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Science for Climate Resilient Communities
IN PARTNERSHIP WITH
CLIMATE CHANGE COMMISSION PHILIPPINES

PHILIPPINE Climate Change ASSESSMENT

WORKING GROUP 1

The Physical Science Basis

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COORDINATING AUTHOR:
Jose Ramon T. Villarin, SJ

CONTRIBUTING AUTHORS:
John Leo C. Algo, Thelma A. Cinco, Faye Abigail T. Cruz, Rosalina G. de Guzman, Flaviana D. Hilario, Gemma Teresa T. Narisma, Andrea Monica D. Ortiz, Fernando P. Siringan, Lourdes V. Tibig

TECHNICAL COORDINATORS:
Rodel D. Lasco
Perlyn M. Pulhin

TECHNICAL AND LOGISTICAL SUPPORT:
Rafaela Jane P. Delfino and Sandee G. Recabar

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36th Flr. One Corporate Center Bldg. Julia Vargas corner,
Meralco Avenue, Ortigas Pasig City 1605 Philippines
Tel: +63-2-755-2332 loc. 2276
Email: info@omlopezcenter.org
Website: www.omlopezcenter.org

Layout and cover by: Jan Daniel Belmonte and John Rey Espinueva

Please send feedback and suggestions to: info@omlopezcenter.org

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About the Authors

John Leo C. Algo

Mr. Algo is a young climate researcher and advocate. He is currently a member of the Air Quality Dynamics group of the Manila Observatory, researching on the properties of black carbon and its impacts on urban climate and public health. He previously served as a researcher for Clean Air Asia and the Regional Climate Systems division of the Manila Observatory, focusing on modeling regional climate for projecting temperature and rainfall changes. He graduated with a BS degree in Environmental Science in 2014 from the Ateneo de Manila University and is currently earning his MS Atmospheric Science degree from the same institution. He was mentored by former US Vice President Al Gore during the 31st Climate Reality Leadership Corps Training, organized by The Climate Reality Project. He serves as a resource speaker and writer with the Philippine Youth Climate Movement, aiming to creatively educate and empower the public, especially the youth, about climate change in collaboration with other organizations. He was also the Philippine youth representative to the 40th UNESCO World Heritage Committee held in Istanbul, Turkey.

Thelma A. Cinco

Ms. Cinco works as a climatologist/meteorologist for the last 25 years and the lead person in Regional Downscaling of Climate projections for the Philippines using Providing Regional Climate Impacts (PRECIS) and Conformal Cubic Atmospheric Model (CCAM). She is actively involved in different research studies on climate change/variability, impact assessment to various socio-economic sectors in the Philippines and served as the focal person in the project of South East Asia Climate Modelling. She is currently the chief of the Impact Assessment and Application Section (IAAS), Climatology and Agrometeorology Division (CAD) of the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA). She has also published research papers in various refereed local and international journals.

Faye Abigail T. Cruz, PhD

Dr. Cruz is a climate scientist at the Manila Observatory. She obtained her PhD in Climate Science at the University of New South Wales (Australia) and MS in Physics at the Ateneo de Manila University. She is actively engaged in research concerning regional climate and climate change, extreme weather events, and land surface–atmosphere interactions. As an International Research Fellow of the Japan Society for the Promotion of Science (JSPS), she conducted her research on regional climate change in the Philippines and in Southeast Asia at the Meteorological Research Institute (Japan). She is also currently involved in the Southeast Asia Regional Climate Downscaling (SEACLID) / Coordinated Regional Climate Downscaling Experiment (CORDEX) Southeast Asia Project under the CORDEX project of the World Climate Research Programme (WCRP). This project aims to increase high-resolution climate change projections for Southeast Asia, and enhance climate change knowledge in the region.

Rosalina G. de Guzman

Ms. de Guzman works as a climatologist and is currently the Chief of Climate and Agromet Data Section of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). She has more than 25 years of experiences in climate research, focusing mainly on the assessment of climate trends and statistical data analysis. In recent years she has also been involved in seasonal climate prediction and in the implementation of several projects on climate change which is geared towards the enhancement of climate information for climate risk management. She has also published research papers in various refereed local and international journals. She has made innovation in climate data management which resulted in the real time integration of climate data from all observing facilities of PAGASA.

Flaviana D. Hilario, PhD

Dr. Hilario is currently the Deputy Administrator for Research and Development of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). She has shown sustained commitment to excellence in delivering timely and relevant scientific knowledge in the fields of Climatology, Meteorology, Agrometeorology, Remote Sensing and Climate Change for immediate and long-term benefits of the country. She has also published research papers in various refereed local and international journals. She is also recognized for her efforts at infusing a culture of research in her Agency that resulted in the formulation of various critical climate change action plans in the Philippines, which help prepare the country for the uncertain climatic future.

Gemma Teresa T. Narisma, PhD

Dr. Narisma has a BS in Applied Physics degree and an MS in Environmental Science from the University of the Philippines, Diliman. She finished her PhD in Atmospheric Science at the Macquarie University in Australia where her research work focused on the impact of land cover change on the Australian climate. After her PhD, she then joined the Center for Sustainability and the Global Environment (SAGE) at the University of Wisconsin, Madison as a Research Associate. She is currently an Associate Professor at the Physics Department of the Ateneo de Manila University. She is also the Associate Director for Research and the Head of the Regional Climate Systems Program of the Manila Observatory. She is also involved in the Southeast Asia Regional Climate Downscaling (SEACLID) / Coordinated Regional Climate Downscaling Experiment (CORDEX) Southeast Asia Project under the CORDEX project of the World Climate Research Programme (WCRP).

Andrea Monica D. Ortiz

Ms. Ortiz is an environmental scientist who has worked for the Ateneo School of Government and the Manila Observatory. Her work focused on integrated risk analysis, disaster risk reduction, climate change adaptation, and resilience in Metro Manila and the Philippines. A graduate of Philippine Science High School, she received her BSc from the University of Oregon and her Masteral degrees from the University of Copenhagen and the University of Natural Resources and Life Sciences Vienna. She is currently a PhD candidate at the Grantham Centre for Sustainable Futures at the University of Sheffield, studying climate change impacts and adaptation in agriculture through the use of climate and crop models.

Fernando P. Siringan, PhD

Dr. Siringan is a faculty member of the UP Marine Science Institute where he specializes in marine/coastal ecology, sedimentology and seismic stratigraphy. He earned his PhD in geology from Rice University and is currently investigating the role played by relative sea level and climate changes in the development of present-day coastal environments.

Lourdes V. Tibig

Ms. Tibig is a retired government servant, having worked with the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) as a meteorologist for 32 years. She has remained committed to climate change initiatives, both in government and the private sector. Currently, she has been appointed to the National Panel of Technical Experts (NPTE) of the Climate Change Commission. Her engagement in the field of climate change includes doing researches and projects on climate, climatology and climate trends, detection and attribution of observed impacts to climate change, and climate change adaptation. She has also served as referee for international journals on climate/climate change, in addition to being active in the preparation of Intergovernmental Panel on Climate Change (IPCC) global scientific assessment reports (AR); a Government Reviewer for IPCC AR4, Lead Author of the WGII contribution to IPCC AR5 and participant in the scoping meeting for the IPCC Special Report on Climate Change, Oceans and the Cryosphere. Two of the books on climate change in the Philippines in which she had been a co-author had been awarded Most Outstanding Book of the Year in 2001 and in 2015 by the National Academy of Science and Technology (NAST), Philippines.

Jose Ramon T. Villarin, SJ, PhD

Fr. Villarin is the President of Ateneo de Manila University in the Philippines. He received his doctorate in Atmospheric Sciences from Georgia Institute of Technology (Atlanta, Georgia) and his master's degree in Physics from Marquette University (Milwaukee, Wisconsin). He is currently the chairperson of the Manila Observatory, a scientific research institute, and a member of the National Panel of Technical Experts of the Philippine government's Climate Change Commission. His past work on climate change included being lead reviewer of greenhouse gas emission inventories of Parties to the UNFCCC and a member of the Consultative Group of Experts for developing countries. He was a member of the Intergovernmental Panel on Climate Change (IPCC) which received a Nobel Peace Prize in 2007. In 2000, he was declared National Outstanding Young Scientist and in 2002, his book "Disturbing Climate" was given an Outstanding Book Award by the National Academy of Science and Technology (NAST), Philippines. His other responsibilities include being chair of Synergeia, an NGO engaged in public education reform, and writing a column ("God's Word Today") with other Jesuits for a major newspaper.

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Foreword

Climate change has been much publicized in the media in recent years, so much so that the term may be losing its original meaning and intended impact. Yet, the need to act is ever more urgent and the will to act is growing, moving toward the tipping point. The challenge for those of us working in the field of climate change is to ensure that this all-encompassing term continues to convey the serious implications of the phenomenon and retains its relevance for our audiences.

This was our objective for producing the Philippine Climate Change Assessment (PhilCCA). This report contains comprehensive information on climate change science in the Philippines in order to guide everyone in making strategic decisions which will help us all confront this most challenging issue of our time.

Climate change refers to a global phenomenon, generally characterized by changes in weather patterns over extended periods of time. Upon closer investigation, however, because climate varies throughout the globe, the changes in climate actually refer to an assortment of effects which affect regions, countries, and communities differently, rendering everyone vulnerable to climate change in varying ways and degrees. Given this complexity, adapting to climate change necessitates a localized approach, using context-specific and up-to-date information.

At the international level, the Intergovernmental Panel on Climate Change (IPCC) is the recognized body providing regular assessments on the science of climate change and its projected environmental and socio-economic impacts, through its three working groups (WG): WG1: The Physical Science Basis; WG II: Impacts, Adaptation and Vulnerability; and WG III: Mitigation of Climate Change. This First Edition PhilCCA WG 1 Report is patterned after the IPCC reports, with particular focus on the Philippines, one of the countries consistently ranked most vulnerable to the effects of climate change.

We at the Oscar M. Lopez Center believe that science is the necessary foundation to guide policies, investments, innovations and other day-to-day decisions; with our research, we aim to become a leading catalyst for climate resilience. For this reason, we embarked on this project in collaboration with the Climate Change Commission. We could not have done it without them and the experts who volunteered their time, wisdom and energy as authors; to all of them, we are truly grateful.

To you who now hold this resource in your hands, we thank you for your confidence and hope you will use the information contained herein to pursue our shared vision of a climate-resilient Philippines.

MARIANNE G. QUEBRAL
Executive Director

RODEL D. LASCO
Scientific Director

Executive Summary

The global mean warming of 0.85°C from 1880 to 2012 cannot simply be explained by natural variability. This warming is *extremely likely* due to human activities that have increased greenhouse gas (GHG) concentrations in the atmosphere, which have risen to unprecedented levels in the last 800,000 years.

The annual mean temperature for the tropical and maritime climate of the Philippines is 26.6°C, with high variability in rainfall influenced by large-scale systems (e.g., the northeast and southwest monsoons, tropical cyclones, El Niño Southern Oscillation [ENSO]) and local-scale systems (e.g., sea and lake breezes, urban heat islands).

From 1951 to 2010, the annual mean temperature in the country increased by 0.65°C with a mean rate of 0.11°C per decade. In terms of temperature variability, more hot days and warm nights, and less cold days and nights have been observed over this period. Observation records from 1951 to 2008 also indicate an increasing trend in the intensity and frequency of extreme rainfall events in many parts of the country, with significant increases observed in certain places such as Baguio, Tacloban, and Iloilo.

On average, about 20 tropical cyclones (TC) enter the country every year, with the variation in yearly count driven by factors such as ENSO. Trends in TC frequency (or the number of TCs per year) indicate no appreciable increase in the observational record. Although preliminary studies have been done on TC tracks and intensity, there are no conclusive trends at this time.

Trends in sea surface temperature (SST) near the Philippines show that temperatures have been increasing by around 0.23°C ± 0.02°C per decade from 1981 to 2014. An estimate of the observed increase in global mean SST from 1979 to 2012 is 0.124°C ± 0.03°C for every decade. For sea level rise, there is little available information on local sea level rise and as such, information on sea level rise for the entire country is limited.

While global climate change is largely driven by GHG levels in the atmosphere, it is important to note the impacts of aerosols from biomass burning and pollution, land use and land cover change arising from agriculture and urbanization, and other such drivers on local climate and ecosystems, and their potential feedbacks on the greenhouse effect. The influence of the interplay between these local driving factors and GHGs on Philippine climate has yet to be examined.

Future changes in Philippine climate relative to the baseline period (1971–2000) have been studied for the 2020s (2006–2035) and 2050s (2036–2065) in response to various emission pathways. In one particular mid-range emission scenario, climate projections indicate increases in annual mean temperatures ranging from 0.9°C to 1.1°C in the 2020s and 1.8°C to 2.2°C in the 2050s.

The dry season (March–May) is projected to be drier over most areas. The wet or southwest monsoon season (June–November) will likely be wetter with rainfall increase ranging from 0.9% to 63% for Luzon and 2% to 22% for Visayas. On the other hand, rainfall is projected to decline over Mindanao during this same season. Rainfall during the northeast monsoon season (December–February) is also projected to increase, particularly over the eastern part of the country. In general, by 2020 and 2050, dry days are likely to be more frequent over the Philippines, with more heavy rainfall days expected over Luzon and Visayas.

Due to constraints such as accessibility to general circulation model (GCM) data, the availability of ground data, computational resources and technical expertise, these climate projections are limited. However, efforts are underway to update climate projections for the Philippines using multiple GCMs and finer-resolution or regional climate models driven by different GHG levels that are expected in this century.

This initial assessment of the state of climate change science in the Philippines indicates that climate science in the country is still in its infancy. This report identifies many areas that need further examination, such as the influence of large-scale climate drivers (e.g., ENSO, the Madden-Julian Oscillation, the Pacific Decadal Oscillation) on Philippine climate, the effect of sea level rise on saltwater intrusion and storm surges along coastal areas, and local climate impacts of aerosols and land use change, as well as their interaction with the enhanced greenhouse effect. However, such studies require reliable long-term observation records with adequate spatial coverage that is representative of local climate in the country. Local researchers are strongly encouraged to publish their work not only to contribute to the global pool of scientific knowledge, but more importantly to provide information and insight that can be used by policymakers to make well-informed, strategic decisions. In light of the high climate-related risk faced by the Philippines and other countries similarly situated in our region, it is therefore important to magnify and sustain ongoing research activities and to establish a mechanism to consolidate, synthesize, and share scientific data that will be relevant for impact assessment, adaptation and mitigation planning, and development policy formulation.

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Definition of Terms

Adaptation
Climate change adaptation refers to the process of making adjustments in natural and human systems as a response to actual or projected climate and its effects. Adaptation initiatives are conducted in an effort to reduce harmful effects and benefit from favorable opportunities.

Adaptive capacity
The capability or potential of a system to respond to both adverse and positive consequences brought about by climate change. Building the adaptive capacity of a system reduces its vulnerability to climate change and increases its resilience to its damaging effects.

Aerosol
Colloidal systems of fine solid or liquid droplets in a gaseous medium, which may be formed through natural processes and anthropogenic activities. They appear throughout the environment in different forms, such as haze, smoke, fog, and dust, and may directly or indirectly affect climate.

Albedo
The fraction of solar radiation reflected back from a surface, such as the Earth. Surfaces covered by ice and snow have high albedo, compared to those covered by soil or vegetation.

Anomaly
Deviations from the reference or "normal" value of a climate element, which are used to compare the changes over time. For example, a positive temperature anomaly indicates a value higher than the reference temperature, whereas a negative anomaly means a lower temperature.

Antarctic Circumpolar Current (ACC)
The major means of water exchange between oceans, and the largest ocean current today. The ACC is the only current that flows completely around the globe, moving eastward through the southern portions of the Atlantic, Indian, and Pacific Oceans as it circles Antarctica.

Anthropogenic
Means human-induced or resulting from human activities. It is often used in reference to environmental changes.

Atlantic Meridional Overturning Circulation (AMOC)
An ocean circulation system in the Atlantic described by warm upper ocean waters that flow northwards, followed by a return southward flow of cooler waters in the deep ocean. This circulation plays an important role in the Earth's climate system because it brings a considerable amount of heat from the Tropics and Southern Hemisphere toward the North Atlantic, which is then transferred to the atmosphere.

Baseline
The reference set of quantifiable data from which change is measured or the period relative to which anomalies are computed.

Bias
In climate studies, this can refer to the time independent difference between the climate model output and observed value.

Biodiversity
Biological diversity or the variety of all living organisms from terrestrial, marine, aquatic, and other ecosystems, including variabilities at the genetic, species, and ecosystem levels.

Biomass burning
The burning of both living and dead vegetation, which influences the climate through impacts on the atmospheric and surface albedo. Biomass burning restores nutrients to the soil, but causes the release of smoke, secondary pollutants, and particles into the atmosphere.

Biospheric feedback
A climate feedback that involves biological processes and may occur in land or ocean ecosystems.

Carbon budget
The projected maximum amount of carbon that can be released into the atmosphere while still having a reasonable chance of limiting global temperature rise.

Climate
The average weather or state of atmospheric conditions as described statistically in terms of mean and variability over a period of time. The World Meteorological Association prescribes a period of 30 years for averaging the relevant variables such as temperature, precipitation, and wind.

Climate change
A significant change in the state of the climate that persists for an extended period, which can be identified by statistical changes in the mean or variability of its properties. The United States Framework Convention on Climate Change defines it as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Climate change may be due to natural internal processes of the system, natural external forcings, or anthropogenic forcings.

Climate feedback
A process by which climate change influences a property of the Earth's system. Positive feedbacks are those that amplify the change while negative feedbacks are those that diminish them.

Climate model
A mathematical way of demonstrating the climate and the interactions between its various components. Models are research tools that provide representation of the climate system in a variety of ways, ranging from rather simple to very complex.

Convection
A method of energy transfer by fluid motion, such as by liquids and gases, between two areas with different temperatures.

Coral bleaching
The whitening or lightening of corals as a result of the loss of symbiotic algae which gives them their colors. Coral bleaching occurs as a response to abrupt physical changes in the ocean, such as an increase in sea surface temperature.

Coral Triangle
An area stretching across Indonesia, the Philippines, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste, which is said to be the epicenter for biodiversity of corals, fish, and other marine organisms.

Coupled Model Intercomparison Project Phase 5 (CMIP5)
A standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs), established under the World Climate Research Programme.

Disaster risk reduction
Concepts and practices aimed at reducing damages caused by natural hazards through systematic efforts to analyze and manage their causal factors.

Downscaling
The process of getting higher resolution (local to regional scales) information from global data or large-scale models using methods such as dynamical downscaling and statistical downscaling.

Drought
A period of abnormally dry conditions caused by significantly low levels of precipitation resulting in water shortages and serious hydrological imbalance.

Ecosystem
A functional and dynamic system of living organisms interacting within themselves and their non-living environment.

El Niño Southern Oscillation (ENSO)
A naturally occurring coupled atmosphere-ocean phenomenon associated with fluctuating ocean temperatures in the tropical Pacific, and sea level pressure patterns across the Pacific (i.e., Southern Oscillation). During an El Niño event, the weak prevailing trade winds decrease upwelling and affect ocean currents, resulting in warmer than normal sea surface temperatures in the eastern equatorial Pacific. This has a great impact on climate patterns in many parts of the world, including major changes to wind, sea surface temperature, and precipitation patterns in the Pacific region. The cold phase of the El Niño is called the La Niña.

Emission
Something that is sent out or given off by a source, such as energy radiation. As an example, burning of fossil fuels cause the release of GHG emissions into the atmosphere.

Evaporative cooling
The decrease in temperature, or cooling, resulting from the evaporation of water from the Earth's surface.

Extreme weather event
A weather event whose occurrence is unexpected and unusual for a particular time and place, based on recorded weather history.

Flux
Rate of transfer or flow of a property through an area. Heat flux and radiative flux are specific cases of energy flux involving the rate of heat and radiation transfer, respectively.

Fossil fuel
Natural carbon-based fuels such as coal, oil, and natural gas that were formed from fossil hydrocarbon de-

posits of decayed animals and plants in a process that took place over millions of years.

General Circulation Model (GCM)
See climate model.

Global warming
The gradual increase in the Earth's average surface temperature, as one of the consequences of radiative forcing due to the increase of GHG emissions from anthropogenic sources.

Greenhouse effect
The process by which GHGs, clouds and aerosol trap a measure of heat in the Earth's atmosphere by absorbing terrestrial radiation, and warms the Earth's surface and the troposphere.

Greenhouse gas (GHG)
Any of a number of naturally occurring or anthropogenic gases in the atmosphere that absorb and emit radiation, effectively causing the greenhouse effect. The primary GHGs in the Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3).

Hadley Cell
A pattern of atmospheric circulation in which warm air rises near the equator, cools as it travels towards the poles at high altitude, sinks as cold air, and once again warms as it travels towards the equator.

Heat waves
A prolonged period of excessively hot weather that may have adverse effects on the health of humans and other organisms.

Holocene epoch
The geologic time era of the last 10,000 years, which includes the period in which modern human society began.

Indonesian Throughflow
The system of surface currents flowing from the Pacific to the Indian Ocean, through the Indonesian Sea. Indonesian throughflow is one of the primary links of the global exchange of water and heat between ocean basins and is an essential element of global climate system.

Industrial Revolution
A period from the second half of the 18th century to the 19th century that saw a rapid increase in industrial growth due to the invention of machines and other developments. The industrial revolution defines the start of the buildup of carbon dioxide in the atmosphere because of the significant increase in use of fossil fuels during the period.

Intergovernmental Panel on Climate Change (IPCC)
An international body established in 1998 by the United Nations Environment Programme and the World Meteorological Association, which conducts regular assessments of the scientific basis of climate change and its significant components.

Intertropical Convergence Zone (ITCZ)
An area near the equator where the trade winds from the north and south hemispheres converge, resulting in a low pressure area, strong convection and precipitation. The ITCZ moves throughout the year.

Land subsidence
The gradual settling or sudden sinking of the Earth's surface due to the movement of materials at its subsurface.

Land use/land cover change
Land use refers to the set of human actions undertaken on a certain land cover type. Land cover change or land use change refers to the alteration of the traditional use or management of a land area, which may lead to a change in its land cover. It is now being recognized as an important driver of regional climate, given the recent extensive modifications of the earth's surface due to development.

Landfall
The event when the center or eye of a tropical cyclone hits land after being formed and travelling over the ocean.

Madden-Julian Oscillation (MJO)
A major contributor to intraseasonal atmospheric variability in tropical regions with a period from approximately 30 to 90 days. The MJO moves eastwards, and affects precipitation, especially over the Indian and western Pacific Oceans.

Mangrove
A group of flowering plants that grows in intertidal zones of marine coastal ecosystems in tropical and subtropical regions. The term "mangrove" may refer to individual plants or the forest ecosystem they belong to.

Mitigation
Human interventions designed to make the effects of climate change less severe by reducing the sources of GHG emissions or enhancing sinks that would remove them from the atmosphere.

Monsoon
The seasonal reversals in the surface wind flow and their associated precipitation that result from the temperature difference between the ocean and the land. Within the year, the Philippines experiences two types of monsoons: the southwest monsoon, locally called habagat, and the northeast monsoon, known as amihan.

North Atlantic Oscillation (NAO)
A dominant mode of climate variability in the North Atlantic measured by the difference in surface pressure between the subtropical (Azores) high and the subpolar (Icelandic) low, which affects westerly winds and storm tracks in the North Atlantic with accompanying impacts on temperature and precipitation.

Ocean acidification
The increase in acidity or decrease in pH level of the ocean over a period of time primarily due to its absorption of carbon dioxide from the atmosphere.

Pacific Decadal Oscillation (PDO)
A pattern of the coupled atmosphere-ocean variability in the Pacific Basin occurring at decadal timescales that can be described by sea surface temperature anomalies over the North Pacific. While ENSO cycles typically last only from 6-18 months, the PDO can last from 20-30 years. Like the ENSO, the PDO also consists of warm and cool phases.

Paleo
A period in the geologic past before the development of measuring instruments, for which only proxy records are available.

Particulate matter
The mixture of all solid and liquid particles in air.

Philippine Area of Responsibility (PAR)
The specific geographic region designated by the World Meteorological Association for which the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) is responsible for monitoring and providing weather information locally and internationally.

Radiative forcing
A quantifiable change in the net radiative flux at the tropopause as a result of the influence of external drivers of climate change, such as an increased concentration of GHGs in the atmosphere.

Radiative imbalance
A disruption in the balance of absorbed and radiated energy in the Earth's surface that results from radiative forcing.

Regional Climate Model (GCM)
A climate model with high resolution that is used to dynamically downscale global reanalyses or climate model output over a defined area.

Remote sensing
The science of obtaining information about properties of objects without coming into contact with the object, typically through the use of satellites.

Representative Concentration Pathways (RCPs)
Scenarios used for climate modeling and research, which takes into account emissions and concentrations of GHGs, aerosols and chemically active gases, as well as land use/land cover, and plotting them against a time series to describe possible climate futures.

Sea-level rise
An increase in the mean sea level, which may be brought about by a change in the volume of the ocean.

Sea surface temperature (SST)
The temperature of the surface of the ocean.

Southern Annular Mode (SAM)
The north–south movement of the westerly wind belt that circles Antarctica. SAM, also known as the Antarctic Oscillation (AAO), is a low-frequency mode of climate variability dominating the middle to higher latitudes of the southern hemisphere.

Stratigraphy
A branch of geology that studies stratification or layering of rock strata.

Stratosphere
The region of the atmosphere located above the troposphere, which extends approximately from 10–17 km to 50 km above the Earth's surface. The stratosphere contains a layer in which the concentration of ozone is highest, also otherwise known as the ozone layer.

Synoptic scale
Large-scale weather systems, ranging in size from several hundred to several thousands of kilometers.

Teleconnection
The statistical link between climate variables located in widely separated regions of the globe due to large-

scale systems, e.g., coupled modes of ocean-atmosphere variability, mid-latitude jets, etc.

Thermal expansion
The increase in volume and decrease in density of the ocean as a result of higher ocean temperature.

Trade winds
The wind system which blows steadily from the tropics towards the equator. The winds are northeasterly in the northern hemisphere (northeast trades) and southeasterly in the southern hemisphere (southeast trades).

Tropical cyclone
The general term for a cyclone that forms over the tropical oceans. Cyclones are low pressure systems in which winds spin inward in a circularly symmetric spiral, bringing with it intense rain and winds. Tropical depressions, tropical storms, hurricanes, and typhoons, are all forms of tropical cyclones.

Troposphere
The lowest part of the atmosphere, which is from the Earth's surface to the tropopause at about 10–20 km altitude, where clouds and weather phenomena occur.

Urban heat island
A phenomenon whereby urban regions tend to have warmer air temperatures compared to the surrounding rural areas because of the low albedo of asphalt roads, concrete buildings, and other structures which have replaced vegetation and open land commonly present in rural areas.

Urbanization
The conversion of land from a natural or agricultural state to cities, accompanied by the rural to urban migration of the population.

Variability
Climate variability refers to the variations in the normal state of the climate, as reflected by statistically significant differences in the mean state, standard deviations, occurrence of extremes, and other indicators.

Volatile organic compounds
Carbon-based compounds with high vapor pressures that allow them to quickly evaporate but significantly affect the chemistry of the atmosphere.

Vulnerability
The predisposition of a system to cope with the adverse effects of climate change. Vulnerability to climate change is a combination of several factors, including the degree of exposure and sensitivity to climate risks and the capacity of the system to adapt to changes.

Walker Circulation
Temperature-driven atmospheric circulation described by air rising in the west, and falling in the east over the tropical Pacific Ocean.

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CHAPTER 1

Introduction

AUTHOR

Jose Ramon T. Villarin, SJ

Climate change is a complex global phenomenon. It occurs on various space and time scales, involves different components of the earth system (i.e., land, water, and atmosphere), and affects both the natural and social order. While planetary scale changes in the climate have been driven largely by natural factors in the earth's geological past, the current scientific consensus on the diagnosis and prognosis of this phenomenon focuses on the chemical changes in the atmosphere that are being driven by human activity and are now thought to be interfering with the climate system. There is agreement on the observation of an unprecedented surge in the so-called anthropogenic (or human-induced) greenhouse gases (GHGs) in the last two centuries. There is consensus that surface temperatures on land and sea are on the rise. The likelihood that the observed rise in planetary temperatures is linked to these increased levels of GHGs is high.

A planet-wide phenomenon such as climate change leaves us wondering how this would play out at finer spatial scales (e.g., the level of communities and ecosystems) and greater temporal resolution (e.g., at intervals of weeks or months rather than years or decades). This unresolved problem is one of the most important challenges of the climate issue.

The 2016 Philippine Climate Change Assessment Report (PhilCCA) synthesizes scientific information from international and local literature in order to provide an assessment of climate change for the Philippines and identify gaps in the scientific literature. The report of Working Group 1 of the PhilCCA is drawn from recent literature such as published peer-reviewed journals, international reports, and reports deemed important (albeit unpublished) from government and nongovernment institutions and organizations. It was edited and reviewed by expert physical scientists, meteorologists, climate scientists, and marine scientists from the Philippines. This document provides current scientific information on climate change science in the Philippines and can serve as a guide for climate researchers, adaptation and mitigation practitioners, and policymakers.

The report starts with the global picture then proceeds to describe the local climate system of the Philippines. As the country is an archipelago, a separate section focuses on the marine environment as it interacts with climate. This is followed by a section on factors that drive local changes in climate apart from those that come from planetary-scale GHGs, since it is acknowledged that at the local or regional level, the global current of climate change has to contend with finer-resolution effects such as those that come from changes in the land surface. The report ends with a discussion of what Philippine climate can or will be in this century.

In particular, Chapter 2 highlights the key findings on the observed and projected changes in global and regional climate. These are drawn from Working Group I (WGI) of the Intergovernmental Panel on Climate Change (IPCC) through its Fifth Assessment Report (AR5), The Physical Science Basis (IPCC, 2013). This chapter provides the context for the subsequent discussion of the present and future state of Philippine climate. The characteristics of the present Philippine climate are described in Chapter 3, including the large-scale systems that affect the climate at varying temporal scales, such as the monsoons, tropical cyclones, and the El Niño Southern Oscillation (ENSO). Chapter 4 then examines the historical changes in the Philippine climate, namely the observed trends and changes in temperature, rainfall, winds, and tropical cyclones. This is followed by a discussion on the observed trends and changes in sea surface temperature and sea level in the Philippines in Chapter 5. While elevated levels of atmospheric GHGs have a pronounced impact on the observed recent changes in the global climate, Chapter 6 identifies other drivers that may also have a notable influence on climate, particularly at regional and local scales. The interaction or possible feedback of these local climate driving factors with the greenhouse warming effect remains to be seen. Finally in Chapter 7, projections of Philippine climate are presented, with a discussion on how these were arrived at and the potential sources of uncertainty accompanying these projections.

To complete our understanding and help guide future research, each chapter identifies important gaps in climate change science in the Philippines. This first attempt at a scientific assessment of climate change for the Philippines is by no means comprehensive. Even if most of the findings in this report are based on published sources, it is acknowledged that climate research in this country is still very much in its infancy. For a vital issue such as global climate change, the dearth of local knowledge compounds the risk already borne by our vulnerable people.

If this report is to mean anything at all, it lies in the hope that from what has been presented here, decision-makers and people of science might be dared to make strategic decisions that will help us confront one of the most difficult and urgent issues of our time.

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CHAPTER 2

Global Changes in Climate

AUTHORS

Andrea Monica D. Ortiz
John Leo C. Algo
Faye Abigail T. Cruz
Jose Ramon T. Villarin, SJ
Lourdes V. Tibig

2.1 CHAPTER SUMMARY

In 2013, the Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report (AR5). Working Group I (WGI) of the IPCC deals mainly with the physical processes in the atmosphere, ocean, and terrestrial systems that are related to climate change. In the AR5, the IPCC summarizes the work of WGI by stating that the "*warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased*" (IPCC, 2013a; IPCC, 2013b). Furthermore, the IPCC finds that "*it is **extremely likely***" (i.e., 95%–100% likelihood) "*that human influence has been the dominant cause of the observed warming since the mid-20th century*" (IPCC, 2013b).

Increased greenhouse gas levels

Human influence on the climate system is most evident from the increase in greenhouse gases (e.g., carbon dioxide or CO_2, methane or CH_4, and nitrous oxide or N_2O) at levels not seen in at least the past 800,000 years (IPCC, 2013b). In terms of CO_2 for instance, from 1750 to 2011, human activities—mainly from fossil fuel combustion, cement production, and land use change—released 555 ± 85 GtC into the atmosphere. The atmosphere has retained about 40% of this total, and the ocean about 30% leading to ocean acidification, while the rest have been absorbed on land. Despite a number of climate change mitigation initiatives, the rate of anthropogenic GHG emission into the atmosphere continues to increase. In 2011, for instance, the annual CO_2 emission rate from fossil fuel burning and cement production was 9.5 ± 0.8 GtC/yr (IPCC, 2013b). The increase in atmospheric CO_2 concentration as a result of these emissions contributes to a positive radiative forcing that leads to more energy absorbed by the climate system.

Warming temperatures

The uptake of energy by the climate system has led to observed increases in temperature, the global mean of which was 0.85 [0.65 to 1.06] °C from 1880 to 2012. The last three decades have also been warmer than any other decade during 1850 to 2012. The effects of the increased warming are the following (IPCC, 2013b):

- The upper ocean (0–700 m), where more than 60% of the energy uptake is stored, has warmed from 1971 to 2010. In particular, ocean temperatures in the upper 75 m increased by 0.11°C ± 0.02°C/decade over this time period.

