-3°C hotter than normal. While the severity of the May 2010 heat wave was clear in the weather station data, the precipitation record for that month showed few indications of low rainfall, based on weather station data. Figure 6.3 shows the number of stations in May 2010 ranking in the top temperature and rainfall metrics in relation to the month of May (29 other Mays) between 1981-2010, across 13 stations near which a disaster was reported. Monthly average and maximum (i.e., the hottest day of May) temperatures are ranked as two indicators of extreme heat, and total monthly rainfall and dry days are ranked as two indicators for drought.

Out of the 13 stations analysed in the regions affected by the heat and drought, the following was discovered:

- May 2010 ranked as the **warmest May** in 30 years at **five stations**
- May 2010 ranked in the **top five warmest months of May** at **eleven stations**
- The hottest day in **May 2010 ranked as the hottest day** in historical record in **six stations**
- The hottest day in **May 2010 ranked in the top five hottest days** in historical record at **12 stations**
- Despite reported drought conditions, May 2010 was **not ranked as the driest May in historical record** for total monthly rainfall in any the 13 stations
- Despite reported drought conditions, May 2010 was ranked in the **top five driest months of May** in historical record for total monthly rainfall in just **three of the 13 stations**

This analysis shows that, while the extreme heat of May 2010 was consistently visible in the historical temperature data, the reported drought did not correspond to extreme shortages in precipitation. Figure 6.3 summarizes these results.

Figure 6.3. Rankings of May 2010 monthly and daily records for temperature (6.3a) and rainfall (6.3b) at 13 weather stations in the affected drought area in relation to the 1981-2010 historical record for the month of May. Full data is depicted in Appendix F.



Note: Weather station data provided by DMH (2015)

A similar picture emerges when examining the precipitation data for four historical floods, suggesting that anomalous rainfall was also not the leading cause of the extreme event.

Table 6.2 shows the analysis of the flooding events in Myanmar based on historical data from 1981 to 2010. These floods occurred in August 1997, August-September 2002, September 2009, and September 2010. Just as with the drought of May 2010, a minority of data points are within the top five wettest for the period 1981-2010 (see Appendix F for detailed analysis). The results show that temperature extremes are consistently detectable in the weather data, while hydrological extremes are less visible.

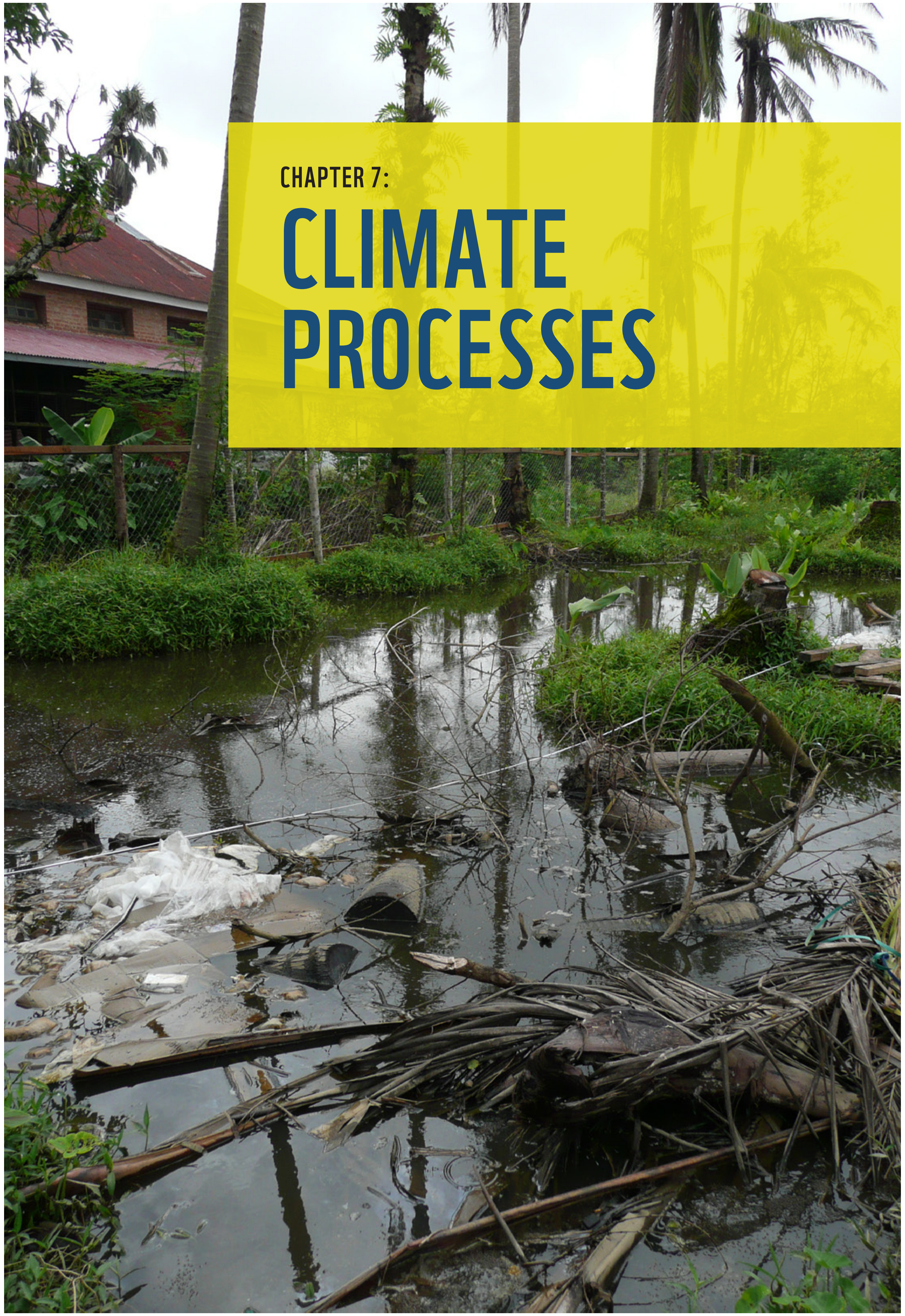
Table 6.2. *Rankings of monthly rainfall metrics for four flooding events at affected weather stations in relation to all such months from 1981-2010.*

Date of Flood	# Stations in Affected Area	Month(s) of the flood ranked in top 5 rainiest	Top 5 ranked monthly wettest days occurred during flood month(s)
August 1997	9 stations	1 station	2 stations
August-September 2002	8 stations	4 stations	3 stations
September 2009	1 station	0 stations	0 stations
July 2010	2 stations	0 stations	1 station

Note: Weather station data provided by DMH (2015).

Drought and flood events involve complex interactions between many environmental and human variables including rainfall, temperature, land-use practices and land cover, among others. Extreme high temperatures can lead to drought even in the presence of climatically normal rainfall. Droughts and floods in a given time and place may be influenced by rainfall in prior months and in other parts of the country, by human activity such as deforestation or water management practices, or a combination of such factors. Examining weather data alone may therefore miss important environmental and human contributors to these extreme events. Temperature is measured differently than precipitation, so measurement techniques for precipitation could be less sensitive to extremes than temperature measurements.

A report of an extreme heat or drought event in the ReliefWeb or EM-DAT databases reflects not only exposure to extreme weather but also local social and economic vulnerability. To fully understand historical hydrometerological extremes and their impacts, and to disentangle these factors of uncertainty, detailed social and environmental data such as forest cover, population density etc. are necessary.



CHAPTER 7:

CLIMATE PROCESSES

This section synthesises current understanding of two critical and interrelated climate processes in Myanmar: tropical cyclones and monsoons.

A tropical cyclone is a strong, cyclonic-scale disturbance that originates over tropical oceans, which is distinguished from weaker systems by exceeding a threshold wind speed beyond 32 ms^{-1} (IPCC, 2012).

Monsoons are a seasonal phenomenon that generally produce the majority of wet season rainfall within the tropics. A monsoon is defined as “a tropical and subtropical seasonal reversal in both the surface winds and associated precipitation, caused by differential heating between a continental-scale land mass and the adjacent ocean” (IPCC, 2014).

7.1 TROPICAL CYCLONES

Tropical cyclones arrive in Myanmar via the Bay of Bengal. An average of 10 tropical cyclones form in the Bay of Bengal each year, and historically, just 6.4 percent of all cyclones that form here reach land in Myanmar (Union of Myanmar, 2009). There are two peaks in tropical cyclone activity in the region each year – the first occurring just prior to the onset of the monsoon season from April to May, and the second occurring in the post-monsoon season from October to November (Fosu and Wang, 2014). The post-monsoon cyclones in the Bay of Bengal tend to arise from Pacific typhoons, with origins in the South China Sea. The conditions that allow tropical cyclones to form in this region include high sea surface temperatures above 28°C, a thermodynamically unstable atmosphere, and low vertical wind shear (Tasnim *et al.*, 2015).

Since 1990, the total number of tropical cyclones reaching Myanmar has increased, and there has been a rise in tropical cyclone events occurring just before the monsoon season, while those occurring after the monsoon season have decreased (Wang *et al.*, 2013). Since about 1980, cyclones generated in the Bay of Bengal have been more likely to develop into hurricane-force storms, meaning that they reach 119km/hour or greater sustained wind speeds (Wang *et al.*, 2013). Typically, landfalling cyclones arrive via the northeastern portion of the Bay of Bengal along Myanmar’s northern coast or, more commonly, in Bangladesh.

Cyclone Nargis

Perhaps the most devastating example of cyclone strength in Myanmar was Nargis, a Category 4 storm[2] with sustained wind speeds of 217km/hour, which killed an estimated 140,000 individuals (Tasnim *et al.*, 2015; Lin *et al.*, 2009). Cyclone Nargis hit Myanmar’s Delta Region on May 2, 2008, and ranks among the deadliest cyclones ever to make landfall (Kreft *et al.*, 2016).

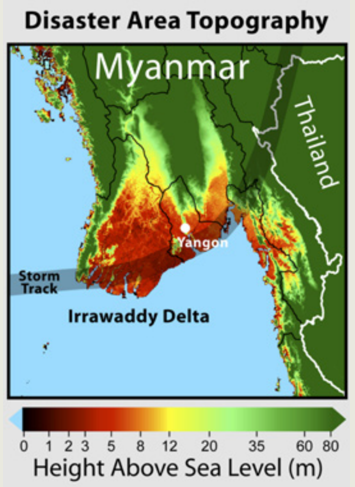
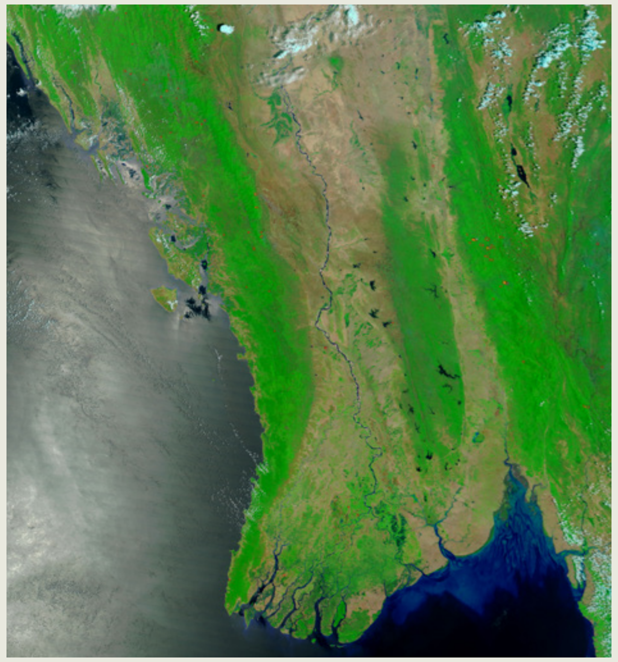


Figure 7.1. *Storm track and elevation of regions of Myanmar hit by Cyclone Nargis in 2008.* Source: Robert A. Rohde, Wikimedia Commons

The storm surge is estimated to have been 3-4 meters high and reached 50 kilometers upstream from the mouth of the Yangon River (Tasnim *et al.*, 2015). Much of the damage to structures from the storm resulted from the very high wind speeds and intense wave action, as well as inland flooding via irrigation channels connected to the main waterway. Figure 7.2 shows a before and after aerial view of the flooding damage caused by Nargis in the Delta region.

