Institute of Strategy and Policy on Natural Resources and Environment

VIET NAM ASSESSMENT REPORT ON

CLIMATE CHANGE (VARCC)

HA NOI, 2009

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Foreword

Minister of Natural Resources and Environment

Global Climate Change – commonly known as global warming and associated sea level rise – is one of the most serious challenges facing the human beings in the 21st century. Natural disasters and extreme climatic phenomena are increasing in number, affecting the lives of humans across the globe.

Viet Nam is likely to be one of the several countries most adversely affected by climate change. During the last 50 years, Viet Nam's annual average surface temperature has increased by approximately 0.5 - 0.7°C, while the sea level along it's coastline has risen by approximately 20 cm. The El-Nino and La-Nina phenomena have caused increasingly adverse impacts to Viet Nam. Climate change has resulted in more severe and/or frequent occurrences of natural disasters, especially cyclonic storms, floods and droughts becoming more extreme in Viet Nam.

Together with the world's community, Viet Nam has made strong commitments to combat against climate change through for example, its ratification the United Nations Framework Convention on Climate Change, the approval of the National Target Program to Respond to Climate Change, and recently the announcement of the Climate Change and Sea Level Rise Scenarios for Viet Nam. Recognizing potential and long term and widely spatial impacts of climate change, Viet Nam has looked forwards to developing its long term policies on, and clear-sighted vision in, climate change mitigation and adaptation endeavors, and has attached much more significance to the mainstreaming of climate change responsive solutions into national socio-economic development strategies, policies and plans with a view to achieving sustainable development of the country.

The Institute of Strategy and Policy on Natural Resources and Environment (ISPONRE) under the Ministry of Natural Resources and Environment (MONRE), has in collaboration with national and international experts, been primarily responsible for preparing the Viet Nam Assessment Report on Climate Change (VARCC) within the technical assistance framework of the United Nations Environment Programme (UNEP). This is the report typically developed under the guidance of UNEP with a view to providing an overview of climate changes, their potentially negative impacts and responsive measures of nations worldwide. The report has three chapters: 1) Overview of global climate change; 2) Climate change and scenarios in Viet Nam, and 3) Climate change impacts and strategy, options to cope with climate change in Viet Nam. The report may serve as a good reference for a wider range of target audience including policy-makers, scientists and those who are interested in climate changes and climate change responsive efforts in Viet Nam.

MONRE would like to express our sincere thanks to UNEP for its financial and technical supports, and to national and international experts and relevant agencies and organizations for their contributions to the development and refinement of the report. MONRE also highly appreciates great efforts that ISPONRE has contributed to ensure the successful development of the important report

Dr. Pham Khoi Nguyen
Minister of Natural Resources and Environment
November 2009

Foreword

UNEP's Representative for the Asia and the Pacific

The United Nations Environment Programme (UNEP) is mandated to regularly assess major environmental developments and trends. This mandate is implemented through the Global Environment Outlook (GEO) process, which involves global, regional, subregional, national and city-level assessments. The GEO process is participatory, consultative, and focuses on capacity-building to produce scientifically authoritative information for environmental management and policy development for a wide target audience. The Viet Nam Assessment Report on Climate Change 2009, conducted by the Institute of Strategy and Policy on natural resource and environment (ISPONRE), is one of the outputs of this capacity-building programme. The report assesses climate change impacts and their implications to help decision makers understand the need for urgent action and to mobilize public awareness and participation.

As a peninsula country located in the tropical monsoon belt of Southeast Asia, Viet Nam his one of the nations with a high potential of being most negatively impacted by climate change. The country is already experiencing changes in fundamental climatic elements as well as extreme weather phenomena such as storms, heavy rains, and droughts. Temperature is rising by 0.5-0.7^{0}C per 50 years, from the South to the North, and the frequency of cold fronts has decreased by 2.45 events per 50 years. Its coastal areas bear the brunt of tropical storms arising from the East Sea, with an average of almost 7 storms yearly. It has been observed that tropical cyclone frequency has increased by 2.15 events per 50 years, and the sea level has risen between 20cm per 50 years.

The scenario analysis in the report indicates that the overall temperature in Viet Nam in 2100, compared with the period of 1980-1999 is likely to increase by between 1.1-1.9 ^{0}C and 2.1-3.6^{0}C; annual rainfall is likely to increase by between 1.6% - 14.6%; and sea level is likely to rise by between 11.5cm - 68 cm. Of these possible impacts of climate change, sea level rising at a speed of 0.5-0.6 cm per year is the most worrying, particularly for Southern Viet Nam.

The potential impacts of climate change are likely to be most serious in the agricultural and the water resources sectors, and that flood inundation and droughts are likely to occur more frequently due to an increase in rainfall intensity and decline in number of rainy days. Large cultivation areas in the Mekong and Red River deltas are likely to be affected by salt water intrusion due to sea level rise. Climate change is also likely to result in increasing extinction of biodiversity, especially native plant species and economic value species such as Siadora Vietnamese and textured wood. Sea level rise could result in a decline in mangrove forest area, adversely affect indigo forests and forest planted on the sulfated land of South Viet Nam, and change boundary distribution of primary and secondary forests. The Red River Delta and Quang Ninh province, the North Central Coast, South Central Coast and the Mekong River Delta were identified as the most vulnerable areas. Finally, the report outlines government initiatives mentioned in the Report to reduce greenhouse gas (GHG) production in many sectors such as energy efficiency, protection and increase of forest cover, and strengthening the development of the climate observation and monitoring system.

UNEP's Medium-term Strategy (2010-2013) directs the organization to strengthen the ability of countries' to integrate climate change responses into their national development processes, supported by scientific information, integrated climate impact assessment and local climate data. I believe this report responds to this mandate and provides important information and options for the government of Viet Nam, through MONRE, to help sustain the quality of life and livelihoods of the country's residents.

Young-Woo Park

Dr. Young - Woo Park

Regional Director and Representative
United Nations Environment Programme
Regional Office for the Asia and the Pacific
November 2009

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Acronyms

ADB	Asian Development Bank
C	Carbon
CC	Climate change
CH_4	Methane
CM	Centimeter
CO_2	Carbon dioxide
CCS	Carbon capture and storage
FRL	Cold front
GEF	Global Environmental Facility
GHG	Green House Gas
INVN	Initial National Communication of Viet Nam on Climate Change
IPCC	Intergovernmental Panel on Climate Change
PPB	Parts per billion by volume
PPM	Parts per million by volume
TC	Tropical cyclone
TCAVN	Tropical cyclone affecting Viet Nam
TCOSCS	Tropical cyclone forming over the East Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank
WMO	World Meteorological Organisation
SRES	Special Report on Emission Scenarios (IPCC)
ALGAS	The Asia Least Cost Greenhouse Gas Abatement Strategy Project

Summary

1. Earth, is the only planet in our solar system known to harbor life - life that is incredibly diverse. The recent evidences of global warming, sea level rise, natural disasters, crop failures, epidemic diseases, etc are threatening the life on Earth. Urgent actions for mitigation and adaptation on climate change are required to be taken now in order to sustain the lives of humans while there is no authentic evidence of modern science for any other place in a universe where humans can shelter in.

2. The evolution of the Earth's climate is a complex process with the participation and reciprocal influence between many various elements. Subsequent to experiences of a number of changes leading to serious disasters in its history such as ice ages, the earth climate was back to normal to support the lives on the Earth. Air, water, land and living being are the elements with high influence to the global climate. Natually occurring green house gases such as water vapour, CO_2, CH_4, O_3 and N_2O blanket the Earth and keep it about 30^0C warmer than it would be without these gases in the atmosphere. This is called the Green House Effect. However, green house gas emissions from human activities have caused rapid changes in climate change in the past century. The concentration of the main green house gases: CO_2, CH_4, O_3, N_2O and CFC in the atmosphere have exhibited unprecedented increase leading to perturb the capacity of thermal exchange of the Earth's surface and increase the Earth's average surface air temperature by about 0.75^0C. Along with global warming, increases and/ or decreases in rainfall at several locations have been reported and changes in both the frequency and intensity of heavy rains have occurred. In addition, total ice volume for the globe has decreased; in the Arctic Ocean, ice volume has been decreasing at a rate of 2.7% annually from early 1974 up to present, mean sea level across the globe has also risen by 1.8mm annually counting from 1961 and 3.1mm annually counting from 1993.

3. Climate scenarios for the 21st century were developed based on SRES scenarios of green house gas emission trends. According to the said SRES scenario of lowest green house gas emission (B1) in the years 2090 – 2099 compared with the period of 1980-1999, the global mean surface temperature is projected to increase by 1.8^0C and global mean sea level is projected to rise by 0.18 – 0.38mm. According to the SRES scenario of highest green house gas emission (A1FI) in the years 2090 – 2099 with respect to the years 1980 – 1999, the global mean temperature increase is projected to be as high as 4.0^0C and global mean sea level rise is projected to be between 0.26 – 0.59mm due to thermal expansion of sea water and exclusive of dynamic changes by thawing and melting of ice caps.

Along with the temperature increases and rise in sea level, sunshine spells are projected to increase; increase in tropical cyclone intensity is also projected. A hotter climate and sea level rise shall continue beyond the 21st century irrespective of a collective action by all countries towards stabilization of concentration of green house gases in the earth's atmosphere.

4. Viet Nam has a tropical and monsoon climate of the Southeast peninsula of European-Asian mainland which is extended over latitude 15^0 and it lies totally at the tropic inner-belt of Northern hemisphere with a profound impact of the East sea. In the territory of Viet Nam, the sun's altitude is

fairly large resulting in a regular illumination time, abundant sun's radiation in total and the radiation balance is positive in general.

The atmospheric circulation over Viet Nam is a part of the Southeast Asia monsoon circulation which is both associated with the South Asian monsoon, especially in the summer and under influence of the East Asian monsoon especially in the winter. In the winter, every time frigid polar air breaks out, the cold air will overflow into Viet Nam after a cold front. A number of cold fronts flock into Viet Nam each month of the winter with an average frequency of 3 to 4. During summer, inter tropical convergence zone moves over Viet Nam in the North - South direction. Viet Nam is also affected by inland movement of tropical cyclones creating bad weather associated with thick dense cloud and heavy rain. Annually, there are 11 tropical cyclones with an average quantity originating in the area of East Sea and almost two-thirds of them directly influence the geographical boundary of Viet Nam and especially in the coastal zones. There are two monsoon circulation systems prevailing in the region during the year: Northeastern winds and Southwest or Southeast winds. Winds' average speed is approximately 0.8 - 6.2 m/s throughout the year and it increases gradually from the mountainous regions to the coastal deltas and islands. The record maximum speed of winds ever recorded was 59 m/s as observed in Quy Nhon during a storm that landed over the South-Central region in September 1972.

Average duration of sunshine hours in a year is 1,400-3,000 hours approximately and that duration decreases gradually from the South to the North, from delta to mountain and from low altitude to high altitude. The lowest record temperature is – 3.7^{0}C and highest record is 42.9^{0}C. Annual average rainfall is 700 – 5,000 mm with 11 heavy rain centers (>2,400mm) and 8 light rain centers (<1,400 mm). Rainy season in the North, Central Highlands and the South starts from April, May to September and October under the rainy regime of southwest monsoon and in the coastal zones of the North-Central and South-Central from August, September to December and January under the rainy regime of northeast monsoon. Average evaporation volume in a year is about 800-1,500 mm and decreases gradually from the South to the North, from deltas to mountains and from low altitude to high altitude. Annual humidity index ranges between 1 and 5 approximately - this means annual rainfall is 1-5 times higher than evaporation volume under the monsoon rainy regime; there are many dry months in any climate belt. Typical weather consists of hoarfrost, drizzling rain, fog, etc., mainly in the winter and associated with squalls in the summer. In addition, dry hot winds appear, leading to droughts mainly during the summer, in the west and in the coastal zones of the North Central and South Central. Droughts in Viet Nam consist of Winter-Spring drought which coincides with the dry season of the North, Central Highlands and the South and the summer drought coincides with the west dry hot winds of the Central.

There are 7 climate zones formed in Viet Nam's territory: North West, North East, North Delta, North Central which belong to climate area of the North, and South Central, Central Highlands, and the South which belong to climate area of the South. The degree of change in observed climatic elements exceeding the trend is calculated by standard deviation which is as under: for average temperature of January: 0.7^{0}C – 1.5^{0}C; for average temperature of July: 0.3^{0}C – 0.7^{0}C; for annual average temperature: 0.3^{0}C – 0.5^{0}C; for frequency of cold fronts: 4.36; the frequency of formation of tropical cyclones in the East Sea: 2.93, for frequency of tropical cyclones hitting Viet Nam: 2.58; and annual average sea level rise: 3.5 – 5.4 cm.

The degree of observed rainfall change is calculated by fluctuation frequency of annual rainfall 12-30%; of rainy months: 25-80% and of light rain months being over 50% increasing and even exceeding beyond 100%. Trend for the period from 1955 to 2007 (calculated for the annual average temperature: 0.05 – 0.2^0C/decade, for the cold fronts: 0.049 per year, for the formation of tropical cyclones in the East Sea: 0.0138 per year, for tropical cyclones affecting Viet Nam: 0.043 per year, for sea level rise in Hon Dau (the North): 0.205 cm/year, in Son Tra (the Central): 0.26 cm/year, in Vung Tau (the South): 0.398 cm/year. Rainfall does not have a clear and consistent trend pattern but in comparison with the previous decade, the rainfall in recent decades has decreased in most locality of the North and increased in most locality of the South.

5. Up to now, Viet Nam has developed and reported future scenarios of climate change 3 times namely in the years 1994, 1998 and 2007. An updated version of the future scenarios of 2009 has officially been published by the Ministry of Natural Resources and Environment of Viet Nam as "Climate Change, Sea Level Rise for Viet Nam" in the year 2009.

According to the scenario built in 1994 (called temporarily "Scenario 1994"), the temperature for 2070 compared with the period of 1980-1999 (average for the year) was projected to increase in the range 1.2^0C – 4.5^0C in the climate zones of the North (North West, North East, North Delta, North Central) and in the range 0.5^0C – 3.0^0C in the climate zones of the South (South Central, Central Highlands, the South) and the sea level shall rise to be as high as 15 – 90cm along the coastline.

According to the Scenario 1998 (based on IS92a emission scenarios): the temperature for 2070s as compared with the period of 1980-1999 was projected to increase by 1.5^0C in the coastal deltas and 2.5^0C in the mountains; rainfall in the rainy season to increase 0 – 5% in the climate zones of the North (North West, North East, North Delta), Central Highlands, the South and 0 – 10% in the climate zones of the Central; rainfall in the dry season to decrease from 5% and increase up to 5% in the climate zones of the North, Central Highlands, the South and increase 0 – 5% in the climate zones of the Central, and the sea level to rise by 45cm.

According to the Scenario 2007 (based on IPCC's Special Report on Emission Scenarios): the temperature by the end of the 21st century compared with the period of 1980-1999 is projected to increase between 1.1 – 1.9^0C in low and between 2.1–3.6^0C in high emission scenario; annual rainfall to increase between 1.0 – 5.2% in low and between 1.8 – 10.1% in high emission scenario, the sea level to rise by 65 cm in low and by 100 cm in high emission scenario.

The scenario on Viet Nam's future climate change presented in this report for temperature and rainfall is based on the scenario 2009, meaning that the mean surface air temperature shall increase between 1.1 – 1.9^0C in low and between 2.1 – 3.6^0C in high emission scenario; rainfall shall increase between 1.0 – 5.2% in low and 1.8 – 10.1% in high emission scenario, and the sea level shall rise by 65 cm in low and by 100 cm in high emission scenario.

6. Potential impacts of projected climate change in Viet Nam in all the sectors and developmental activities are presented in this report with various manifestations.

The impact of climate change is likely to be crucial in the water resources, agriculture, forestry, fishery, energy, transportation and health sectors. As regards the water resources, the annual outflow in the large, medium and small rivers is projected to change mainly to the negative and flood flow is likely to change mainly to the positive. As regards agriculture, adaptive scope of tropical plants are likely to be enlarged and that of subtropical plants be narrowed considerably. The droughts and floods are projected to increase evenly and especially, over a considerable part of cultivation areas in the coastal deltas; Red and Mekong river deltas are likely to be under salt-marsh due to sea level rise. Along with them, the availability of agricultural water resources is also likely to be influenced by climate change. As regards forestry, sea level rise is likely to shrink the area of mangrove forest, forest cover consisting of oil-bearing family trees shall be enlarged to the North at the higher altitudes; forest cover consisting of defoliation trees with many of drought-resistant varieties are likely to expand prominently and they can contribute to the spread of forest-fire and higher exposure to insect pests. As regards fisheries, the salt water intrusion deep towards inland shall result in loss of some freshwater aquatic species, some of them shall migrate to the North or submerge in a deeper water environment, and the coral reefs shall be deteriorated. As regards energy, climate change impacts shall adversely influence the offshore oil-rigs, seaports, coastal traffic roads especially along the Northern-Southern railway line, increasing energy consumption to the drain pumps in the low coastal zones installed to freshen pits, and to enhance the reserve volume and hence the flow in the lakes used for generation of hydroelectricity. Regarding human health, increasing dangers due to heat stress to the elderly, cardiovascular cases and other tropical diseases such as malaria, petechial fever; diarrheal diseases due to growing bacteria and pathogenic microbes are projected.

The potential impacts of climate change for various climatic zones of Viet Nam are likely to be different and need to be considered based on regional priorities.

In the North West and North East, frequency of cold fronts is likely to decrease with the rise in the surface air temperature and frequency of heat waves is likely to increase, the hot season is projected to be longer and the cold season is projected to be shorter in duration. Other than the projected increases and/or decreases in seasonal rainfall, unusual rainfall pattern, frequency of floods and droughts is likely to increase; evaporation will be more pronounced and humidity is likely to decrease in a warmer atmosphere. In the North Deltas and coastal zones of Quang Ninh also, similar to the North West and North East, the frequency of cold fronts is likely to decrease, temperature and frequency of heat-waves increase, hot season shall be longer lasting and cold season shall be narrowed, rainy season shall be unusual, flood and drought frequency may increase evenly. Along the seaside of the Central region, sea level is projected to rise at a rate of 0.5 – 0.6cm per year. In the Central Highlands region, the rise in surface temperature would also be accompanied by an increase in total annual rainfall in the future. An enhanced variability in seasonal rainfall and an increase in the frequency of floods and droughts are also projected. In the South, the development and movement of tropical cyclones can become more unstable as compared to that in the past and typhoon season is likely to commence sooner. The maximum temperature is projected to continue to rise and attain a new record. The monthly sunshine duration in near future is likely to be increase. In the long term, rainfall during rainy season will likely increase, while the intra-seasonal variability in rainfall during dry season is projected to enhance. Rainy season shall become more unstable than in the past. The projected rise in sea level at a rate of 0.5-0.6 cm per year is the most significant consequence of climate change in the South of Viet Nam. In general, the North Delta and Quang Ninh province, the North Central Coast, South Central Coast and the Mekong River Delta are the most vulnerable areas to potential impacts of the climate change in Viet Nam.

7. Viet Nam is developing a low carbon economy and mitigation policies on climate change through programmes and projects aiming to reduce the green house gas emissions in many sectors such as energy, industry, transportation, forestry and agriculture.

Many approaches for utilization of energy efficiency and energy savings in public lighting system, domestic, industry and transportation, etc have been applied in Viet Nam. Viet Nam is also promoting research, promotion and implementation of increase in use of the biological, solar, wind, hydro and geothermal energy.

Viet Nam is developing a guideline for sustainable agriculture practices which enhances the utilization of biomass energy; develop the biogas system and low carbon emissions in eco-agriculture sector aimed at reducing the green house gas emissions in wet rice cultivation.

Viet Nam is committed to protect and enhance the number of green house gas sinks in forestry, especially Five Million Hectare Reforestration Programme. Viet Nam is also committed to develop the agriculture which improves the sustainable cultivations to adapt to the climate change.

8. Viet Nam is developing a number of strategies to adapt to the impacts of climate change so as to reduce the vulnerability of society to climate change. The general orientation is to integrate options for mitigation and adaptation on climate change in all its socio-economic development activities, plans, programmes and projects through identification of appropriate coping strategies and responses, with special consideration on the impacts of sea level rise to the coastal infrastructures and livelihood of coastal communities.

In order to facilitate developing the strategy to adapt to climate change, strengthening of monitoring networks, promoting research and forecasting of extreme events should be paid special focus in the future.

Chapter 1

Overview of Global Climate Change

1.1 Overview of the climate system

Climate consists of physical and chemical processes under interaction with solar radiation on the Earth. Solar radiation is the main source of energy on the Earth, forming and maintaining both human and creature life, including plants and animal.

The Earth is just one of the planets in the solar system. Therefore, only one part of solar energy comes to the Earth. In term of the total solar energy coming to the Earth, one third will be reflected back out to the universe due to clouds and glaciers, while two third of the energy will be absorbed by the Earth, including the atmosphere, hydrosphere, cryosphere and biosphere

The Atmosphere

The Earth is covered by an air envelope called the atmosphere. The atmosphere is a layer of gases surrounding the Earth like a vast ocean, with human and creatures living in this ocean.

The air density is reduced at higher levels and around half of the atmosphere concentrates in the lowest level below 5 km from the earth's surface.

The atmosphere interacts with other the components in the Earth system such as the hydrosphere, cryosphere, geosphere and biosphere, and is the main component of climatology, as well as climate change.

The Hydrosphere

The ocean is the main component of hydrosphere, accounting for 71% of the Earth's area. The volume of ocean is 1,340 million km^3 and its average depth is 3,711m.

The ocean plays an important role in climate equable through important characteristic of water: heat capacity is higher, transparent is stronger and the potential of heat transfer to deeper layers. Therefore, while absorbing the solar heat, the ocean does not rapidly warm, but is kept warm when heat is lost.

The Cryosphere

The cryosphere consists of those regions of the globe, both land and sea, covered by snow and ice. These include Antarctica, the Arctic Ocean, Greenland, Northern Canada, Northern Siberia, and most high mountain ranges throughout the world, where sub-zero temperatures persist for the majority of the year.

Snow and ice have a high albedo (reflectivity) that is, they reflect much of the solar radiation they receive. Some parts of the Antarctic continent reflect as much as 70% of incoming solar radiation, compared to the global average of 31%.

In modern research on climate change, the cryosphere is strongly considered given that global warming has a significant impact on the maintenance and presence of the cryosphere; glacier melt results in reductions in the cryosphere area and increasing global temperature and sea level rise.

The Geosphere

The geosphere consists of the soils, the sediments and rocks of the Earth's land masses, and the continental and oceanic crust. Each of these parts of the geosphere play a role in the regulation and variation of global climate.

The soils are unequally distributed among the two hemispheres and in each hemisphere, with the soils also unequally distributed among the latitudes.

The mainland area is 40% in the Northern hemisphere and only 19% in the Southern hemisphere. In the Northern hemisphere, the mainland is spread along the latitudes while in the Southern hemisphere 73% of the mainland is in the tropical areas.

The mainland climate is more severe compared with the ocean climate and the climate change in the mainland is more obvious than in the ocean.

The Biosphere

The biosphere, both on land and in the oceans, affects the albedo of the Earth's surface, including adsorption and reflection albedo.

The most important part of the biosphere with regards to the climate system, in general, and with climate change, in particular, is the forests. Forests can absorb CO_2 to reduce GHG emission, one of the most serious challenges for the global environment.

Millions of spores, viruses, bacteria, pollen and other minute organic species are transported into the atmosphere by winds, where they can scatter incoming solar radiation, and so influence the global energy budget.

The human and other economic development activities have significant effects on the climate system through emission of CO_2, CH_4 and N_2O, which cause GHG concentrations to increase, leading to climate change.

1.2 The Green house effect and green house gases (GHG)

1.2.1 The green house effect

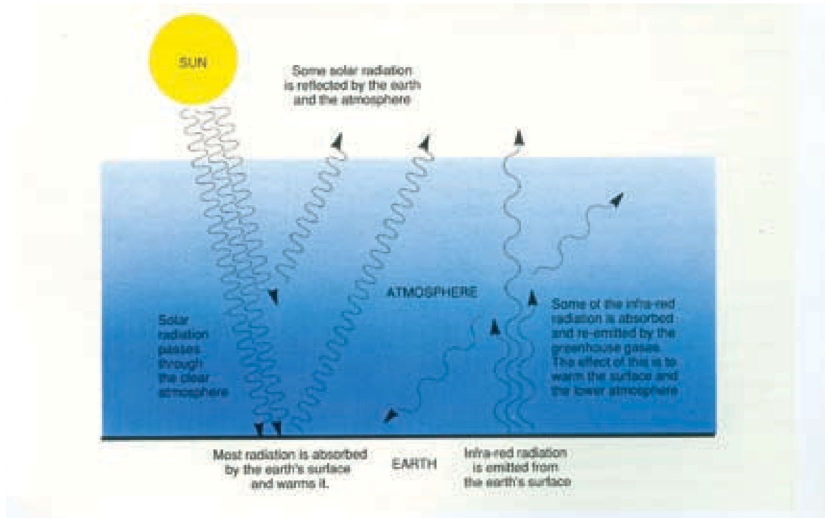
The "green house effect" is the heating of the Earth due to the presence of GHGs. It is called this because of a similar effect produced by the glass panes of a green house. Shorter-wavelength solar radiation from the sun passes through the Earth's atmosphere, and is then absorbed by the surface of the Earth, causing it to warm. Part of the absorbed energy is then reradiated back into the atmosphere as long wave infrared radiation. A fraction of this long wave radiation escapes back into space; but most of the radiation cannot pass through the GHG in the atmosphere. The GHG selectively transmits the infrared waves, trapping some, while allowing others to pass through into space. The GHGs absorb these waves and re-emits them downwards, causing the lower atmosphere to warm.

With the inherent amount in the atmosphere, GHGs cause the natural green house effect, which increases the surface temperature of the Earth by 33^0C, or in other words, raises the global mean surface temperature to 15^0C from -18^0C.

The green house effect has existed in the Earth's system since its formation, together with its atmosphere and climate system, which nearly remained intact until the pre-industrial era. Since then (from approximately

1750), however, humans, through socio-economic development activities, especially the industrialization, have emitted into the atmosphere many gases with extremely dangerous green house effects, such as CO_2, CH_4 and N_2O, as well as HFCs, PFCs and SF6, which have increased the concentration of GHGs in the atmosphere, intensified the green house effect and, as a result, further increased the temperature of the Earth's surface and the lower convection layer of the atmosphere, causing the climate change the Earth has experienced in more recent times. The green house effect supplementing for the natural green house effect is called the artificial green house effect *(Figure 1.1)*.

Figure 1.1. Illustration for the green house effect



Source: Climate Change 1994, IPCC

1.2.2 Green house gases

Carbon dioxide

Carbon dioxide (CO_2) is the GHG that accounts for half of the total amount of GHGs and has contributed 60% to the increase in atmospheric temperature.

Since the world began its process of industrialization, together with the increase in the population and agricultural development, the quantity of CO_2 emission has greatly increased. From 1765 to present, CO_2 concentrations in the atmosphere have increased by 28% (31±4%). The increase in CO_2 concentration mainly originated from the burning of fossil fuels, such as coal, oil, and their exploitation. Coal burning generates the largest amount of CO_2, followed by the burning of oil (petroleum) and gases. Coal and oil-fired thermal power plants, as well as automobiles and other means of transport fueled by petrol or oil, are sources that generate a great amount of CO_2, accounting for 80 – 85% of the total additional amount of CO_2 in the atmosphere. The consumption of fossil fuels alone has contributed to the increase of the total amount of CO_2 in the atmosphere by 0.5 - 1% per year.

Deforestation for cultivation and civil construction also contribute to reducing the capacity of CO_2 absorption of this "carbon sink".

Methane

Methane (CH_4) is the second most important GHG created by human activities. The sources of methane mainly originate from wet rice cultivation, livestock's excrement, and disintegrated materials in the soil, marshes and fuel-exploiting mines. Methane also originates from coalmines, oilrigs or leaking gas pipelines.

Methane in the atmosphere was found from around 1940. Official measurements, however, were not conducted until the end of the 1960s. Methane concentration in the atmosphere at present has increased by 145% in comparison with that in the pre-industrial era.

Ozone

Nowadays, people regularly mention the hazard of the depletion of ozone in the stratosphere, which works as the shield protecting living beings on Earth from ultraviolet radiation beams generated by the sun. However, for the troposphere, the increase of ozone concentration is also as dangerous as that of other GHGs.

Ozone in the troposphere, although short-lived, is a GHG. Ozone is created from nature as well as humans' activities, such as automobile engines, motorcycles and power plants. The ozone content in the troposphere has increased by 35±15% in comparison with that in the pre-industrial era.

Nitrogen Oxide (N_2O)

Like methane, official measurements of N_2O concentration in the atmosphere had not been undertaken until about 10 years ago. From air bubble samples taken from ice, researchers have found that the N_2O concentration has increased by about 8% from the beginning of the century to the present and is continuing to rise. The N_2O today originates from the burning of fuels, the use of fertilizers, the production of chemicals, and deforestation.

These human activities have increased the inherent amount of nitrogen oxide in the atmosphere by about 15% (17±5%).

Chlorofluorocarbon (CFC)

Unlike other GHGs with natural origins, CFC is a completely artificial product. Produced since the 1930s, CFC is a chemical that has been widely used in refrigeration equipments such as refrigerators, air conditioners, refrigerant machines, cosmetic sprays, and sprays for washing electronic accessories. The use of this chemical increased sharply until the 1970s, when people found that it had the ability to destroy the ozone layer and its duration of existence was very long. Since 1995, the increase of CFC concentration has slowed down and there is a trend of reduction. According to the Montreal Protocol, the production of all CFC agents will be stopped all over the world from 2010.

Water vapor (H_2O)

Water vapor plays an important role in controlling the Earth's temperature by creating clouds. Clouds created by water vapor can prevent Earth radiation from escaping to space and increases the Earth's temperature. Unlike many other gases that more or less permanently exist in the atmosphere due to their long life time, water vapor, after being formed, swiftly disappears when clouds dissipate after rains. In addition, because the amount of water vapor in nature is quite stable, its role in contributing to an increase in the global temperature is different from that of other gases. The role of water vapor in climate change is still being studied.

1.3 The history of climate change

1.3.1 Climate change in the past hundreds of thousands of years

The Earth's climate history has experienced a number of changes due to its natural evolution as well as abrupt causes. Major volcanic eruptions have generated into the atmosphere a great amount of dust that has prevented solar radiation from reaching Earth and, consequently, cooled the Earth's surface for a long time. A volcanic eruption can prevent some solar radiation from reaching the Earth and increase the temperature of temperature-absorbing layers in the stratosphere by several degrees. This was shown through the activities of the Pinatubo volcano (the Philippines) in 1982 and 1991. During the time of this volcanic eruption, incoming solar radiation remarkably decreased at the Earth's surface.

During these cycles, the Earth's surface temperature normally decreased by 5°C-7^{0}C, or even 10°C–15^{0}C in areas of middle to high latitudes in the Northern hemisphere. During the iceless age from about 125,000–130,000 BCE, the average temperature of the Northern hemisphere was 2^{0}C higher than that in the pre-industrial era.

1.3.2 Climate change in the last 20,000 years

The Earth experienced the last ice age in around 18,000 years BCE. During this period, ice covered most of North America, North Europe and North Asia, with the sea level about 120m lower than it is today. Many evidences have shown that the temperature in about 5,000 – 6,000 years BCE was higher than that of today.

From the 14th century, Europe experienced a short ice age that lasted several hundreds of years.

Figures acquired show that the general trend is, from the end of the 19th century to the present, the global average air temperature in the 20th century has increased by 0,6^{0}C and the 1990s was the hottest decade in the last millennium (IPCC, 2001). Figure 1.2 describes the above said temperature trends in the 20th century.

1.3.3 Causes of modern climate change

The fundamental cause of modern climate change is the excessive increase in the amount of GHGs generated by human activities that leads to the increase in GHGs concentration in the atmosphere.

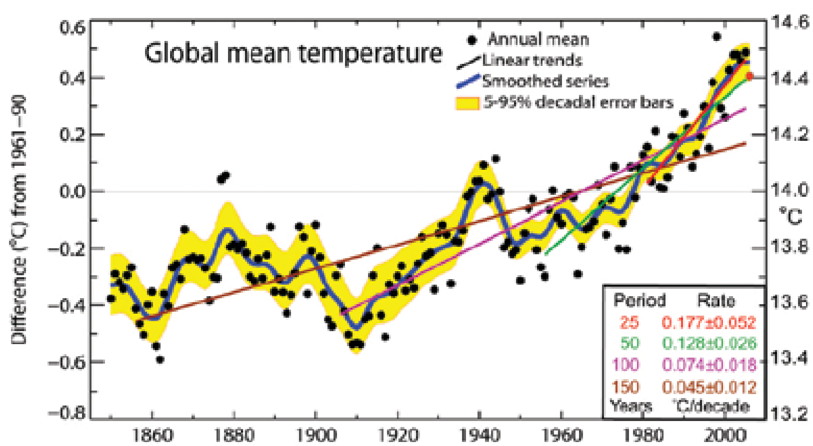
The artificial amount of GHGs generated during the period from 1975 to 2004 increased by 0.43 billion tonnes of CO_2 equivalent (CO_2eq) per annum, and while in the last 10 years it has increased by 0.92 billion tonnes per annum, due to the increase in energy production, transportation, industries, forestry (mainly deforestation), and agriculture.

The amount of GHGs generated on Earth has fostered the increase in the GHG concentration in the atmosphere, especially those of permanent gases, such as CO_2, CH_4 and N_2O.

The CO_2 concentration in the atmosphere had increased from 280 ppm to 379 ppm in 2005. The annual rate of increase of CO_2 concentration in the last 10 years, from 1996 to 2005, was 1.9 of a million per year.

The CH_4 concentration in the atmosphere increased from 715 ppb in the pre-industrial era to 3,732 ppb at the beginning of the 1970s and 1,774 ppb in 2005.

Figure 1.2. Observed global surface temperature anomaly during the period 1880-2007 (°C)



Source: http://www.ipcc.ch/graphics/ar4-wg1/jpg/faq-3-1-fig-1.jpg

Table 1.1. Components of pressured radiation (W/m^2)

Effect	Component	Detail	Single-valued estimation	Respective scope	Space scope	Reliability level	
				From	To		
Artificial	Permanent green house gases	CO_2	1.66	1.49	1.83	Global	High
		CH_4	0.48	0.43	0.53	Global	High
		N_2O	0.16	0.14	0.18		
		Halo Carbons	0.34	0.31	0.37		
	Ozone	Stratosphere	-0.05	-0.15	0.05	Continental – Global	Medium
		Troposphere	0.35	0.25			
	Stratospheric water vapor emitted from CH_4		0.07	0.02	0.12	Global	Low
	Ground reflex	Land use	-0.2	-0.4	0.0	Continental – Global	Medium – Low
		Black carbon on snow	0.1	0.0	0.2		
	Aerosol	Direct effect	-0.5	-0.9	-0.1	Continental – Global	Medium – Low
		Effect through cloud reflex	-0.7	-0.8	-0.3	Continental – Global	Low
	Linear reflex		0.01	0.003	0.03	Continental	Low
Natural	Solar radiation diffusion		0.12	0.06	0.30	Global	Low
Total			**1.6**	**0.6**	**2.4**	-	-

Source: IPCC, AR4, 2007

The N_2O concentration in the atmosphere increased from 270 ppb in the pre-industrial era to 319 ppb in 2005.

Consequently, pressured radiation, the factor that transforms the increase in GHGs into rise in temperature, has continuously been increasing globally and across all continents.

The major role of pressured radiation originates from permanent GHGs (Table 1.1). The positive radiation pressure of CO_2, CH_4, and N_2O is 2.3 (2.1–2.5) W/m^2, while the negative radiation pressure of aerosol is – 0.5 (-0.9 - -0.1) W/m^2 and that of cloud reflectivity is -0.7 (-0.8 - 0.3)W/m^2. As a result, pressured radiation reaches 1.6 (0.6 – 2.4) W/m^2, leading to global warming, the fundamental characteristic of modern climate change.

Table 1.2. The development of standard deviation of trends in temperature over continents in the 20th century

Region	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
North America	-0.2	-0.3	0.2	0.3	0.2	0.1	0.0	0.2	0.5	0.7
South America	-0.1	-0.2	0.0	0.2	0.1	0.2	0.1	0.0	0.2	0.4
Europe	-0.2	-0.1	0.0	0.1	0.2	0.0	0.1	0.0	0.4	0.8
Africa	-0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.3	0.5	0.7
Asia	-0.2	0.0	0.0	0.1	0.1	0.1	0.0	0.3	0.7	0.9
Australia	0.1	-0.1	0.0	0.0	-0.2	0.1	0.1	0.3	0.5	0.5
Globe	-0.2	0.0	0.1	0.2	0.1	0.4	0.4	0.2	0.4	0.7
Continents	-0.2	0.0	0.1	0.2	0.1	0.0	0.0	0.3	0.5	0.8
Oceans	-0.2	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.6

Source: IPCC, AR4, 2007

1.4 Changes observed in the last 150 years

1.4.1 Global climate change

Temperature

In the 20th century, the temperature in all continents and oceans had an obvious increasing trend (Table 1.2; Figure 1.3). The standard deviation of the global average temperature was 0.24^{0}C, the largest difference between two continuous years was 0.29^{0}C (between 1976 and 1977), and the rate of trend of temperature increase was 0.75^{0}C, faster than that in any other century in history from the 11th century to the present.

It is noticeable that in the last 5 decades, from 1956 to 2005, the temperature has increased by 0.64^{0}C±0.13^{0}C, twice faster than it did in the 20th century. It is clear that the trend of temperature change has become more rapid in recent years.

