EFFECTS OF CO_2 AND CH_4 EMISSIONS ON CLIMATE VARIABILITY IN THE TROPICS

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CERTIFICATION

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DEDICATION

This work is dedicated to God the father, God the son and God the Holy Spirit

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ABSTRACT

Climate variability is indicated as anomalies in weather parameters such as rainfall and temperature. These are being influenced by greenhouse gas emissions such as carbon dioxide (CO_2) and methane (CH_4), amongst others. This variability is usually studied using General Circulation Models (GCMs) and empirical models obtained from analyses of data at synoptic weather stations. The GCMs give different predictions from model to model due to parameterisations of microprocesses embedded in them. Likewise, empirical models are often applicable to locations of studies and most stations in the tropics are yet to be analysed. Hence, this work was aimed at analysing and modelling both CO_2 and CH_4 concentrations over the entire tropics with a view to understanding their contributions to climate variability.

Daily concentration data of CO_2 and CH_4 from the 12 stations, with minimum of 10-year data, within latitude 30°N and 30°S were obtained from World Data Centre for Greenhouse Gases, Japan. These data, between January 1996 and December 2005, were analysed using standardized anomalies, moving average and autocorrelation methods. Box-Jenkins iterative method which combines both moving average and auto regression analyses, was employed for modelling the concentrations (ψ_i) of the gases as a function of time. The suitability of the developed model was determined by comparing the predicted and measured monthly concentrations of these gases for the period January 2006 to December 2008. The standard deviations (σ_i) of the concentrations of these modelled gases were correlated with Roy Spencer's tropical temperature anomaly data to ascertain their warming effect.

The standardized anomalies showed seasonal variations and smoothening of these data by moving average revealed monotonic increase with time. The autocorrelation function showed that CO_2 can be predicted with higher accuracy than CH_4. The developed model was of the form: $\psi_1 = a_1 + b_1(120+t) + c_1(120+t)^2 + \sigma_1$ for CO_2 and $\psi_2 = a_2 + b_2(120+t) + c_2(120+t)^2 - \sigma_2$ for CH_4, where a_i, b_i, c_i and t represent the intercept, linear term coefficient, quadratic term coefficient and predicted month respectively. The mean annual concentrations calculated using the model for CO_2 and CH_4 in the northern hemisphere stations ranged from 381.5±0.3 to 384.3±0.3 ppm and 1793.5±1.4 to 1832.9±1.7 ppb respectively, while the measured values ranged from 382.9±0.2 to 384.5±0.2 ppm and 1787.3±1.4 to 1823.3±1.0 ppb respectively.

Similar agreement was obtained between calculated and measured values for southern hemisphere stations. The correlation coefficient between predicted and measured concentrations of CO_2 and CH_4 for year 2006 to 2008 was 0.99 and 0.96 respectively. The σ_i for CO_2 and CH_4 concentrations in northern hemisphere ranged from 0.3 to 0.9 and 0.5 to 3.3 respectively, while those in southern hemisphere ranged from 0.4 to 0.7 and 0.2 to 4.2 respectively. The σ_i increased with climatic warming and had highest value for 1998, the warmest among the years considered.

Concentrations of both CO_2 and CH_4 increased monotonically with time. The developed model predicted CO_2 and CH_4 concentrations adequately in the tropics and could also be used to predict their future concentrations and climate warming effectively.

Keywords: Climate variability, Greenhouse gases, Temperature anomaly, Model
Word count: 483

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LIST OF ACRONYMS

%	Percentage
µ	Micro
AR	Autoregressive
ARMA	Autoregressive moving average
ASCII	American Standard Code for Information Interchange
asl	above sea level
B.C.E	before the Common Era
Br	Bromine
$CaCO_3$	Calcium carbonate
CCl_4	Tetra chloromethane
CFCs	Chlorofluoro Carbons
CH_3CCl_3	Tri chloromethane
CH_4	Methane
Cl	Chlorine
CO	Carbon monoxide
CO_2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organization
CV	Coefficient of variation
E	East
ENSO	El Nino and its Southern Oscillation counterpart
EPA	Environmental Protection Agency
F	Fluorine
GCM	Global Climate Model / General Circulation Model
Gen.	Genesis
GISS	Goddard Institute for Space Study
H_2O	Water
HCFCs	Hydrochlorofluoro Carbons
ICSU	International Council of Scientific Union
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared radiation
JMA	Japan Meteorological Agency
Km	Kilometer

LAT	Latitude
LONG	Longitude
m	Meter
MA	Moving average
MD	Mean deviation
MS	Microsoft
N	North
N_2	Nitrogen
N_2O	Nitrous oxide
NOAA/GMD	National Oceanographic and Atmospheric Administration
O_2	Oxygen
O_3	Ozone
^oC	Degree Celsius
^oF	Degree Fahrenheit
^oN	Degree North
OPEC	Organization of Petroleum Exporting Countries
^oS	Degree South
ppb	Parts per billion
ppm	Parts per million
S	South
SD	Standard deviation
SE	Standard Error
SO_2	Sulphur (IV) oxide or Sulphur dioxide
UK	United Kingdom
UNEP	United Nation Education Program
USA	United State of America
USAID	United States Agency for International Development
W m^{-2}	Watt per meter square
W	West
WDCGG	World Data Centre for Greenhouse Gases
WMO	World Meteorological Organization

CHAPTER ONE

INTRODUCTION

1.1 The physics of climate and weather

Climate and weather are driven mainly by solar radiation, which are subsequently redistributed through radiative, advective and hydrological processes. Climate and weather have a very great impact on living organisms on the planet whereby ecological systems have evolved over a geological time scale to suit the prevailing climate. The past two decades have brought disturbing evidence that human activities may be causing significant changes in global climate (IPCC, 2007).

Climate fluctuations are not new and several of them abound in Biblical times. A typical example is when Joseph interpreted Pharaoh's dream about the impending famine that was about to come upon the land of Egypt which he claimed shall be grievous because the years of great plenty as at then shall be forgotten (Gen. 41). What is new is that the number of people affected by the possibility of starvation has increased because there are now billions of people rather than the thousands of Biblical times (Schneider and Dickinson, 1974).