Nargis was an unprecedented storm in Myanmar for several reasons. First, its track had initially been moving across the Bay of Bengal towards the northwest but shifted its direction towards the east, which is unusual for cyclones in this particular area during the pre-monsoon time period (Raju *et al.*, 2011). Second, cyclones derive much of their strength from warm, deep ocean waters. Cyclone Nargis passed over an area that featured unusually warm upper ocean waters extending deeper than normal – about 75 to 100 meters – which provided extra energy to fuel the rapid strengthening of Nargis from a Category 1 storm to Category 4 in a span of just 24 hours (Lin *et al.*, 2009). Third, Cyclone Nargis made landfall across the Ayeyarwaddy River Delta, a location where no known cyclones has made landfall in historical record between 1977 and 2008 (Tasmin *et al.*, 2015; Fritz *et al.*, 2010). Cyclones in the region typically track much further north in Myanmar and Bangladesh, rarely hitting the southern coast of Myanmar (Tasmin *et al.*, 2015; Shibayama *et al* 2009). Therefore, residents had never experienced such storm surges and may not have understood the danger posed to them by the storm, likely increasing its death toll.

Before



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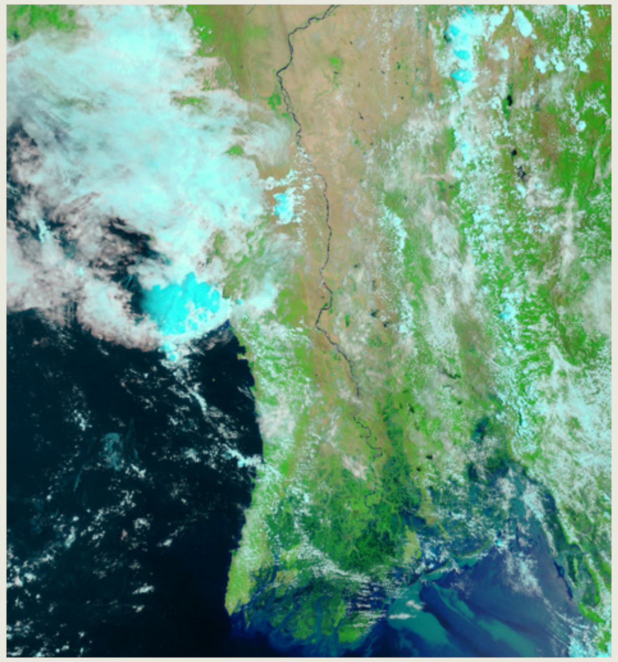

Figure 7.2. *NASA’s Terra satellite image of the Myanmar coast on April 15th, 2008 (left), before Tropical Cyclone Nargis flooded the region, compared to NASA’s Terra Satellite image of the coastal region on May 5th, 2008 (right), showing the devastation of flooding caused by Tropical Cyclone Nargis.*
Source: NASA/MODIS Rapid Response Team

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[2] Storm categories are defined by the Saffir-Simpson Hurricane Wind Scale. The scale, which is a 1 to 5 rating based on a hurricane’s sustained wind speed, estimates potential property damage. The storms are defined as Category 1 (119-153 km/hour), Category 2 (154-177km/hour), Category 3 (178-208 km/hour), Category 4 (209-251 km/hour), and Category 5 (252km/hour or higher). More information can be found at http://www.nhc.noaa.gov/aboutsshws.php.

Cyclones and climate change

There is a pressing need for information about how tropical storms like Cyclone Nargis (see Box) will be affected by climate change, so that society can adapt and improve resilience. However, directly linking anthropogenic climate change and increased tropical cyclone activity in the Bay of Bengal is challenging due to large natural variability, limited historical data and limited ability of climate models to simulate tropical cyclones (Christensen *et al.*, 2013; IPCC, 2013). The IPCC has stated that research on future changes in the frequency, intensity and duration of tropical cyclones as a result of climate change is inconclusive (IPCC, 2012).

To address some of these challenges, ongoing research is being conducted into the changing nature of the underlying conditions that drive the formation and intensity of cyclones, which can provide an idea of how cyclone activity might change in a warmer world. Studies suggest that, as the reliability of projected changes in sea surface temperature patterns and modes of atmosphere-ocean variability such as the El Nino-Southern Oscillation (ENSO) improves, the ability to project global and regional tropical cyclone activity will also improve (Christensen *et al.*, 2013). Research indicates that there is a projected increase in extreme precipitation near the center of tropical cyclones making landfall along the coasts of Bay of Bengal, and that there will likely be a global increase in maximum wind speeds and intensity of the strongest tropical cyclones as upper ocean temperatures warm with climate change (Christensen, 2013; Knutson *et al.*, 2010).

While predicted cyclone changes over the 21st-century are uncertain, the already-high human vulnerability to cyclones is likely to increase given population growth and rapid development. Furthermore, sea level rises alone will allow storm surges from cyclones of the same magnitude to reach further inland (Wong *et al.et al.*, 2014; IPCC, 2014). An increase in the land area inundated by tropical cyclones will result in more damage to communities, infrastructure and ecosystems that were not previously in the flood zone. Building resilience will thus require planning for coastal inundation and impacts farther inland.

Impacts and vulnerabilities

The Global Climate Risk Index lists Myanmar as the second-most vulnerable country to weather-related extreme events that occurred between 1995 and 2014 (Kreft, *et al.*, 2016). This ranking is, in large part, due to the financial damage and loss of life that was suffered as a result of Cyclone Nargis in 2008. Tropical cyclones will continue to pose critical hazards due to their strong winds, heavy precipitation and coastal storm surges (Christensen *et al.*, 2013; Raju *et al.*, 2011; Emanuel, 2005). The severity of the impacts from these hazards is highly dependent on the level of exposure and vulnerability of communities to cyclones (IPCC, 2012; Peduzzi *et al.*, 2012). This means that, over the course of the next century, the most vulnerable people and ecosystems in Myanmar are likely to be those situated in the low-lying coastal regions along the western border of the country and the delta, where they are exposed to floods, cyclones and their associated winds and storm surges, intense rainfall and sea level rise (Rao *et al.*, 2013).

The degree of vulnerability in the future will partially depend upon a variety of factors unrelated to climate, such as the added pressures of population growth, land-use change, and deforestation. These will continue to degrade natural defenses against tropical storms and coastal flooding. The more scientists can understand how tropical cyclones will change, including how these natural defenses themselves are directly affected by climate change, the better coastal regions in Myanmar will be able to adapt and improve resilience.

Much of the vulnerability to coastal flooding lies in the proximity of residents, infrastructure and habitat to the coast (Rao *et al.*, 2013). The Ayeyarwaddy Delta region of Myanmar sits open and vulnerable to storm surges as it is currently home to an estimated 40 percent of Myanmar's population and a landscape covered by rice paddy farms (Tasnim *et al.*, 2015). Saltwater intrusion from storm surges into the low-lying deltas of Myanmar are harmful to rice production in the region, where 85 percent of national rice production occurs. The practice of clearing mangroves for shrimp farming and wood for fuel use and building materials can exacerbate coastal flooding risks by removing natural vegetative coastal protection from extreme storms. Regardless of how cyclones shift in response to climate change, increased sea levels will allow salt water to reach further inland during coastal storms (Walsh *et al.*, 2016). A rise in sea levels would force coastal fishing and farming communities to clear and occupy new lands further from the coast, disrupting already fractured habitats. To reduce these vulnerabilities, it will be critical for Myanmar to advance early and accurate prediction of tropical cyclones, robust emergency response strategies and policy shifts that reduce the long-term vulnerability of people and assets. Cost-effective, ecosystem-based adaptation approaches like mangrove reforestation in denuded areas can play an important role in these efforts. (See Section 8 for examples of how planners are beginning to reduce vulnerability).

7.2 MONSOONS

Some large-scale trends in global (Zhang and Zhou, 2011) and regional monsoon systems (Christensen *et al.*, 2014) may have implications for Myanmar. A broad-scale analysis of the Northern Hemisphere, using 100 years of data identified an overall increasing in monsoon rainfall from 1901 to 1955, after which a declining trend was seen up to 2001 (Zhang and Zhou, 2011). Many studies have analyzed observed records of monsoon and other types of rainfall in various regions (see Table 7.1) A decreasing trend in monsoons has been recorded at the global and regional scale in Asia, while some studies have demonstrated an increased incidence of heavy rainfall events and wet regions getting wetter while dry areas show a decline in rainfall.

Table 7.1. *Observed changes in global, regional and national rainfall.*

Type of rainfall event	Spatial scale	Direction of change	Sources
Global land monsoon	Global	Decreasing trend since 1955	Zhang and Zhou, 2011
Rainfall	Southeast Asia	Wet period getting wetter and dry period getting drier	Hijioka *et al.*, 2015
Rainfall (year round)	South Asia	More heavy and less light precipitation	Hijioka *et al.*, 2015
Decrease in monsoon rainfall	South Asia	Decrease	Annamalai *et al.*, 2013
Peak-season (monsoon) precipitation	South Asia	Decrease	Singh *et al.*, 2014
Monsoon season length	Myanmar	Decrease	Lwin, 2002
Annual rainfall	Myanmar	Decrease	Lwin, 2002
Monsoon rainfall	Myanmar	Decrease	Lwin, 2002
Drought years (of moderate intensity)	Myanmar	Decrease	Lwin, 2002
Monsoon strength	Myanmar	Decrease (since 1987)	Lwin, 2002
Extreme rainfall	Myanmar	Decrease	Hijioka *et al.*, 2015

Climatology

Myanmar is influenced by both the South Asian and East Asian monsoons (D'Arrigo *et al.*, 2011, D'Arrigo and Ummenhofer, 2015) from which it receives most of its annual rainfall (Sen Roy and Kaur, 2000). It is located in a transitional zone between the regions where the Indian summer monsoon and the East Asian and western North Pacific summer monsoon occur (Wang and LinHo, 2002; Zhang *et al.*, 2002). The summer monsoon accounts for between 75 percent (Sen Roy and Kaur, 2000) and 90 percent (Lwin, 2002) of Myanmar's total annual rainfall. Generally, the monsoon reaches southern Myanmar around the third week of May and withdraws at the beginning of October. For the purpose of many analyses, the monsoon period is considered to be June to September (Sen Roy and Kaur, 2000).

According to Lwin (2002), the normal onset date of the monsoon for the entire country is considered to be June 1, while the withdrawal is more gradual and less systematic. In an average year, 179cm of rainfall occurs nationwide during the monsoon season, ranging from between 156cm and 224cm year to year, based on data from 1947-1979 (Sen Roy and Kaur, 2000). August is the wettest month, followed by July.

Observed changes in Myanmar

Analysis of observed records by Lwin (2002) indicate that the monsoon in Myanmar has seen its length shortening due to its late onset and early withdrawal. The analysis demonstrated that annual rainfall, monsoon rainfall and monsoon strength have decreased, while the number of drought years have also declined. Extreme rainfall in Myanmar has also declined (Hijioka *et al.*, 2014). See Table 7.1 for summary.

Comparing data from 1988-2000 with the 1955-2000 base period, the duration of the monsoon is becoming shorter (Lwin, 2002). The departure from normal is most pronounced in central Myanmar, where the duration is shorter by 30 days, followed by northern Myanmar with 24 days. A late onset of the monsoon has been observed, with the late onset averaging seven days during the 1977-2000 period, while in 1992 onset was delayed by about two weeks in. Central and southern regions have experienced the largest departure from normal, based on an analysis of the period 1988-2000. The analysis also indicates an early withdrawal of the monsoon, shortening its duration by an average of eight days (Lwin, 2002). Northern and central Myanmar have experienced the earliest withdrawal of the monsoon, followed by the Delta region and southern Myanmar.

Decreasing trends in extreme rainfall events have been reported in Myanmar (Hijioka *et al.*, 2014). Research by Lwin (2002), using annual data from 1951-2000 records of 20 stations, shows a wet phase until 1977, while deficit rainfall was observed after this, especially in the 1980s and 1990s. Drought conditions were more prevalent in the 1980s and 1990s (based on 36 weather stations, data from 1951 to 1998) (Lwin, 2002). Analysis done in this report using data from 19 stations demonstrates that total annual rainfall has increased in recent decades (1981-2010). Although there was no statistically meaningful trend in the number of rainy days (defined as days with rainfall >1mm) per year between 1981 and 2010, annual precipitation totals increased, implying that rainfall events became more intense. The variation in weather station locations and time periods used in the different analysis, along with data quality, could have contributed to this discrepancy.

How climate change is affecting monsoon processes

Global monsoon precipitation is likely to strengthen over this century due to climate change, increasing both in area and intensity, while monsoon circulation is expected to weaken (Christensen *et al.*, 2014). Climate projections show an increase in total global monsoon rainfall, which is attributed largely to the increase in atmospheric moisture content (Christensen *et al.*, 2014). Figure 7.3 illustrates how climate change affectes monsoon circulation and rainfall.