There are 11 years in the period from 1995 to 2006 (except 1996) that are classified in the list of 12 years with the highest annual mean global surface air temperature in the history of temperature observation since 1850, of which 1998 and 2005 are the hottest. Five years, from 2001 to 2005, alone have a surface air temperature 0.44^{0}C higher than the average baseline for the period 1961 - 1990.

It is also noticeable that the rate of temperature increase in the Arctic is twice higher than the global average rate, as a consequence of the highly complex ice albedo feedback mechanism.

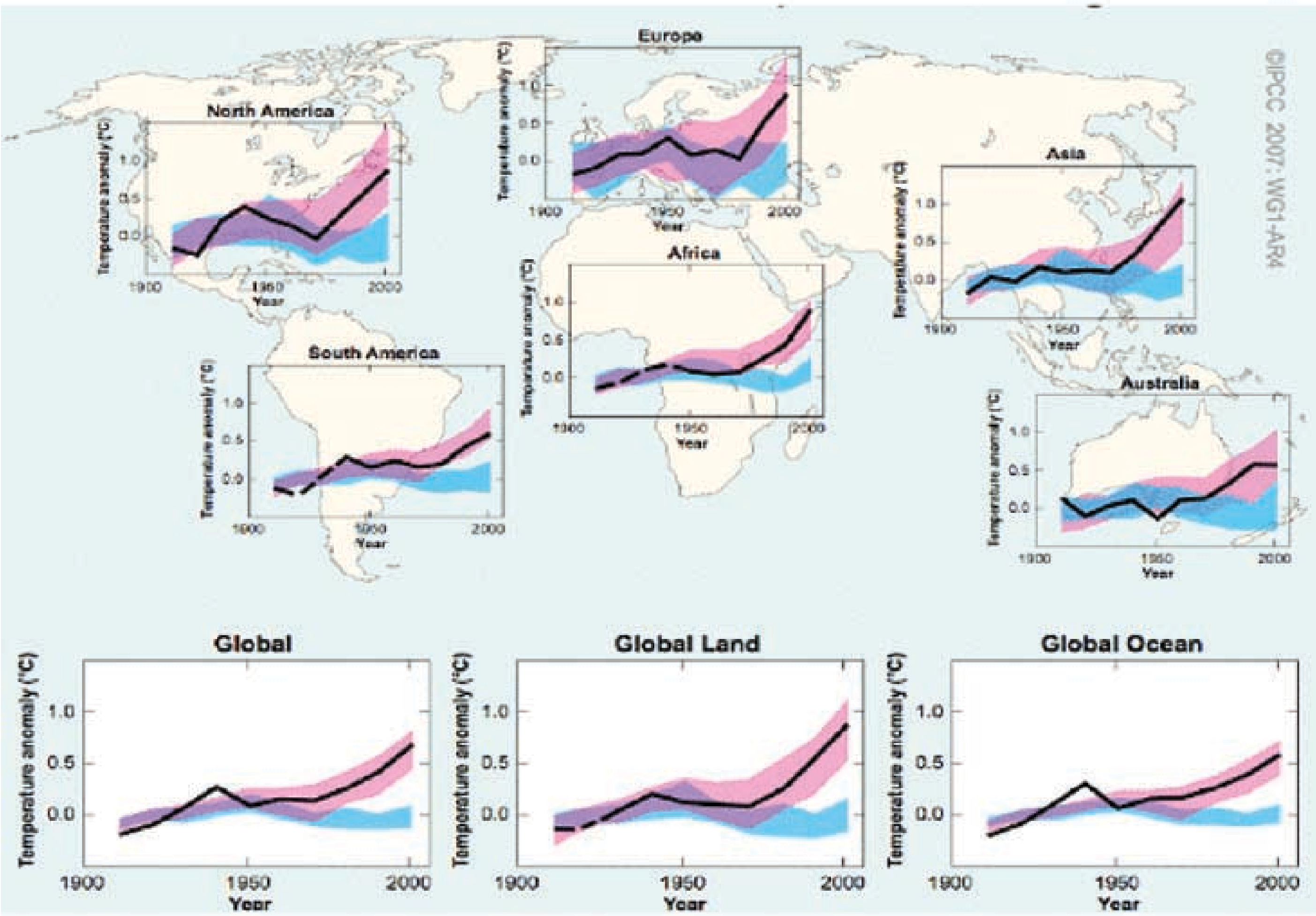
The temperature extremes also tend to correspond with the average temperature, which has lead to a decrease in the number of cold nights, an increase in the number of hot days, and a decrease in the diurnal temperature range by about 0.07^{0}C per decade.

Rainfall

During the period 1901–2005, the trend of change in rainfall greatly varied among regions and sub-regions in the same region, as well as during different periods of time in each sub-region.

In North America, rainfall has increased in many areas, especially in Northern Canada,

Figure 1.3. Observed Temperature anomalies across major continents



Source: http://www.ipcc.ch/graphics/ar4-wg1/jpg/faq-9-2-fig-1.jpg

while decreasing in the Southwest of the U.S., the Northeast of Mexico, and the Bafa peninsula with the rate of decrease at about 2% per decade, causing droughts in recent years.

In South America, precipitation has increased in the Amazon basin and on the Southeastern coast, while it has decreased in Chile and on the Western coast.

In Africa, precipitation decreased in South Africa, especially in Sahel, during the period 1960 – 1980.

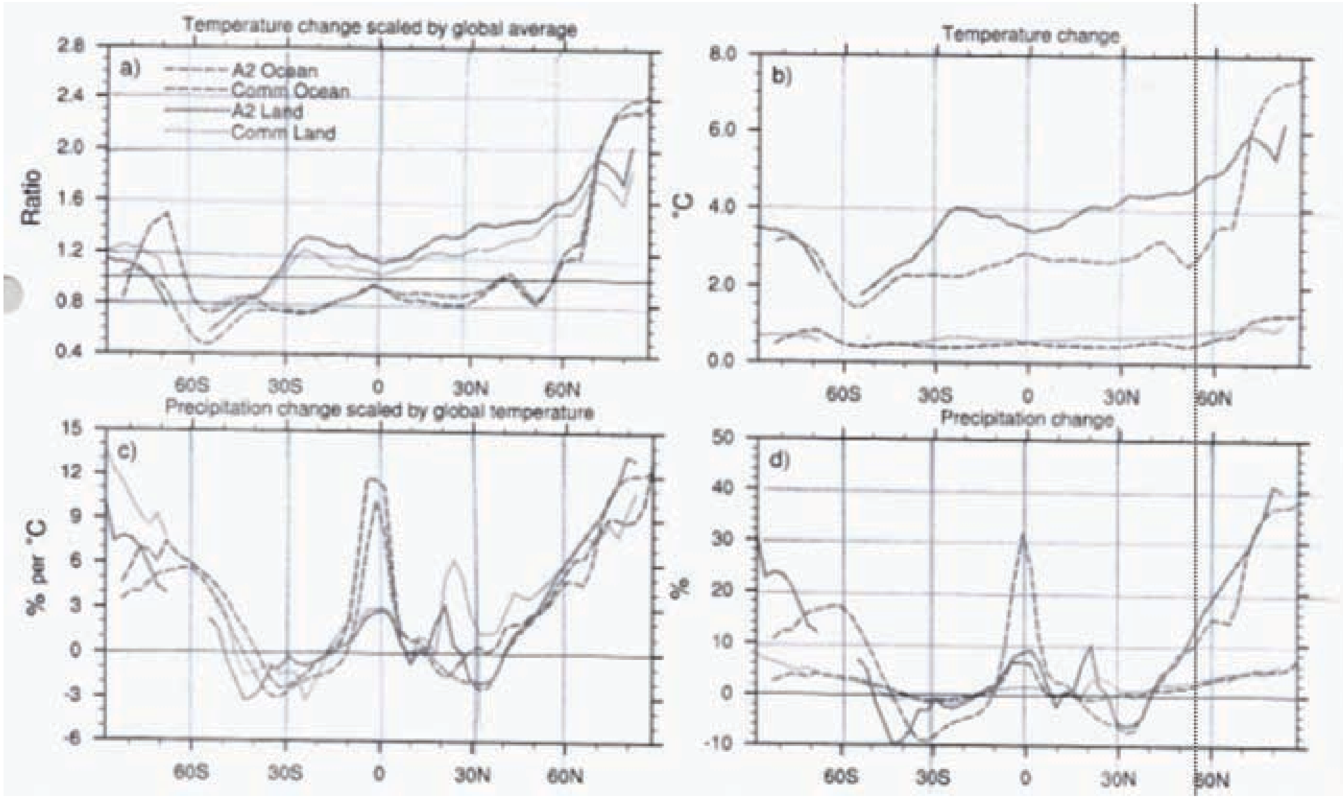
In the tropical zone, precipitation decreased in South Asia and West Africa with the trend value of 7.5 % during the period 1901–2005. Australia is the area with the most obvious local features in the trend of precipitation change due to the strong impacts from ENSO.

In zones of middle and high latitudes, rainfall has sharply increased in the Central North America, Northeastern America, Northern Europe, Northern Asia and Central Asia.

Worldwide, precipitation increased in zones north of the 30 degrees North latitude during the period 1901–2005, while it has decreased in the tropical latitudes since the 1990s.

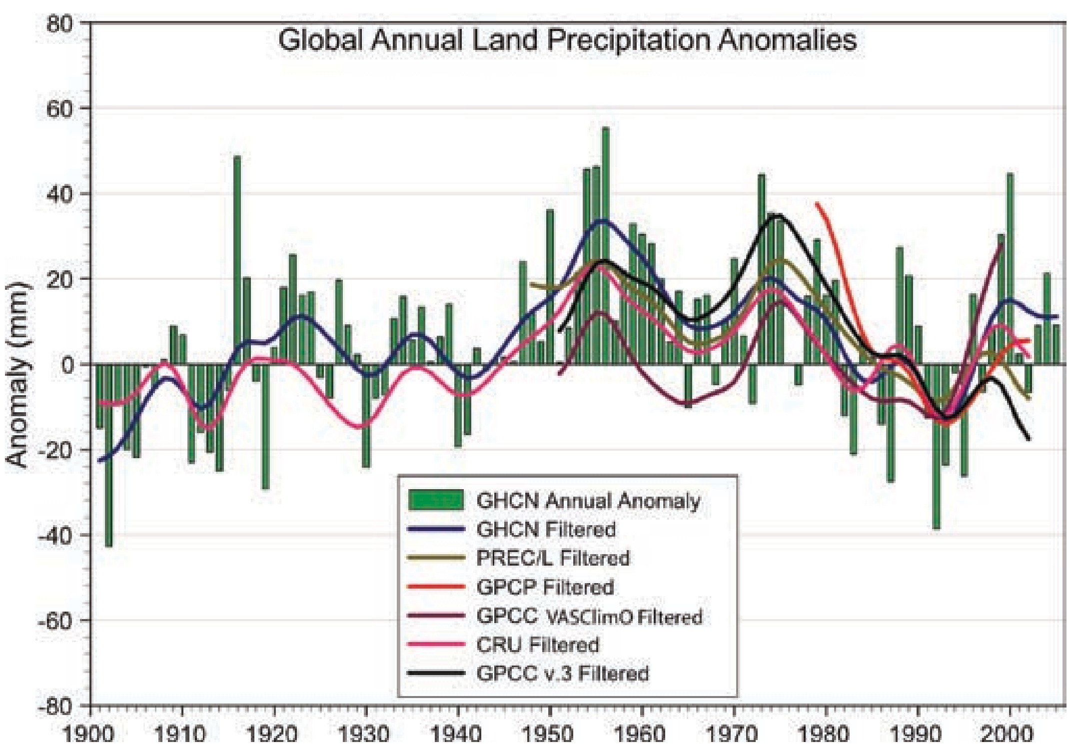
The frequency of heavy rains has increased in many areas, including places where rainfall tends to decrease.

Figure 1.4. Changes in Temperature and rainfall in different regions in 21st century



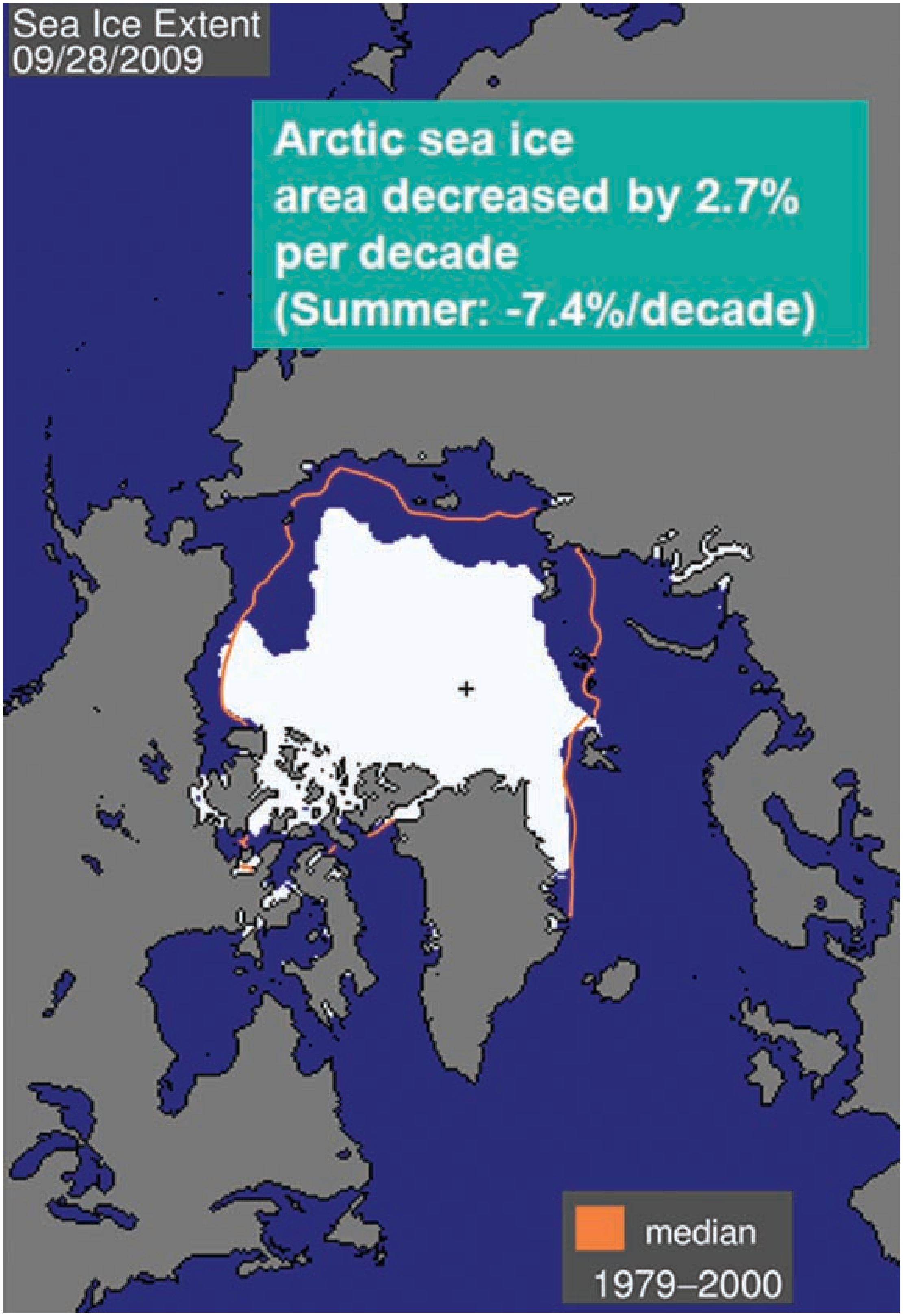
Sources: IPCC, AR4, 2007

Figure 1.5. Observed global mean precipitation anomalies over land area during 1900-2007



Source: http://www.ipcc.ch/graphics/ar4-wg1/jpg/fig-3-12.jpg

Figure 1.6. Melting of Arctic Ice has been pronounced in recent



Source: NOAA web site

Drought and currents

In the Northern hemisphere, the trend of drought became significant from the middle of the 1950s over most of North Africa, especially in Sahel, as well as in Canada and Alaska. In the Southern hemisphere, drought became serious from 1974 to 1998.

In the Western part of the U.S., although overall precipitation has tended to increase in recent decades, severe droughts have occurred from 1999 to 2004.

The currents in most rivers of the world have experienced profound changes throughout decades and among years in the same decade.

The currents have intensified in many river basins in the U.S., while have decreased in many river basins in Canada in the last 30 - 50 years.

On the Lena River basin in Siberia, the current has also increased in association with the increase in temperature and the reduction of the coverage of ice. In the Basin of the Hwang-ho River, the current sharply decreased in the final years of the 20^{th} century due to an increase in water consumption, temperature and evaporation, while the total rainfall amount has remained unchanged.

In Africa, all the currents of rivers in Niger, Senegal and Zambia have decreased.

The changes in tropical cyclone (TC)

Worldwide, the changes in TC are affected by the sea water temperature, the strength and frequency of ENSO and the changes in the orbits of TC themselves.

Since the 1970s, there has been an increase in both the intensity and existence time of TC in the Atlantic, in accordance with sea water temperature increase in the tropical sea. The intensity of TC tends to increase even in areas where both the frequency and existence time of TC tends to decrease.

The trend of increase in the formation of TC is most obvious in the North Pacific, Southwestern Pacific and Indian Ocean.

The temperature change in polar zones and ice-spheres

In the 20^{th} century, together with the increase in the ground temperature, there was a decrease in the amount of ice cover worldwide.

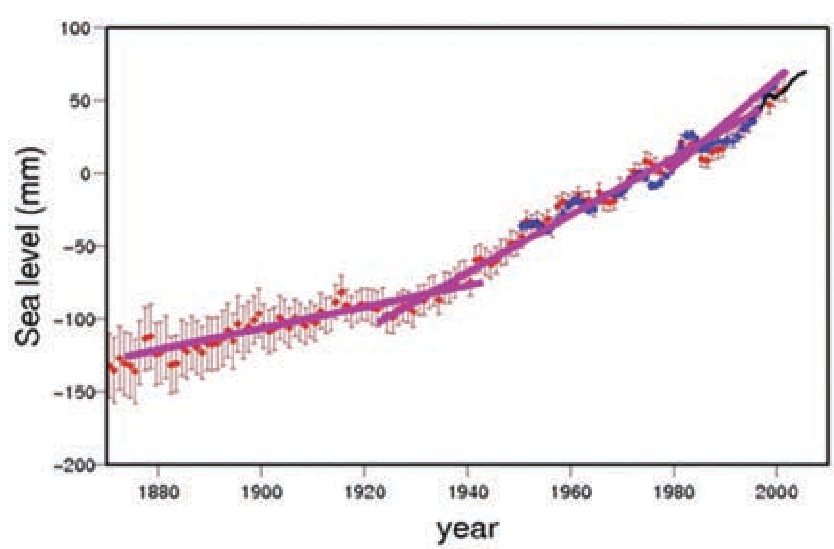
Observations since 1978 have shown that the annual average amount of ice in the Arctic Ocean decreased by about 2.7% per decade.

A remarkable amount of ice in both hemispheres has also been melting. In the North hemisphere, the ice-covered area has decreased by 7% in comparison with that in 1900, and the temperature in the mount of the eternal ice layer has increased by 3^0C in comparison with that in 1982.

The change in sea level

The average global sea level records suggest increases of 1.8 mm per year since 1961 and increases of 3.1mm per year since 1993.

Figure 1.7. The global mean sea level has risen by 43 mm as of 2007.



Source: Updated from http://www.ipcc.ch/graphics/ar4-wg1/jpg/fig-5-13.jpg

1.4.2 Climate change in the troposphere of the atmosphere

The change in temperature

During the period 1958–2005, the temperature in the troposphere tended to increase, which corresponded with the trend of the ground temperature. The rate of temperature increase in the lower tropospheric layer has stayed at about 0.16–0.18^{0}C per decade since 1979.

Conversely, the temperature trend of the lower stratospheric layer indicates a decrease by 0.3–0.6^{0}C per decade.

The change in wind

From the 1960s to the 1990s, the middle-latitude West wind tended to increase in both seasons and both hemisphere, Northern and Southern.

In addition, the Northern boundary (Northern hemisphere) and the Southern boundary (Southern hemisphere) of the west wind streams have moved towards the poles. The orbit of temperate cyclone in the Atlantic of the Northern hemisphere has also moved towards the Arctic.

1.4.3 The changes in natural systems and ecosystems

The changes in physical systems

From 1970 to present, it is likely that temperature changes have brought about the following impacts on physical systems:

1. The quantitative increase and expansion of icy lakes
2. The increase of the clay layer over permafrost and tundra in mountainous areas
3. The currents of glaciers increase and reach their peak early in spring
4. The warming-up of rivers and lakes and, as a result, the change in the temperature mechanism and water quality.

The changes in the eco-systems

Eco-systems have experienced the following changes:

1. The post-spring material indicators arrive earlier
2. The spring greenization arrives earlier
3. An increase in plankton communities in high-latitude seas and high-altitude lakes
4. Fish in rivers begin their migration earlier.

Other effects

1. The increase in CO_2 concentration has led to an increase in the acidification level in oceans. The average pH of the seawater layer close to the surface has decreased by 0.1 since the pre-industrial era.
2. Temperature increase has affected agricultural and forestry management in high latitudes and health care in Europe.
3. The rise of sea level affected submerged areas and mangrove forests and caused coastal floods in some areas.

1.5 Global Climate Change Scenarios

1.5.1 Classification of climate change scenarios

From 1990, hundreds of scenarios on GHG emissions have been developed with consideration for the global situation in the 21st century. Based on the objectives of GHG reduction, these scenarios could be divided in four groups:

- Scenarios with stable GHG concentration in the atmosphere
- Scenarios with stable global emission
- Scenarios belonging to the emission lobby
- Other scenarios.

In the strategies for climate change mitigation of IPCC, however, the focus has been on the first scenario among the above-said scenario pathways: stable GHG concentrations in the atmosphere.

1.5.2 Green House Gas Emission Scenarios

Future Global Scenarios

GHG emissions are the direct product of socio-economic development and the picture of global GHG emissions reflects the socio-economic development pathways of the world. IPCC has developed the Special Report on Emissions Scenarios (SRES) on different scenario pathways for the future. The main economic factors relating to GHG emissions include:

- Population development
- Development of energy technology
- Social and environment options.

SRES refers to 6 scenarios of global GHG emission pathways: A1FI, A1T, A1B, A2, B1 and B2, grouped into four scenario families: of which A1, A2, B1 and B2 can be summarized as following:

The A1 family

- Assumes a world of very rapid economic growth,
- Global population that peaks mid-century.
- Rapid introduction of new and more efficient technologies.
- Infrastructure is equal in different regions in the world.

The A1 family is divided into three groups that describe alternative directions of technological change:

- Fossil intensive (A1FI).
- Non-fossil energy resources with the introduction of new technologies (A1T) and
- A balance across all sources (A1B).

The A2 family

- Describes a very heterogeneous world with high population growth.
- Slow economic development

The B1 family describes a convergent world.

- With the same global population as A1.
- With more rapid changes in economic structures toward a service and information economy, deceasing utilization of raw materials energy saving and increasing clean energy.
- The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 family

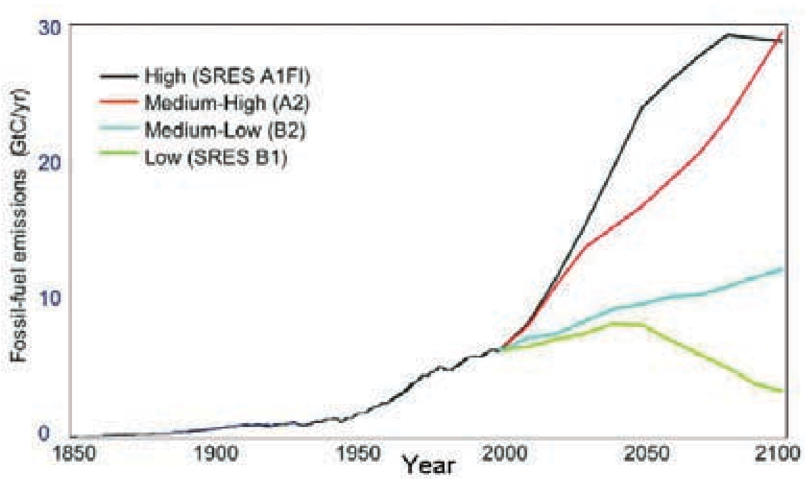
- Describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability.
- It is a world with continuously increasing global population at a rate lower than A2,

Table 1.3. CO_2 Concentrations in the atmosphere in different scenarios (ppm)

Scenario	2050	2100
A1B	510	730
A1T	500	580
A1FI	610	970
A2	590	850
B1	470	550
B2	480	620
IS92a	510	740

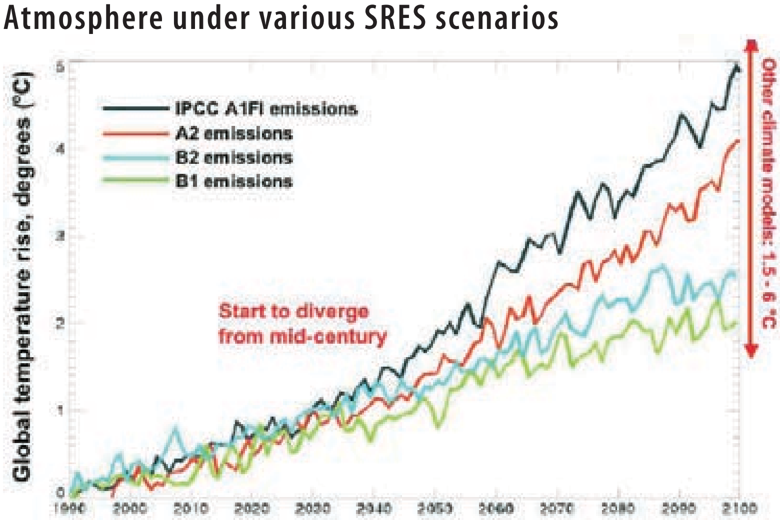
Source: IPCC, Climate Change 2001, Synthesis Report

Figure 1.8. Projected fossil fuel based carbon dioxide emissions under various SRES scenarios



Source: Updated from Fig 3.1 and 5.1 of IPCC Synthesis Report, 2007

Figure 1.9. Projected Changes in Global Mean Surface Temperature due to increasing GHG emissions in the Atmosphere under various SRES scenarios



Source: Updated from http://www.ipcc.ch/graphics/ar4-wg1/jpg/ts32.jpg and http://www.ipcc.ch/graphics/ar4-wg1/jpg/spm5.jpg

- Intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines.
- While the scenario is also oriented toward environmental protection and social equity, it focuses on the local level.

CO_2 Scenarios

IPCC has estimated the projections of climate change, their impacts, potential adaptation strategies and mitigation measures based on 6 scenarios of GHG emissions pathways. Global future and the scenario IS92a is considered as neutral among 6 scenarios in 1992 (Table 1.3).

IPCC also estimated that if CO_2 emission resulting from changes in land use purposes can remain in the land biosphere, the concentration of this GHG will be reduced to 42 – 70 ppm. If the tanks for storing GHG are successfully developed, the GHGs concentration in 2050 will be in the 450 – 550 ppm range and by 2100, the concentration will be 500 – 900 ppm.

1.5.3 Climate Change Scenarios

The 21st century global changes

The Fourth Assessment Report of IPCC shows that the continued release of GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century. Global average temperature will increase by at least by 1.8°C (1.1°C – 2.9°C) at the end of the 21st century (2090-2099) under the B1 scenario and by 4.0°C (2.4°C – 6.4°C) under the A1FI scenario. (Table 1.4)

Together with the increase in surface air temperature and sea level rise, other changes that can be observed are as follow:

- The time of severe heat-wave and heavy rain is increased.
- Intensity of tropical cyclone have increased and the frequency of the cyclones has also probably increased.
- The orbit of extra-tropical cyclone has moved towards the North.
- Rainfall has increased in higher areas and reduced in most of non-tropical areas.

It may be noted that the numeric value here is the average estimation (or best estimate) and the range is the lower and upper value of the average figure.

Changes beyond the 21st century

To the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. If the radiative forcing was to be stabilised, keeping all the radiative forcing agents constant at B1 or A1B levels in 2100, model experiments show that a further increase in global average temperature of about 0.5°C would still be expected by 2200. In addition, thermal expansion alone would lead to a 0.3 to 0.8m increase in sea level rise by 2300 (relative to 1980-1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean.

1.6 Impacts of future climate change

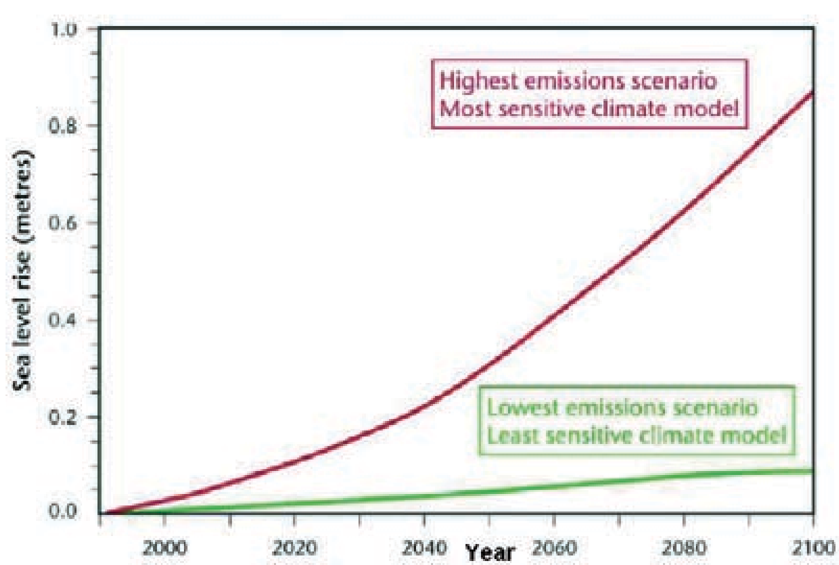
The warming of the planet will be gradual, but the effects of extreme weather events – more intense storms, floods, droughts and heat waves – will be abrupt and more acutely felt. Although climate change is a global phenomenon, its consequences will not be evenly distributed. The developing countries and small island nations will be the first and hardest hit. The impact of climate change

Table 1.4. Projections of temperature change and sea level rise at the end of 21st century

Case	Temperature change (°C at 2090-2099 relative to 1980-1999)		Sea level rise (at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
	0.6	0.3 – 0.9	Not available
B1 Scenario	1.8	1.1 – 2.9	0.18- 0.38
A1T Scenario	2.4	1.4 – 3.8	0.20 -0.45
B2 Scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B Scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 Scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI Scenario	4.0	2.4 - 6.4	0.26 – 0.59

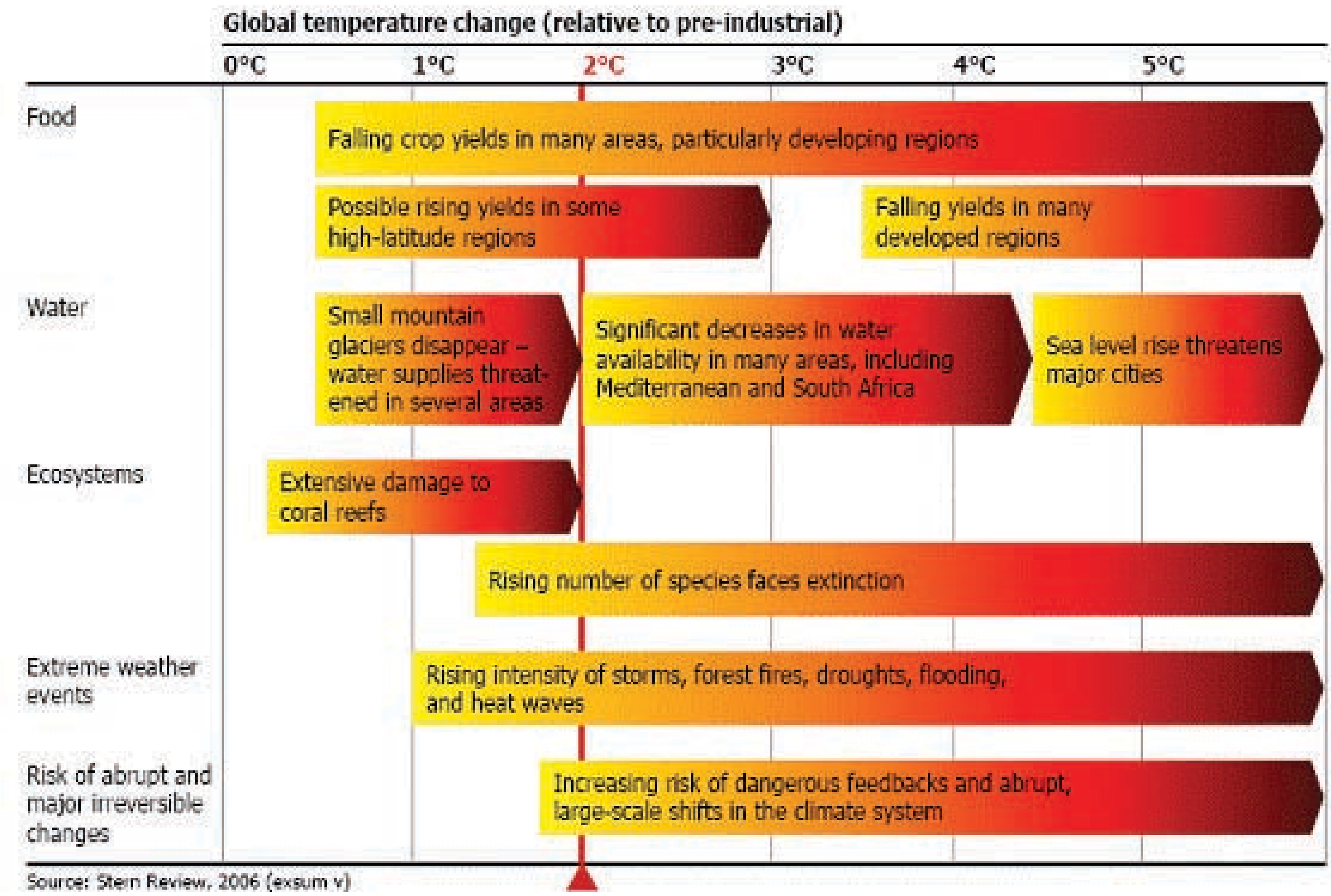
Source: IPPC, AR4, 2007

Figure 1.10. Projected Rise in Sea Level due to Increasing GHG emissions in the Atmosphere



Source: Updated from http://www.ipcc.ch/graphics/ar4-wg1/jpg/faq-5-1-fig-1.jpg

Figure 1.11. The broad impacts of climate change as a function of varying degree of temperature rise



(Source: Stern Review, 2006)

will be across the sectors and across nations. Some of the key impacts of climate change are summarized in Figure 1.11.

1.6.1 Impacts on systems and sectors

Ecosystems

- For increases in global average temperature exceeding 1.5^{0}C to 2.5°C and in concomitant atmospheric CO_2 concentrations, major changes are projected in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services.
- Acidification of ocean will have negative impacts on the structure of snails and arcas, etc.

Food

- Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1^{0}C to 3^{0}C, but above this it is projected to decrease.
- At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1^{0}C to 2^{0}C).

Coasts

- Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas.
- Annually, many millions more people than at present are projected to experience floods every year due to sea level rise. The numbers affected will be largest in the densely populated and low-lying megadeltas of Asia and Africa with small islands being especially vulnerable.

Industry, settlements and society

- The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources and those in areas prone to extreme weather events.
- Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas.

Health

- The health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases.
- Climate change is projected to bring some benefits in temperate areas, such as fewer deaths from cold exposure. Overall, however, it is expected that the benefits will be outweighed by the negative health effects of rising temperatures.

Water Resources

- Water resources are a key for all sectors and regions for each region and each watershed.
- Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanization. On a regional scale, mountain snow pack, glaciers and small ice caps play a crucial role in freshwater availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate.
- Changes in precipitation and temperature lead to changes in runoff and water availability. Runoff is projected with high confidence to increase by 10 to 40% by the middle of the century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10 to 30% over some arid regions at mid-latitudes and arid and semi-arid tropics, due to decreases in rainfall and higher rates of evapotranspiration. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, such as agriculture, water supply, energy production and health.
- It is likely that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Increased temperatures

will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality. In coastal areas, sea level rise will exacerbate water resource constraints due to increased salinisation of groundwater supplies.

1.6.2 Impacts on regions

Africa

- By 2020, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change.
- In some countries, yields from rain-fed agriculture could reduce agricultural productivity, including access to food, which is projected to be severely compromised, especially in arid and semi-arid areas. This would further adversely affect food security and exacerbate malnutrition.
- Ecosystems will change in terms of species or the movement of species to other areas.

Asia

- By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease.
- Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts, are expected to rise in East, South and South-East Asia, due to projected changes in the hydrological cycle.

Australia and New Zealand

- By 2030, water security problems are projected to exacerbate.
- Significant loss of biodiversity is projected to occur.
- Production from agriculture and forestry is projected to decline.

Europe

- Climate change is expected to magnify regional differences in Europe's natural resources and assets.
- By 2070, hydropower potential will be reduced by 6%, of which Northern and Eastern Europe's will increase by 15 – 30% and the Mediterranean's will decrease by 20 – 50%.
- Reduced snow cover.

Latin America

- The productivity of some important crops is projected to decrease, along with livestock productivity. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase.
- Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.
- By mid-century, increases in temperature and associated decreases in soil water are projected to lead to the gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation.

North America

- By mid-century, warming in western mountains is projected to cause decreased snow, more winter flooding and reduced summer flows.
- In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with increased variability among regions.
- Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts.