Climate can be explained simply as the sum of all statistical weather information that helps describe the average meteorology of a place or region i.e. weather conditions of an area over time (Kellert, 1997; Kerski and Ross, 2005). It requires an interaction between the land, ocean, atmosphere and cryosphere system (ice and snow) over a relatively long period of time. Since climate is a temporal and spatial average it is much more predictable than weather.

Climate can also be classified into short periods of the year: wet, dry, and so on. However many factors have continued to influence climate, but scientists have determined that human activities have become a dominant force, and are responsible for most of the warming observed over the past 50 years.

Climate factors including temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns, and the occurrence of extreme events also affect the intensification, spread and survival of crop diseases. Thus, higher temperature and humidity, and greater precipitation have been resulting in the spread of plant diseases, as wet vegetation promotes the germination of spores with the proliferation of fungi and bacteria, including increment in insects population which

are sensitive to temperature because they are cold-blooded. In addition, temperature is important for plant growth and development since there is an optimum temperature range requirement for maximum yield for any crop. Likewise, abnormal temperature increase for a crop over its optimum temperature could reduce photosynthesis and shorten the growing period i.e. growth rate, just as high temperature during flowering may lower the grain number, size and quality (Fraisse et al., 2009).

Weather, on the other hand, can be explained as the state of the atmosphere at a given time and place, and are exhibited by changes in such parameters as air temperature, air pressure, humidity, clouds, amount of precipitation, number of hours of sunlight an area receives, and wind (Ahrens, 1998; Griffiths, 1985).

Weather fluctuates greatly and is very difficult to predict unlike climate. However, when weather is averaged over space and time, the fact that the globe is warming emerges clearly from the data (Le Treut et al., 2007).

Extreme weather and climate events have received increased attention in the last few years due to the high rate of loss of human life and exponentially increasing costs associated with them (Easterling et al., 2000).

In summary, climate and weather have impact on man in terms of his day to day activities and survival, such as feeding and clothing, and his means of livelihood.

1.2 **Parameters that influence climate and weather**

The nature of both weather and climate is expressed in terms of the same basic elements that are measured regularly. The most important of them are: the temperature of air, the humidity of the air, the types and amount of precipitation, the pressure exerted by the air and the speed and direction of the wind. These elements constitute the variables from which weather patterns and climate types are deciphered. Changes in one of these elements often produce changes in the others. These basic elements are usually referred to as internal factors that cause climate change (Lutgens and Tarbuck, 1986). Other factors from which climate are determined include latitude, air circulation, ocean currents, and the local physical geography of an area with latitude, perhaps, being the most important factor of climate because it has the most direct influence on average yearly temperature

(Kellert, 1997; Moran and Morgan, 1991). The internal cause of climate is linked to factors within the earth system and is related to changes in the nature and behaviour of the major components of the climate system, namely the atmosphere, hydrosphere, biosphere, land surface and cryosphere. The external cause is linked to factors outside the earth especially the sun which is also referred to as Milankovitch variations, and solar output variations. Also, the human causes include global atmospheric pollution, deforestation, desertification (McGregor and Nieuwolt, 1998) and land use practices. However, it must be noted that weather is also influenced by the same parameters as classified above and meteorologists had recognized three general climate zones based on latitude. These are polar, temperate and tropical climate zones. The polar climate zones lies above latitudes 66½ ^{o}N and 66½ ^{o}S; the temperate climate zone lies between latitudes 23½ ^{o} and 66½ ^{o} for both the northern and southern hemisphere and the tropical climate zone lies between latitudes 23½ ^{o}N and 23½ ^{o}S (Kellert, 1997).

1.2.1 **Man's impact on climate**

Wesler (1953) reported that man's influence on climate began to show up several thousand years ago in sequence with the development of agriculture which changes natural conditions. Also, the side effects of man's economic activity via industrial development, including rapid progress in technology during recent decades, have progressively increased the pollutant content of the atmosphere such as the ejected waste of industrial enterprises including gaseous admixtures (CO_2, SO_2, CO), solid particles (soot, dust), and other components.

Many other studies have pointed to the burning of fossil fuels, such as coal and oil as part of the many human activities which influence the earth's climate whereby large amounts of CO_2 are released into the atmosphere (Kellert, 1997). In essence, human activities, including greenhouse gas emissions (e.g. CO_2, CH_4, N_2O), aerosol emissions (e.g. sulphate, carbon, nitrate and dust), and land use change (e.g. deforestation, land development) are increasingly affecting global climate.

1.3 **Consequences of Climate Change/variability**

The consequences of climate variability and climate change are so numerous, but can be categorized into agricultural, economic, environmental, social, and health issues. However, USAID (2007) reported that these consequences are potentially more significant for the poor in developing countries than those living in more prosperous nations. Often, the poor are dependent on economic activities that are sensitive to the climate e.g. agriculture and forestry activities which likewise depend on the local weather and climate conditions; a change in those conditions would directly impact productivity levels and diminish means of livelihoods.

In essence, observations and data are consequently the foundation of climate change science, and they have shown evidence that the global climate has changed and is still changing.

1.4 Justification for the research

Over 45% of the world's population resides in the tropics and majority of the countries depend on agriculture as the main sector of their economy where climate is usually one of the main factors that influence production. Also, in the tropics, due to large increases in population, there is a widespread and very dangerous imbalance between needs and production of food. Thus, whenever normal production is disturbed by factors such as exceptional weather conditions serious famines may occur which could result in mass starvation of several millions of people whose agricultural production is on subsistence basis. In addition, the increase in the industrial/technological development in this part of the world is resulting in the utilization of fossil fuels, including oil and coal. This is enhancing global atmospheric pollution as a result of greenhouse gas emissions which is contributing to temperature rise and also causing climate change. However, Climate change is usually studied using General Circulation models (GCMs) and Empirical models. But Empirical models are preferred because the solutions of GCMs are complex and imprecise to solve. Also, in the Tropics the data for most of these greenhouse gases are just been documented for a few numbers of years with these data mainly for CO_2 and CH_4 which are yet to be analyzed to ascertain their contributions to climate change. Thus, the essence of this work is to investigate the anomalous variation of the earth's atmosphere in terms of the increment in the concentration of CO_2 and

CH_4 gases and their trends to the expected climate in the tropics in order to be able to understand their contributions to climate variability using Empirical models.