- Ice sheets in Greenland and the Antarctic, glaciers, Arctic sea ice, and spring snow cover in the Northern Hemisphere have continued to decrease in mass and extent over the last 20 years.

- Ocean thermal expansion caused by warming, and changes in glaciers, Greenland and Antarctic ice sheets and land water storage have contributed to the high rate of sea level rise. Global mean sea level increased by 0.19 ± 0.02 m from 1901 to 2010.

Climate projections

The future climate largely depends on the projected cumulative CO_2 emissions in this century. These projected emissions vary according to socioeconomic development and climate policies, and are described in four pathways called Representative Concentration Pathways (RCPs). These four RCPs lead to different global temperature bands by the end of the 21st century (2081–2100) that range from "0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), and 2.6°C to 4.8°C (RCP8.5)." These temperature increases are relative to the baseline period of 1986–2005 (IPCC, 2013b).

These projections indicate that by the end of the 21st century, the change in the global surface temperature is "*likely to exceed 1.5°C relative to 1850 to 1900*" for nearly all RCP scenarios. Model simulations show that to limit anthropogenic warming in this century to less than 2°C (relative to the 1861–1880 period), cumulative anthropogenic CO_2 emissions need to remain below the 1000 GtC level. As of 2011, 515 ± 70 GtC have already been emitted (IPCC, 2013b).

The impact of warming on the global water cycle will not be uniform. It will result in higher differences in precipitation between wet and dry seasons and may vary according to region. Global ocean temperatures will continue to increase, and the heat from the surface will be distributed to the deep ocean with potential impacts on ocean circulation. The reduction in Arctic sea ice cover is very likely to continue due to the warming, with further projected decreases in global glacier volume and in spring snow cover in the Northern Hemisphere by the end of the 21st century. Increased ocean thermal expansion and loss of mass from ice sheets and glaciers will affect global mean sea level, which is projected to continue to increase in the 21st century. Other effects on the ocean include increased acidification due to greater oceanic uptake of CO_2 (IPCC, 2013b).

The IPCC concludes that further warming and changes in climate will occur during the 21st century and beyond unless GHG emissions are substantially and sustainably reduced. GHG concentrations in the atmosphere do not decrease immediately with reduced emissions; therefore, emission reduction efforts are urgently needed considering the prospect of warming and its impacts that can last well beyond this century.

2.2 INTRODUCTION

The Physical Science Basis of the Fifth Assessment Report (AR5) of Working Group I (WGI) of the Intergovernmental Panel on Climate Change (IPCC) was released in September 2013 (IPCC, 2013a). Some of the major points of the AR5 are discussed in this chapter, with particular focus on those components of the climate system that are relevant to the Philippine setting, such as temperature, precipitation, sea level, and weather extremes. Specifically, this section includes recent observations of changes in these system components, the assessment of current knowledge of various processes within and among these components, and analysis of interactions and how these contribute to global climate change.

This chapter presents the changes in global climate that serve as the frame for assessing local changes in Philippine climate. The information in this section can be used to characterize local changes in climate as these are influenced to a greater or lesser extent by global climatic processes. Information on global climate impacts can also be the frame for assessing policy and guiding national and local decision-making processes.

Regional changes in climate are covered in the IPCC's special report on Asia from the AR5. Climate projections at the regional scale depend on the projected climate at the global scale, which in turn depends on varying scenarios of global development in this century.

Throughout this chapter, different terms that indicate varying probabilities of outcome are used (Table 1.2 of Cubasch et al., 2013). The range of outcome probabilities is based on the quantitative analysis of empirical data and model results, and the qualitative evaluation of and agreement on the evidence. These terms are listed below together with their corresponding level of outcome probability:

Term	**Likelihood of outcome**
Virtually certain	99%–100% probability
Very likely	90%–100% probability
Likely	66%–100% probability
About as likely as not	33%–66% probability
Unlikely	0%–33% probability
Very unlikely	0%–10% probability
Exceptionally unlikely	0%–1% probability

In addition, when appropriate, AR5 also uses terms such as extremely likely (95%–100% probability), more likely than not (more than 50%–100% probability), and extremely unlikely (0%–5% probability) (Cubasch et al., 2013). Uncertainty is quantified using 90% uncertainty interval, reported in square brackets, and this interval is expected to have a 90% likelihood of covering the value that is being estimated, wherein the upper endpoint of the uncertainty interval has a 95% likelihood of exceeding the value that is being estimated and the lower endpoint has a 95% likelihood of being less than that value. A best estimate of that value is also given where available. Uncertainty intervals are not necessarily symmetric about the corresponding best estimate (Cubasch et al., 2013).

2.3 OBSERVATIONS OF CHANGES IN THE GLOBAL CLIMATE

2.3.1 Changes in Temperature

2.3.1.1 Surface temperatures

The IPCC reports in its AR5 that “it is *certain* that global mean surface temperature (GMST) has increased since the late 19th century” (Figure 2.1), and “virtually certain that maximum and minimum temperatures over land have increased on a global scale since 1950” (Stocker et al., 2013). Records from observations and independently analyzed datasets show that surface temperatures over land and ocean have increased (Stocker et al., 2013).

The 2000s is the warmest decade on historical record, and the last three decades have been warmer than the earlier decades. The global combined land and ocean temperature data show an increase of 0.85 [0.65 to 1.06] °C during 1880–2012, about 0.89 [0.69 to 1.08] °C during 1901–2012, and about 0.72 [0.49 to 0.89] °C during 1951–2012 (Stocker et al., 2013). These temperature increases (Figure 2.2) were calculated using datasets from Hadley Centre/Climatic Research Unit gridded surface temperature data set 4 (HadCRUT4), Merged Land-Ocean Surface Temperature Analysis (MLOST), and the Goddard Institute for Space Studies Surface Temperature Analysis (GISTEMP) (Hansen, Ruedy, Sato, & Lo, 2010; Morice, Kennedy, Rayner, & Jones, 2012; Stocker et al., 2013; Vose et al., 2012).

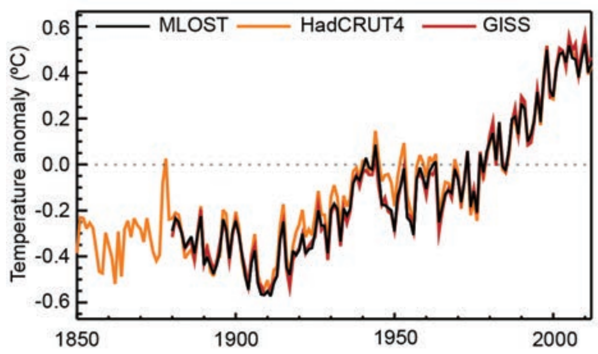

Figure 2.1 Anomalies in annual global mean surface temperature (GMST) relative to a 1961–1990 baseline. Taken from land-surface air temperature (LSAT) and sea surface temperature (SST) data sets (HadCRUT4, GISS, and NCDC MLOST). (Hartmann et al., 2013, Figure 2.20)

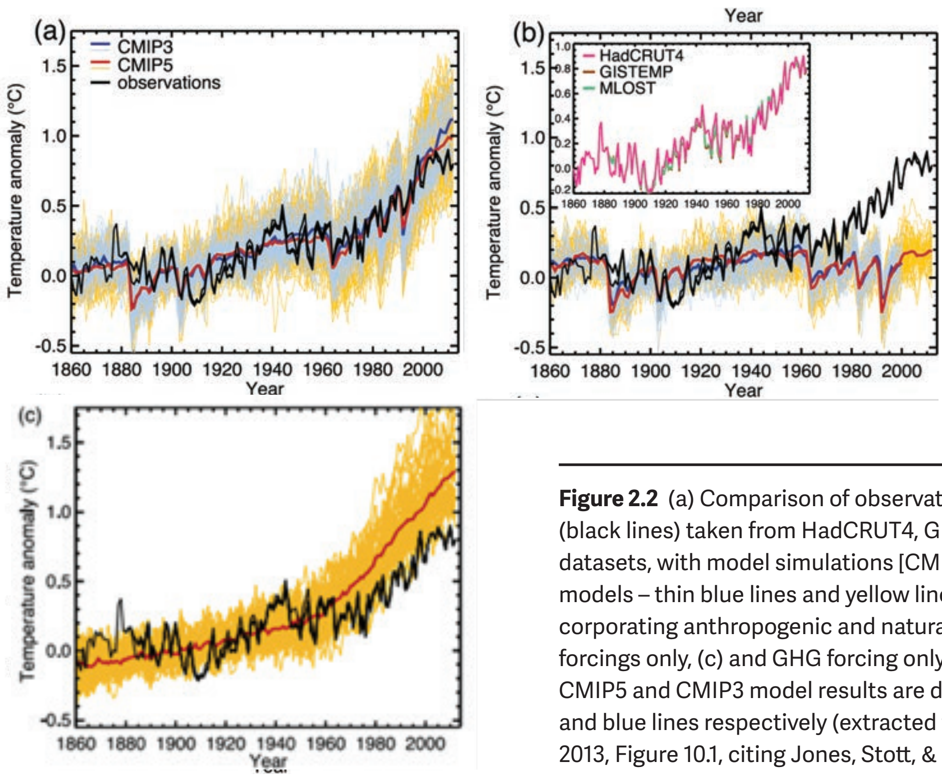

Figure 2.2 (a) Comparison of observational plots of GMST (black lines) taken from HadCRUT4, GISTEMP, and MLOST datasets, with model simulations [CMIP3 and CMIP5 models – thin blue lines and yellow lines respectively] incorporating anthropogenic and natural forcings; (b) natural forcings only, (c) and GHG forcing only. Averaged values of CMIP5 and CMIP3 model results are denoted by thick red and blue lines respectively (extracted from Bindoff et al., 2013, Figure 10.1, citing Jones, Stott, & Christidis, 2013).

The IPCC AR5 also states that the rate of warming varies each year and each decade such that some periods may have relatively weaker trends. The warming trend from 1998 to 2012 (0.05 [–0.05 to +0.15] °C per decade) is smaller than the rate of warming from 1951 to 2012 (0.12 [0.08 to 0.14] °C per decade), and the trend uncertainty is large for short records (Stocker et al., 2013).

Urban heat island and land use change may have increased the estimated global mean land surface air temperature trends over the past century but it is *unlikely* to be more than 10% (Stocker et al., 2013). While the impacts of urban heat island and land use change on regional trends for highly urbanized areas may be higher than 10% (Fujibe, 2009; Ren, Chu, Chen, & Ren, 2007; Yan, Li, Li, & Jones, 2010), urban areas comprise less than 2% of the total global land area, which limits its contribution to surface warming.

It is *very likely* that mean annual temperature has increased over the past century over most of Asia, where increasing annual mean temperature trends have been observed in Southeast Asia during the 20th century. In Southeast Asia, temperature has increased at a rate of 0.14°C to 0.20°C per decade since the 1960s (Christensen et al., 2013; Tangang, Juneng, & Ahmad, 2007). Hot days and warm nights have also become more frequent during the same period, with less occurrences of cooler conditions (Caesar et al., 2011; Christensen et al., 2013; Manton et al., 2001).

2.3.1.2 Troposphere and stratosphere temperatures

In the atmosphere, the troposphere is the layer closest to the earth, with thickness ranging from 7 to 20 km. The stratosphere is the layer of the earth's atmosphere above the troposphere that extends to about 50 km above the earth's surface. The IPCC reports in AR5 that it is *virtually certain* that tropospheric warming and stratospheric cooling occurred on a global scale since the mid-20th century based on measurements using satellite sensors and radiosondes (Hartmann et al., 2013; Stocker et al., 2013). However, there is still disagreement on the rate of temperature changes due to insufficient data, except over the northern hemisphere extra-tropical troposphere (Hartmann et al., 2013; Stocker et al., 2013).

2.3.1.3 Ocean temperatures

Ocean temperatures in the upper 75 m increased by 0.11°C ± 0.02°C/decade during 1971 to 2010 (IPCC, 2013b). Warming in the upper ocean (< 700 m depth) from 1971 to 2010 is also *virtually certain*. However, changes before 1971 are less certain because of fewer data samples. It is likely that the temperature of ocean layer between 700 m and 2000 m increased during 1957 to 2009. While there were *likely* no significant warming trends in the deeper parts of the ocean, i.e., between 2000 m and 3000 m depth, the ocean layer below 3000 m depth has *likely* warmed during 1992 to 2005 (IPCC, 2013b).

2.3.2 Changes in Energy Budget and Heat Content

Since the 1970s, it has been observed that more energy received from the sun remains in the atmosphere, leading to a "radiative imbalance." As a result of this imbalance, it is reported by the IPCC that it is *virtually certain* that Earth has gained about 274 [196 to 351] x 10^{21} J of energy from 1971–2010, which has an equivalent heating rate of 0.42 W m^{-2} over the surface of the Earth (Rhein et al., 2013; Stocker et al., 2013; Trenberth, 2009). The atmospheric net energy imbalance can vary with the weather, climate (e.g., the El Niño-Southern Oscillation or ENSO), sunspot cycle, and volcanic eruptions (Trenberth, Fasullo, & Balmaseda, 2014).

The result of the gained energy is a warmer planet, which can manifest as melting ice, and the warming of the ocean, atmosphere, and land. The total heating rate is mainly due to ocean warming (93%), wherein 64% of this total is due to warming of the upper ocean. Continental warming and melting ice (e.g., Arctic sea ice, ice sheets, and glaciers) each represents 3% of the earth's warming, while the remaining 1% is due to the warming of the atmosphere (Levitus et al., 2012; Rhein et al., 2013; Stocker et al., 2013).

2.3.3 Changes in Circulation and Modes of Variability

2.3.3.1 North Atlantic Oscillation, Southern Annular Mode, El Niño Southern Oscillation

It is difficult to determine long-term changes in the atmospheric circulation due to its high inter-annual and decadal variability. However, there is *high confidence* that recent changes have offset past changes in northern mid-latitude westerly winds and the North Atlantic Oscillation (NAO) index, which increased around the latter half of the 20th century, and that the weakening of the Pacific Walker circulation during the 20th century has reversed (Hartmann et al., 2013; Stocker et al., 2013). Regarding the decadal changes in the winter NAO index since the 20th century, similar patterns have been observed within the past 500 years. Based on strong evidence for the Northern Hemisphere, "it is *likely* that circulation features have moved poleward since the 1970s, involving a widening of the tropical belt, a poleward shift of storm tracks and jet streams and a contraction of the northern polar vortex" (Hartmann et al., 2013; Stocker et al., 2013).

The Southern Annular Mode (SAM), also known as the Antarctic Oscillation (AAO), is a dominant mode of atmospheric variability in the southern hemisphere that has impacts on rainfall variability. It describes the north to south movement of westerly winds (or low pressure), where it contracts towards Antarctica in its positive phase and expands towards the equator in its negative phase (Australian Government Bureau of Meteorology, n.d.). Since the 1950s, SAM has *likely* become more positive, and the increased strength during the summer has not been observed in the last 400 years (*medium confidence*) (Hartmann et al., 2013; Stocker et al., 2013).

Another mode of climate variability is the El Niño-Southern Oscillation (ENSO). ENSO is associated with anomalies in the sea surface temperatures in the equatorial Pacific, which have significant global and regional climate impacts. The high variability of ENSO in the past 7,000 years is indicated with *high confidence* in high-resolution coral records (Stocker et al., 2013).

2.3.3.2 Ocean circulation

There is more evidence showing the interannual and decadal variability in major ocean circulation systems. In AR5, the IPCC reports an intensification and widening of the subtropical gyres in both North and South Pacific since 1993 (*very likely*) (Stocker et al., 2013). There is no evident trend in the Atlantic Meridional Overturning Circulation (AMOC), as well as in the transports of the Indonesian Throughflow, or in the transports between the Atlantic Ocean and Nordic Seas. While there is no trend in Antarctic Circumpolar Current (ACC), data from 1950–2010 shows a 1° southward shift (Stocker et al., 2013).

2.3.4 Changes in the Water Cycle

2.3.4.1 Introduction to the water cycle

Water is essential to human and natural systems, and its movement in the climate system, i.e., the water cycle, is important for sustaining life on Earth. Water moves from different reservoirs of ocean, atmosphere, cryosphere, and land surface through processes such as evaporation, condensation, and precipitation, and in different forms as liquid, solid, and vapor (gas) (Figure 2.3; Stocker et al., 2013; Trenberth, Smith, Qian, Dai, & Fasullo, 2007). The water cycle also affects the energy cycle and the salinity of oceans, which affects ocean density and consequently circulation (Stocker et al., 2013; Trenberth et al., 2007).

2.3.4.2 Observations of water cycle change in the atmosphere

Changes and trends in precipitation and evaporation are harder to measure given the available records. There is *low confidence* in global precipitation changes over land before 1951, and *medium confidence* after this period (Stocker et al., 2013). There has been an increase in precipitation over Northern Hemisphere mid-latitude land areas but there is *low confidence* in the trends in other areas. However, there is currently *medium confidence* in the human influence on global precipitation changes over land (IPCC, 2013b).

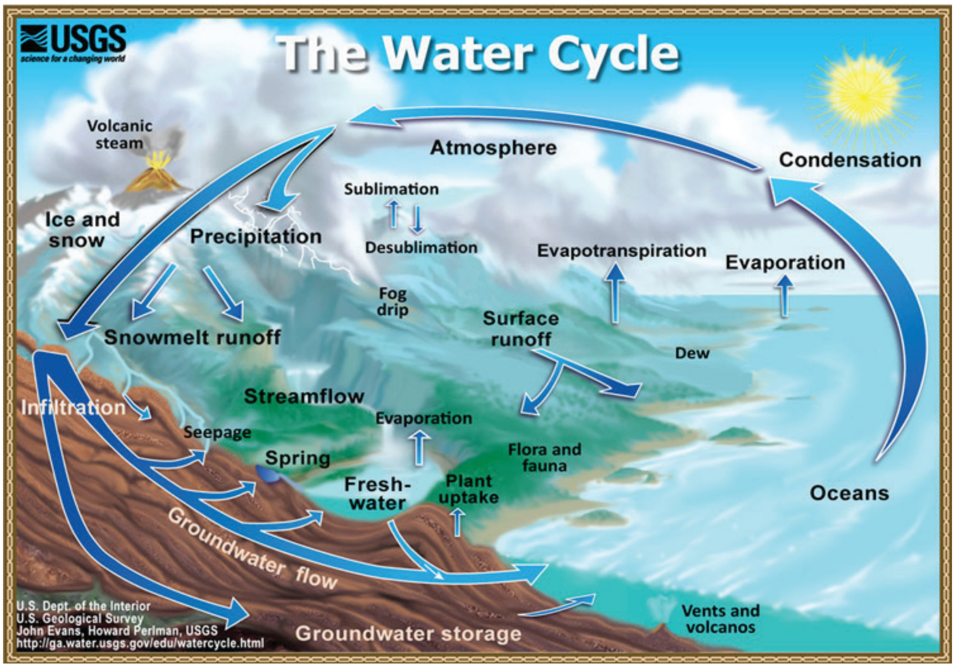

Figure 2.3 Overview of the water cycle (United States Geological Survey, n.d.).

There is still *low confidence* in terms of global-scale variability and trends in clouds. On the other hand, the increase in global near surface and tropospheric specific humidity since the 1970s is *very likely*, based on observations from various measurements (Stocker et al., 2013). Because warming increases saturation vapor pressure of air, higher tropospheric water vapor is anticipated, accompanying the observed increase in temperature as noted in Section 2.3.1. However, it is with *medium confidence* that the near-surface moistening trend over land has declined in the recent years, which consequently lowers relative humidity near the land surface (Stocker et al., 2013). While atmospheric water vapor content can be influenced by natural and anthropogenic warming, the recent rate of increase can largely be attributed to human influence with *medium confidence* (IPCC, 2013b).

A significant development since the Fourth Assessment Report (AR4) of the IPCC is that the AR5 notes that recent analyses no longer support the previous findings on the increase in global runoff in the 20th century, as well as the global-scale increasing trends in droughts since the 1970s. However, it is *likely* that positive and negative changes in drought frequency and intensity have occurred in specific regions (Stocker et al., 2013).

There is regional variability in the precipitation change patterns. In Asia, trends in precipitation, including extremes, are characterized by strong variability due to different regional topographical features, weather systems, and circulation patterns. Aldrian & Djamil (2008) found that the ratio of rainfall in the wet season increased between 1955 and 2005 in East Java with implications of drier conditions during the dry season, and also noted drying trends similar to other areas such as the Philippines. However, most areas in Asia lack sufficient observational records to draw conclusions about trends in annual precipitation over the past century.

A review by Chang (2011) showed that most studies indicate an increase in the frequency of extreme high precipitation events in Southeast Asia. There have been more heavy (top 10% by rainfall amount) and light (bottom 5%) rain events in Southeast Asia, but fewer moderate (25% to 75%) events (Christensen et al., 2013; Lau & Wu, 2007). There has also been an increasing trend in both the annual total wet-day precipitation (22 mm per decade), and rainfall during extreme wet days (10 mm per decade) (Alexander et al., 2006; Caesar et al., 2011; Christensen et al., 2013).

2.3.4.3 Ocean and surface fluxes

Observed oceanic surface salinity shows significant trends since the 1950s. It is *very likely* that salinity has increased over areas with high salinity, such as in the mid-latitudes where evaporation is dominant, e.g., Atlantic Ocean. On the other hand, salinity has decreased over areas with low salinity, such as in the polar areas and tropics where rainfall is dominant, e.g., the Pacific and Southern Oceans (Stocker et al., 2013). The salinity gradient has increased by 0.13 [0.08 to 0.17] from 1950 to 2008 (Durack & Wijffels, 2010; Stocker et al., 2013). While there are similarities in the spatial patterns of the average and trends in salinity, and the mean distribution of the difference between evaporation and precipitation, uncertainties in the data make it difficult to be used to identify trends in evaporation or precipitation over the oceans for the same time period (Stocker et al., 2013). The observed changes in surface and subsurface salinity are also *very likely* partly due to human influence (IPCC, 2013b).

2.4 CHANGES IN SEA LEVEL

The rate of global mean sea level (GMSL) rise has increased in the late 19th to early 20th century compared to the past 2,000 years, as reported by the IPCC in AR5 with *high confidence* (Stocker et al., 2013). Through combined proxy records that were used as data for the past two thousand years, it was determined that between 1905 and 1945, global sea level started to rise faster than the late Holocene background rate (Church & White, 2011; Gehrels & Woodworth, 2013; Lambeck, Anzidei, Antonioli, Benini, & Esposito, 2004). Paleo data, instrumental records, comprised mainly of tide gauge measurements, and satellite-based radar altimeter measurements also indicate that it is *likely* that GMSL rise has accelerated since the early 1900s (Stocker et al., 2013).

Between 1901 and 2010, the average rate of GMSL increase was *very likely* about 1.7 [1.5 to 1.9] mm per year, and it was about 2.0 [1.7 to 2.3] mm per year between 1971 and 2010 (IPCC, 2013b). In the most recent years from 1993 to 2010, the sea level rose by around 3.2 [2.8 to 3.6] mm per year (Ablain, Cazenave, Valladeau, & Guinehut, 2009; Beckley et al., 2010; Church & White, 2011; IPCC, 2013b; Leuliette & Scharroo, 2010; Masters et al., 2012; Nerem, Chambers, Choe, & Mitchum, 2010). These values suggest accelerating rates of GMSL over time.

GMSL increased by 0.19 [0.17 to 0.21] m from 1901 to 2010 (IPCC, 2013b). It is estimated with *high confidence* that the increase in GMSL during 1993 to 2010 can be explained by ocean thermal expansion, melting of the Greenland and Antarctic ice sheets (i.e., frozen water over land), and changes in land water storage and glaciers (IPCC, 2013b).

2.5 CHANGES IN CARBON AND OTHER BIOGEOCHEMICAL CYCLES

The IPCC reports in AR5 that human activity is responsible for the increase in atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) since the beginning of the Industrial Revolution in the 18th century (IPCC, 2013b). The atmospheric concentration of CO_2, a major greenhouse gas (GHG), has increased 40% compared to records from the pre-industrial era at 391 parts per million (ppm) in 2011 (Ballantyne, Alden, Miller, Tans, & White, 2012; IPCC, 2013b). The concentrations of CH_4 and N_2O in 2011 are also higher than pre-industrial levels by 150% (at 1803 parts per billion [ppb]), and 20% (at 324 ppb), respectively (IPCC, 2013b; Prather, Holmes, & Hsu, 2012). These GHG concentrations are unprecedented in the past 800,000 years (IPCC, 2013b).

The increase in CO_2 concentrations is caused primarily by the combustion of fossil fuel, cement production, and land use change. About 30% of the CO_2 emitted is taken in by the ocean, leading to increased levels of ocean acidity, which is indicated by changes in pH (IPCC, 2013b). A decrease of 0.1 in the ocean pH since the beginning of the industrial area is reported in AR5 with *high confidence* (IPCC, 2013b). This translates to a current mean pH of 8.1, a 25% increase in ocean acidity for the past two centuries (Feely, Doney, & Cooley, 2009; Orr, Pantoja, & Pörtner, 2005).

2.6 GLOBAL CLIMATE PROJECTIONS

Changes in future climate are projected based on a set of scenarios using climate models of varying complexity. The framework for climate simulations was the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme (IPCC, 2013b).

The Representative Concentration Pathways (RCPs) are a new set of scenarios used for the climate model simulations as reported in AR5 (Moss et al., 2010). These are based on different GHG and aerosol (air pollutant) concentrations in the atmosphere, as well as land use and land cover change, that yield corresponding radiative forcings (in units of

W m^{-2}) by the year 2100 (relative to 1750), which in turn lead to matching global increases in temperature. Four RCP scenarios were generated, which include two intermediate scenarios (RCP4.5 and RCP6), a high-emissions scenario (RCP8.5), and a "peak-and-decay" scenario where radiative forcing reaches a maximum around mid-21st century before decreasing to 2.6 W m^{-2} (RCP2.6) (Meinshausen et al., 2011; Moss et al., 2008).

The following are summaries of the global projections for different components of the climate system.

In view of the results of the climate models, the IPCC warns that further warming and changes in the climate system will occur due to the continued rate of anthropogenic GHG emissions. Efforts to reduce emissions are urgently needed to mitigate these changes.

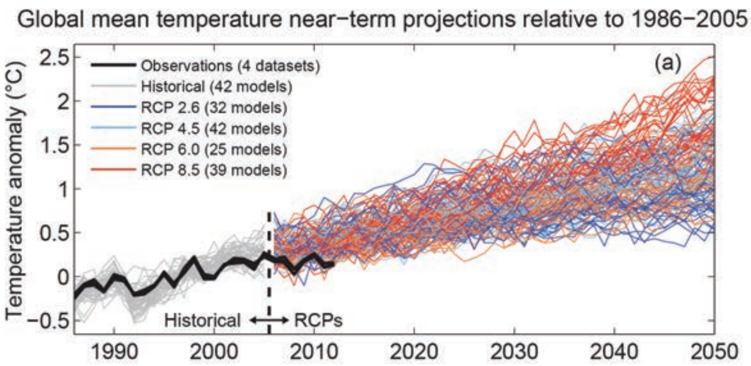

Figure 2.4 Projected values of annual mean GMST from 1986 to 2050 relative to 1986–2005 baseline under all RCP scenarios (taken from CMIP5 model simulations), including observational estimates (i.e., HadCRUT4, ECMWF ERA-Interim, GISTEMP, and NOAA for the period 1986–2012 [black lines]) (Extracted from Stocker et al., 2013, Figure TS.14).

2.6.1 Temperature

Under the RCP scenarios, the global mean surface temperature (GMST) is projected to increase, albeit at varying degrees (Figure 2.4). The change in GMST between the time periods of 2016–2035 and 1986–2005 is in the range of 0.3°C to 0.7°C (*medium confidence*) (IPCC, 2013b; Stocker et al., 2013). All RCP scenarios except RCP 2.6 also indicate the GMST increase relative to the 1850–1900 mean value to be *likely* higher than 1.5°C by the end of the 21st century (IPCC, 2013b).

The CMIP5 model simulations project GMST to increase by 0.4°C to 1.6°C (RCP2.6), 0.9°C to 2.0°C (RCP4.5), 0.8°C to 1.8°C (RCP6.0), and 1.4°C to 2.6°C (RCP8.5) by 2046–2065 relative to 1986–2005. For the years 2081–2100, increase of GMST is projected to be in the ranges of 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), and 2.6°C to 4.8°C (RCP8.5) (Table SPM.2 of IPCC, 2013b). These values are generally similar with previous studies using the SRES scenarios (Joshi, Hawkins, Sutton, Lowe, & Frame, 2011; Knutti & Sedláček, 2013).

Temperature changes will differ per region. It is with *high confidence* that the near-term warming over tropics and subtropics is projected to be higher than over the mid-latitudes, relative to natural internal variability (IPCC, 2013b). Land surface temperatures will also have higher mean increases than the ocean (*very high confidence*) (IPCC, 2013b).

More (less) occurrences of warm (cold) days over land are *likely* in the early 21st century, and *virtually certain* by late 21st century (Figure 2.5; IPCC, 2013b; Stocker et al., 2013). It is *very likely* that heat waves and warm spells will occur more frequently and with a longer duration in the long-term, but may be at a different rate than the average warming (Kirtman et al., 2013; Stocker et al., 2013).

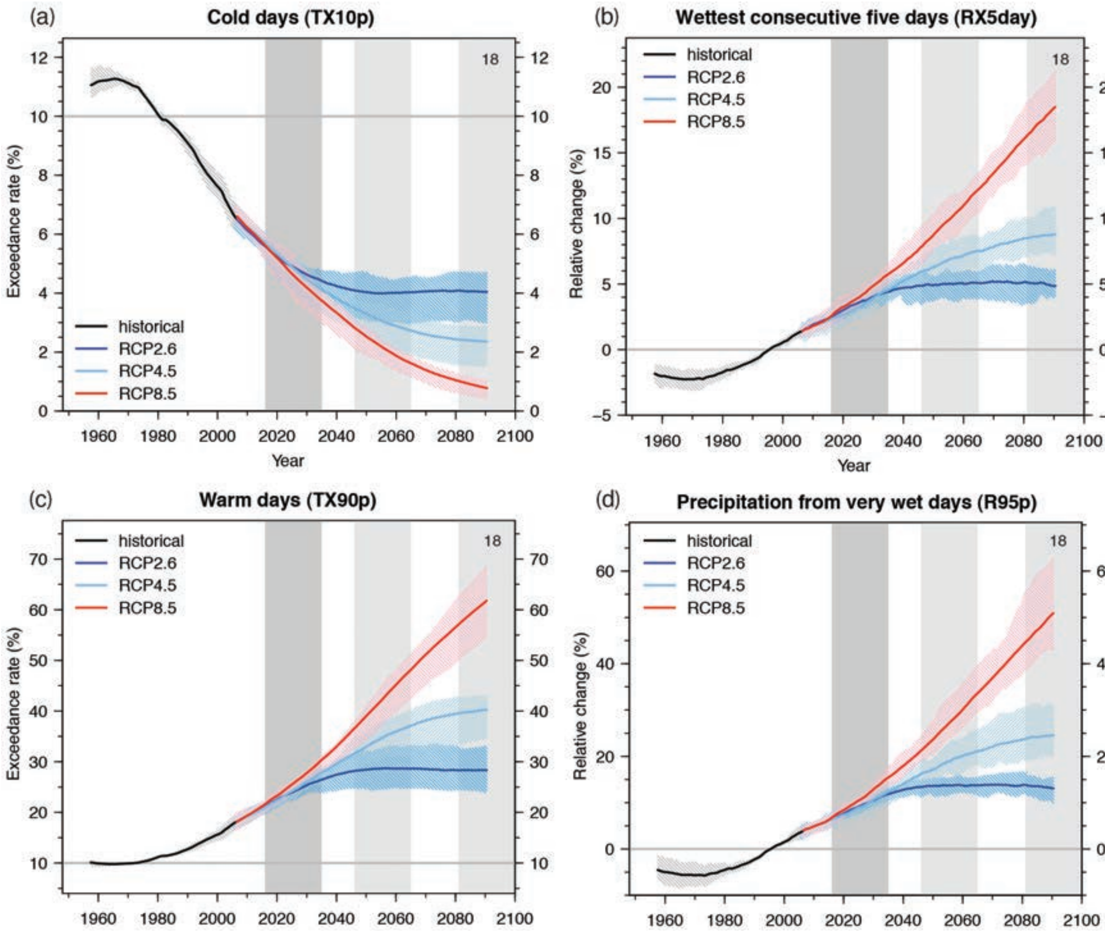

Figure 2.5 Global estimates of (a) cold day events (TX10p), (b) wettest consecutive 5 days (RX5day), (c) warm day events (TX90p) and (d) very wet day precipitation events (R95p). Projections are from CMIP5 simulations using the RCP2.6, RCP4.5 and RCP8.5 scenarios. The ensemble median is indicated by solid lines while the interquartile spread of model results is indicated by the shaded envelopes (extracted from Stocker et al., 2013 Box TFE.9, Figure 1 [a-d]).