Polar Regions

- The main projected biophysical effects are reductions in the thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems and human communities in the Arctic.
- By mid-century, with the temperature likely to increase by 4^0C, 10 – 40% tundra in the North Pole could change into forest and 10 – 25% of desert could be transformed into tundra.

Small Islands

- Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus, threatening vital infrastructure, settlements and facilities that support the livelihood of island communities.
- By mid-century, climate change is expected to reduce water resources in many small islands.

Circulation of ocean

According to research findings based on complex model simulations, circulation of some oceans may be degraded by mid-century and end-century of 21^{st} decade, leading to changes in ecosystems, fisheries and ocean chemical properties due to the supplement of oxygen concentration.

Glacier melt, the variation of sea water in longer time scale will impact the coastal zones, causing inundation in low land and small islands. Those changes can be prolonged for thousand years if the increased temperature is 1-4^0C compared with 1990 – 2000. The sea level rising for decades should be considered.

General conclusions

Climate change will have significant effect on different sectors and regions. Some systems, sectors and regions are likely to be especially affected by climate change.

Systems and sectors:

- Tropical rainforests.
- Mangroves and salt marshes.
- Water resources in some dry regions at mid-latitudes and in the dry tropics.
- Agriculture in low latitudes.

Regions:

- The Arctic.
- Africa, especially the Sahel dessert.
- Small Islands.

1.7 Climate Change Adaptation Strategies

The fourth climate change assessment report of IPCC (AR4) describes the main areas of climate change adaptation strategies which include the following:

1.7.1 Prospects of adaptation measures

Societies across the world have a long record of adapting and reducing their vulnerability to the impacts of weather and climate related events such as floods, droughts and storms. The adaptation measures already implemented have demonstrated the potential to reduce the risk from climate change, especially the short-term risks.

In order to face the challenges associated with the adverse impacts of climate change, climate change adaptation strategies need to be considered important and complementary with climate change mitigation strategies.

A wide array of adaptation options are available. Some planned adaptation is already occurring on a limited basis. Many adaptation actions have multiple drivers, such as the Bangladesh National Water Management Plan and the coastal defense plans of The Netherlands and Norway, which incorporate specific climate change scenarios.

Comprehensive estimates of the costs and benefits of adaptation at the global level are limited in number. However, the number of adaptation cost and benefit estimates at the regional and project levels for impacts on specific sectors, such as agriculture, energy demand for heating and cooling, water resources management and infrastructure, is growing. Based on these studies there is high confidence that there are viable adaptation options that can be implemented in some of these sectors at low cost and/or with high benefit-cost ratios. Empirical research also suggests that higher benefit-cost ratios can be achieved by implementing some adaptation measures at an early stage compared to retrofitting long-lived infrastructure at a later date.

1.7.2 Climate Change Adaptation in some sectors

Water

- Expanded rainwater harvesting.
- Water storage and conservation techniques.
- Water reuse, desalination.
- Water-use and irrigation efficiency.

Agriculture

- Adjustment of planting dates and crop variety.
- Crop relocation.
- Improved land management.

Infrastructure/ settlement

- Seawalls and storm surge barriers planning.
- Dune reinforcement.

Tourism

- Diversification of tourism attractions and Revenues.
- Shifting ski slopes to higher altitudes.
- Artificial snow-making.

Human health

- Heat-health action plans.
- Emergency medical services.
- Improved climate-sensitive disease surveillance and control.
- Safe water and improved sanitation.

Transport

- Realignment/relocation.

- Design standards and planning for roads, rail and other infrastructure.

Energy

- Strengthening of overhead transmission and distribution infrastructure.
- Underground cabling for utilities.
- Energy efficiency.
- Use of renewable sources; reduced dependence on single sources of energy.

1.8 Climate change mitigation strategies

The fourth climate change assessment report of the IPCC presents a number of mitigation options summarized as follows:

1.8.1 Potentials for the implementation of climate change mitigation options

At the beginning of 21st century, evidences from both bottom-up and top-down studies have indicated that there is high agreement and credible evidence of substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels.

1.8.2 Some policies and options for climate change mitigation

Energy Supply

- Improved supply and distribution efficiency.
- Fuel switching from coal to gas.
- Nuclear power; renewable heat and power (hydropower, solar, wind, geothermal, etc.,).
- Bioenergy.
- Early applications of carbon dioxide capture and storage (CCS).

Transport

- More fuel-efficient vehicles.
- Hybrid vehicles; cleaner diesel vehicles; biofuels.
- Modal shifts from road transport to rail and public transport systems.
- Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.

Industry

- More efficient end-use electrical equipment.
- Heat and power recovery.
- Control of non-CO_2 gas emissions.
- Wide array of process-specific technologies; advanced energy efficiency.
- CCS for cement, thermal power plants.

Agriculture

- Restoration of cultivated peaty soils and degraded lands.
- Improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions.
- Improved nitrogen fertiliser application techniques to reduce N_2O emissions.
- Improvements of crop yields.

Forestry/forests

- Afforestation, reforestation
- Forest management; reduced deforestation

- Use of forestry products for bioenergy to replace fossil fuel use
- Tree species improvement to increase biomass productivity and carbon

Waste

- Landfill CH_4 recovery;
- Energy production from landfill;
- Optimise CH_4 oxidation.

1.8.3 Sustainable Development Roadmap

As mentioned earlier, by the end of 20th century, millions of people had already suffered the initial challenges with the global average temperature increasing by 0.7^{0}C (0.8^{0}C for inland and 0.6^{0}C for ocean). The warming trend is still continuing with projections for average increases in temperature for different scenarios in the 2^{0}C - 4^{0}C range by 2100.

Human beings and society have the option to arrest this trend through strategies to limit the GHG emissions. A realistic objective is to restrict the global average temperature rise to a level not exceeding 2^{0}C higher than pre-industrial times.

To achieve this objective, human's have to identify suitable milestones – a sustainable roadmap to ensure that GHG concentrations in the atmosphere do not exceed 450 ppm CO_2eq, meaning that total GHG emissions in 21st century does not exceed 1.456 billion tonnes CO_2eq, which translates to 14.5 billion tonnes CO_2 released on average each year. This objective has been proposed to be implemented according to the following roadmap:

- Total global GHG emissions in 2050 have to reduced by 50% compared with 1990 level, of which the peak GHG emissions period will be in 2020.
- Developed countries reach their maximum GHG emissions level in 2012-2015, with the GHG emissions being reduced by 30% in 2020 and 80% in 2050.
- Developing countries reach their maximum GHG emissions level in 2020, the peak being 80% higher than the current situation and by 2050, have reduced their emissions levels by 20% compared with 1990.

1.9 Conclusions

1. The Earth is a planet of the solar system that absorbs the sun's power and transforms it into other types of energy, consisting of atmosphere, hydrosphere, geosphere and biosphere.
2. The atmosphere interacts with other factors/components in climate system and is the main factor in climatology and climate change.
3. In the atmosphere, the presence of natural GHGs such as water vapour, CO_2, CH_4, N_2O, O_3 has maintained the average temperature of the land surface at 15^{0}C.
4. In the 20th century and the first few years of 21st century, the global average temperature increased by 0.75^{0}C, the rainfall increased in some locations and decreased in others, while floods and droughts have increased, the intensity of tropical cyclones has increased, the total amount of global ice has decreased, and the sea level has risen up to 1.8mm per year from 1961 and up to 3.1mm per year from 1993.
5. Climate change has the potential to cause significant changes in natural system, ecosystem and many other impacts.

6. By the end of the 21st century, the global average temperature is projected to increase by at least by 1.1 - 2.9^{0}C and could reach the highest peak at 2.4 - 6.4^{0}C, the sea level rise is expected to be at least 0.18-0.38 cm and could reach a highest peak of 0.26-0.59 cm, with these projections demanding sustainable population development, economic and social development and environmental solutions.

7. In the coming decades, countries across the globe are projected to face rising average temperatures, increasing risk of heat waves, and intense precipitation events, but declining annual average precipitation, as well as rising sea levels.

8. Climate Change projections suggest that such impacts are expected to continue and amplify over the coming decades. The potential impacts of climate change in the 21st century will adversely effect all sectors and all regions of the world.

9. To overcome the threat of climate change, mitigation and adaptation strategies and options have been developed, of which the most important point is the implementation of the sustainable emissions roadmap, so that the temperature rise in the 21st century does not exceed the critical threshold of over 2^{0}C.

Viet Nam's key climatic elements are likely to undergo changes quite dramatically in time and space. In the context of global climate change (CC), there will be changes in Viet Nam which may significantly affect the socio-economic activities.

Chapter 2

Climate Change and Scenarios in Viet Nam

2.1 Overview of Viet Nam's climate features

2.1.1 Climatic Features

Geographical context

Stretching across 15 latitudes, situated completely in the interior tropical zone of the Northern hemisphere, closer to the tropics than the equator and heavily influenced by the East Sea, Viet Nam has the monsoon tropical climate of a peninsula in the Southeast of the European - Asian continent.

Viet Namese territory includes the mainland, the area of which is 332,000 square kms and the waters, which are many times larger than the mainland, along with thousands of islands of various sizes in the East Sea.

On the mainland, the Northern-most point (in Ha Giang province) is located at the latitude of 23 degrees and 22 minutes North, the Southern-most tip (in Ca Mau province) is situated at the latitude of 8 degrees and 30 minutes North, the Western-most point (in Lai Chau province) is situated at the longitude of 102 degrees and 10 minutes East, and the Eastern-most point (in Khanh Hoa province) is located at the longitude of 109 degrees and 24 minutes East. Across the sea, the Spratly archipelagos stretch across the longitude of 116 degrees East, and reach the latitude of 7 degrees North.

Although, the mainland of the territory stretches across 15 latitudes, its width is quite narrow. The widest part (in the North) spreads no more than 600 kms wide, while the narrowest point (in Quang Binh province) is only 50 kms wide.

There are 5 main terrain groups in Vietnamese territory, namely: mountains, karst, valleys and mountainous hollows, sedimentary deltas and coasts, the most important of which are mountains and sedimentary deltas.

There are 7 forms of mountainous terrain group: over 2,500 meters high mountains, concentrated in the North West of Viet Nam; average mountains, from 1,500 to 2,500 meters high, concentrated in the North East, North West, North Central, and South Central; low mountains, from 500 to 1,000 meters high, scattered all over the territory; mountainous plateau, concentrated in the Central Highlands and the North West of Viet Nam; highlands concentrated in the Central Highlands; hills concentrated in the North East; and semi-plains, which are normally found in the mid-land of the North and the South.

There are 3 forms of agglomerated deltas: horizontally narrow mountain-based deltas in the Central; eroded-agglomerated or agglomerated-eroded terraced deltas; and deltas consolidated by rivers in the North and the South.

Water bodies include river systems and the East Sea. From the North to the South, there are 9 major river systems, with a basin area of 10,000 km^2 each. Travelling from North to South, these are the Bang Giang-Ky Cung, Thai Binh, Red, Ma, Ca, Thu Bon, Ba, Dong Nai - Vam Co and Mekong river system. The East Sea has a total area of 3,447 km^2, with a total water volume of 3,928 million km^2. In addition, it has two large gulfs: the Tonkin gulf (150,000 km^2) and the Thailand gulf (462,000 km^2).

Based on geographical conditions, it is possible to specify 7 different regions or zones representing the climate of the Nation: the North West, the North East, the North Delta, the North Central, the South Central, the Central Highlands and the South of Viet Nam.

Incoming Solar Radiation

All areas in the Vietnamese territory, irrespective of wheather they are high lands or low lands, mainland or islands, are influenced by the interior tropical radiation: the remarkably high latitude of the sun, the evenly distributed sunlight time, abundant solar radiation quantity, and the permanently positive radiation balance.

At each point, the sun crosses the zenith two times annually, from 5 to 68 days before and after the summer solstice. The time difference between these two days, when the sun crosses the zenith, reaches 136 days at the South and only 10 days at the Northern edge of the territory. The lowest latitude of the sun (on the winter solstice) reaches 58^0 3' at the Southern edge and 43^0 11' at the Northern edge.

The daylight duration is over 12 hours during the time from the spring equinox to the fall equinox, and less than 12 hours during the time from the fall equinox to the spring equinox. At the Northern edge of the territory, the longest day lasts 13 hours 28 minutes and the shortest day lasts 10 hours 29 minutes. At the Southern edge of the territory, the longest day lasts 12 hours 30 minutes and the shortest day lasts 11 hours 29 minutes.

In Vietnamese territory, the annual total daylight time ranges between 4,300 – 4,500 hours and is evenly distributed among latitudes. This daylight time, however, is not evenly distributed among the months. At the Southern edge of the territory, the shortest monthly daylight time is 356 hours and the longest is 385, while at the Northern edge of the territory, the shortest and longest monthly daylight time is 327 and 415 hours, respectively.

Owing to the high latitude of the sun and the evenly distributed daylight time, the annual solar radiation quantity (Q_θ) reaches 230 - 250 kcal/cm^2/year. It reaches 25 - 26 kcal/cm^2/month at its peak and 11 - 12 kcal/cm^2/month at its bottom.

Due to the presence of clouds, the total actual radiation quantity (Q) is about 85 - 190 kcal/cm^2/year, substantially low in the North and relatively high in the South. In addition, the total actual radiation quantity in higher altitudes is also lower than that in adjacent lower altitudes.

In Vietnamese territory, the net radiation balance (B) is about 40 - 120 kcal/cm^2/year, substantially low in the North, relatively high in the South, and gradually descending in relation to the geographical altitude. In the North of the Hai Van mountain pass, the annual radiation balance is always lower than 100 kcal/cm^2/year.

The radiation balance in the South is not only high, but also evenly distributed over the months. Meanwhile, the radiation balance in the North is not only low, but also has high amplitude: it is very low in the winter months and reaches its bottom in the later half of this season, due to the impacts of drizzly weather.

Atmospheric circulation

The atmospheric circulation in Viet Nam is a part of the Southeast Asian monsoon circulation, with 3 distinct features as follows:

1. Being, not only closely associated with the South Asian monsoon, especially in summer, but is also strongly influenced by the Northeast Asian monsoon, especially in winter.
2. Being, not only influenced by the tropical, sub-tropical and temperate circulations of the Northern hemisphere, but also closely associated with the tropical and sub-tropical circulations of the Southern hemisphere.
3. Being strongly influenced by the Pacific equatorial sea in both winter and summer.

There are two permanent atmospheric pressure centers, which play major roles in the circulation mechanism in Viet Nam: equatorial low pressure, subtropical high pressure, and seasonal atmospheric pressure centers; Asian continental high pressure, Aleutian low pressure in winter and South Asian continental low pressure centers; and Oceanic continental high pressure centers in summer.

Across the longitudes of East Asia, the position of the Southern limit of the polar front that traverses in January is 8^0 north, and the position of the Northern limit of the tropical convergent zone in July is 25 - 27^0 North. Vietnamese territory is entirely situated in the area specified by these two boundaries. As a result, it bears the influences of, not only the winter time polar fronts, but also the summer tropical convergent zone.

The monsoon circulation in Viet Nam is a combination of the South Asian and Northeast Asian monsoon systems with distinct characteristics in two major seasons: Winter (November - March), Summer (May - September), and two transitional seasons: Spring (April) and Fall (October).

In winter, the polar air current from the Asian continental high pressure penetrates deeply into low latitudes, is reinforced by the Eastern side of the Tibet Plateau, then overflows to the South in a northeast direction. Whenever the Asian continental high pressure breaks out, the polar air overflows to the South following the cold front. Many cold fronts from the western part of low pressures in the South China static front strip also move to Viet Nam. Consequently, there are 3 - 4 spells of cold fronts overflowing into Viet Nam during each winter month. Taking into account spells occurring in transitional months, and at the beginning and end of the summer months, the average number of cold front spells passing through North Viet Nam reaches about 29 per year.

In winter, following each spell of cold front is the time of sustaining influences of the Asian continental high pressure cell. When the influence of the continental high pressure cell decreases, the operation of the trade wind monsoon resumes, especially in the Southern latitudes. As a result, the prevalent air masses in Viet Nam are the polar air denatured when passing the ocean or the continent and the Pacific tropical air.

In the Northern latitudes, the intervening period between two cold fronts in winter is normally 5 - 10 days. When the cold fronts have penetrated, the average temperature decreases by 4 - 5^0C. The cold, sometimes extremely cold, weather is normally sustained for a long time in cloudless or partly cloudy conditions at the beginning of winter, or cloudy and drizzly conditions in the later half of winter. Closer to the South, the lower the frequency of cold fronts, the lower the rate of temperature fall caused by fronts, and the more insignificant the dry and cold weather in the first half of winter, or the humid and cold weather in the second half of winter.

In summer, the main air flow on the ground is from the southwest in the Southern territory and the southeast in the Northern territory. Prevalent air blocks in Vietnamese territory are the equatorial and tropical blocks originating from high pressures of the Southern hemisphere and the maritime tropical block originating from the Pacific subtropical high pressure.

The convergence of the above air blocks is a characteristic feature of the summer monsoon in Southeast Asia, in general, and Viet Nam, in particular. In addition, there is the presence of tropical air from the Bay of Bengal in Viet Nam, whenever the South Asian continental low pressure develops towards the East and covers almost all of the Vietnamese territory, along with southern China, causing the dry and hot west wind weather along the eastern side of the Truong Son range, mainly in the North and Middle of the Central.

In many cases, the tropical convergent strip in Southeast Asia is connected with the monsoon trench in North India and spreads over to the east. The convection strongly operates in the convergent strip in association with the stormy and rainy season in Southeast Asia.

During summer months, the South Asian continental low pressure and the Pacific subtropical high pressure always advance and retreat in an east - west direction, together with the movement, in north - south direction, of the tropical convergent strip, followed by the movement of the operating zone of tropical cyclones, with extremely bad weather, dense clouds and storms.

Annually, in the East Sea, on average 11 storms and tropical low pressures develop, half of which are tropical cyclones originating from the West Pacific waters. Two-thirds of tropical cyclones move towards the west, northwest or southwest, land in, or directly influence Vietnamese geographical regions, especially coastal areas.

Manifestations of the spring circulation bear specific features of the transitional circulation mechanism from winter to summer. Similarly, the specific features of the fall circulation show the transition from the summer circulation mechanism to the winter circulation mechanism.

2.1.2 The distribution of climatic elements

Air pressure and wind

Air pressure and wind are two of the most important climatic elements reflecting the circulation conditions in the context of flat and clear terrain.

Air pressure decreases regularly in association with altitude: The 100 meters higher the altitude is, the 10 - 12hPa lower the average air pressure is. The highest annual average air pressure in Viet Nam is 1010.1hPa, recorded at the Vinh weather station and the lowest is 841.4hPa, recorded at the Sapa weather station. This value at Mount Fansipan would surely be even lower at around 670 - 690hPa.

The air pressure becomes relatively high during winter and reaches its peak in December and January, while becoming relatively lower in the summer months and reaching its bottom in July and August. The average air pressure in January is 1,015-1,018hPa measured at weather stations at sub -10 meter altitudes in the North and North Central, and 1,011 - 1,016hPa at similar stations in South Central and the South. The average air pressure in July is 1,001 - 1,004hPa in the North and North Central, and 1,003 - 1,009hPa in South Central and the South, under the above-mentioned conditions.

The highest air pressure always occurs in the winter months, while the lowest air pressure always occurs in the summer months. The record high pressure is 1,035.9hPa recorded at Lang weather station on November 18, 1996 and the record low pressure is 827.0hPa recorded at the Sapa weather station on July 24, 1971.

There are 3 distinct features of the wind directions in Viet Nam as follows:

1. Reflection the circulation conditions, the major wind directions change seasonally. Under the condition of clear terrain, the prevalent wind directions in winter are north-biased (Northwest, North and Northeast) and in summer are south-biased (Southwest, South and Southeast). The spring (fall) directions reflect the transitional features from winter (summer) to summer (winter).
2. The level of persistency in prevalent winds decreases from the sea to the mainland. The frequency of the prevalent wind direction in January and July reaches 60 - 70 %. The persistency in wind direction at offshore islands is higher, while in coastal deltas it is only 40 - 50 %.
3. In any month, at most localities, some winds of various frequencies do not follow the prevalent directions.
4. The prevalent wind directions in each season are closely associated with the geographical conditions, especially the terrain.

The highest average wind velocity is 6.2 m/s specified in Phu Quy Island (Binh Thuan province), and the lowest is 0.8 m/s specified in Lai Chau Township. In general, the annual average wind velocity is over 4 m/s in coastal deltas, 1 - 2 m/s in the North, 1.5 - 2.5 m/s in the North Central, 1.5 - 4.0 m/s in the South Central and the South. Regarding the average wind velocity, there are no common features of difference among seasons. In many areas, the winter winds are stronger than the summer winds, while in some places, the summer winds are stronger than the winter winds. The normal annual amplitude, however, never exceeds 30 %.

According to the available data, the strongest wind was reported to be 59 m/s in Quy Nhon in September 1972. Various wind velocities of over 40 m/s in the North Delta and the coastal areas of Quang Ninh province, 35 - 45 m/s in the South Central, and 20 - 30 m/s in the Central Highlands and the South, have been recorded.

Clouds and sunlight

The annual average total cloud cover, measured in one-tenth(s) of the sky, irrespective of upper clouds or lower clouds, reaches 6.5 - 8.0 in the North East, North West, North Delta, and North Central; and about 5.5 - 7.0 in South Central, Central Highlands and the South. Regarding different areas, there is more cloud at higher altitudes than at lower altitudes, and over the mainland than over islands. Moreover, there is also more cloud cover within centers of high rainfall than in adjacent localities and vice versa.

The monthly average total cloud cover, whether in areas with high or low rainfall, is normally less than half of the sky. The annual oscillogram of the total cloud cover varies between Northern and Southern areas.

The normal annual average amount of cloud cover (without calculating kinds and forms of cloud at altitudes higher than 1,500m) is 5.5 - 7.5 in Northern areas, and 4.0 - 6.0 in Southern areas. Within the same region, the quantity of low clouds at higher altitudes is larger than at lower altitudes, over the mainland than over islands, and in areas with high rainfall than in areas with low rainfall.

The annual oscillogram of low cloud quantity varies among areas, especially during times of drizzling rain in the North (January - April), and dry and hot west winds in the Central (June - August). During the time of widespread drizzling rains, the monthly average coverage of lower clouds in the North East, North Delta, and North Central, reaches from seven to eight tenths of the sky, while that in many areas of the South Central, Central Highlands, and the South, only reaches from two to four tenths of the sky. Conversely, during the active phase of the dry and hot west wind, the monthly average coverage of lower clouds in the Central coastal areas is always lower than five tenths of the sky, while those in other region are always higher than that level.

The annual sunlight duration in Viet Nam is about 1,400 – 3,000 hours. The highest sunlight duration is twice as larger as the shortest sunlight duration. The intensity of sunlight decreases from the South to the North, from waters to the mainland, and from lower altitude areas to higher altitude areas. To some extent, the sunlight distribution is similar to the total radiation distribution and opposite to the cloud distribution.

In general, Southern areas have over 2,000 hours of sunlight/year and the South Central coastal deltas have 2,600 – 3,000 hours of sunlight/year. Meanwhile, most Northern areas have less than 2,000 hours of sunlight/year, of which localities on the Eastern side of the Hoang Lien Son range have only 1,400 – 1,600 hours of sunlight/year.

There is a highly uneven distribution of sunlight between Northern areas and Southern areas in winter months. In January, the amount of sunlight is very low in the North and very high in the South. In July, sunlight is evenly distributed among all areas from the North to the South.

The sunlight season, defined as the time with average hours of sunlight over 100, lasts from April/May to November/December in the North, and the whole year in the South. In high altitude areas, the sunlight season may arrive later and end earlier than in adjacent lower altitude areas.

Temperature

According to analysis based on measured meteorological data at weather stations, the highest annual average temperature is 27.7^0C, and the lowest is 12.8^0C in Hoang Lien Son. Because the altitude-dependent temperature gradient in Viet Nam is about 0.5^0C/ 100m, the annual average temperature at the highest point in Hoang Lien Son range is only 8^0C.

According to the annual average temperature chart, the isothermal line of 24^0C runs from the North Central coastal delta, along the coast to South Central (the 14^{th} latitude), then turns to the West until the Viet - Lao border, and separates the North West, North East, North Delta, part of the mountainous areas of North Central and South Central, and Central Highlands, with high temperatures, from relatively low temperatures across the rest of the territory.

The surface air temperature is relatively low in winter and reaches its bottom in January, while being relatively high in summer and reaching its peak in July. The average temperature in January in Viet Nam is from 2 - 26^0C, and decreases gradually from the South to the North, from the low lands to the high lands. Meanwhile, the average temperature in July is from 10 - 30^0C, relatively equal among Northern and Southern latitudes, but more swiftly decreases in accordance with the geographical altitude than in January.

The total temperature degree days in Viet Nam is from 3,000 to 10,000°C for the whole year, from 1,400 to 4,400 in 6 winter and spring months (November to April), and from 1,600 – 5,600 in 6 summer and fall months (May to October).

The coldness in winter is the effect of not only the radiation conditions, but also the Northeast monsoon. In many Northern mountainous areas, subzero temperatures have been recorded, the lowest of which was negative 3.7⁰C at Hoang Lien Son on December 14, 1975. Meanwhile, the temperature in the Spratly Islands never goes under 21⁰C.

The highest temperature normally appears in March, April and May in the Southern areas, and May, June, and July in the Northern areas.

The highest recorded temperature that has been reported was 42.7⁰C (in Tuong Duong on May 12, 1966). Temperatures of over 40⁰C have been recorded in almost all areas in recent decades. However, the value of this indicator has never reached 30⁰C in Sapa or Dalat, or even 25⁰C in Hoang Lien Son.

The daily oscillogram of temperature is nearly the same among geographical areas: it reaches the lowest point in the early morning or at dawn, increases gradually, and reaches its peak by late midday, then decreases gradually until night. In general, the daily amplitude of the temperature is always above 6⁰C, except in some mountainous areas and on some islands.

The annual oscillogram of temperature is not as equal among geographical areas as the daily oscillogram. The temperature reaches its lowest points in December and July all over the country. In February and March, the temperature slightly increases in Northern locations due to the impacts of drizzly weather, while sharply increasing in Southern locations. As a result, the temperature in many Southern locations reaches its peak in late winter months. From April, May to July and August, the temperature increases and reaches its highest point in Northern locations, and remains high in Southern locations. Since September, it gradually decreases until mid-winter.

With the above annual oscillogram, the Northeast monsoon season is also the cold season across many Northern latitude locations. With a stable average temperature less than 20⁰C, the cold season lasts 4 - 5 months in the North Delta and 1 - 3 months in North Central. In South Central, Central Highlands, and the South, not taking into account high mountainous areas, there is almost no month that meets the standards of the cold season.

In medium and high mountainous areas, the cold season lasts longer, begins earlier and ends later. The temperature in areas at altitude of 1,500 m and above meets the standards of the cold season for almost whole year.

Replacing the cold season is the hot season, with an average temperature of over 25⁰C. The hot season lasts 4 - 5 months in the North, 9 - 10 months in South Central, and even longer in the South. Vice versa, in medium and high mountainous areas, the hot season lasts shorter, begins later and ends earlier. The hot season nearly does not exist in areas at altitude of 1,000m and above.

The annual temperature oscillogram greatly varies among different regions: 10 - 14°C in the North, 9 - 13⁰C in North Central, 4 - 8⁰C in South Central and Central Highlands, and only 3 - 4⁰C in the South. The isothermal line of temperature amplitude of 8⁰C crosses Southern mountainous areas of North Central and the North of South Central.

The annual average temperature on the ground is about 1.5 - 5.0⁰C, higher than

Figure 2.1. Pattern of Climate Change in Various Regions of Viet Nam

ANNUAL AVERAGE TEMPERATURE

Source: Nguyen Duy Chinh, Institute of Meteorology, Hydrology and Environment that in the air, relatively low in the winter months and relatively high in the summer months. The lowest ground temperature was reportedly negative 6.4^{0}C measured in Sapa on December 31, 1975, while the highest ground temperature was 74.7^{0}C measured in Buon Ma Thuot on May 23, 1982. A ground temperature of 70^{0}C has been recorded in many places. In general, the absolutely lowest temperature on the ground is only 1 - 2^{0}C lower than that in the air, but the absolute highest temperature on the ground is over 30^{0}C, higher than that in the air.

Rain, evaporation and humidity

The annual rainfall in Viet Nam is within a range of about 700 - 5,000mm. The most common numeric value of rainfall recorded is about 1,400 - 2,400mm. Places with rainfall beyond this normal value are areas with high rainfall, such as: Sin Ho (Lai Chau, 2,400-3,200mm); Sa Pa (Lao Cai, 2,400-3,200mm); Bac Quang (Ha Giang, 2,400-5,200mm); Mong Cai (Quang Ninh, 2,400-2,800mm); Tam Đao (Vinh Phuc, 2,400-2,800mm); Ky Anh (Ha Tinh, 2,400-2,800mm); Nam Đong (Thua Thien-Hue, 2,400-3,800mm); Tra My (Quang Nam, 2,400-4,000mm); Ba To (Quang Ngai, 2,400-3,600mm); Bao Loc (Lam Đong, 2,400-2,800mm); Phu Quoc (Kien Giang, 2,400-3,200mm), and areas with low rainfall, such as: Bao Lac (Cao Bang, 1,200-1,400mm); Na Sam-Đong Đang (Lang Son, 1,100-1,400mm); Yen Chau (Son La, 1,200-1,400mm); Song Ma (Son La, 1,100-1,400mm); Mương Xen (Nghe An, 800-1,400mm); Ayunpa (Gia Lai, 1,200-1,400mm); Nha Ho (Ninh Thuan, 700-1,400mm), and Phan Thiet (Binh Thuan, 1,100-1,400mm).

In general, the annual rainfall in the North exceeds that in the South. The terrain, especially large mountain systems, plays an extremely important role in the annual rainfall distribution. In addition, the annual rainfall distribution also has an inconsistent relation with the islandic features. Most islands in the North and North Central have lower rainfall than the adjacent mainland, while islands in the South Central and South, such as Phu Quoc and/or the Spratly Islands, have higher rainfall than the adjacent mainland in the same region.

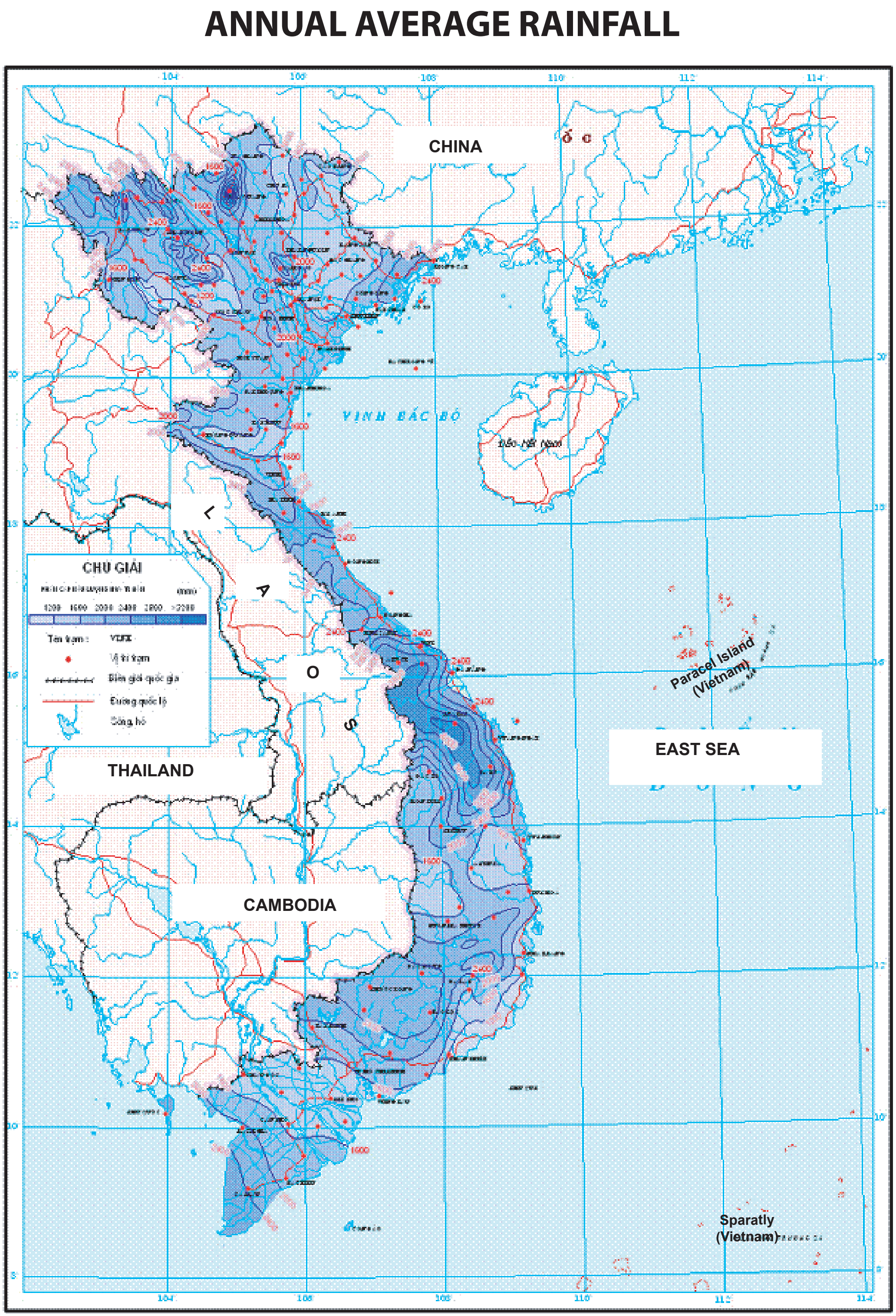
The annual average number of rainy days is 60 - 200. The difference in the number of rainy days is not as profound as that of rainfall, but there are also some centers with a large number of rainy days, namely: Sa Pa (Lao Cai), Bac Quang (Ha Giang), Yen Bai, Tam Đao (Vinh Phu), Kim Cuong (Ha Tinh), A Luoi (Thua Thien - Hue), Đak Nong, and the Spratly Islands, and some centers with a small number of rainy days, namely: Tan Yen (Bac Giang), Bach Long Vi (Hai Phong), Hoang Sa (Quang Nam), Cam Ranh (Khanh Hoa), Ayunpa (Gia Lai), Ba Tri (Ben Tre), and My Tho (Tien Giang).

The annual oscillogram of rainy days is similar to that of rainfall. However, because drizzling rains regularly appear in late winter, an additional maximum of rainy days appears in many places in the North and North Central in February and March. Considering Yen Bai province alone, the number of rainy days in months of prevalent drizzling rains is even higher than that in the main rainy season.

The majority of rainy days have rainfall less than 5 mm/day. The normal annual average number of rainy days with high rainfall (equal to and above 50 mm/day) is 5 - 15. The highest number of rainy days does not exceed 30, while the lowest is not less than 2.

The highest daily rainfall is only 107 mm in Song Ma (Son La), while it reaches 788 mm in Do Luong (Nghe An). The numeric value of this parameter is relatively high in the North and North Central, while relatively

Figure 2.2. Distribution of Annual Average Rainfall in Viet Nam



Source: Nguyen Duy Chinh, Institute of Meteorology, Hydrology and Environment low in the South Central, Central Highlands and South.

The rainy season, defined as the time when the monthly average rainfall is over 100 mm, is specified as follows:

North West, North East: The rainy season begins in April and May, reaches its peak in July and August, and ends in September and October.

North Delta: The rainy season begins in April and May, reaches its peak in July and August, and ends in October and November.

North Central: The rainy season begins in May and June, becomes especially unstable in July and the first half of August, reaches its peak in September and October, and ends in November and December.

South Central: The rainy season begins in August and September, reaches its peak in October and November, and ends in December.

Southern Central Pole: The rainy season begins in April and May, reaches its peak in August, and ends in November.

Central Highlands: The rainy season begins in April and May, reaches its peak in August, and ends in October and November.

The South: The rainy season begins in May, reaches its peak in September and October, and ends in November.

The normal annual average absolute humidity is within a range of about 13 - 30 grams per cubic meter and decreases sharply in accordance with geographical altitude. The normal monthly average absolute humidity is within a range of about 13 - 30 grams per cubic meter, relatively high in summer and reaches its peak in July and August, while relatively low in winter and reaching its peak in December and January.

The normal annual average relative humidity is about 80 - 85%, reaches 86 - 87% in high mountainous areas with high rainfall in the North, but decreases to only 77 - 78% in some areas of the South Central Coast, Central Highlands and South. The annual oscillogram of relative humidity is heavily influenced by the rain mechanism. In the North East and North Delta, the relative humidity is quite low in the beginning and middle of winter, increases in the later half of winter due to heavy drizzly rains, then decreases, and then increases again in the summer months. In North Central and South Central, the humidity is relatively low in the summer months and quite high in winter. In the North West, Central Highlands and South, the humidity is quite low in the middle and at the end of winter, while quite high during summer.

The normal annual average evaporation quantity (PICHE) is 800 - 1,500 mm, reaches its peak at 2,326 mm (in Cam Ranh), and its bottom at 494 mm in the high mountainous areas with high rainfall (Hoang Lien Son range). The evaporation quantity of the North is smaller than that of the South, and that of the high lands is smaller than that of the low lands.

The annual oscillogram of the evaporation quantity greatly varies among different regions: in the North East, North Delta, North Central and the North of South Central, the evaporation quantity is relatively small in winter and relatively high in summer. Conversely, in the Central Highlands, Southern Central Pole and South, the evaporation quantity in winter overwhelms that in summer.