The total surface area affected by the monsoon is also projected to increase. Globally, future monsoon onset dates are likely to be either early or remain unchanged, while monsoon retreat dates are likely to be delayed, resulting in the lengthening of the monsoon (Hijioka *et al.*, 2014). However, the opposite is being observed to date in Myanmar, where the monsoon season is shortening due to the late onset and early withdrawal (Lwin, 2002). For many parts of the world, including Myanmar, regional projections in monsoon intensity and timing in the future remain uncertain due to natural variability, land use change, aerosol impacts and uncertainties about the local climate effects of anthropogenic warming.

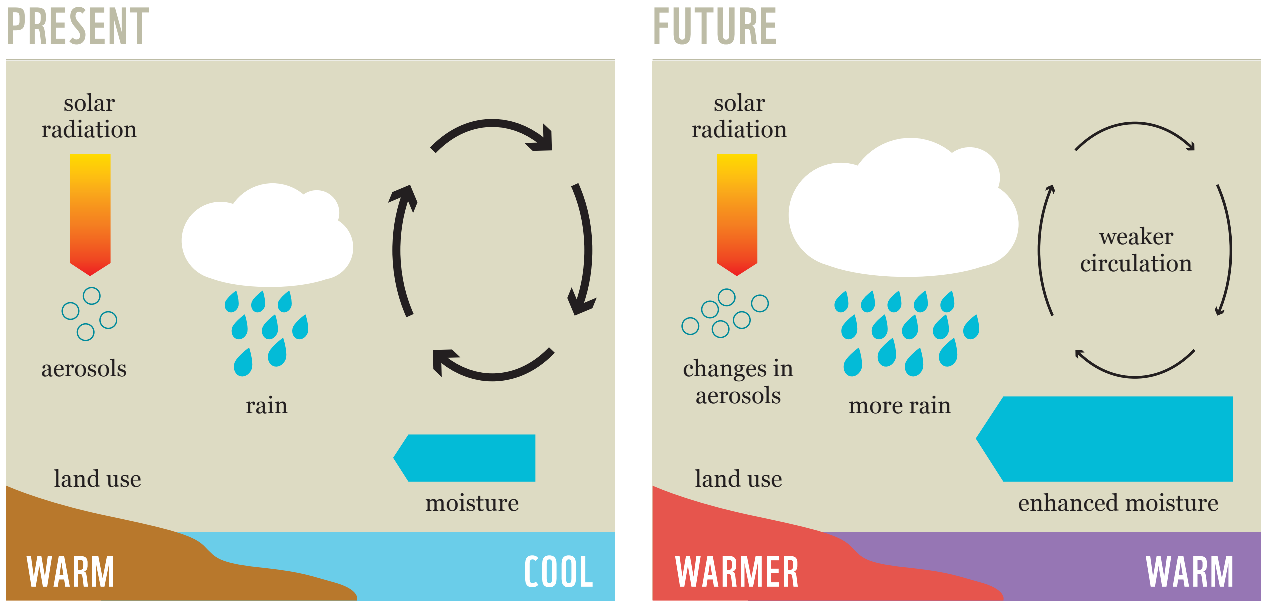

Figure 7.3. *Schematic diagram illustrating the main ways that human activity influences monsoon rainfall. As the climate warms, increasing water vapor transport from the ocean into land increases because warmer air contains more water vapor. This also increases the potential for heavy rainfall. Warming-related changes in large-scale circulation influence the strength and extent of the overall monsoon circulation. Land use change and atmospheric aerosol loading can also affect the amount of solar radiation that is absorbed in the atmosphere and land, potentially moderating the land–sea temperature difference.*
Source: Christensen et al., 2014.

There will be different responses by the various regional monsoon systems to greenhouse gas forcing. The intensity and area increases in monsoon precipitation are fueled in large part by atmospheric moisture content increases with higher temperatures. The rainy season length and total precipitation depend on a range of factors, such as air moisture content, configuration and strength of atmospheric circulation, regional distribution of land and ocean and topography. An increase in total monsoon rainfall is expected, even if there is a weakening or no change in monsoon circulation, due largely to the increases in atmospheric moisture content, leading to increased frequency of extreme rains and subsequent flooding hazards (Christensen *et al.*, 2014).

Climate models project a 5-15 percent increase in global monsoon rainfall. The weakening of tropical wind circulation is expected to decrease monsoon rainfall in some areas, even though the total monsoon rainfall globally is expected to increase (Hijioka *et al.*, 2014). The projected overall increase in monsoon rainfall is associated with an increase in the risk of extreme rain events in most regions (Hijioka *et al.*, 2014). The projections in this report indicate that rainfall patterns will vary by region and season. Projections show that precipitation gains are most likely to occur during the monsoon season (consistent with global and regional projections for monsoon rainfall), whereas it is unclear whether precipitation will increase or decrease during the cool and hot seasons.

Extreme precipitation increases during the monsoon season are very likely in East, South, and Southeast Asia according to the latest IPCC assessment (IPCC, 2013). An increase in mean precipitation in the East Asian summer monsoons is seen in more than 85 percent of Coupled Model Intercomparison Project-5 (CMIP5) models, while an increase in heavy precipitation events is shown by more than 95 percent of models. For the Indian summer monsoon, increases in the mean and extreme precipitation are projected by all models and scenarios (Hijioka *et al.*, 2014).

Table 7.2. *Projected changes in global and regional rainfall.*

Type of rainfall event	Spatial scale	Direction of change	Sources
Monsoon rainfall	Global	Increase	Christensen *et al.*, 2014
Monsoon length	Global	Increase	Hijioka *et al.*, 2015
Extreme rain events	Global	Increase	Hijioka *et al.*, 2015
Extreme rain during monsoon	East, South, and Southeast Asia	Increase	IPCC, 2013

There are several factors that affect monsoons, including aerosols and major modes of climate variability such as the El Niño–Southern Oscillation (ENSO). These drivers are described in Appendix G.

CHAPTER 8:

APPLICATIONS OF CLIMATE RISK INFORMATION TO SECTORS

Climate projections can equip decision-makers with information about emerging risks which can be taken into account in planning activities. Due to the range of outcomes in the climate projections, evolving vulnerabilities and future actions people will take to address climate-related problems, it is important to take a flexible adaptation pathway approach. This approach means that planning must account for the range of possible climate futures, it does not limit future adaptation options and it allows for re-evaluation and changes in approach if new information arises. This will require building resilience to accommodate the potential impacts of climate changes on ecosystems, livelihoods, infrastructure and economic growth[3].

Examples of interventions that can be deployed in Myanmar to prepare for climate change include:

- Maintaining forests and other ecosystems, which provide essential services such as clean drinking water and erosion control, while following forest management practices (e.g. planting native species resilient to projected climate conditions) that are adapted to changing climatic and environmental conditions;
- Reviewing and modifying conservation strategies to facilitate ecosystems and biodiversity to adapt to change (e.g. wildlife corridors to upland or inland areas) without major loss of ecosystem services;
- Changing practices in specific sectors, e.g., crop choices, planting patterns and improving water-use efficiency for agriculture;
- Strengthening infrastructure, including through the use of ecosystem-based adaptation approaches such as mangrove forests, to help communities withstand more frequent flooding events;
- Developing preparedness and response strategies to cope with increasing heat stresses, changes in the hydrological cycle and other climate hazards that pose risks to human health, wildlife and ecosystems.

This section briefly examines how planners can begin to consider and apply climate risk information to build resilience in several sectors to the impacts climate change. For each sector, an overview of the climate risks are discussed, as are indicators that can be used to track vulnerability and resiliency. Lastly, an example of how this information is already being used in township vulnerability assessments and adaptation planning is presented.

Linkages between sectors should also be considered when planning. Impacts will often affect several sectors in different ways, while responses and adaptation measures taken in one sector may have implications for other sectors as well. Responses to climate impacts – such as adaptation policies – will have implications and knock-on effects, which need to be identified and planned for. With Myanmar's economy rapidly expanding after the recent transition to democracy, the country has a unique opportunity to integrate climate risks into current planning that will set the stage for decades of future development. Ecosystem-based adaptation interventions that rely on and protect valuable ecosystem services should be an important component of any resilience building efforts.

[3] For more information on applications and sectoral impacts, see IPCC Fifth Assessment Report Working Group II: Impacts, Adaptation, and Vulnerability (2014)

8.1 BIODIVERSITY AND ECOSYSTEM SERVICES

Climate change will impact ecosystems and species in multiple ways, with each ecosystem or species responding differently to climate variables, leading to complex interactions in a linked system. In addition to the main climate variables (total precipitation, mean and maximum temperature, extreme heat), careful consideration is needed of other variables that may be essential for species (e.g., frost days in the mountainous far north, ocean acidification and salinity levels, shifts in seasons, etc.), as well as the impacts of extreme events. Once these are identified, expert consultations will be needed to identify thresholds of species and ecosystems. In some instances, this information may not exist and, therefore, identifying “known unknowns” is essential. Once research needs are identified, collaboration with scientists and sector experts is vital to build resilience in protected areas and other critical wildlife habitats and modify specific species conservation plans.

Range-restricted species, slow-moving species, low-dispersal species and species already facing high threats are likely to be the most vulnerable to climate change. In terms of investing in adaptation measures, it will be necessary in many cases to consider trade-offs between conserving vulnerable species and species that are most likely to survive in a changing climate. Indirect effects of climate change need to be considered and planned for, including cascading impacts on other sectors and human responses to climate change (e.g., migration, expanding agricultural areas, land use change, infrastructure development, etc.) and their resulting effects on biodiversity. Accounting for extreme events and possible surprises is also critical when planning any adaptation interventions for wildlife and biodiversity, (e.g., restoration using species appropriate for a changing climate, wildlife corridors, etc.).

Existing protected area management plans and species action plans need to be reviewed in the light of a changing climate. They should be updated or changed to prevent maladaptation and to “climate-smart” existing activities by reviewing them considering the observed and projected changes documented in this report. Improved monitoring of species and ecosystem response to changing variables, along with on-going reevaluation of the effectiveness of climate-adapted conservation measures as the climate continues to change, is essential.

Assessing climate risk to natural capital and ecosystem services

The climate risk information generated for this report was also incorporated into a nationwide assessment of Myanmar’s ecosystems and the benefits they provide to people. Using climate projections, analyses show how key benefits provided by forests, such as clean drinking water and sediment and flood retention, are likely to change as temperatures increase and rainfall patterns change across the country (Mandle *et al.*, 2016). This assessment provides an important information baseline for adaptation planning, demonstrating the climate resilience benefits provided by ecosystems nationwide and the need to keep them intact as the effects of climate change increase in the future.

8.2 COASTAL ZONES

Myanmar's extensive coastline of 1930 kilometers will experience rising seas and increasingly frequent and extreme hazards, with the low-lying Delta region likely to be most affected. Sea level rise alone will cause larger areas to be inundated during storm surges and coastal floods, even if the intensity of cyclones and coastal storms remain the same. The projections for Myanmar indicate a rise of 20-41cm by the 2050s and 37-83cm by the 2080s, with the highest projected sea level rise for this period almost 1.2 meters. It is essential that all coastal-based development activities and sectors take these projections into account, along with precipitation changes, increasing temperatures and other changes such as saline intrusion and ocean acidification.

Major climate variables, along with other key parameters such as salinity levels and ocean acidity, will impact coastal, marine and estuarine biodiversity. Mangroves and other coastal ecosystems, which play a vital role in reducing coastal vulnerability, are also at risk themselves due to increasing sea levels, higher temperatures and changes in precipitation patterns. Identification and monitoring of thresholds for these systems – tipping points at which they will no longer provide benefits to people – are key to ecosystem-based adaptation planning. This includes plans in coastal areas for reforestation to ensure replanted areas survive future inundation. Studies and assessments on coastal flood recurrence rates and inundation areas are critical to building resilience across all sectors and activities along Myanmar's coast.

8.3 HEALTH

Changing rainfall patterns, warming temperatures and changes in extreme heat and other extreme events pose major challenges to the health sector (Smith et al., 2016). Warming has enabled some vectors and pathogens to spread to new regions, because the spread of disease vectors such as mosquitos is associated with warming temperatures and changing rainfall patterns. Extreme events, such as floods, can spread waterborne diseases, while droughts can also cause the spread of pathogens as water flows diminish and stagnation reduces water quality (Smith et al., 2016). Food insecurity, already a challenge in many regions of Myanmar, could increase as a changing climate and extreme events impact crops and crop productivity, leading to increased rates of malnutrition and the need for additional food aid (WFP, 2016).