1.5 Objectives of the research work

The objectives of this research work are to:

1. Analyze the variations of greenhouse gases (CO_2 and CH_4) in the tropics within latitude 30^oN and 30^oS in terms of:
    (i) time variation of concentration of greenhouse gases and their mean cumulative rate of concentration
    (ii) spatial variation of concentration of greenhouse gases at 5^o latitudinal and longitudinal intervals.
2. Evaluate the correlation of the variations of these greenhouse gas concentrations with global warming

CHAPTER TWO

LITERATURE REVIEW

2.1 Climate change/variability

Climate variability is the term used for changes in climate over time scales of less than 100 years. However, both climate variability and change are measured using the same parameters.

Climate variability is often used to denote deviations of climate statistics over a given period of time (such as specific month, season, or year) from the long-term climate statistics relating to the corresponding calendar period (Yeh and Fu, 1985). In this sense, climate variability is measured by those deviations which are usually termed anomalies.

Climatic anomaly is the deviation of a particular climatic variable from the mean or normal over specified time. It is through observations that it can be shown that there had been changes in climate. Also it is the statistics of changes in weather over times that identify climate change (Le Treut et al., 2007).

Weather conditions and climate variability have an impact on the environment and major economic activities such as agriculture and tourism. Weather conditions may range from minutes (turbulence) to hours (diurnal) and to days, while climate variability may range from months to years. For convenience, climate variability could be described on seasonal, inter-annual and decadal time scales. When the time scale for climate reaches weeks, the whole atmosphere is often treated as an integral system in which there are strong connections between the variation in one place and that in another (Yeh and Fu, 1985). Thus, climate variability is primarily caused by interactions between the ocean and the atmosphere, and changes in associated circulation patterns. Much of the variability is natural, reoccurring at time scales that vary from months to decades and even longer.

Climate variability can also be explained as the variations in the mean state of climate on all temporal and spatial scales beyond that of individual weather events. Examples of climate variability include extended droughts, unusual tropical

storms, atypical floods and conditions that result from periodic El Nino and La Nina events (Intergovernmental Panel on Climate Change (IPCC), 2001; United State Agency for International Development (USAID), 2007).

Presently, there is no comprehensive theory of climate to explain its variability, as each theory that had been proposed to explain climatic variation are empirical in nature depending on the set of assumptions made (Lutgens and Tarbuck, 1986).

Climate variability is due to both natural and human activities. The natural activities could be short or long term events. They include solar variation, ocean currents, El Nino and many other causes. Human activities have been shown to influence climate in many ways, such as land use changes, like the irrigation of historically semi-arid areas for farmland, the paving and development of sprawling urban areas, the draining of wetlands, and increased aerosols in our atmosphere. Perhaps, the most significant human influence today is the increasing concentrations of greenhouse gases in the atmosphere, mainly CO_2 and CH_4, which have modified the earth – atmospheric energy balance, leading to a warming of the system (IPCC, 2007).

Climate change just like climate variability is any long-term significant change in the expected patterns of average weather of a specific region over an appropriately significant period of time. It reflects abnormal variations to the expected climate within the earth's atmosphere and subsequent effects on other parts of the earth (Climate change, 2009).

Climate change refers to shifts in the mean state of the climate or in its variability, persisting for an extended period (decades or longer). It may be due to natural changes or persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2001). There are many causes of climate change, but no real consensus of opinion among researchers in this subject seems yet to have emerged as to which of these or other factors may be dominant (McIntosh and Thom, 1973; Budyko, 1974; Houghton, 2004).

Statistically significant changes in climate occurring over a time scale of decades or longer constitute the "climate change". There are parameters responsible for climate change which have the capacity to store or release vast amount of energy on time scales ranging from days to centuries. Evidence shows that climate has

changed in the past, is still changing now and will continue to change in the future. It is therefore necessary to know the trend and cause that would produce this change since human activities may have influence on climate (Schneider and Dickinson, 1974).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosol (IPCC, 1996). However, many scientists are concerned that human activities may be causing changes in earth's atmosphere, which in turn may be altering climates around the world (Kellert, 1997).

Modern climate change is dominated by human induced changes in atmospheric composition, which are now large enough to exceed the bounds of the natural variability (Karl and Trenberth, 2003). The IPCC (2007) has affirmed that the dominant causes of climate change are human activities.

Climate patterns, variability and change are of great importance for the economic, social and environmental health of a people, nation, or region and are usually indicated by El Nino and its Southern Oscillation effects, rainfall variations or trends, temperature trends, e.t.c. In addition, human induced accelerated climate change has the potential to disrupt and destroy ecosystems. It is therefore, important to better understand and monitor weather patterns, variability and change.

2.1.1 **Natural climatic change/variability**

Natural, long term climate change/variability occurs in responses to fluctuations in the amount of solar energy reaching the earth, variations in the earth's orbital parameters, changing ocean currents etc. Also, shorter term events such as volcanoes and El Nino and its Southern Oscillation (ENSO) causes climate change. El Nino disrupts normal atmospheric weather patterns around the world, causing some areas to have stronger than normal storms, and some areas less stormy weather. It also causes changes in ocean currents and temperatures (Climate change, 2009).

El Nino leads, to a shift in time and duration of tropical rainfall. For example, areas that usually receives heavy rainfall, particularly in Indonesia and Australia, experiences drought which often leads to famine and devastating bush fire. El Nino which is an example of natural climatic variability releases heat from the ocean which eventually causes a general positive anomalies in global mean

temperature by shifting heat around different parts of climate system. The major impacts of El Nino are temperature anomalies, changes in precipitation variability, floods and drought throughout the world. El Nino events happen irregularly and have an average periodicity of 4 years. Its impacts are felt most and strongest in the tropics (Trenberth, 1997; El Nino-Southern oscillation, 2009).