The annual humidity index ($A = \frac{R}{E}$, in which: R stands for rainfall and E stands for the evaporation quantity PICHE) is about 1 - 5. In some cases, it is equal to and above 5, namely in Bac Quang (7.69) and Tra My (5.88), or equal to and under 1, namely in Nha Ho (0.41), Cam Ranh (0.69), Phan Thiet (0.79), and Nha Trang (0.96).

In general, the humidity index in the North is higher than that in the South, and higher in the high lands than that in the low lands.

The humidity index has a clear annual oscillogram. From December and January to February and March, the popular 'A' all over the country is equal to and under 1. From May to November, the popular index in many places is equal to and above 1. Especially in North Central and South Central, the humidity index in June, July and August in many places is equal to and under 1, due to the influence of the hot and dry west wind.

Some special weather phenomena

Hoarfrost

One of the most special weather phenomena in winter is the hoarfrost. 70 out 160 weather stations have been able to record hoarfrost occurrence each year during winter. The number of weather station reporting hoarfrost is very high in the Northern mountainous and midland provinces, namely: Lai Chau, Son La, Lao Cai, Yen Bai, Ha Giang, Cao Bang, Lang Son, Bac Giang, Bac Can, Phu Tho, Hoa Binh, Ha Tay, and Quang Ninh. Hoarfrost even occurs in the North Delta and the mountainous areas of North Central and the Central Highlands. In general, hoarfrost occurs in winter, especially in December and January.

Drizzly rain

Like hoarfrost, drizzly rain is a special weather phenomenon in winter in the North. The normal annual average number of drizzly rain days is 2 - 20 in the North West, 5 - 50 in the North East and North Delta, and 4 - 40 in North Central. Drizzly rains have also been observed in some areas of the South Central coast. Drizzly rains normally occur in winter, concentrated over three months in the middle and at the end of the season, i.e. January, February, and March.

Fog

The normal annual average number of foggy days in Viet Nam is within a range of 10 - 80. Areas with more than 80 foggy days per year are: Muong Te (Lai Chau), Tuan Giao (Đien Bien), Hoang Lien Son, Sa Pa (Lao Cai), Yen Chau, Moc Chau (Son La), Cho Ra (Cao Bang), Bac Can, A Luoi (Thua Thien - Hue), Tra My (Quang Nam), and Đa Lat (Lam Đong).

In almost all provinces, there are few places where the annual average number of foggy days is under 10. There is more fog in the North than in the South, in the mountainous areas than in the deltas, and over the mainland than over islands. The fog is quite dense during winter, especially during January, February and March, while being relatively thinner during summer, especially in July and August.

Thunderstorms

The normal annual average number of thunder storm days in Viet Nam is within the range of 20 - 80. The numeric value of this phenomena exceeds 80 in Bac Quang (Ha Giang), Mai Chau (Hoa Binh), Hoi Xuan (Thanh Hoa), So Sao (Binh Duong), Phuoc Long, Moc Hoa (Long An), and Rach Gia (Kien Giang). Meanwhile, there are some areas with less than 20 thunderstorm days, namely: Con Co (Quang Binh), Hoang Sa (Quang Nam), Ba To (Quang Ngai), Nha Trang, Cam Ranh, the Spratly Islands, (Khanh Hoa), and An Khe (Gia Lai).

There are more thunderstorm days in the South than in the North. In the same region, there are more thunderstorms in the mountainous areas than in coastal deltas. Islands are places with the smallest number of thunderstorms.

Thunderstorms occur almost all year round, but mostly during the rainy season, followed by hailstorms. The normal annual average number of days with hailstorms in Viet Nam is 0.1 - 1.0. The numeric value of this phenomena exceeds 1.0 only in some places in the Northwest, i.e. Tam Duong, Muong Te, Sin Ho, Lai Chau, Pha Din (Lai Chau), Moc Chau (Son La), Than Uyen (Yen Bai), and Pho Bang (Ha Giang).

Dry and hot wind from the West (Lao Wind)

One of the most special weather phenomena during summer is the dry and hot wind from the West. This dry and hot weather changes the precipitation regime in many coastal areas in the North Central and South Central.

The normal annual average number of days with dry and hot weather is 20 - 40 in the North West low mountainous areas, 5 - 20 in the North East low mountainous areas, 10 - 20 in the North Delta, and 30 - 60 in the North Central and South Central coastal deltas. In some lowland areas in the North Central and South Central, there are on average over 60 days with dry and hot weather per year.

The season of dry and hot weather begins from March or April, reaches its peak in May, June and July in the North, or June, July and August in South Central, and ends in August (as for the North) or September (as for the South Central)

Droughts

Drought is estimated by the dryness index (K= $\frac{E}{R}$, in which E stands for the evaporation quantity PICHE; and R stands for the rainfall) and the frequency of drought months, months with the rainfall less than 10 mm (as for November, December, January and February); less than 30 mm (as for March, April, September, and October), and less than 80 mm (as for May, June, July, and August).

The drought situation in different regions can be described as follows:

North West: The dryness frequency is very high in the winter and spring months.

North East: The dryness frequency is very high in the winter and spring months.

North Delta: The dryness frequency is relatively high in the winter and early spring months.

North Central: The dryness frequency is extremely high in June and July.

South Central: The dryness frequency is high from January to August, especially in

Table 2.1. The number of tropical cyclones developing in the East Sea and having direct influences on Viet Nam

Number of tropical cyclones	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Developing in the East Sea	0.1	0.1	0.1	0.1	0.5	1.0	1.8	1.9	1.8	1.9	1.3	0.4	11.0
Having direct influences on Viet Nam	0.0	0.0	0.1	0.1	0.1	0.7	0.7	1.2	1.4	1.3	1.0	0.3	6.9

Source: Institute of Meteorology, Hydrology and Environment

areas with low rainfall, such as Ninh Thuan province.

Central Highlands: The dryness frequency is high during most of winter and early spring, from December to March.

The South: The dryness frequency is high from mid-winter to the end of spring, from December to April.

Storms and tropical low pressure

Annually, in the East Sea, there are on average 11 storms and tropical low pressures (Table 2.1), more than a half of which are storms originating from the Northwest Pacific.

Storms originate/strengthen in the East Sea in almost all months, especially in the summer months. The stormy season in the East Sea is from May to December, of which July, August, September, and November, are the months with the highest frequencies of storms, with 2 storms each on average. The storm frequency in the East Sea greatly varies depending on the year. There are records of 18 storms occurring in the year with the highest frequency (1973 - 1974), while only 4 in the year with the lowest frequency (1966).

In 45 years, the entire coastal line of Viet Nam has suffered from direct influences from as many as 311 tropical storms, equal to an average annual frequency of 6.9, which accounts for 62.7% of the total number of tropical storms in the East Sea.

The stormy season in Viet Nam lasts from June to December, of which there are at least 0.3 storms per month on average. The highest frequency is 1.4 (in September).

The number of storms and tropical low pressures affecting Viet Nam also varies depending on the year.

2.1.3. Viet Nam's climatic delimitation

The division system and criteria for climatic delimitation

The division system in the map of climatic delimitation is constructed based on fundamental and nornal rules of climatic division in the territory. The manifestations of climatic division are various and the level of division is very complicated. However, all climatic divisions originate from a certain decisive factor expressed on the basis of climatic elements reflecting thermal resources, including the sun's radiation, sunlight, temperature, and parameters reflecting the rain-humidity resources, including rain, humidity and the humidity index.

Fundamentally, the division system of the map of Viet Nam's climatic delimitation represents two major groups of climatic division:

1. Division of thermal resources: Principally the reduction of specific values representing the winter thermal resources in the North, originating from the significant difference in the circulation mechanisms, firstly the impacts of the winter circulation across the Northern latitudes.
2. Division of humidity resources: Principally the profound difference in the rainy and humid season between the Central Coastal areas and Northern/ Southern areas due to the impacts of the Truong Son range; the dephasing in the rainy season between the Northwest and the Northeast due to the impacts of the Hoang Lien Son range, between the Mid-Northern mountainous and midland areas and North Delta, and between the Central Highlands and South due to geographical conditions, primarily the

terrain. As a result, there are two levels in the division system of the map of Viet Nam's climatic delimitation: climatic zone and climatic region.

+ Climatic zone: Climatic zones are specified as separate territorial parts, with different thermal resources. The climatic zone connects areas with relative similarities in thermal resources based on the following criteria:

- Annual temperature amplitude,
- The annual average total radiation quantity,
- Annual average daylight hours.

+ Climatic region: Climatic regions are specified as separate localities in the same climatic zone, with the relative similarities in the rain and humidity mechanisms based on each or both of these following criteria:

- The time of the rainy season,
- Three months with the highest rainfall.
- The boundary between two climatic zones in Viet Nam's territory is specified based on following criteria:
- The annual temperature amplitude equal to 9^0C
- The annual average total radiation quantity equal to 140 kcal/cm^2
- The annual average number of light hours equal to 2,000 hours

The boundaries between climatic regions are specified based on the separating lines between localities with different rainy seasons or peak of rainy seasons.

The results of climatic delimitation are shown in the map of climatic delimitation (Figure 2.1 and Table 2.2).

Climatic resources in regions

The B1 climatic region (North West)

The B1 climatic region is situated in the Northwest, including Lai Chau, Son La and Dien Bien provinces, with the normal geographical altitude from 100 - 800 m.

General climatic features of the B1 region are:

A cold winter with a large amount of sunlight, the occurrence of hoarfrost in many years, little amount of drizzly rain, hot summers, a high frequency of dry and hot West wind,

Table 2.2. Some criteria of climatic zones and regions

Climatic zone	North (B)				South (N)		
The annual temperature amplitude (^{0}C)	> 9^0C				< 9^0C		
The annual average total radiation quantity (kcal/cm^2/year)	>140				> 140		
The annual average number of daylight hours	>2,000				> 2,000		
Climatic region	B1	B2	B3	B4	N1	N2	N3
Rainy season	Apr. – Sep.	Apr. – Oct.	May – Oct.	Aug.-Dec.	Aug.-Dec.	May – Oct.	May – Oct.
Three months with the highest rainfall	Jun.-Aug.	Jun.-Aug.	Jul.-Sep.	Aug.-Oct.	Sep.-Nov.	Jul.-Sep.	Aug.-Oct.

Source: Climatology and Climatic Resources in Viet Nam not being directly influenced by storms and tropical low pressures, high rainfall, and the close alignment of the rainy season and the hot season.

The B2 climatic region (North East)

The B2 climatic region mainly includes the Mid-Northern and Northeastern provinces, namely: Lao Cai, Yen Bai, Hoa Binh, Ha Giang, Tuyen Quang, Phu Tho, Cao Bang, Lang Son, Bac Kan, Thai Nguyen and Quang Ninh, with the normal geographical altitude from 50 - 500 m.

General climatic features of the B2 region are: A cold winter with a small amount of sunlight; the occurrence of hoarfrost in many years, a large amount of drizzly rain, hot summer, a low frequency of dry and hot West wind, being directly influenced by a number of tropical storms, especially in the Northeast, high rainfall, and the close alignment of the rainy season and the hot season.

The B3 climatic region (North Delta)

The B3 climatic region mainly includes North Delta provinces and cities and adjacent midland provinces, namely: Phu Tho, Vinh Phuc, Bac Giang, Bac Ninh, Ha Noi, Hai Phong, Hai Duong, Hung Yen, Ha Nam, Nam Đinh, Thai Binh and Ninh Binh, with the normal geographical altitude being under 50m.

General climatic features of the B3 region are: a cold winter with a small amount of sunlight; the occurrence of hoarfrost in certain years, a large amount of drizzly rain, hot summer, a low frequency of dry and hot West wind, being directly influenced by tropical storms, high rainfall, and the close alignment of the rainy season and the hot season.

The B4 climatic region (North Central)

The B4 climatic region mainly includes Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri and Thua Thien - Hue provinces, with the normal geographical altitude being under 100m.

General climatic features of the B4 region are: a relatively cold winter with a relatively small amount of sunlight; the occurrence of hoarfrost in certain years in several areas, drizzly rains, a high frequency of dry and hot West wind in summer, high temperature, high rainfall in the second six months, and no alignment of the rainy season and the hot season.

The N1 climatic region (South Central)

The N1 climatic region includes Da Nang city and Quang Nam, Quang Ngai, Binh Đinh, Phu Yen, Khanh Hoa, Ninh Thuan and Binh Thuan provinces, , with the normal geographical altitude being under 100 m.

General climatic features of the Southern Central are: a warm winter with a high amount of sunlight and a high frequency of dry and hot West wind in summer. The rainy season occurs in late summer and early winter. The rainfall is especially low, while the amount of sunlight is especially high in the Southern part (the Southern Central Pole).

The N2 climatic region (Central Highlands)

The N2 climatic region includes Kon Tum, Gia Lai, Dak Lak, Dak Nong and Lam Dong province, with the normal geographical altitude within the range 100 - 800 m.

Prominent climatic features of the Central Highlands climatic region are: a relatively low temperature baseline (in comparison with adjacent regions, due to the influences of the geographical altitude) which decreases remarkably (to below 20^{0}C) in mid winter (December and January), then swiftly increases, reaching its peak in the transitional months from winter to summer (April - May); high rainfall in summer, very low rainfall in winter, extreme drought in months

Table 2.3. Normal numeric value of some climatic parameters across climatic regions

Climatic region		North West	North East	North Delta	North Central	South Central	Central Highlands	South
Normal geographical altitude (m)		100-800	50-500	0-50	0-100	0-100	100-180	0-50
Radiation -Light resources	Annual average total radiation quantity (kcal / cm^2)	120-135	105-130	105-130	105-140	140-160	150-170	150-170
	Annual average radiation balance (kcal /cm^2)	65-75	60-70	65-75	65-80	75-100	75-100	75-100
	Annual average number of light hours	1,800-2,000	1,400-1,700	1,400-1,700	1,500-2,000	2,000-2,500	2,000-2,500	2,400-3,000
	Number of months with over 200 light hours	1-2	0-1	0-1	1-3	3-5	4-6	6-9
	Number of months with less than 200 light hours	0-1	1-3	3-4	2-3	0-1	0	0
Thermal resources	Annual average temperature (^0C)	18-22	18-23	23-24	23-25	25-27	21-24	26.5-27.5
	Average temperature in the hottest month (^0C)	26-27	26-28	28.5-29.5	28-30	28.5-30	24-28	28-29
	Absolute maximum temperature (^0C)	38-41	38-41	38-41	40-42	40-42	37-40	38-40
	Average temperature in the coldest month (^0C)	13-16	12-16	15-16.5	16.5-19.5	20-24	19-21	24-26
	Absolute minimum temperature (^0C)	-2-2	-2-2	2-5	3-8	8-13	3-9	14-18
	Month(s) with temperature above 25^0C	2-4	3-5	5	5-6	6-9	3-5	11-12
	Month(s) with temperature below 20^0C	3-4	3-4	3	0-3	0	0-2	0
Wind resource	Annual average wind velocity (m/s)	0.8-1.5	1-2	2-3	1.5-3	1.5-3.5	1.5-3	1.5-3.5
	The highest wind velocity (m/s)	30-40	30-40	30-40	30-40	30-40	20-35	20-35
	Prevalent wind direction in winter	Northeast, East, Southeast	East, Northeast	Northeast, East	Northwest, North, Northeast	Northwest, North, Northeast	North, Northeast	Northeast, East, Southeast
	Prevalent wind direction in summer	Northeast, East, Southeast	East, Southeast	Southeast, East	Southwest, South, Southeast	Southwest, South, Southeast	West, Southwest	Southwest, West

Climatic region		North West	North East	North Delta	North Central	South Central	Central Highlands	South
Rain - humidity resources	Annual average rainfall (mm)	1200-2000	1400-2000	1400-1800	1400-2000	1200-2000	1400-2000	1600-2000
	Month(s) with the rainfall over 200mm	9-5	4-7	4-5	3-4	3-4	4-6	4-6
	Month(s) with the rainfall under 50mm	3-5	9-5	3-4	2-4	3-4	3-5	4-5
	Rainy season	Apr.-Sep.	Apr. - Oct.	May - Oct.	Aug. - Dec.	Aug. - Dec.	May – Oct.	May – Oct.
	Three months with the highest rainfall	Apr.- Aug.	Apr. -Aug.	Jul. – Sep.	Aug. – Oct.	Sep. – Nov.	Jul. – Sep.	Aug. – Oct.
	The highest daily rainfall (mm)	200-500	150-500	300-500	300-500	300-500	200-400	150-350
	Annual average evaporation quantity (mm)	800-1,000	600-1,000	700-1,000	700-1,000	1,000-1,600	900-1,600	1,100-1,500
	Annual average relative humidity (%)	82-85	82-85	84-85	84-86	80-84	78-84	78-84
	Humidity index	1.2-2.2	1.2-2.2	1.5-2.2	1.2-2.2	0.6-2.2	1.2-2.0	1.2-2.0

Source: Climatology and Climatic Resources in Viet Nam

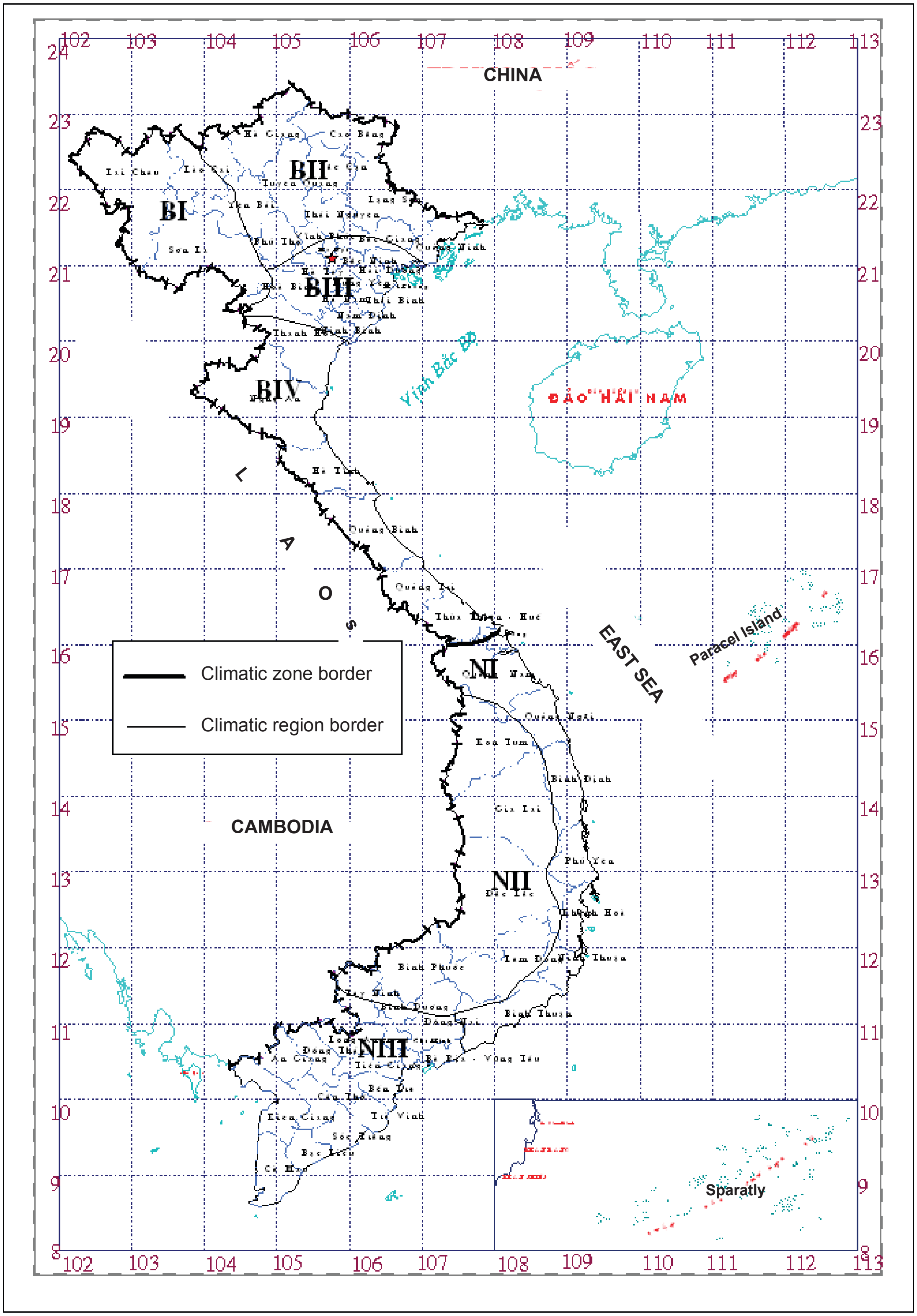
with high temperatures in late winter and early summer. Like the South, the Central Highlands has a much clearer contrast in the rainy season than in hot season.

The N3 climatic region (The South)

The N3 climatic region includes Southwestern and Southeastern provinces and slightly stretches to Binh Thuan province, with the normal geographical altitude being less than 50m.

General climatic features of the South climatic region are: a plentiful amount of sunlight and high temperatures all year-round; the rainy season basically coincides with summer, while the dry season mainly includes middle and late winter and the early summer months. The contrast in the rainy season is much clearer than that in the hot season.

Figure 2.3. Map depicting climatic regions in Viet Nam



Source: Climatology and Climatic Resources in Viet Nam

2.2 Manifestations of climate change in the last 100 years

2.2.1 Changes of typical climatic elements

The observed change in some climate elements is much higher than the normal trend. In addition, climate elements have seasonal changes such as in the tropical cyclone season, and the rainy season etc.

Changes in the frequency of cold front in the North

The influence of the zone-polar air on Viet Nam's climate is normally expressed by the frequency of cold fronts crossing the North region (FRL). The change in frequency of cold fronts is considered one of the most typical element of climate change in Viet Nam. According to figures for the period 1961 - 2000, the change in this parameter has some noticeable features:

The fluctuation of annual FRL frequency:

1. The standard deviation (S = $\left[\frac{1}{n}\sum_{t=1}^{n}(x_t - \bar{x})^2\right]^{\frac{1}{2}}$ in which $\bar{x} = \frac{1}{n}\sum_{t=1}^{n} x_t$ is the numeric average) of the annual FRL frequency is 2.93. With an average numeric value of 27.3, FRL has an annual rate of change of 16%, which is quite low in comparison with other parameters (Table 2.4).
2. There were only 17 years (42.5 %) when FRL was lower than the average (the negative deviation), while there were 23 years (57.5 %) when FRL was higher than the average (the positive deviation).
3. There were no 3 continuous years when FRL was higher than the average, while there was a 5 continuous year period (1961 - 1965) when FRL was lower than the average.
4. The FRL frequency was so low in 1994 (16) and so high in 1970 (40) that they are regarded as extraordinary phenomena.

The fluctuation of monthly FRL frequency:

1. The standard deviation of the FRL frequency in the months of the FRL season (September - June) was from 1 to 1.5, while in the months not in the FRL season is from 0.1 to 0.2. However, the normal rate of change of months in the FRL season is only about 30 - 50%, while that of months out of the FRL season is approximately 200%.
2. FRL reached extraordinary peaks in following months:

   Jan/1994: 9 fronts

   Feb/1964: 5 fronts

   Feb/1988: 5 fronts

   Mar/1970: 5 fronts

   Mar/1985: 5 fronts

   Jun/1970: 4 fronts

   Jun/1976: 4 fronts

   Cold fronts that appear in July and August in certain years are also regarded as extraordinary.

Table 2.4. The standard deviation and the change rate of the FRL

Indicator	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Standard deviation (front)	1.57	1.04	1.04	1.39	1.07	1.36	0.22	0.36	1.10	1.10	1.68	0.94	4.36
Changing rate (%)	39.3	30.2	30.2	53.5	41.1	97.1	220.0	180.0	91.7	45.8	46.7	27.6	16.0

Source: Institute of Meteorology, Hydrology and Environment

3. FRL was extraordinary low in following months:

   Jan/1965: 1 fronts

   Jan/1993: 1 fronts

   Feb/1994: 0

   Mar/1990: 0

   Dec/1994: 1 fronts

The fluctuation in the FRL season

The fluctuation in the FRL season has some noticeable features:

1. There were 23 years (57.5%) when the FRL season exactly began in September, while there were 6 years (15%) when it began earlier, and 11 years (27.5%) when it began 1 - 2 months later.
2. There were 28 years (70%) when the FRL season precisely ended in June, while there were 10 years (25%) when it ends earlier, and 2 years (5%) when it ended 1 - 2 months later.
3. The peak month of the FRL season may be one of 6 months, from November to April. However, high frequencies also fell in January (42.5%), December (27.5%) and November (22.5%). There were also certain years when FRL in February, March and April was higher than that in other months (Table 2.5).

Table 2.5. The number of cold fronts affecting Viet Nam from 1961 to 2000

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1961	4	4	2	2	3	1	0	0	1	2	2	3	24
62	3	2	4	3	3	0	0	0	0	2	4	4	25
63	4	4	2	1	0	1	0	0	1	4	2	4	23
64	3	5	2	0	2	1	0	0	1	3	3	4	24
65	1	3	2	3	2	2	0	0	1	1	4	3	22
66	2	3	3	4	3	3	0	0	1	3	5	2	29
67	5	2	1	5	2	0	0	0	2	2	2	5	26
68	3	4	3	5	3	0	0	0	2	3	3	2	27
69	5	3	3	1	1	3	1	1	1	1	4	3	27
1970	5	4	5	4	3	4	0	1	1	4	4	5	40
71	4	2	3	2	3	1	0	1	3	4	3	3	29
72	2	2	3	3	0	0	0	0	2	3	5	5	25
73	4	3	2	3	4	2	0	0	3	4	2	4	31
74	4	2	2	3	2	1	0	0	1	3	5	3	26
75	4	3	3	3	3	3	0	0	0	3	3	4	29
76	4	4	3	3	4	4	0	0	2	4	7	2	37
77	5	3	3	3	0	2	0	0	2	3	4	4	31
78	4	1	4	3	4	2	0	0	2	3	4	4	31
79	5	2	2	2		2	0	0	3	4	5	2	30
1980	4	3	4	2	4	1	0	0	0	3	1	5	27
81	3	4	4	4	3	3	0	0	1	3	4	5	34
82	3	3	2	4	2	3	0	0	3	1	5	4	30
83	4	2	3	2	1	1	0	0	1	2	5	3	24
84	4	4	3	3	3	2	0	0	2	4	3	4	32

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
85	4	3	5	3	1	1	0	0	1	2	4	4	27
86	2	4	3	3	4	3	0	0	2	2	5	3	31
87	4	1	1	4	4	2	0	0	2	3	3	3	27
88	6	5	4	2	3	0	0	1	2	2	5	3	33
89	4	1	3	3	2	0	1	1	2	2	3	3	25
1990	6	3	0	4	4	2	0	0	0	1	3	1	24
91	5	2	4	1	2	1	0	0	1	3	5	3	27
92	3	3	3	1	2	1	0	0	0	2	4	2	21
93	1	2	2	1	2	2	0	0	0	2	4	4	20
94	3	0	3	1	3	0	0	0	0	2	4	4	20
95	5	4	3	2	2	0	0	0	1	3	4	5	29
96	9	3	2	4	2	0	0	0	0	1	3	3	27
97	4	3	4	2	3	1	0	0	2	3	2	4	28
98	7	4	3	1	3	1	0	1	2	1	4	1	28
99	3	3	3	2	4	0	0	0	0	1	3	4	23
2000	4	4	4	4	3	1	0	0	0	3	3	4	30
Total	158	114	115	105	102	57	2	6	49	99	144	135	1092
Average	4.0	2.9	2.9	2.6	2.6	1.4	0.1	0.2	1.2	2.5	3.6	3.4	27.3

Source: Center for Meteorology and Climatology , Institute of Meteorology, Hydrology and Environment

Fluctuation in the frequency of tropical cyclones

Fluctuation in the frequency of tropical stormsmoving across the East Sea as tropical cyclone

From 1961 to 2000, there were 439 tropical cyclones in the East Sea, equal to 11 whirls per year on average. The East Sea's tropical cyclone season, defined as the time with no less than 1 whirl/month, begins in June and ends in November.

In the above 40 years, the change in East Sea tropical cyclones has followed noticeable characteristics:

1. East Sea tropical cyclones have a standard deviation of 2.93 and a rate of change of 27%. The numeric value of the standard deviation and the normal rate of change of East Sea tropical cyclones in months during the East Sea tropical cyclone season are 0.75 - 1.24 and 57 - 95 % respectively (Table 2.6). In months outside this season, the standard deviation is smaller, while the rate if change is many times higher.
2. There were 15 years (37.5%) when the number of East Sea tropical cyclones was higher than the average, and 16 years (40%) when the number was lower than the average. Therefore, the number of years with a positive standard deviation is nearly equal to those with a negative standard deviation, and almost twice as larger as those with a zero standard deviation.
3. The number of East Sea tropical cyclones reached its peak in 1981 (20) and was the least in 1969 (5). If calculated, based on 5-year periods, the largest number of East Sea tropical cyclones were recorded in the 5-year period from 1971 to 1975 (68), while the smallest number was recorded in the last 5-year period of the 20^{th} century, i.e, from 1996 to 2000 (43).

Table 2.6. The standard deviation and change rate of East Sea tropical cyclone

Indicator	Jan.	Feb.	Mar.	Apr.	May	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual	Year
Standard deviation (whirls)	0.26	0.22	0.33	0.33	0.77	0.75	1.08	1.09	1.03	1.42	1.24	0.60	2.93
Change rate (%)	347	440	264	264	64	75	60	61	57	75	95	150	27

Source: Institute of Meteorology, Hydrology and Environment

4. The number of East Sea tropical cyclones has decreased gradually through decades from 1961 - 1970 (114), 1971 - 1980 (113), to 1981 - 1990 (109) and reached its bottom in the decade of 1991 - 2000 (103).
5. There were 17 years when the East Sea tropical cyclone season began before June (42.5%), 17 years when it finished exactly in June (42.5%) and 6 years after June (15%). Similarly, there are 14 years when the East Sea tropical cyclone season ended after November (35%), 17 years exactly in November (42.5%), and 9 years prior to November (22.5%).

Fluctuation in the frequency of tropical cyclones affecting Viet Nam (Viet Nam tropical cyclones).

During the period 1961 - 2000, fluctuation in the frequency of Viet Nam tropical cyclones had some noticeable features:

- ***Fluctuations in the annual frequency of tropical cyclones affecting Viet Nam***

1. The standard deviation and the rate of change of the annual Viet Nam tropical cyclone frequency are 2.58 and 35% respectively. Consequently, fluctuations in tropical cyclones affecting Viet Nam is slightly clearer than that of tropical cyclones operating across the East Sea (Table 2.7).
2. There were 19 years when the number of Viet Nam tropical cyclones was higher than the average and 21 years when the number of Viet Nam tropical cyclones was lower than the average. Generally speaking, the number of positive standard deviation years was equal to that of negative standard deviation years.
3. Years with positive standard deviation normally intermingle with years with negative standard deviation. However, there are 4 continuous years (1983, 1984, 1985 and 1986) when the number of Viet Nam tropical cyclones was higher than the average, and another 4 continuous years (1997, 1998, 1999 and 2000) when the number of Viet Nam tropical cyclones was lower than the average.
4. 1973 is the year with the largest number of Viet Nam tropical cyclone (12), followed by 1964, 1970, 1971, and 1989, with 11 whirls each while 1976 is the year with the smallest number (2), followed by 1969, 1977 and 1987, with 3 whirls each. Therefore, the year with the highest number of East Sea tropical cyclones does not coincide with the year when tropical cyclones had the strongest impact on Viet Nam. Similarly, the year with the lowest number of East Sea tropical cyclones is not the year when tropical cyclones had the least impact on Viet Nam.

- ***Fluctuation in the monthly frequency of Viet Nam tropical cyclones***

1. The standard deviation of Viet Nam tropical cyclone frequency is 0.7 - 1.4

Table 2.7. The standard deviation and the change rate of tropical cyclones affecting Viet Nam

Indicator	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual	Year
Standard deviation (whirls)	0.016	0.022	0.022	0.37	0.75	0.70	0.89	1.35	1.39	1.07	0.73	2.58	2.93
Change rate (%)	63	44	44	45	107	77	99	123	87	97	243	35	27

Source: Institute of Meteorology, Hydrology and Environment

in months within the Viet Nam tropical cyclone season (June - November) and 0.010 - 0.73 in months outside the season (December - May). The changing rates of Viet Nam tropical cyclone frequency within these two month groups are 75-125% and 44-243%, respectively.

2. The number of Viet Nam tropical cyclones reached its peak in October 1983 (6) for months within the season, and May 1983 for months outside the season.

3. In any month, whether within or outside the season, there were also certain years with no tropical cyclones affecting Viet Nam. Certainly, the possibility of no tropical cyclones is relatively high in months outside the tropical cyclone season, and relatively low in months within the tropical cyclone season. Moreover, the possibility of no tropical cyclones is relatively low in months with relatively high average frequency of tropical cyclones.

- ***Fluctuation in the tropical cyclone season***

During the period from 1961 - 2000, tropical cyclone frequency varied among different months. The total number of tropical cyclones in October reached 64, while in January there was only 1. It is obvious that there is a difference between the time with a large number of tropical cyclones and the time with a small number of, or no, tropical cyclones.

If the tropical cyclone season is defined as the time when the monthly average tropical cyclone frequency is no less than 0.5, the season of tropical cyclone affecting Viet Nam is from June to November. Consequently, tropical cyclones occurring in December, January or February are considered late forming tropical cyclones, and those occurring in March, April and May are considered early forming tropical cyclones.

Fluctuation in the tropical cyclone season in Viet Nam have following features:

1. The start time of the tropical cyclone season varies among years, but the most common times are in June and July.

2. 15% of tropical cyclone seasons begin in March, April and May, while the same percentage of seasons begin in August, September and October. 70% of tropical cyclone seasons begin in June and July, of which June accounts for 45%.

3. The end time of the tropical cyclone season varies among years, but the most common time is in November.

   30% of tropical cyclone seasons end in September and November, while 20% end in December and January. There are some tropical cyclones in February in certain years. 42.5% of tropical cyclones end in November, coinciding with the average tropical cyclone season.

4. The month with the highest frequency of tropical cyclones varies greatly depending on the year. In 40 years,

Table 2.8. The beginning, peak and ending frequencies of tropical cyclone

Tropical cyclone season	Beginning		Peak		Ending	
Indicator	Number of year(s)	Rate (%)	Number of year(s)	Rate (%)	Number of year(s)	Rate (%)
March	1	2.5	0	0.0	0	0.0
April	2	5.0	0	0.0	0	0.0
May	3	7.5	0	0.0	0	0.0
June	18	45.0	1	2.5	0	0.0
July	10	25.0	3	7.5	0	0.0
August	3	7.5	7	17.5	0	0.0
September	1	2.5	14	35.0	5	12.5
October	2	5.0	12	30.0	7	17.5
November	0	0.0	3	7.5	19	47.5
December	0	0.0	0	0.0	8	20.0
January	0	0.0	0	0.0	0	0.0
February	0	0.0	0	0.0	1	2.5
Total	40	100.0	4.0	100.0	40	100.0

Source: Institute of Meteorology, Hydrology and Environment

the month with the highest frequency of tropical cyclones has been June (2.5%), July (7.5%), August (17.5%), September (35%), October (30%), and November (7.5%). So, September, with an average tropical cyclone frequency of 1.4 whirls/year, and October, with an average tropical cyclone frequency of 1.6 whirls/year, are the peak months of most tropical cyclone seasons in Viet Nam (Table 2.8).

Fluctuations in temperature

Fluctuations in the average temperature

Fluctuations in the average temperature throughout the years have had the following characteristics:

1. Fluctuations in the average temperature are relatively large in winter, especially in the main winter months (December, January and February), and relatively small in summer, especially in the main summer months (June, July and August). The standard deviation of the January average temperature is 1.2 - 1.8^{0}C in the North and 0.6 – 1.2^{0}C in the South. As for the July average temperature, the value of the standard deviation is 0.3 – 0.8^{0}C all over the country (Table 2.9).
2. Fluctuations in the average temperature in April and October, which represents the transitional period between seasons, are not as large as those in January, and not as small as that in July. The value of the standard deviation in these two months is 0.5 - 1.2^{0}C. The point is, the standard deviation of the April average temperature in several Northern mountainous areas is still very high and not less than those of January or February.
3. The annual average temperature is lower than that of any months, even mid-summer months.

Table 2.9. The standard deviation of some temperature indicators in typical terrains (^0C)

Region	Typical stations	Average temperature					Annual highest temperature	Annual lowest temperature
		Jan.	Apr.	Jul.	Oct.	Year		
North West	Lai Chau	1.0	0.9	0.5	0.8	0.3	1.33	2.45
North East	Sa Pa	1.5	1.1	0.4	0.7	0.4	0.72	1.17
North Delta	Ha Noi	1.4	1.2	0.5	0.9	0.5	1.07	1.46
North Central	Vinh	1.4	1.3	0.7	0.7	0.5	0.82	1.37
South Central	Da Nang	1.1	0.7	0.5	0.6	0.3	0.93	1.51
Central Highlands	Da Lat	0.7	0.6	0.3	0.4	0.3	1.29	1.72
The South	Tan Son Nhat	0.9	0.6	0.5	0.5	0.4	0.69	1.38

Source: Institute of Meteorology, Hydrology and Environment

4. In the same area, there is no remarkable difference among indicators reflecting temperature fluctuations between mountainous regions and deltas, high mountainous areas and low mountainous areas, as well as islands and the adjacent mainland.

Fluctuations in temperature extremes

Fluctuations in the maximum and minimum temperatures throughout the years have some noticeable characteristics as follows:

1. Fluctuations in the maximum temperature are partly similar to those in the average temperature in July and the summer months. Similarly, fluctuations in the minimum temperature are partly similar to those in the average temperature in January and the winter months.
2. The standard deviation of the maximum temperature is within the range 0.7^0C-1.3^0C, nearly equal to that of the average temperature in transitional months, but lower than that of the average temperature in January, and higher than that of the average temperature in July.