2.6.2 Atmosphere: Water Cycle

Similar to temperature changes, changes in the water cycle will not be uniform. Differences in precipitation between wet and dry seasons in some areas will be higher (IPCC, 2013b). Projections indicate that the zonal mean precipitation will *more likely than not* decrease in the subtropics but *very likely* increase in the high latitudes, as well as some areas in the mid-latitudes, in the near-term (Figure 2.6; Kirtman et al., 2013; Stocker et al., 2013). Heavy precipitation events over land will *likely* be more frequent and intense. However, natural internal variability and anthropogenic aerosol emissions may affect near-term changes in the water cycle, and at the regional scale (Stocker et al., 2013). Furthermore, as global temperatures continue to rise, heavy precipitation events will very likely intensify and be more frequent over the wet tropics and over most mid-latitude land areas by late 21st century (IPCC, 2013b). The monsoon circulation will likely weaken in the 21st century, but its associated precipitation will likely increase because of more moisture in the atmosphere. In many regions, the duration of the monsoon season will likely be longer with earlier or minimal change in onset dates and later retreat dates (IPCC, 2013b).

The IPCC reports that while it is distinct from anthropogenic global warming, ENSO and its warm and cool phases (known as El Niño and La Niña respectively) "will remain the dominant mode of interannual variability in the tropical Pacific, with global effects in the 21st century" (IPCC, 2013b). It is also likely that regional rainfall variability associated with ENSO will increase. However, its high natural variability raises the uncertainty in the projected changes (IPCC, 2013b; Stocker et al., 2013).

In a warmer climate, projected increases in near-surface specific humidity and evaporation over land are *very likely and likely*, respectively. On the other hand, it is still uncertain how soil moisture and runoff will change in the near future (Kirtman et al., 2013; Stocker et al., 2013).

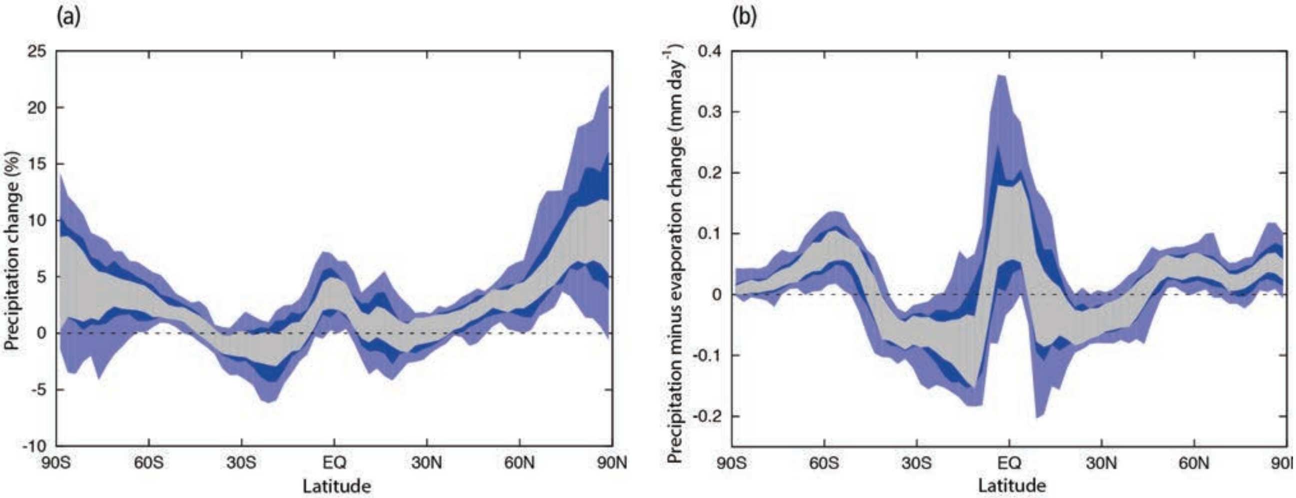

Figure 2.6 Modeled changes in annual and zonally averaged (a) precipitation and (b) precipitation minus evaporation (mm/day), covering the 2016–2035 period compared to the 1986–2005 baseline, using CMIP5 under the RCP4.5 scenario. Light blue areas indicate the 5 to 95% range, the dark blue the 17 to 83% spread of values. The grey areas cover the 1σ range of natural variability calculated from pre-industrial control simulations (Kirtman et al., 2013, Figure 11.13).

2.6.3 Ocean

As GMST increases, ocean temperature is projected to continue to increase, which has impacts on ocean circulation (IPCC, 2013b). The warming will be most pronounced in the ocean surface over the tropical and subtropical regions in the Northern Hemisphere, and with *high confidence*, in the deep ocean of the Southern Ocean (IPCC, 2013b). By the end of the 21st century, the range of estimates from the RCP scenarios shows ocean temperature increasing by 0.6°C to 2.0°C in the top 100 m, and by 0.3°C to 0.6°C at a depth of 1 km (IPCC, 2013b).

2.6.4 Sea Level

Compared with AR4, there is more confidence in AR5 of the continued increase in GMSL in the 21st century (IPCC, 2013b). With *medium confidence*, the estimated increase in sea level in 2081–2100 relative to 1986–2005 ranges from 0.26–0.55 m (RCP2.6), 0.32–0.63 m (RCP4.5), 0.33–0.63 m (RCP6.0), and 0.45–0.82 m (RCP8.5) (IPCC, 2013b). However, it is difficult to assess the “probability of specific levels above the *likely* range” because of insufficient evidence and the *low confidence* in projections from semi-empirical models (Grinsted, Moore, & Jevrejeva, 2009; Jevrejeva, Moore, & Grinsted, 2012; Rahmstorf, Foster, & Cazenave, 2012; Schaeffer, Hare, Rahmstorf, & Vermeer, 2012; Stocker et al., 2013).

Sea level will *very likely* increase over about 95% of the ocean by the end of the 21st century, but will have regional variability. Changes in about 70% of coastlines are projected to be within one-fifth of the change in GMSL (IPCC, 2013b; Stocker et al., 2013).

2.6.5 Carbon and Other Biogeochemical Cycles

As discussed earlier in the chapter, there is strong evidence for climate change based on atmospheric data and other paleoclimate observations. There is *high confidence* that there is positive feedback between climate and the carbon cycle, such that the impact of climate change on the carbon cycle can further enhance atmospheric CO_2 levels (IPCC, 2013b).

All RCP scenarios project further ocean uptake of anthropogenic CO_2 through the 21st century leading to higher ocean acidification (*very high confidence*). At the end of the 21st century, the projected decrease in surface ocean pH ranges 0.06–0.07 (RCP 2.6), 0.14–0.15 (RCP 4.5), 0.20–0.21 (RCP 6.0), and 0.30–0.32 (RCP8.5) (IPCC, 2013b). Unlike the ocean uptake, there is less certainty on land carbon uptake. While most models indicate continued land carbon uptake, a decrease in land carbon is also possible because of the changes in climate and land use (IPCC, 2013b).

2.6.6 Regional (Asian/Southeast Asian) Climate Projections

The IPCC AR5 assesses that temperature is *very likely* to increase in the 21st century in Southeast Asia with regional differences. A median warming over land ranging from 0.8°C (RCP2.6) to 3.2°C (RCP8.5) by 2081–2100 is projected for the region (Christensen et al., 2013). Projections of future annual precipitation change indicate a moderate increase of 1% (RCP2.6) to 8% (RCP8.5) for the region by 2081–2100 relative to 1986–2005 (Christensen et al., 2013). Table 2.1 indicates the annual and seasonal temperature and precipitation projections in Southeast Asia under the RCP 4.5 scenario (Christensen et al., 2013).

An increase in precipitation extremes associated with the monsoon is *very likely* in many regions, including Southeast Asia (Stocker et al., 2013). It is *likely* that the frequency of tropical cyclones will decrease or not change on a global scale, and that the associated intensity and rain rates will increase in the 21st century. Also, there is a spatial variability in future changes in tropical cyclones with *low confidence* in regional projections of frequency and intensity (Stocker et al., 2013). Uncertainties in the projection of modes of atmosphere-ocean variability (e.g. ENSO) and in the understanding of the influence of these climate modes on tropical cyclones affect the reliability of projections of tropical cyclone activity (Christensen et al., 2013). However, there is *medium confidence* that precipitation will intensify around the center of tropical cyclones making landfall in areas including Southeast Asia (Stocker et al., 2013). In addition, if there is an increase in intensity and/or frequency in El Niño events, enhanced warming and lower precipitation is anticipated for the region (*low confidence*) (see Table 14.3 in Christensen et al., 2013).

Table 2.1 Projected temperature and precipitation values under the RCP 4.5 scenario for Southeast Asia (Christensen et al., 2013, Table 14.1).

RCP4.5			Temperature (C)					Precipitation (%)				
REGION	MONTH	Year	min	25%	50%	75%	max	min	25%	50%	75&	max
Southeast	DJF	2035	0.3	0.5	0.7	0.8	1.1	-2	1	2	4	12
Asia (land)		2065	0.6	1.1	1.3	1.6	2.2	-1	1	3	8	13
		2100	0.8	1.4	1.6	2.2	3	-5	2	6	9	19
	JJA	2035	0.3	0.6	0.7	0.8	1.2	-3	0	1	3	7
		2065	0.7	1.1	1.2	1.5	2.2	-2	0	3	7	13
		2100	0.8	1.4	1.5	2	2.7	-3	2	4	9	19
	Annual	2035	0.3	0.6	0.7	0.8	1.2	-2	0	1	3	8
		2065	0.7	1.1	1.2	1.6	2.2	-1	1	3	7	13
		2100	0.8	1.4	1.6	2.1	2.7	-2	2	5	10	18
Southeast	DJF	2035	0.3	0.5	0.6	0.7	1.1	-3	0	2	3	9
Asia (sea)		2065	0.6	0.9	1.1	1.3	1.9	-4	0	3	6	10
		2100	0.9	1.2	1.4	1.7	2.5	-5	1	3	6	11
	JJA	2035	0.3	0.5	0.6	0.6	1	-4	0	1	2	7
		2065	0.7	0.9	1.1	1.3	1.9	-2	2	3	5	9
		2100	0.9	1.2	1.4	1.7	2.5	-1	2	3	6	16
	Annual	2035	0.3	0.5	0.6	0.7	1	-4	0	2	3	8
		2065	0.6	1	1.1	1.3	1.9	-2	1	3	5	7
		2100	0.9	1.2	1.4	1.7	2.5	-3	2	4	6	9

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CHAPTER 3

The Philippine Climate

AUTHORS

Faye Abigail T. Cruz
Lourdes V. Tibig
Jose Ramon T. Villarin, SJ
Rosalina G. de Guzman
Thelma A. Cinco
Gemma Teresa T. Narisma
Flaviana D. Hilario

3.1 CHAPTER SUMMARY

The Philippines has a tropical and maritime climate with relatively high temperature and humidity, and with seasonal and spatial variability in rainfall. The climate is mainly influenced by the country's location, physical geography, and by large-scale systems, such as monsoons, tropical cyclones, and the El Niño-Southern Oscillation (ENSO).

On average, the seasonal temperature varies from about 25.5°C in January (coolest month) to 28.3°C in May (hottest month). Station data indicate that altitude, not latitude, is the more significant factor affecting the spatial variability in temperature.

Rainfall is an important driver of climate variability in the Philippines. The Philippine climate is classified under four climate types using the Modified Coronas Classification, which is based on the geographical distribution of the seasonal variation and amount of rainfall (Coronas, 1920; Kintanar, 1984). The spatial variability in the seasonal rainfall over the Philippines is influenced by large-scale systems, such as monsoons, North Pacific trades, tropical cyclones, the Inter-tropical Convergence Zone (ITCZ), easterly waves, and the tail-end effects of synoptic scale waves in the subtropical zone (Francisco et al., 2006). Topography, vegetation cover, land use, and proximity to water bodies also affect rainfall at local and diurnal scales.

As with other countries in Asia, monsoons have a strong impact on the seasonal and spatial variability of Philippine climate (Chang, Wang, McBride, & Liu, 2005). Within the year, the Philippines experiences two types of monsoons: the southwest monsoon (SWM), locally called *habagat*, and the northeast monsoon (NEM), known as *amihan*. Originating as trades from the Indian Ocean, the SWM reaches the Philippines usually in May, peaks around August, and retreats in October (Flores & Balagot, 1969; Francisco et al., 2006). This monsoon brings abundant rainfall over the western coast of the country (Asuncion & Jose, 1980; Cayanan, Chen, Argete, Yen, & Nilo, 2011; Cruz, Narisma, Villafuerte II, Cheng Chua, & Olaguera, 2013). On the other hand, the NEM is from October until March (Francisco et al., 2006). The influence of the NEM on rainfall is more pronounced on the eastern (windward) side of the Philippines (Francisco et al., 2006; Yumul, Cruz, Servando, & Dimalanta, 2011). The intra-seasonal cycle of the southeast Asian monsoon rainfall can be influenced by the Madden-Julian Oscillation (MJO). On the other hand, its interannual variability is strongly linked with the ENSO phenomenon (Salinger et al., 2014).

Tropical cyclones also contribute to rainfall in the Philippines, and can bring strong winds and heavy rainfall with destructive impacts. Every year, an average of 19 to 20 tropical cyclones enter the Philippine Area of Responsibility and about 7 to 9 make landfall (Cayanan et al., 2011; Cinco et al., 2016; Yumul, Cruz, Servando, & Dimalanta, 2008; Yumul et al., 2011). Maximum occurrences have been noted during July to September (Cinco et al., 2016) and during October to November (Lyon & Camargo, 2009), with the least occurrences during February and March (Cinco et al., 2016; Lyon & Camargo, 2009). Tropical cyclones may interact with other weather systems, e.g., southwest monsoon, resulting in enhanced rainfall over certain areas (Cayanan et al., 2011).

The ENSO is another major driver of interannual climate variability over the Philippines and the rest of Asia. The warm (El Niño) and cold (La Niña) phases of the ENSO affect seasonal rainfall in the Philippines. During an El Niño year, prolonged dry periods are typically experienced over the western side of the Pacific (Jaranilla-Sanchez, Wang, & Koike, 2011; Jose, Francisco, & Cruz, 1996), while heavy rainfall and flooding are experienced during La Niña years (Pullen et al., 2015; Yumul et al., 2008). The severity of the rainfall anomalies can depend on the duration of the ENSO events (Yumul Jr., Dimalanta, Servando, & Hilario, 2010). Tropical cyclone activity in the Pacific can also be affected by ENSO events, e.g., a number of strong tropical cyclones have entered the Philippine Area of Responsibility (PAR) during El Niño years (Cinco et al., 2016; Yumul et al., 2008).

At decadal scales, the interannual variability of ENSO and its climate effects are modulated by the Pacific Decadal Oscillation (PDO) (Salinger et al., 2014; Zhang, Wallace, & Battisti, 1997). During warm (cold) phases of the PDO, ENSO tends to be a strong (weak) source of interannual climate variability (Salinger et al., 2014). In the Philippines, the PDO had a minimal influence on the impact of ENSO on extreme rainfall in recent decades (Villafuerte II et al., 2014). However, the PDO can affect the number of landfalling tropical cyclones during ENSO years (Kubota & Chan, 2009). On the other hand, extreme winter rainfall in the Philippines can be affected by intense MJO activity, as seen in 2007–2008 (Pullen et al., 2015).

3.2 INTRODUCTION

The Philippines has a tropical and maritime climate with relatively high temperature, humidity, and rainfall, as indicated in the Köppen-Geiger climate map (Peel, Finlayson, & McMahon, 2007; PAGASA, n.d.). This climate is mainly influenced by its location, physical geography, and by large-scale climate systems. The Philippine archipelago consists of more than 7,000 islands, situated within latitude 4.7° N, and 21.2° N and longitude 116.7° E and 126.6° E (which may not include the full extent of the country's small islands and territorial waters), and has a total land area of ~300,000 sq. km (Figure 3.1) (Cinco, de Guzman, Hilario, & Wilson, 2014).

The country has an extensive coastline of 36,289 km surrounded by the Philippine Sea and the Pacific Ocean on the east, the West Philippine Sea on the west, and the Sulu and Celebes Seas on the south (Long & Giri, 2011). The islands of Luzon and Mindanao have a complex topography consisting of plains, hills, valleys, and high mountains ranging up to 3 km (~2.95 km for Mt. Apo) (Francisco et al., 2006). However, most of the smaller islands also have mountainous areas. All these geographic features play an important role in defining the climate profile of the country.

In this chapter, key climatic features and relevant large-scale systems affecting Philippine climate, such as the northeast and southwest monsoons, tropical cyclones, and ENSO, are discussed in more detail.

3.3 SEASONAL CHARACTERISTICS

3.3.1 Temperature

The mean annual temperature of the Philippines is 26.6°C. On average, the seasonal temperature varies from 25.5°C in January (coolest month) to 28.3°C in May (hottest month) (PAGASA, n.d.). The months of December to February are relatively cool, while it is warm from March to May. Based on station data, it is observed that altitude, not latitude, is a more significant factor affecting the spatial variability in temperature (PAGASA, n.d.). For example, the mean annual temperature recorded in Baguio station is lower than the national average due to its high elevation. Because of this cool bias, it is often excluded in the calculation of the mean temperature for the Philippines.

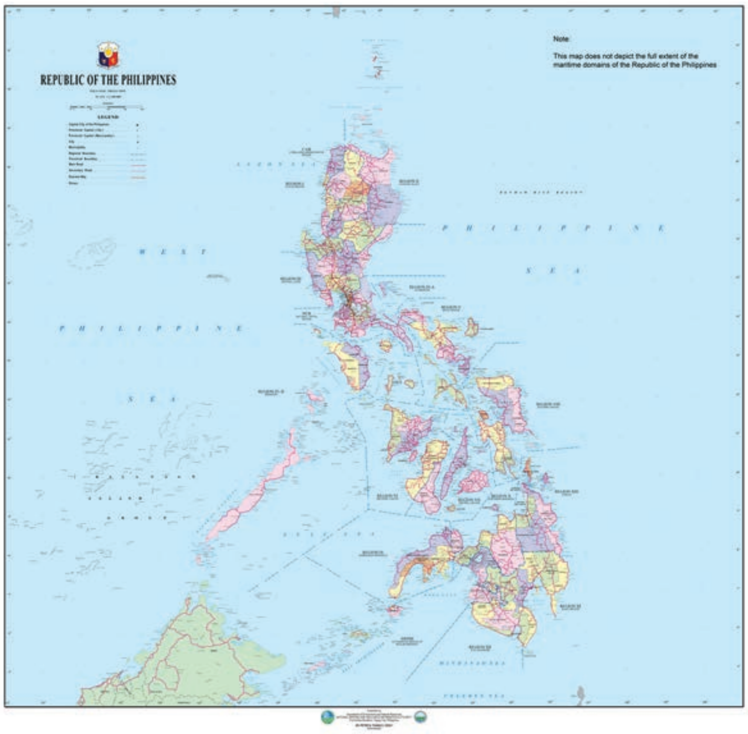

Figure 3.1 Map of the Philippines (Source: National Mapping and Resource Information Authority [NAMRIA])

3.3.2 Rainfall

Rainfall is an important driver of climate variability in the Philippines. The mean annual rainfall in the country varies from 965 mm to 4,064 mm (Cinco et al., 2016; PAGASA, n.d.). The spatial variability in the seasonal rainfall over the Philippines is mainly due to the seasonality, direction, and location of the large-scale weather systems, such as monsoons and tropical cyclones. Rainfall is also influenced by the location of the Intertropical Convergence Zone (ITCZ) where the northeasterly winds in the Northern Hemisphere and the southeasterly winds in the Southern Hemisphere converge along the equator. From December to February, the ITCZ is located south of the equator. It moves northward until it reaches north of the Philippines around August to September, and then moves southward before December (Yumul et al., 2011). Topography, vegetation cover, land use, and proximity to water bodies also affect rainfall via local-scale processes, e.g., sea and lake breezes and urban heat island effects, particularly at the diurnal timescales.

Around March to (early) May, it is relatively dry over the country when the prevailing winds are the north Pacific trade winds (easterlies). On average, the rainy season starts around the middle of May and typically lasts until September, with rainfall particularly high over the western coast of the country. However, the timing of this wet season can vary depending on the onset of the southwesterly wind that flows over the Philippines, associated with the Asian summer monsoon (Akasaka, 2010). The ITCZ is also over the northern part of the country during the boreal summer and may influence rainfall in this area. From late September to early October, rainfall increases over the eastern side of the Philippines and reaches a maximum in November to February when the eastern (western) coast of the Philippines experience wet (dry) conditions associated with the northeasterly winds of the East Asian winter monsoon (Akasaka, 2010; Villafuerte II et al., 2014). During the months of December to March, rainfall over the eastern side of the country has also been attributed to the “tail-end of the cold front” (or tail-end effects of synoptic scale waves in the subtropical zone), which moves from north to south and is over Mindanao during January to February (Faustino-Eslava, Yumul Jr., Servando, & Dimalanta, 2011; Yumul Jr., Dimalanta, Servando, & Cruz, 2013). Rainfall over the southern region may also be influenced by the ITCZ, which is around this area at this time.

The climate of the Philippines is classified by PAGASA under four climate types using the Modified Coronas Classification (Figure 3.2; Coronas, 1920; Kintanar, 1984). This climate typology is based on variation in space and time of rainfall. Type I climate is defined by two pronounced seasons: a wet season from May to October, and a dry season from November to April. Areas along the western side of the Philippines have this climate type, which is strongly influenced by the southwest monsoon. On the other hand, Type II climate has a pronounced peak in the wet season from November to December without a defined dry season. Areas that have Type II climate are situated along the eastern side of the country, which are exposed to the northeast monsoon, trades, and easterlies. Type III climate has no pronounced seasonal cycle but has relatively high rainfall from May to October, similar to Type I. Areas with Type III climate are located over the central plains of Cagayan Valley, central Visayas, and northwestern Mindanao. Type IV climate has rainfall more or less distributed throughout the year. Areas in eastern Visayas and Mindanao have this climate type (Francisco et al., 2006; Moron et al., 2009). On the other hand, McGregor and Nieuwulf (1998) classifies the Philippines to have three seasons based on the influence of the northeast monsoon, the north Pacific trades, and the southwest monsoon (Francisco et al., 2006).

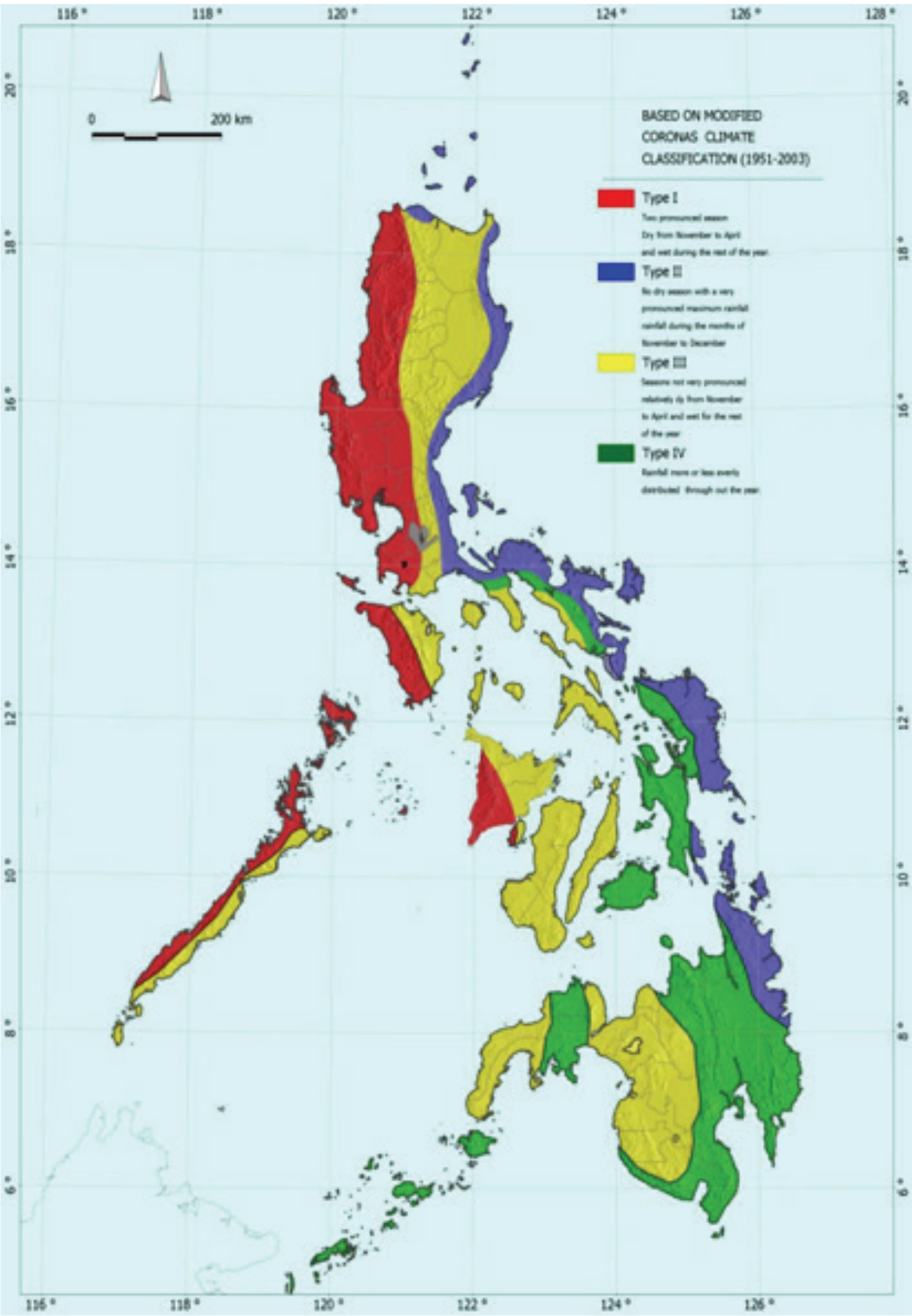

Figure 3.2 The modified Coronas climate atlas (PAGASA, 2011, Figure 16)

3.4 MONSOONS

As with other countries in Asia, monsoons have a strong impact on the seasonal and spatial variability of Philippine climate (Chang et al., 2005). Monsoons are described by the seasonal reversal in the wind flow with accompanying rainfall that result from the temperature difference between the ocean and the land (e.g., Asian continent) throughout the year (Cayanan et al., 2011; Salinger et al., 2014). The Asian monsoon can be subdivided into different regions: East Asian summer monsoon (EASM), Indian summer monsoon (ISM), and western North Pacific summer monsoon (WNPSM) (Figure 3.3; B. Wang & LinHo, 2002; Yihui & Chan, 2005). Most of the Philippines is within the WNPSM region, which has not been studied as extensively as the EASM and ISM (Gadgil, 2003; B. Wang & LinHo, 2002; Yihui & Chan, 2005). The intraseasonal cycle of the southeast Asian monsoon rainfall can be influenced by the Madden-Julian Oscillation (MJO). On the other hand, its interannual variability is strongly linked with the ENSO phenomenon (Salinger et al., 2014).

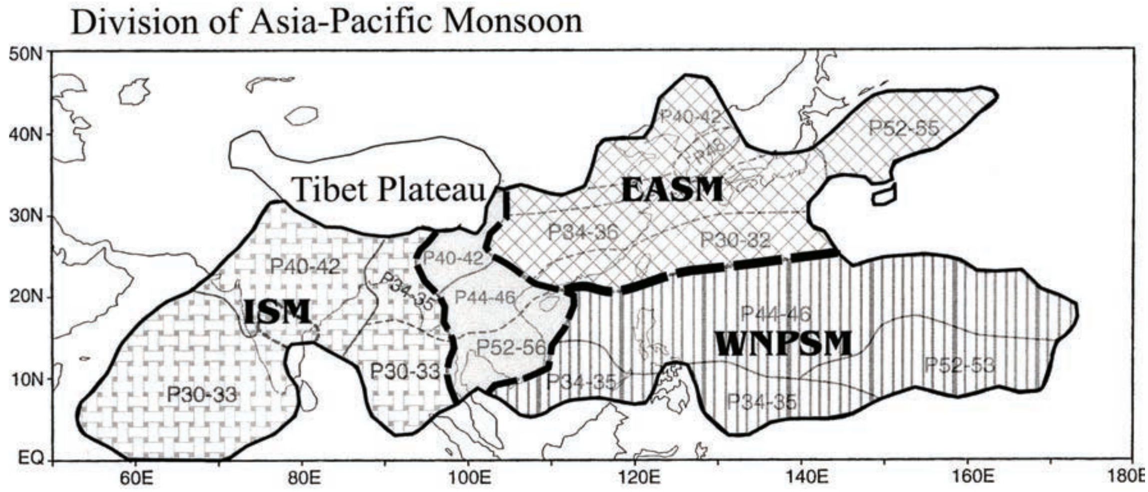

Figure 3.3 The different subregions of the Asia-Pacific monsoon. The ISM and WNPSM are tropical areas while the EASM is subtropical (B. Wang & LinHo, 2002, Figure 9).

Within the year, the Philippines experiences two types of monsoons: the southwest monsoon (SWM), locally called *habagat*, and the northeast monsoon (NEM), also known as *amihan*. Originating as trades from the Indian Ocean, the SWM reaches the Philippines usually in May but the onset can vary every year (Lau & Yang, 1997; Moron et al., 2009). The timing of this monsoon can vary depending on the patterns of transition in the atmospheric circulations over the region, such as the monsoon trough over the northern West Philippine Sea, the shift in the western side of the western North Pacific subtropical high, and the movement of the easterly wave (Akasaka, 2010). The peak of the summer monsoon is reached around August and then it retreats in October but can persist until December (Akasaka, 2010; Flores & Balagot, 1969; Francisco et al., 2006).

The strong, moist southwesterly winds of the summer monsoon can bring as much as 43% of the mean annual rainfall over the Philippines (Asuncion & Jose, 1980; Cayanan et al., 2011) and up to 90% over the northwestern region (Cruz et al., 2013). In addition, the intensity of the rainfall associated with the SWM can also be indirectly affected by tropical cyclones north of Luzon, such that the southwesterly winds can be enhanced and move towards the Cordillera Mountain ranges, resulting in enhanced vertical motion and rainfall over western Luzon (Cayanan et al., 2011). On the other hand, the NEM or the winter monsoon is driven by the temperature contrast between the warmer ocean temperatures and the cold continental Asia. Unlike SWM, the influence of the NEM on rainfall is more pronounced on the eastern (windward) side of the Philippines, while the western (leeward) side is dry. The NEM is from October until March (Francisco et al., 2006; Yumul et al., 2011).

3.5 TROPICAL CYCLONES

Table 3.1 Classification of Tropical Cyclones (Source: PAGASA)

Category	Maximum sustained winds (kph)
Tropical Depression	≤ 61
Tropical Storm	62–88
Severe Tropical Storm	89–117
Typhoon	118–220
Super Typhoon	≥220

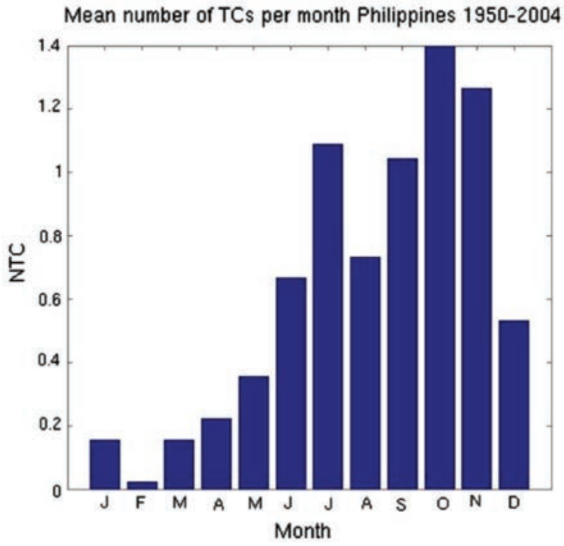

Figure 3.4 Average number of TCs per month in the Philippines for the period 1950–2002 (Lyon & Camargo, 2009, with corrected time interval in Figure 8).

Tropical cyclones also contribute to rainfall in the Philippines and can bring strong winds and heavy rainfall with destructive impacts (Ribera, García-Herrera, & Gimeno, 2008; Yumul Jr. et al., 2012). The Philippines experiences an average of 19 to 20 tropical cyclones per year (Cayanan et al., 2011). On average, 7 to 9 of these tropical cyclones that enter the Philippine Area of Responsibility (PAR) make landfall (Yumul et al., 2008, 2011). A recent study by Cinco et al. (2016) indicates that an annual average of 9 tropical cyclones cross the Philippines out of the 19.4 tropical cyclones within PAR. Tropical cyclones are classified based on the intensity of their associated winds. In the Philippines, PAGASA uses five categories based on 10-minute averages of the winds (Table 3.1).

Most of these typhoons pass over the northern and north-eastern part of Luzon and eastern Visayas (Cinco et al., 2016; Ribera, García-Herrera, Gimeno, & Hernandez, 2005). In the vicinity of the Philippines, and based on the 1950–2002 record, the tropical cyclone distribution is described as bimodal with a maximum occurrence in October, a secondary peak in July, and the least occurrence in February (Figure 3.4; Lyon & Camargo, 2009). On the other hand, the monthly distribution of typhoons during the time period of 1901–1934 showed that typhoon activity is high from July to October with peak occurrence during August and September, and few events from January to March (Figure 3.5; Ribera et al., 2005). This monthly distribution is similar with Cinco et al. (2016) using 1951–2013 data with the high occurrence during July to September (see Figure 4.12 in Chapter 4). The months of July, October, and November also had the most number of tropical cyclones that made landfall (Cinco et al., 2016).