In many places, heat is often a significant weather-related killer. Heat waves and an increase in the frequency of very hot days, coupled with high humidity, can cause death and severe health complications. The elderly and young are most at risk, while outdoor workers can also be severely affected by heat. An analysis of extreme heat conducted for this study showed that extreme heat days during the warmest months are projected to become four to seventeen times more frequent by the middle of the century. The implications of such a large increase in extreme heat will need to be considered in public sector plans. Interventions to prevent heat exposure (e.g. increasing cooling, ventilation or insulation of buildings, creating cooling stations) and other adaptation measures will be necessary to combat heat-related deaths.

8.4 AGRICULTURE

Agriculture is the main industry in Myanmar and the largest employer of the labour force. Climate changes affecting the agricultural sector therefore present a substantial challenge to food security, nutrition and livelihoods. Crops and livestock are sensitive to numerous climate variables – with benefits from higher carbon dioxide concentrations but potentially detrimental changes in rainfall patterns, as well as higher night-time temperatures, heat waves and the loss of coastal agricultural land to sea level rise. Climate change is also expected to alter the frequency and magnitude of extreme events such as droughts and floods, which can destroy crop plantations and kill livestock. Shifts in the seasonality and frequency of monsoon breaks may also require adjustments in planting calendars. Other stresses exacerbated by climate change include an increase in weeds, diseases and insect pests that may find the new climate more hospitable. Given that agriculture is a managed system, climatic thresholds related to various crops – e.g. the damaging thresholds of specific variables like night-time temperatures, solar radiation and rainfall – are known in many cases, although the impacts of additional variables and specific impacts on local farming systems requires further research (Rosenzweig and Hillel, 2015).

Projections of future climate changes enable informed planning and the utilisation of existing options and technologies that build resilience in the agriculture sector. These include shifts in sowing and harvesting windows, adjustments in plant density, changes in water application that improve water efficiency, best management practices that improve soils and reduce erosion and planting of cultivars and species with greater tolerance to extreme weather. These practices may be necessary to adapt to climate change even as progress is made toward closing yield gaps through agricultural development. As a recent analysis of ecosystem services in Myanmar highlighted, for many priority agriculture areas, maintaining forests upstream will be critical to reducing flood risk and providing other benefits like sediment retention for water quality. Other interventions to reduce soil loss in agricultural areas will also be important to reduce impacts on water supplies downstream, as increased sedimentation from extreme storms will worsen effects on water quality (Mandle *et al.*, 2016).

8.5 INFRASTRUCTURE

Critical infrastructure systems in Myanmar include energy, transportation, buildings, telecommunications, and water supply and wastewater. As Myanmar develops, people become more and more dependent upon these systems. As this infrastructure becomes more important to everyday life, any risks that climate change poses to these systems will have ripple effects on livelihoods.

Decision makers from each of the various infrastructure sectors need to plan for climate change. Managing uncertainties in seasonal water flow will require collaboration with water managers around strategies (e.g., reservoirs and dams) geared towards maintaining water and hydropower supply while minimising flood risk. Energy suppliers can use temperature projections to alter the design of power systems so that they can operate under extreme temperatures, as well as planning for more frequent peak-load scenarios. Buildings, roads and railways projected to be located in flood plains and low-lying coastal areas may need to be relocated, and evacuation routes identified. During an extreme event like a flood, improving the resilience of telecommunications infrastructure such as cell phone towers will allow the other infrastructure systems, as well as decision-makers, to maintain vital communication during a disaster.

Planners can begin by surveying current and future infrastructure vulnerabilities to highlight priority areas for adaptation. It will also be critical to evaluate the interdependencies among these various infrastructure systems to prevent failures from one system to affect another.

With so much infrastructure development planned in the coming decades in Myanmar – including numerous hydropower dams – planning, siting and developing infrastructure based on climate risk is an especially important priority. In many cases, designs will need to be revised to account for increasing extreme hazards like floods and droughts, and in others, may no longer bring positive economic returns. Increasing rainfall variability, for example, may challenge the feasibility of certain hydropower projects, as it becomes more difficult to generate energy with increasingly uncertain flows. In other cases, infrastructure may need to be relocated entirely based on projected changes (e.g., along coastlines or in floodplains – both likely to see increased inundation). It is critical that climate resilience be a central consideration in the feasibility evaluations of proposed and future infrastructure projects.

8.6 WATER RESOURCES

Water from rivers, streams and aquifers in Myanmar is vital; for maintaining the quality of ecosystems; providing healthy drinking water to the population; supporting agriculture; and supplying the nation with hydropower. However, steady, predictable seasonal water flows are unlikely to be maintained in the future due to climate change, deforestation and other human actions that affect water. Proper management of water resources is critical to prevent flooding of settlements and protect against the effects of drought.

As the projections for future precipitation changes encompass a wide range of possible outcomes, there are certain actions which planners can take to manage this uncertainty when developing adaptation plans. For example, while projections in the cold and hot seasons span a range that suggests seasonal rainfall could either increase or decrease, all model outcomes presented in this report suggest at least some form of increase in precipitation for the wet season in every region by 2041-2070. This is a starting point that stakeholders across Myanmar can use to begin planning for more summer monsoon rainfall in agriculture, hydropower, conservation areas, dams and flood management.

Year-to-year variation will still occur in the face of climate change, and not every future year, nor every location, will always experience greater than average rainfall in the wet season. There may be years where there is lower rainfall and even drought in the wet season, and the climate models do not capture all possible scenarios. Nevertheless, the climate models, our best tools for long-term projections, suggest that the long-term trend will be towards greater rainfall as the century progresses.

As the long-term direction of precipitation in the dry season months from November to March is uncertain, the ability of short-term weather models to predict seasonal precipitation will be key for decision makers in the future. Stakeholders will need to communicate with one another to ensure adequate water supplies are available to all sectors.

Perhaps most importantly for planning in the water-resource management sector, recent trends and future projections both indicate increasing variability characterised by intensifying fluctuations between dry and wet periods and more frequent extreme weather events. It is critical for the water resources sector to engage other stakeholders in managing this increasing variability. Water resource managers can work with other regions to secure additional drinking water sources for Yangon – this should help to address increasing scarcity in the dry season. They should also plan for increased flooding with the disaster risk reduction sector and, similarly, work with farmers to implement both flood defenses and water-efficiency measures.

8.7 URBAN AREAS

Urban areas are characterised by dense populations, buildings and infrastructure, making them both sources of resilience and, at the same time, vulnerable to climate change. On one hand, having more resources available in a small geographical area can allow people to respond to a disaster more quickly than in rural areas. On the other, greater numbers of human lives and assets are at risk. The intersecting components of infrastructure – energy, transportation and water – can have a domino effect during an extreme event, with an impact on one sector in turn affecting other sectors. Managing these intersecting components in urban areas is critical to improving climate change resilience.

To address these risks, the first step is for decision makers to take stock of current vulnerabilities. This includes developing indicators of current at-risk neighbourhoods across a city which could include household income, age, stability of infrastructure, water quality and availability, sanitation, access to transportation and social networks.

Once these vulnerabilities are known, the second step is for leaders and managers to look at how these various indicators will be vulnerable in the face of the climate projections presented in this report. Questions for city decision makers in Myanmar at this stage could include:

- Are the most vulnerable neighbourhoods in an area that is will be flooded by 2050 if sea levels rise by 20-41cm?
- If temperatures in Yangon rise approximately 2-4°C on average in the hot season, do public health measures need to be taken?
- With the increased likelihood of short-duration heavy rain events, does the city have adequate drainage capacity to deal with excess water?
- If heat waves become longer and more intense, do energy suppliers have the generation capacity to manage increased demand? In turn, how might the effects of black-outs and brown-outs impact other sectors such as hospitals, transportation and emergency alert systems?

By looking at a city's vulnerabilities today, and comparing them to how they might fare under future climate conditions, decision makers can implement adaptation measures to improve resilience in the urban sector.

8.8 TOWNSHIP PLANNING: BUILDING RESILIENCE IN THE AYEYARWADDY DELTA AND CENTRAL DRY ZONE

Most of Myanmar's 51.4 million people (Department of Population, 2014) and relative assets are concentrated in the Ayeyarwaddy Delta area and the Dry Zone. These two physiogeographic regions are also the most exposed to extreme weather events: cyclones and tropical-storms, storm-surges and floods as well as droughts and heat waves. The exposure of people and assets to recurrent, severe natural hazards, with low socio-economic and infrastructural capacity to withstand and recover from shocks – and a high dependence on climate-sensitive sectors such as agriculture – explain the high vulnerability of Myanmar.

Climate projections indicate further changes that will increase Myanmar's vulnerability. If the rapid onset disasters generated by cyclones and floods have immediate devastating consequences, other "silent" phenomena such as the salinisation of ground-water in the Delta due to a rise in sea-levels, and reduction of agriculture productivity due to higher temperatures and changing rainfall patterns, will have significant long-term effects on Myanmar's society and economy. The 2014 census confirms patterns of climate-driven migrations in several areas, especially the Dry Zone, where it is becoming increasingly difficult to farm.

Although the country is evolving towards the service sector, manufacturing and energy production, it still largely depends on agriculture, which is 90 percent rain-fed, contributes to 37 percent of GDP and occupies 85 percent of the workforce. The *Myanmar Climate Change Strategy and Action Plan 2016-2030* found that the capacity of the country to attain its ambitious development objectives by 2030 will be challenged unless it urgently adapts to present and future changes in climate. It also stresses that adapting to climate change cannot happen solely at national level, and must be a primary concern at the township, city and community levels.

Climate data applied to the Township Climate Change Adaptation Programme

Facilitating local adaptation is one of the key objectives of the Myanmar Climate Change Alliance (MCCA) programme implemented by the United Nations Human Settlements Programme (UN-Habitat) and the United Nations Environment Programme (UN-Environment) under the Ministry of Natural Resources and Environmental Conservation (MoNREC) and its Environmental Conservation Department, with funds from the European Union. In 2015, the MCCA selected one township in the Dry Zone – Pakokku (Magway Division) – and one in the Delta – Labutta (Ayeyarwaddy Division) – to conduct a Township Climate Change Adaptation Programme to help communities adapt to the negative effects of climate change in the short, mid and long-term. This approach, once documented, will become the approach adopted at the national level and will be replicated in other townships.

Figure 8.1. *The three phases of adaptation assessment and planning for Pakkoku and Labutta.*

The programme is composed of three main phases (Figure 8.1). In Phase 1, climate data, including trends and future projections, is used to provide historic views of changes – augmented with local perceptions and records. For Phase 2, possible adaptation measures resulting from the Vulnerability Assessment (VA) are prioritised around three main objectives: healthy ecosystems that continue providing vital services for communities; a resilient economy that continues performing and improving under the new climatic conditions; and resilient infrastructure that continues to protect and serve the other objectives. In Phase 3, measures to maintain, restore, and enhance ecosystem services, socio-economic measures – such as vocational training – and resilient architecture and spatial planning are implemented.

Phase 1 is the foundation of the adaptation work and the stage at which the climate data is first applied. The VA gives township authorities and communities a clear view of how observed and future changes will affect their capacity to improve their living standards through development or to simply maintain them. To do that, the VA involves the township in studying what, and where, their main vulnerabilities are, and what needs to be done to mitigate or reduce the negative effects of climate change. This is a participatory process that makes use of primary and secondary data alike – consultations carried out by the assessment team in the township and existing historical studies – and which takes into account both scientific and technical analysis and local "groundtruthing" and perceptions of changes.

Figure 8.2. *A community member in Pakokku lists the possible adaptation measures to reduce the effects of the projected changes. Projections, pictured in the background, have been presented and the potential hazards and relative impacts discussed with the communities. This is part of the vulnerability assessment and forms the basis for the planning phase (MCCA/UN-Habitat-UN-Environment).*

The first step is to make use of available climate data to understand what is occurring at the local level and to downscale climate change projections. These results were discussed at the local level and compared to residents' perceptions of observed changes. Elders in Pakokku, for instance, confirmed that rainfall patterns have been erratic in the last twenty years, while people in Labutta confirmed inundation of areas to unprecedented levels, salinisation that may be related to sea level rise, stronger winds and storms and erratic rainfall. "Ownership" of these results is essential for the township to be able to engage in actual adaptation. Communities have indeed observed and suffered from climate changes already, lending projections higher credibility. Where historic data from nearby weather stations is insufficient to show significant variation trends over 30 years, the experience of people – especially farmers – is invaluable for providing direct reporting of observed climate changes.