Fluctuations in the annual temperature oscillogram

Fluctuations in the annual temperature are evident from the values detailed in Table 2.10. The main manifestations of these fluctuations are as follows:

1. In the North, the beginning and ending days of the time with an average temperature above 25^0C fluctuates in a period of approximately 2 months. The beginning day of the time with the average temperature below 20^0C also fluctuates in a similar manner, while the fluctuation scope of the ending day of the cold season is larger.
2. The month with the minimum lowest temperature in the North, North Central, and South Central Coast, in many years is January, but in certain years is December or February. However, these three months in the Central Highlands and the South are November, December and January.
3. Annually, the months with the maximum highest temperature in the North, North Central, and South Central Coast are June, July and August, while these three months in the Central Highlands and South are March, April and May.

Table 2.10. The frequencies of the coldest and hottest months

Indicator	Coldest				Hottest					
Month	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**
Ha Noi		24	47	29				40	53	7
Da Nang		25	68	7				49	36	15
Tan Son Nhat	6	45	49	0	3	77	20			

Source: Institute of Meteorology, Hydrology and Environment

Fluctuations in rain

Fluctuations in rainfall

Fluctuations in rainfall are indicated by both the absolute value (the standard deviation) and the relative rate of change (Sr $= \frac{S}{\bar{x}}$). Fluctuations in rainfall have following features:

1. In the same area, the standard deviation of annual rainfall is larger than that of monthly rainfall, and that of the month with high rainfall is larger than that of the month with low rainfall. Conversely, the rate of change of annual rainfall is smaller than that of monthly rainfall, and that of the months in the rainy season is smaller than that of the months in the dry season (Table 2.11).
2. The rate of change of annual rainfall exceeds 20% in the North Central, South Central Coast and Central Highlands, while staying below 20% in the North West, North East, North Delta, and South. Therefore, the annual rainfall in Central areas is not as stable as it is in the North and the South.
3. In January, the rate of change of the rainfall exceeds 100% in the North West, North East, North Delta, Central Highlands and South, which are in the middle of the dry season, and stays at only about 50 - 80% in the North Central and South Central Coast, which have just passed the rainy season. In July, the rate of change of the rainfall is approximately 100 % in the North Central and South

Table 2.11. The standard deviation (S; mm) and the rainfall rate of change (Sr; %) in several typical localities

Region	Typical station	Indicator	Jan.	Apr.	Jul.	Oct.	Year
North West	Lai Chau	S	29.0	55.5	129.3	61.9	286.7
		Sr	99	42	28	68	14
North East	Sa Pa	S	46.4	75.2	161.9	113.6	402.8
		Sr	69	36	36	54	14
North Delta	Ha Noi	S	21.6	53.4	101.8	104.8	320.0
		Sr	102	55	39	72	19
North Central	Vinh	S	29.0	37.7	119.2	353.0	514.0
		Sr	55	59	102	69	25
South Central	Da Nang	S	76.6	50.7	83.1	276.6	545.4
		Sr	98	143	98	44	26
Central Highlands	Da Lat	S	12.1	89.8	83.2	100.3	237.1
		Sr	159	55	36	41	13
The South	Tan Son Nhat	S	19.3	50.7	93.5	91.8	284.9
			140	101	32	34	15

Source: Institute of Meteorology, Hydrology and Environment

Central Coast, which are in the middle of the dry and hot West Wind season, and stays at only 25-50% in the North West, North East, North Delta, Central Highlands and South, which are in the middle of the rainy season.

Fluctuations in the rainy season

1. The rainy season also fluctuates strongly throughout the years in terms of the beginning time, peak months and the ending time. In general, the rainy season fluctuates in the range of 3 - 4 months or more, depending on the rain oscillogram of each region.

- The North West, North East, and North Delta: The earliest onset of the rainy season is in March and April, while the latest ending time is in November and December. The peak month of the rainy season can be one of the months within the rainy season (May, June, July, August, September, and October), or even November in the case of Ha Noi in 1984 (Table 2.12).
- The North Central: The earliest onset of the rainy season is in April and May, while the latest ending time is in December. The peak month of the rainy season can be one of the months within the rainy season or earlier (June, July, August, September, October, and November).
- The South Central Coast: The earliest onset of the rainy season is in July, while the latest ending times are in December or January. The peak month of the rainy season can be one of the three months of September, October or November.
- The Central Highlands and South: The earliest onset of the rainy season is in

Table 2.12. The beginning (B), ending (E) and peak (P) frequencies of the rainy season in typical localities of regions (%)

Region	Typical station	Indicator	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
North West	Lai Chau	B			14.3	59.1	20.4	6.2						
		P					6.1	30.6	44.9	18.4				
		E								18.4	51.0	24.5	6.1	
North East	Sa Pa	B	3.9	3.9	25.5	52.9	13.8							
		P					9.8	15.7	31.4	31.4	7.8	3.9		
		E								2.0	11.8	43.1	39.2	3.9
North Delta	Ha Noi	B				28.1	49.5	17.5	2.9	1.0	1.0			
		P					6.8	10.7	22.3	38.8	18.5	1.9	1.0	
		E							4.8	12.6	41.8	34.0	6.8	
North Central	Vinh	B				2.7	11.0	8.2	13.7	39.7	20.6	4.1		
		P						5.5	2.7	8.2	42.5	35.6	5.5	
		E						1.4	6.8	1.4		17.8	60.3	12.3
South Central	Da Nang	B							8.6	29.3	53.5	8.6		
		P									17.2	65.5	17.3	
		E									1.7	3.5	24.1	70.7
Central Highlands	Da Lat	B			16.1	55.4	16.1	3.5	5.4	3.5				
		P				5.3	14.0	3.5	7.0	15.8	38.6	15.8		
		E					1.8				10.7	50.0	35.7	1.8
South	Tan Son Nhat	B			1.2	15.7	71.1	12.0						
		P					6.0	21.7	19.3	13.3	27.7	12.0		
											1.2	44.6	49.4	4.8

Source: Institute of Meteorology, Hydrology and Environment

March and April, while the latest ending time is in November and December. The peak month of the rainy season can be one of the months within the rainy season or earlier (April, May, June, July, August, September, and October).

2. The beginning (ending, peak) months of the rainy season, specified based on the average rainfall, are also the months with the highest beginning (ending, peak) frequencies of the rainy season.

3. Because rainy seasons are specified based on the absolute value of the monthly rainfall, the annual rainy season and rainy season fluctuations in areas with high or low rainfall do not coincide with those in adjacent areas in the same region.

2.2.2 The trends of change in several typical climatic factors in Viet Nam

The trend of change in important weather patterns

The frequency of cold fronts crossing the North

In the decade 1961-1970, there were 268 cold fronts, which crossed the North. The numeric value of this factor increased to 288 in the decade 1971-1980 and stayed intact in the decade 1981-1990. In the last decade, the number of cold fronts crossing the North was only 249, even smaller than that in the decade of 1961-1970 (Table 2.13).

The trend equation of the frequency of cold fronts crossing the North in the period 1961 - 2000 is formulated as:

$Yx = 28.3 - 0.049x$

In fact, the decreasing trend of FRL only began from the decade 1971-1980.

The frequencies of tropical cyclone operating in the East Sea

In the decade 1961-1970, there were 114 tropical cyclones which originated/developed in the East Sea. That number decreased to 113 in the decade 1971-1980 and 109 in the decade 1981-1990. In the decade 1991 - 2000, the number of tropical cyclone originating/developing in the East Sea was only 103.

The trend equation of tropical cyclone originating/developing in the East Sea is formulated as:

$Yx = 12.1 – 0.0548x$

The decreasing trend of tropical cyclone originating/developing in the East Sea is relatively consistent in the four decades from 1961 to 2000, especially in recent years.

The frequencies of tropical cyclone affecting Viet Nam.

In the decade 1961-1970, there were 74 tropical cyclones affecting Viet Nam. That number only marginally increased to 76 - 77 in the next two decades 1971-1980 and 1981-

Table 2.13. The frequencies of some weather patterns in recent decades

Decade	Cold fronts crossing the North	Tropical cyclones in the East Sea	Tropical cyclones affecting Viet Nam	The annual average number of drizzly days in Ha Noi
1961-1970	268	114	74	29.7
1971-1980	288	113	77	35.8
1981-1990	287	109	76	28.7
1991-2000	249	103	68	14.5

Source: Institute of Meteorology, Hydrology and Environment

1990. In the decade 1991 - 2000, the number of tropical cyclones decreased significantly to only 68.

The trend equation of tropical cyclones affecting Viet Nam is formulated as:

Yx = 8.0 – 0.0303x

In fact, the decreasing trend has begun since the decade of 1971 - 1980 and is most obvious in recent years.

The number of drizzly days in Ha Noi:

The annual average number of drizzly days in Ha Noi was 29.7 in the decade 1961-1970, increasing to 35.8 in the decade 1971-1980, then gradually decreasing in the decade 1981-1990 and reaching 14.5 days/year in the last 10 years.

The trend equation for the annual number of drizzly days in Ha Noi is formulated as:

Yx = 37.6 – 0.51x

The decreasing trend begun at the end of the decade 1971 - 1980 and has been sustained until more recent years.

The trend of change in temperature

The annual average temperature

In Ha Noi, the annual average temperature in the decade 1931-1940 was 23.3^{0}C, the lowest in the 70-year history of temperature observation. In the decade 1941-1950, the value of this indicator increased to 23.6^{0}C. The temperature slightly decreased in the next 3 decades. In the decade 1981-1990, the annual average temperature recovered to 23.6^{0}C and reached 24.1^{0}C in the decade 1991 – 2000 (Table 2.2).

Yx = 23.4 + 0.006x

Similar to Ha Noi, in Da Nang, the average temperature in the decade 1931-1940 was 25.4^{0}C, the lowest in the 70-year history of temperature observation. Since then, the temperature has gradually increased, reaching a peak of 26.0 ^{0}C in the decade 1961 - 1970. In the decade 1971 - 1980, the value decreased to 25.8^{0}C and has remained intact in the recent 3 decades.

The trend equation for the annual average temperature in Da Nang is formulated as:

Yx = 25.5 + 0.0056x

In Tan Son Nhat, the decadal average temperature stayed at 26.9-27.0^{0}C, during the period from 1931 to 1960. This value has consistently increased since then to 27.2^{0}C in the decade 1971-1980; 27.3^{0}C in the decade 1981-1990 and 27.6^{0}C in the decade 1991-2000.

The trend equation of the annual average temperature in Tan Son Nhat is formulated as:

Yx = 26.8 + 0.0130x

Therefore, the trend for the annual average temperature in the last 7 decades is observed to be increasing. This trend is quite obvious and consistent in Tan Son Nhat and Ha Noi, while not as obvious in Da Nang.

The average temperature in January

In Ha Noi, the average temperature in January in the decade 1931-1940 was 15.9^{0}C, the lowest in the 70-year history of temperature observation. This value suddenly increased in the decade 1941-1950, which made it the decade with the highest January temperature. Since then, the January temperature has gradually decreased, staying at only 16.5^{0}C in the decade 1971-1980. Since the decade 1981-1990, the temperature has increased until the end of the decade 1991-2000.

The trend equation for the January average temperature in Ha Noi is formulated as:

Yx = 16.5 + 0.003x

In Da Nang, the January average temperature in the decade 1931-1940 was 21.1^{0}C, the lowest among decades with temperature observation. After that, the temperature gradually increased until the end of the decade 1961-1970. The January average temperature gradually decreased in the next two decades (1971-1980 and 1981-1990) before increasing sharply in the decade 1991-2000.

The trend equation for the January average temperature in Da Nang is formulated as:

$Yx = 21.2 + 0.0067x$

In Tan Son Nhat, the January average temperature during the three decades 1931-1940, 1941-1950, and 1951-1960, stayed at 25.8^{0}C before slightly decreasing in the decade 1961-1970. The January average temperature increased during the next two decades from 1971 to 1990 before sharply increasing in the decade 1991-2000, especially in 1998.

The trend equation for the January average temperature in Tan Son Nhat is formulated as:

$Yx = 25.6 + 0.0095x$

Therefore, in the above 3 areas, the trend of the January average temperature is not obvious. This is because, the January average temperature has just begun to increase in the last 10 - 20 years.

The average temperature in July

In Ha Noi, the July average temperature was 28.6^{0}C in the decade 1931-1940, increasing to 28.8^{0}C in two decades 1941-1950 and 1951-1960, reaching 29.2^{0}C in the decade 1961-1970, before slightly decreasing in the decade 1971-1980. In the decade 1981-1990, the value of this indicator increased to 29.3^{0}C. The final decade of the last century, 1991-2000, had the highest July average temperature out of 7 decades, with temperature records touching 29.4^{0}C.

The trend equation for the July average temperature in Ha Noi is formulated as:

$Yx = 28.6 + 0.0099x$

In Da Nang, the July average temperature was 28.7^{0}C in the decade 1931-1940, increasing to 28.9^{0}C in the decade 1941-1950, 29.2^{0}C in the decade 1951-1960, and reaching 29.5^{0}C in the two decades from 1961 to 1980. In the decade 1981-1990, the July average temperature decreased to just 29.1^{0}C, before increasing again to 29.2^{0}C in the decade 1991-2000.

The trend equation for the July average temperature in Da Nang is formulated as:

$Yx = 28.9 + 0.0066\ x$

In Tan Son Nhat, the July average temperature was 26.8^{0}C in the two decades 1931-1940 and 1941-1950, reaching 27.2^{0}C in the decade 1951-1960 and 27.4^{0}C in the decade 1961-1970, and since remaining stable until the end of the 20th century.

The trend equation for the July average temperature in Tan Son Nhat is formulated as:

$Yx = 26.7 + 0.0142x$

Therefore, the increasing trend of the July temperature in Ha Noi and Tan Son Nhat is quite obvious and consistent, while that in Da Nang is not consistent, due to the relatively high temperature foundation in Da Nang in the two decades from 1961 to 1980.

The trend of change in the rainfall

The trend of change in rainfall during 100 last years

In Ha Noi, the annual average rainfall was 1,521mm in the decade 1911-1920, the lowest in the 90-year chain of climate observation. In the decade 1921-1930, the annual average rainfall increased to 1,889 mm,

Table 2.14. The annual average temperature ($\overline{T}$ N), the January average temperature ($\overline{T}$ January) and the July average temperature ($\overline{T}$ July) in recent decades (^{0}C)

Decade	$\overline{T}$ N			$\overline{T}$ January			$\overline{T}$ July		
	Ha Noi	Da Nang	Tan Son Nhat	Ha Noi	Da Nang	Tan Son Nhat	Ha Noi	Da Nang	Tan Son Nhat
1931-1940	23.3	25.4	27.0	15.9	21.1	25.8	28.6	28.7	26.8
1941-1950	23.6	25.5	26.9	17.5	21.4	25.8	28.8	28.9	26.8
1951-1960	23.5	25.8	27.0	16.5	21.5	25.8	28.8	29.2	27.2
1961-1970	23.5	26.0	27.2	16.3	21.6	25.6	29.2	29.5	27.4
1971-1980	23.4	25.8	27.3	16.0	21.4	25.9	29.0	29.5	27.4
1981-1990	23.6	25.8	27.4	16.4	21.3	25.9	29.3	29.1	27.4
1991-2000	24.1	25.8	27.6	17.0	21.7	26.3	29.4	29.2	27.4

Source: Climatology and Climatic Resources in Viet Nam

Table 2.15. Temperature Trends during the period of 1957-2007

Climate Zone	Weather station	Survey period	Increase (^{0}C/year)
North West	Dien Bien	1958 – 2007	0.0232
	Moc Chau	1961 – 2007	0.0121
North East	Sa Pa	1958 – 2007	0.0037
	Ha Giang	1960 – 2007	0.0176
	Bac Quang	1961 – 2007	0.0160
North Delta	Phu Lien	1958 – 2007	0.0111
	Bach Long Vi	1958 – 2007	0.0106
	Ninh Binh	1960 – 2007	0.119
North Central	Vinh	1958 – 2007	0.0167
	Tuong Duong	1961 – 2007	0.0177
	Ba To	1980 – 2007	0.0110
South Central	Quy Nhon	1958 – 2007	0.0150
	Nha Trang	1958 – 2007	0.0090
Central Highlands	Buon Ma Thuot	1958 – 2007	0.0148
	Da Lat	1964 – 2007	0.0047
South	Can Tho	1958 – 2007	0.0054
	Rach Gia	1957 – 2007	0.0045

Source: Institute of Meteorology, Hydrology and Environment

before decreasing to 1,691 mm in the decade 931-1940. With an annual average rainfall of 1,845 mm, 1941-1950 is considered the decade with the highest rainfall.

The two decades of 1951-1960 and 1961-1970 had relatively low rainfall. The rainfall marginally increased in the decade 1971-1980, then decreased continuously in the two most recent decades, 1981-1990 and 1991-2000.

The trend equation for the annual rainfall in Ha Noi is formulated as:

$$Yx = 1644.8 + 0.3391x$$

In Da Nang, the annual average rainfall was 1,919 mm in the decade 1931-1940, the lowest in the 7 decades of available observational records. After that, the rainfall increased to 2,223 mm in the decade 1941-1950 before decreasing to 1970 mm in the decade of 1951-1960. The two decades 1961-1970 and 1971-1980 had relatively high rainfall of 2,095 mm and 2,019 mm, respectively. The rainfall decreased remarkably in the decade of 1981-1990, before sharply increasing to 2,434 mm in the decade of 1991-2000.

The trend equation for the annual rainfall in Da Nang is formulated as:

$$Yx = 1930.7+ 1.0261x$$

In Tan Son Nhat, the annual average rainfall was 1,829 mm in the decade 1911-1920, reaching 2,063 mm in the decade 1921-1930. This is the decade with the highest rainfall in the 90-year chain of observation in Tan Son Nhat.

The two decades 1941-1950 and 1951-1960 had medium-level rainfall of 1,924 and 1,926 mm, respectively. In the decade of 1951-1960, the average rainfall was 1,805 mm, the lowest in the 9 most recent decades.

The decade 1961-1970 had relatively high rainfall of 2,005 mm. Since then, the rainfall has decreased, with this trend being sustained during the last 3 decades.

The trend equation for the annual rainfall in Tan Son Nhat is formulated as:

$$Yx = 1793.6 - 4.674x$$

It shows that the average rainfall in Tan Son Nhat has increased to 2.1373 mm per year over the past 50 years.

In each area, the trend of change in the rainfall during the last 9 decades is inconsistent: increasing in certain periods and decreasing in other periods. Across Viet Nam's territory, the trend of change of the rainfall also greatly varies among the different regions (Table 2.16).

The trend of change in rainfall during 50 last years

In last 50 years, the increasing trend and the decreasing trend of rainfall did not have a close relationship with the time. However, if we only consider the average level of increase and decrease during the survey period, we can see the North Region rainfall trend decreasing and the one of South Region increasing in last 50 years (Table 2.17)

The average increasing or decreasing level for the last 50 years is often below 10 mm/year.

Specifically, at some rainiest weather stations in Viet Nam (e.g., Nam Dong, Ba To), the

Table 2.16. The annual average rainfall in recent decades (mm)

Decade	Ha Noi	Da Nang	Tan Son Nhat
1911-1920	1,521		1,829
1921-1930	1,789		2,063
1931-1940	1,691	1,919	1,924
1941-1950	1,845	2,223	1,926
1951-1960	1,622	1,970	1,805
1961-1970	1,557	2,095	2,005
1971-1980	1,788	2,019	1,828
1981-1990	1,697	1,962	1,813
1991-2000	1,590	2,434	1,850

Source: Institute of Meteorology, Hydrology and Environment

level of increase in rainfall in the last 30 years (1978-2007) attains 10 mm/year.

The trend of change in sea level

The trend equation of sea level at Hon Dau station (it is typical of the North Region coast for period 1965-2006) is formulated as:

Yx=185.6 + 0.205x

It shows that the average sea level has increased by 0.20 cm per year at Hon Dau station.

The trend equation of sea level at Son Tra (it is typical of the mid-region coast for the period 1978-2006) is formulated as:

Yx=90.1+0.260x

It shows that the average sea level has increased by 0.260 cm per year at Son Tra station.

The trend equation of sea level at Vung Tau station (it is typical for the South Region coast for the period 1981-2006) is formulated as:

Yx=257.2 + 0.398x

It shows that the average sea level has increased by 0.398 cm per year at Vung Tau station.

The temperature and rainfall changes in periods of time at selected key weather stations, which have been observed for many years, are illustrated in the figures below.

Table 2.17. The increasing or decreasing level of rainfall for period 1957-2007

Climate Zone	Weather station	Survey time	Increasing level (mm/year)	Decreasing level (mm/year)
North West	Lai Chau	1957 - 2007		0.262
	Son La	1961 - 2007		1.979
	Moc Chau	1961 - 2007		2.967
North East	Sa Pa	1958 - 2007		6.013
	Ha Giang	1958 - 2007		3.854
	Bac Giang	1959 - 2007	0.587	
North Delta	Ha Noi	1961 - 2007		1.893
	Bach Long Vi	1960 - 2007		1.567
	Ninh Binh	1959 - 2007		5.464
North Central	Tuong Duong	1961 - 2007		1.810
	Dong Ha	1974 - 2007		12.325
	Nam Dong	1977 - 2007	43.402	
South Central	Ba To	1980 - 2007	29.624	
	Nha Trang	1961 - 2007	6.454	
	Phan Thiet	1958 - 2007		0.079
Central Highlands	Pleicu	1960 - 2007	0.832	
	Buon Me Thuot	1960 - 2007	7.258	
	Dac Nong	1978 - 2007	20.473	
	Da Lat	1954 - 2007	1.038	
South	Vung Tau	1954 - 2007	0.531	
	Can Tho	1961 - 2007	6.935	
	Rach Gia	1958 - 2007	6.909	
	Ca Mau	1958 - 2007	2.600	
	Con Dao	1957 - 2007		0.649

Source: Institute of Meteorology, Hydrology and Environment

Figure 2.4.1. Multi year oscillogram and the trend of annual average air temperature - Ha Noi station

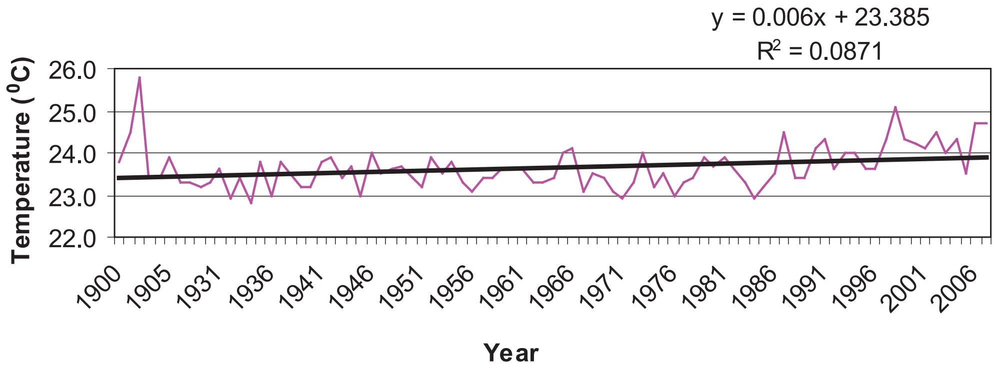


Figure 2.4.2. Multi year oscillogram and the trend of annual average temperature - Da Nang station

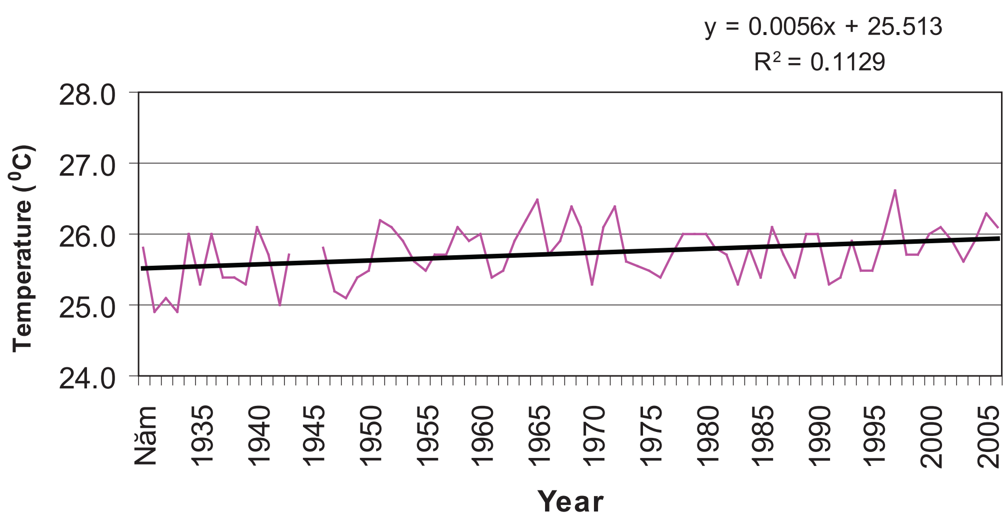


Figure 2.4.3. Multi year oscillogram and the trend of annual average air temperature - Tan Son Nhat station

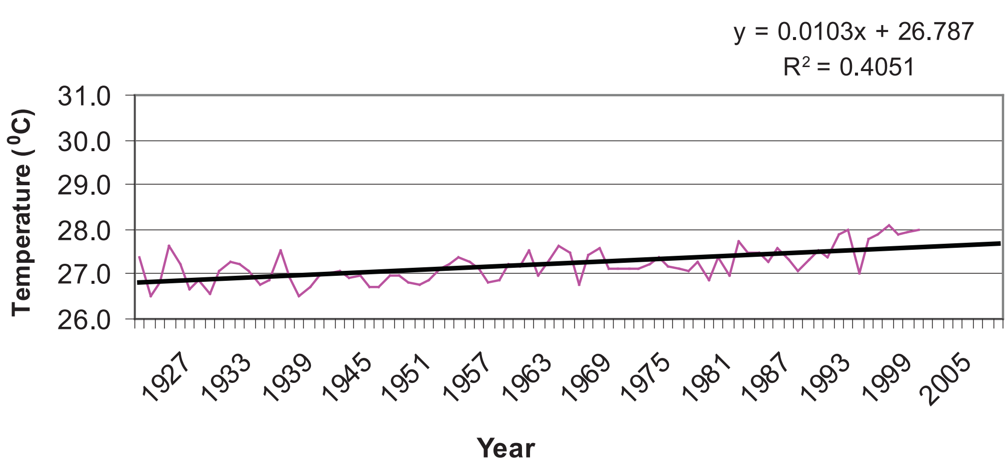


Figure 2.4.4. Multi year oscillogram and the trend of January average air temperature - Ha Noi station

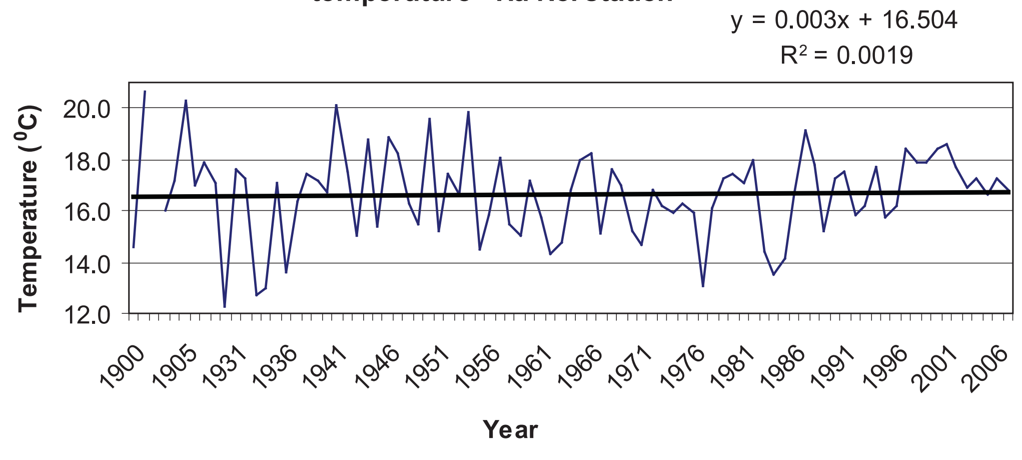


Figure 2.4.5. Multi year oscillogram and the trend of January average temperature - Da Nang station

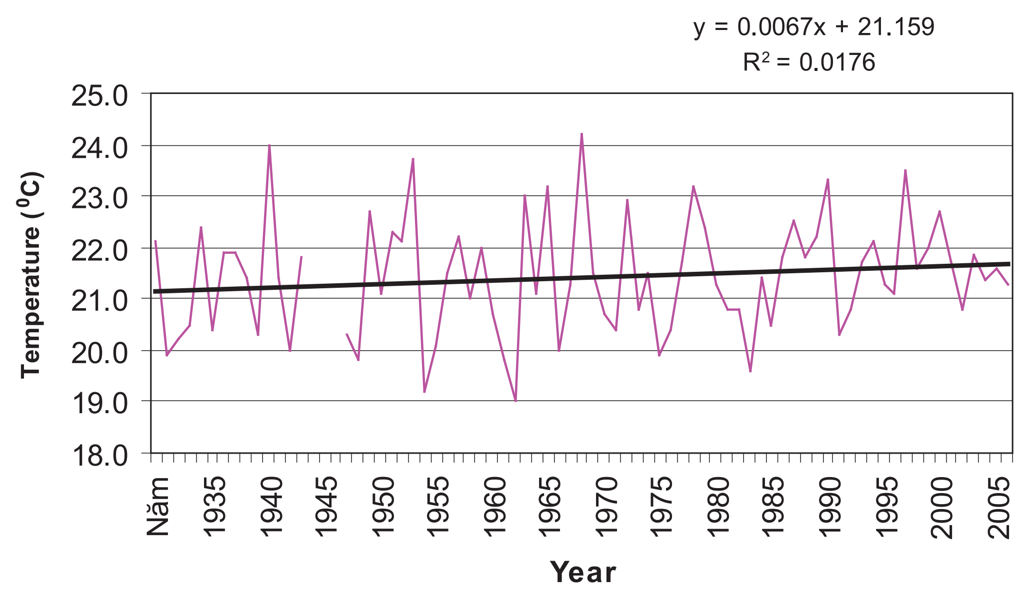


Figure 2.4.6. Multi year oscillogram and the trend of January average air temperature - Tan Son Nhat station

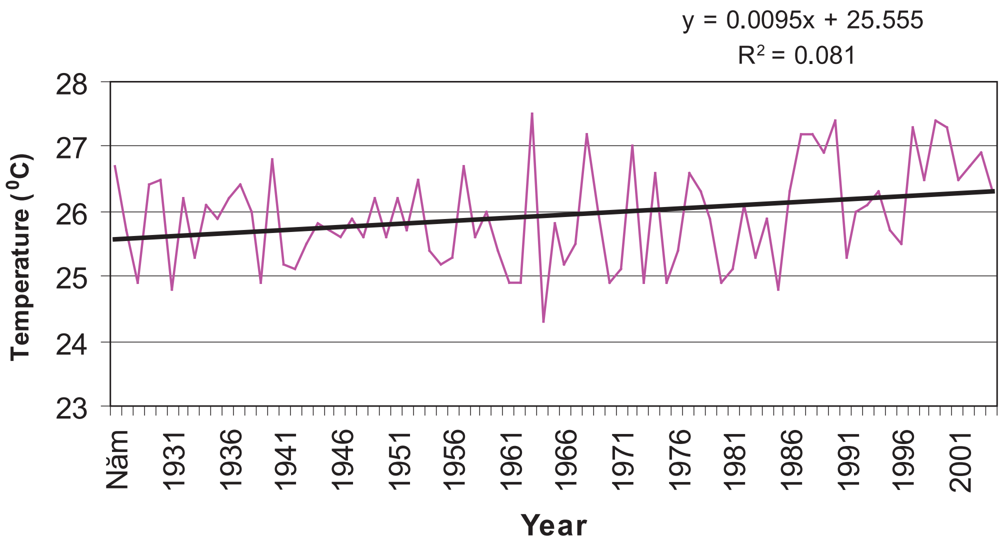


Figure 2.4.7. Multi year oscillogram and the trend of July average air temperature - Ha Noi station

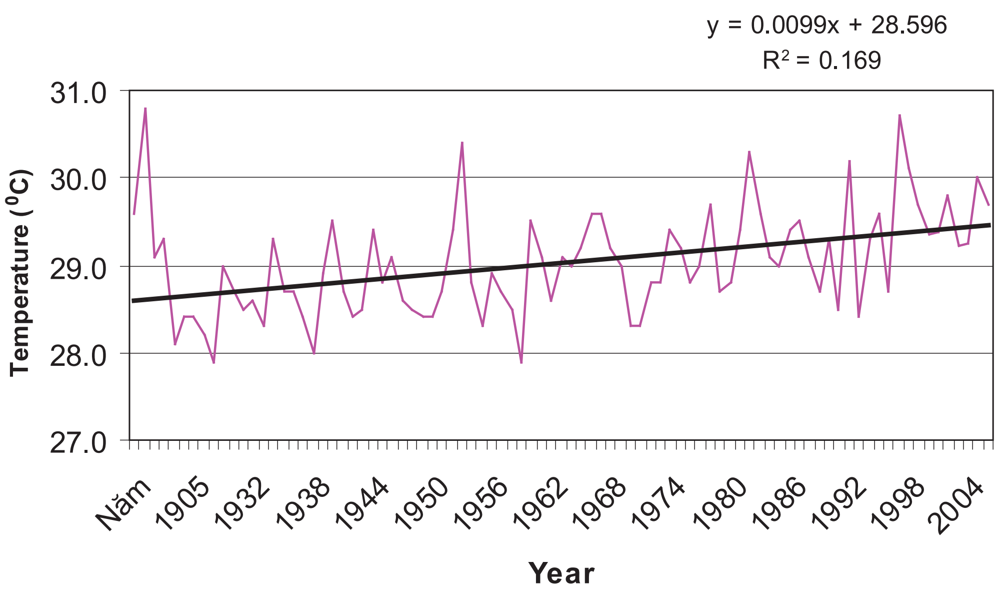


Figure 2.4.8. Multi year oscillogram and the trend of July average temperature - Da Nang station

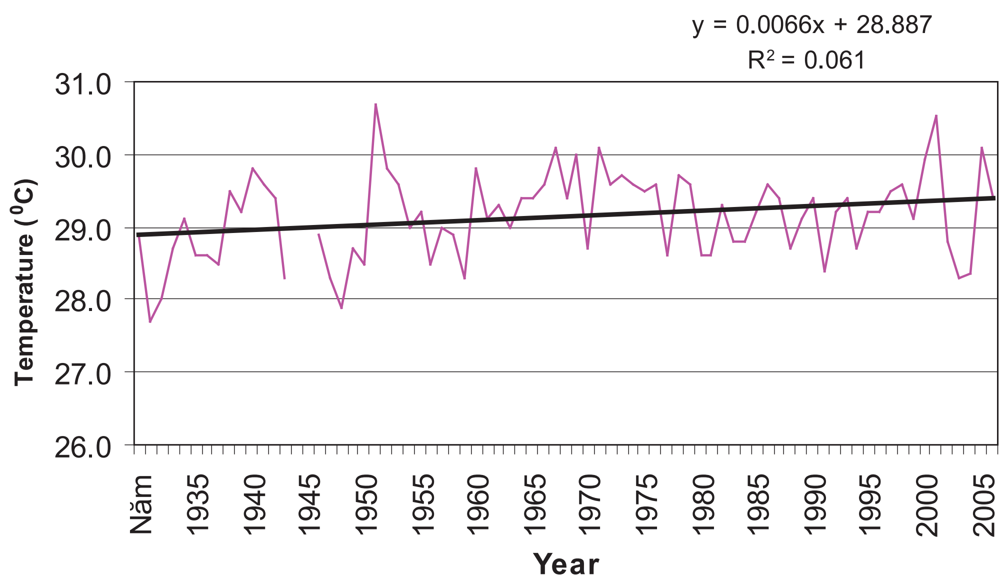


Figure 2.4.9. Multi year oscillogram and the trend of July average air temperature - Tan Son Nhat station

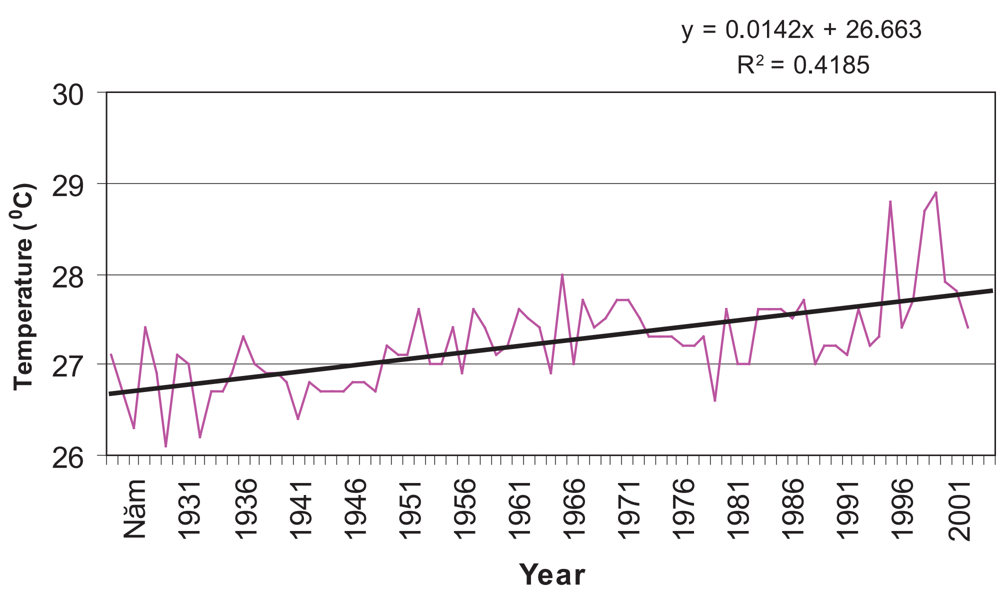


Figure 2.4.10. Multi year oscillogram and the trend of annual rainfall - Ha Noi station