The earth usually absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted into space. A portion of this outgoing terrestrial radiation is itself absorbed by gases in the atmosphere, warms the earth's surface and atmosphere, creating what is known as the 'natural greenhouse effect'. Without the natural heat trapping properties of these atmospheric gases, the average surface temperature of the earth would be about -5^{o}C lower (IPCC, 2001).

2.1.2 **Anthropogenic climatic change/variability**

IPCC (1996) stated that human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiations, or the emissions and absorption of terrestrial radiation. Also, in 2001 the IPCC further asserted that the concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities. The IPCC made it known that new evidence showed that most of the observed warming over the last 50 years is likely due to the increase in greenhouse gas concentrations. However, the International Council of Scientific Union (ICSU) had earlier reported in 1985 that the anthropogenic factors believed to be important in modifying the energy budget in the climate system and changes of climate include increases in CO_2 and other trace gases due to the growth in energy consumption and the change in content and magnitude of atmospheric pollution. Other sources of anthropogenic emission which leads to the warming of the atmosphere, usually referred to as the greenhouse effect, include: inputs from fossil fuel consumption, cement manufacture, flaring of natural gas, bush burning, agricultural practices and other human practices.

There are linkages between natural climate variations and anthropogenically induced changes. For example there is correlation between El Nino event and greenhouse gas concentration effects.

2.1.3 **Indirect measures of deciphering Climate Change/ Variability**

Proxy data is a data that substitutes for, or acts as a proxy for, the actual data we are seeking. In essence the term proxy is used to denote any material that provides an indirect measure of climate (Wigley et al., 1981). Thus, a climate proxy is a local quantitative record (e.g. thickness and chemical properties of tree rings, pollen of different species) that is interpreted as a climate variable (e.g. temperature or rainfall) using a transfer function that is based on physical principles and recently observed correlations between two records (Le Treut et al., 2007).

2.1.3.1 **Clues from historical data**

Clues about past climate can be obtained from information provided by farmer's logs, travellers' diaries, newspapers, and other written or documented records. The length of the growing season in a given location will vary with rainfall and temperature. For example, historical grape harvest dates have been used to reconstruct summer temperatures in Paris, France from 1370 to 1879. This method is not perfect but along with the use of other indirect measures, it allows a reasonable reconstruction of climate over a long period of time (National Oceanographic and Atmospheric Administration (NOAA) Paleoclimatology Program, 2002).

2.1.3.2 **Corals**

Corals build their skeletons from $CaCO_3$, a mineral extracted from sea water, through which some corals form annual rings as they grow. The carbonate contains isotopes of oxygen, as well as trace metals which are similar to those of tree rings which can be used to determine temperature. Hence, they too can be used to determine the temperature of the water in which they grow. When the temperature is warm the coral will grow faster than when the temperature is cold. So, warmer years will make wider growth rings and colder years will create thinner rings. These temperature recordings can then be used to reconstruct climate of coral growth (Solow and Huppert, 2004; DeLong et al., 2007).

2.1.3.3 **Fossil Pollen**

All flowering plants produce pollen grains with distinctive shapes which can be used to identify the type of plant from which they came from. Since pollen grains, which are usually very tough, are well preserved in the sediment layers in the bottom of a pond, lake or ocean, an analysis of the pollen grains in each layer tells us what kinds of plants were growing at the time the sediment was deposited. Inferences can then be made about the climate based on the types of plants found in each layer (Ge and Xiankun, 2002; Bradley, 1999).

2.1.3.4 **Tree Rings**

Tree growth is influenced by climatic conditions. Also, the patterns in tree ring width, density and isotopic composition reflect variations in climate.

In temperate regions where there is a distinct growing season, trees generally produce one ring a year due to rapid growth in the spring and summer, and little growth in autumn and winter. A warm and elongated summer year results in a wider ring. Patterns in the width, wood density, and gaseous (hydrogen and oxygen) isotopic composition of tree rings can be used to estimate temperature. Thus, this can be used to record climatic conditions of each year. Likewise, trees can grow to be hundreds of years old and can contain annually resolved records of climate for centuries (Yamaguchi, 1986; International Arctic Science Committee, 2010).

2.1.3.5 **Ice Cores**

Ice core provide key information about past climates, including surface temperatures and atmospheric chemical composition. The bubbles sealed in the ice are the only available samples of these past atmospheres. They also reveal a highly correlated evolution of temperature changes and atmospheric compositions. Scientists have observed a relationship between local temperature and deuterium concentration in ice collected during periods that temperature was also known (Nakazawa and Fujita, 2006; Ice core, 2008).

2.2 Historical overview on climate change/variability

The anomalies about changes of climate can be traced back to Aristotle, the 4th Century Greek philosopher, who lived between 384 – 322 B.C.E (Shaw, 1926). In the middle ages, storms and pestilence were so readily ascribed to the displeasures of the gods over the sons of men, such that efforts to systematize knowledge were rare including the common ground by which climatic variations were to be understood in terms of the general circulation of the atmosphere, pressure, temperature and rainfall measurements (Lamb and Johnson, 1959).

The theory of the interpretation of climate change in terms of the variable content of the atmosphere depends on the fact that the greenhouse gases are almost transparent to solar radiation and partially opaque to the long waves radiated back to space from the earth (Callendar, 1949).

According to the estimate of Machta (1971), the concentration of CO_2 in the atmosphere which has potential impact on climate may increase by as much as 20% during the latter half of the century as a result of fossil fuel combustion. Likewise, Rasool and Schneider (1971) explained that in the last few decades the concentration of CO_2 in the atmosphere appears to have increased by 7%.