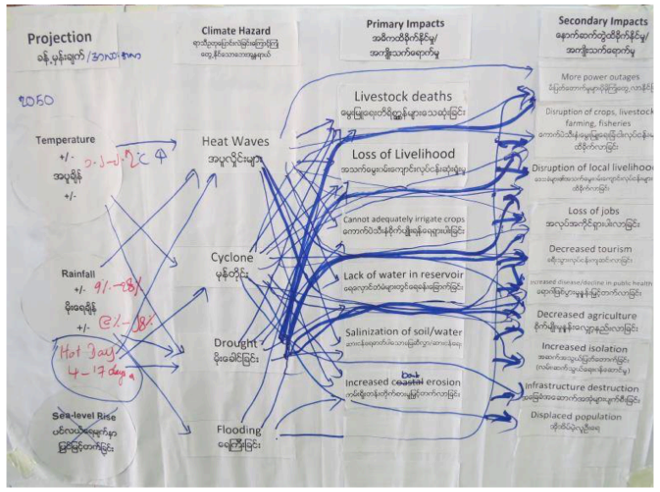

Figure 8.3. *Expected changes in climate will result in primary and secondary impacts on communities. This exercise is conducted in a participatory manner during local consultations, so that communities understand the actual consequences of climate change (UN-Habitat).*

Experts from CCSR and WWF, facilitated by MCCA, presented the projections to the communities in Pakokku and engaged them in envisioning the primary and secondary impacts that these changes may provoke (Figure 8.3). This is an effective exercise as it allows communities to reflect on their current and future vulnerabilities and prepare for the planning phase.

Taking the climate change projections as a starting point, the townships then used detailed, disaggregated data from the 2014 census provided by the Ministry of Population. This provides important information on the conditions of the townships – for example the percentage and location of people depending on rainwater harvesting for drinking water, migration rates and construction materials – which contributes to an assessment of the overall vulnerability of the township to climate change.

When all of the data has been gathered, a vulnerability index is established and findings validated with the township. On this basis, the township then undertakes Phase 2, drawing up a Strategic Adaptation Plan to prevent and reduce impacts by investing in adaptive measures for prioritised sectors and locations. Key objectives for overall adaptation are then established.

The Labutta Adaptation Plan, for example, is organised around three pillars, each with its own priority goals and specific activities, all of which are supported by the climate risk information documented in this report:

1) Maintaining and enhancing healthy ecosystems to support living standards, given the high dependency of people on ecosystem services;
2) Protecting and improving socioeconomic conditions by diversifying the economy and increasing skills and education to promote employability, as well as migration with dignity where necessary;
3) Ensuring that the people of Labutta have access to resilient housing and community infrastructure to protect them from heightened risks of hazards, and that the transport system continues to support people and economy.

The township can use this plan to guide programming and budgeting for adaptation efforts, but it also serves to communicate with donors and national authorities about investment priorities. In Phase 3, MCCA implements a number of the adaptive measures prioritised. This can include soft and hard interventions, green and gray infrastructure and management and planning solutions: examples include building household-level water harvesting facilities, planting mangroves, reinforcing cyclone shelters, supporting vocational training and allocating funds to test salt-resistant crops. (Fee *et al.*, 2017a; Fee *et al.*, 2017b)

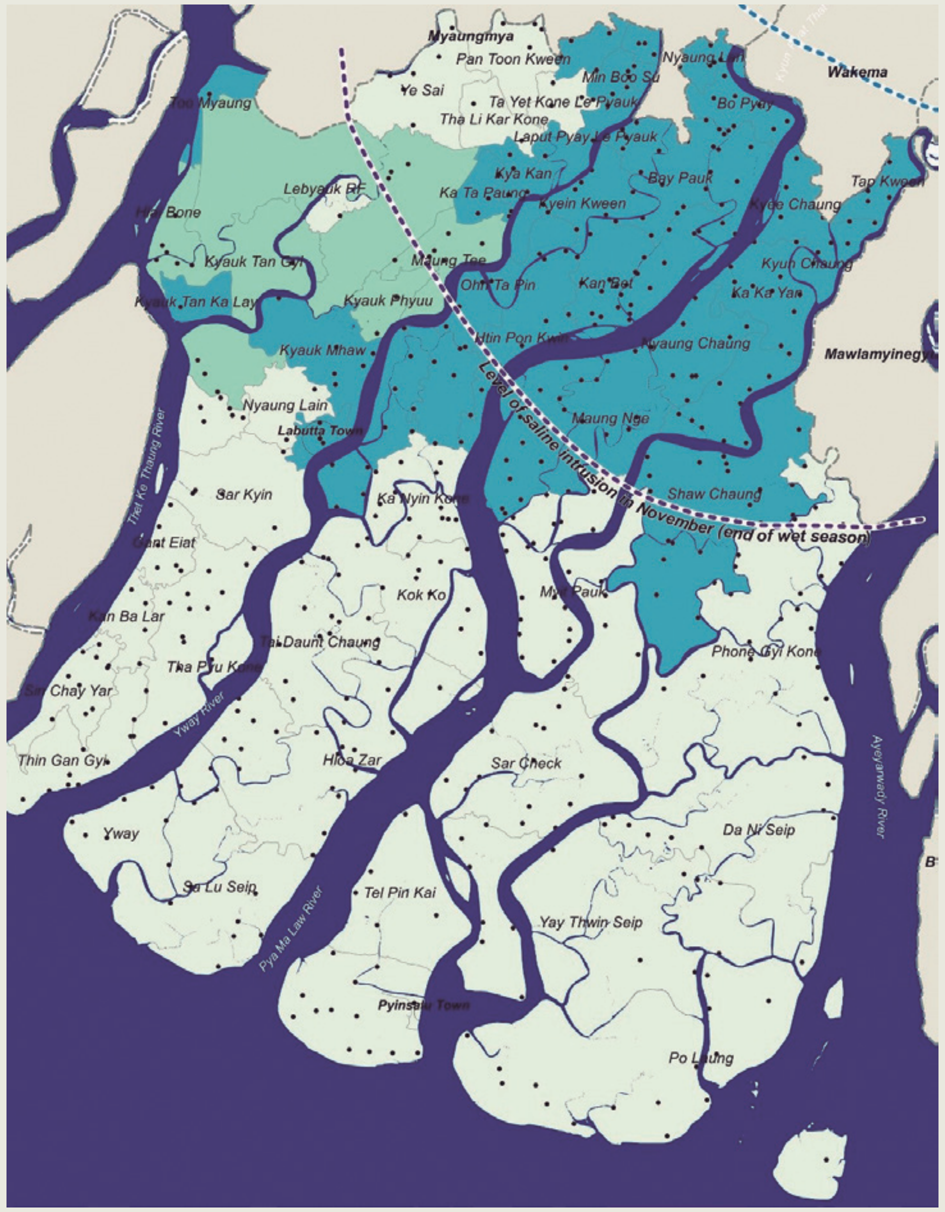

Figure 8.4. *Climate projections for 2050 applied to spatial analysis show the loss of importance of drinking water availability for a large portion of Labutta. Blue areas are still able to access drinking water in the Township in 2050, a major reduction from current areas due to sea level rise and saline intrusion (MCCA, draft).*

CONCLUSIONS

The effects of climate change in Myanmar are already being felt and will increase in the coming decades, challenging a vulnerable population highly centered on climate-dependent livelihoods and ecosystem services. This vulnerability can be expected to increase in the future, as climate models project rising sea levels that would have devastating effects on the coastline, increased temperatures that will challenge agriculture productivity and affect human health through more frequent extreme hot days, and changing monsoon rainfall patterns that will affect agricultural livelihoods nationwide. It is thus critical that all sectors—biodiversity and ecosystem services, coastal zones, health, agriculture, infrastructure, water resources and urban areas—begin planning for these risks to ensure continued economic growth is climate-resilient.

Through vulnerability assessments in two highly vulnerable and nationally important regions in the dry zone and Ayeyarwaddy Delta, MCCA has demonstrated an important real example of how the climate risk information in this report can be used to inform planning. The anticipated replication of these assessments in additional townships throughout Myanmar will provide further opportunities to incorporate and address these critical climate risks. As the MCCA example shows, however, this report provides only one important piece of the information necessary to begin planning for and addressing climate change.

While it relies on the best available information, including the most recent global climate models and datasets, precise projections of climate change are impossible given inherent uncertainties. One important way to reduce that uncertainty is through the approach followed in these pages by showing the full range of possible futures that could arise from climate change—rather than 'most likely' numbers that can be misleading. Further efforts, including the official climate projections to be released by DMH in the coming months and future assessments relying on additional local weather station data, coupled with the regular consultation of local communities demonstrated by the MCCA approach, will be critical to create even greater understanding of how climate change is affecting Myanmar.

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APPENDIX A:

CURRENT CLIMATOLOGY

Daily average temperatures, daily maximum temperatures, and precipitation for each of the Myanmar physiographic regions are shown in Table A.1, Table A.2, and Table A.3, respectively based on climate model outputs. The NASA NEX-GDDP baseline data reflects bias-corrected model values averaged over a .25 degree (~25km) grid. These values are based on gridded datasets developed from observed weather station data and weather model results[4]. For this and other reasons, the actual observed station temperatures may differ from the model baseline shown here.

Table A.1. *Mean temperature climatology. Average daily mean temperature over the 1980 to 2005 time period by region and season (°C).*
Source data: NASA NEX-GDDP (2015)

Region	Annual	Hot Season (MARCH TO MAY)	Wet Season (JUNE TO OCTOBER)	Cool Season (NOVEMBER TO FEBRUARY)
Myanmar (All Regions)	**23.6°C**	**25.1°C**	**25.1°C**	**20.5°C**
Ayeyarwady Delta	27.1°C	28.4°C	27.2°C	25.8°C
Central Dry Zone	23.9°C	25.7°C	25.3°C	20.8°C
Northern Hilly	20.8°C	21.8°C	23.9°C	16.3°C
Rakhine Coastal	25.2°C	26.8°C	26.2°C	22.9°C
Eastern Hilly	22.1°C	23.9°C	23.9°C	18.4°C
Southern Coastal	26.8°C	28.2°C	26.8°C	25.8°C
Yangon Deltaic	27.6°C	29.4°C	27.6°C	26.2°C
Southern Interior	26.2°C	28.2°C	26.7°C	24.2°C

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[4] Modeled reanalysis gridded data are based on the Global Meteorological Forcing Dataset (GMFD) for Land Surface Modeling (Sheffield et al., 2006).

Table A.2. *Maximum temperature climatology. Average daily maximum temperature over the 1980 to 2005 time period by region and season (°C).*
Source data: NASA NEX-GDDP (2015)

Region	Annual	Hot Season (MARCH TO MAY)	Wet Season (JUNE TO OCTOBER)	Cool Season (NOVEMBER TO FEBRUARY)
Myanmar (All Regions)	**28.7°C**	**31.1°C**	**28.7°C**	**27.0°C**
Ayeyarwady Delta	31.6°C	33.7°C	30.2°C	31.7°C
Central Dry Zone	28.9°C	31.5°C	28.7°C	27.1°C
Northern Hilly	26.0°C	27.7°C	27.7°C	22.7°C
Rakhine Coastal	29.7°C	32.1°C	29.1°C	28.8°C
Eastern Hilly	28.0°C	31.1°C	27.9°C	25.7°C
Southern Coastal	30.9°C	32.9°C	29.8°C	30.9°C
Yangon Deltaic	32.6°C	35.4°C	30.8°C	32.8°C
Southern Interior	31.9°C	35.1°C	30.3°C	31.5°C

Table A.3. *Precipitation climatology. Average cumulative rainfall totals over the 1980 to 2005 time period by region and season (mm).*
Source data: NASA NEX-GDDP (2015)

Region	Annual	Hot Season (MARCH TO MAY)	Wet Season (JUNE TO OCTOBER)	Cool Season (NOVEMBER TO FEBRUARY)
Myanmar (All Regions)	**2000 mm**	**300 mm**	**1700 mm**	**100 mm**
Ayeyarwady Delta	3100 mm	300 mm	2700 mm	100 mm
Central Dry Zone	2500 mm	300 mm	2100 mm	100 mm
Northern Hilly	1600 mm	300 mm	1300 mm	100 mm
Rakhine Coastal	3200 mm	300 mm	2800 mm	100 mm
Eastern Hilly	1400 mm	200 mm	1100 mm	100 mm
Southern Coastal	2600 mm	400 mm	2000 mm	200 mm
Yangon Deltaic	2600 mm	300 mm	2300 mm	100 mm
Southern Interior	1900 mm	300 mm	1600 mm	100 mm

APPENDIX B:

METHODS FOR DEVELOPING CLIMATE CHANGE PROJECTIONS

Temperature and Precipitation

Temperature and precipitation projections were developed using the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset released in 2015 (NASA, 2015). It is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The two RCPs in the dataset are RCP 4.5 and RCP 8.5. The CMIP5 GCM simulations were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5. Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100. The spatial resolution of the dataset is 0.25 degrees (approximately 25 km x 25 km).