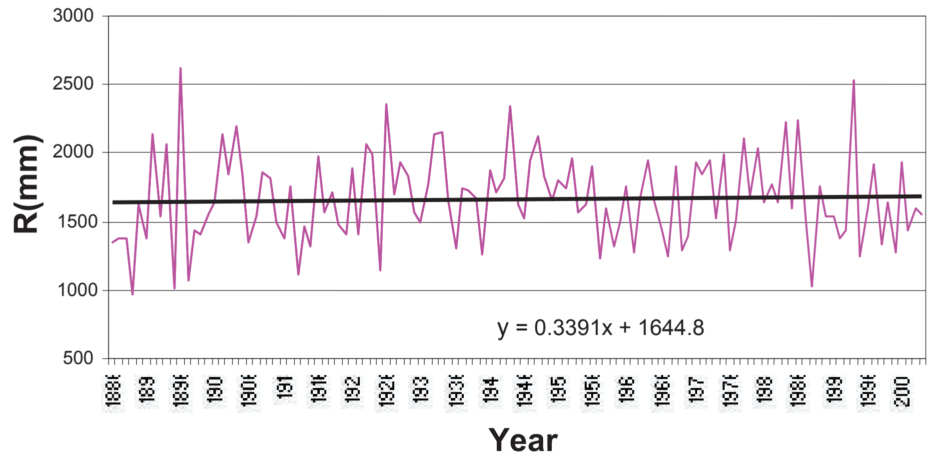


Figure 2.4.11. Multi year oscillogram and the trend of annual rainfall - Ha Noi station

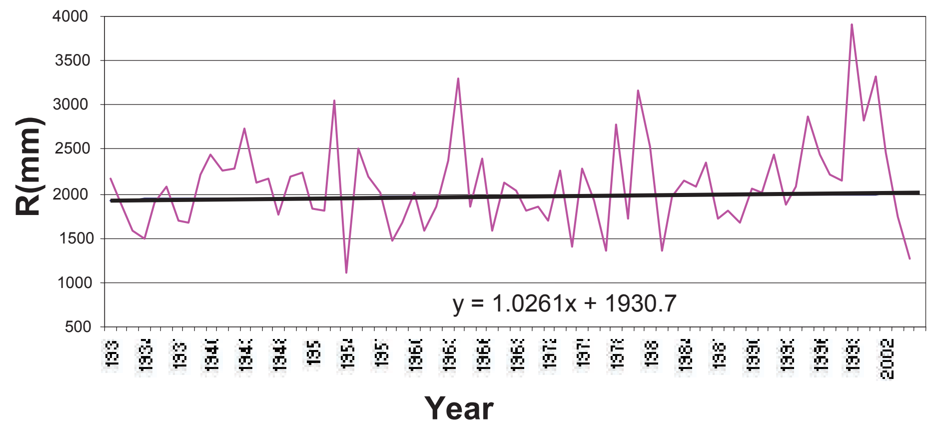
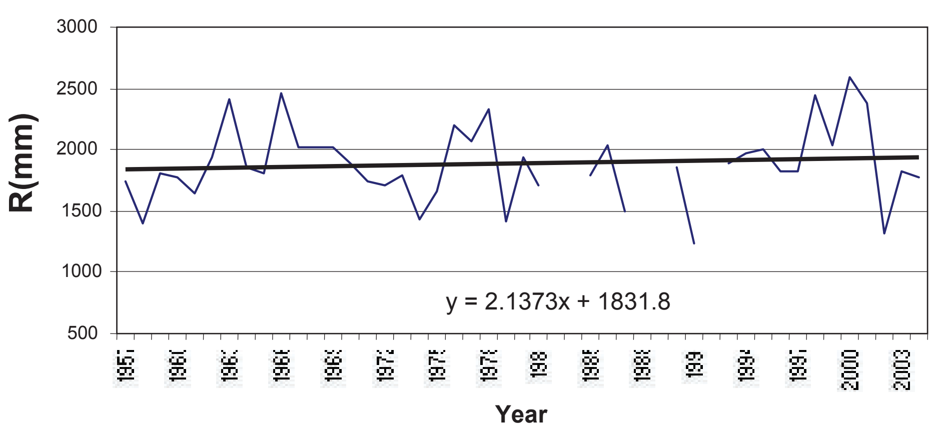


Figure 2.4.12. Multi year oscillogram and the trend of annual rainfall - Ha Noi station



2.3 Climate change scenarios in Viet Nam

2.3.1 Scenarios in 1994

In 1994, based on the climate change scenario of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), the experts who participated in the project "Climate Change in Asia" developed the first climate change scenario for Viet Nam, called as climate change in 1994 (Table 2.18)

According to this scenario, Viet Nam was projected to have the following changes with respect to the period 1980-1999:

- Temperature will increase from 1.2^{0}C – 4.5^{0}C in the North and 0.5^{0}C – 3.0^{0}C in the South,
- Rainfall will increase from 0 – 10% in rainy season and increase or decrease by 10% in dry seasons in the Southwest (SW) monsoon (North, Central Highlands, South),
- Rainfall will reduce by 5% or increase by 10% in rainy season and increase by 10% during dry season in the Northeast (NE) monsoon (North Central, South Central),
- Sea level will rise within the range 15 – 90 mm.
- In general, the increased temperature and sea level rise projections in the 1994 scenario are in line the overall scenario for Southeast Asia, reflecting the warming potential in the North and the South, and providing a detailed overview of impacts from global warming with different circulation stages.

2.3.2 Scenarios in 1998

Target and contents of climate change scenarios research

Similar to other countries in the region, climate change scenarios in Viet Nam were developed for 3 main climatic elements: temperature, rainfall and sea level, and the time slice milestones were 2010s, 2050s and 2070s.

The main issues relevant to the contents of these projections of climate change scenarios are as follow:

- Characteristics and variability of different parameters of climate change projections,
- Climate change trends in the time span considered,

Table 2.18. Climate change scenarios for 2070

Areas	The increasing level of temperature (^{0}C)	Rainfall increase (+) or decrease (%)		Sea level rise
North West	1.2 – 4.5	+ 0-1.0	-10-+10	
North East	1.2 – 4.5	+ 0-1.0	-10-+10	15- 90
North Delta	1.2 – 4.5	+ 0-1.0	-10-+10	15- 90
North Central	1.2 – 4.5	-5-+10	+ 0-10	15- 90
South Central	0.5 – 3.0	-5-+10	+ 0-10	15- 90
Central Highlands	0.5 – 3.0	+ 0-1.0	-10-+10	-
South	0.5 – 3.0	+ 0-1.0	-10-+10	15- 90

Source: ADB, Climate Change in Asia

- Possibility for application of climate change scenarios proposed by CSIRO.

Selection of climate change scenarios

According to the "Manual on Methodology for Climate Change Assessment and Coping Strategy", the selected contents of climate change have to meet the following requirements:

Requirement 1: Climate change scenarios have to be in the framework of global warming theory and scenarios.

The projections are based on the fact that if the CO_2 concentration in the atmosphere doubles, the increase in global mean surface air temperature is likely to be 1.5 – 3.5^{0}C (Houghton, 1996) or 1.5 – 4.5^{0}C (IPCC, 2001)

It can be recognized that some scenarios are not in the above range. However, those estimations are drawn out from climate change theoretical context.

Requirement 2: The scenarios should be reliable in term of physical methodology. It means that the simulations should not contradict with physical law.

Requirement 3: The simulations have to select sufficient parameters both in time and space, which can be applied for the assessment of climate change assessment impacts for national economy sectors.

Requirement 4: The simulation reflects the scope of climate change in the future for research purposes.

Characteristics of climate relating to climate change scenarios

The following characteristics of climate change should be considered when selecting climate change simulations:

1. Change in temperature, rainfall is likely to be significant in term of numeric value, as well as the starting time, peak time and ending time of seasons but not large enough to change the season rules of each region.
2. Change in climatic elements is significant. However the general trend of change from one year to another is likely to be small

   For temperature, the change rate is likely to be 0.005 – 0.0015^{0}C/year for monthly average temperature and 0.001 – 0.010/ year for annual average temperature.

   For rainfall, the change rate is likely to be 0.1 – 2.0 mm/year for monthly rainfall in the rainy reason and 0.5 – 5.0 mm/ year for yearly rainfall.
3. For each parameter, the climate change trend in different regions or areas is not likely to be identical.

   In addition, the trend of one parameter at one station in different months of the same years is likely to be probably different.

Recommendations for the selection of climate change scenarios in Viet Nam

The inconsistent and unclear change of temperature and/or rainfall in the past 100 year and sea level in Cua Ong and Hon Dau in three past decades do not provide the reliable foundation to develop a climate change simulation system in Viet Nam. However, the specific characteristics of different regions in term of temperature and rainfall, are still fully reflected in climate observations. Therefore, it is necessary to apply CSIRO simulations independently for different regions (coastal or inland) and monsoon systems causing rain (Northeast or Southeast).

For downscaling regional scenarios from temperature scenarios in Viet Nam, they should be divided into the following groups:

Coastal group: North Delta, North Central Coast, Central, South Central and the South.

Inland group: North West, North East and the Central Highlands.

Southwest monsoon group: North West, North East, North Delta, Central Highland, Southern most part of South Central and the South.

Northeast monsoon group: North Central and the Northern most part of South Central.

The scenarios on temperature, rainfall and sea level rise in different areas of Viet Nam show that the fluctuations in rainfall do not significantly change, but the magnitude of increase in temperature is lower compared with the 1994 scenario. The 1998 scenario also reflects impacts of climate change with temperature systems in different latitude regions and rainfall areas, as mentioned in the 1994 scenario.

2.3.3 Scenarios in 2009

In 2009, in order to implement the National Target Program in Response to Climate Change, experts of Institute of Meteorology, Hydrology and Environment have developed the Climate Change scenario as the guidelive for Ministries, sectors and provinces to

Table 2.19. Climate change projections according to 1998 scenario

Factors	Region		Year 2010	Year 2050	Year 2070
Temperature is increasing (°C)	North West, North East		0.5	1.0	2.5
	North Delta		0.3	1.1	1.5
	North Central		0.3	1.1	1.5
	Middle of Central		0.3	1.1	1.5
	South Central		0.3	1.1	1.5
	Central Highlands		0.5	1.8	2.5
	South		0.3	1.1	1.5
Rainfall amount is increasing (+) or decreasing (-) (%)	North West, North East	Rainy	0	0-+5	0-+5
		Dry	0	-5-+5	-5-+5
	North Delta	Rainy	0	0-+5	0-+5
		Dry	0	-5-+5	-5-+5
	North Central	Rainy	0	0-+10	0-+10
		Dry	0	0-+5	0-+5
	Middle of Central	Rainy	0	0-+10	0-+10
		Dry	0	0-+5	0-+5
	Northern part of South Central	Rainy	0	0-+10	0-+10
		Dry	0	0-+5	0-+5
	Central Highlands	Rainy	0	0-+5	0-+5
		Dry	0	-5-+5	-5-+5
	South and Southern most part of South Central	Rainy	0	0-+5	0-+5
		Dry	0	-5-+5	-5-+5
	South	Rainy	0	0-+5	0-+5
		Dry	0	-5-+5	-5-+5
Sea level rise (cm)	All coastal line	-	9	33	45

Source: Viet Nam Initial National Communication, 2003

develop action plans on Response to Climate Change. The scenario has been officially published by Ministry of Natural Resources and Environment in June 2009.

Through the application of Statistical Downscaling methods and MAGICC/SCENGEN tools using the model simulations referred to in IPCC AR4, the authors identified the average annual increase in temperature, changes of rainfall and sea level rise for each decade in the 21st century.

The Scenarios are divided in 3 groups according to IPCC emissions scenarios, including:

- High emissions group: A1FI, A2
- Medium emissions group: A1B, B2
- Low emissions group: A1T, B1

Similar to the 1994 and 1998 scenarios, the target areas are the 7 main climate areas of Viet Nam: North West, North East, North Delta, North Central, South Central, Central Highland and the South.

Except for the A1FI emission scenario referred to in IPCC's AR4, other emissions scenarios in the SRES family show that the estimated temperature projections are not that much different from the climate change scenarios projected in 1998. The temperature in all regions in the years centered around 2050, 2070, and 2100, are projected to increase by 1.3 – 1.6^{0}C, 1.6 – 1.9^{0}C and 1.9 – 2.2^{0}C, respectively compared with the period 1980-1999.

In addition, the A1FI emissions scenario referred to in the IPCC's AR4 also suggests that the rainfall amount is likely to increase during rainy season in coastal zones of the Central and South areas of Viet Nam.

Compared with climate change scenarios developed in 1994 and 1998, the scenarios developed in 2007 present the estimated results for each decade, but do not

Table 2.20. Projections of average increase in temperature (^{0}C) in different decades compared with the period of 1980-1999

Region	Scenario	Annual average temperature			Average temperature Dec. – Feb.			Average temperature Jun. – Aug.		
		2050	2070	2100	2050	2070	2100	2050	2070	2100
North West	A1FI	1.7	2.9	4.2	1.9	3.2	4.6	1.4	2.6	3.8
	B1	1.6	1.9	2.2	1.6	1.9	2.3	1.4	3.1	2.3
North East	A1FI	1.7	2.8	4.5	1.9	3.1	4.6	1.8	1.8	4.6
	B1	1.6	1.9	2.2	1.6	1.9	2.3	1.4	2.7	1.3
North Delta	A1FI	1.6	2.8	4.1	1.9	3.1	4.6	1.6	1.7	4.0
	B1	1.4	1.8	2.1	1.6	1.9	2.3	1.3	1.6	2.1
North Central	A1FI	1.6	2.6	3.7	1.5	2.6	3.9	1.5	2.7	3.9
	B1	1.3	1.6	2.0	1.4	1.7	2.0	1.3	1.7	1.9
South Central	A1F1	1.6	2.7	3.9	1.3	2.5	3.6	1.6	2.7	3.9
	B1	1.4	1.7	2.1	1.3	1.7	1.9	1.4	1.7	2.1
Central Highlands	A1FI	1.7	2.8	4.0	1.4	2.7	3.8	1.6	2.7	4.4
	B1	1.5	1.8	2.1	1.4	1.6	1.9	1.4	1.7	2.1
South	A1FI	1.6	2.6	3.7	1.3	2.4	3.4	1.6	2.7	3.9
		1.4	1.6	1.9	1.2	1.5	1.8	1.4	1.7	2.0

Source: Nguyen Van Thang, Hoang Duc Cuong –Institute of Meteorology,Hydrology and Environment

Table 2.21. Projections of change in rainfall rate (%) in different decades compared with the period of 1980-1999

Region	Scenario	Annual average temperature			Average winter temperature Dec. – Feb.			Average summer temperature Jun. – Aug.		
		2050	2070	2100	2050	2070	2100	2050	2070	2100
North West	A1FI	6.0	10.0	14.6	15.1	25.4	37.1	5.1	8.6	12.6
	B1	5.1	6.4	7.2	13.0	16.1	18.4	4.4	5.5	6.2
North East	A1FI	3.8	6.4	9.3	5.3	8.9	13.1	1.5	2.5	3.7
	B1	3.2	4.0	4.6	4.6	5.7	11.5	1.3	1.6	1.9
North Delta	A1FI	4.6	7.7	11.2	3.1	5.2	7.6	3.8	7.4	9.2
	B1	3.9	4.9	5.6	2.7	3.3	3.8	3.2	4.0	4.6
North Central	A1FI	4.2	7.1	10.3	5.6	9.4	13.8	7.6	12.8	18.8
	B1	3.6	4.5	5.2	4.9	6.0	6.8	6.6	8.2	9.3
South Central	A1FI	2.7	4.6	6.7	3.5	5.9	8.7	12.3	20.7	30.3
	B1	2.3	2.9	3.5	3.1	3.8	4.3	10.6	13.2	15.1
Central Highlands	A1FI	2.8	4.7	6.9	-2.5	-3.6	-6.2	3.3	5.5	8.1
	B1	2.4	3.0	3.5	-2.2	-2.7	-3.1	2.9	3.5	4.0
South	A1FI	1.2	2.0	3.0	-4.8	-8.2	-11.9	0.3	0.5	0.8
	B1	1.0	1.3	1.6	-4.2	-5.2	-5.9	0.4	0.6	0.9

Source: Nguyen Van Thang, Hoang Duc Cuong –Institute of Meteorology, Hydrology and Environment

Table 2.22. Projected sea level rise scenarios (mm) compared the period 1980-1999

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1FI	3.0	4.8	7.1	10.0	13.7	18.2	23.2	28.6	34.1	39.7
B1	3.1	5.2	7.7	10.5	13.4	16.3	19.2	21.9	24.6	26.9

Source: Nguyen Van Thang, Hoang Duc Cuong –Institute of Meteorology, Hydrology and Environment

systematically reflect the temperature estimation for the mountainous and plain areas of Viet Nam.

In June 2009, the Ministry of Natural Resources and Environment promulgated the official text of "Climate Change, Sea Level Rise Scenarios for Viet Nam". These updated climate change scenarios for Viet Nam are presented as under:

Temperature

In the low emission scenario, annual mean temperatures in 2020, 2050, 2070 and 2100 are projected to increase by 0.3 to 0.6^{0}C, 0.8 to 1.4^{0}C, 1.0 to 1.7^{0}C and 1.1 to 1.9^{0}C respectively, relative to the baseline period (1980 – 1999).

In the medium emission scenario, annual mean temperatures in 2020, 2050, 2070 and 2100 are projected to increase by 0.3 to 0.5^{0}C, 0.8 to 1.5^{0}C, 1.2 to 2.1^{0}C and 1.6 to 2.8^{0}C respectively, relative to the baseline period (1980 – 1999).

In the high emission scenario, annual mean temperatures in 2020, 2050, 2070 and 2100 are projected to increase by 0.3 – 0.6^{0}C, 0.8 –1.5^{0}C, 1.3 –2.2^{0}C and 2.1 –3.6^{0}C respectively, relative to the baseline period (1980 – 1999).

Generally, the increase in temperature is fairly high in Northern climate zones and fairly low in Southern climate zones.

Rainfall

In the low emission scenario, annual rainfall in 2020, 2050, 2070 and 2100 are projected to increase about 0.3 – 1.6%, 0.7 – 3.9%, 0.9 – 4.8% and 1.0 – 5.2%, respectively, relative to the baseline period (1980 – 1999).

In the medium emission scenario, annual rainfall in 2020, 2050, 2070 and 2100 are projected to increase about 0.3 – 1.6%, 0.7 – 4.0%, 1.0 – 5.9% and 1.4 – 7.5%, respectively, relative to the baseline period (1980 – 1999).

In the high emission scenario, annual rainfall in 2020, 2050, 2070 and 2100 are projected to increase about 0.3 – 1.8%, 0.7 – 3.8%, 1.1 – 6.1% and 1.8 – 10.1%, respectively, relative to the baseline period (1980 – 1999).

The projected change in rainfall between Northern climate zones and Southern climate zones is more than the projected change in temperature.

Sea level rise

In the low emission scenario, sea level rise in 2020, 2050, 2070 and 2100 are projected to be about 11, 28, 42 and 65 cm, respectively.

In the medium emission scenario, sea level rise in 2020, 2050, 2070 and 2100 are projected to be about 12, 30, 46 and 75 cm, respectively.

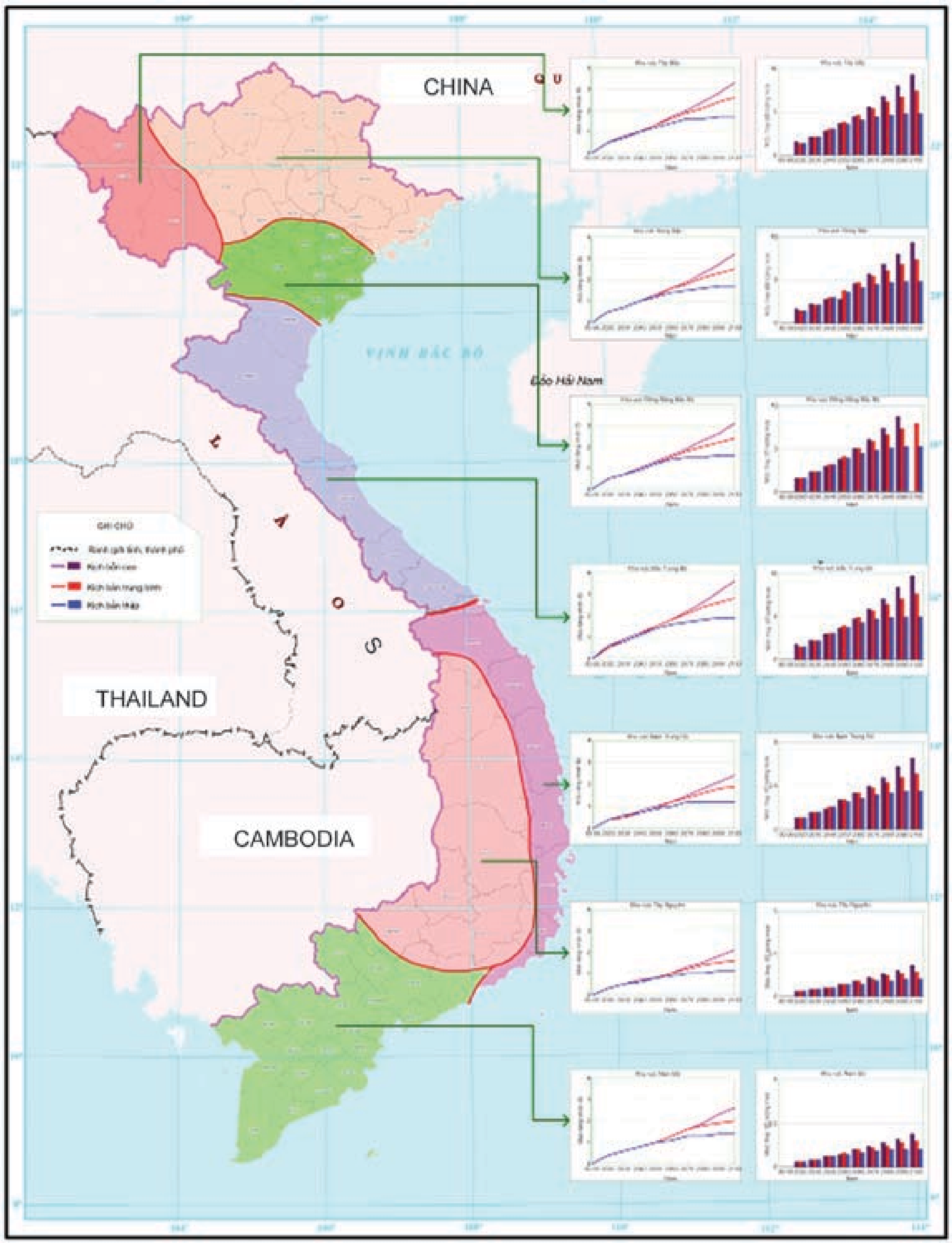
In the high emission scenario, sea level rise in 2020, 2050, 2070 and 2100 are projected to

Table 2.23: Climate change and sea level scenarios for Viet Nam

Parameters	Climate zones	2020			2050			2070			2100		
		Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
The increase in temperature (^0C)	North West	0.5	0.5	0.5	1.2	1.3	1.3	1.6	1.9	2.0	1.7	2.6	3.3
	North East	0.5	0.5	0.5	1.2	1.2	1.3	1.5	1.8	1.9	1.7	2.5	3.2
	North Delta	0.5	0.5	0.5	1.2	1.2	1.3	1.5	1.8	1.9	1.6	2.4	3.1
	North Central	0.6	0.6	0.6	1.4	1.5	1.5	1.7	2.1	2.2	1.9	2.8	3,6
	South Central	0.4	0.4	0.4	0.9	0.9	1.0	1.2	1.4	1.5	1.2	1.9	2,4
	Central Highlands	0.3	0.3	0.3	0.8	0.8	0.8	1.0	1.2	1.3	1.1	1.6	2.1
	South	0.4	0.4	0.4	1.0	1.0	1.0	1.3	1.6	1.6	1.4	2.0	2.6
The increase in rainfall (%)	North West	1.4	1.4	1.6	3.6	3.8	3.7	4.4	5.4	5.6	4.8	7.4	9.3
	North East	1.4	1.4	1.7	3.6	3.8	2.8	4.5	5.4	5.7	4.8	7.3	9.3
	North Delta	1.6	1.6	1.6	3.9	4.1	3.8	4.8	5.9	6.1	5.2	7.9	10.1
	North Central	1.5	1.5	1.8	3.8	4.0	3.7	4.7	5.7	5.9	5.0	7.7	9.7
	South Central	0.7	0.7	0.7	1.6	1.7	1.7	2.0	2.4	2.5	2.2	3.2	4.1
	Central Highlands	0.3	0.3	0.3	0.7	0.7	0.7	0.9	1.0	1.1	1.0	1.4	1.8
	South	0.3	0.3	0.3	0.7	0.8	0.7	0.9	1.1	1.2	1.0	1.5	1.9
Sea level rise (mm)	Total year	11	12	12	28	30	33	42	46	57	65	75	100

Source: Climate Change, Sea Level Rise Scenarios for Viet Nam, MONRE, 2009

Figure 2.5. Projected changes in mean annual temperature (^{0}C) and annual rainfall (%) of Viet Nam climate zones relative to the average for 1980 – 1999 according to low (B1), medium (B2) and high (A2) emission scenarios



Source: Climate Change, Sea Level Rise Scenarios for Viet Nam, MONRE, 2009 be about 12, 33, 57 and 100 cm, respectively.

Generally, the projection on sea level rise for Viet Nam in the next decade is much higher than the projection of the IPCC.

2.4 Conclusions

1. Viet Nam has the typical tropical climate of a peninsula in the South East of the Europe-Asia continent, prolonged on multiple latitudes, deeply affected by the East Sea, sunny weather, high temperatures, the rainy season, and suffers from many weather calamities like hoarfrost, frosty winters, typhoons, floods and drought and therefore, is likely to suffer considerably from climate change.
2. In the territory of Viet Nam, there are 7 different climate regions in term of temperature, rainfall, intensity and frequency of coldness, tropical cyclone, floods, and drought. Therefore, the magnitude of regional climate change is expected to be different for 7 regions.
3. In the last 100 years, the standard deviation of the change in each climate parameter is very high compared with the trend of those parameters suggesting thereby that intra seasonal and inter annual variability has increased.
4. The trends of some important parameters recorded in the last 50 years include:
   - The temperature is rising by 0.05 – 0.20^{0}C for each decade, from the South to the North, from plains to mountainous area.
   - The rainfall in the North has largely increased, while decreases in the South have been observed with respect to the normal, at a trend of below 16 mm per year.
   - The cold front frequency has decreased from 0.49 events per decade.
   - Tropical cyclone frequency that affects Viet Nam has increased by 0.43 event per decade.
   - The sea level has risen at a rate of 2-4cm per decade.
5. It is projected that by the end of 21st century, in comparison with the period 1980-1999, the annual mean temperature in Viet Nam will increase by 1.1-1.9^{0}C and 2.1-3.6^{0}C in low and high emissions scenarios respectively, the rainfall increase is likely to be 1.0-5.2% and 1.8-10.1% in low and high emissions scenarios respectively, and the sea level rise is likely to be in the range of 65 - 100cm.

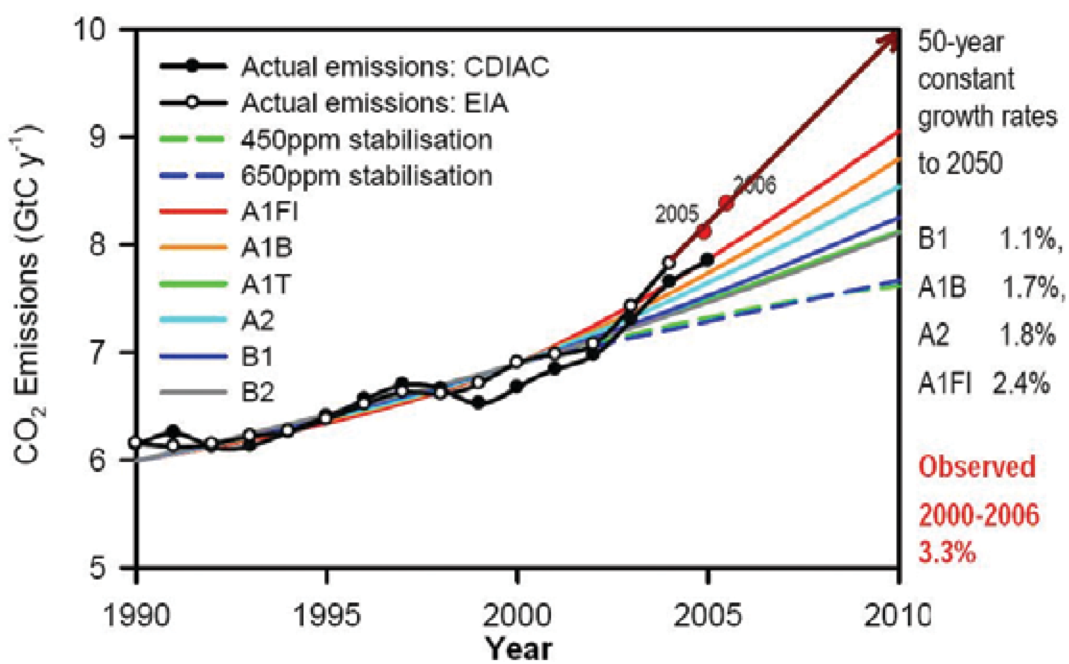
Chapter 3

Climate change impacts and strategy, options to cope with climate change in Viet Nam

3.1 Impacts of climate change in Viet Nam

The climate change scenario projections included in the previous chapter are based on the premise that the future GHG emissions pathways for the world would be within the range determined by the lowest emission B1 and the highest emission A1FI pathways, as outlined in SRES in 2001. However, since the adoption of SRES in simulations using global and regional climate models for inferring future projections of climate change, observations show that the world has continued to emit GHG rather aggressively and that the rate of increase in global GHG emissions between the years 2000 and 2006 stood at 3.3%, as against a maximum of 2.4% envisaged in the SRES – A1FI pathway (Figure 3.1).

Figure 3.1. Current Global Trends (3.3% per year) and projected SRES green house gas emission pathways; also included here are emission pathways for stabilization scenarios



Source: Updated from http://www.ipcc.ch/graphics/ar4-wg1/jpg/spm5.jpg

Following the publication of The Stern Report on the "Economics of Climate Change" in 2006, world leaders have been negotiating seriously on ways and means to restrict GHG concentrations in the atmosphere to 450 ppm, such that the global mean rise in surface temperature does not exceed the critical threshold of 2^0C, beyond which some of the impacts could be catastrophic and even irreversible in some parts of the world (in particular small islands and developing countries with long coast lines).

It is hoped that the collective wisdom of leaders from across the world would prevail upon reaching an equitable agreement in Copenhagen in December 2009 in order to implement drastic cuts in global GHG emissions with legally binding targets on the Developed World, by introducing advanced low carbon technologies and carbon capture and storage, and encouraging societies across the world to move toward a more sustainable consumption pathway for a safer future and a greener Earth.

3.1.1 Impacts of climate change on main sectors

Impacts on water resources

Viet Nam is located in the down streams of two major international rivers: the Mekong and Red Rivers. The area of Mekong river basin is about 795,000 km^2 (including Tonlesap and its delta), while its annual water runoff to the East Sea is 505 billion m^3. The Red River has a basin of 169,000 km^2 in area; annually transporting to the East Sea 138 billion m^3 of water. The impacts of climate change on water runoff from the Red and Mekong Rivers will be as follows:

Compared with the present, by the decade 2070, annual run-off is projected to increase within the range of +5.8 to 19.0% for Red River and from +4.2 to 14.5% for Mekong River, low-flow changes are likely to be in the range of -10.3 – 14.5% for the Red River and -2.0 – 24.0% for Mekong River while flood-top discharge will likely change within the range of +12.0 – 5.0% for the Red River and +15.0 – 7% for Mekong River.

In summary, in both rivers, the decline in annual run-off is likely to be higher for low-flow, and surplus in annual run-off is likely to be higher for flood-top discharge.

In medium and small rivers, annual run-off would likey reduce or increase by a similar or higher amount.

Impacts on agriculture

With the projected warming of the country, the adaptation time of tropical crops will be extended. As estimated, the allocation of vegetation is likely to change as follows:

- The planting boundary of tropical trees/ crops would move towards higher mountainous regions and northwards. On the other hand, the adaptation area of subtropical plants would become narrower. By the 2070s, the mountainous tropical trees would be able to grow at an altitude 100-550 meters higher and move 100-200 km northwards in comparison with the present.
- Due to abnormal changes in rainfall intensity, flood inundation and droughts would occur more frequently.
- Significant cultivation areas in the Mekong and North Deltas would be affected by salt water intrusion due to sea level rise.

Impacts on forest ecosystems

Climate Change would affect forest coverage and forest ecology in various ways:

- Sea level rise would result in decrease in mangrove forest area, and adversely affect indigo forests, as well as forests planted on the sulfated land of provinces in the South of Viet Nam.
- It is possible that there would be changes in boundary distribution of primary forest, as well as secondary forest. For instance, dipterocarpaceae trees (tropical lowland rainforest trees) would expand towards higher altitudes. Deciduous forest with drought stand varieties would also develop more.
- The increasing temperature in combination with abundant solar radiation, would promote photosynthesis processes, leading to an acceleration of the assimilation process of verdurous trees. However, due to an increase of evapo-transpiration, soil moisture would be reduced, and, as a consequence, the biomass growth index of forest trees would decline.
- The threats of extinction for animal and plant species would increase, with some important timber plants, such as aloe wood, boswood, textured wood, siadora Viet Namese, etc., likely to be exhausted.
- The increase in temperature and drought frequency/intensity would also lead to increasing danger from forest fires and the development and spreading of plant pests and diseases.

Impacts on aquatic eco-systems

Salinity intrusion would lead to the following consequences:

- The habitat of fresh water living creatures occupying water bodies near the coast would become smaller due to sea water intrusion.

Figure 3.2. Some Pictures of 5 Million Hectare Reforestation Programme

- Mangrove forests would reduce in area and density, affecting the ecosystems of some aquaculture species.
- The decline in fixing-organic-matter capacity of seaweed ecological system would result in a decrease in the sources of photosynthesis products and nutrition for living creatures in the sea and in river-beds. Thus, the quality of living habitat for various living aqua-creatures would get worse.

The increase in water temperature would lead to:

- Clearer thermal vertical stratification that, in turn, would affect the biological habit of living creatures.
- With the increase in water temperature, some species would move northwards or "dive" to deeper depths which would change the vertical distribution structure of aqua-creatures.
- Increasing temperatures would also accelerate mineralization and organic decomposition processes, affecting the food system of living creatures. The living creatures should consume more energy for respiration, as well as for other living activities, reducing the productivity and commercial quality of aquaculture and sea products.
- Degeneration or destruction of coral reef, changing the physiological and bio-chemical processes occurring during interactions between coral reefs and algea (complex marine forms called seaweeds).
- Due to an increase in rainfall intensity, the salt concentration of seawater would reduce by 10 - 20%, during longer time span (it could prolong from some days to some weeks). As a result, brackish water and coastal living creatures, especially dual crust mollusks (e.g. arcas and oysters, etc.) would die massively because they could not survive changes in salt concentration.

Impacts of climate change on income from sea products and fisheries:

- Due to sea level rise along the coastline of Viet Nam, hydro-physical hydro-biological and hydro-chemical regimes would be degraded, and, as a result, the existing coenosium would change its structure and components, supplemental reserve would be seriously reduced.
- Due to increasing water temperature, the distribution of profit making and economical resources would become more dispersed. Meanwhile, the number of tropical fishes with low commercial value, with the exception of tuna, would increase. The number of sub-tropical fish with high commercial value, would decrease or even disappear. Most fish that breed in coral reef would vanish.
- Phytoplankton, the first link of food chain for plankton and juvenile fish, would be destroyed leading to sharp decreases in the number of plankton - the main flood source for animals in the middle and upper layers.

Impacts on the energy and transportation sectors

Sea level rise along the coastline of Viet Nam will lead to the following impacts:

- The activities of oil drill platforms in the sea, the transport system of oil and associated gas, and gas power plants built on the coast, would be adversely affected by potentially increasing expenditures on existing infrastructure's maintenance, repair and operation.
- The seaports, including wharves, quays, and stores that were designed according

to the current water level would need to be modified, or even moved to other places. The North-South railway and transport lines close to the sea, along with electricity transformer stations and transmission lines in the coastal areas, would be also affected.

- The run-off regimes of major rivers where hydropower stations were built would change, which would obviously affect the water regulation mechanism there. Sea level rise would also inundate lowlands, leading to an increase in energy requirements for pumping out water for drainage.

Climate change impacts on the transportation sectors:

- Increasing temperatures would affect expenditures on coalmine ventilation and cooling, resulting in increased expenditures for cooling, decreasing the efficiency and energy productivity of thermal power plants.
- Power consumption for living, industrial, and commercial activities, would be also higher due to intensive use of electric ventilators and air conditioners.
- Increasing evapo-transpiration, in combination with abnormal fluctuations in the rainfall regime and the enhanced variability of rainfall, would lead to changes in water reserve and the discharge of hydropower reservoirs, hence, adversely affecting hydropower generation.