In 1974, Schneider and Dickinson asserted that the understanding and prediction of climate change have recently acquired a sense of urgency as a result of serious climate related food shortages and with the realization that human activities may have an influence on climate. It was further reported by Oeschger, et al., (1975) that during the past 110 years, industrial activity has released to the atmosphere an amount of CO_2 comparable to the natural atmospheric level. Likewise, Keeling and Bacastow (1977) made long-term measurements at several stations and provided firm evidence that the atmospheric global concentration of CO_2 is increasing on a global scale. The increase is usually ascribed to the burning of fossil fuels, but changes in the carbon content on the biosphere may also contribute.

Newell and Dopplick (1979) made it known that it was generally agreed that increasing CO_2 will lead to higher atmospheric temperature. This was corroborated by Madden and Ramanathan (1980) that the possible climatic effects of large increases in atmospheric CO_2 due to burning of fossil fuels may constitute one of the most important environmental problems of the coming decades. Thus, the climatic

effects of an increase in the CO_2 content of the atmosphere have been the subject of many investigators (Manabe and Wetherald, 1980).

During the last century, man induced climatic changes on local and global scale have become a major concern primarily through changes in atmospheric composition and earth surface properties. The effects due to increase in CO_2 and other trace gases from growth of energy consumption and the changes of atmospheric pollution due to human activity are modifying the energy budget in the climate system and thus the changes of climate (Yeh and Fu, 1985).

In 1988, the IPCC was jointly established by the World Meteorological Agency (WMO) and the United Nation Environmental Program (UNEP). The IPCC, which is the most authoritative group on warming, comprise about 2,500 scientists from more than 130 countries, and is now recognized as the prime source of scientific and technical information on climate change and its environmental and socio-economic impacts. So far, the IPCC has presented four assessment reports on climate change (1990, 1996, 2001 and 2007) which confirmed that global warming is taking place and that human activities were probably to blame.

Ikeme (2005) affirmed that climate change is expected to bring about a shift in climate belts resulting in greater aridity in the tropics with huge impacts on energy production and supply. Likewise, Busallachi, et al (2005) asserted that there are many scientific challenges regarding human influence on climate, including the linkages between natural climate variations and anthropogenically- induced changes.

Climate change creates both risks and opportunities world-wide. By understanding, planning for and adapting to a changing climate, individuals and societies can take advantage of opportunities and reduce risks (USAID, 2007).

2.3 Greenhouse Gases

Greenhouse gases are gases which are transparent to the sun's short wave radiation, but are not transparent to the long wave radiation of Stefan's law, thus trapping heat within an atmosphere containing those gases. These variable gases when they absorb infrared radiation emitted from the earth's surface gain kinetic energy which they share with neighboring air molecules by collision, thus, increasing the average kinetic energy of the air, which results in an increase in air

temperature. Hence, most of the infrared energy emitted at the earth's surface keeps the lower atmosphere warm (Ahrens, 1998; Clayton, 1996; Houghton, 1998).

The greenhouse effect can be enhanced if the concentration of these greenhouse gases such as CO_2 and CH_4, which absorb in the infrared, is increased. For example, the maximum absorption of CO_2 lies within the wavelength range of 13 to 17 μm. The earth's long wave radiation is maximum at around 245 K equivalent to a wavelength range of between 10 and 20 μm. The overlap of these wavelengths makes CO_2 an efficient greenhouse gas (Houghton, 2004). The concentration of CO_2 in the atmosphere has being increasing because of the burning of fossil fuels and this will increase more rapidly in the future as the world consumption of fossil fuel accelerates. The increase in the atmospheric concentration of greenhouse gases is an important global issue because of the risk of adverse climate change (Khandekar, 2000). In recent years, changes in the composition of the atmosphere arising from human activities have been well documented and monitoring of these atmospheric concentrations shows that CO_2 as well as other greenhouse gases have increased during the past few decades via industrialization and other practices (IPCC, 1990).

There is a growing recognition that a significant percentage of the 20th century warming is due to emission of greenhouse gases.

Water vapor is the most important greenhouse gas, but human activities do not affect it directly. The three most powerful long-lived greenhouse gases in the atmosphere affected by human activities are CO_2, CH_4, and N_2O (Wallington et al., 2004). Amongst these three most powerful long-lived greenhouse gases in the atmosphere CO_2 is the most effective on climate change and next to it is CH_4 which is much more effective as a greenhouse gas but has less effect on climate change due to their smaller atmospheric concentration (Stang, 2009).

2.3.1 **Types and Sources of Greenhouse Gases**

Water vapour is a greenhouse gas whose concentration is not influenced directly by man. In 1996, the IPCC recognized other greenhouse gases apart from CO_2 whose concentrations have grown significantly since pre-industrial times (i.e. since about 1750) as a result of the influence of man to include CH_4 and N_2O. Likewise, the IPCC in 1990 had earlier reported that the atmospheric concentration

of CO_2 and other greenhouse gases had been increasing steadily since the late eighteenth century leading to enhanced radiative heating of the earth. An increase in radiative heating of the earth will warm the earth's surface and atmosphere and may alter the large-scale circulation patterns.

2.3.1.1 **Water Vapour**

Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapour.

Water vapour is neither long-lived nor well mixed in the atmosphere. It varies spatially from 0 to 2% by volume of air (IPCC, 1996). In addition, atmospheric water can exist in three physical states including gaseous, liquid and solid. Human activities are not believed to directly affect the average global concentrations of water vapour; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity, yet increased concentrations of water vapour affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation (IPCC, 1990). In this work we shall be dealing with other greenhouse gases apart from water vapour.

2.3.1.2 **Carbon dioxi**de

It is estimated that extraction and burning of fossil fuels is the source of about 70-90% of anthropogenic CO_2 emissions (Strong, 1992). However, Novelli et al. (1995) made it known that the largest source of CO_2 to the atmosphere is the combustion of anthropogenic fossil fuels, followed by emissions from deforestation and oxidation of CO to CO_2.