Tropical cyclones may interact with other weather systems, e.g., southwest monsoon, resulting in enhanced rainfall over certain areas. Examples of these events include the heavy rainfall documented over Panay Island during the passage of Typhoon Fengshen (local name Frank) in June 2008 (Yumul Jr. et al., 2012), and over the western seaboard of Luzon due to Typhoon Morakot (local name Kiko) in August 2009 (Yumul Jr. et al., 2013). An extended discussion on tropical cyclones can be found in Chapter 4 of this report.

3.6 LARGE-SCALE OSCILLATIONS

3.6.1 El Niño Southern Oscillation

A major driver of inter-annual global climate variability is the atmosphere-ocean interactions in the tropical Pacific, associated with the El Niño Southern Oscillation (ENSO) (Salinger et al., 2014). The two phases of ENSO: the El Niño (warm) phase and the La Niña (cool) phase, usually develop over 12 to 18 months, generally starting from April to June, and reaching its peak during December to February (Salinger et al., 2014; Yumul et al., 2008). During an El Niño year, the horizontal Walker circulation weakens and the meridional Hadley Cell intensifies leading to weaker easterly trade winds along the equatorial Pacific (Salinger et al., 2014). Sea surface temperatures (SSTs) are warmer than normal over the eastern equatorial Pacific and the Indian Ocean, and land surface temperatures are higher over south and southeast Asia.

The area of high rainfall moves to the east and leads to above normal rainfall in the eastern end of the Pacific and below normal rainfall over the western end of the Pacific, including the Philippines (Salinger et al., 2014). The opposite condition occurs during a La Niña episode, such that trade winds are stronger and SSTs are cooler than normal over the eastern Pacific and Indian Ocean. The area of strong tropical convection moves westward, resulting in above-normal rainfall over the western Pacific (Salinger et al., 2014).

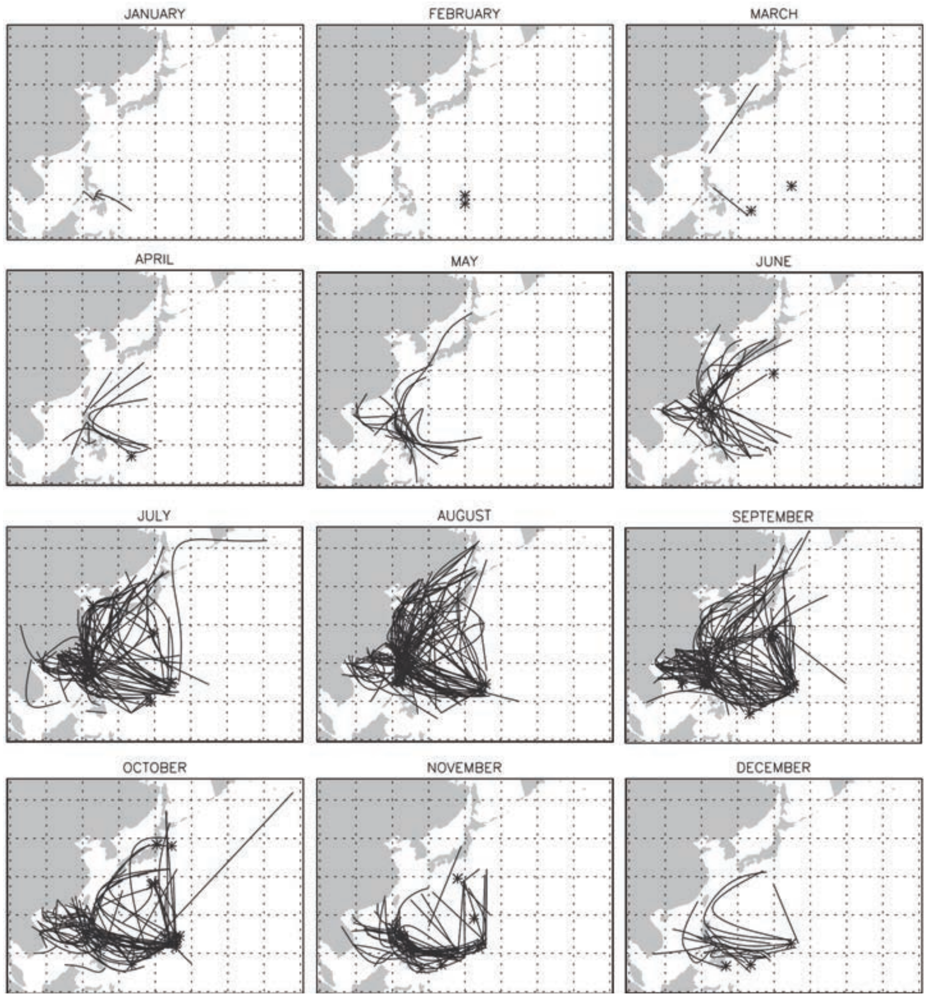

Figure 3.5 Plot of typhoon paths per month for the period 1901 to 1934. Asterisks mark events with only one observation point (Ribera et al., 2005, Figure 2).

ENSO activity can be measured and monitored by indices based on its atmospheric and oceanic components. The Southern Oscillation Index (SOI) measures the difference in sea level pressure between Tahiti (southwest Pacific) and Darwin (Australia). During an El Niño event, the average sea level pressure in Tahiti is lower than in Darwin (Salinger et al., 2014; Yumul Jr. et al., 2010). On the other hand, the Niño 3.4 index measures the average SST anomaly over the east-central equatorial Pacific Ocean (or the Niño 3.4 region: 5°N–5°S, 170°W–120°W) (Salinger et al., 2014). The Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) uses the Oceanic Niño Index (ONI), which is similar to the Niño 3.4 index but with the SST anomaly derived from a centered 30-year base period (rather than a fixed period) over a three-month running average.

Using this index, there have been different criteria defined for an El Niño episode, as well as the intensity of the event (i.e., weak, moderate, or strong). For example, Yumul et al. (2010) specified that the index should be at least 0.5°C over three consecutive months. Cruz et al. (2013) also used this 0.5°C threshold for the ONI (but using a base period of 1971–2000) for at least six consecutive overlapping 3-month seasons.

Recent studies have indicated a different type of El Niño called the El Niño Modoki or Central Pacific ("Date Line") El Niño. During El Niño Modoki, SST anomalies are located over the central Pacific, and not over the eastern Pacific as in the case of the traditional eastern Pacific El Niño (Kao & Yu, 2009; Salinger et al., 2014). These two El Niños also differ in characteristics, evolution, and teleconnections with the Indian Ocean (Kao & Yu, 2009).

3.6.1.1 Impact of ENSO on rainfall

The warm and cold phases of the ENSO affect seasonal rainfall in the Philippines. On the western side of the Pacific including the Philippines, prolonged dry periods are observed at the end of the year during El Niño years (e.g., Jaranilla-Sanchez et al., 2011; Jose et al., 1996), while heavy rainfall and flooding are associated with La Niña years (Pullen et al., 2015; Yumul et al., 2008). In the case of El Niño Modoki events, rainfall is expected to be high, such as the heavy rainfall seen over eastern Luzon in 2004 (Yumul et al., 2011; Yumul Jr. et al., 2010).

Recent work has shown the strong influence of ENSO on the seasonal and interannual variations of extreme rainfall in the Philippines (Villafuerte II et al., 2014; Villafuerte II, Matsumoto, & Kubota, 2015; Villafuerte II & Matsumoto, 2014). Extreme events over the country from 2004 to 2008 have been related to ENSO events (Yumul et al., 2011). The severity of the rainfall anomalies can depend on the duration of such events (Yumul Jr. et al., 2010).

However, there can be a reversal in the seasonal response of rainfall to ENSO during July to September as compared with October to December for both phases (Lyon, Cristi, Verceles, Hilario, & Abastillas, 2006). Because of the impact of ENSO on the atmospheric circulation over the western North Pacific, above (below) normal rainfall can also happen over north and central Philippines during the summer of an El Niño (La Niña) year before the onset of anomalously dry (wet) conditions in the fall (Lyon & Camargo, 2009; Lyon et al., 2006).

3.6.1.2 Impact of ENSO on tropical cyclones

Tropical cyclone activity in the Pacific can also be affected by ENSO events. Lyon et al. (2014) provides a brief review of studies which found changes in the genesis locations of tropical cyclones during El Niño (La Niña) years, which could affect the track, lifetime, and intensity of the tropical cyclones, e.g., a tendency to have more intense typhoons with a longer lifetime during El Niño years. A number of strong tropical cyclones have entered the Philippine Area of Responsibility (PAR) during El Niño years, as indicated in Figure 3.6, e.g., in 1987 and in 2004 (Cinco et al., 2016; Yumul et al., 2008). On the other hand, intense tropical cyclones may cross northern Philippines more frequently during La Niña years (Lyon et al., 2014; Saunders, Chandler, Merchant, & Roberts, 2000). On a seasonal scale, tropical cyclone activity tends to be enhanced (reduced) during July to September of El Niño (La Niña) years, while this trend reverses from October to December (Lyon & Camargo, 2009; Lyon et al., 2014).

3.6.2 Pacific Decadal Oscillation

At decadal scales, the year-to-year variability of ENSO and its impact on climate can be modulated by the Pacific Decadal Oscillation (PDO) (Salinger et al., 2014; Zhang et al., 1997). The PDO is characterized by patterns of SST anomalies over the North Pacific. It has warm and cold phases that last for decades. During warm (cold) phases of the PDO, ENSO tends to have a weak (strong) influence on inter-annual climate variability (Salinger et al., 2014). Climate anomalies can be enhanced (weakened) when the PDO and ENSO are in phase (out of phase) (S. Wang, Huang, He, & Guan, 2014). In the Philippines, Villafuerte II et al. (2014) found that the PDO has minimal influence on the impact of ENSO on extreme rainfall during their period of study. Further research is still needed on examining the impact of PDO on the decadal variability of rainfall in the Philippines. On the other hand, Kubota and Chan (2009) note that the variation in the annual number of landfalling tropical cyclones in the Philippines during ENSO years from 1902 to 2005 is related to phases of the PDO.

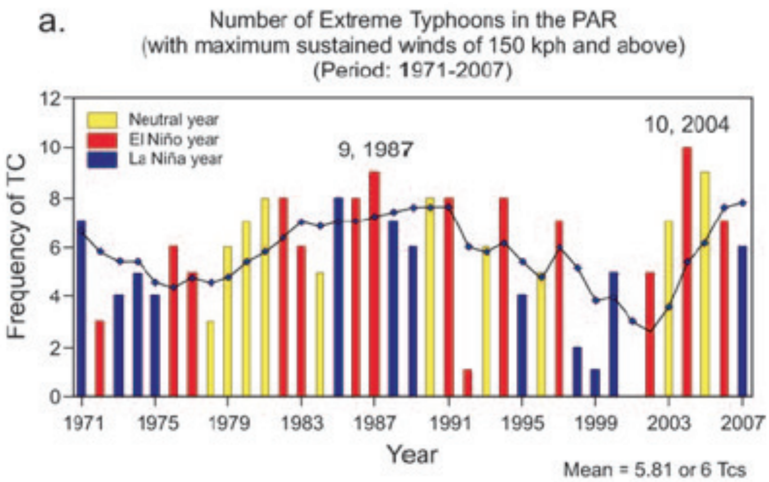

Figure 3.6 Number of typhoons per year with at least 150 kph sustained winds entering the PAR. Years are labeled according to El Niño, La Niña, or neutral conditions. Note that there were no such typhoons in 2001 (Yumul et al., 2008, Figure 5A).

3.6.3 Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is another tropical mode of variability that can influence the intraseasonal variations in rainfall over the Philippines. The MJO is typically a 30- to 60-day (but may also range from 20 to 90 days) oscillation that moves eastward near the equator, and involves variations in wind and rainfall (Xavier, Rahmat, Cheong, & Wallace, 2014). Most active during winter in the Northern Hemisphere, MJO activity can be described by winds and remotely sensed measurements of outgoing longwave radiation, associated with convection (Pullen et al., 2015). The phase and amplitude of the MJO can affect the likelihood and spatial distribution of extreme rainfall events in Southeast Asia, such that the probability of rainfall extremes on land from November to March increases by 30% to 50% during the active phase of the MJO but decreases by 20% to 25% during its suppressed phase (Xavier et al., 2014). In the Philippines, Pullen et al. (2015) showed the influence of the intense MJO activity on the extreme winter rainfall in 2007–2008.

3.7 DIRECTIONS FOR FUTURE STUDIES

This chapter briefly described the climate of the Philippines and the large-scale systems that influence it. While there have been attempts to analyze the complex interactions and feedbacks, such as those between tropical cyclones and monsoon rainfall events, these studies tend to be based on particular cases rather than seen in a climatological context. The comprehensive understanding of the role of these large-scale climate drivers (e.g., ENSO, MJO, PDO) and their interactions in determining Philippine climate is important if we are to have a fuller picture of climate change and its different driving forces, such as the radiative forcing caused by rising levels of anthropogenic greenhouse gases.

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CHAPTER 4

Historical Changes In Philippine Climate

AUTHORS

Lourdes V. Tibig
Thelma A. Cinco
Rosalina G. de Guzman
Flaviana D. Hilario
Faye Abigail T. Cruz
Jose Ramon T. Villarin, SJ

4.1 CHAPTER SUMMARY

In the Philippines, analysis of temperature trends for the period 1951–2010 shows an increase of 0.65°C in annual mean temperatures (Cinco, de Guzman, Hilario, & Wilson, 2014; Comiso et al., 2014; PAGASA, 2011). Over the last 60 years, the mean rate of increase is 0.11°C per decade, with the rate increasing to 0.16°C per decade in the last 30 years (1981–2010). Anomalous positive changes in temperature are observed after 1987, with interannual variations in this warmer period as evidenced by various downward trends during the period 1989–1996. The highest positive anomaly occurred in 1998, during the peak of one of the most significant El Niño events in the equatorial Pacific which caused widespread drought in the Philippines.

An increase of 0.36°C has been observed in the mean annual maximum temperature over the 60-year period, with the highest positive anomaly (+0.9°C) observed during the 1998 El Niño event (PAGASA, 2011). On minimum temperature (nocturnal), the analysis of anomalies shows an increasing trend. Negative temperature anomalies were observed before 1987 and positive increasing anomalies thereafter with highest value of +0.9°C during the 1998 El Niño. There has been an increase of 1.0°C in minimum temperatures over the 60-year period, three times greater than the increase in maximum temperatures (PAGASA, 2011). The large increase in the nocturnal temperatures over the observed period indicates that nights are becoming warmer in the Philippines, demonstrating reduced diurnal variability or increased convergence of daytime and nocturnal temperatures.

The analysis of extreme daily temperature from 1951 to 2008 show some statistically significant trends (95% probability) of increase in the number of hot days and warm nights, and a decrease in the number of cold days and cool nights (Cinco et al., 2014; Comiso et al., 2014; PAGASA, 2011). Previous assessments of climate trends in the country and in Southeast Asia and the Pacific using the same indices (Griffiths et al., 2005; Manton et al., 2001; PAGASA, 2007) have generally agreed with these trends, with some variation due to differences in the time periods used.

On average, the trend in the number of days with maximum temperatures above the 99th percentile (hot days) is significantly increasing in most parts of the country. For cold nights, statistically significant decreasing trends are noted in most areas of the country. This means that the number of cold nights in many areas of the Philippines during the period 1951–2008 decreased relative to the normal values for the period 1971–2000.

There is high temporal and spatial variability of rainfall in the Philippines (Villafuerte II et al., 2014), even as some observations already point to a decreasing trend in mean rainfall during the southwest monsoon season as indicated in the study of Cruz, Narisma, Villafuerte II, Cheng Chua, and Olaguera (2013). Decadal variability in rainfall needs to be further investigated. For instance, Jose, Francisco, and Cruz (1996) showed an increasing trend in both seasonal and annual total rainfall during 1951–1992 in the northwestern section of the Philippines, whereas Cruz et al. (F. T. Cruz et al., 2013) which used rainfall data from 1961–2010, showed a drying trend over the same region. Hilario, de Guzman, Ortega, Hayman, and Alexander (2009) pointed out that remarkable floods were experienced in the country in the 1960s, 1970s, and 2000s, and also, several drought events were recorded in the 1980s and 1990s.

Analysis of extreme daily rainfall intensity, i.e., amount of rainfall above the top four events during the year (PAGASA, 2011) (or events that exceeded the 99th percentile of rainfall intensity [Cinco et al., 2014]), shows an increasing trend during the period 1951–2008 in most parts of the country but with significant increases (95%) observed only in Baguio, Iloilo, and Tacloban. However, one station, Coron Island, revealed significant decrease in extreme rainfall intensity.

Changes in monsoon-related extreme precipitation and winds due to climate change are still not well understood. In the Indo-Pacific region that is covered by the southeast Asian and north Australian monsoon, Caesar et al. (2011) found low spatial coherence in the trends of rainfall extremes across the region between 1971 and 2005. However, there is a general trend towards wetter conditions in the few instances where the trends in precipitation extremes were significant (Alexander et al., 2006; Caesar et al., 2011).

On monsoon activity (in particular, the southwest monsoon or the locally termed *habagat*), the most notable extreme event was the enhancement of the southwest monsoon that was observed on 6–8 August 2012. This event brought about extreme flooding over Metro Manila and surrounding provinces causing damage to infrastructure and agriculture amounting to about PhP639 million and PhP1.6 billion, respectively, according to National Disaster Risk Reduction and Management Council (NDRRMC) reports. A death toll of 95 persons was recorded and more than 800,000 families were left homeless.

On tropical cyclone (TC) activity, it is important to note that the Philippines is located in the Western North Pacific (WNP), the basin where the most number of TCs develop (Ying, Knutson, Lee, & Kamahori, 2012). From 1951 to 2013, a total of 1,220 TCs entered within the Philippine Area of Responsibility (PAR), of which about half (49%) originated outside the PAR in the Western Pacific Ocean, 43% formed within the PAR, mostly in the eastern part, and the remaining 8% formed in the West Philippine Sea (Cinco et al., 2016). The highest number of recorded TCs per year is 32 (in 1993); the lowest is 11 (in 1998 and in 2010). One of the factors that is seen to drive the variation of TC frequency is the El Niño Southern Oscillation (ENSO or El Niño). For example, there can be shifts in the TC genesis location during El Niño (La Niña) years, i.e., farther to the southeast (northwest) of the climatological mean genesis point, leading to changes in the track, intensity, and lifetime of the TCs (Lyon, Giannini, Gonzalez, & Robertson, 2014). More typhoons also cross the northern Philippines in La Niña years compared to El Niño years (Lyon et al., 2014; Saunders, Chandler, Merchant, & Roberts, 2000).

In terms of the number of TCs landfalling (crossing) the Philippines, there is no trend during the 1948–2010 period but there is a significant decreasing trend in the number of landfalling typhoons since the mid-1990s (Ying et al., 2012). Cinco et al. (2016) updated this finding using 1951–2013 data and showed a slightly decreasing trend, especially in the last 20 years. Cinco et al. (2016) also reports that fewer typhoons (above 118 kph) have affected the country, even as Ying et al. (2012) highlights the uncertainty in the recent trends in the frequency of intense typhoons. Satellite-based intensity data have been used to examine trends since 1981 but conclusions can be limited given the short period of these datasets, which also makes it difficult to discount natural variability (Ying et al., 2012). It is also worth noting that Ying et al. (2012) cites three prevailing tracks of TCs in the WNP: a track moving westward; a recurving track heading towards Japan or Korea; and a recurving track moving northeast, east of 140°E. Trends in the tracks of these TCs have yet to be analyzed. It is also still uncertain whether there is a discernible human influence on these TC changes in the WNP region (Ying et al., 2012).

4.2 TEMPERATURE

4.2.1 Trends and changes in temperature

In the Philippines, analysis of temperature trends for 1951–2010 shows an increase of 0.65°C in annual mean temperatures (Cinco et al., 2014; Comiso et al., 2014; PAGASA, 2011). Figure 4.1 shows temperature anomalies[1] versus the 1971–2000 (normal) value for the period 1951–2010. Over the last 60 years, the mean rate of increase is 0.0108°C per year, with the rate increasing to 0.0164°C per year in the last 30 years (1981–2010) (PAGASA, 2011). Before 1987, temperatures were generally cooler than normal. Beyond 1987, anomalous positive temperatures have been observed, with a larger rate of increase over time relative to the overall trend. However, the interannual variations in the warmer period are still evident as downward trends can be observed from 1989 to 1996. The highest positive anomaly occurred in 1998, during the one of the most significant El Niño events in the equatorial Pacific which caused widespread drought in the Philippines.

Figure 4.2 shows the variation of the annual diurnal maximum temperature for the period 1951–2010. The deviation from the 1971–2000 normal varies over the entire period from positive to negative with a rising trend in 1987, falling down to below zero in 1995–1996, 1999, and 2008–2009. An increasing trend (statistically significant at 95% level) is noted in the 5-year linear running mean. An increase of 0.36°C has been observed in the mean annual maximum temperature over the 60-year period, with the highest positive anomaly (+0.9°C) observed during the 1998 El Niño year (PAGASA, 2011).

The analysis of minimum temperature (nocturnal) anomalies relative to the 1971–2000 normal value in Figure 4.3 shows a higher increasing trend. Negative temperature anomalies were observed before 1987 and positive increasing anomalies thereafter with the highest value of +0.9°C during the 1998 El Niño. This means that the highest value of annual minimum temperature during the 1951–2010 period was observed in 1998. An increase of 1.0°C over the 60-year period is seen, which is three times greater than the increase in maximum temperatures (PAGASA, 2011). The large increase in the minimum temperatures (nocturnal) over the observed period indicates that nights are becoming warmer in the Philippines, demonstrating reduced variability and increased convergence of daytime and nocturnal temperatures.

[1] Temperature anomalies are deviations from a reference temperature, which are used to compare the changes over time. A positive temperature anomaly indicates a value higher than the reference temperature, whereas a negative anomaly means a lower temperature. The reference or "normal"

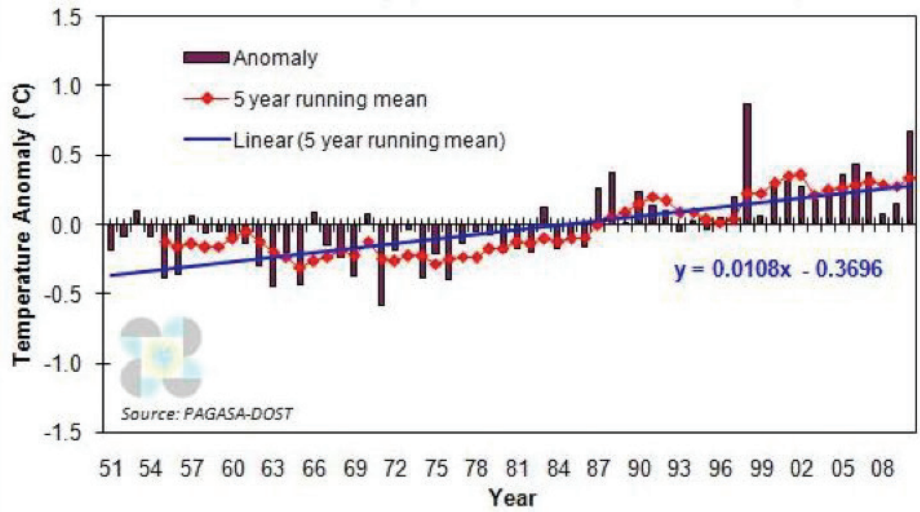

Figure 4.1 Annual mean temperature anomalies from 1971–2000 mean value for the period 1951—2010 in the Philippines (PAGASA, 2011, Figure 6)

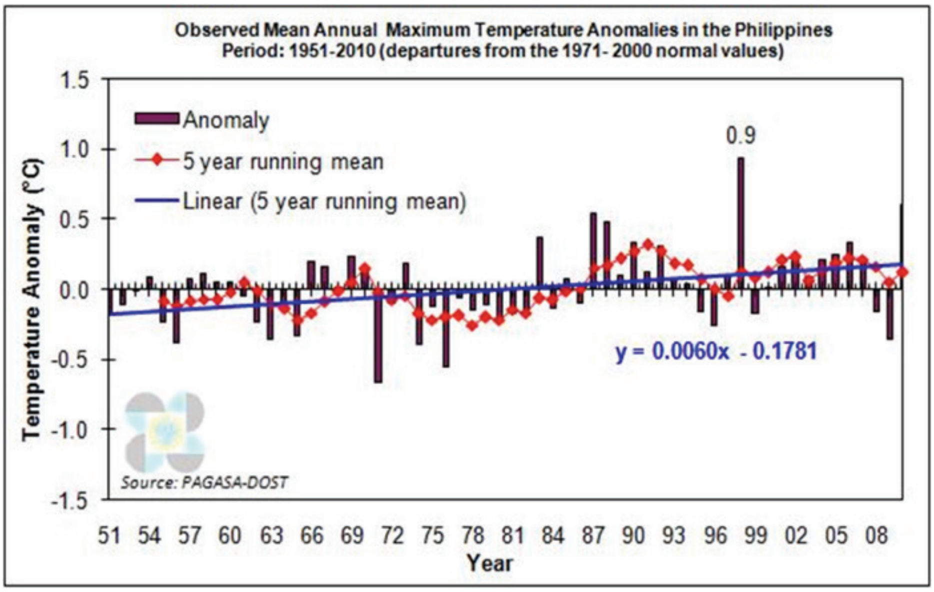

Figure 4.2 Annual maximum temperature anomalies from 1971–2000 mean value for the period 1951–2010 in the Philippines (PAGASA, 2011, Figure 7)

4.2.2 Extreme daily temperature indices (linear trends of extreme values—hot days, warm nights, and cool days and cold nights)

Analysis of extreme daily temperature from 1951 to 2008 showed some statistically significant trends (95% probability), i.e., an increase in the number of hot days and warm nights, and a decrease in the number of cold days and cool nights (Cinco et al., 2014; Comiso et al., 2014; PAGASA, 2011). Previous assessments of climate trends in the country and in Southeast Asia and the Pacific using the same indices (Griffiths et al., 2005; Manton et al., 2001; PAGASA, 2007) have generally indicated these same trends, in spite of variations in the coefficients used and the time interval of observations. The trends in the number of hot days (or days with maximum temperature above the mean 99th percentile) are significantly increasing (▲) in most parts of the country (Figure 4.4). However, significantly decreasing (▼) trends are also seen in some areas of the Bicol region, Visayas (e.g., Roxas), and Mindanao (e.g., Dipolog).

For cold nights, there are statistically significant decreasing trends (▼) indicated by the downward trends in number of days with minimum temperature below the 1st percentile, which are noted in most areas all over the country. This means that the number of cold nights in many areas of the Philippines during the period 1951–2008 decreased relative to the normal values for the period 1971–2000. However, a few places (e.g., Iba and Dagupan, in the main island of Luzon) exhibit significant increasing (▲) trends (Figure 4.5).

These extreme daily temperature trends, particularly those for cold nights and hot days, are found to be spatially coherent throughout the country (Cinco et al., 2014). The statistically significant trends in extreme events, as well as the observed mean trends described in Section 4.2.1, indicate the recent warming of the climate in the Philippines (Cinco et al., 2014).

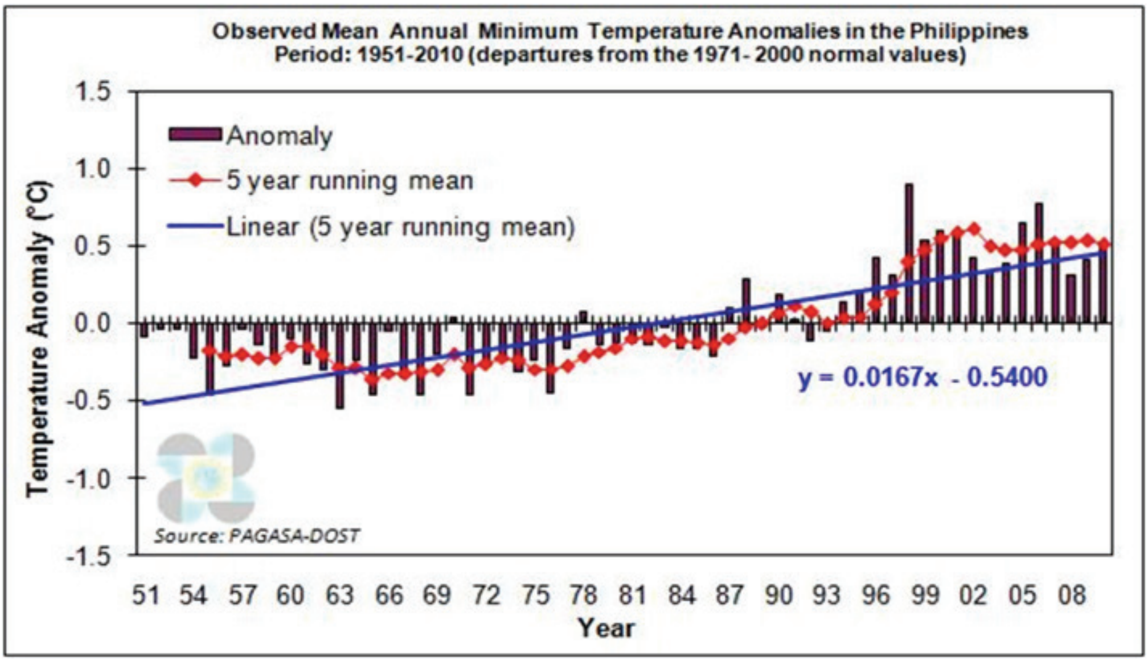

Figure 4.3 Annual minimum temperature anomalies from 1971–2000 mean value for the period 1951 to 2010 in the Philippines (PAGASA, 2011, Figure 8).

The IPCC AR4 (Trenberth, Smith, Qian, Dai, & Fasullo, 2007, as cited in Alexander et al., 2006) reported a statistically significant increase in the number of warm nights and a statistically significant reduction in the numbers of cold nights for 70% to 75% of the sampled global land area with long-term observational data. More recent analyses available since the IPCC AR4 are consistent with the assessment of increase in warm days and nights and a reduction in cold days and nights on the global basis (IPCC, 2012, 2013). Correspondingly, in Southeast Asia, studies reveal a warming trend with increased mean surface temperature for inter-annual means at the national and regional scale (Cinco et al., 2014; Comiso et al., 2014; R. V. Cruz et al., 2007; Griffiths et al., 2005; Manton et al., 2001; Thomas, Albert, & Perez, 2013).

The most recent global assessments of the IPCC (2012, 2013) explicitly state that observations gathered since 1950 offer evidence of change in some extremes; and that globally, it is very likely (above 90% probability) that there has been an overall decrease in the number of cold days

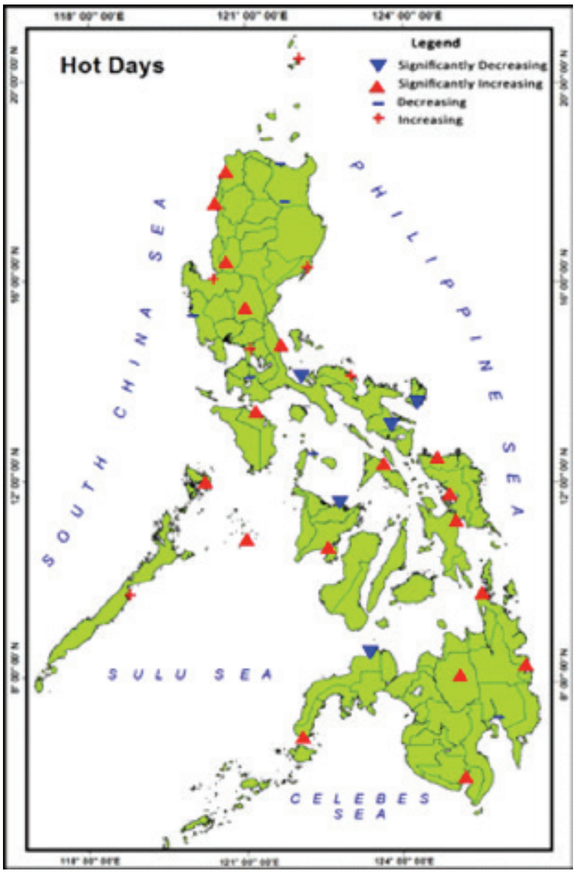

Figure 4.4 Trends in the frequency of hot days, i.e., days with maximum temperature above the 99th percentile of the reference period of 1971–2000 (PAGASA, 2011, Figure 12)

and nights, and an overall increase in the number of warm days and nights for most land areas with sufficient data. It is also important to highlight the fact that the observational evidence also indicates there is medium confidence (a summary term in IPCC assessment reports for level of confidence indicating medium evidence and medium level of agreement in the studies being synthesized) that the length of warm spells or heat waves has increased in many regions of the globe with sufficient observational data since the mid-20th century, and it is likely (66–100% probability) that the frequency of heat waves has increased in large parts of Europe, Australia, and Asia (IPCC, 2013).