Climate change would lead to changes in some of the characteristics of typhoons and the typhoon season, which would impact on energy sector infrastructure, firstly offshore drill platforms, but also systems to transport oil and gas to the shore, electricity transmission and distribution systems.

Impacts on human health

- An warmer climate would have adverse impacts on human health. Extreme weather would lead to increased heat stress, threatening particularly old people, suffering from cardiac diseases and mental disorders. A warmer climate would also change the seasonal structure of vector borne diseases, while a warmer winter in North Viet Nam would result in changes in the biological rhythm of the people.
- There are many infectious diseases which would be exacerbated by climate change such as malaria, synaptic filariasis, dengue fever, Japanese encephalitis, arboviral diseases, and other diseases common in humid tropical regions, through facilitating the growth and development of various viruses and insects (disease carriers), leading to an increase in patients and the death rate.

3.1.2 Impacts of climate change on major regions

Climate change can bring about many negative impacts for the major geographical regions of Viet Nam:

Potential impacts of climate change on the Northwestern and Northeastern mountainous areas

Surely, climate change will bring about many changes in the annual weather and the long-term climate mechanism, especially in major factors.

- The frequency of cold fronts in the Northern latitudes in the coming decades may slightly decrease in comparison with previous decades. The rate of cold fronts penetrating into the Northwest over that penetrating into the Northeast will be somewhat lower in comparison with that of the past. Fluctuations in the frequency of cold fronts throughout the years may become stronger and the regularity of the cold front season may become more unstable. The cold front season may arrive later and end earlier, the peak time of cold fronts in mid-winter may not be as obvious as previously, and the intervals between cold fronts in mid-summer may last longer.

- The normal temperature in the coming years will be higher than the existing normal baseline of previous decades. Surely, there will be an increase in the numeric value of higher temperatures and the frequency of hot sunlight spells in medium and low mountainous areas. It is very likely that temperature, or total temperature belts, will retreat to higher mountainous areas and, consequently, the area of regions with low temperatures will be reduced. The hot season in lowland areas will last longer and the cold season will last shorter in all regions.
- Rainfall in the coming years may increase in some places, decrease in other places, and remain relatively equal to that of previous decades. The point is that, in the more distant future, precipitation in the rainy season will increase, and rainfall in the dry season, although it may not increase, will fluctuate more strongly. The number of rainless years in centers with high rainfall such as Bac Quang and Sapa, will overwhelm that in other areas, while the number in centers with low rainfall, such as Song Ma, Yen Chau and Bao Lac will not be smaller than in adjacent localities.

  The irregularity of the rain mechanism will also become more profound: all records of high rainfall (daily and monthly rainfall, etc.) will increase, together with a rise in the frequency of large-scale heavy rains, as well as severe droughts.

  It is worth noticing that in the Northeastern mountainous area, the amount of drizzly rain will continue to decrease in the transitional months from the dry season to the rainy season.

  Both the dry season and the rainy season will become less regular, they may begin too early or end too late; rains will be more concentrated in the peak months of the rainy season, while droughts will be more severe in the final months of the dry season.
- The evaporation quantity in the coming years and decades may be higher than the common level of the previous decades, contributing to increased water shortages and raising the frequency and intensity of droughts.
- The relative humidity in the coming years and decades may decrease in comparison with that in the previous decades, mainly due to the increase in the temperature foundation.

Annual weather changes may affect national economic industries in the region:

- Regional electricity distribution may become more convenient after large hydropower plants have been constructed and put into operation. However, floods, especially flash floods in mountainuos areas, will still be a permanent threat in the rainy season. Conversely, in the dry season, peak power availability will remarkably decline, while the frequency of droughts will increase.
- The boundary of tropical crops will move to higher mountainous areas, while the adaptation scope of sub-tropical plants will be reduced, bringing about a decrease in some cold-climate

plants, such as pomu wood, redwood and medicinal plants etc. Temperature increases and humidity decreases will reduce the biomass growth index and increase the hazard of forest fires.

- It is necessary to implement a number of improvements and adjustments in conventional practices in agriculture to adapt to the higher temperatures, the longer hot seasons and the shorter cold season. It is likely that the crop structure and the seasonal schedule for crops in certain areas, with unsuitable conditions of temperature and humidity for the physiological needs of high-valued crops, will have to be adjusted.
- Higher temperatures would also contribute to an increase in the hazard of pests, while the higher frequency of droughts is likely to increase the production costs, or reduce the productivity and quality of some major crops.
- Warming in the Northwest and Northeast may adversely the tourism industry. Resorts such as Sapa and Bac Ha may lose part of their attractiveness in the eyes of visitors and people looking for a comfortable and pleasant stay in mountainous areas.

In addition, the higher temperatures will also increase the growth and development speed of a number of bacteria, pests, and pathogenic vectors, and, consequently, the number of people catching diseases or infection.

Potential impacts of climate change on the Northern midland, North Delta and Quang Ninh province.

Surely, climate change will bring about noticeable changes in the annual weather sequences as well as the weather mechanism, especially in the following factors:

- Tropical cyclones operating in the East Sea and Tropical cyclones affecting or penetrating into the Northern coast in the coming decades may increase in intensity in comparison with previous decades. Moreover, the stormy season in the coastal strip and the North Delta may become more unstable, and it is possible that the stormy season will arrive before June and last until November or December.
- Likewise in the Northwestern and Northeastern mountainous areas, the frequency and intensity of cold fronts crossing the delta and the Northern coastal strip in the coming decades may decrease in comparison with those in previous decades, while the frequency of fluctuations throughout the years may become stronger and the regularity of the cold front season may be more unstable.
- The normal temperature in the coming years will be higher than the baseline level of the previous decades. The maximum temperature may reach new records. The duration of existence and intensity of hot sunlight spells, especially spells at the beginning of the season in the Delta and the Northern coast may be relatively equal to those in the North Central. Certainly, records of low temperature may not get lower and there may be fewer hoarfrosts. In general, the cold season will be less cold and shorter, while the summer will arrive earlier, last longer and be more severe.
- Rainfall in the coming years and decades may increase in some places while decrease in others, but the difference from the baseline level of previous decades is likely to be relatively small. The point is, in the more distant future, precipitation in the rainy season will increase and precipitation in the dry season, although

remain unperturbed, will fluctuate more strongly. It is likely that islands, which used to have lower rainfall than that of Southern islands and adjacent deltas will have above normal rainfall. The instability of the rain mechanism and the rainy season will become more profound over time. Meanwhile, records of high daily, monthly and annual rainfalls will be higher, while, conversely, the time with no rain or little rain will last longer. The amount of drizzly rain will continue to decrease and contribute to an increase in droughts at the end of winter and the beginning of spring.

- The rate of surface evaporation in the coming years and decades may be higher than the baseline level of the previous decades, which would increase the dryness index in association with the increase in drought frequency.
- Along the coastal delta strip, the sea level will continue to rise at a speed of about 0.5 -0.6 cm/year, higher than that in the previous decades.

Potential changes in climate parameters may lead to the following impacts:

- The currents of rivers, especially the exhausted currents may decrease although there is the possibility that the flood currents may increase in certain years as a consequence of more intense rainfall episodes. Water sources, especially in the dry season, may become scarcer, causing many difficulties to life and industrial production.
- The adaptative capacity of some sub-tropical crops will decrease, which makes the role of winter crop less significant. In the relatively long-term future, crop structure and seasonal characteristics may need to be adjusted towards utilizing the conditions of higher temperature thresholds.
- In agriculture, the production costs for a production unit may increase due to the needs for more frequent irrigation and enhanced anti-drought measures.
- The rise of the sea level will not only reduce the area of mangrove forests but tides will also penetrate further into the estuarial delta area of the North Delta. On the other hand, the rise of the sea level would require improvements in transportation works, as well as bridges and ports in the coastal areas and islands. The rise of the sea level would also require additional expenses for construction works, industrial bases and power plants etc., in coastal areas and islands.
- In the daily life of Northern coastal delta inhabitants, the demand for water will be higher, while the amount of water available will be reduced significantly. Water shortage, substandard sanitation and hygiene conditions, and an increase of severe storms will lead to the emergence of diarrhoeal and many other infectious diseases, especially summer diseases.

Potential impacts of climate change on the North Central and South Central Coastal Deltas

Surely, climate change will bring about substantial changes in the annual weather as well as the weather mechanism, especially in the following factors:

- Tropical cyclones originating in the East Sea and Tropical cyclones affecting or penetrating into the Central coast in the coming decades may increase (in frequency and/or intensity) in comparison with those in previous decades. The stormy season in the coastal strips may also fluctuate more strongly; begining before August and lasting until December, or being restricted to the months of August and September.

- The number of cold fronts crossing the North Central during winter may decrease as a consequence of climate change while that crossing the South Central may be restricted to a fewer number. The cold front season may be shorter, while the number of cold-front interval months may increase.
- The mean surface air temperature in the coming years and decades will be higher than that in previous decades. The season of dry and hot westerly wind will tend to arrive earlier and end later than in the past. The number of spells of extremely high temperatures and the duration of hot spells may increase, while those of low temperatures may be sustained for a longer time period. The cold season in the North Central provinces will, more than likely, be shorter, and the Southern boundary of the cold season will move to higher latitudes than at present. The phenomenon of hoarfrost, inherently rare in the Northern provinces of the North Central, will possibly disappear altogether.
- Rainfall in the coming years and decades may increase in some places while decreasing in others, but the difference from the baseline level of the previous decades is likely to be relatively small. The point is, in the more distant future, the normal rainfall will increase remarkably, especially during the rainy season. It is possible that centers with high seasonal rainfall, such as Ky Anh, Tra My, Ba To and those with low seasonal rainfall, such as Tuong Duong, Ninh Thuan may become even more typical and vice versa.

  Precipitation that inherently concentrates during fall and winter months will become even more concentrated. The dry season will continue to last from December and January to August and/or September in the South Central, while in the North Central, May and June may become permanently dry and hot months like in the South Central.

  In the Northern provinces of the North Central, drizzle rains may be scarcer.

  Along the Central Coastal delta strip, the records of high daily, monthly and annual rainfalls will become higher in the future. Droughts will also occur more regularly and will be more severe.

  The evaporation quantity in the coming decades may be higher than the baseline level of previous decades, which will increase the dryness index and drought intensity.

  The sea level along the coastline of Viet Nam will continue to rise at a speed of about 0.5 -0.6cm / year in the coming decades.

These changes in climatic attributes will naturally lead to the following impacts on some socio-economic sectors/activities:

- The annual currents of most rivers will decrease, although, the flood current may remain intact or slightly increase, while the exhausted current may decrease remarkably. Water sources, especially in most months of the dry season, may become scarcer, especially in extreme South Central provinces.
- In the near future, crop structure and seasonal characteristics will need to be

adjusted to adapt to a higher temperature baseline. The production costs for an agricultural product unit may increase due to the need for more regular irrigation and longer anti-drought time.

- The rise of the sea level will reduce the area of mangrove forests, bring about coastal erosion, and create many difficulties for fishermen conducting their fishing activities, due to a decline in productivity and, hence, abundance of most aquatic resources.
- The rise of the sea level will shrink the available land for developing residential area alongside the coast, increase the possibility of coastal erosion, and directly threaten transportation works, construction works, industrial bases, and available infrastructure in some cities alongside coastal lines from the North to the South.
- The increase in temperatures and water shortages will also bring about additional stresses to normal life and contribute to an increase in the variety of diseases, such as heat strokes, cardiovascular or respiratory disease (asthma attacks), and diarrhoeal disease, especially during summer.

Potential impacts of climate change on the Central Highlands

Climate change will bring about many changes in the annual weather, as well as the climate mechanism, especially the following factors:

- It is becoming increasingly rare for cold fronts to penetrate deep into lowlands in the Central Highlands through the river valleys of the South Central. Similar to previous decades, the direct influences of polar-zone air blocks in the Central Highlands are weaker than those in Northern provinces of the South Central.
- Tropical cyclones will continue to have adverse impacts on the Central Highlands, especially in areas adjacent to the South Central. It is possible that there will be hurricanes landing on the South Central, continuing to penetrate deep into the Central Highlands.
- The normal surface air temperature in the coming decades will be higher than previous decades. Maximum temperatures may achieve higher records, especially in low mountainous areas and the middle-stream and down-stream areas of major rivers. Hot sunshine spells may occur with higher frequency over low mountainous slopes, hollows and river valleys. In the trend of temperature increase, temperature and total temperature belts will retreat to higher mountainous areas. The hot season in middle and low mountainous areas will last longer, while the cold season in middle and high mountainous areas will be shorter.
- The rainfall in the coming decades may increase in some places, while decreasing in others, but the difference from the common level of previous decades will be relatively small. The point is, in the future, rainfall in the rainy season will increase, while in the dry season it will fluctuate more strongly. Centers with high rainfall, such as Bao Loc and Phuoc Long, and those with low rainfall, such as Ayunpa, and Dak Lay, will continue to be places with the highest or lowest annual rainfall in the Central Highlands. However, in certain years, rainfall in high rainfall centers will not be higher, while in low rainfall centers it will not be lower, than those in adjacent areas.

- The instability of the rain mechanism will become more pronounced. Records of high daily, monthly and annual rainfalls will, more than likely, be higher, while droughts in the latter half of winter will become more severe. The beginning, ending and peak times of the rainy and the dry seasons will be more variable.
- The evaporation quantity in the coming decades will be higher, contributing to more severe drought conditions in the early months of the year.

Changes in annual weather may affect many socio-economic activities in the regions:

- The annual currents of rivers will decrease in comparison with those in previous decades, mainly due to a decrease in exhausted currents. Floods, especially flashfloods, will still pose a permanent threat to middle-stream and downstream areas of river basin in the rainy season. Conversely, due to more severe droughts, water sources for agricultural production and domestic uses in the dry season will become scarcer in most areas.
- Adjustments and improvements need to be implemented in agriculture practices to suitably adapt to a higher temperature baseline and more variable rain mechanism. The production of high-valued industrial crops, such as coffee and rubber, will require higher expenses, consequently, leading to an increase in product prices.
- A remarkable area of tropical forests in the Central Highlands, with trees, such as pine, pomu wood and cold-favoring plants, will possibly disappear, due to the movement of high temperature belts to high mountainous areas. Conversely, typical tropical crops, especially industrial crops, will have favorable conditions to develop in certain places where current conditions are somewhat below tropical standards.
- Higher temperatures will also result in the emergence and development of a number of bacteria, pests and diseases that can threaten crops, livestock and even inhabitants living in the Central Highlands.

Potential impacts of climate change on the South

Climate change will bring about many changes in the annual weather pattern in the South, which will be expressed through fundamental parameters as follows:

- The number of tropical cyclones originating in the East Sea and tropical cyclones affecting or penetrating into the South in the coming decades may remain unchanged in comparison with previous decades. The point is the tropical cyclones season may become more unstable. It is possible that some tropical cyclones will land on the South in the period from September, October to November, which is the stormy season in the South Central and North Central latitudes.
- The temperature in the coming years and decades will be higher than the baseline level in previous decades. It is likely that new records of maximum temperature will be achieved in some areas. Baking sun in the early months of the year may become more severe and contribute to an increase in drought intensity.
- Rainfall in the coming decades may increase in some places, while decreasing in others, but generally will be close to the baseline level in previous decades. In the more distant future, rainfall in the rainy season will increase, while in the dry season it will fluctuate more strongly.

Rainfall distribution across (Southern) areas will change remarkably and the rainy season may be more unstable. The rainy season, irrespective of beginning or ending times, may have enhanced intra-seasonal variability over the years. The most significant change in the rain mechanism is likely to be in relation to rain intensity. Records of daily rainfall or rainfall in major spells of rainfall may increase to a level equal, or nearly equal, to those in South Central.

- The evaporation quantity will increase together with the rise in temperature. Consequently, the annual dryness index will be higher, especially in the latter months of the dry season (i.e. April and May).
- The sea level will continue to rise at a rate of about 0.5 -0.6cm/year and is likely to become the most threatening change to coastal habitats and infrastructure in Viet Nam.

Changes in annual weather events may bring about significant impacts on socio-economic activities:

- The flow of the current of the Mekong River will tend to weaken, mainly due to a decrease in the exhausted current flow. From now to 2070, the flood current will tend towards positive change, while exhausted current will tend towards negative change.
- Due to an unstable rain mechanism, although, the change in rainfall will be insignificant, water resources in the dry season will become scarcer, especially in years when the (previous) rainy season ended early and the (present) rainy season arrived late. Droughts will not only increase in intensity in the dry season, but will also possibly occur at certain times during the rainy season.
- Higher temperatures will foster evaporation over wet rice fields in the South, increasing demands for irrigation water, as well as enhancing production costs for each crop and the cost of each product unit. In addition, due to higher temperature and stronger evaporation, the threat of forest fires in the dry months will be higher.
- The sea level becoming remarkably higher along the coastline in Viet Nam, in the future, will bring about salinity intrusion and salt water inundation in the Mekong River Delta. An estimated 85 percent of the people in the Mekong Delta are supported by agriculture. It is estimated that the inundated area will increase remarkably in the second half of the 21st century in comparison with the 20th century. More than one-third of the delta, where 17 million people live and nearly half the country's rice is grown, could be submerged if sea levels rise by three feet in the decades to come. Even under the low emissions growth scenario, one-fifth of the delta would be flooded. Storm surges could periodically raise the sea level even further, while the intrusion of salt water and industrial pollution could contaminate much of the remaining delta area. The risks of sea level rise for Viet Nam go far beyond the Mekong Delta, to the North Delta in the north, where large areas could be inundated near the capital, Ha Noi.

The rise of the sea level will reduce the areal extent of mangrove forests and bring about negative impacts for indigo forests and forests on alum soil. In addition, the penetration of seawater into the mainland, not only narrows the habitats of some fresh-water aquatic creatures, but also remarkably reduces the amount of water for people's livelihood and irrigation of crops. The penetration of seawater inland also worsens the soil degradation in coastal areas.

- The increase in temperature and more serious water shortages will negatively affect sanitation and hygiene conditions, and create favorable conditions for the alteration of the geographical distribution of insect vectors that spread infectious diseases.

3.2 Development of green house gas mitigation policies and options

3.2.1 GHG emission reduction policies

Viet Nam's national plans include an attempt to integrate environmental concerns and GHG mitigation strategies into the development plans of ministries and enterprises. Viet Nam has considered a set of options for GHG reduction in the following main areas:

GHG reduction orientation in energy

In order to implement national environmental policy in combination with GHG mitigation strategies, the principles of an energy development strategy should be ensure: the maintenance of rapid, stable and sustainable economic growth, the mitigation of GHG emissions, and the protection of the climate system. This principle should be implemented through the following solutions:

1. Improvements in the efficient and economical use of energy;
2. Utilization of new and renewable energy sources;
3. Economical use of energy in transportation.

GHG reduction orientation in forestry

The overall objective of forestry development in the next 20 year is to develop the socialized forestry, forestry protection, forest rehabilitation, and sustained development, to ensure the environmental protection capacity of the forestry; conservation of natural forestry areas; protection of biodiversity; wide application of new and advanced scientific technologies available in the world and make green business from forestry resources to meet the demands of the economic sector; contribute to hunger alleviation and poverty reduction; gradually improve the living conditions of ethnic minority people who have lived in and next to forests, and to create a sustainable foundation for national security.

Forestry development orientation takes into account GHG mitigation in Viet Nam, based on the Forestry Development Strategy for 2001 – 2020 of Viet Nam, through implementing activities to mitigate emissions and enhance GHG sinks. Orientations stated in this Strategy include:

1. To promote the implementation of the program effectively to plant 5 million hectares of forests in marginal/degraded land, in order to increase the forest coverage to 43% by 2010 to 2020,
2. To conserve and restore existing forests,
3. To rehabilitate combined forest,
4. To prevent forest fires.

GHG reduction orientation in agriculture

The objective of Viet Nam's agricultural strategy in first 20 years of the 21st century is to develop the agricultural sector with a variety of good practices, targeting sustainable development, through the application of new scientific achievements and advanced technologies, which can compete in local and overseas markets, and meet the food requirements of our citizens and export purpose.

Agricultural development orientations which take into account the GHG mitigation goals of Viet Nam are:

1. Development and application of sustainable agricultural farming techniques to enhance the agricultural production and to mitigate GHG emissions (e.g., actions to prevent the burning of crop residue).
2. Improvement in manure management and irrigation-drainage management in rice fields.
3. Strengthening the capacities of agriculture research institutions.
4. Improving meal and eating traditions of people so that the meal would include not only rice.
5. Exploiting sources of methane through the exploration of opportunities and challenges for methane capture.

3.2.2 Options for improvement in energy efficiency

In order to improve energy efficiency, different measures should be taken:

1. Improvements in lighting efficiency of energy use and conservation:

- Improving lighting efficiency in public and households.
- Setting up lighting norms and saving regulations.
- Step by step testing and popularization of efficient lighting appliances.
- Supporting policies for enterprise in lighting manufacture, management and education.

2. Improving energy efficiency and saving energy in enterprises:

- Providing information on energy and effective energy services.
- Carrying out programs on energy efficiency, monitoring the implementation of effective energy and environment programs and projects.
- Improving the efficiency of industrial boilers.
- Using industrial motors with high efficiency.
- Using highly efficient vehicles.

3. Implementation of Demand-side Management (DSM) Programs

- Management of additional load to reduce the differences between electricity power availability and consumption.
- Reduction of losses in electricity dissemination/transmission and distribution.
- Development and implementation of a program on urban energy efficiency and rural electrification.
- Development and implementation of a program on high-efficiency household appliances.

4. Effective energy use and saving in buildings:

- Strengthening capacity in construction design taking into account energy efficiency.
- Setting up energy norms for construction materials.
- Standardizing and encouraging the use of high-efficiency equipment.
- Conducting energy audit on big buildings.

5. Economical use of energy in transport sector:

- Developing public transport for cities to meet 25-30% of transportation needs in 2001-2010 and up to 50-60% by 2010-2020.
- Encouraging economical-fuel vehicles.
- Upgrading transport infrastructure and improving the quality of means of transportation.
- Controlling gas emissions from vehicles.

3.2.3 Promoting researches, deploying and enhancing the use of new and renewable energy sources

Research and development of solar energy

Viet Nam experts have zoned solar radiation energy in the entire Vietnamese territory. According to that illustration, the solar energy resource in Viet Nam is estimated to be about 1,300-2,200kwh/m^2/year, rather abundant in the Southern regions, with highest value in the South and the Central South of Viet Nam and lower in the North, with lowest value in the North Delta.

Solar energy in Viet Nam is used under three modes:

- Solar Energy dryers

Drying facilities use solar energy in agricultural sector, medicine, seafood and centrifugal cement pillars. In Viet Nam, 10 industrial drying systems and 60 simple drying systems have already been installed. However, industrial drying systems have high costs and the light is not stable, and the simple drying system has low cost and the efficiency and duration is also low.

- Water distillation

Water distillation facilities are drying systems which have the size of 10 – 40 m^2 and a capacity of 3-5 litre/m^2/day. The movable and tray shape system has a capacity of 4 – 5 litre/m^2/day. Most of those facilities are quite large and their life-span is short.

- Water heater

Common boiling systems have the areas of 10 – 50 m^2 with capacities of 1,000 – 5,000 litres of hot water at 50 -70^{0}C per day, and some household boiling systems have areas of 1 – 3m^2 with capacities of 100 – 300 litres of hot water per day. However, as complicated operation and the hot water in cooling day is not produced and high cost, that system has not widely installed.

- Photovoltaic cells

Photovoltaic cells were firstly used in the South. Currently, around 40 photovoltaic electricity stations with a capacity of 500 – 1,000 Wp have been installed in communes, and 800 stations with the capacity of 22.5 – 50 Wp are used to serve hospitals, medical centers and cultural house, etc.

Research on and development of wind energy

Viet Nam's National Scientific and Technology Programme 1996 – 2000 "Strategy and sustainable energy development" stated in its overview assessment that wind energy potential in Viet Nam is low, mainly on remote island, several coastal areas or terrain wind.

The report on wind energy potential shows that the energy density (kwh/m^2/year) is 2,700 – 4,500 on remote island, 1,700 – 4,200 on coastal island, 700 – 1,000 in coastal areas of Cat Hai – Cat Van, 400 – 500 in South

Figure 3.3. Wind Power being exploited in Binh Thuan

Source: Department of Hydro - Meteorology and Climate Change

of Central coastal areas, 450 -550 in South coastal areas, 500 – 600 in Central Highlands, < 500 in inland areas, and 2,000 – 3,000 in windy terrain areas. The authors believe that the potential of wind energy application in Viet Nam is limited on its remote islands, coastal island and windy terrain areas.

In Viet Nam, the potential of wind energy is not high, mainly on islands and in coastal areas. According to reports done by the Viet Nam's Institute of Energy, the potential of wind energy in Viet Nam is about average when compared with other countries in the region and across the world. It is considered that wind velocity in many inland areas is not suitable for electricity generation and only about 3,000 km of coastal and some mountainous areas have rather rich potential for the use of wind energy.

A project for wind power potentials executed by the Global Physics Institute (Viet Nam Academy of Science and Technology) carried out a survey of wind velocity at heights of 10, 20, 30 and 40 m, identifying wind gradients and directions in Phuoc Mai peninsula (Binh Dinh province) from January 1998 to April 1999, and proposed to develop a wind power plant there.

Several projects, programs and activities of wind electricity generation have been executed in Viet Nam during recent years.

- The Institute of Energy, with the task of implementing a wind engine with low capacity for electricity generation on remote islands to serve a programme on rural electricification installed engines for electricity generation from wind energy with a capacity of 150 – 500W in some areas of islands at the end of the 1980s and the beginning of the 1990s.
- The Institute of Energy developed a wind engine with a capacity of 150W (wind diameter is 1.7m, producing electricity for a 15V battery charge). Up until the year 2000, 30 wind engines had been installed to meet the electricity demands of household.
- The Ha Noi University of Technology has imported and installed 3 wind energy engines with a capacity of 150W, 5 engines designed by the Institute of Transport Technology, and 12 wind engines with a capacity of 150W designed by the Ho Chi Minh University of Technology.
- The Ho Chi Minh University of Technology has developed three pilot wind energy villages, two in Khanh Hoa and one in Can Gio, with 50 small wind engines in each village. Total wind energy installed by Ho Chi Minh University of Technology is 500, with the most common capacity being 150 – 200W.
- In early 2000, Viet Nam prepared a plan to develop a wind power generating station for electricity generation from wind energy, including 40 engines with a capacity of 500 kW.

- The Institute of Transport Technology has developed pilot models for electricity generation from wind energy of 500W with 6 models already operational. The Institute of Mechanic production has researched the development of a wind electricity generation engine, with a capacity of 1.5 – 5kW.
- The Institute of Energy Technology (Vietnamese Academy of Science and Technology) has installed wind electricity generation equipment with a capacity of 120 – 250W, exported from China for some local areas.
- Many electricity generation facilities from wind energy have been installed in Tu Bong (Khanh Hoa), Bach Long Vi (Hai Phong), Kon Tum and Hai Thinh
- Recently, projects on electricity production from wind energy have been implemented in Binh Dinh with a capacity of 15MW, in Khanh Hoa with a capacity of 20 MW, Ninh Thuan with a capacity of 625 MW, and Bach Long Vi with 800 kW.

Research on and development of small and micro hydro-power plants

According to research and assessment of Viet Nam's Institute of Energy, the total theoretical, technical and economic hydropower potential of Viet Nam is about 1,600-2,000 MW, accounting for 7-10% of yield. Out of that potential, there are about 500 small hydro-power plants (100-10,000kW), accounting for 87-90%, and about 5-7% of micro hydro-power plants (5 – 100kW).

Iterm of small hydro-power plant potential, 610 stations may be installed and exploited with a total output capacity of 1,310MW in 26 provinces, with the highest in Daklak (196MW), Lao Cai (100MW), Son La (86.5MW), Gia Lai (75MW), and Thanh Hoa (77.5MW).

Figure 3.4. Small hydro-electricity plant at Muc River

Source: Department of Hydro - Meteorology and Climate Change

After 1990, many households have invested in the installation of micro hydro-power plant with a capacity 0.1 – 1KW, provided at low cost.

Up until 2003, more than 500 hydro power plants (5kW-10MW/plant) had been installed with total output capacity of 97,273kW. In addition, 110-130 thousand micro plants (5-20W/plant) had been installed and exploited.

Development and application of biogas and biomass

In 1992, the University of Agriculture and Forestry in Ho Chi Minh city deployed a program of biomass in many areas and installed 6,000 plastic bags.

In 1994, the Viet Nam Gardening Association (VACVINA)) piloted a program of biomass and have installed 2,000 bags in 33 areas.

In 1996, under a program of National Targets for Rural Clean Drinking Water Supply and Environmental Sanitation, about 200 - 300 fixed cover biogas tanks and systems were constructed and installed in Ha Tay and Nam Dinh Provinces in 1996, and 1,000 ones in the Dan Phuong districts of Ha Tay province in 1999.

So far, about 70,000 biogas tanks and systems, out of which several thousands are plastic bags and the rest are solid concrete tanks have been constructed and installed. Biogas technology has been widely popularized and there have been many services of biogas technology.

In 2000, biomass, including woods, wood refuses and agricultural by-products, etc., was used under modes of thermal power and electricity, accounting for 14 tonne of oil equivalent (TOE).

3.2.4 Protecting and enhancing GHG storage and sinks

The forest development orientation of Viet Nam is to strengthen activities to develop forest natural resources and improve forest cover to 36% by 2005 and 43% by 2010; to speed up forest allocation and land allocation, integration of forest and agriculture, and to prevent forest burning and destroying; promote plantation of economic forests, create the wood source, and provide the material for the pulp and paper industry, and production of household commodities and art objects for export.

Based on this orientation, the overall objective of forestry development of Viet Nam in next 20 years of the 21st century are:

- To develop the socialized forestry, forestry protection, and forest rehabilitation and development, to ensure the environmental protection capacity of the forestry; conservation of natural forestry area, and the protection of biodiversity;
- Wide application of new and advanced scientific technologies available across the world and make business from forestry to meet the demands of the economic sector;
- Contribute to hunger alleviation and poverty reduction; gradually improve the living conditions of ethnic minority people who lived in and next to the forests, and create a sustainable foundation for national security.

Based on the forest development strategy of Viet Nam for the period 2001-2020, the activities related to forestry and forestry development have been in compliance with policies of environment protection and GHG emissions mitigation/GHG sink increase. To this end, Viet Nam has been applying the following important options:

- Focus on implementing a program of plantation of 5 million hectares of forest (Project 661), which was approved by the Viet Nam National Assembly in 1997, with the aims of increasing the forest coverage up to 43% by the end of the period 2010-2020.
- Develop an action plan to prevent the degradation of forest resources, restore the forest by measures, such as the conservation of existing forest, delimitation for forest restoration, the planting of new forest, limiting the exploitation of natural forest, and the preventing forest fire.
- Stabilize the structure of 3 kinds of forests, including protection forests, special-use forests and production forests.
- Implement integrated social policies, such as allocating forest land to local households for planting, settlement program, "poverty alleviation" with the

aims of actively supporting the program of planting 5 million hectares of forest.

- Improve the living standard of the people in mountainous areas. Attract as many local households as possible to participate in activities to protect forests, plant forests and carry out forestry business.
- Socialize at a high level the forestry on the basis of a multi-component economy. Renovate the production relationship in forestry.

3.2.5 Agricultural Development Orientation and improvement of sustainable cultivation to adapt to climate change

The strategic objective of the Agriculture and Rural Sector Development strategy for the period 2001-2010 includes:

- Build up the sound commodity agriculture development with diversity and sustainability, and step by step modernize on the basis of application of new and highly efficient technologies which can be competitive on domestic and international markets.
- Develop a new rural area with appropriate agriculture-industry-services, with industrialization and modernization linking with urbanization,
- Ensuring to improvement of all members in rural areas, without hunger, poverty, reaching a life of sufficiency, prosperity, democratic rural society, equality, civilization while keeping traditional cultural characters of the nation.

Agricultural development orientation, taking into account GHG mitigation, basically requires meeting the demands for food and food products from people, as well as for export, meanwhile to mitigate GHG emission from agricultural sector.

Agricultural farming practices to increase production and mitigate GHG emission should be developed and applied comprising of:

- Study and develop new agricultural farming techniques, both increasing agricultural production and crop yield and mitigating GHG emissions.
  + Selecting short-duration, high yield and quality rice varieties, replacing transplantation by direct sowing practices, transfering from rice mono-culture systems to systems of two rice crops and one secondary crop, or one rice and one secondary crop.
  + Applying pill-form fertilizer (NPK) instead of fertilizer casting, as before.
  + Studying and enhancing food processing for animals, while selecting high quality, productive breeds.
- Improvement of irrigation-drainage management in rice fields.

  In irrigated rice fields, the implementation of water drainage, during maximum stem spreading and after grain-filling phases, would save water, increase rice yield and mitigate methane emissions.
- Establishing a data bank and equipping calculation facilities to serve specialized research in agriculture and climate change.
- Improving the meal and eating tradition of the people, so that the meal includes not only rice, but also various vegetables, and other foodstuffs, to ensure the provision of adequate calories and reduce the pressure on rice cultivation. Some rice fields could also be used to cultivate secondary crops and other trees instead of rice.

3.2.6 Research on GHG reduction through CH_4 recovery in energy production and transportation

Methane Recovery from surface and underground coal mining and petrol exploitation

The coal industry in Viet Nam has existed for more than a decade. Coal mining activities in Viet Nam are mainly in Quang Ninh province, with the capacity down to 300 m being 3.88 billion tonnes. The main activities of coal mining occur in Quang Ninh, with a capacity of 3.88 million tonnes down to 300m. Coal capacity in exploitation master planning is 2.6 million tons, in which 2 million tonnes is pitted. Coal in Quang Ninh is Anthracite with a calorific value of 6,000 – 8,000kcal/kg.

The North Delta is predicted as a potentially high capacity source of brown coal, with around 250 billion tonnes with a calorific value of 4,000 – 5,000 kcal/kg. This is a energy source, but also a potentially significant GHG emission source.

Coal production in Viet Nam coul reach 30 – 35 million tonnes of run-of-mine coal/year. In 2004, coal production was 27.3 million tonnes of run-of-mine coal and coal consumption was 25 million tonnes. After 2010, Viet Nam has plans to produce 40 – 45 million tonnes of coal/year.

Survey results from the Institute for Mining Science and Technology on the capacity of some typical mines shows that the capacity of Mao Khe is 1.8 billion m^3 (from a height of 100 m to a depth of 300 m), while the capacity of Nga Hai is 1.48 million m^3 (from the Earth's surface to a depth of 300m).

Gas emissions from some coal mining of Quang Ninh (Mao Khe, Thanh Cong, XN 916, and Khe Cham) could reach 7.12 – 14.66 m^3/day and night by 2010. According to this calculation, after 2005, the number of mining areas with gas emissions of 15 m^3/tonnes/day and night was very high. Therefore, methane recovery from pit is imperative to ensure the safety of production, recovery of energy resources, and to contribute to reduction in GHG emissions.

Viet Nam has received and researched the technology for attracting methane from pit to be used in the metallurgy sector, electricity generation, and domestic activities and technology on underground gasification to convert coal fuel to natural gas for electricity production, or to chemical products, such as Hydro and Methanol.

The coal industry in Viet Nam plans to collaborate with advanced industrial countries, such as Germany and Japan, to implement methane capture projects, especially CDM projects to reduce GHG emissions from coal production.

Petrol exploration has high annual reserves and production outputs. However, there is only one project on methane recovery on the collection and utilization of gas co-generation for Rang Dong, with a reduction capacity of 6.77 million CO_{2eq} in 10 years.

Methane Recovery from large landfill in big cities

Total waste generation in big cities in Viet Nam is significant. In Ha Noi, the total annually amount of solid waste collected was 245 – 365 thousand tonnes in 1995 – 1998, and up to half a million tonnes in recent years.

In most of the big cities in the country, solid waste is mainly treated by dumping. Most of the landfills do not meet hygienic standards. Therefore, in addition to the impact on community, the CH_4 emissions are quite high.

From the beginning of the 1990s, many projects have been implemented focusing on methane recovery from landfills for electricity generation or use as other fuel sources. For example, in 1997, experts from the Asia Least Cost Greenhouse Gas Abatement Strategy Project (ALGAS project) proposed a project for methane recovery from a large landfill in Ho Chi Minh city. The CDM project developed the idea of methane recovery from landfill. Among the proposed list, two projects related to methane recovery are:

- Electricity generation from methane recovery from a Ho Chi Minh city landfill, with the potential for CO_2 reduction of 321 thousand tonnes CO_{2eq}.
- Collection and utilization of methane from Thuong Ly landfill (Hai Phong) with a reduction capacity of 9 thousand tonnes of CO_{2eq}.

3.3 Strategy and climate change adaptation options in Viet Nam

3.3.1 Development and implementation of options to respond to climate change

Water resources

- Building reservoirs with a total additional capacity of 15-20 billion m^3.
- Upgrading and raising the scale of the drainage system.
- Upgrading existing sea and river-mouth dykes, and step by step building new sea dykes.
- Limiting the population growth rate and organizing new resettlement areas in coastal area
- Reclaiming areas, especially in hilly midland areas in the North of Viet Nam, for agricultural production.
- Using water scientifically and effectively.
- Exploiting, while protecting water sources.
- Conducting studies in long-term water resources prediction.

Agriculture

- Development of crop patterns suitable to climate change.
- Effective use of irrigation water in a planned manner.
- Upgrading of the irrigation system for agriculture.
- Development of new varieties that could survive severe environmental conditions.
- Reserve and storage of local crop varieties, including establishing a crop seed bank.
- Development of farming techniques appropriate to climate change.