CO_2 in the atmosphere has increased by 10% during the past 50 years and may now be increasing even more rapidly. It has presumably increased greatly since the beginning of the industrial revolution in the eighteenth century (Plass, 1956). Also, Mitchell (1970) affirmed that CO_2 content of the atmosphere appears to have increased by more than 10% from 1890 to 1965, half of this since 1944. However, Oeschger et al. (1975) affirmed that measurements of the atmospheric CO_2 content had been reported since the beginning of the last century, but the values scatter over a considerable range, both because of the different analytical techniques used and

because of local variations of the CO_2 content which result from incomplete atmospheric mixing. Therefore, based on these measurements no large-scale interpretations could be made with any confidence. In addition, Keeling and Bacastow (1977) stressred that long-term measurement at several stations had provided firm evidence that the atmospheric concentration of CO_2 is increasing on a global scale.

The IPCC (1996) reported that CO_2 has increased by about 30% since pre-industrial time. In nature, carbon is cycled between various atmospheric, oceanic, land biotic and mineral reservoirs. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2 and its present concentration is largely due to anthropogenic emissions of CO_2 (IPCC, 2001). Forest clearing, biomass burning, and some non-energy production processes (e.g. cement production) also emit notable quantities of CO_2 (EPA, 2002).

2.3.1.3 **Methane**

CH_4 is been introduced into the atmosphere anthropogenically through biomass burning, fuel sources and natural gas (Cicerone and Oremland, 1988). It has been measured directly in the atmosphere since 1974 (Le Treut et al., 2007). IPCC (1996) affirmed that CH_4 has increased by about 145% since pre-industrial time till 1992. Although, the global budget of CH_4 is not well known, the largest sources are from wetlands, rice cultivation, fuel sources and ruminant animals. Other sources include natural gas effluent and oceans (Novelli et al., 1995). According to present understanding, CH_4 is formed by microbially mediated reactions in anaerobic environment, in water logged soils, in swamps, in rice fields and in the guts of various animals including cattle and termites. It is also emitted during the production and distribution of natural gas and petroleum, and is released as a by- product of coal mining and incomplete fossil fuel combustion (Bolin and McElroy, 1985; Cess et al., 1993; EPA, 2002).

The IPCC (2001) has estimated that slightly more than half of the current CH_4 flux to the atmosphere is anthropogenic, resulting from human activities such as agriculture, fossil fuel and waste disposal.

2.3.1.4 **Nitrous Oxide**

The concentration of N_2O has increased by about 15% since pre-industrial time till 1992 and its subsequent impact on the future climate has also been emphasized by IPCC. The anthropogenic sources of N_2O include agricultural soils, especially the use of synthetic and manure fertilizers, fossil fuel combustion, adipic (nylon) and nitric acid production, waste water treatment and waste combustion, and biomass burning (IPCC, 1996; EPA, 2002).

2.4 Greenhouse Effect

The greenhouse effect is the phenomenon in which variable (trace) gases such as water vapour, CO_2, CH_4, N_2O, O_3 and CFCs present in the atmosphere have the effects of potentially raising global temperature. These variable gases absorb infrared radiation emitted from the earth's surface, and gain kinetic energy, which they share with neighboring air molecules by collision, thus, increasing the average kinetic energy of the air, which results in an increase in temperature. Hence, most of the infrared energy emitted by the earth's surface keeps the lower atmosphere warm (Ahrens, 1998; Greenhouse effect, 2009).

It has been known for over hundred years that water vapour, CO_2, CH_4, N_2O and O_3 naturally present in the atmosphere trap heat in the atmosphere. Without the natural greenhouse effect the planet would be permanently frozen and devoid of life (Wallington et al., 2004).

The enhanced greenhouse effect refers to changes in the earth's radiation balance due to the accumulation in the atmosphere of radiatively active greenhouse gases. In addition to CO_2, other green house gases include CH_4, N_2O, tropospheric O_3 and CFCs. Their effect is to accelerate the warming effect beyond the acceptable levels (Ikeme, 2005; EPA, 2002).

Several classes of halogenated substances that contain F, Cl, or Br are also greenhouse gases, but they are for the most part, solely a product of industrial activities (Greenhouse gas, 2009).

Human economic activities has in the last 100 years, contributed to an increase in the concentration of greenhouse gases in the atmosphere leading to the enhanced greenhouse effect (IPCC, 1996) which in turn is expected to result in climate change, arguably the most important and dangerous, and certainly the most

complex global environmental issue to date (Holdren, 1992; Kandikar and Sagar, 1979).

Among the first set of researchers to propose the "greenhouse effect" of the atmosphere, which is a concept that explains that the earth's atmosphere acts somewhat like the glass of a greenhouse, letting through the sunlight (the short-wave light rays) while retaining a portion of the long wave radiation from the earth's surface which if emitted would have cooled the earth was the French mathematician Jean Baptiste – Joseph de Fourier in 1827. He warned that human industrialization could modify climate change. Others that further elaborate his work are Tyndall (1861) and Langley (1890).

John Tyndall was the first person to propose the "greenhouse" warming hypothesis. In 1859, he identified through laboratory experiments the absorption of thermal radiation by complex molecules (as opposed to the primary bimolecular atmospheric constituents O_2 and molecular N_2). He noted that changes in the amount of any of the radiatively active constituents of the atmosphere such as H_2O or CO_2 could have produced 'all the mutations of climate which the researchers of geologist reveal' and suggested that ice ages were caused by variations of the atmospheric levels of these gases. Also, Langley (1890) calculated the absorption coefficient for CO_2 and water vapour while measuring the intensity of radiation from the moon.

In 1895, Svante Arrhenius (1896), the Swedish chemist followed with some classic experiments on the absorption of heat radiation in gases. He noted the release of large amount of CO_2 by the burning of fossil fuel and was the first to estimate how changes in global concentration of CO_2 might affect mean global surface temperature, and also showed that a doubling of atmospheric CO_2 would warm the earth by 5-6 ^{o}C. He further addressed the question of whether such changes in the atmospheric CO_2 concentrations were reasonable and likely to be true. He then made some calculations of the human impact on climate with a climate prediction based on greenhouse gases, suggesting that a 40% increase or decrease in the atmospheric abundance of the trace gas CO_2 might trigger the glacial advances and retreats. One hundred years later, it could be found that CO_2 did indeed vary by this amount between glacial and interglacial periods. However, it now appears that the initial climatic change preceded the change in CO_2 but was

enhanced by it (Le Treut et al., 2007). His work was motivated by a desire to explain temperature variation of the earth's surface during the quaternary and glaciations cycles.