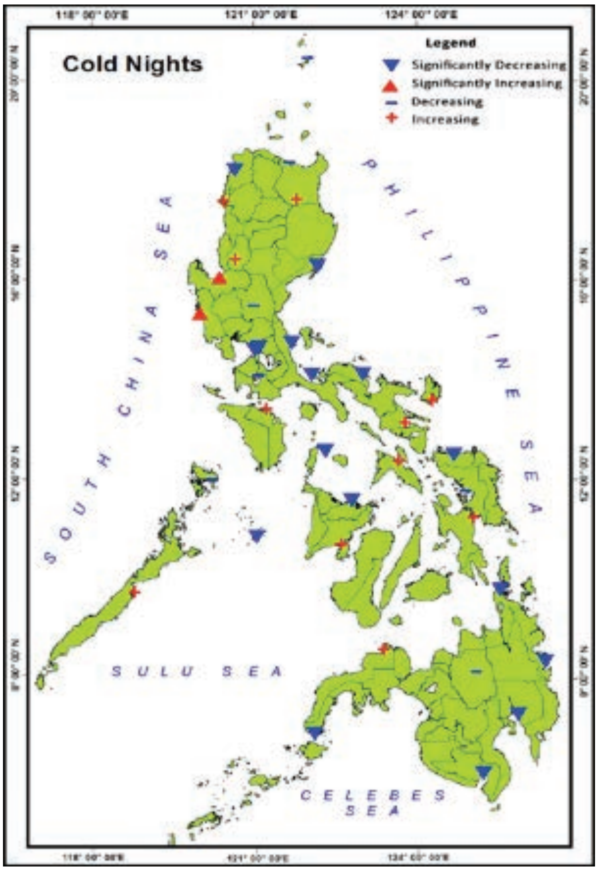

Figure 4.5 Trends in the frequency of cold nights, i.e., days with minimum temperature below the 1st percentile of the reference period of 1971–2000 (PAGASA, 2011, Figure 13)

4.3 RAINFALL

4.3.1 Trends and changes in rainfall

There is high temporal and spatial variability of rainfall in the Philippines (Villafuerte II et al., 2014), with some observations already indicating a decreasing trend in mean rainfall during the southwest monsoon season (F. T. Cruz et al., 2013).

Apparently diverging conclusions concerning decadal variability in rainfall suggest that rainfall variability needs to be further investigated. For instance, Jose et al. (1996) showed an increasing trend in both seasonal and annual total rainfall during 1951–1992 in the northwestern section of the Philippines, while F.T. Cruz et al. (2013), which used rainfall data from 1961–2010, showed a drying trend over the same region. Hilario et al. (2009) pointed out that remarkable floods were experienced in the country in the 1960s, 1970s, and 2000s, and that several drought events were also recorded in the 1980s and 1990s.

Rainfall is a major driver of climate variability in the Philippines, and is influenced by synoptic systems such as monsoons and the El Niño Southern Oscillation (ENSO), and mesoscale processes. Seasonal changes in rainfall are associated with changes in tropical cyclone activity in the Western North Pacific, monsoon intensity, and changes in the timing of monsoon rains (Hilario et al., 2009). Studies indicate that ENSO events have greatly influenced seasonal and interannual rainfall over the country, including monsoon performance. For instance, drought and stresses on water resources often occur during mature El Niño events, and heavy rainfall during La Niña events (Hilario et al., 2009). To illustrate these findings, Hilario et al. (2009) listed 9 of the 12 La Niña events with their intensities, based on the mean sea surface temperature (SST) anomaly for the Niño 3.4 region (Table 4.1). Heavy rainfall associated with enhanced monsoons during these ENSO events resulted in floods and landslides (Hilario et al., 2009).

Lyon et al. (2014) notes that the impact of ENSO on rainfall can depend on the interaction of the life cycle of ENSO with the seasonal variability of rainfall of a particular region. For example, during an El Niño year, drier than normal conditions in the Philippines are typically expected in the boreal fall (October–December) and winter (January–March), which can last until the following spring (April–June) (Lyon et al., 2014). However, ENSO events frequently develop during the boreal summer (July–September) when the southwest monsoon is the prevailing circulation, and when tropical cyclone activity is also high. Recent studies show that the seasonal rainfall response to ENSO reverses sign between the boreal summer (July–September) and fall (October–December) during both ENSO phases (Lyon & Camargo, 2009; Lyon, Cristi, Verceles, Hilario, & Abastillas, 2006; Lyon et al., 2014). The analysis of the observational data reveals that during July to September of El Niño years, above-average rainfall occurs over north-central Philippines before the expected below-average conditions in the subsequent October–December period. In contrast, below-average rainfall occurs over north-central Philippines in July–September during

Table 4.1 La Niña events. Higher intensities are indicated by more negative values of the Oceanic Niño Index (ONI) (Hilario et al., 2009, Table 1, Source: Climate Prediction Center, http://www.cpc.noaa.gov).

La Niña event	ONI Value
JJA 1970 – DJF 1971/72	–1.4
AMJ 1973 – JJA 1974	–2.0
SON 1984 – ASO 1985	–1.1
AMJ 1988 – AMJ 1989	–2.0
ASO 1995 – FMA 1996	–0.8
JJA 1998 – MJJ 2000	–1.7
SON 2000 – JFM 2001	–0.7
Early 2006	–0.8
JAS 2007 – AMJ 2008	–1.5

La Niña years before becoming wetter than normal in the following October–December period (Lyon & Camargo, 2009; Lyon et al., 2006, 2014).

On the influence of monsoons on rainfall variability, Villafuerte et al. (2014) highlighted the governing influence of monsoonal activity which is well-pronounced during July–September, particularly in the western sections of the country. On the other hand, the study of F.T. Cruz et al. (2013) on monsoon variability in the Philippines during the 1961–2010 period found that there has been a decreasing trend in the southwest monsoon (SWM) total rainfall received in the western half of the country where the impact of the southwest monsoon is well pronounced. A gradual decline of the monsoon total rainfall at the rate of 0.026% to 0.075% every decade is seen in six of the nine meteorological stations investigated (Ambulong, Baguio, Coron, Dagupan, Iba and Vigan), as well as its rainfall distribution. This has been observed even as the Loo, Billa, and Singh (2015) study indicates that most of the floods that occur in Southeast Asian countries that include the Philippines are associated with the summer East Asian summer monsoon (EASM) downpour. There was also an increasing trend in the number of days without rain in Ambulong (2.9% per decade), Baguio (5.9% per decade), and Dagupan (4.0% per decade) as well as a decreasing trend in the days with heavy rainfall (F. T. Cruz et al., 2013). Findings of the F.T. Cruz et al. (2013) study imply a shift towards a longer dry period and a general drying trend in the recent years during the SWM season over western Philippines.

In a study to determine the spatio-temporal variability of the onset of the summer monsoon, Moron et al. (2009) used a local agronomic definition applied to daily station rainfall data and gridded U.S. Climate Prediction Center Merged Analysis of Precipitation (CMAP) pentad estimates. The onset date is defined in the study as "the first wet day of a 5-day period receiving at least 40 mm without any 15-day dry spell receiving <5mm in the 30 days following the start of that period". Results indicate the closeness of the median onset date with the mean. The median onset date varies according to station location, ranging between 5 April and 26 June across the 76 stations used in the analysis (Table 4.2 and Figure 4.6). There is an earlier occurrence (more than 15 days) in the east (with Type II climate) than in the west (with Type I climate). The onset date can also vary according to elevation, such that stations at higher elevations tend to have earlier onset than in the lowlands, likely due to orographic enhancement of convection. Stations along the western coast and the inner islands (Visayan, Bohol, etc.) of the central Philippines tend to have the latest onset dates due to its location either on relatively flat area or on rain-shadowed areas. The onset occurs across western Philippines around mid-May on average, whereas it is indicated as a seasonal increase in rainfall over eastern Philippines. The signal of the onset date are found to be stronger over the central Philippines, roughly from Southern Luzon to Northern Mindanao (Moron et al., 2009).

4.3.2 Floods and droughts

Floods in the Philippines are usually due to monsoon surges (intensification of the monsoons) and slow-moving tropical cyclones in the Philippine Area of Responsibility (PAR). The interannual intensity of the monsoon is related to La Niña events (Hilario et al., 2009). Historically, the worst flood years during the southwest monsoon were 1962 and 1972, and for the northeast monsoon, 1924, 1964, 1970, 1971, and 1973, 1975 (Asuncion & Jose, 1981). Updated records of the worst flood years during the northeast monsoon include the 2000, 2001 and 2006 events (Hilario et al., 2009).

One of the most recent flooding events was caused by Typhoon Ondoy (international codename: Ketsana). Typhoon Ondoy brought the worst rainfall to Metro Manila on record on September 26, 2009, submerging approximately 80% of the nation's capital. On that day, the maximum 24-hour rainfall of 455 mm was recorded at the Science Garden observation station. Figures 4.7 and 4.8 show the cumulative rainfall during the passage of Typhoon Ondoy on September 24–27 and the flooding rains of the typhoon.

Table 4.2. Onset date statistics for all stations, and stations grouped using different classifications. There is rapid onset across the entire Philippines, even if it is less evident across the eastern Philippines because of the moist easterly winds (Moron et al., 2009, extracted from Table 1)

Region	Number of stations	25th, 50th, and 75th percentiles of station-average onset date	Inter-quartile range of station-average (days)	Station-average inter-quartile range (days)
All stations	76	May 4, May 12, May 22	18	34
Western Philippines	44	May 7, May 20, May 26	19	30
Eastern Philippines	32	April 27, May 11, May 18	21	38
Type I	22	May 11, May 21, May 26	15	25
Type II	17	April 20, April 29, May 7	17	32
Type III	20	May 5, May 20, May 31	26	37
Type IV	17	May 5, May 18, May 28	23	42
Nine stations of PA-GASA	9	May 12, May 21, May 26	14	24

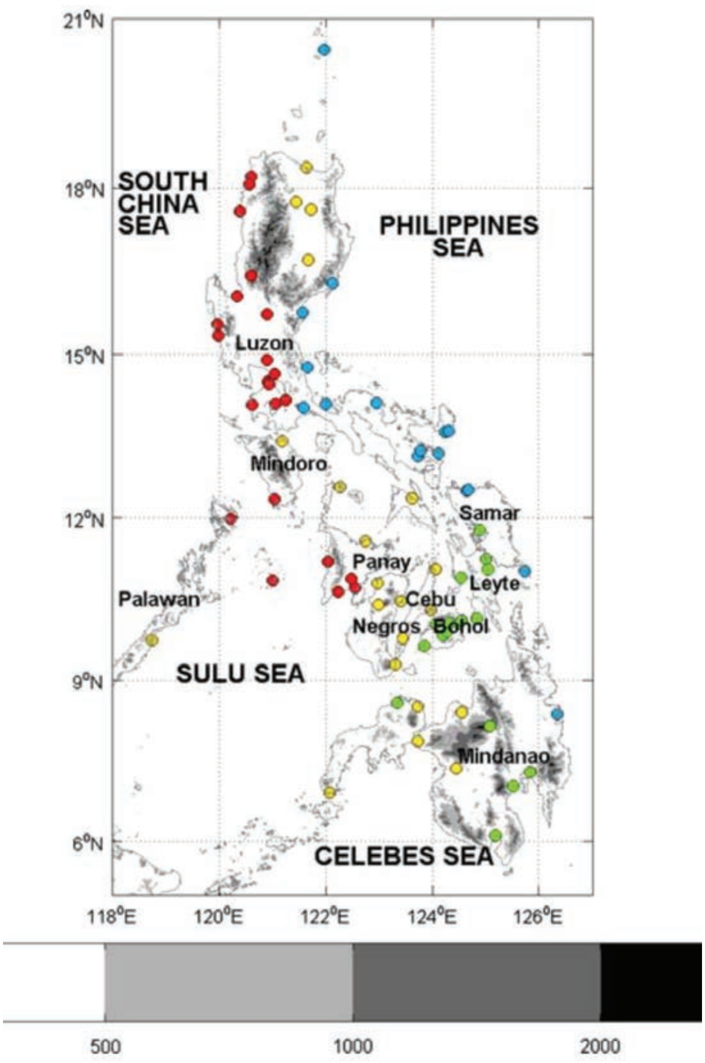

Figure 4.6 Topography (in units of m; shaded) and station locations where the colors indicate the climate types based on the modified Coronas climate classification (Type I: red; Type II: blue; Type III: yellow; Type IV: green (Moron et al., 2009, Figure 1)

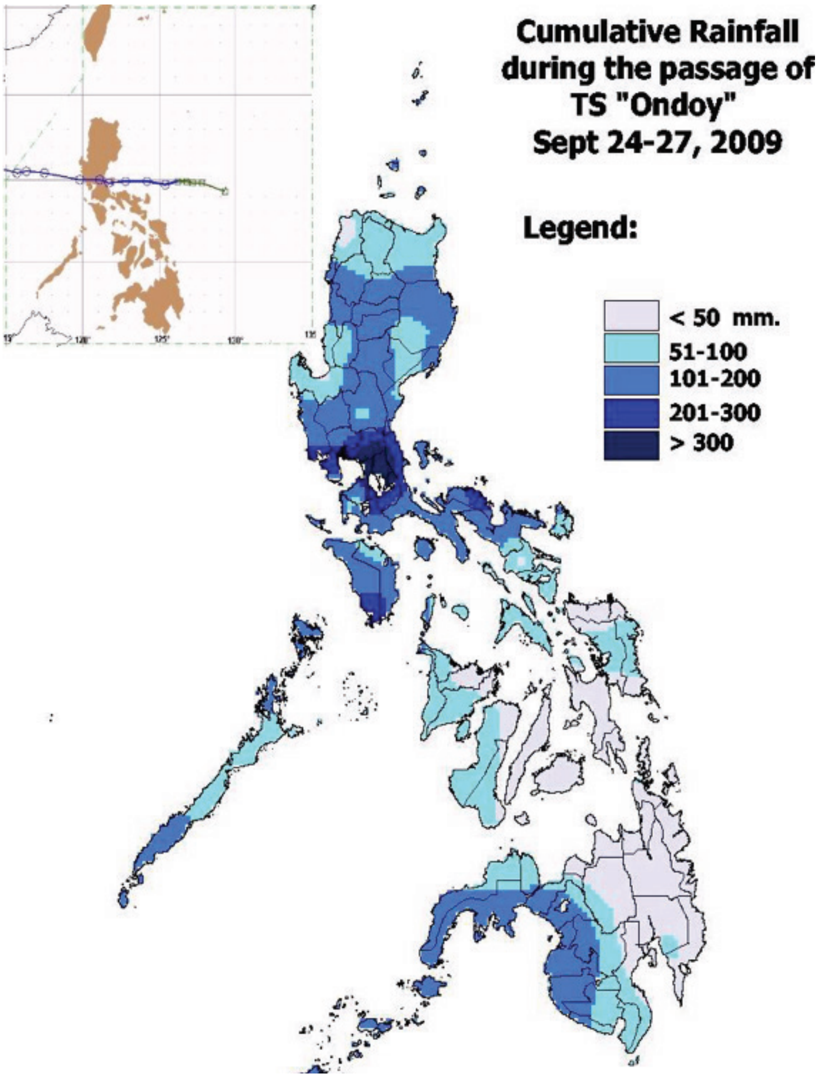

Figure 4.7 Cumulative rainfall during Tropical Storm Ondoy (24–27 September 2009) (Source: PAGASA)

Drought defines an event where precipitation is lower than expected and insufficient to meet the demands of society and the environment, lasting over a long period of time (Hilario et al., 2009; Wilhite, 2006).

Table 4.3 lists the drought events and areas affected in the Philippines during 1968–1998. The most significant drought events occurred in 1982–1983, 1986–1987, and 1997–1998, which were associated with El Niño events, but the drought in 1989–1990 occurred during a neutral condition (Hilario et al., 2009).

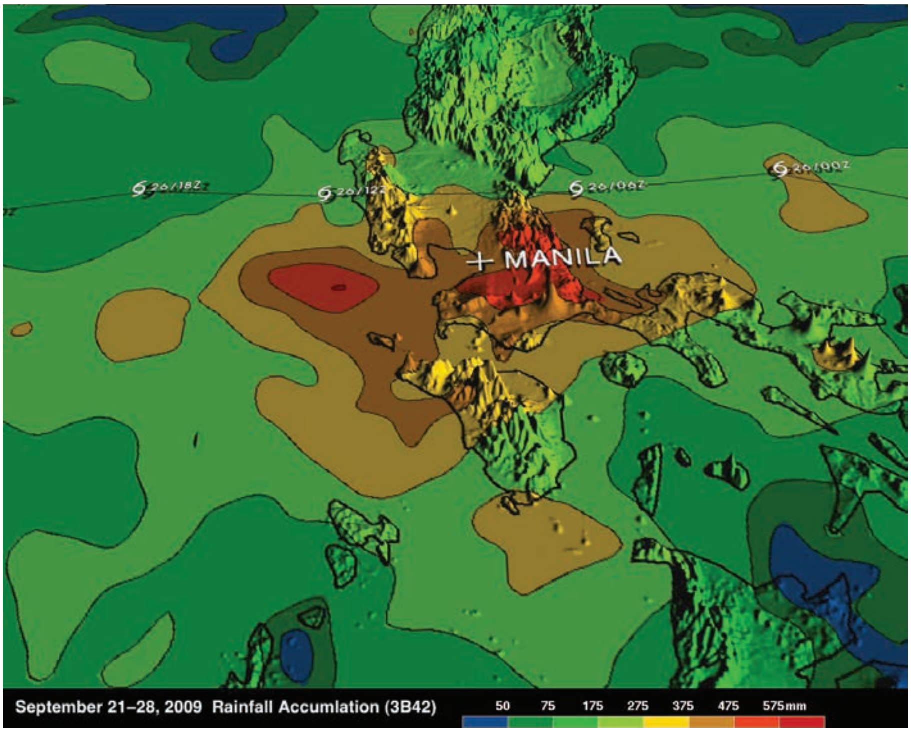

Figure 4.8 Map of flooding rains of Typhoon Ketsana over the Philippines using data from NASA's TRMM satellite (Source: SSAI/NASA, Hal Pierce; NASA, 2009)

Table 4.3 Significant drought events in the Philippines during 1968–1998 (Hilario et al., 2009, Table 2)

Drought event	Areas affected	Damages
1968–1969	Moderate to severe drought over most of the Philippines with Bicol region as most severely affected	Total loss of 5x10^5 Mt of rice and corn production
1972–1973	Central Luzon, Palawan, Visayas, and Mindanao	Total loss of 6.3x10^5 Mt of rice and corn production
1977–1978	All of Mindanao except Davao	Total loss of 7.5x10^5 Mt of rice and corn production
1982–1983 October 1982–March 1983 April–September 1983	Western and Central Luzon, Southern Tagalog provinces, Northern Visayas, Bohol, and Western Mindanao; Moderate to severe drought affected most of Luzon, Negros Occidental, and Iloilo	Total loss of 6.4x10^5 Mt of rice and corn; Insurance claims mounted to PhP38 M; Hydropower generation loss was PhP316 M
1986–1987 October 1986–March 1987 April 1987–September 1987	Severe drought affected Bicol region, Southern Negros, Cebu, and Western Mindanao; Severe drought affected mainland Luzon, Central Visayas, and Western Mindanao	Estimated agricultural damages of PhP47 M; Estimated hydroenergy generation loss was PhP671 M
1989–1990 October 1989–March 1990	Drought affected Cagayan Valley, Panay Island, Guimaras, Palawan, and Southern Mindanao; Affected rice and corn area: 283,562 hectares; Major multipurpose water reservoirs reduced inflow	Estimated 5x10^5 Mt of rice and corn production losses; hydropower generation loss of PhP348 M; 10% cutback in water production in Metro Manila
1991–1992	Severe drought affected Manila, Central and Western Visayas, and Cagayan Valley; Affected agricultural area: 461,800 hectares; 20% shortfall in Metro Manila's water supply	PhP4.09 B in agricultural losses
1997–1998	About 70% of the Philippines experienced severe drought; About 292,000 hectares of rice and corn area completely damaged	622,106 Mt of rice production loss and 565,240 Mt of corn amounting to PhP3 B; water shortages; forest fires and human health impacts

4.3.3 Climate Extremes (Extreme Rainfall Indices)

The trend of extreme daily rainfall intensity was analyzed for the period 1951–2008 based on the amount of rainfall above the top four events during the year (PAGASA, 2011) (or events that exceeded the 99th percentile of rainfall intensity [Cinco et al., 2014]). The results in Figure 4.9 show an increasing trend (+) in most parts of the country, with significant trends (95%,▲) observed only in Baguio (in Luzon), and Tacloban and Iloilo (in the Visayas). However, one station, Coron Island (in Luzon), indicates a significant decrease (▼) in extreme rainfall intensity. Figure 4.10 shows the trend in the frequency of extreme daily rainfall indicated by the number of days with rainfall values greater than the top four events during the year (PAGASA, 2011) (or the number of days with rainfall exceeding the mean 99th percentile [Cinco et al., 2014]). Most of the stations in the country show an increasing (+) trend in the number of days of extreme rainfall events. A few stations (Laoag and Calapan, both in Luzon) and Tacloban and Iloilo (both in Visayas) exhibit significant increases (▲), while Coron and Cuyo (in Luzon) showed significant decrease (▼) in the frequency of intense daily rainfall. Although the period 1951–2008 analysis has shown increases in both the frequency and intensity of extreme daily rainfall events in most stations throughout the Philippines, majority of the stations do not show a high level of statistical significance at the 95% probability level. A high level of variability is seen in these stations.

The trends and variability in rainfall extremes in the Philippines were investigated by Villafuerte et al. (2014), using the 1951–2010 daily rainfall data from 35 selected meteorological stations and 7 extreme precipitation indices. Results of this study show significant decreasing trends in seasonal wet day total rainfall associated with positive trends in maximum length of dry spells, thus indicating a tendency toward a drier dry season (January–March). Conversely, wetter conditions during the rainy (July–September) season in northwest and central Philippines are indicated by significant increasing trends in maximum 5-day rainfall and negative trends in the maximum length of dry spells. Moreover, an extended time series (1911–2010) analysis at selected stations showed that the trends in the 1951–2010 analysis could be consistent with the continuous long-term trends (in Aparri and Masbate), or representative of inter-decadal variability (in Dagupan and Iloilo) (Villafuerte II et al., 2014). It is also noted that ENSO largely influences the yearly variations in the extreme rainfall indices, such that statistically significant drier (wetter) conditions over the Philippines occur, particularly near the mature stage of the El Niño (La Niña) event (Villafuerte II et al., 2014).

Globally, recent observational and modeling studies have shown that the warmest (coldest) temperature extremes, i.e., minimum temperatures have significantly increased (decreased) over the 20th century and will increase (decrease) throughout the 21st century (Arblaster & Alexander, 2005; IPCC, 2012, 2013). On the other hand, while changes in precipitation (rainfall) extremes are less coherent than those in temperature (Alexander et al., 2006), there is evidence that suggests that globally, there have been more flood/drought-inducing events in the recent record that could continue in the future.

Consistent with observed warming, extreme rainfall events (with 350-mm rainfall or higher) have been more frequent in the latter part of the 20th century (Thomas et al., 2013). However, there are no clear trends in annual total rainfall, due in part to the decadal variation caused by changes in atmospheric circulation.

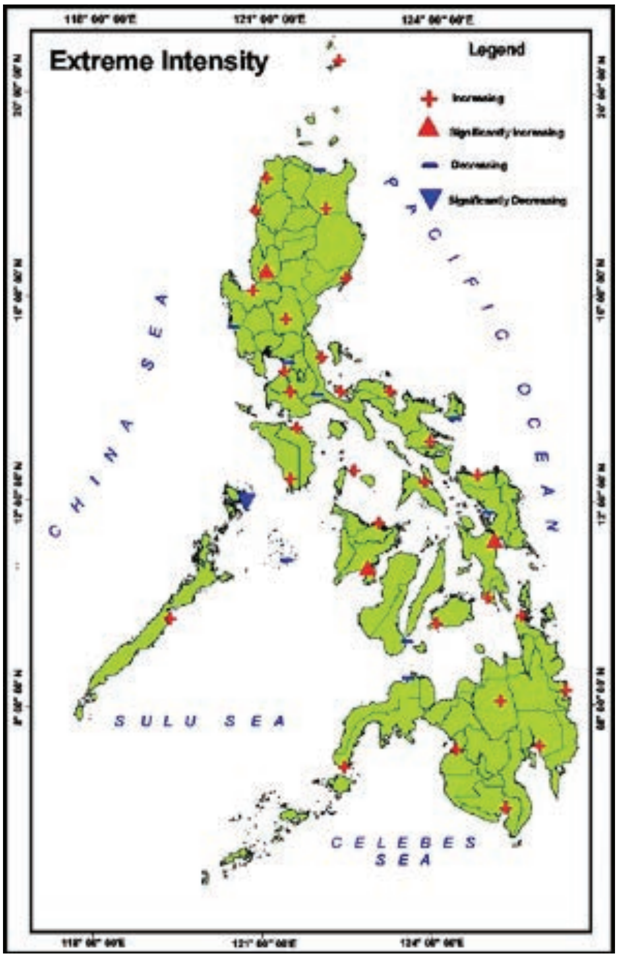

Figure 4.9 Trends in extreme daily rainfall intensity, i.e., rainfall values greater than the top four events during the year, from 1951–2008 (reference period: 1971–2000) (PAGASA, 2011, Figure 14)

4.3.4 Extreme monsoon performance

On monsoon activity, the most notable extreme event was the enhanced southwest monsoon or locally termed as *habagat* that was observed on 6–8 August 2012 based on PAGASA records. This brought great flooding over Metro Manila and surrounding provinces and caused damage to infrastructure and agriculture amounting to about PhP639 M and PhP1.6 B, respectively, according to the National Disaster Risk Reduction and Management Council (NDRRMC) reports. A death toll of 95 persons was recorded and more than 800,000 families were left homeless. Daily rainfall of 323.4 mm (on August 6), 391.4 mm (on August 7), and 292.6 mm (on August 8) were recorded at the Science Garden PAGASA station in Quezon City. The total three-day rainfall of 1,007.4 mm for August 6–8 was almost double the monthly normal rainfall in August (504.2 mm) at the observing station. The daily rainfall was continuous for 24 days from July 16 to August 8 with a peak on August 6–8.

Changes in monsoon-related extreme precipitation and winds due to climate change are not well understood. In the Indo-Pacific region covering the southeast Asian and north Australian monsoon, Caesar et al. (2011) found low spatial coherence in trends in rainfall extremes across the region between 1971 and 2005. However, a general trend towards wetter conditions was observed in the few instances where the trends in precipitation extremes were significant (Alexander et al., 2006; Caesar et al., 2011).

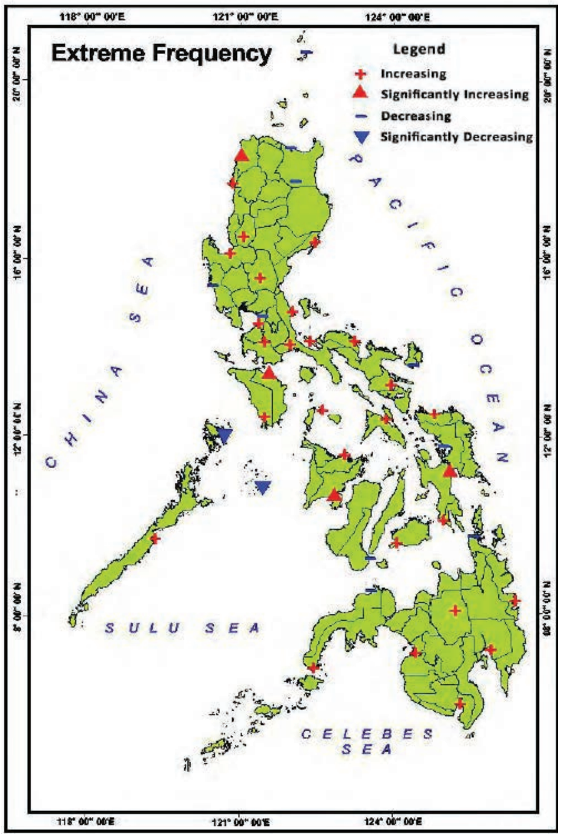

Figure 4.10 Trends in extreme daily rainfall frequency, i.e., number of days with rainfall values greater than the top four events during the year, from 1951–2008 (reference period: 1971–2000) (PAGASA, 2011, Figure 15).

4.4 TROPICAL CYCLONES

The Philippines is located in the Western North Pacific (WNP) area, where about one-third of the world's tropical cyclones (TCs) develop (Cinco et al., 2016). During the period 1951–2013, a total of 1,220 TCs entered the Philippine Area of Responsibility (PAR), an area bounded by 25°N 120°E, 20°N 120°E, 15°N 115°E, 5°N 120°E, 5°N 135°E, and 25°N 135°E. About half (49%) of the TCs that enter the PAR formed in the Western Pacific Ocean, 43% mostly in the eastern part of PAR, and the remaining 8% in the West Philippine Sea, as shown in Figure 4.11a. The analysis further shows that the areas where these TCs exited the PAR were over the West Philippine Sea (14%), mainland Asia (27%), within the PAR itself (22%), to the north towards Japan (32%), and in the Western Pacific Ocean (5%) as can be seen in Figure 4.11b.

There is an annual average of 19.4 TCs within the PAR, with an annual average of nine making landfall (cross) in the Philippines. The months from July to September had the most number of TCs in the PAR, while on the other hand, July, October, and November were the months when many TCs made landfall (Figure 4.12) (Cinco et al., 2016).

To show which areas in the country were most affected by these TCs, a spatial analysis was made (Figure 4.13). The highest number of TCs crossed the northeastern Philippines (shown shaded in the figure), while the region with the least number with very few to none during the period was the southwestern part of the country (shown horizontally hatched in the same figure) (Cinco et al., 2016).

A 2012 study which used 1965–2000 dataset of TC occurrence in the WNP indicates that during July to September in this period, most TCs in the WNP are generated in the Philippine Sea and the West Philippine Sea within the region from 10°N to 25°N (Ying et al., 2012). The study describes the three prevailing tracks of TCs in the WNP, which consists of a track moving westward; a recurving track heading towards Japan or Korea; and a recurving track moving northeast, east of 140°E.

4.4.1 Trends and Changes in Tropical Cyclone Frequency, Intensity, and Trajectory

PAGASA (2011) indicates that the annual frequency (i.e., number per year) of TC occurrence in the PAR as shown in the 1948–2010 time series reveals no indication of increasing trends (Figure 4.14). The highest number per year is 32 (in 1993), while the lowest is 11 (in 1998 and in 2010). There is no significant trend in the annual TC number but there is a slightly decreasing trend in the number of TCs crossing the Philippines, especially in the last 20 years, as shown in Figure 4.15 (Cinco et al., 2016).

Summarizing the analysis of TC intensity in the PAR, Cinco et al. (2016) found an annual average of five tropical depressions (with maximum winds less than 63 kph), six tropical storms (with maximum winds of 64–117 kph) and nine typhoons (with maximum winds greater than 118 kph) during 1971–2013. There are no trends in the number of the low intensity TCs, but typhoons have decreased in frequency, signaling that TCs entering the PAR were less intense during the period (Table 4.4; Figure 6 of Cinco et al., 2016).

In terms of extreme TCs (with maximum winds greater than 150 kph), there has been an average of 5.8 per year occurring in the PAR (Cinco et al., 2016; PAGASA, 2011). Analysis of the typhoon chronology in the Philippines from 1566 to 1900, elaborated in 1935 by the Spanish Jesuit Fr. Miguel Selga, showed that during the 1866–1900 period, the record is considered indicative of the total typhoon incidence in the Western Pacific Basin, and that the typhoons making landfall in the Philippines extracted from the chronology had an annual average value of 5.5 (García-Herrera, Ribera, Hernández, & Gimeno, 2007). However, differences in these past records, e.g., typhoon definition, instruments, and reporting also need to be considered when comparing with present observations.

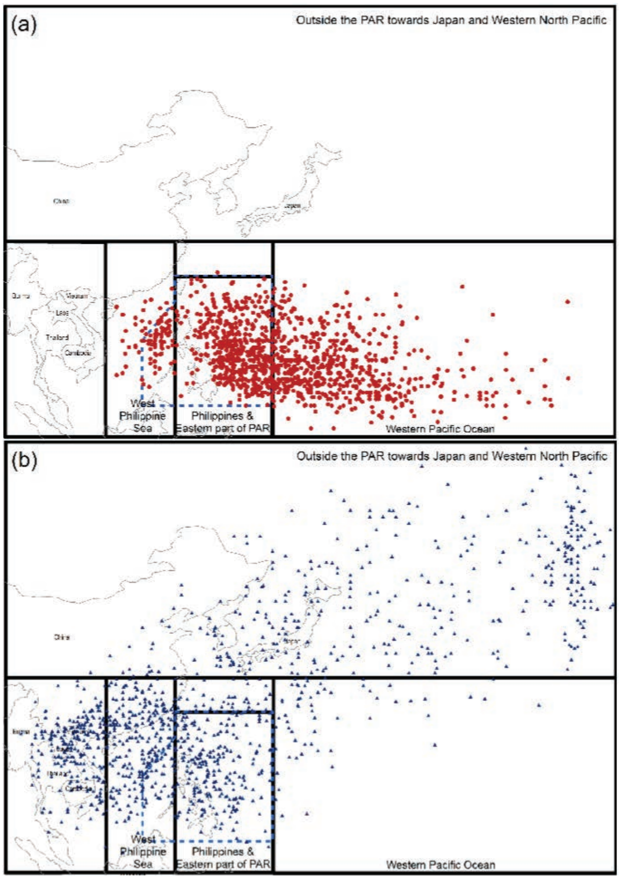

Figure 4.11 Areas of (a) TC formation (circles) and (b) TC exit/dissipation (triangles) covering the period 1951–2013. The blue dashed line indicates the PAR (Cinco et al., 2016, Figure 1).