For the analysis carried out for Myanmar, two time slices were developed to represent 30-year averages – 2020s (2011-2040) and 2050s (2041-2070). Temperature change factors reflect changes in seasonal and annual averages of daily mean temperature in reference to the base period. Precipitation change factors reflect percent changes in total seasonal and annual precipitation in reference to the base period. All change factors are relative to the 1980-2005 base period.

The low and high estimates were computed to capture a range of possible future outcomes. The low estimate value reflects the 25th percentile among 21 model projections under RCP4.5 and the high estimate reflects the 75th percentile for RCP8.5. Presenting the projections as a range most accurately represents possible future climate conditions for decision-makers and planners applying risk-based approaches to climate change adaptation and resiliency.

Sea Level Rise

Projections are provided for 13 climate-model grid boxes along the coast of Myanmar. These are the corresponding data points from the climate models that run the entire coastline of the nation.

CCSR developed a three-component strategy for sea level rise projections. First, the ocean term is comprised of two elements: global thermal expansion and local ocean height. The ocean term is taken from the 24 Coupled Model Intercomparison Project 5 (CMIP5) models (http://cmip-pcmdi.llnl.gov/cmip5/data_portal.html; Taylor *et al.*, 2012); while the first is global, the second is for an individual ocean grid box, after re-gridding to a 1° x 1° grid. Second, ice melt was estimated for the Greenland Ice Sheet, the two Antarctic Ice Sheets, and glaciers and ice caps. All but the last are based on Bamber and Aspinall, 2013; ice melt for glaciers and ice caps are based on Marzion *et al.*, 2012; Radic *et al.*, 2013. For the ice loss terms, the fingerprint terms that represent the effects of corresponding planetary response of ice loss on sea level rise are not included (these are the gravitational, isostatic, and rotational effects resulting from ice mass loss). Third, we included land water storage based on IPCC AR5 WG1 (Church *et al.*, 2013). For each of these three components of sea level change, set percentiles of the distribution were estimated (10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles). The sum of all components at each percentile is assumed to give the aggregate model-outcome range of sea level rise projections. Decadal projections were generated by averaging over ten-year intervals and subtracting average values for 2000-2004.

APPENDIX C:

TEMPERATURE PROJECTIONS

Table C.1 shows the projected national average warming in Myanmar and average warming for the eight regions for 2011-2040, and their respective absolute temperature values.

Projections for 2041-2070 are shown in Table C.2, and Figure C.1 maps the warming for 2041-2070 across the nation. Note that the temperature increases are smaller during the wet season (paler orange color on map) and larger for the remainder of the year (darker orange on map), especially in the East and North of the country.

To provide additional perspective on changes in temperature, Table C.3 presents how temperatures are projected to shift in six towns and cities in the 2011-2040 time period, and Table C.4 illustrates these shifts in the 2041-2070 time frame. Note that uncertainty of projections increases at smaller spatial scales.

Table C.1. *Projected change in mean temperature (°C) in 2011-2040 compared to the 1980-2005 average for the nation of Myanmar and in eight major regions.*
Source data: NASA NEX-GDDP (2015)

Region	Annual		Hot Season (MARCH TO MAY)		Wet Season (JUNE TO OCTOBER)		Cool Season (NOVEMBER TO FEBRUARY)	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Myanmar (All Regions)	+0.7°C	+1.1°C	+0.8°C	+1.2°C	+0.6°C	+1.1°C	+0.7°C	+1.2°C
Ayeyarwady Delta	+0.5°C	+0.9°C	+0.6°C	+0.9°C	+0.5°C	+0.8°C	+0.5°C	+1.0°C
Central Dry Zone	+0.7°C	+1.1°C	+0.9°C	+1.2°C	+0.6°C	+1.0°C	+0.7°C	+1.2°C
Northern Hilly	+0.7°C	+1.2°C	+0.8°C	+1.3°C	+0.6°C	+1.2°C	+0.7°C	+1.2°C
Rakhine Coastal	+0.7°C	+0.9°C	+0.7°C	+1.0°C	+0.6°C	+0.9°C	+0.7°C	+1.1°C
Eastern Hilly	+0.7°C	+1.2°C	+0.9°C	+1.4°C	+0.6°C	+1.2°C	+0.7°C	+1.3°C
Southern Coastal	+0.6°C	+1.0°C	+0.6°C	+1.1°C	+0.6°C	+0.9°C	+0.6°C	+1.0°C
Yangon Deltaic	+0.6°C	+1.0°C	+0.7°C	+1.1°C	+0.6°C	+1.0°C	+0.6°C	+1.1°C
Southern Interior	+0.7°C	+1.1°C	+0.8°C	+1.2°C	+0.6°C	+1.1°C	+0.7°C	+1.1°C

Note:
Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP.
High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

Table C.2. *Projected change in mean temperature (°C) in 2041-2070 compared to the 1980-2005 average in eight major regions and for the nation of Myanmar. Source data: NASA NEX-GDDP (2015)*

Region	Annual		Hot Season (MARCH TO MAY)		Wet Season (JUNE TO OCTOBER)		Cool Season (NOVEMBER TO FEBRUARY)	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Myanmar (All Regions)	+1.3°C	+2.7°C	+1.4°C	+2.9°C	+1.1°C	+2.4°C	+1.3°C	+2.8°C
Ayeyarwaddy Delta	+1.1°C	+2.1°C	+1.2°C	+2.4°C	+1.0°C	+2.0°C	+1.1°C	+2.4°C
Central Dry Zone	+1.2°C	+2.7°C	+1.5°C	+2.9°C	+1.1°C	+2.3°C	+1.3°C	+2.9°C
Northern Hilly	+1.4°C	+2.8°C	+1.5°C	+2.9°C	+1.2°C	+2.7°C	+1.4°C	+2.9°C
Rakhine Coastal	+1.2°C	+2.4°C	+1.3°C	+2.7°C	+1.1°C	+2.1°C	+1.2°C	+2.6°C
Eastern Hilly	+1.4°C	+2.8°C	+1.6°C	+3.1°C	+1.2°C	+2.5°C	+1.5°C	+2.8°C
Southern Coastal	+1.1°C	+2.4°C	+1.2°C	+2.6°C	+1.0°C	+2.2°C	+1.1°C	+2.5°C
Yangon Deltaic	+1.2°C	+2.4°C	+1.2°C	+2.7°C	+1.1°C	+2.2°C	+1.2°C	+2.7°C
Southern Interior	+1.3°C	+2.6°C	+1.4°C	+2.9°C	+1.1°C	+2.3°C	+1.3°C	+2.7°C

Note: Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP.
High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

Table C.3. *Projected change in mean temperature (°C) in 2011-2040 compared to the 1980-2005 average in six towns and cities. Source data: NASA NEX-GDDP (2015)*

Town/citiy	Annual		Hot Season (MARCH TO MAY)		Wet Season (JUNE TO OCTOBER)		Cool Season (NOVEMBER TO FEBRUARY)	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Dawei	+0.6°C	+1.0°C	+0.7°C	+1.1°C	+0.6°C	+1.0°C	+0.5°C	+1.0°C
Yangon	+0.6°C	+1.0°C	+0.7°C	+1.1°C	+0.6°C	+1.0°C	+0.6°C	+1.1°C
Naypyidaw	+0.7°C	+1.2°C	+1.0°C	+1.3°C	+0.6°C	+1.2°C	+0.7°C	+1.2°C
Mandalay	+0.7°C	+1.2°C	+0.9°C	+1.3°C	+0.6°C	+1.1°C	+0.8°C	+1.2°C
Pakokku	+0.7°C	+1.2°C	+0.9°C	+1.3°C	+0.6°C	+1.0°C	+0.7°C	+1.2°C
Labutta	+0.5°C	+0.8°C	+0.6°C	+0.9°C	+0.5°C	+0.8°C	+0.5°C	+0.9°C

Note: Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP. High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

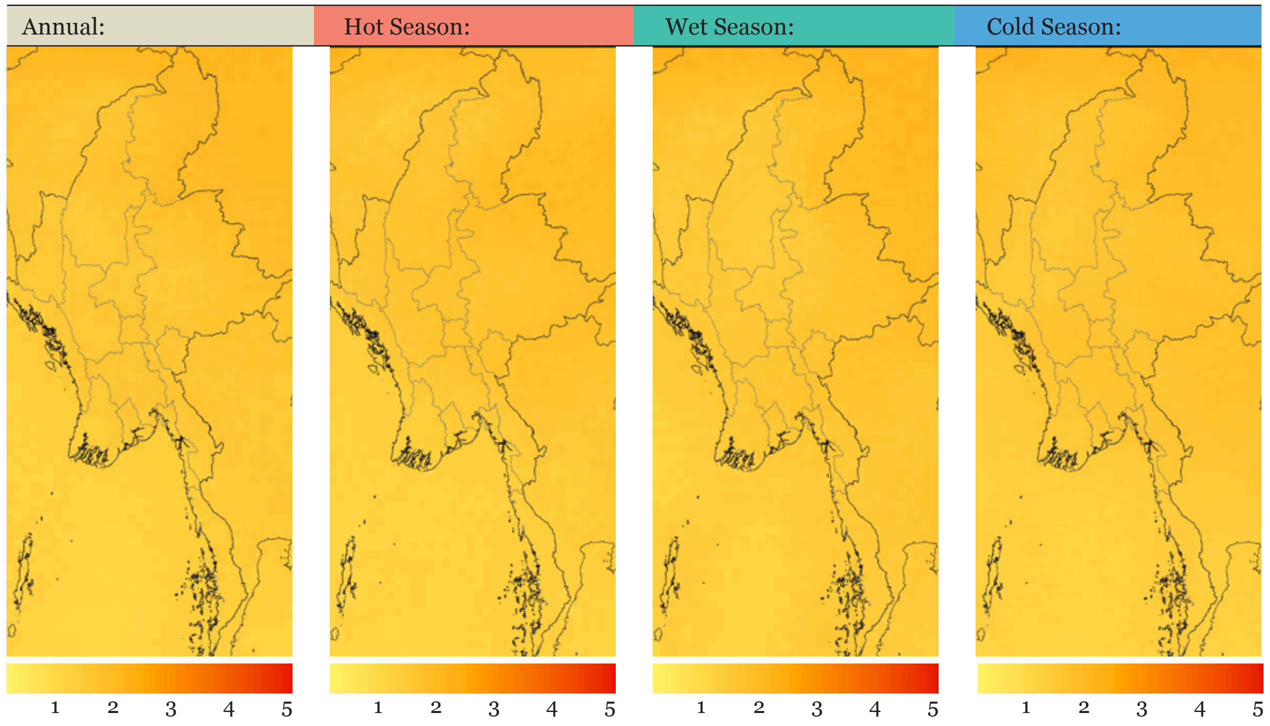
Table C.4. *Projected change in mean temperature (°C) in 2041-2070 compared to the 1980-2005 average in six towns and cities. Source data: NASA NEX-GDDP (2015)*

Town/citiy	Annual		Hot Season (MARCH TO MAY)		Wet Season (JUNE TO OCTOBER)		Cool Season (NOVEMBER TO FEBRUARY)	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Dawei	+1.1°C	+2.5°C	+1.2°C	+2.6°C	+1.1°C	+2.3°C	+1.1°C	+2.5°C
Yangon	+1.2°C	+2.4°C	+1.3°C	+2.7°C	+1.1°C	+2.2°C	+1.2°C	+2.7°C
Naypyidaw	+1.3°C	+2.8°C	+1.6°C	+3.1°C	+1.1°C	+2.3°C	+1.4°C	+2.9°C
Mandalay	+1.2°C	+2.8°C	+1.5°C	+3.1°C	+1.0°C	+2.4°C	+1.4°C	+2.9°C
Pakokku	+1.2°C	+2.7°C	+1.5°C	+3.1°C	+1.0°C	+2.3°C	+1.3°C	+2.9°C
Labutta	+1.1°C	+2.0°C	+1.2°C	+2.3°C	+1.0°C	+1.9°C	+1.1°C	+2.3°C