In 1899, the American geologist T.C. Chamberlain whose work focused mainly on the processes of CO_2 emissions into the atmosphere from volcanic eruptions, the absorption and out-gassing of CO_2 into and out of the world's oceans, and the role of rock formation and weathering in controlling terrestrial carbon reservoirs supported the principal conclusions of Arrhenius in his work and further elaborated on how concentrations of atmospheric CO_2 might change with time.

The studies of Arrhenius and Chamberlain did not receive much support among the atmospheric science community of that time, since the general consensus was that the absorption of long wave radiation (emanating from the earth) by water vapour was so strong that the absorption by CO_2 was negligible (Khandekar, 2000).

In 1938, G.S. Callendar, a British engineer, re-introduced the work of Arrhenius and the possible impacts of CO_2 on the atmosphere and the earth's climate, whereby he was the first to study this work quantitatively. He solved a set of equations linking greenhouse gases and climate change and found that a doubling of atmospheric CO_2 concentration resulted in an increase in the mean global temperature of 2^oC, with considerably more warming at the poles. He further linked the increasing fossil fuel combustion with a rise in CO_2 and its greenhouse effects.

Callendar's report induced a world wide interest in the CO_2 cycle because of the great importance of the atmospheric CO_2 content for the radiation balance of the earth. He also reviewed the available data on CO_2 and concluded that its levels were rising as a result of human activities with three quarters of this concentration remaining in the atmosphere thereby causing an eventual increase in atmospheric warming.

In 1940, Callendar further demonstrated that increased concentration could have significant global effects on the surface temperature of the earth whereby he suggested that the increase in atmospheric CO_2 concentrations may account for the observed slight rise of average temperature in Northern latitudes during recent decades. He also speculated for the first time that humans could have significant influence on the atmospheric CO_2 concentrations, but estimated that it would take several centuries of continued industrial emissions to achieve doubling

concentrations. Callendar's work rekindled interest among atmospheric scientists about the role of CO_2 on past as well as future climates, leading to the publication of several papers linking CO_2 concentration with atmospheric temperature increase.

In 1949, Callendar also speculated that an increase in the CO_2 concentration in the atmosphere may result in the gradual rise of the atmospheric temperature as a result of man's influence due to his demand for heat and power which led to the transfer of large quantities of 'fossil' carbon from the rocks to the air.

In 1958, Callendar as a result of his much interest in the effect of human activities on the natural circulation of carbon which demands a knowledge of the amount of CO_2 in the atmosphere both then and in the immediate past presented the average amount of the CO_2 obtained from 30 of the most extensive series of observations between 1886 and 1956 with the reliability of the 19^{th} century measurements. It was observed that there was an increasing concentration in CO_2 due to industrial activity and from clearing, draining and burning of vegetation.

In 1956, Plass suggested that CO_2 which has increased by about 10% during the past 50 years as a result of human activity since the beginning of the industrial revolution in the eighteenth century also accounts for climatic variations. He computed that doubling the present CO_2 content should raise the average surface temperature of the earth by 3.6 ^{o}C, while halving it should lower the temperature by the same amount. He stated that if at the end of this century measurements show that the CO_2 content of the atmosphere has risen appreciably and at the same time the temperature has continued to rise throughout the world, it will be firmly established that CO_2 is an important factor in causing climatic change.

In 1957, the well-known American geophysicist Roger Revelle and his companion Hans Suess in an important paper presentation proposed that "human beings are carrying out a large scale geophysical experiment through world-wide industrial activity that could lead to a building of CO_2 greater than the rate of CO_2 productions from volcanoes". They explained why part of the emitted CO_2 was observed to accumulate in the atmosphere rather than being completely absorbed by the oceans. However, they also pointed out that their consequences were unknown. Roger Revelle was instrumental in establishing the first station for long-term monitoring of atmospheric CO_2 in 1957 at Mauna Loa (Hawaii) and in launching an accelerated international research program on the potential human influence on the

climate system. Another CO_2 monitoring station was later established at the South Pole and several global CO_2 monitoring networks were established during the 1970s and 1980s. These networks have established the steady build up of atmospheric CO_2 data. The year 1958 was designated as the international geophysical Year and saw the start of an ongoing program of continuous measurements of atmospheric CO_2 levels at Mauna Loa, Hawaii, by Charles Keeling. This has shown that CO_2 concentration levels are steadily rising (from 315ppm in 1958 to 370ppm in 2007). Since then several authors have being affirming this increment in greenhouse gases which has greenhouse effect and an important role in modifying the vertical distribution of temperature in the atmosphere by controlling flux of infrared radiation and the global mean temperature rise roughly by 0.01^oC per ppm CO_2 increase (Manabe and Wetherald, 1967; Oxford Dictionary of Scientists, 2003; Roger Revelle, 2010).

The Mauna Loa and the South Pole stations clearly showed the seasonal cycles with opposite phases. The much larger amplitude in the Mauna Loa data is attributed to the larger land and vegetation areas of the Northern hemisphere (Khandekar, 2000). Most measurements of other greenhouse gases in the atmosphere such as CH_4 and N_2O started only a few decades ago.

In the 1950s, the greenhouse gases of concern remained CO_2 and water vapour, the same two identified by Tyndall a century earlier. It was not until the 1970s that other greenhouse gases – CH_4, N_2O and CFCs – were widely recognised as important anthropogenic greenhouse gases (Ramanathan, 1975; Wang et al., 1976).

In 1974, Bryson also explained that a one percent change in greenhouse gas concentration would change the surface temperature by about 0.3^oC and likely move the ITD Southward by 0.6^o latitudinally and reduce the West Africa monsoon rainfall by over 100mm per annum. Also, Crane (1981) affirmed that it must be recognized that increased CO_2 concentrations also have a direct effect on the temperature of the atmosphere as well as on that of the earth's surface.