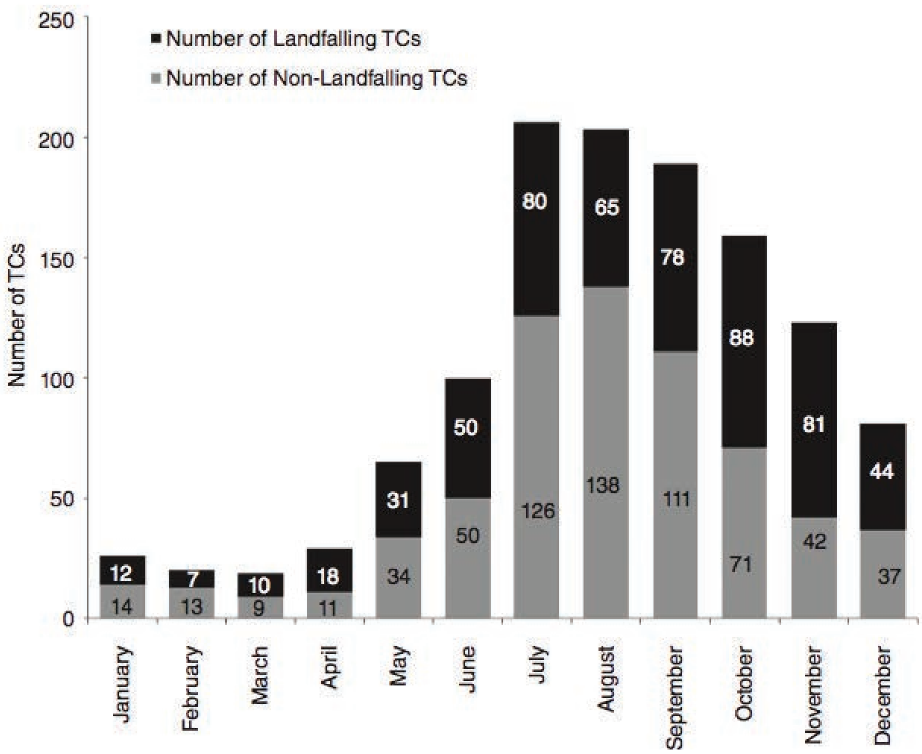

Figure 4.12 Number of landfalling and non-landfalling TCs entering the PAR from 1951 to 2013 (Cinco et al., 2016, Figure 4).

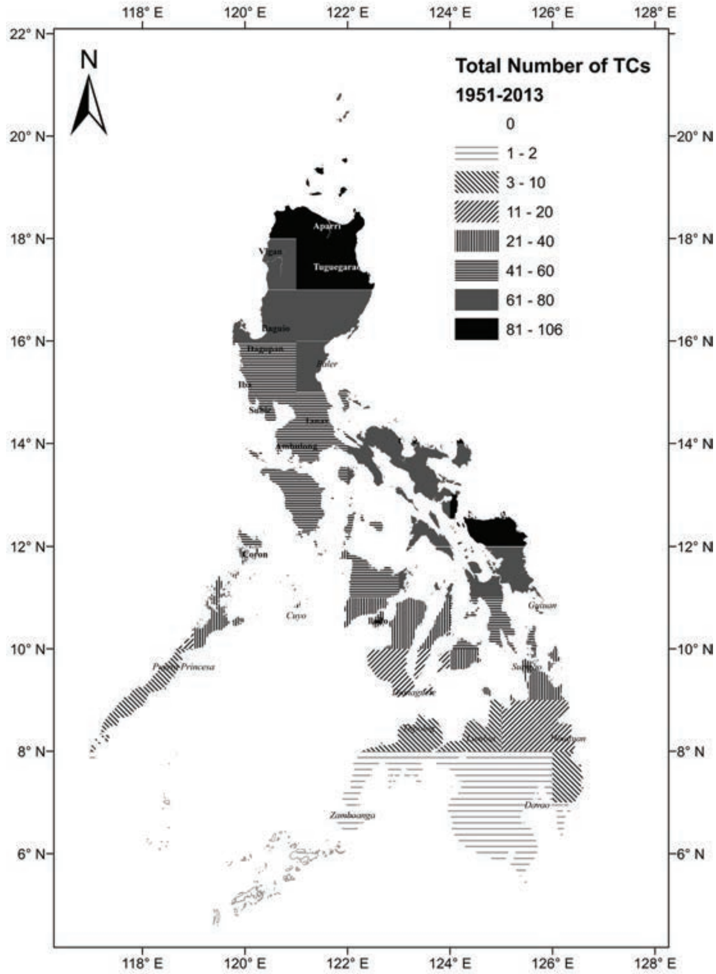

Figure 4.13 Total number of TCs per 1° x 1° grid, for the period 1951–2013 (Cinco et al., 2016 Figure 3).

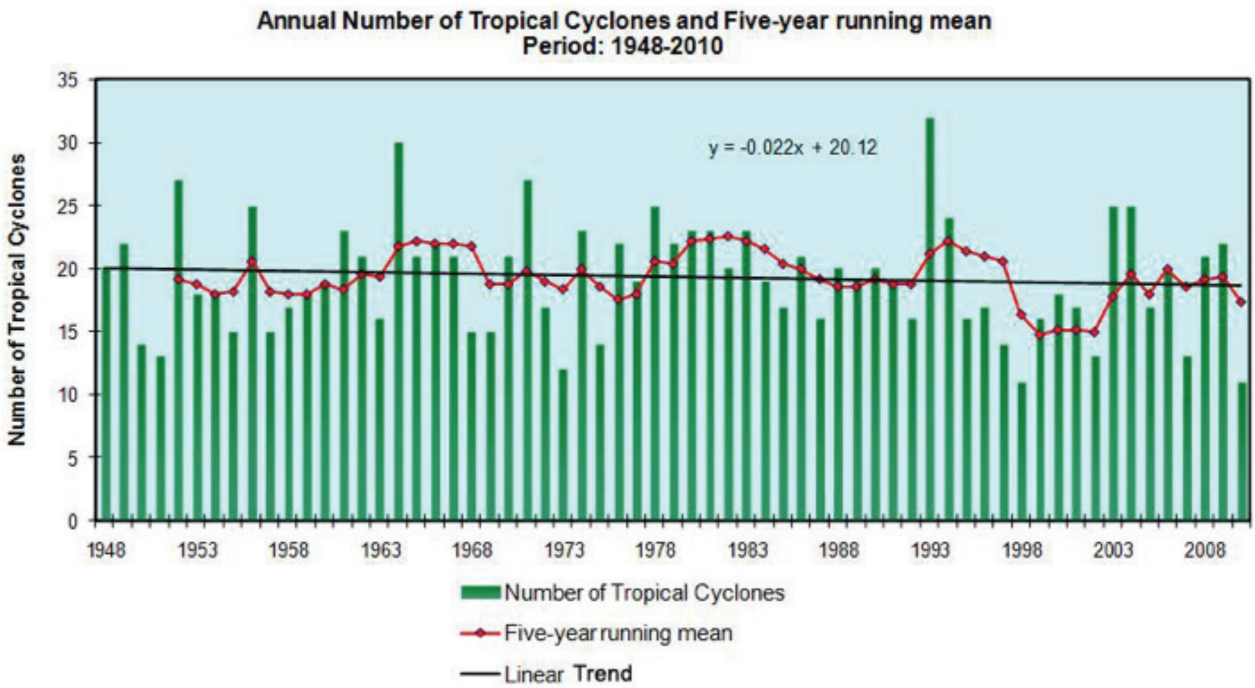

Figure 4.14 Annual number of tropical cyclones within the PAR from 1948–2010 (PAGASA, 2011, Figure 9)

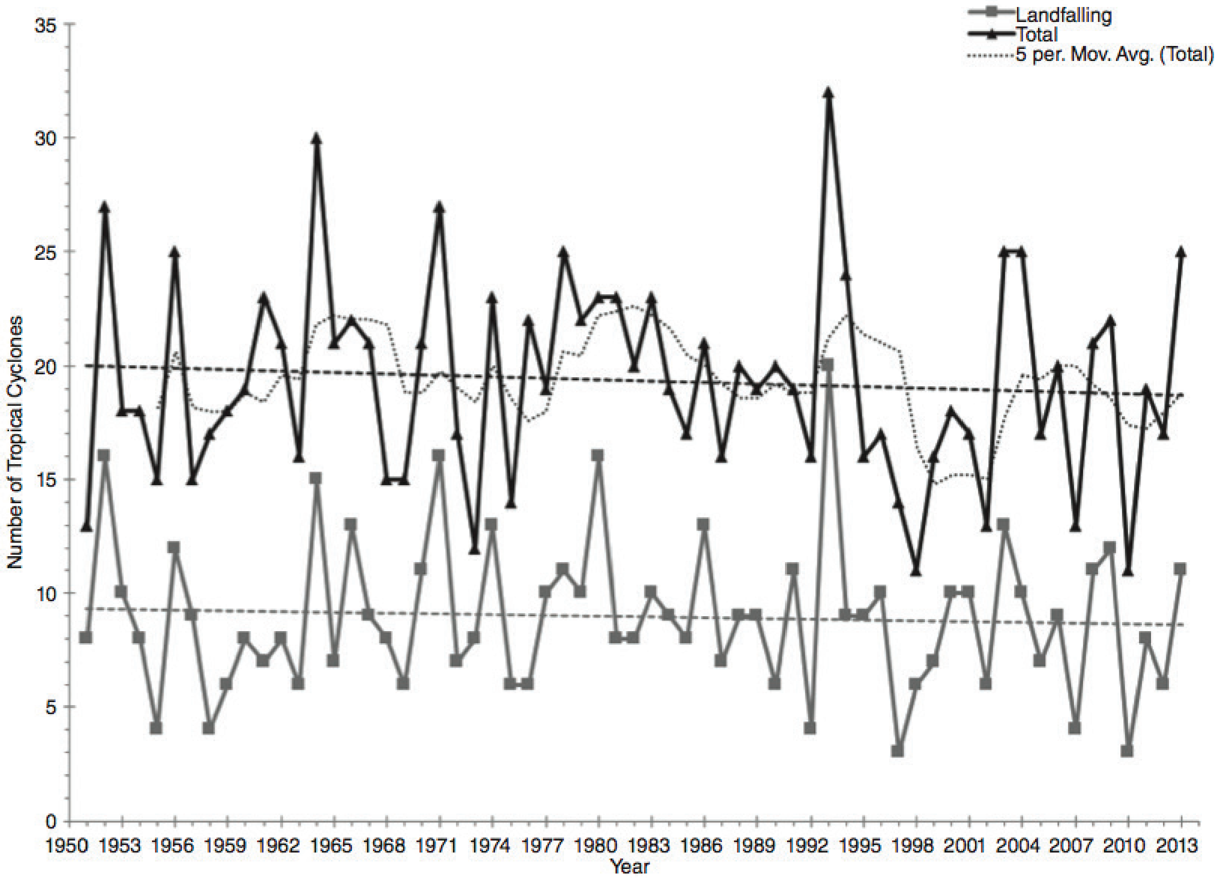

Figure 4.15 Total number of TCs (including landfalling TCs as indicated by the grey line) per year in the PAR. The dotted line shows the 5-year running mean, while the dashed line the linear trend for the period 1951 to 2013 (Cinco et al., 2016, Figure 2).

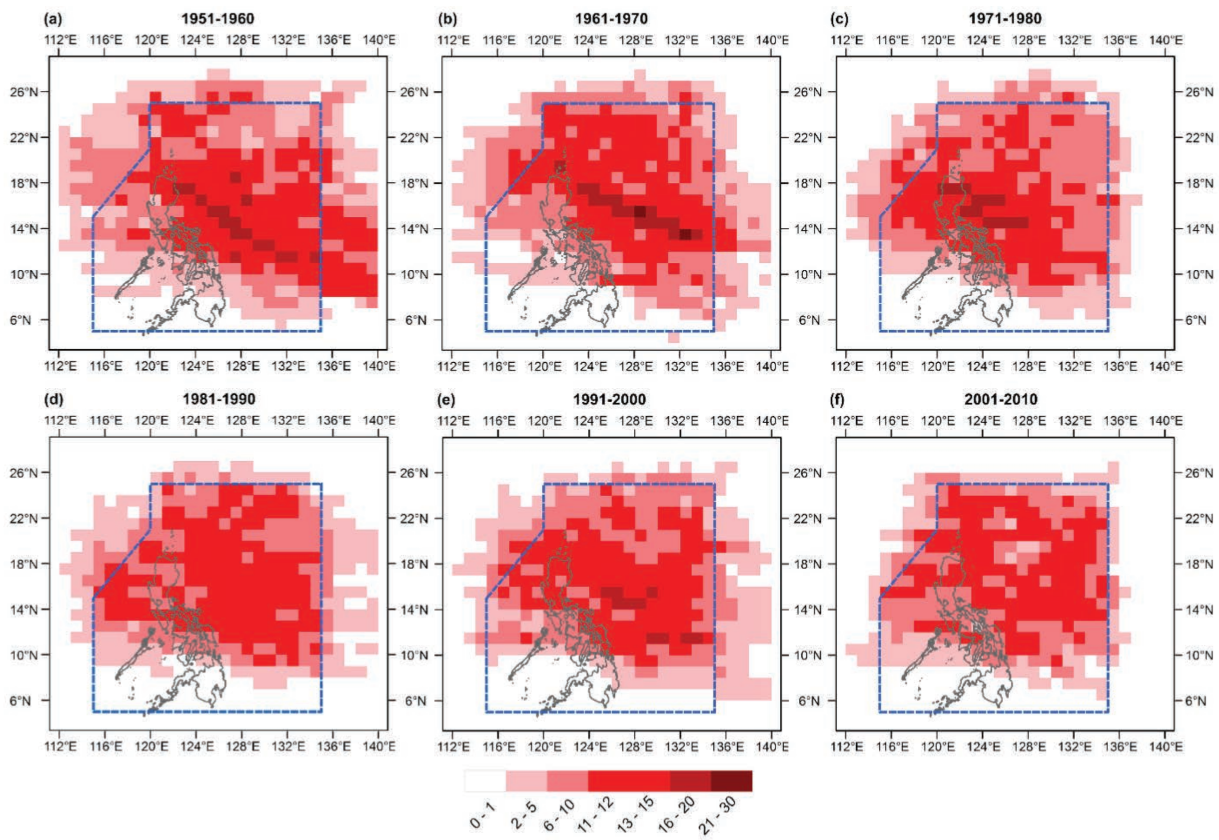

Figure 4.16 Number of TCs per decade plotted on a 1° x 1° grid from 1951–2010. The PAR is indicated by blue dashed line (Cinco et al., 2016, Figure 5).

Table 4.4 Number of TCs per decade entering the PAR according to category for the period 1951 to 2010 (Cinco et al., 2016, Table 1).

Decade	Total number of TCs		Number of tropical depression (TD)		Number of tropical storm (TS)		Number of typhoons (TY)	
	Entered	Crossed	Entered	Crossed	Entered	Crossed	Entered	Crossed
1951–1960	185	85	27	14	37	16	121	55
1961–1970	205	91	41	14	57	25	107	51
1971–1980	204	104	56	25	57	28	91	50
1981–1990	198	87	33	12	59	27	106	48
1991–2000	183	89	41	19	61	37	81	33
2001–2010	184	83	49	27	55	28	80	30
Total	1159	539	247	111	326	161	586	267
Mean	193	90	41	19	54	27	98	45

One of the factors in the seasonal and yearly variations of TC frequency is associated with the ENSO or El Niño event. During July to September of El Niño (La Niña) years, there is a tendency for enhanced (reduced) tropical cyclone activity due to higher (lower) atmospheric moisture availability that affects the genesis of TCs, and this subsequently reverses during October to December (Lyon & Camargo, 2009; Lyon et al., 2014). Other studies have shown a shift in genesis location during El Niño (La Niña) years, i.e., farther to the southeast (northwest) of the climatological mean genesis point, leading to changes in the track, intensity, and lifetime of the TCs (Camargo, Emanuel, & Sobel, 2007; Lyon et al., 2014). More typhoons also cross the northern Philippines in La Niña years compared to El Niño years (Lyon et al., 2014; Saunders et al., 2000). Also, Kubota and Chan (2009) showed that the interdecadal variation in the yearly number of TC landfall in the Philippines during 1902 to 2005 is related with the phases of both ENSO and the Pacific Decadal Oscillation (PDO). For example, there are fewer (more) landfalling TCs in the Philippines during El Niño (La Niña) years during the low phase of the PDO (Kubota & Chan, 2009).

Furthermore, Zhao, Wu, and Wang (2013) found that the decadal variability in the frequency of intense TCs (category 4 and 5) over the Western North Pacific during 1948–2010 largely depends on shifts in the TC track associated with changes in genesis locations. However, the combined effect of changes in sea surface temperature and vertical wind shear can also influence decadal variations (Zhao et al., 2013).

Overall, observations indicate inter-decadal variability in frequency, intensity, and power dissipation index (PDI) of TCs over the Western North Pacific region (Ying et al., 2012). Satellite-based intensity data have been used to examine trends since 1981 but conclusions can be limited given the short period of these datasets, which also makes it difficult to discount natural variability. Although there are indications of a rising tendency in the PDI, as well as a low-frequency correlation with sea surface temperatures (SST), issues of data homogeneity in the region further complicate the effort to ascertain the role of natural variability (Ying et al., 2012).

In summary, it is still uncertain whether there is a discernible human influence on these TC changes in the WNP region (Ying et al., 2012). While there are no significant trends in the frequency, intensity, and landfall of TCs, costs of damages in the country are becoming increasingly high as seen in the aftermath of Typhoon Yolanda which claimed thousands of lives and caused extensive damage to property and infrastructure (Cinco et al., 2016; Lagmay et al., 2015).

4.5 WIND PATTERNS

4.5.1 Trends and Changes in Winds

An effort to assess extreme winds is the PAGASA report summary of extreme wind observations made at meteorological stations during the 1948–1996 period (Rellin, Jesuitas, Sulapat, & Valeroso, 2011). The data include the maximum wind speeds observed in a given month during the whole period. Taking the maximum over 12 months yields the maximum observed wind speed during the 48-year period for the station in question. The data show large geographical variations in extreme winds. The general trend indicates that the extreme winds are stronger in the northern and eastern parts of the country. This is in agreement with the general pattern of typhoon trajectories over the country.

4.6 DIRECTIONS FOR FUTURE STUDIES

Zwiers et al. (2013) noted the challenges in the research on extremes, such as the quality of observational records, and limitations in methods for analysis, in the understanding of the processes behind extreme events, and in the ability to resolve the natural variability of extremes in models. In other words, natural and warming-related variability are difficult to ascertain.

In the Philippines, one of the numerous challenges is the physical science assessment of climate change. Assessment of observational evidence of climate change and trends is constrained by the limited number of observing stations across the country and the fact that the current observing network does not adequately represent the diversity of local climates across the country. The Philippines is archipelagic and is composed of more than 7,000 islands, but it has a very limited number of long-term observing stations. Moreover, most of the long-term weather stations (mostly synoptic) were established near airports, and not many have been added over the years. Moreover, after many of these synoptic stations were set up, a number of changes such as infrastructure (e.g., mostly added buildings and runways) have made recent observations less representative of the real ambient conditions unless these stations were relocated.

Efforts can be directed to the analysis of an older set of historical observations made in the late 19th to the early 20th century, since analysis of longer datasets can discern significant change over time.

In view of the observational, analytical, and modeling work done in various places such as the national meteorological/hydrological agency, academic institutions, and the different national and local research centers, there is need for a mechanism to collate, integrate, and transform all the work into different sets of outputs that will be relevant for impact assessments, adaptation and mitigation planning, and knowledge management.

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CHAPTER 5

Observed Changes in Ocean Climate and Sea Level in the Philippines

AUTHORS

Andrea Monica D. Ortiz
John Leo C. Algo
Fernando P. Siringan
Faye Abigail T. Cruz

5.1 CHAPTER SUMMARY

The complex interaction between the ocean and the atmosphere significantly influences the long-term development of weather and climate that affect the earth's many ecosystems (Manabe, 1969). The oceans transport and store large amounts of heat, freshwater, and carbon. Its exchange and interaction with climate is a crucial component of planetary heating and the redistribution of heat and water around the earth (IPCC, 2013).

Because of the enhanced greenhouse effect and subsequent warming, ocean dynamics are being affected and are expected to change under future climate scenarios. In the understanding of oceans and their relationship to climate, several factors can be observed and monitored, including changes in sea surface temperature (SST) and sea level rise (SLR), based on the historical record as well as paleo-ocean SST and sea level based on proxy data.

The Philippines, being an archipelagic country, is greatly affected by the ocean and its dynamics. There is large-scale variability in SST due to the El Niño Southern Oscillation (ENSO). In addition, trends show that ocean surface temperatures have been increasing. Globally, an estimate of the observed increase in SST from 1979 to 2012 is 0.124°C ± 0.03°C for every decade (Hartmann et al., 2013). Near the Philippines, SST have been increasing by around 0.23°C ± 0.02°C per decade from 1981 to 2014 (Comiso, Perez, & Stock, 2015). Current projections indicate the continued increase in global ocean temperatures (IPCC, 2013).

In the IPCC AR5, Working Group I reports that the rate of SLR at a global scale since the mid-19th century is higher than the past two thousand years. It is reported with high confidence that about 75% of the global SLR since the early 1970s is due to changes in glaciers and ocean thermal expansion as a result of warming (IPCC, 2013). Although the dynamics and impacts of melting glacier ice and sea-ice have yet to be fully understood, historical data from a global and local perspective have shown that sea levels have been rising and may pose a hazard particularly to coastal ecosystems and settlements.

While some studies have been carried out in limited localities, there is still a gap in the availability of local sea level rise data. Thus, information on sea level rise for the entire country is limited. Satellite data are often used, coupled with tide gauge station data, to provide context about local sea level rise.

5.2 SEA SURFACE TEMPERATURE

Introduction and global trends

The monitoring of sea surface temperature (SST) is an important aspect of understanding climate and its changes. Global SST data are generated to monitor climate change, but SST is also an important variable in climate system modeling, e.g., for comparison with ocean models, and as boundary condition for atmospheric models (Reynolds & Smith, 1994). Using different SST data in models can affect moist convection and circulation, especially over tropical regions, which consequently influence temperature and precipitation locally, as well as around the world via global teleconnections (Hurrell & Trenberth, 1999).

Long-term trends and variability in observed ocean temperature indicate contributions from both natural and anthropogenic forcings. As mentioned in Chapter 2, the IPCC (2013) reported an increase in the ocean temperature in the upper 75 m by 0.11°C ± 0.02°C/decade during 1971–2010. Based on scientific literature, records, and monitoring, it is virtually certain that the upper ocean (above 700 m) has warmed from the last four decades (1971–2010), and human activities have very likely contributed to the upper-ocean warming during this period (IPCC, 2013; Stocker et al., 2013).

The IPCC also reports that it is likely that the ocean layer below 3,000 m warmed from 1992 to 2005, especially in the Southern Ocean. However, the IPCC reports that there is less certainty in changes prior to 1971 because of relatively sparse sampling in earlier time periods. Instrumental biases have been identified and corrected as much as possible (IPCC, 2013).

Southeast Asia and the Philippines

In the tropics and in the Pacific where the Philippines is located, there is a general understanding that the temperatures of the sea surface are higher than normal during ENSO events. However, there is a lack of direct monitoring by the country and so SST data are typically obtained from satellite images and global data. In addition, there are still significant differences among SST analyses and there is no set that is universally the best for all purposes (Hurrell & Trenberth, 1999). Because of the variability in the changes in the ocean during ENSO, more research should be undertaken to gain better understanding of the physical processes during this event (Salamante & Villanoy, 2000).

In a study by Salamante and Villanoy (2000), the spatial and temporal variations of SST of the water surrounding the Philippines and its relationship with ENSO events were examined using an Empirical Orthogonal Function (EOF) analysis on satellite-based monthly SST. Three periods are considered: strong, weak, and non-ENSO events. Based on these satellite images, SST in the Sulu Sea was estimated to reach 26°C to 30°C during non-ENSO events, but may be warmer by 1°C during a weak ENSO year whilst maintaining the minimum temperature. On the other hand, temperature is estimated to be from 27°C to 31°C during a strong ENSO event. In the Celebes Sea, SST ranges from 29°C to 30°C during the year in all cases (Salamante & Villanoy, 2000). In the Philippine Sea, SST variations tend to be similar in the winter during weak and non-ENSO events but the minimum temperature can vary by 1.4°C in July (Salamante & Villanoy, 2000).

Results from the first three EOF modes describe the link between SST variations and ENSO events, particularly over the West Philippine Sea and the Philippine Sea, such as decreased inflow of cold water from the north, lower upwelling, and weak seasonal variability (Salamante & Villanoy, 2000). Salamante & Villanoy (2000) also note that circulation in the West Philippine Sea basin can be affected by changes in the prevailing winds during ENSO, leading to a warmer upper ocean.

In a regional study of SST in the Coral Triangle region, Manessa and As-syakur (2011) investigated patterns of SST variability and the relationship with ENSO in the Coral Triangle using monthly SST data from the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) for the period 1982–2009. Since the Coral Triangle region is around the warm pool of El Niño (La Niña), SST is highly variable in this region, where some areas indicate warming (Gaol & Nababan, 2011; Hoegh-Guldberg, 2011; Manessa & As-syakur, 2011; Peñaflor, Skirving, Strong, Heron, & David, 2009; Sukresno & Kasa, 2008; Susanto, Moore, & Marra, 2006). This study is relevant to the region particularly because above-normal SST has been linked to widespread coral bleaching and ocean acidification (Hoegh-Guldberg, 2011; Manessa & As-syakur, 2011). Warm ocean conditions will be critical for the Philippines and the Coral Triangle itself, which is a center of marine biodiversity (Manessa & As-syakur, 2011; Veron et al., 2009). The NOAA AVHRR data showed that one zone of the Coral Triangle region covering the eastern Philippines and Palawan/North Borneo have SST temperatures that are low during January and February, and are high between May and June, which they attribute to the monthly variation in the sun's position relative to the equator (Manessa & As-syakur, 2011). The study also showed positive SST tendencies (i.e., increasing trend) over this zone in all months, except for May, August, and October over Palawan/North Borneo.

In a recent study, Comiso et al. (2015) estimated that monthly SST in the Western Pacific region, including the Philippine Sea, have been increasing by around 0.23°C ± 0.02°C per decade from 1981 to 2014 based on high resolution NOAA SST data provided by NOAA/OAR/ESRL/PSO. Observations also show a higher increasing trend in the annual minimum SST values compared with the annual maximum SST, which indicates a likely warmer ocean mixed layer. Furthermore, the correlation of SST in the Pacific with maximum winds associated with strong typhoons may have implications on the likelihood of intense typhoons in the future given warmer SST (Comiso et al., 2015).

Touching on impacts and projections

Situated in the Indo-Pacific area, the Philippine archipelago is rich in species and ecosystem biodiversity. Changes in climate will have an impact on both terrestrial and aquatic ecosystems. Coastal areas will most likely be vulnerable, with its high population density who also heavily rely on coastal resources. In addition, coral reefs generate significant economic benefits for the country (Capili, Ibay, & Villarin, 2005).

The warming of ocean waters has already resulted in high losses and damages to coastal resources, as evidenced by the mass bleaching of corals during the 1997–1998 ENSO. Warmer conditions will increase susceptibility to stress, in addition to overfishing, ocean acidification, and destruction of natural habitat that cause fish catch decline (Capili et al., 2005).

The ocean temperature continues to increase under this changing climate. Globally, an estimate of the observed increase in SST from 1979 to 2012 is 0.124°C ± 0.03°C for every decade (see Table 2.5 of Hartmann et al., 2013). Current projections indicate the continued increase in global ocean temperatures (IPCC, 2013). More information on the impacts of climate change, including warming oceans, can be found in the report of Working Group II of the Philippine Climate Change Assessment.

5.2.1 Paleo-Sea Surface Temperatures

Isotopic time series from coral skeletons have been used to estimate and understand paleo-sea surface temperatures and salinity, particularly in tropical oceans. Quinn et al. (1998) used data from a 335-year (1657–1992) coral stable isotope record over New Caledonia, a relatively undersampled site, to help fill gaps in climate records. In contrast to the eastern equatorial Pacific, the warm phase of ENSO results in lower SST and reduced rainfall at New Caledonia.

A warming trend was found based on the long-term coral $\delta^{18}O$-based SST, but with decadal variability (Quinn et al., 1998). Annual average SSTs between 1658 and 1900 are estimated to be about 0.3°C colder than the 20th century average, with decadal variations ranging from 0.5°C to 0.8°C (Figure 5.1). There is only modest agreement with other coral records in the Pacific, but the mean annual $\delta^{18}O$ record from Cebu, Philippines also indicates an increasing trend (Figure 5.2).

Relevant to the relationship of anthropogenic activities to a warming climate is their finding of a reduction in coral $\delta^{13}C$ (carbon isotope) values starting from the mid-1800s, which may indicate the anthropogenic impact on the carbon reservoir (Quinn et al., 1998). It is important to note that large-scale emissions of CO_2 began in the 1950s, with the annual average emissions increasing at a higher rate than the 1850–1950 average (IPCC, 2013).

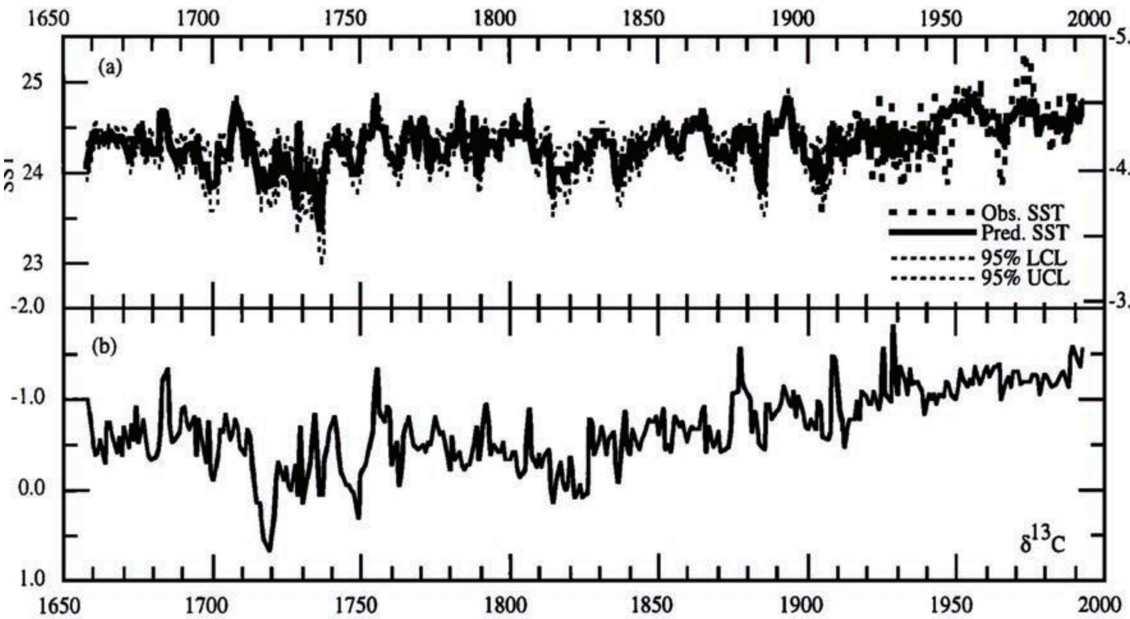

Figure 5.1 Plot of (a) mean annual coral $\delta^{18}O$ and (b) $\delta^{13}C$ over a 335-year record. Solid line in (a) shows modeled SST variations (Quinn et al., 1998, Figure 6).

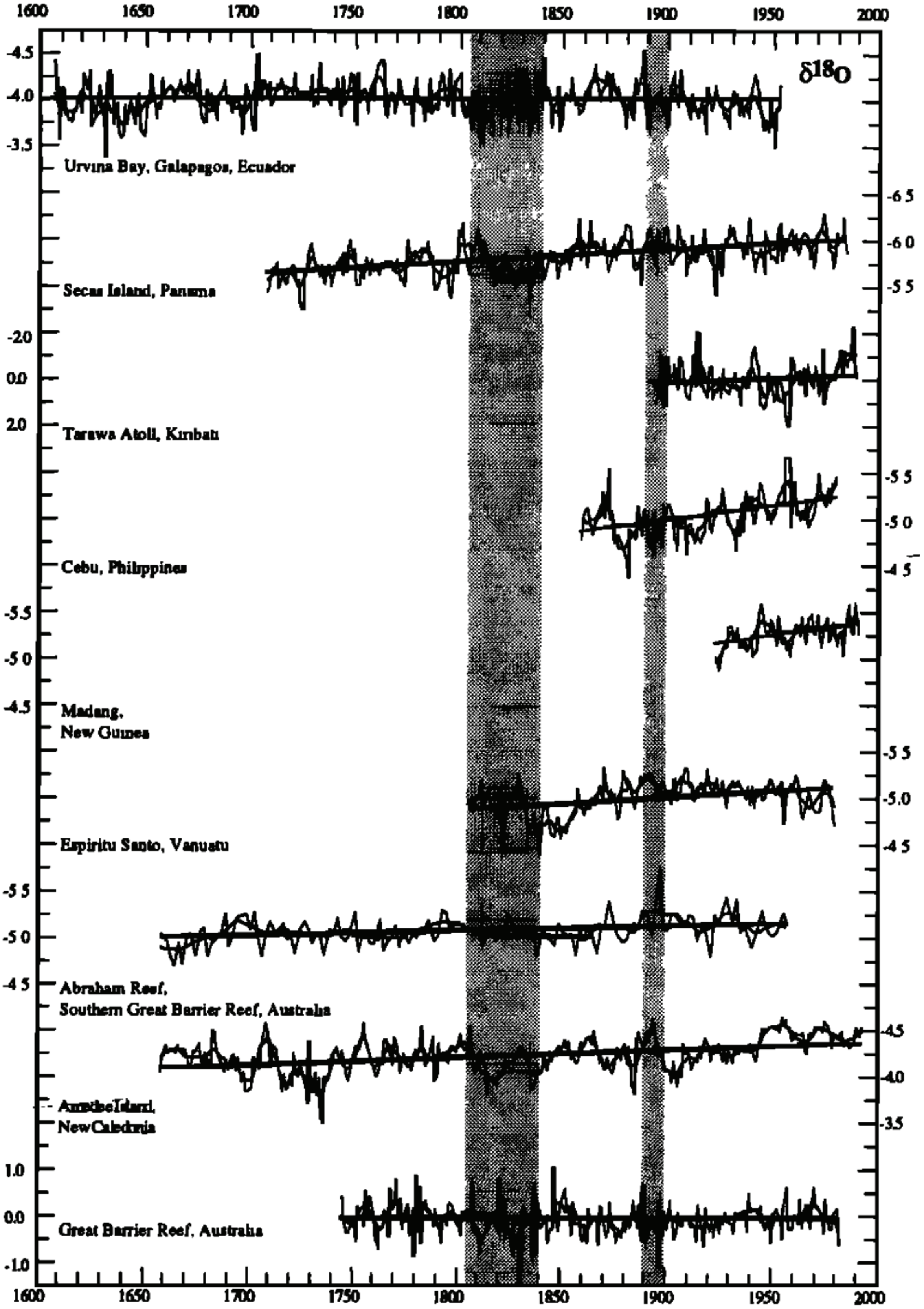

Figure 5.2 Pan-Pacific coral time series (Quinn et al., 1998, Figure 10).