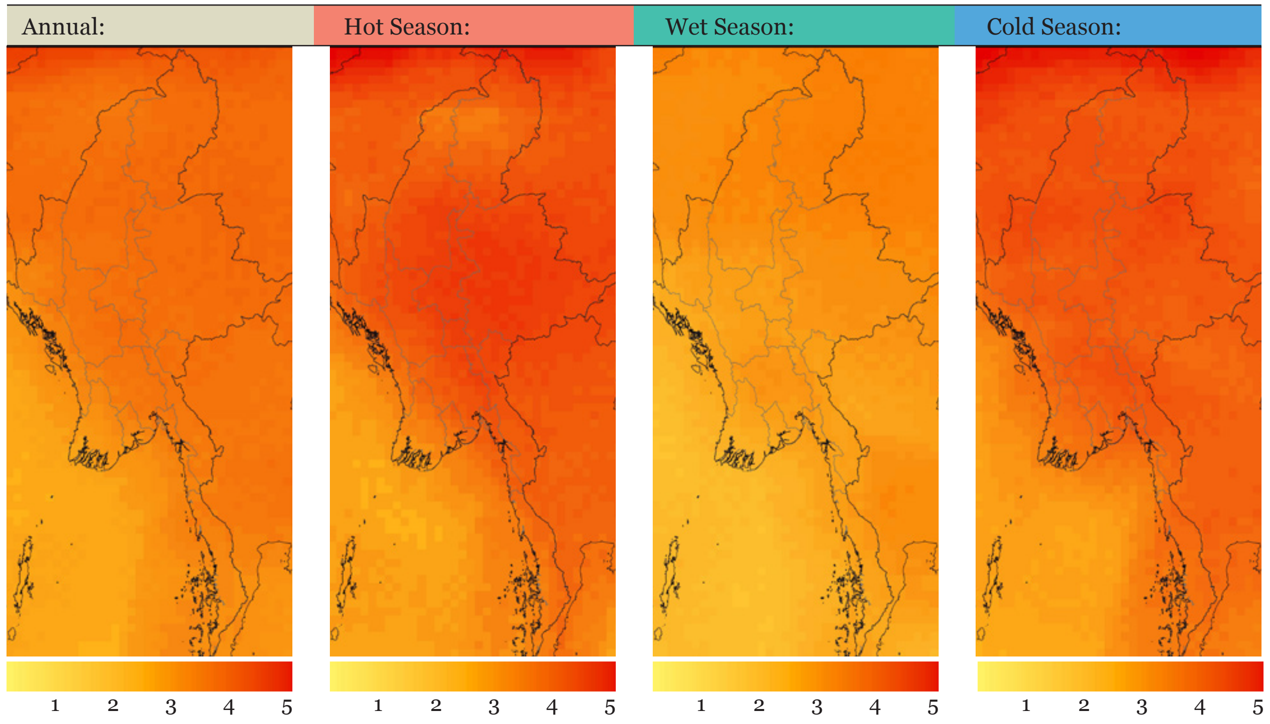
Note: Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP.
High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

Figure C.1. *Mean temperature change (°C) projections in the 2041-2070 period compared to the 1980-2005 average.*
Source data: NASA NEX-GDDP (2015)

LOW ESTIMATE



HIGH ESTIMATE



Note:

Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP 4.5

High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5

Hot season refers to the time period from February to May

Wet season refers to the time period from June to October

Cold season refers to the time period from November to January

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APPENDIX D:

PRECIPITATION PROJECTIONS

Table D.1. *Projected change in mean precipitation (%) in the 2011-2040 period compared to the 1980-2005 average in eight major regions and for the nation of Myanmar.*
Source data: NASA NEX-GDDP (2015)

Town/citiy	**Annual**		**Hot Season** (MARCH TO MAY)		**Wet Season** (JUNE TO OCTOBER)		**Cool Season** (NOVEMBER TO FEBRUARY)	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Myanmar (All Regions)	+1%	+11%	-11%	+12%	+2%	+12%	-23%	+11%
Ayeyarwady Delta	-1%	+11%	-13%	+18%	0%	+10%	-27%	+13%
Central Dry Zone	+2%	+11%	-14%	+13%	+3%	+12%	-32%	+9%
Northern Hilly	+2%	+13%	-10%	+14%	+3%	+16%	-19%	+8%
Rakhine Coastal	0%	+9%	-17%	+14%	+2%	+10%	-30%	+8%
Eastern Hilly	0%	+10%	-11%	+11%	+2%	+12%	-25%	+9%
Southern Coastal	-1%	+8%	-10%	+8%	-2%	+9%	-11%	+18%
Yangon Deltaic	0%	+12%	-12%	+19%	+1%	+11%	-29%	+14%
Southern Interior	+1%	+11%	-11%	+11%	+1%	+13%	-28%	+14%

Table D.2. *Projected change in mean precipitation (%) in the 2041-2070 period compared to the 1980-2005 average in eight major regions and for the nation of Myanmar.*
Source data: NASA NEX-GDDP (2015)

Town/citiy	**Annual**		**Hot Season** (MARCH TO MAY)		**Wet Season** (JUNE TO OCTOBER)		**Cool Season** (NOVEMBER TO FEBRUARY)	
	Low Estimate1	High Estimate2	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Myanmar (All Regions)	+6%	+23%	-7%	+19%	+6%	+27%	-12%	+11%
Ayeyarwady Delta	+3%	+23%	-7%	+19%	+3%	+25%	-9%	+15%
Central Dry Zone	+8%	+22%	-12%	+14%	+9%	+26%	-19%	+6%
Northern Hilly	+7%	+27%	-4%	+33%	+7%	+30%	-14%	+10%
Rakhine Coastal	+5%	+20%	-17%	+12%	+6%	+23%	-20%	+2%
Eastern Hilly	+7%	+24%	-8%	+14%	+7%	+30%	-15%	+7%
Southern Coastal	+3%	+16%	-2%	+13%	+1%	+18%	-1%	+29%
Yangon Deltaic	+5%	+24%	-4%	+17%	+5%	+26%	-5%	+15%
Southern Interior	+7%	+25%	-5%	+11%	+7%	+29%	-6%	+15%

Note:

Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP.

High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

Table D.3. *Projected change in mean precipitation (%) in 2011-2040 period compared to the 1980-2005 average in six towns and cities (top value).*
Source data: NASA NEX-GDDP (2015)

Town/citiy	**Annual**		**Hot Season** (MARCH TO MAY)		**Wet Season** (JUNE TO OCTOBER)		**Cool Season** (NOVEMBER TO FEBRUARY)	
	Low Estimate[1]	High Estimate[2]	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Dawei	-3%	+9%	-11%	+7%	-3%	+11%	-5%	+21%
Yangon	+1%	+12%	-11%	+20%	+1%	+11%	-26%	+13%
Naypyidaw	+2%	+13%	-12%	+13%	+2%	+12%	-40%	+3%
Mandalay	+1%	+10%	-11%	+18%	+4%	+11%	-35%	+11%
Pakokku	+1%	+12%	-13%	+14%	+3%	+11%	-38%	+4%
Labutta	-1%	+11%	-11%	+17%	0%	+10%	-26%	+15%

Note:

Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP.

High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

Table D.4. *Projected change in mean precipitation (%) in 2011-2040 period compared to the 1980-2005 average in six towns and cities.*
Source data: NASA NEX-GDDP (2015)

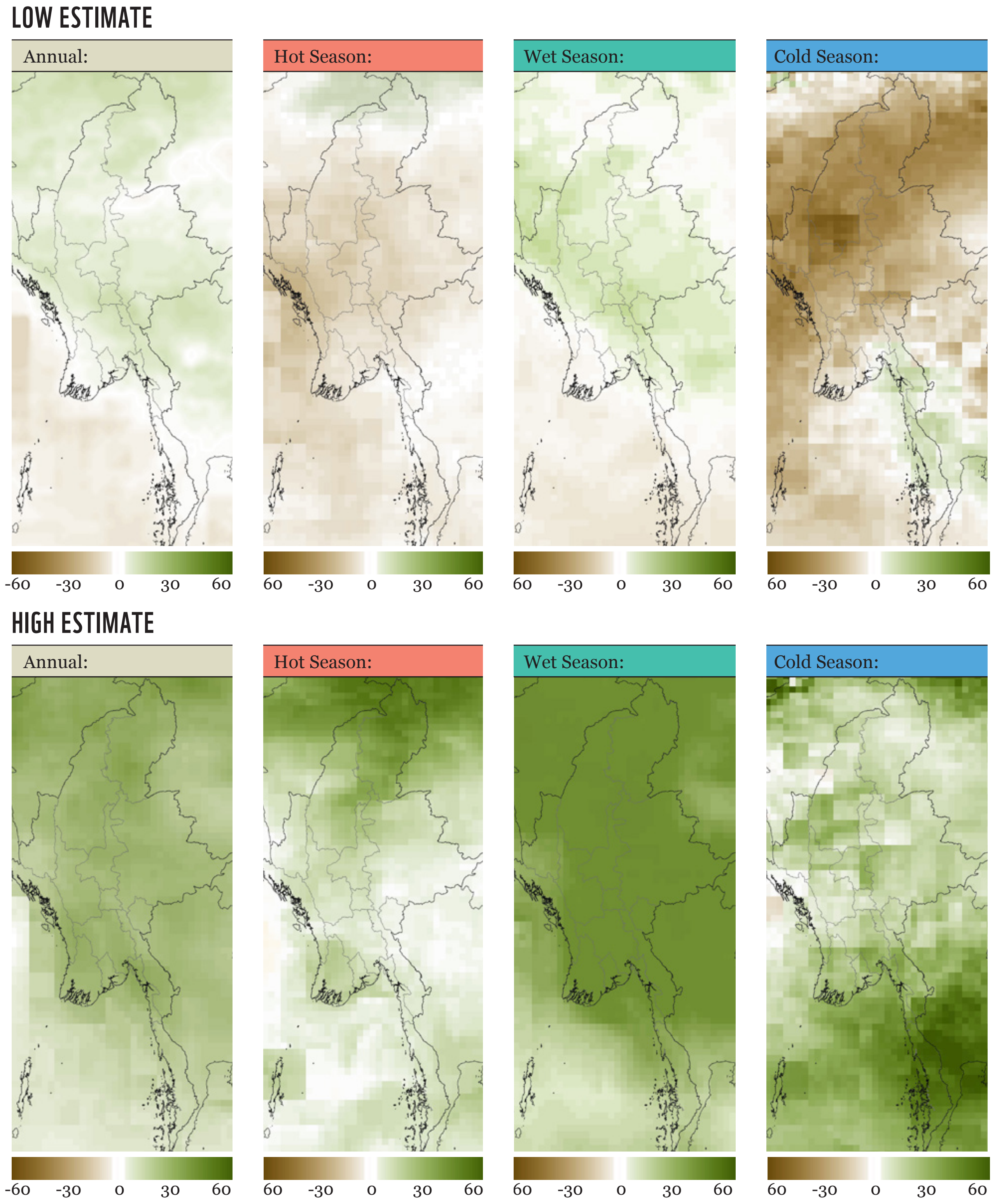
Town/citiy	**Annual**		**Hot Season** (MARCH TO MAY)		**Wet Season** (JUNE TO OCTOBER)		**Cool Season** (NOVEMBER TO FEBRUARY)	
	Low Estimate[1]	High Estimate[2]	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Dawei	+3%	+19%	0%	+11%	0%	+21%	+3%	+32%
Yangon	+5%	+23%	-4%	+16%	+5%	+26%	-7%	+12%
Naypyidaw	+10%	+23%	-10%	+12%	+10%	+31%	-21%	+3%
Mandalay	+7%	+26%	-11%	+18%	+7%	+30%	-26%	+12%
Pakokku	+6%	+23%	-15%	+17%	+9%	+28%	-27%	+9%
Labutta	+3%	+23%	-7%	+17%	+3%	+24%	-8%	+15%

Note:

Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP.

High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5.

Figure D.1. *Mean precipitation change (%) projections in 2041-2070 compared to the 1980-2005 average.*
Source data: NASA NEX-GDDP (2015)



Low estimate refers to the 25th percentile of model outcomes in greenhouse gas emissions scenario RCP 4.5

High estimate refers to the 75th percentile of model outcomes in greenhouse gas emissions scenario RCP 8.5

Hot season refers to the time period from February to May

Wet season refers to the time period from June to October

Cold season refers to the time period from November to January

APPENDIX E:

SEA LEVEL RISE PROJECTIONS

In the following table, the following information is provided for each grid box:

- Grid box - Arbitrary number assigned to the grid box (running from north to south)
- Lat - the latitude for the grid box
- Lon - the longitude for the grid box
- Column headings - the percentile of the distribution shown in that column
- Row headings - three future time slices for which the projections are provided, 2020s, 2050s, and 2080s.