Forestry

- Enhancing reforestation, firstly in watersheds, then re-greening bare lands and hills, and protecting and developing mangrove forests.
- Protecting natural forest and taking steps to end natural forest exploitation. Preventing forest fires.
- Establishing a bank of seeds of natural forest trees, in order to protect some valuable varieties.
- Enhancing timber processing efficiency and limiting the use of wood as a material.
- Selecting and replicating plant varieties suitable for natural conditions taking into account their vulnerability to climate change.

Fisheries

- Changing farming structure in some wetland areas from rice monoculture to fish-rice rotation systems.
- Taking into account sea level rise and increasing of temperatures while building infrastructures, quays, ports, and store houses, etc.
- Developing plan for brackish water aquaculture for Central Viet Nam with 2000 km of coast and sandy land to create an effective and multiform business, without affecting agricultural land.
- Building back-up dykes behind sea dykes to create transitional belts between agricultural land and sea.
- Building storm shelter port systems along the coast, as well as on islands.
- Establishing natural ecological reserves, especially coral reefs and atolls.

Coastal zones

There are 3 strategic options for active adaptation to sea level rise:

- Full protection: implement all-sided protection measures to maintain the present situation, effectively responsing to sea level rise.
- Adaptation: reform infrastructures and habits of the people living in the coastal zone to adapt to sea level rise.
- Withdrawal: avoid natural impacts of sea level rise by resettlement, moving houses and infrastructures from threatened areas.

Energy and Transportation

- Taking into account climate change factors in planning for energy and transport development.
- Upgrading and reconstructing transport infrastructure in areas threatened by sea level rise and flood.
- Ensure demand side management of energy (DSM) is based on highly efficient energy use, economical and rational use of energy, and ensuring energy security and safety.
- Developing strategies to response and adapt to the vagary of weather.

Medicine and Human Health

- Improve public knowledge of family sanitation and culture through national programs, such as "Clean Water and Environmental Sanitation", "Garden - pond – breeding facilities", and "Biogas", etc.
- Developing a national plan and programs for medical control and monitoring in areas that have a high danger of infections.
- Establishing green, clean and beautiful areas.
- Promoting public awareness on climate change.
- Preventing infection and disease transmission from outside.

3.3.2 Climate observation and monitoring in Viet Nam

Observations and monitoring on climate change

Surface monitoring system

Climate observation and monitoring systems in Viet Nam, set up since the end of the 19^{th} century, consists of a meteorological surface station network and some other specialized stations. Ha Noi meteorological station was established first, in 1898. Currently, after more than 100 years of establishment and development, the meteorological station network in Viet Nam consists of 166 meteorological surface stations. Meteorological surface stations conduct all, or part of, meteorological element observations, such as weather phenomena, atmospheric pressure, wind, cloud, solar radiation, sun-shine duration, air and soil temperatures, rain, precipitation, humidity, and evaporation.

Two thirds of all station are in the North. In the North, station numbers account for half of station in the country.

Stations have been established in different the periods, but mostly from 1945 to 1975. Most meteorological data series are long enough for climate research and climate change monitoring. There are more than 130 stations that have 30-year and longer observation data series, and more than 60 stations with 60-year and longer observation records.

Meteorological surface stations are classified into 3 categories based on the number of observational meteorological parameters, times of observations per day and responsibility of observation data transmission.

Class-1 meteorological stations conduct all meteorological element observations, 8 times a day (1 hour, 4 hours, 7 hours, 10 hours, 13 hours, 16 hours, 19 hours, and 22 hours)

Class-2 meteorological stations conduct all meteorological element observations, except atmospheric pressure and temperature in deep land, 4 (1 hour, 7 hours, 13 hours, and 19 hours) or 8 times per days with the monitoring being conducted over a long time period.

Class-3 meteorological stations conduct all meteorological element observations, except atmospheric pressure and temperature in deep land. These stations may (or may not) be involved in the data transmission system.

Specialized meteorological station network

Specialized meteorological stations include 10 upper-air meteorological stations, 5 weather radar stations, 37 agro-meteorological stations, 20 marine hydro-meteorological stations, and 902 rain-gauge sites.

Upper-air meteorological stations conduct observations of temperatures, humidity, wind, or only of wind within atmospheric layers below 30 -35 km, one or two times or more a day, and transmit observed data to international and/or domestic meteorological forecasting centers.

Weather radar stations conduct observations at locations, as well as the intensity and sphere of climate systems, such as typhoons, tropical low pressure, rainstorms, and large rain range, etc., within the atmospheric layers below 100 – 300 km, and within the radius of radar operation.

Agro-meteorological stations conduct observations on both hydro-meteorological factors and the growth and development of some crops, mainly wet rice.

Marine hydro-meteorological stations conduct 4 observations a day on sea level, sea temperature and salinity.

The rain-gauge station network in Viet Nam conducts observations of precipitation by using direct rain measuring instruments or rain recorders in different areas, with the density of multi-fold of those done by the meteorological surface station network.

The hydrological station network conduct observations on water level, run-off, temperature, and some parameters of water quality, to serve flood forecasting and warning, water and water resource use and management.

Environment monitoring station network

In close relationship with the meteorological surface station network, is the water and air environment monitoring station network.

The first environment monitoring station in Viet Nam was established in 1987. So far, environment monitoring stations have developed into a systematic network comprising of:

- 1 ground atmospheric monitoring station belonging to the World Meteorological Organization (WMO) Basic Pollution Monitoring Network,
- 3 urban/industrial zone pollution monitoring stations,
- 22 rainfall and dust deposition sampling stations,
- 51 river water quality monitoring stations,
- 48 salinity monitoring sites,
- 11 reservoir environment monitoring stations,
- 6 marine environment stations.

The environment factors observed are the following:

- Cumulated dust deposition, rainfall chemical compositions, SO_2, NOx and CO,
- Hydro-chemical constituents (BOD, COD, pH, and DO), heavy metals hydrocarbon, coliform, and salinity.

In addition, Viet Nam has 3 stations to conduct observations on connective ozone and UV radiation.

Observations and researches on climate change

Observations and researches on climate change in Viet Nam include:

1. To preliminarily correct and edit specific characteristics of observed parameters of each meteorology station about each observation parameter, according to a standard procedure and set up a file of observation data .
2. To gather the meteorological records of all stations for the National Documentation Center and to (i) correct and edit all meteorological data from all the stations and (ii) to set up monthly and annual reviews on every observation factor in the whole network.
3. To promulgate meteorological observation data in monthly hydro-meteorological magazines,
4. To do preliminary research on and promulgate annual meteorological research results in annual hydro-meteorological characteristic magazines
5. To carry out researches or special themes or subject on:

- To analyze year-after-year changes in the characteristics of typical meteorological parameters
  * Cold front variability,
  * Tropical Cyclone of East Sea,
  * Tropical Cyclones hitting Viet Nam
  * Arithmetic average value of the main parameters,
  * Extremes of the main parameters,
  * Rain and drought situation, floods, ElNino, LaNina, etc.
- To assess the level of changes of each parameter characteristics during the whole observation process,
- To identify climate anomalies among the series of meteorological observations,
- To study climate changes over decades and define the sudden changes of principal climate factors in recent years or decades .

Box 3.1. Climate Change and Biological Diversity in Viet Nam

Viet Nam is considered to be one of countries in which shall be affected hardly by global climate change. In the last years, the country had met face to face with storms, floods and droughts, and the present is suffering the consequence of a damaging 38-day cold-wave unprecedented in history, which could be to a large extent, attributed to global climate change. Consequences by global climate change to Viet Nam are more evident in which have the impacts to biodiversity, as the valuable resources but Viet Nam still do not have the serious studies in this field. Eventually, the Earth's temperature shall continue to be hotter and the sea level shall also become higher. Basing on the reliable studies in the world for Maldives islands, Bangladesh and in some of other area and comparing with Viet Nam's natural conditions, we can anticipate the consequences of climate change in which shall influence strongly two great deltas: the Mekong Delta and the North Delta, areas along the seacoast, and forest ecological systems in the whole country.

- Two deltas and coastal areas of our country wherein mangrove forest and system of flooded land with an abundance of organism kinds are the very sensitive ecological systems and easy to be injured.
    - High sea level rise along with intensity of storms, change of sediment component, degree of saltiness and water pollution level shall menace to the depression and life condition of mangrove forest as well as organisms' diversity here.
    - When the sea level rises, half of the 68 wetlands which are classified as national importance, shall be influenced seriously, sea water shall penetrate into the inland deeply and shall kill freshwater zoological and botanical species of this important ecological system, as well as shall influence the source of freshwater for life purposes and cultivation systems in many areas.
    - 36 protected areas, of which include 8 national parks and 11 national reserves, shall be inundated areas (according to the evaluation results made by ICEM).
- Marine ecological systems shall be injured. Coral reefs, where important seafood species and other sea organisms live and as a shields against the erosion of the coast and for the protection of mangrove forests, shall receed, as the result of increasing sea temperature and, at the same time, higher rainfall shall cause alluvial pollution to the water and agricultural chemicals poured from the estuary are possible to cause.
- There is large biological diversity in our country, but they have been degraded seriously by other reasons. Climate change, along with its consequences, such as floods, droughts, forest fires, erosion, and landslide, shall impulse the recession of biological diversity promptly and seriously, especially in the ecological systems of tropical forest of which is not intact and dangerous and pressing species with a little quantity.

Translate from: Prof. Dr. Vo Quy: Global climate change and biological diversity. Seminar on Global climate change and settlement solutions of Viet Nam, 2008

Box 3.2. Influence of Climate Change to the Biodiversity in the Agriculture in Viet Nam

Biological diversity and Climate change have a close and interactive relationship and, simultaneously, the levels and properties of these interactions shall vary, in accordance with space and time; Climate change is an important reason causing the declination of biological diversity. Conversely, a declination of biological diversity and downfall of natural organisms shall also contribute to result in a climate change. It's possible to analyze impacts of biological diversity and climate change consisting of sea level rise and temperatures, change in the bio-climatologic cycle (the number of days with a temperature <20^{0}C shall decrease and the number of days with a temperature >25^{0}C shall increase); change in water resources – declination of their quality and quantity, change in the land surface quality and quantity; natural phenomenon, such as storm, cyclone, ENSO, floods, flash floods, droughts, while devolution shall occur with a higher intensity and/or frequency.

In Viet Nam, the sea level rise shall lead to a loss of low-lying lands and ecological systems of wetland in the two biggest deltas, where the long-standing population communities live with the high poverty-stricken rate in the whole country; These areas have the largest agricultural production potential within the country and possess natural organisms of native species of which consist of nature and biosphere reserves.

The temperature's increase shall cause a change in the disposition areas and structure of biome in several coastal ecological systems: tropical species shall decrease in the coastal ecological systems, moving to the higher zones and latitudes of the terrestrial ecological system, the temperate species shall decrease; string structure and food net will also vary. Climate change shall increase the recession of some of wild trees – a precious gene in creating new varieties and simultaneously, it shall disappear some agricultural nurslings by not adapting to climate change.

Climate change will influence inland water-basins (river, lake, swamp etc) by changing the temperature of water and water-level, resulting in a large weather change (rain, storm, drought, and forest-fire regimes, etc.) and in water flow; especially the frequency and timing of large floods and droughts shall decrease the biological output consisting of crop plants in the fields of agriculture, industry and forestry. The widespread loss of native botanical species shall cause serious consequences to the economy.

Translated from Prof. Dr. Le Van Khoa: Climate change – Threat to the Viet Nam agriculture and rural. Seminar on Global climate change and Adaptation Options of Viet Nam, 2008

Box 3.3. Climate Change Causing a Direct Impact to the Harmful Insects for Agricultural and Industrial Production

Agriculture is a sensitive sector to climate. Climate change causes variation in the ecological system in agriculture by increasing the average temperature. The eco-climatologic (crop) cycle and water system have become more variable (the frequency and intensity of drought, floods, and rainfall has already undergone changes) and pestilent insect group have changed in regards to their breeding behavior and resistance to pesticides.

Climate change shall influence seriously the floristic composition and the forest ecological system. The disposition and limitation of primeval and secondary forest areas shall be moved and shall increase the threat of extinction of species and lead to disappearances of valuable and rare genes. The dry weather and extensive droughts shall increase the forest-fire risk, and growth of pestilent insects, leading to epidemic diseases harmful to the forest-trees.

The productivity and life cycle of termites (Isopteran coleopteran), a seriously harmful insect to the architectures, dikes and embankments shall also be influenced directly by climate change. Termites are known to have generally survived and cause massive damage to the architectures at the top after large floods.

Translated from Prof. PhD. Truong Quang Hoc, Prof. Dr. Tran Duc Hinh: Climate change – Impact to the pathogenic vector and harmful insect. Seminar on Global climate change and Adaptation Options of Viet Nam, 2008.

Box 3.4. Impacts of Climate Change on the Ecology of Mangrove Forest

The result of a study on climate change and the ecology of mangrove forest (EMF) in Viet Nam shows that there are 6 factors affecting this sensitive ecology: (1) Air temperature, (2) Rainfall, (3) Northeast monsoon, (4) Storms; (5) Flood-tides; (6) Activities of humans (Hồng, 1993).

Moreover, there is an indirect link between climate change and EMF due to the change of sea level. Some factors have immediate effects while others have long term effects such as Northeast monsoon the increase of river streams, heavy rainfall in local areas, the deposition of alluvium, and the effects on humans (Hồng, 1993).

- The Northeast monsoon plays an important role in sea level rise in Viet Nam. The monsoon appears in the dry season until November of the previous year to April of the next year, in conjunction with the period of the highest tide level in a year (from October to December). As the result, the salt water intrudes into the mainland, especially in Mekong River Delta.

According to the documents of the Mekong River Commission (1993), when the speed of the wind is 5m/s, the sea level rises 20 cm, if there is no wind, the sea level only increases 4cm. Where salt and brackish water intrudes, trees in the mainland are salty by the stream.

- The increase of river stream is one main reason, but it usually happens in the rainy season and has effects in the short term. Especially, the sea level rises most prominently in the day of storms combining with flood tides that cause enormous asset damages to the coastal community and the erosion of the coast, including the areas of defending mangrove forest (MF). In mountainous areas, when the rain is too intense and heavy, flash floods and landslides occur, seriously degrading primeval forests.
- The adverse effects of human activities include destroying MF for damming to grow rice and shrimp ponds overwhelmingly in the area of the tidal marsh and to prevent the movement of the tide. As a result, they affect the growth and development of all kinds of mangrove trees. They also destroy the source for living of sea fish and tidal animals, change the stream flow, and decrease its dispersal in tidal marshes and coastal areas. Using underground water to adjust the salt level in the large areas of feeding shrimps, as well as using water for living, wastefully can cause the degradation of the underground water sources seriously, although, these sources are necessary for kinds of mangrove trees and creatures living in mud. They also affect the geological structure of coastal areas (Hong et al, 2007).
- Sea level rise and monsoons, storms, and flood-tides erode the shore. In the East of Ca Mau peninsula, Northeast monsoons and flood-tides have washed away kilometers of road from Ghenh Hao to Dat Mui hamlet. There is 20-30m of land loss in the width of the river mouth of Bo De, Rach Goc, and the area of Khai Long, which results in trees in mangrove forests, including ancient Avicennia marine, fall down every year. The flood-tide sends sand into the shore that makes kinds of mangrove trees with the roots on the land buried or dead (Hong 1991).
- The sea level rise shall create favourable conditions for some mangrove trees in invading interior land and agricultural lands, especially in Quang Binh and in the South-West; thence forward it shall influence the food output and biological diversity. The number of freshwater animal and botanical species shall disappear and shall be replaced with brackish water species.
- The sea level rise shall also hinder deposition of alluvia to the tide-expanses and the natural regeneration of mangrove trees, such as mam tree, vinegary cypress etc.

Translated from Prof. PhD. Phan Nguyen Hong, Dr. Le Xuan Tien: Mangrove forest and settlement capacity to the sea level rise level. Seminar on Global climate change and settlement solutions of Viet Nam, 2008.

Box 3.5. Influences of High Sea Level rise

Influencing the water supply of coastal areas by a saltiness increase of surface and underground water, increasing salty penetration by a sea level rise.

According to the UN report on the occasion of World Environment Day (5th June 2007), water volume for domestic purposes and agricultural production in coastal areas and islands shall decrease due to sea level rise.

Viet Nam is a nation along a sea coast with 3,230 km of seaside, the North was formed by the North Delta, the South took form by the fat alluvium of the lower section of the Mekong river, the Central is a narrow strip of land, extending the length of the country and connecting the North Delta with the Mekong delta. With a unique geographic situation and topographic and geomorphologic character, Viet Nam, according to the IPCC projections, shall be one of 12 nations to be seriously influenced by sea level rise.

In case the sea level rises by 1 meter:

- The lost area of land of Viet Nam shall be > 12.3%, which shall result in losing the residences of 23% of the population (17 million people), 27% of natural organisms, 33% of reserves, and 23% of biological diversity zones have been influenced.
- According to a research report by the World Bank, published on the "Influence of high sea level rise in the developing countries", the North Delta and the Mekong delta shall be influenced hardest.

In case the sea level rises by 2 meters:

- The lost area of land of Viet Nam shall be > 16% along with 1/3 GDP upwards shall be influenced.
- Climate change shall result in unpredictable weather phenomenon. Storms shall have a degree of stronger ruination with every passing day. Damages caused by storms in Viet Nam were up to 1.2 billion USD in 2006.

Translated from Ass. Prof. Dr. Trinh Viet An, Center for Coastal and Island Estuary Dynamics – Global climate change – Problems have been invented to the agriculture and rural development – Institute of Water Resources. Ha Noi, July 2007

3.4 Conclusions

1. The natural changes in climate elements have occurred in Viet Nam, as well as other countries. The trend of recent climate change in Viet Nam, as also observed in the trend of global climate change, is beyond the level of natural change.
2. For the last 50 years, changes in many climate parameters have been observed in Viet Nam. These include:

- The temperature has been increasing at a rate of 0.05-0.20^{0}C per decade,
- FRL has been decreasing by 0.49 per decade
- The frequency of tropical cyclones in East Sea has increased by 0.14 per decade,
- Tropical cyclones affecting Viet Nam have decreased in frequency by 0.42 per decade,
- Sea level has been increasing from 2.1-4.0 cm per decade.

3. The annual mean rainfall does not exhibit any significant increasing or decreasing trend. However, the annual rainfall has been decreasing in almost every provinces of the South, with an average decrease of below 100 mm per decade.
4. In recent decades, the temperature has been increasing and the sea level rising. The temperature will increase from 1.1 - 1.9^{0}C and 2.1-3.6^{0}C at low and high emissions scenarios respectively; the rainfall will increase from 1.0 – 5.2% and 1.8 – 10.1% at low and high emissions scenarios respectively; the sea level will rise by 65 cm and by 100 cm at low and high scenarios respectively, by the end of the 21st century compared with the end of the 20th century.
5. Climate change will have strong impacts on different socio-economic sectors, and seriously impact on water resources and agriculture. Climate change will also affect all regions, especially to the North Delta and Quang Ninh province, the North Central, South Central and the Mekong River Delta.
6. Although Viet Nam does not have the any legally binding commitment under the KYOTO protocol to reduce GHGs. Viet Nam has its own policies for sustainable development to limit GHG emissions in all sectors together with social-economic development. Viet Nam has a number of polices for GHG reduction, such as enhancing energy efficiency, promoting the utilization of renewable energy and the 5 Million Hectares Reforestation Program.
7. Viet Nam has been developing strategies for adaptation with climate change in all social-economic sectors and in all areas of country, especially the strategy to adapt with sea level rise in the coastal areas from North to South.
8. Viet Nam has taken in consideration many aspects of climate change, including climate change observation and monitoring; research; scenario development; evaluation of climate change impact; development and implementation of strategies and options to adapt with climate change.

References

1. Ministry of Natural Resources and Environment. Climate Change, Sea Level Rise Scenarios for Viet Nam, 2009.
2. Ministry of Natural Resources and Environment. Viet Nam Initial National Communication on climate change under United Nations Framework Convention on Climate Change. Ha Noi, 2003.
3. The GEF Small Grants Programme. Climate Change (training documents on climate change). Center of Science and Technology on Meteorology, Hydrology and Environment, 2006.
4. The Asian Development Bank. Climate Change in Asia, 1994.
5. UNDP. Human Development Report. Ha Noi, 2007.
6. UNEP - ROAP. Guiding Manual for Development of National and City Assessment Report on Climate Change.
7. Nguyen Trong Hieu. An Overview of Climate Change in Viet Nam. Center of Science and Technology on Meteorology, Hydrology and Environment, 2008.
8. Nguyen Trong Hieu. An Overview of Climate Change - Climate change in Ha Noi Viet Nam Academy of Science and Technology, Institute of Geography, 2006.
9. Truong Quang Hoc, Tran Duc Hinh. Climate Change and Impacts on the spread of diseases and pests. Conference on "Climate change and Viet Nam's response", 2008.
10. Phan Nguyen Hong, Le Xuan Tuan. Mangrove forest and capacity to cope with sea level rise. Conference on "Climate change and adaptation in Viet Nam", 2008.
11. Le Van Khoa. Climate Change - Threat to rural areas in Viet Nam. Conference on "Climate change and adaptation in Viet Nam", 2008.
12. Nguyen Duc Ngu, Nguyen Trong Hieu. Climate and Viet Nam's climate resources. Scientific and Technical Publishing House of Ha Noi, 2004.
13. Nguyen Duc Ngu, Nguyen Trong Hieu. Situation of Climate Change in Viet Nam. Institute of Meteorology and Hydrology, 1998.
14. Le Dinh Quang, Tran Duy Binh, Nguyen Trong Hieu. Strategy for climate change mitigation and adaptation in the world and in Viet Nam. Center of Science and Technology on Meteorology, Hydrology and Environment, 2006.
15. Vo Quy. Global Climate Change and Biodiversity. Conference on "Climate change and adaptation in Viet Nam", 2006.
16. Nguyen Van Thang, Hoang Duc Cuong. Study on Establishing the Climate Change Scenarios Period 2010 - 2100 with low, medium and high-level scenarios from 2010 to 2100 for 7 climate regions in Viet Nam. Institute of Meteorology and Hydrology, 2007.
17. Le Nguyen Tuong, Ngo Si Giai et al. Assessment on adaptability and ready response to climate change, Institute of Meteorology and Hydrology, 2006.

APPENDIX 1: Climate Change Terminologies

Aerosols: A collection of airborne particles solid or liquid, with a typical size between 0.01 and 10 micrometers (μm), and residing in the atmosphere for, at least, several hours. Aerosols may be of either natural or anthropogenic in origin. Aerosols may influence climate in two ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation, or modifying the optical properties and lifetime of clouds. The term has also come to be associated erroneously with the propellant used in "aerosol sprays".

Climate change: Climate change refers to any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer). Climate change may result from:

- natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun;
- natural processes within the climate system (e.g. changes in ocean circulation);
- human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.)

Mitigation: A human intervention to reduce the sources or enhance the sinks of substances that pollute the environment, for example green house gases.

Climate (change) scenario: A climate scenario consists of projections of possible climate futures, containing developments of driving forces, green house gas emissions, temperature change, and sea level rise, and their key relationships. A climate change scenario is the difference between a climate scenario and the current climate.

Emission scenario: Representation of the future development of emissions of green house gases based on a set of assumptions about driving forces and their key relationships.

Anthropogenic emissions: Emissions of particles or substances resulting from human activities, such as fossil fuel use, industry and agriculture.

Adaptation: Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates, harms or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation

System vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. This is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

APPENDIX 2: GHG Emissions in Viet Nam

1. National GHG emissions in the 1990s

1.1 Inventory methodology and data

Under the project of Viet Nam Initial Communication for United Nation Framework Convention on Climate Change (UNFCC), Viet Nam conducted GHG inventory for the year 1994. In addition, Viet Nam also conducted GHG inventory in 1998 under the National Program for UNFCC implementation.

GHG inventory in 1994 and 1998 was conducted for sectors with high emissions, including energy, industrial processes, forestry and land use change, agriculture and waste.

The inventory was conducted according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC) 1996. The data used for inventory came mainly from the Statistic Year Book of GSO, published by a statistical publisher.

1.2 GHG inventory in 1994

For GHG emissions, 1994 was considered as a typical year for the early-to-mid 1990s. Below is the GHG inventory for the main socio-economic sectors.

1.2.1 GHG in Energy sector

- **GHG emissions from fuel combustion**

In 1994, Viet Nam produced 6.2 million tons of coal, and 7.1 million tonnes of oil. All crude oil was exported. Coal was partly exported and partly used to meet domestic needs. Conversely, Viet Nam imports around 3 – 4 million tonnes of petrol (firewood remains an important fuel source in the Viet Nam energy structure. However, this emissions sources was not inventoried).

Coal and petrol was consumed by many sectors including Energy Industry, Industry and Construction, Transport, Services/ Commercial, Household, Agriculture, Forestry and Fishery, etc. Total GHG emissions from fuel combustion were 21.580

Table A1. Green house gas emissions by energy consuming sectors in 1994

Unit: thousand tonnes

Sector	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Energy Industry	4,115.07	0.109	0.045	11.759	0.836	0.246	2.979
Industry and Construction	7,671.17	0.433	0.081	22.061	5.199	0.931	5.359
Transport	3,634.43	0.465	0.043	35.822	158.724	30.342	1.365
Services/Commercial	1,974.69	0.242	0.022	2.421	19.198	1.964	1.118
Household	1,806.04	118.777	1.545	40.011	1,931.933	231.216	286.69
Agriculture, Forestry and Fishery	887.73	0.098	0.007	14.537	12.355	2.446	0.511
Others	1490.87	0.385	0.013	2.155	1.59	0.222	0.812
Total emission	21,580.0	120.589	1.756	128.763	2,129.836	267.367	298.84

Source: Viet Nam Initial National Communication, 2003

Table A2. Total methane emission from exploitation in Viet Nam

Unit: thousand tonnes

Exploitation type	CH_4
Underground coal mining	37.362
Surface coal mining	2.387
Oil exploration	0.748
Gas exploration + gas burning	4.565
Leaking	1.702
Total	46.764

Source: Viet Nam Initial National Communication, 2003

million tonnes of CO_2; 120.509 thousand tonnes of CH_4 and around 2 thousand tonnes of N_2O (Table A1)

- **GHG Emission**

The CH_4 generated from fuel (coal, oil and gas) was 46.764 thousand tonnes, in which the CH_4 from underground coal mining and surface coal mining accounted for 39.749 thousand tonnes, while from the oil exploitation, gas exploitation and leaking equaled 7.015 thousand tonnes (Table A2)

1.2.2 GHG emissions from industrial processes

Industrial process that cause emissions are cement production, use of hydrated lime, soda production, soda consumption, steel manufacturing, paper and pulp production, food and beverage processing industries, etc. The physical and chemical actions from those processes emitted CO_2, CH_4, NOx, and SO_2.

The total GHG emissions from industrial process in 1994 were primarily 3.807 million tonnes of CO_2, 1.612 million tonnes of SO_2. (Table A3).

1.2.3 GHG emissions from forestry and land use change

• CO_2 sequestration by forest biomass growth

In 1994, Viet Nam had 8,252 thousand ha of natural forest, 1,049.7 thousand ha of planting forest and 9,778 thousand ha classified as forestland without forest. The total number of planting trees in 1994 was 350 million, with the growth rate of natural forest around 0.05-4.0 tdm/ha/year (tonne of dry biomass

Table A3. Industrial processes and GHG in Viet Nam in 1994

Unit: thousand tonnes

Industrial processes	CO_2	NO_x	CO	SO_2	NMVOC
Cement production	2,677.24			1,611.18	
Use of hydrated lime	651.99				
Soda production	0.52				
Soda consumption	2.24				
Steel manufacture	475.2	0.011		0.012	0.008
Paper and pulp production		0.230	0.861	1.076	0.569
Beverage					0.136
Food processing industries					4.075
Total	3,807.19	0.241	0.861	1,612.266	4.788

Source: Viet Nam Initial National Communication, 2003

per ha annually), of planting forest 3.0-8.45 tdm/ha/year and of bared land 0.05-1.50 tdm/ha/year. The total amount of CO_2 sequestered by forests in 1994 amount to 39.272 million tonnes.

- **CO_2 emissions from forest and grassland conversio*n***

In 1994, there were 338,000ha of land use change, of which 40,600ha involved evergreen forest. GHGs emissions from these activities in the year 1994 were estimated at: CO_2: 56.72 million tonnes; CH_4: 0.18 million tonnes; N_2O: 0.00124 million tonnes; CO: 1.57 million tonnes; NOx: 0.0447 million tonnes.

- **CO_2 sequestration by natural regeneration in abandoned farmland**

The natural regeneration of forest in abandoned farmland or degraded forest for the period of about the last 20 years is 820,000 ha. The estimated sequestered CO_2 amount to around: 11.05 million tonnes.

- **CO_2 emissions in the inventory year by soil from previous land use change and management:**

In 1994, with more than 20 millions ha of clay, hundreds of thousands of ha of volcanic soil, sand soil, wet soil, and peat soil, and 27,815 tonnes of lime used for the reform of soil for planting trees, the estimated CO_2 emissions amounted to 8.824 million tonnes.

- **GHGs emission/sequestration in forestry and land use change**

Green house gases (in CO_2 equivalent) emitted into the atmosphere by forestry and land use change in 1994 was 69.7 million tonnes, while sequestration was 50.32 million tonnes and emission/sequestration balance was 19.39 million tonnes (Table A4)

Table A4. GHG inventory in forestry and land use change in 1994

Unit: Million tons CO_2

Emission/absorption type	Emission	Absorption
CO_2 absorption by biomass growth		39.27
CO_2 emission due to land use change	56.72	
CH_4, N_2O Emissions (estimated in CO_2 equivalent)	4.16	
CO_2 absorption by natural regeneration		11.05
CO_2 emission from soil	8.82	
Total:	19.38	

Source: Viet Nam Initial National Communication, 2003

1.2.4 GHG emissions from the agricultural sector

- **Livestock**

In 1994, with 18 thousands dairy cattles, 3.449 million non-dairy cattles, 39.77 million buffalo, 137.779 domestic poultry, 15.588 million pigs and hundreds of thousand goat and sheep, methane emissions from the livestock sector were estimated at 465.565 thousand tonnes, 336.585 thousand tonnes of which were from enteric fermentation and 128.980 thousand tonnes from manure management.

- **Rice cultivation**

The total area of rice cultivated in 1994 was 6.599 million ha, more than 60% of which was under constant irrigation, while the rest was not constantly irrigated. Total methane emissions from wetland rice fields were estimated at 1,559.7 Gg, of which, 873.8 thousand tonnes were released in the North of Viet Nam and 685.9 thousand tonnes in the South.

- **Savanna land**

With the burning of 20,000 ha of shrub savanna and 260,000 ha of grass savanna, the total emissions generated by this sub-sector for the year 1994 were estimated at 15.91 thousand tones of CH_4, 417.5 thousand tones of CO, 0.20 thousand tones of N_2O, and 7.11 thousand tones of NOx.

- *Field burning of agricultural residues*

The main field crop residue burning sources are rice and sugarcane residues in the South. The emissions produced by this sub-sector as reported in 1994 were as follows: 51.72 thousand tonnes of CH_4, 1,086.07 thousand tones of CO, 1.19 thousand tones of N_2O, and 43.17 thousand tones of NO_x.

• *Agricultural soil*

N_2O emissions from agricultural soil relating to the microbial processes of nitrification and denitrification in the soil for the year 1994 were estimated as 26.02 thousand tonnes of N_2O, of which 16.63 thousand tonnes came from direct emissions from the soil, 0.004 thousands tonnes from fertilizer and 9.39 thousands tonnes from indirect emission sources.

• *Total Green House Gas Emission from the Agricultural Sector*

Total GHG emissions from the Agricultural Sector estimated for the year 1994 includes 2,092.8 thousand tonnes of CH_4, 27.4 thousand tonnes of N_2O, 1,503.6 thousand tonnes of CO and 50.3 thousand tonnes of NO_x. Calculated by CO_2 equivalent, green house gas emission in the agricultural sector were estimated to be 52.45 million tonnes, which made it the highest emitter among all GHG emitting sectors (Table A5)

1.2.5 GHG emissions from waste sector

• CH_4 emission from solid waste

In 1994, the total population in urban areas was 14,425,600, of which 10,238,000 lived in four major cities (Ha Noi, Ho Chi Minh City, Hai Phong, and Da Nang). The average, DOC composition for Viet Nam in 1994 was equals to 8.1% MSW, while CH_4 emissions from domestic wastewater were 66.3 thousand tonnes.

• Methane emissions from domestic and commercial wastewater

The proportion of wastewater anaerobically treated and the methane emissions coefficient was 5% and 75% respectively. Methane emissions from domestic wastewater treatment in Viet Nam were estimated at 1.027 thousand tonnes for the year 1994.

Table A5. GHG emissions from agricultural sector in 1994

Sub sector		CH_4 (thousand ton)	N_2O (thousand ton)	CO (thousand ton)	NO_X (thousand ton)	CO_2 (million ton)	Rate (%)
Rice cultivation		1,559.7	-	-	-	32.75	62.4
Livestock	Enteric fermentation manure	336.6	0.001	-	-	7.07	13.5
	Manure management	129.0	-	-	-	2.71	5.2
Agricultural soil		-	26.0	-	-	8.06	15.4
Prescribed burning of savannas		15.9	0.2	417.5	7.1	0.4	0.7
Field burning of agriculture residues		51.7	1.2	1,086.1	43.2	1.46	2.8
Total		2,092.8	27.4	1,503.6	50.3	52.45	100

Source: Viet Nam Initial National Communication, 2003

Table A6. Emission (CO_2 equivalent) from waste sources in Viet Nam, 1994

Emission source	CH_4 (thousand tons)	N_2O (thousand tons)	Emission equivalent	CO_2 Equivalent (thousand tons)
Solid waste	66.298		21	1,392.258
Domestic and commercial waste water	1.027		21	21.567
Industrial waste water	0.790		21	16.59
Emission from human		3.660	310	1,134.600
Total	68.115	3.660		2,565.015

Source: Viet Nam Initial National Communication, 2003

- **Estimation of methane emissions from industrial wastewater**

Industrial wastes mainly come from beer, wine, milk, sugar, seafood processing, vegetable oil, paper industry, rubber industry, with the volume of wastewater produced ranging from tens to hundreds m^3/tonnes in the above-said sectors, estimates of total methane emissions from industrial wastewater processing in 1994 standing at 0.79 thousand tonnes .

- **Human's emission**

The population of Viet Nam in 1994 was approximately 70.8 million, with N_2O emissions from humans in 1994 estimated at 3.66 thousand tonnes.

- **GHG emissions from the waste sector**

Estimated GHGs emissions from various waste sources in 1994 was 68.63 thousand tonnes of CH_4 and 3.66 thousand tonnes of N_2O, equal to 2,575.8 thousand tonnes of CO_2 equivalent (Table A6).

1.3 Summary of Viet Nam's National GHG Inventory in 1994

With 5 green house gas emission sources, namely, energy, industrial processes, forestry and land use change, agriculture, and wastes, the total national GHG emissions in CO_2 equivalent for the year 1994 stood at 103.8393 million tonnes, with highest emission coming from the energy sector and lowest emissions from waste sector (Table A7)

1.4 GHG emission inventory in 1998

1998 is considered as a typical year in the middle to latter parts of the 1990s. According to estimates undertaken by Focal Point of UNFCCC in Viet Nam (Ministry of Natural Resource and Environment), total GHG emissions in the year 1998 were 120.8 million tonnes CO_2 equivalent (Table A8).

The highest GHG emissions for the year 1998 also came from the agricultural sector (47%), with the lowest emissions coming from the waste sector (2%). Compared with 1994, emissions from the agricultural sector were reduced by 2%, although, emissions from

Table A7. Results of GHG inventory in 1994

Emission sector	Emissions in CO_2 equivalent (thousand tons)	(%)
Energy	43.2	36
Industrial processes	5.6	5
Forestry and land use change	57.3	47
Agriculture	12.1	10
Waste	2.6	2
Total emission	120.8	100

Source: Viet Nam Initial National Communication, 2003

Table A8. GHG emission from main sectors in 1998

Emission sector	Emissions in CO_2 equivalent (thousand tonnes)	Percent of the total (%)
Energy	43.2	36
Industrial processes	5.6	5
Forestry and land use change	57.3	47
Agriculture	12.1	10
Waste	2.6	2
Total emission	120.8	100

Source: Office of Viet Nam National Steering Committee for UNFCCC

Table A9. GHG emission in the years 2010 and 2020

Unit: million CO_{2eq}

Sector	1994	2000	2010	2020
Energy	25.64	45.92	105.17	196.98
Forestry and land use change	19.38	4.20	21.70	28.4
Agriculture	52.45	52.50	57.20	64.70
Total	97.47	102.60	140.67	233.28

Source: Viet Nam Initial National Communication, 2003

the energy sector had increased by 20%. One notable point was that the active national reforestation programme led to reductions in GHG emissions from the forestry sector, while land use change related emissions were reduced from 19.38 million tonnes in 1994 to 12.1 million tonnes in 1998.

2. GHG emissions in future years

According to National Initial Communication of Viet Nam for UNFCCC, GHG emissions in Viet Nam's main sectors, including energy, forestry and land use change, and agriculture are estimated to be about 140.67 million tonnes in 2010 and 233.28 million tonnes in 2020 (Table A9). One point of note here is that while the emissions from industrial processes and waste sectors would still account for around6.1% (same at 1994); the total GHG emissions in the decades 2010 and 2020 will be 149.39 and 247.74 million tonnes, respectively.

As such, compared with 1994, National GHG emissions in the decades of 2010 and 2020 will be 410% and 768% respectively for energy; and 109% and 123% respectively for agriculture. From the year 2000, in the forestry and land use change sectors in particular, the CO_2 sequestration will exceed CO_2 emissions. During this time, energy will replace agriculture as highest CO_2 emission sector.