5.3 SEA LEVEL

Introduction and global trends

Sea level rise (SLR) is a consequence of climate change and increasing greenhouse gas levels. It has potentially serious impacts on coastal ecosystems and settlements. Observational records indicate the increase in global sea level in the 20th century (Hu & Deser, 2013).

In the Fifth Assessment Report of the IPCC, Working Group I reports that the rate of SLR at a global scale since the mid-19th century is higher than the past two thousand years. It is reported with high confidence that about 75% of this global SLR since the early 1970s is due to changes in glaciers and ocean thermal expansion as a result of warming. A major source of this ice loss from the past decade is from the increasing ice loss in the Greenland Ice Sheet, as a result of both higher surface melting and ice discharge to the ocean (Nick et al., 2013).

Climate-induced SLR is mainly a result of (1) thermal expansion of seawater as it warms (related to warming ocean temperatures), and (2) the melting of land-based ice. Land-based ice is comprised of (a) small glaciers, (b) the Greenland Ice Sheet, and (c) the West Antarctic Ice Sheet (Nicholls, 2011; Perrette, Landerer, Riva, Frieler, & Meinshausen, 2013). In its Fifth Assessment Report, the IPCC reports with high confidence that the sum of these contributions to the global mean SLR from 1993 to 2010 is 2.8 [2.3 to 3.4] mm per year. The contribution from ocean thermal expansion brought about by warming is 1.1 [0.8 to 1.4] mm per year, which is almost 40% of the total.

While there is scientific evidence of global changes to mean sea level, the degree of change in sea level has a geographic dependence. Changes in wind and ocean currents, as well as gravitational effect of ice sheets, can affect local sea levels (Perrette et al., 2013).

Figure 5.3 shows the non-uniform changes in sea level during 1993 to 2009. Regions in red—close to the Philippines and other Pacific small islands—exhibit the highest sea level changes annually. However, different physical processes at varying time scales influence the spatial variability of sea level rise. Continued measurements from remotely-sensed and in situ instruments, and improved global coupled climate models are necessary to understand and identify these processes in the sea level record (Willis, Chambers, Kuo, & Chum, 2010).

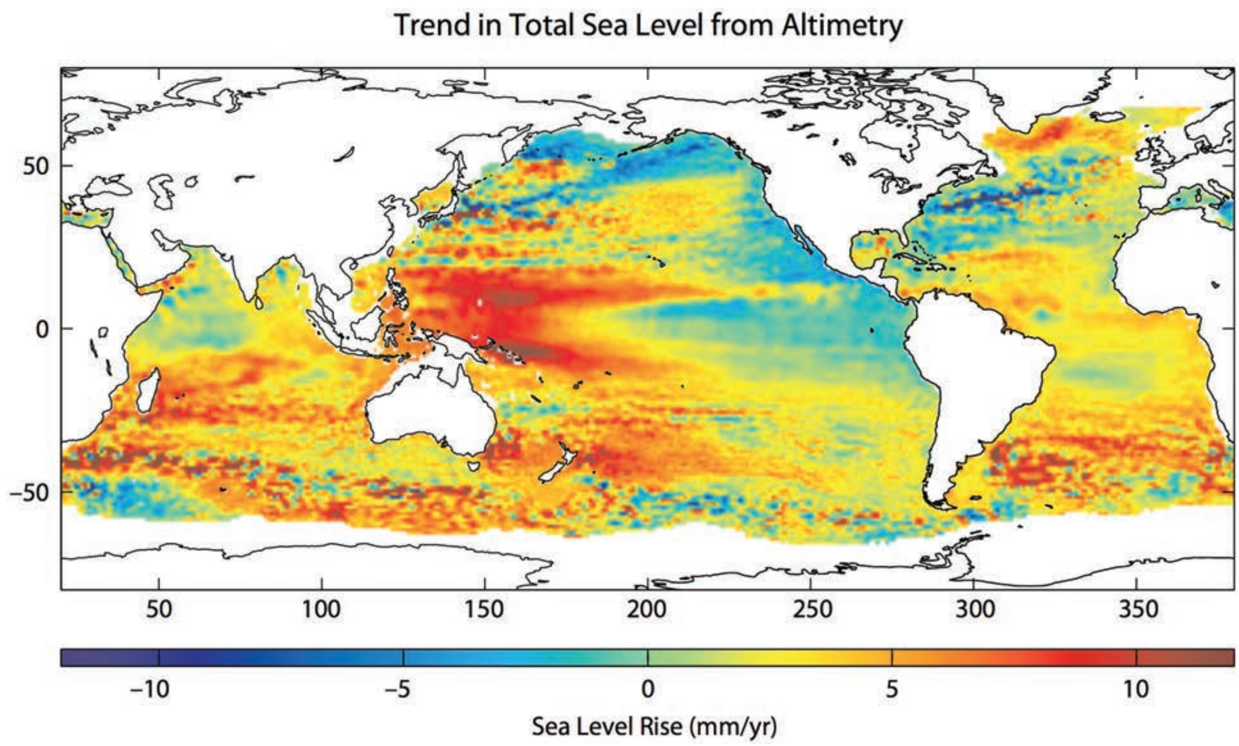

Figure 5.3 Map of sea level change per year (mm/year) for the period 1993-2009 based on satellite radar altimeter data (Willis et al., 2010, Figure 1).

Local sea levels

The Philippine archipelago has an extensive coastline of approximately 36,289 km (Long & Giri, 2011). The majority of the country's growing population live in coastal lowlands, placing them at risk to the impacts of increased sea levels (Berdin, Siringan, & Maeda, 2003; Capili et al., 2005; Reyes & Blanco, 2012).

There is a limitation in the availability of local sea level rise data, which constrains information on sea level rise for the entire country. Satellite data are often coupled with tide gauge station data to provide context about local sea level rise.

In the Philippines, rising sea levels have been observed in several sites (Legazpi, Cebu, Davao and Jolo) since the 1970s (Lasco, Pulhin, Sanchez, Villamor, & Villegas, 2008). On the other hand, mean sea level in Manila has been increasing, at an average rate of 1.3 mm per year since the 1900s, which increased to about 2.6 cm per year in the 1960s (Lasco, Pulhin, Sanchez, Villamor, & Villegas, 2008; Reyes & Blanco, 2012; Rodolfo & Siringan, 2006). Figure 5.4 shows the increasing trends in sea level, as well as in Metro Manila groundwater use that has enhanced land subsidence in the city (Rodolfo & Siringan, 2006). In the 1980s, a rise of almost 15 cm is recorded in the Manila, Legazpi, and Davao stations (Lasco et al., 2008).

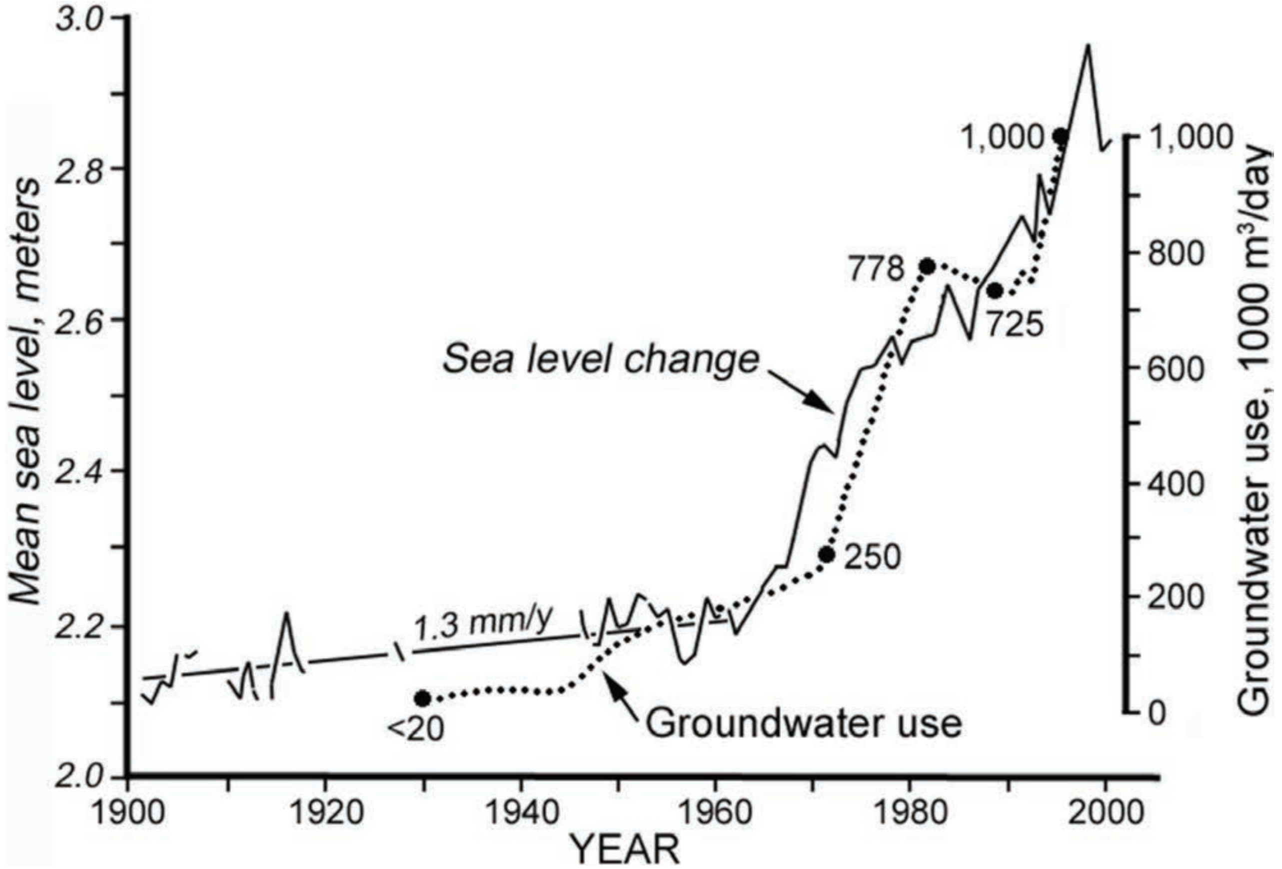

Figure 5.4 Combined plot of sea level change at Manila South Harbor and groundwater use in Metro Manila from 1902 to 2000 (Rodolfo & Siringan, 2006, Figure 2).

In a study by Reyes and Blanco (2012), sea level anomaly data records from 1991 to 2010 from six satellite altimetry missions were obtained from the Radar Altimetry Database System (RADS) of the Delft Institute of Earth-Oriented Space Research (DEOS) of the Delft University of Technology in the Netherlands. Tide gauge records from the Manila South Harbor, La Union, Subic Bay, Currimao, Puerto Princesa, and Occidental Mindoro stations were also obtained from the National Mapping and Resource Information Authority (NAMRIA) of the Philippines. Their study showed that the Manila South Harbor Station has recorded rising sea levels since 1964 (Figure 5.5). Records from other tide stations show a slight increasing trend as well (Figure 5.6); however, there are data gaps in the San Fernando station, likely due to operational problems at the station (Reyes & Blanco, 2012). Merged satellite altimetry data over two decades (1991–2010) indicate variability in sea level anomalies in Bolinao, a coastal area in the province of Pangasinan (Figure 5.7). However, increases in sea level are higher than decreases (Reyes & Blanco, 2012).

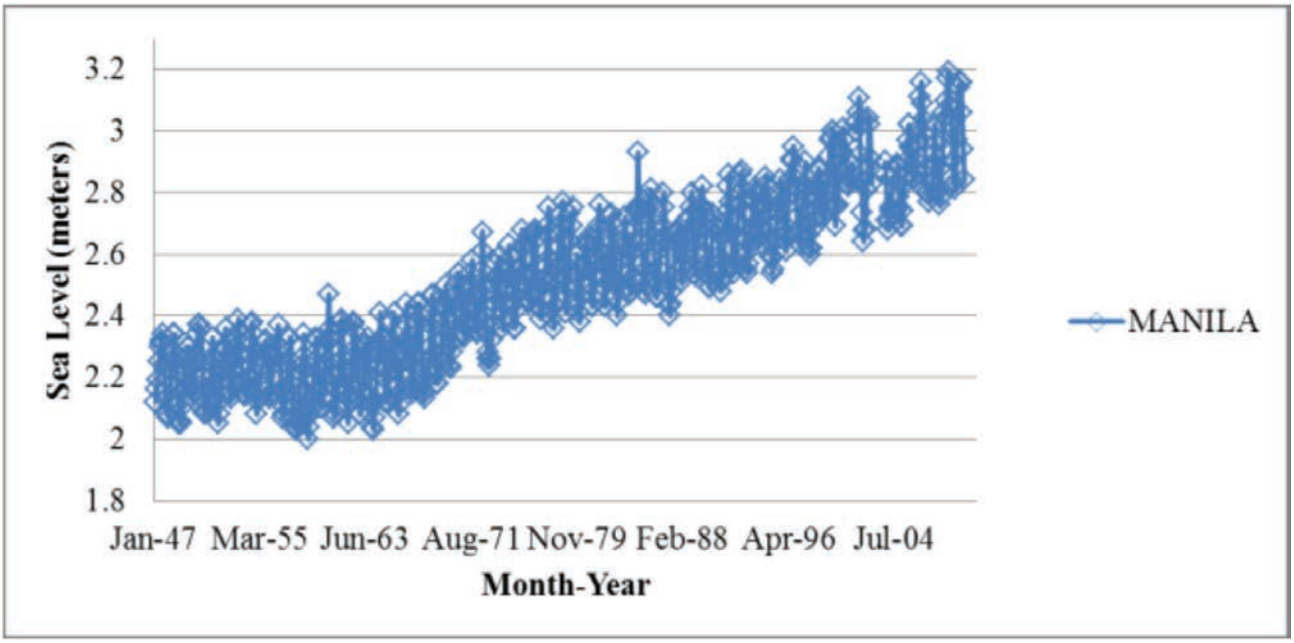

Figure 5.5 Monthly sea levels at the Manila South Harbor tide station (Reyes & Blanco, 2012, Figure 3)

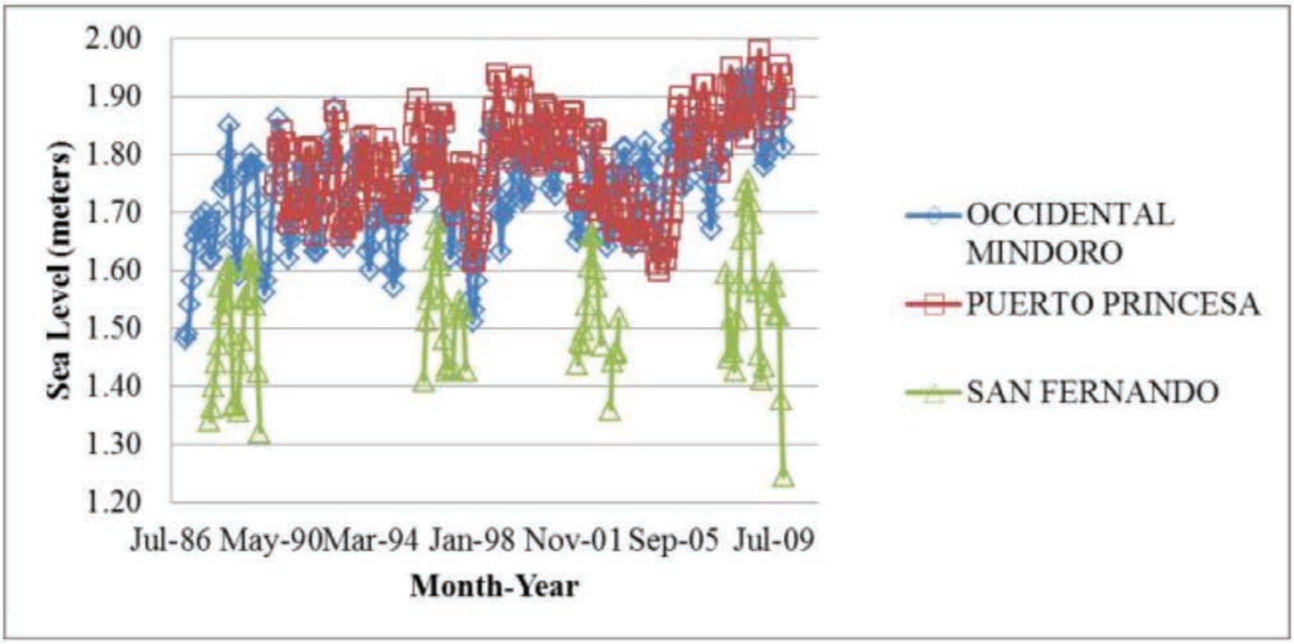

Figure 5.6 Monthly sea levels at the San Jose, Occidental Mindoro station, Puerto Princesa, Palawan station and San Fernando station (Reyes & Blanco, 2012, Figure 4)

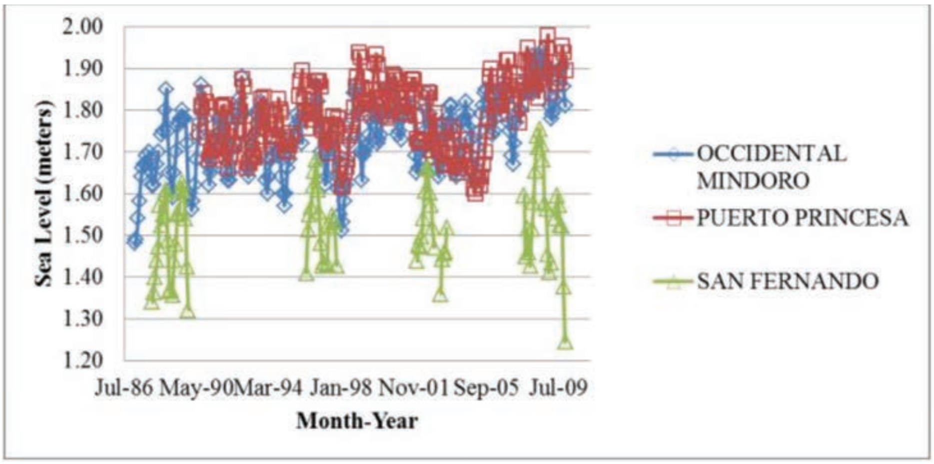

Figure 5.7 Monthly sea level anomalies from merged satellite data in Bolinao, Pangasinan (Reyes & Blanco, 2012, Figure 6).

5.3.1 Paleo Sea Level

This section is based on the work of Berdin et al. (2003) on Holocene changes in sea level in the lower reaches of the Abatan River, where evidence of these changes is abundant near and along the coast of southwestern Bohol. Sea level changes are estimated based on stratigraphy and ^{14}C age dates, together with foraminifera and total organic carbon in sediment cores, as well as tidal notch near the core sites.

The analysis showed a rapid increase in sea level to 2 m below present mean sea level (pmsl) from ca. 8000 to 6000 years before present (yBP), followed by a 1 m rise until ca. 4500 yBP (Figure 5.8). In 4500 to 4300 yBP, sea level increased to 0.7 m above pmsl, then a relative stillstand until ca. 2500 yBP, followed by a decline to its present day level. These historical changes in the sea level have consequently affected the mangroves in that area. The mangroves flourished during the moderate sea level rise from 6000 to 4500 yBP, but were later inundated when sea level rapidly increased around 4500 yBP. However, the mangroves were able to develop again after 2500 yBP as the sea settled to its current level (Berdin et al., 2003).

5.4 DIRECTIONS FOR FUTURE STUDIES

Analyzing records of existing tide gauges and correlating these to sea surface height (SSH) measurements will help in refining relative sea level change trends in the areas of the tide gauges and help identify local drivers of sea level change. Installation of additional tide gauges in areas with fastest rates of sea level rise based on SSH data should be recommended to NAMRIA.

Local researchers can be encouraged to publish their paleo-SST and SLR in different locales in the country. Such studies can be prioritized in areas where human and ecological communities are projected to be highly vulnerable.

Possible topics for future study include the relative significance of local groundwater extraction and land subsidence on sea levels, and the effect of SLR on saline intrusion and storm surges along coastal regions.

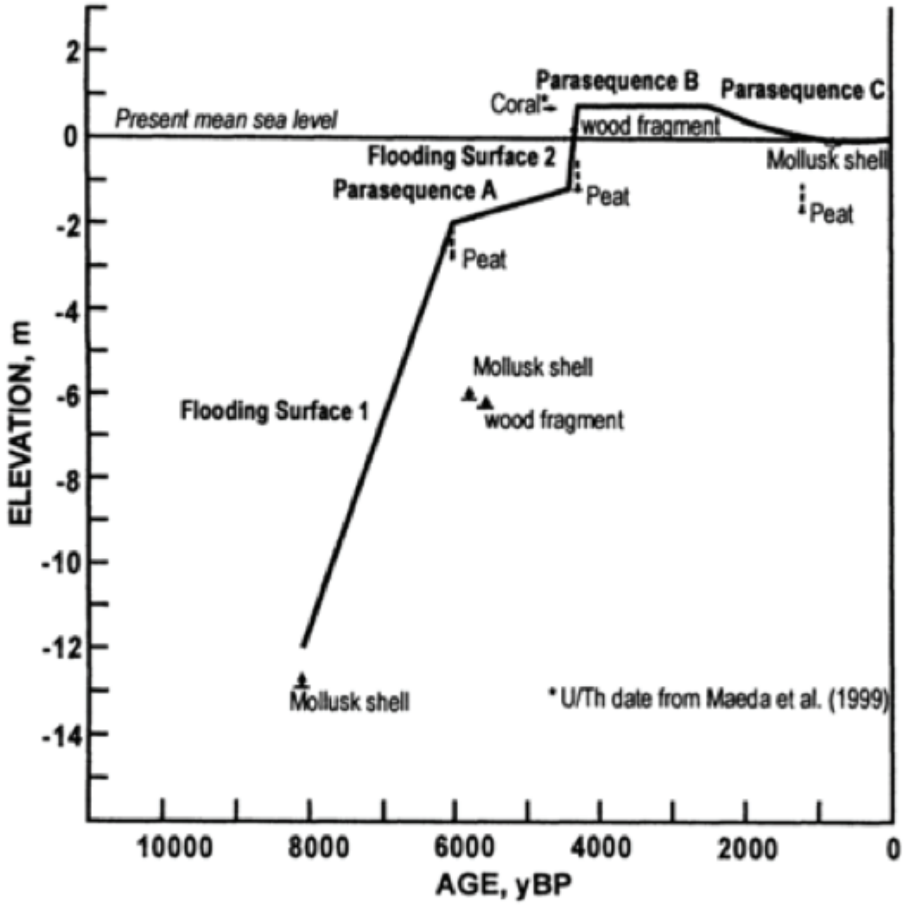

Figure 5.8 Sea level changes in Bohol over the period 8000 yBP to the present, estimated from stratigraphy and sediment cores (Berdin et al., 2003, Figure 6).

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CHAPTER 6

Drivers of Local Changes in Climate

AUTHORS

Faye Abigail T. Cruz
John Leo C. Algo
Jose Ramon T. Villarin, SJ
Gemma Teresa T. Narisma

6.1 CHAPTER SUMMARY

The radiative forcing of climate due to greenhouse gases (GHG) is dominant at the global scale. However, there are other drivers arising from human activities that can also affect climate and ecosystems at the regional scale with potential feedbacks on the greenhouse effect.

Aerosols from biomass burnings, dust, and air pollution can affect regional weather and climate via their direct effect on atmospheric radiation (Jacobson, 2004; Taylor, 2010). However, the extent of their impacts on the Earth's changing energy budget provides the largest uncertainty to current estimates and interpretations.

Land use/land cover change (LULCC) is now being recognized as an important driver of regional climate, given the recent extensive modifications of the earth's surface due to development. Land surface processes influence climate by affecting the surface energy, water, and carbon budgets (Pielke Sr. et al., 2002; Pitman, 2003). Changes in land cover, including deforestation, afforestation, agricultural conversion, and urbanization, can result in changes in temperature, precipitation, wind, and climate extremes (Avila, Pitman, Donat, Alexander, & Abramowitz, 2012; Pielke Sr. et al., 2002; Pitman, 2003). In the Philippines, the last century has seen a significant decrease in forest cover. Forests have been cleared for agricultural expansion, and by 2013, about 32% of Philippine land was agricultural. Aside from affecting the local hydrological cycle, the reduced tropical forest cover affects the carbon budget and surface temperature through changes in evaporative cooling (Bonan, 2008; Lasco & Pulhin, 2000).

The past century is also characterized by the expansion of cities. Urban areas may be only less than 2% of the world's available land surface, but the population living in these areas is exposed to climate change-related hazards such as heat stress, extreme precipitation, flooding, and air pollution. Another impact of urbanization on climate is the "urban heat island" (UHI) effect, which has already been observed in Metro Manila (Pereira & Lopez, 2004; Tiangco, Lagmay, & Argete, 2008). The replacement of natural land cover with materials such as concrete and asphalt creates significant temperature differences between the urban area and its surroundings (Arnfield, 2003; Shepherd, 2005). Aside from increasing the minimum temperature at the surface, the UHI can also cause changes in rainfall intensity and patterns, as well as affect surface hydrology leading to increased runoff and flooding (Shepherd, 2005; Shi et al., 2007).

It is important to understand the relative contributions of LULCC and GHG increase on climate change because of their feedbacks on each other, where one can potentially amplify or attenuate the other. However, this interplay between LULCC and GHG increase has yet to be examined for the Philippines.

6.2 INTRODUCTION

On a global scale, the emission of GHGs is a dominant anthropogenic influence on climate. However, at the regional and local scales, human activities (e.g., land cover change, biomass burning, and urbanization) can also lead to changes in the local climate. This chapter identifies some of the key human-induced drivers on the earth system that can notably affect climate, particularly in the Philippines.

6.3 AEROSOLS AND CLIMATE

Aerosols are colloidal systems of fine solid or liquid droplets in a gaseous medium. They appear throughout the environment in different forms, such as haze, smoke, particulates, fog, dust, and geyser steam. Aerosols can be formed through natural processes (i.e., volcanic eruptions, forest fires, sea salt) and anthropogenic activities (i.e., emissions from combustion, biomass burning, industrial dust).

While aerosols contribute to global climate change, the extent of its impacts on the Earth's changing energy budget provides the largest uncertainty to current estimates and interpretations. This section primarily discusses the contributions of anthropogenic aerosols on climate change in the Philippines.

6.3.1 Biomass Burning

Biomass burning, or the burning of both living and dead vegetation, can influence the climate through its impacts on the atmospheric and surface albedo (Taylor, 2010). Average fire emissions were estimated at 128 ± 51 Tg C year-1 in equatorial Asia from 2000 to 2006 (van der Werf et al., 2008), while all biomass burning in the Asian continent released an estimated 1,100 Tg CO_2 (Streets, Yarber, Woo, & Carmichael, 2003). In the Philippines, about 95% of straw residue from rice, the country's most important food crop, is subjected to open-field burning. From 2002 to 2006, this resulted in 11,850 Gg of CO_2 emissions (Gadde, Bonnet, Menke, & Garivait, 2009).

Burning of crop residues, grasslands, and forests releases GHGs, aerosols, and particulate matter into the atmosphere, which can initially lead to cooling but may cause warming in the long run because of its contribution to increasing CO_2 levels (Gadde et al., 2009; Jacobson, 2004). It can also lead to the rapid decomposition of organic-rich soil horizons and, consequently, the release of more GHGs and other compounds such as black carbon into the atmosphere (Ali, Taylor, & Inubushi, 2006; Bond et al., 2013; Lehmann, 2007).

6.3.2 Urban Air Pollution

Air pollution and climate change are closely interlinked with one another. Specifically, air pollutants such as particulate matter (PM), ozone, and volatile organic compounds (VOCs) can influence trends in climatic parameters such as radiative forcing, temperature, and albedo. On the other hand, changes in climate can also alter the distribution, transport, and concentration of air pollutants.

Urbanization generates substantial amounts of waste such as air pollutants. With more economic activities and increased consumption due to prosperity, urban areas emit higher amounts of air pollutants than non-urban areas (Molina & Molina, 2004).

In most of the largest Philippine cities, mobile sources emitted the highest levels of air pollutants at 65% (Clean Air Initiative for Asian Cities Center, 2009). Specifically, motor vehicles were the largest contributor to volatile organic compounds (VOCs) and carbon monoxide (CO) (Environmental Management Bureau, 2012), as well as to fine PM in Metro Manila (Simpas, Lorenzo, & Cruz, 2014). Outside Metro Manila, biomass burning contributes the most to ambient levels of fine PM (Simpas et al., 2014).

VOCs can be radiatively active and transported above the troposphere, where they can absorb solar or terrestrial infrared radiation, directly contributing to an enhanced greenhouse effect. However, most VOCs act as secondary GHGs by influencing the distribution and concentration of other radiatively active gases in the atmosphere. Its ability to react with NO_x in the troposphere produces ozone, which leads to a warmer planet (Brasseur, Muller, Tie, & Horowitz, 2001; Hester, Harrison, & Derwent, 1995).

6.4 TERRESTRIAL ECOSYSTEMS AND CLIMATE

6.4.1 Land Use/ Land Cover Change

Topography, vegetation cover, and land use affect the climate, particularly at the regional scale, through their influence on the surface energy, water, and carbon budgets (Pielke Sr. et al., 2002; Pitman, 2003). Land conversion, which can be brought about by deforestation, afforestation, agricultural conversions, and urbanization, can result in changes in temperature, precipitation, winds, and soil moisture (Figure 6.1), as well as climate extremes (Avila et al., 2012; Bala et al., 2007; Pielke Sr. et al., 2002; Pitman et al., 2009, 2011, 2012). With the continued changes in land cover, typically due to development, it is important to consider the climate impacts of land use/land cover change (LULCC), especially at the regional scale (Mahmood et al., 2014; McAlpine et al., 2010; Pielke Sr. et al., 2002; Pitman et al., 2011, 2012).

In the Philippines, there has been a significant decrease in forest cover, particularly in the last century (Garrity, Kummer, & Guiang, 1993; Lasco & Pulhin, 2000; Liu, Iverson, & Brown, 1993). About 27 M ha of the 30 M ha total land area was initially covered by tropical rainforest, which has been reduced to only 6.1 M ha as of 1996 (Forest Management Bureau, 1997; Lasco & Pulhin, 2000). Agriculture, shifting cultivation, logging, and ranching are some of the direct and indirect causes of deforestation in the Philippines (Kummer, 1990; Lasco & Pulhin, 2000). The reduction in forest cover affects climate in several ways. Apart from the influence of the forests on carbon budget, tropical forests can lessen warming through evaporative cooling (Bonan, 2008; Lasco & Pulhin, 2000).