Table E.1 shows a range of projections that represent four distribution points of outcomes (percentiles) in each of the three time slices for sea level rise relative to the 2000-2004 baseline period. The projections are sea level rise in centimeters. A percentile refers to what percentage of the outcomes fall beneath a certain threshold. For example, the value shown for the 90th percentile means that 90% of the model outcomes fall below that number, while 10% of the outcomes are higher. The tables show the percentiles as follows:

- 10th percentile - low estimate
- 25th percentile - lower-middle estimate
- 75th percentile - upper-middle estimate
- 90th percentile - high estimate

Table E.1. *Sea level rise projections (in centimeters).*

	Year	Percentile			
		10th	**25th**	**75th**	**90th**
Grid box 1: Lat 20 Lon 91	2020s	3	6	13	19
	2050s	14	21	40	57
	2080s	21	38	82	121
Grid box 2: Lat 19 Lon 91	2020s	3	6	13	19
	2050s	14	21	41	57
	2080s	21	38	83	121
Grid box 3: Lat 18 Lon 92	2020s	3	6	13	18
	2050s	15	21	41	56
	2080s	21	38	82	122
Grid box 4: Lat 18 Lon 93	2020s	3	6	13	18
	2050s	14	21	41	56
	2080s	21	38	82	121
Grid box 5: Lat 17 Lon 93	2020s	3	6	13	18
	2050s	14	21	40	56
	2080s	21	38	82	121
Grid box 6: Lat 16 Lon 93	2020s	3	6	13	18
	2050s	14	21	40	56
	2080s	21	38	81	121
Grid box 7: Lat 14 Lon 94	2020s	3	5	13	19
	2050s	14	21	40	56
	2080s	21	37	82	121
Grid box 8: Lat 15 Lon 95	2020s	3	5	13	19
	2050s	14	20	40	56
	2080s	21	37	81	121
Grid box 9: Lat 14 Lon 96	2020s	3	5	13	18
	2050s	14	20	40	56
	2080s	21	37	81	121
Grid box 10: Lat 13 Lon 96	2020s	3	5	13	18
	2050s	14	20	40	56
	2080s	21	37	81	121
Grid box 11: Lat 12 Lon 96	2020s	3	5	13	19
	2050s	14	20	40	56
	2080s	21	37	81	121
Grid box 12: Lat 11 Lon 96	2020s	3	5	13	18
	2050s	14	21	40	56
	2080s	21	37	81	121
Grid box 13: Lat 10 Lon 96	2020s	3	5	13	18
	2050s	14	21	40	56
	2080s	21	37	81	121

APPENDIX F:

HISTORICAL EXTREMES

Table F.1. *Projected 2011-2040 and 2041-2070 frequency of occurrence of the historical (1981-2010) daily 95th percentile temperatures in a month (i.e., extreme heat days).*
Source data: Weather station data provided by DMH (2015), projections reflect the NASA NEX GDDP dataset.

Month	Region*	Extreme hot day temperature 1981-2010	Historical frequency 1981-2010	Projected number of days per month hotter than historical extreme hot days from 1981-2010			
				2011-2040		2041-2070	
				Low estimate	High estimate	Low estimate	High estimate
March	Coastal	37.4°C	1 day	4 days	5 days	7 days	14 days
	Inland	37.1°C	1 day	4 days	5 days	6 days	14 days
April	Coastal	38.3°C	1 day	4 days	6 days	8 days	17 days
	Inland	39.3°C	1 day	3 days	6 days	7 days	14 days
May	Coastal	38.1°C	1 day	2 days	3 days	4 days	8 days
	Inland	38.8°C	1 day	3 days	4 days	4 days	8 days

*See Figure 2.1 for complete list of coastal and inland stations.

Table F.2. *Rankings of May 2010 temperature and rainfall metrics in relation to all months of May from 1981-2010.*
Source data: Weather station data provided by DMH (2015)

May 2010 Heat Wave		Temperature ranking (out of 30 years)		Rainfall ranking (out of 30 years)	
Affected Station Region	Region	Monthly average	Hottest day	Total Rainfall (1 = least)	Total dry days (<2mm rainfall)
Bago	Bago	2	1	13	6
Chauk	Magway	3	1	12	8
Heho	Shan	1	1	4	6
Henzada	Ayeyarwady	4	2	16	10
Kabaaye	Yangon	1	1	14	7
Kyaukphyu	Rakhine	4	3	20	10
Mandalay	Mandalay	1	1	10	9
Mawlamyine	Mon	1	3	3	2
Minbu	Magway	7	2	24	14
Mingaladon	Yangon	3	2	18	8
Pathein	Ayeyarwady	2	5	14	8
Sittwe	Rakhine	7	11	30	13
Taunggyi	Shan	1	1	3	12

Table F.3. *Rankings of monthly rainfall metrics for four flooding events in relation to all such months from 1981-2010.*
Source data: Weather station data provided by DMH (2015)

Floods				Rainfall ranking (out of 30 years)	
		Affected Station Region	Region	Total Rainfall (1 = most)	Wettest day
2002	August	Bago	Bago	19	22
2002	August	Dawei	Tanintharyi	10	28
2002	August	Henzada	Ayeyarwady	8	10
2002	August	Kabaaye	Yangon	12	15
2002	August	Mandalay	Mandalay	1	5
2002	August	Mawlamyine	Mon	3	8
2002	August	Mingaladon	Yangon	10	19
2002	August	Pathein	Ayeyarwady	5	5
2002	September	Bago	Bago	15	15
2002	September	Henzada	Ayeyarwady	10	25
2002	September	Kabaaye	Yangon	2	5
2002	September	Mandalay	Mandalay	9	13
2002	September	Mingaladon	Yangon	9	9
2002	September	Pathein	Ayeyarwady	21	8
1997	August	Bago	Bago	1	15
1997	August	Heho	Shan	25	30
1997	August	Henzada	Ayeyarwady	6	4
1997	August	Kyaukphyu	Rakhine	23	11
1997	August	Magway	Magway	14	9
1997	August	Mawlamyine	Mon	10	24
1997	August	Pathein	Ayeyarwady	7	1
1997	August	Sittwe	Rakhine	23	20
1997	August	Taunggyi	Shan	28	29
2009	September	Myitkyina	Kachin	14	18
2010	July	Kyaukphyu	Rakhine	23	4
2010	July	Sittwe	Rakhine	19	24

APPENDIX G:

MONSOON DRIVERS

There are several factors that affect monsoons, including aerosols and major modes of climate variability such as the El Niño–Southern Oscillation (ENSO). Aerosols in the atmosphere and associated changes affect the amount of solar radiation reaching the ground and can change circulation, as this has an effect on land-surface warming (Christensen *et al*., 2014).

Aerosols

Aerosols, such as air pollutants, absorb solar radiation, which in turn changes heating distribution in the atmosphere as well (Christensen *et al*., 2014). The influence of aerosols such as black carbon and sulphate on monsoon precipitation is complex (Turner and Annamalai, 2012). Aerosols limit the solar radiation reaching the surface, partially countering the impact of increasing carbon dioxide. In the case of the South Asian Monsoon, this could also cool the northern Indian Ocean, reducing moisture availability in the atmosphere for monsoon rainfall. Climate model studies have shown that the inclusion of sulphate aerosols (in addition to carbon dioxide) restrains the increase in monsoon rainfall. Other indirect effects include effects on cloud lifetime or albedo. Research specific to black carbon is contradictory, with some studies demonstrating increased monsoon rainfall, while others show a decline (Turner and Annamalai, 2012).

Climate model experiments on the South Asian monsoon found that the decline of observed precipitation is mainly attributed to anthropogenic aerosol emissions (Bollasina *et al*., 2011). The results of the study suggest that these aerosols have considerably masked the precipitation increase that would otherwise have occurred due to the warming associated with increased greenhouse gases.

Some climate models include both the direct and indirect effect of aerosols. Over time, it is expected that increasing greenhouse gases may overwhelm the relative effect of aerosols on monsoons (Kitoh *et al*., 2013). Aerosol lifetimes are short compared to greenhouse gases; depending on the type of aerosol, they can last anywhere from 1 to 10 days in the troposphere (lower atmosphere) (Boucher *et al*., 2013).

El Niño–Southern Oscillation (ENSO)

Year-to-year variations in the monsoons in many tropical regions are affected by ENSO. There's uncertainty on how ENSO will change in future, and also how its influence on the monsoon will change (Hijioka *et al*., 2015). Generally, a decline in global monsoon precipitation is seen during El Niño events. This rainfall variability is intensified with warming in climate model simulations, with a strengthening of the relationship between the monsoon and El Niño (Hsu *et al*., 2013).

Studies have also shown a decline in precipitation in Myanmar during El Niño (D'Arrigo *et al*., 2011 and Sen Roy and Sen Roy, 2011), although an earlier study (Sen Roy and Sen Roy, 2011), described that there was no one-to-one relationship between El Niño and monsoon rainfall in Myanmar. Teak tree ring studies in Myanmar have shown negative correlations with sea surface temperature related to El Niño. This is consistent with the relationship between El Niño warm events and drought conditions (and thus decreased teak growth) over South East Asia, caused by the eastward migration of the Walker circulation (D'Arrigo *et al*., 2011). Another study (Sen Roy and Sen Roy, 2011), using monthly precipitation data from 1951 to 2002, showed an overall negative relationship between ENSO and precipitation patterns across Myanmar, with considerable regional level variations in the strength of the relationship.

Next steps in research

While progress has been made in modeling of the Asian monsoon in climate models, there is no single model that best represents the various aspects of the monsoon, such as the climatological annual cycle, interannual variability, and intraseasonal variability (Sperber *et al*., 2013). Observations and projections for the Indian and South Asian Monsoon vary at different scales and regions. Country-specific projections and observed local data will be useful for planning, while regional and global projections provide an insight to possible influences and changes that may occur in the coming decades.

We live in a world already affected by climate change. Global temperatures in 2015 were the hottest since record keeping began, and 15 out of the last 16 hottest years on global record have occurred since the year 2000. At the same time, 2015 brought a glimpse of hope with the globally adopted Paris Agreement, in which over 190 countries agreed to hold global average temperature rise to no more than 2°C above pre-industrial levels and to pursue further efforts to limit warming to 1.5°C. This agreement is of critical importance for Myanmar because it is one of the most vulnerable countries in the world to climate change. While mitigation of greenhouse gas emissions is crucial, the climate changes that are already being felt make adaptation and resilience-building essential national priorities.

The critical first step in putting Myanmar on a pathway toward resilience is to generate climate risk information based upon the best-available science that illustrates the magnitude of climate changes Myanmar will likely see over the coming century. This report describes how Myanmar's climate conditions will change by the 2020s and 2050s, including shifts in temperature, precipitation, sea level rise, and regional drivers of extreme events related to cyclones and the monsoon. Using this information, local, regional, and national policy makers can plan to adapt to these changes.

Understanding and incorporating climate risk information today will be crucial for building long-term resilience across various sectors of Myanmar. The national economy and millions of people are largely dependent upon agriculture, which relies on a predictable seasonal cycle of water and temperature. Investments into infrastructure will have to be built to withstand future climate conditions because they will be in place for decades. If this is not done, planners will risk future expenditures for repairs and upgrades following extreme events. Myanmar is already exposed to a number of natural hazards such as floods, droughts, cyclones and coastal storms – these are events that are exacerbated by climate change. Myanmar's ecosystems provide crucial services for protection against these hazards. For example, mangroves and coastal habitats help reduce the impact from coastal storms and forests play a key role in regulating floods. As such, protecting these ecosystems will be even more important to build climate resilience for Myanmar's many vulnerable populations.

Better understanding and use of climate risk information is also critical as Myanmar develops. With development efforts across the country, we have an opportunity to ensure that these activities are both sustainable and climate-resilient. Using information about how our climate is likely to change in the coming decades will help maintain livelihoods and ensure a more sustainable, resilient economy while keeping our incredible ecosystems and biodiversity intact. In order to achieve this sustainable and climate-resilient future, we need to work together - across ministries and sectors and with a wide range of stakeholders.

Science is telling us that our climate change is already affecting Myanmar and it is likely to worsen in the coming decades. This will lead to ever-increasing impacts on our economy, people, and ecosystems. It is up to us to decide how we want to use this information. I hope that this report will contribute to better integration of climate science into decision-making and planning, which will be essential to our ability to adapt and build much needed resilience to climate change.