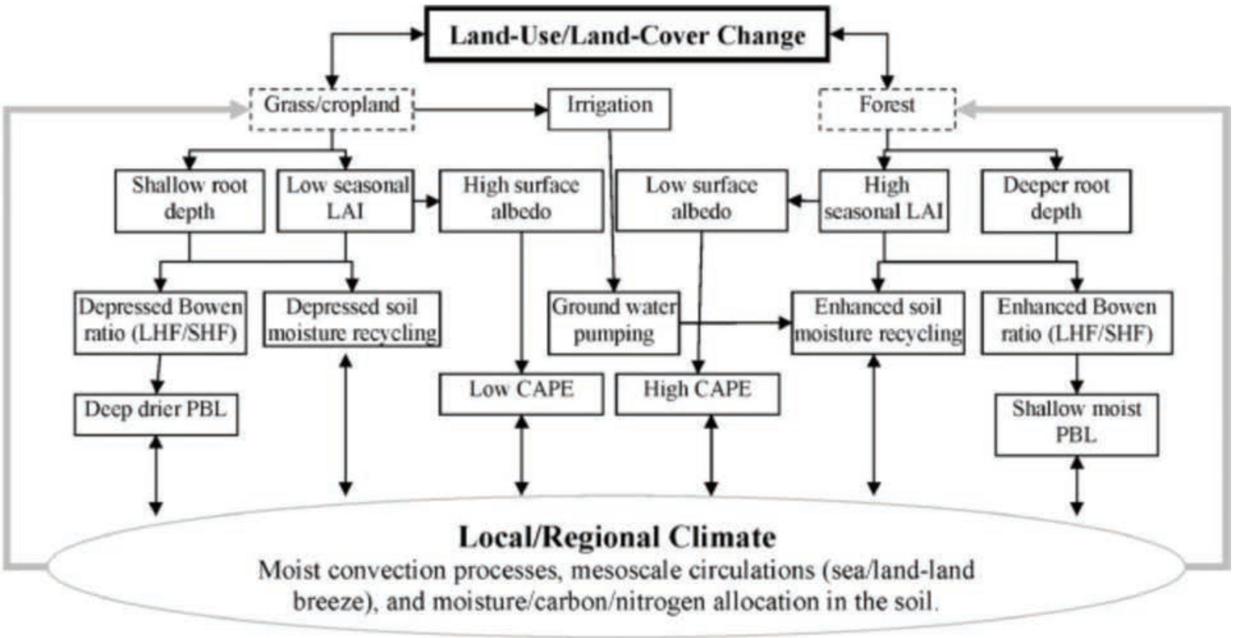

Figure 6.1 Model framework of the interplay of LULCC and local/regional climate (Mahmood et al., 2014, Figure 2, citing R. A. Pielke et al., 2007)

A review by Lawrence and Vandecar (2015) discusses the climate responses to tropical deforestation at different scales. Complete deforestation in Southeast Asia results in lower rainfall, although a gradual decline in forest cover can lead to a modest increase in precipitation. Deforestation in this region can also affect the Asian monsoon circulation, leading to local and remote climate impacts (Lawrence & Vandecar, 2015). A deforestation rate of either 1% or 10% with a 10% preservation target in the region is projected to result in a significant increase in surface albedo (Castillo & Gurney, 2012). There is also a significant decrease in canopy evaporation, and an increase in ground evaporation, which occur rapidly for the 10% deforestation rate and gradually for the 1% deforestation rate (Castillo & Gurney, 2012).

Historical human-induced land cover changes are characterized mostly by the clearing of forests for agricultural expansion. As of 2013, about 32% of the total land area in the Philippines is agricultural (Philippine Statistics Authority, n.d.). Agriculture is an important economic sector, which provides livelihood to about a third of the population. Agricultural activities are a major contributor of GHGs in the Philippines. A total of 17.59 million tons of CO_2 was released annually from rice production from 1981 to 2011, while 6.52 million tons of CO_2 were emitted from livestock, specifically buffaloes and cattle during the same period (Rapera & Quilloy, 2014). In addition, the conversion of land to agriculture has also been shown to have climate impacts. For example, maximum temperatures can be reduced and precipitation increased during the growing season over irrigated fields in India (Pielke Sr. et al., 2011; Roy et al., 2007; Roy, Mahmood, Quintanar, & Gonzalez, 2010). However, these studies also note that the climate impacts can have spatial and seasonal variability, i.e., changes between the dry or wet monsoon seasons.

6.4.2 Urbanization

The past century also saw the expansion of cities. Although urban areas are estimated to be less than 2% of the world's available land surface, a little over half of the population live in these areas (Arnfield, 2003; Pielke Sr. et al., 2007, 2011). The IPCC Fifth Assessment Report indicates the risk in urban areas due to climate change-related hazards such as heat stress, extreme precipitation, flooding, water scarcity, and air pollution. However, the urbanization of a region also changes the physical characteristics of the surface, which has consequent impacts on the local climate and surface hydrology.

6.4.2.1 Urban Heat Island Effect

One impact of urbanization is the “urban heat island” (UHI) effect. The establishment of urban areas replaces vegetation with materials such as concrete and asphalt, and creates a clear temperature gradient between the urban area and its surroundings (Arnfield, 2003; Shepherd, 2005). Kataoka, Matsumoto, Ichinose, and Taniguchi (2009) formulated a heat island index to describe the trend in urban warming over several Asian cities, and found a notable increase of this index in Manila after 1961. Using remote sensing, Pereira and Lopez (2004) estimated that the rate of warming in metropolitan Manila is 0.8°C per year from 1989 to 2002, accompanying the urban growth and decrease in vegetation. The UHI effect in Manila was also evident in remotely-sensed thermal images, particularly in the center of the city, with the highest UHI intensity reaching 2.96°C (Tiangco et al., 2008).

Aside from increases in daily minimum temperature, UHI can also cause changes in rainfall intensity and patterns. Relevant studies on the urban effect on precipitation may be found in Shepherd (2005), Pielke et al. (2007), and Mahmood et al. (2014). For example, rainfall may be higher over the city and downwind of the urban area as a result of convergence due to the UHI and higher surface roughness (Pielke Sr. et al., 2007). Kishtawal, Niyogi, Terawi, Pielke, and Shepherd (2010) also found that heavy rainfall events tend to occur more frequently over urban areas in India compared to rural areas. In addition, the influence of urban air pollution on rainfall may also need to be considered (Mahmood et al., 2014).

Urban areas also affect surface hydrology and are often accompanied by increased flooding events (Bankoff, 2003; Shi et al., 2007). Urbanization can exacerbate the flood hazard of an area because the high impermeability of urban surfaces, as well as drainage systems that divert natural flows, can lead to higher surface runoff and maximum flood discharge (Booth, 1991; Shi et al., 2007). For cities near the coast or rivers, the increased flood hazard from urbanization may also be compounded by other climate change-related impacts, such as sea level rise and increased river flow (Huong & Pathirana, 2013).

6.4.3 Feedbacks of LULCC and GHGs

Understanding the contributions of both land cover change and higher atmospheric GHG levels on climate change is important, especially because of their possible feedbacks on each other. For example, the response of vegetation to high CO_2 levels (i.e., biospheric feedback) may affect the climate impact of LULCC, as was found over Australia (Narisma et al., 2003; Narisma & Pitman, 2004). Precipitation changes due to higher CO_2 concentrations can also influence the LULCC impact on temperature (Pitman et al., 2011). LULCC and increased CO_2 need to be considered, especially in areas with intensive LULCC, when examining changes in climate extremes (Avila et al., 2012; Pitman et al., 2012).

Under optimal growing conditions, a CO_2-rich atmosphere can increase foliage, resulting in a higher leaf area index. This can reduce surface albedo that leads to higher surface temperature, but also increase evapotranspiration, which has a cooling effect. Plants may also become more water-use efficient by opening their stomates less (Field, Jackson, & Mooney, 1995), resulting in lower transpiration and surface evapotranspiration and a warmer surface (Boucher, Jones, & Betts, 2009; Cao, Bala, Caldeira, Nemani, & Ban-Weiss, 2010; Cruz, Pitman, & McGregor, 2010). The effect of CO_2 on plant physiology (e.g., stomatal response) can amplify or mitigate climate changes caused by the radiative effect of CO_2 (e.g., Cao et al., 2010; Peng, Dan, & Dong, 2014). Plants respond differently in a CO_2-enriched environment (Ainsworth & Long, 2005), such that the CO_2 physiological effect on temperature may be more apparent over forests than grasslands (Cruz, Pitman, & Wang, 2010). This suggests that future land cover changes (e.g., deforestation) can affect climate through this CO_2 physiological effect, and not just through its direct influence on the surface energy and water budgets as discussed in Section 6.4.1. This feedback between the LULCC and GHGs has yet to be examined in the Philippine setting.

6.5 DIRECTIONS FOR FUTURE STUDIES

This chapter discussed how human activities can directly affect climate at the local scale, which can also exert feedback on changes brought about by rising levels of GHGs in the atmosphere. However, most of the current published work is outside the Philippine context. There are ongoing efforts to understand the impacts of urbanization on Philippine local climates. For example, a recent study indicated that the urban expansion of metropolitan Manila could enhance the southwest monsoon rainfall by as much as 20% (Dado, 2013). In addition, the local climate impacts of aerosols still need to be further examined. It is therefore recommended that these research areas be pursued to better understand and quantify local-scale drivers, particularly for urban areas in the country.

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CHAPTER 7

Projections of Future Changes in Climate

AUTHORS

Faye Abigail T. Cruz
Jose Ramon T. Villarin, SJ
Lourdes V. Tibig
Gemma Teresa T. Narisma
Flaviana D. Hilario
Thelma A. Cinco
Rosalina G. de Guzman

7.1 CHAPTER SUMMARY

With the continued increase in greenhouse gas (GHG) emissions from human activities, it is important to determine future climate changes at both global and local scales in order to prepare for their impacts. Emissions scenarios have been developed to calculate future GHG concentrations based on projections of population growth, technology access, fossil fuel dependence, energy use, and economic policy and development (Nakicenovic et al., 2000).

Using these scenarios, global circulation models (GCMs) provide climate projections, typically at spatial scales of more than 100 km. However, the coarse spatial resolution of GCMs may not adequately represent particular land surface characteristics of the region, e.g., topography, land use, and coastlines that influence the local climate. Climate models project increased global temperatures accompanying the increases in GHG concentration, as well as the regional variation in precipitation changes, which includes possibilities such as declines in precipitation in the subtropics but increases in the high latitudes.

In order to determine these regional changes, global climate projections are downscaled using dynamical models and statistical models (e.g., Chotamonsak, Salathé, Kreasuwan, Chantara, & Siriwitayakorn, 2011; Silang et al., 2014). High-resolution climate projections are essential for areas such as the Philippines, which has been identified as one of the areas in Southeast Asia most vulnerable to climate change. Aside from the high level of exposure of the population to multiple climate-related hazards such as droughts, cyclones, flooding, and landslides, sufficient local adaptive capacity needs to be developed to respond to the impacts of these hazards (Yusuf & Francisco, 2009).

Future changes in Philippine climate relative to the baseline climate (1971–2000) have been projected by PAGASA (2011) for the 2020s (2006–2035) and 2050s (2036–2065) in response to three emission scenarios characterized as low-range (B2), mid-range (A1B), and high-range (A2). In particular, climate projections under the mid-range scenario indicate increases in annual mean temperatures by 0.9°C to 1.1°C in the 2020s and 1.8°C to 2.2°C in the 2050s. Seasonal mean temperatures, especially during the summer season (March to May), are also projected to increase in the country.

The dry season (March to May) is projected to be drier over most areas. The wet or southwest monsoon season (June to November) will likely be wetter with rainfall increase ranging from 0.9% to 63% for Luzon and 2% to 22% for Visayas. On the other hand, rainfall is projected to decline over Mindanao during this same season. For areas along the eastern coast of the Philippines, rainfall will also increase during the northeast monsoon season (DJF) (PAGASA, 2011).

Dry days are anticipated to be more frequent over the Philippines, particularly south of 15°N latitude in the mid-century, with more heavy rainfall days (i.e., days with rainfall greater than 300 mm) occurring over Luzon and Visayas (PAGASA, 2011; Rahmat et al. 2014).

Because of limitations such as accessibility to GCM data, and the availability of ground data, computational resources, and technical expertise, these climate projections were obtained from only one regional climate model (RCM) downscaled from one GCM for each emission scenario. Efforts are currently underway (e.g., PAGASA, Southeast Asia Climate Downscaling Experiment/ Coordinated Regional Climate Downscaling Experiment–Southeast Asia or SEACLID/CORDEX-SEA project) to provide an updated ensemble of climate projections for the Philippines using multiple GCMs and RCMs driven by the different emission scenarios or representative concentration pathways (RCPs).

7.2 INTRODUCTION

Chapters 4 and 5 discussed the observed historical changes in the Philippine climate in the recent decades as a result of both natural climate variability and anthropogenic influences. With the continued increase in GHG concentrations from human activities such as the use of fossil fuels, biomass burning, agriculture and landscape changes, it is important to determine future climate changes at both global and local scales to prepare for the consequences of such changes. Thus, climate change scenarios are developed to provide information on possible future climates.

7.2.1 Development of Projections

In order to determine future climate change, climate models use projections of GHG concentrations from emission scenarios, in addition to other forcings such as land cover change. The Special Report on Emissions Scenarios (SRES) of the IPCC describes emissions scenarios based on possible developments in the 21st century, which can be used for studies relating to climate change impacts, adaptation, and mitigation (Nakicenovic et al., 2000). Because of the high uncertainty associated with future world development, the likelihood of the occurrence of a particular scenario is not determined (Nakicenovic et al., 2000).

Forty different scenarios were constructed using various modeling approaches to quantify future emissions trajectories from four main "narrative storylines" based on population growth, socioeconomic development, technology access, fossil fuel dependence, and policies implemented (excluding "climate initiatives") (Nakicenovic et al., 2000). Scenarios that share similar features were then grouped into "families" and summarized in Nakicenovic et al. (2000) as follows:

- The A1 storyline and scenario family portrays a world with rapid economic development, population growth that peaks in mid-century, and faster introduction of more efficient technologies. This scenario also describes different technological emphases from fossil-intensive (A1FI), non-fossil (A1T) to balanced across multiple sources (A1B).
- The A2 storyline and scenario family describes a world with more regional economic growth, high population growth, and slower technological change.
- The B1 storyline and scenario family portrays a world with an economy oriented towards service and information, population growth that peaks in mid-century, and use of resource-efficient technologies.
- The B2 storyline and scenario family describes a world with intermediate levels of economic growth, moderate population growth, and slow but more diverse technological change than in A1 and B1.

The SRES scenarios were used in the climate projections of both the Third and Fourth Assessment Reports of the IPCC (i.e., TAR and AR4, respectively). However, these scenarios have been replaced in the Fifth Assessment Report (AR5) of the IPCC in which climate models used projected GHG concentrations based on Representative Concentration Pathways (RCPs). Unlike the SRES scenarios that were based on detailed socioeconomic and technological development narratives, RCPs focus on GHG and aerosol (air pollutant) concentrations, as well as land use and land cover change, and describe pathways that lead to a specific radiative forcing level (in units of $W\ m^{-2}$) by the year 2100 (Vuuren et al., 2011). Radiative forcing measures the change in the energy flux at the top of the earth's atmosphere, which can either be positive or negative resulting in warming or cooling, respectively (IPCC, 2013).

In the literature, there are four pathways that represent scenarios that range from low to medium to high radiative forcing: RCP2.6 (also referred as RCP3PD), RCP4.5, RCP6, and RCP8.5, where the numbers correspond to the radiative forcing of the GHGs by 2100 (Vuuren et al., 2011). RCP2.6 scenario projects the lowest CO_2 equivalent concentrations. For the medium emissions scenarios, RCP4.5 has values close to RCP6 until after mid-21st century but RCP4.5 becomes close to SRES B1 by 2100, while RCP6 is closer to SRES A1B after 2100. The high emissions scenario of RCP8.5 is similar to the SRES A1FI scenario (Cubasch et al., 2013).

7.2.2 Climate Models

Climate models have been useful tools in studying climate change and variability. These numerical models use mathematical equations to describe the physics and dynamics in the climate system, including atmospheric, oceanic, and terrestrial processes and their interactions (Flato et al., 2013). The earth is typically represented using grids in which meteorological variables (including temperature, pressure, winds, humidity) are computed for each grid box at a specified time interval (or time step). Computational resources can limit the spatial and temporal resolution used in model simulations because the time interval used in the calculation depends on the grid spacing (or spatial resolution). Physical parameterization schemes are also used in these models to represent processes that cannot be resolved explicitly, including complex processes or processes that occur at scales smaller than can be resolved by the model grid, such as radiation, microphysics, planetary boundary layer, and land surface dynamics (Flato et al., 2013).

Models vary in complexity from simple energy balance models to coupled climate models to Earth System Models (ESM) (Flato et al., 2013). Atmospheric general circulation models (AGCMs) examine atmospheric processes in detail but may have only prescribed sea surface temperatures with a simplified land surface model to conserve computational resources. A more complete representation of the climate system would require AGCMs to be combined with ocean GCMs (atmosphere-ocean GCMs or AOGCMs) and land surface models to allow exchanges of heat, momentum, and moisture on the land-atmosphere and ocean-atmosphere interfaces. For climate simulations at longer time periods, processes in the biosphere and cryosphere will also need to be included. Unlike AOGCMs, ESMs also have a biogeochemical component to represent carbon cycles, aerosols, and atmospheric chemistry (Flato et al., 2013). Another type of climate model is the Earth System Model of Intermediate Complexity (EMIC), which have simpler representations of some physical processes and have resolutions lower than AOGCMs. Because of their lower computational cost, EMICs have been useful tools in examining climate projections at longer timescales and their associated uncertainties (Flato et al., 2013).

7.2.3 Downscaling

As discussed in Section 7.2.2, global climate models (GCM) provide climate information, both historical and projections at long timescales, but at relatively low spatial resolution because of limitations in computational capacities. With typical horizontal resolutions of more than 100 km, these GCMs are not able to adequately represent some land surface characteristics of the region in fine detail, including topography, land use/land cover, and coastlines that also affect the local dynamics of climate. This is particularly important for the Philippines, which is an archipelago characterized by complex topography. Climate data at higher resolutions are also needed by adaptation and impacts practitioners, e.g., as input to their crop or hydrology models. In order to address this need, downscaling techniques, either dynamical or statistical, have been applied to GCM output.

Dynamical downscaling involves the use of regional climate models (RCMs), which are similar in structure to GCMs but are developed to resolve topographic effects and small-scale features of the climate. The different types of RCMs range from limited-area models, variable-resolution global models, and stretched-grid global models (Salinger et al., 2014). Limited-area models use the output of GCMs as initial and boundary conditions for a particular domain of interest. Thus, model biases in the driving GCM can influence the output from the RCM. The choice of the model domain may also affect the downscaled output. On the other hand, variable-resolution and stretched-grid global models are less constrained, such that initial conditions from a GCM are used but the models are able to do long climate simulations using only bias-corrected SST and sea-ice from the GCM (Salinger et al., 2014). For the Philippines, RCMs have been used to characterize climate features, such as summer monsoon precipitation (Francisco et al., 2006) and future changes in climate (Chotamonsak et al., 2011; Silang et al., 2014).

Statistical models that have been used for downscaling have their own advantages and disadvantages over dynamical models (Robertson, Qian, Tippett, Moron, & Lucero, 2012). Unlike regional climate models, they require less computational resources and can provide information at very fine resolutions for specific locations. However, since they are based on empirical models, statistical models depend on the availability and quality of observations. Consistency among downscaled variables may need to be checked since the physical and dynamical processes in the climate system are not explicitly resolved in these models. Examples of statistical downscaling include the use of stochastic weather generators, analogue methods, and regression models (e.g., Feddersen & Andersen, 2005). Kang, An, Park, Solis, and Stitthichivapak (2007) showed that statistical downscaling of multi-model output can reproduce precipitation over areas in northern Philippines, particularly where precipitation is dominated by large-scale processes. Biases in the GCM may also be reduced using bias correction methods (Ines & Hansen, 2006; Piani et al., 2010). Because observed data is used in deriving the statistical relationships, statistical downscaling may have a higher skill than dynamical downscaling for the present day climate. However, the validity of these relationships becomes uncertain for the future climate, which can affect the skill of statistical models (Salinger et al., 2014).

7.2.4 Model Evaluation and Dealing with Uncertainties

Climate models are continuously undergoing development and have been shown to capture essential features of the past and current climate, particularly at large spatial scales, through robust evaluations (Flato et al., 2013). However, uncertainties still remain in the simulations, and at the regional scale, these may come from the emission (forcing) scenarios ("inter-scenario variability"), variability in the climate response of the GCMs ("inter-model variability") and variability within each model ("internal model variability"), and from subgrid-scale processes (Giorgi & Francisco, 2000). One way of addressing these uncertainties is by generating multiple (ensemble) simulations, such as using multiple RCMs to downscale from a single GCM, using a single RCM to downscale from multiple GCMs, or using multiple RCMs to downscale multiple GCMs (Salinger et al., 2014). Model intercomparison projects (e.g., Regional Climate Model Intercomparison Project [RMIP] for Asia and Coordinated Regional Downscaling Experiment [CORDEX]) have been established to help quantify uncertainties in model results (Fu et al., 2005; Giorgi, Jones, & Asrar, 2009; Salinger et al., 2014).

7.3 REGIONAL CLIMATE PROJECTIONS

As discussed in Chapter 2, the IPCC AR5 indicates that climate models project higher temperatures across Asia accompanying the increases in GHG concentration, where the median change in temperatures over Southeast Asia ranges from 0.8°C (RCP2.6) to 3.2°C (RCP8.5) by 2081–2100 (Christensen et al., 2013). On the other hand, there is regional variation in change in precipitation. Over Southeast Asia, rainfall is projected to moderately increase by 1% (RCP2.6) to 8% (RCP8.5) by the end of the 21st century (Christensen et al., 2013).

The Philippines has been identified as one of the areas in Southeast Asia most vulnerable to climate change. Aside from being exposed to multiple climate-related hazards, such as drought, cyclones, flooding, and landslides, there is insufficient adaptive capacity to respond to the impacts of these hazards (Yusuf & Francisco, 2009). To aid in the preparation of climate adaptation strategies at the national and provincial levels, there have been efforts to use RCMs to identify how these hazards affecting the country will evolve in the future (PAGASA, 2011; Thomas, Albert, & Perez, 2013).

In 2011, PAGASA released a report on the projected future changes in climate for the Philippines (both national and provincial) in the 2020s and 2050s in response to three IPCC SRES emission scenarios: low-range (B2), mid-range (A1B), and high-range (A2), using the PRECIS (Providing Regional Climates for Impact Studies) model with input from the ECHAM4 GCM and HadCM3Q0 GCM (PAGASA, 2011). Although there are differences in the three scenarios, the projected temperature increases diverge starting from the middle of the 21st century. The PRECIS (HadRM3P) model is also used in the Southeast Asia Climate Analyses and Modeling (SEACAM) Framework to downscale climate projections over Southeast Asia under the A1B scenario from the HadCM3Q ensemble and ECHAM5 GCMs (Rahmat et al, 2014). A working paper was also released by the Asian Development Bank in 2013 examining the relationship between disaster risk factors (including climate-related hazards) and the increasing frequency of natural disasters in the Asia-Pacific region (Thomas et al., 2013). In the report, estimates of temperature and rainfall projections for the Philippines under the A1B scenario were provided by the Manila Observatory using the Abdus Salam International Centre for Theoretical Physics Regional Climate Model version 3 (RegCM3) with the ECHAM5/MPI-OM GCM (Manila Observatory, personal communication).

This section describes the changes in climate under the mid-range scenario (A1B), which is described in PAGASA (2011) in more detail. The mid-range scenario was selected since it presents a more plausible future given the strong influence of existing atmospheric greenhouse gases on the future climate in the next three to four decades. In addition, climate changes under the A1B scenario was also used by Thomas et al. (2013) using a different RCM and GCM, as well as by Rahmat et al. (2014). The uncertainty in the projected changes can therefore be reduced if there is agreement among different model projections.

7.3.1 Seasonal Temperature Change

The Philippines is projected to be warmer in the future, relative to the baseline climate: 1971–2000 (PAGASA, 2011; Rahmat et. al. 2014) and 1961–1990 (Thomas et al., 2013). Annual mean temperatures are expected to increase by 0.9°C to 1.1°C in 2020 and by 1.8°C to 2.2°C in 2050 (PAGASA 2011). These estimates are consistent with the projection of 0.8°C to 2.2°C by 2020 and 2050, respectively (Thomas et al., 2013). On the other hand, Rahmat et. al. (2014) estimates up to 1.5°C significant warming in the Philippines in the mid-term (2031-2060).

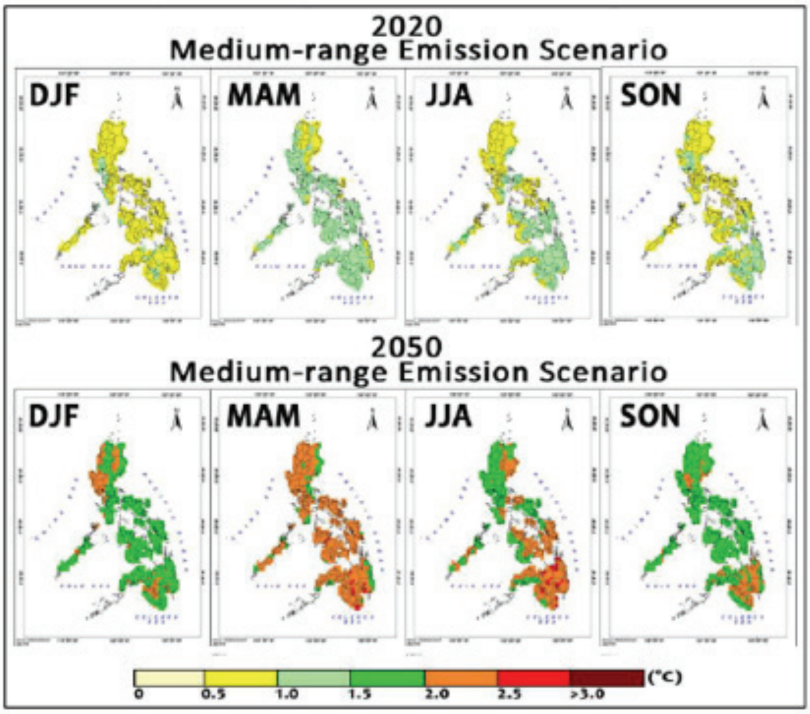

Figure 7.1 Projected seasonal temperature increase (in ˚C) in the Philippines in 2020 and 2050 (PAGASA, 2011, Figure 17)

Figure 7.1 shows that seasonal mean temperatures will also increase in all four seasons: December to February (DJF), March to May (MAM), June to August (JJA), and September to November (SON) in 2020 and 2050, and in all provinces (PAGASA, 2011). However, the country will experience warmer conditions during MAM, making the summer season hotter in the future. Mindanao and southern Visayas will be warmer in both time periods, most notably over the Zamboanga Peninsula (Thomas et al., 2013).

7.3.2 Seasonal Rainfall Change

There is spatial variability in the seasonal rainfall changes in the Philippines. While Luzon will experience an increase or no change in the mean rainfall in the 2020s, it will be drier over most areas in the country, which will persist in the 2050s (Thomas et al., 2013).

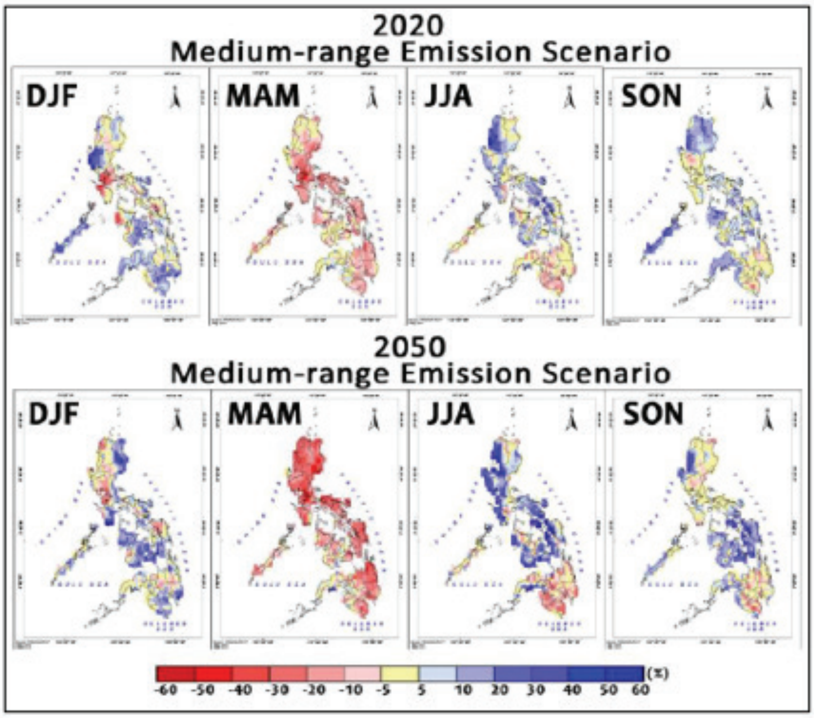

Figure 7.2 Projected seasonal rainfall change (in %) in the Philippines in 2020 and 2050 (PAGASA, 2011, Figure 18)

Projections from PAGASA (2011) indicate that in general, dry seasons will be drier and rainy seasons wetter. Furthermore, projections for the middle of the 21st century indicate drier (wetter) conditions in the early (latter) half of the year, albeit insignificant (Rahmat et al., 2014). During the summer (MAM), most provinces will have less rainfall, particularly in the 2050s (Figure 7.2). On the other hand, rainfall will be higher over most of Luzon (about 0.9% to 63%) and Visayas (2% to 22%) during the southwest monsoon period starting June, but will be lower over Mindanao (Figure 7.2; PAGASA, 2011). Rainfall during the northeast monsoon season (from December to February) is also projected to increase, particularly over the eastern part of the country (with Type II climate), and over certain islands in the Visayas and in the southern part of Mindanao (PAGASA, 2011). During this season, the change in rainfall over western Luzon also shifts from an increase in the 2020s to a decrease in the 2050s (Figure 7.2).

7.3.3 Extreme Events

Accompanying the changes in the mean temperature and rainfall are changes in the extremes, which also have significant impact on the natural and social environments. By 2020 and 2050, projections show that hot days (days with temperatures exceeding 30°C or higher) will be more frequent over the Philippines, as shown in Figure 7.3 (PAGASA, 2011; Thomas et al., 2013). However, the significance of this change was not determined. Changes in rainfall extremes are also anticipated, e.g., more dry days over the Philippines, particularly south of 15°N latitude (Rahmat et al. 2014), and more heavy rainfall days (rainfall >300 mm) over Luzon and Visayas (PAGASA, 2011; Thomas et al., 2013). This finding agrees with the projected increases in the annual maximum one day rainfall (Rx1day) and annual maximum consecutive five days rainfall (Rx5day) in areas above the 15°N latitude, particularly at the end of the century, which can vary depending on the GCM (Rahmat et al. 2014).

7.4 DIRECTIONS FOR FUTURE STUDIES

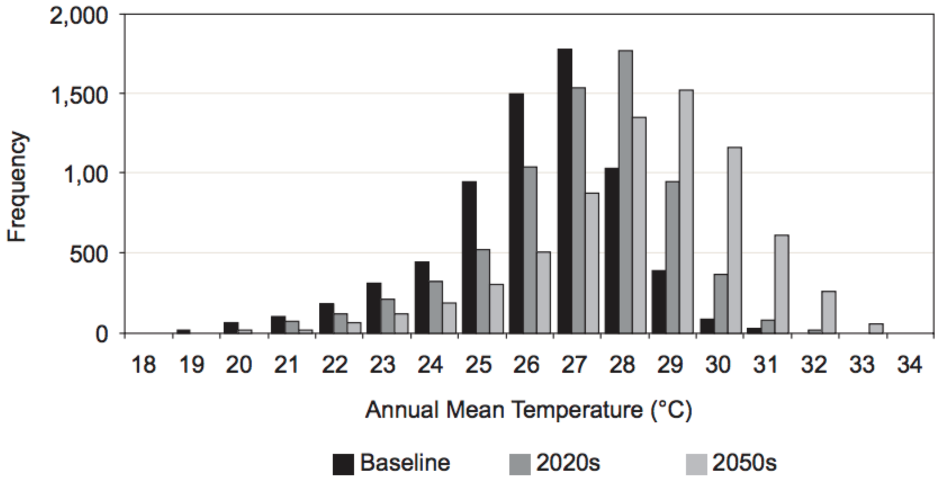

Figure 7.3 Projected annual mean temperature for the Philippines in the 2020s and 2050s relative to the baseline (1961–1990) (Thomas et al., 2013, Figure 7)

The climate projections for the Philippines as discussed in this chapter were derived from a very limited number of GCMs and RCMs, using the SRES emission scenarios. Given the progress in model development, as well as the use of the RCP scenarios in the IPCC AR5 report, there is a need to update these climate projections. Efforts are underway (e.g., PAGASA, SEACLID/CORDEX-SEA project) to provide an updated ensemble of climate projections for Southeast Asia, including the Philippines, using multiple GCMs and RCMs under several RCP scenarios. It is important to enhance the modeling capacities in the country and to sustain activities that generate ensembles of model output to narrow down uncertainties in climate projections. The generation of worst and best case scenarios will also guide the country's disaster risk reduction and climate change adaptation efforts. Further studies can explore how to quantify the uncertainties involved in these projections and the implications on impact assessments. There is also a need for a deeper and more comprehensive analysis on how the underlying physical and dynamical processes in the climate system will evolve in the future.

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Global Changes in Climate
The Philippine Climate
Historical Changes in Philippine Climate
Observed Changes in Ocean Climate and Sea Level in the Philippines
Drivers of Local Changes in Climate
Projections of Future Changes in Climate

Leading scientists in the Philippines reviewed all best available scientific publications from international and local literature to provide the first comprehensive assessment of the climate change science in the country. By sharing the current scientific information on climate change science in the Philippines to climate researchers, adaptation and mitigation practitioners, and policy makers, the report can serve as key reference towards science-based and informed planning, decision-making, and resilience-building.

The Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc.
36th Flr. One Corporate Center, Julia Vargas corner,
Meralco Avenue, Ortigas, Pasig City 1605 Philippines
URL: www.omlopezcenter.org | Email: info@omlopezcenter.org
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