In 1986, Dickerson and Cicerone asserted that atmospheric CH_4 absorbs infrared radiation which directly contributes to the greenhouse effect. Similarly, Novelli et al (1995) made it known that there has been changes recently in the rates of increase in the concentrations of both CO_2 and CH_4 in the atmosphere by both

natural and anthropogenic processes which led to the absorption of IR and a direct contribution to atmospheric warming despite their being present in small amounts.

2.5 Global warming

Global warming is the popular term for the human influence on global climate, although it really means global heating by which the observed global temperature increase is only one consequence. Another consequence of global heating of the troposphere is accelerated land-surface drying and increased atmospheric water vapour (the dominant greenhouse gas). Accelerated drying increases the incidence and severity of droughts whereas additional atmospheric water vapour increases the risk of heavy precipitation events (Karl and Trenberth, 2003).

Global warming caused by an increase in the concentration of greenhouse gases, is the direct result of greenhouse gas-induced radiative forcing (Cess et al., 1993). Lorenz (1970) reported that during the past century or two, routine meteorological measurements have revealed certain progressive changes, such as general warming trend during the first half of the twentieth century. Likewise, earlier historical times had seen changes in vegetation of the sort which evidently demand changes in rainfall or temperature regimes.

The most commonly cited indication of global warming is the trend in globally averaged temperature near the earth's surface, and the average global temperature over the past century which has increased by approximately 0.5^{o}C (or 0.9^{o}F). The global warming that occurred recently coincides with the spread of industrialization, prompting the suggestion that it is the result of accelerated greenhouse effect caused by atmospheric pollutants, especially CO_2 gas (Global warming, 2009).

In the absence of atmospheric circulation, the temperature in the most developed industrial regions would have increased by a value having the order of 1^{o} C, and in large cities by 10^{o}C and more, which presumably would have made life impossible there. The effects of atmospheric circulation weakens these rises in temperature considerably, this weakening being greater, the smaller the area in which the production of additional heat energy is concentrated (Budyko, 1974).

Anthropogenic global warming refers to that percentage of global warming attributed to human activity, including, but not limited to, the introduction of greenhouse gases into the atmosphere. Scientists have noted that human activities are the major causes of global warming that has been measured (IPCC,1996). Also it has been asserted that there is little doubt that in the absence of other climatic perturbations an increase in atmospheric CO_2 concentrations will give rise to globally averaged warming of the lower atmosphere because CO_2 is an absorber of outgoing long-wave radiation whose presence raises the surface temperature. The degree of warming for a given increase in the CO_2 concentration is, however, difficult to predict because it is not easy to predict exactly how much the temperature will rise because of the complexity in the global circulation and its influence on climate in general. This also depend on the complex interactions of physical processes in the atmosphere – ocean – cryosphere – lithosphere – Biosphere system which control climate. It is also difficult to compute changes in cloudiness and the role of the oceans. Associated with the warming are likely to be corresponding changes in the distribution of rainfall and the patterns of the atmospheric circulation (Liss and Crane, 1983; Brimblecombe, 1986).

CH_4 is much more effective than CO_2 as a global warming potential but is less effective on climate change because of its smaller atmospheric concentration than CO_2. The warming effect of CH_4 over a period of 100 years is 25 times stronger than that of CO_2. Fortunately, CH_4 appears in lower concentrations and disappears faster from the atmosphere than CO_2. After about seven years, half of all CH_4 emissions would have transformed into H_2O and CO_2 (methane-a ticking bomb, 2009)

According to U.S researchers who used tree rings and ice cores to determine temperatures over the past 1000 years, 1998 was the hottest year globally for the last millennium. The National climate center of the Australian Bureau of Meteorology affirmed that the hottest three decades of the 20^{th} century were the 1990s, 1980s and 1970s in descending order of hotness. The centre said this supported their prediction of global warming and believed that there has been a discernible human influence. Likewise, a report by marine biologists in October, 2000 estimated that 50-90% of the coral reefs in the Indian Ocean had died since 1998 as a result of warmer seas (Hutchinson Encyclopedia, 2008).

The climate change information centre of Armenia (2007) reported that eleven of the last twelve years (1995 – 2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850.

WMO (2005) reported that the predictions of the variation of global climate over periods of up to several years are particularly evident in the tropical regions. Moreover, it was mentioned that the global mean surface temperature for the year 2004 was 0.44^{o}C above the 1961-1990 annual average (14^{o}C). This value places 2004 as the fourth warmest year in the temperature record since 1861 just behind 2003 (+0.49^{o}C). The last 10 years (1995-2004), with the exception of 1996 are among the warmest on record. Thus, based on the aforementioned it was concluded that the five warmest years in decreasing order are: 1998, 2002, 2003, 2004 and 2001.

In addition WMO (2006) in a statement on the status of the 2005 global climate reported that the analyses made by various leading centers indicate that the global mean surface temperature in 2005 was 0.47^{o}C to 0.58^{o}C above the 1961-1990 annual average of 14^{o}C. This places year 2005 as one of the two warmest years in the temperature record since 1850 (The year 1998 had annual surface temperatures averaging 0.52^{o}C above same 30-year mean). The last 10 years 1996-2005, with the exception of 1996 and 2000, are the warmest on record. Based on this report the five warmest years in decreasing order has been revised as: 1998, 2005, 2002, 2003 and 2004.

In 2007, IPCC reported that in the 20th century, temperature rose 0.7 degrees and the 10 hottest years since records began in the 1850s have been since 1994. A temperature rise of between 1.1 and 6.4 Celsius was predicted by the year 2100. Also, sea level rise will be between 18 and 58 centimeters by the end of the century with an additional 10 to 20 centimeters possible if recent, surprising melting of polar ice sheets continues.

This trend is expected to continue through the present century and beyond leading to rates of global warming that will exceed any experienced during the past several thousand years.

2.6 Radiative Forcing

Radiative forcing is a measure of the effect of different greenhouse gases or aerosols on radiative balance of the tropopause which is a boundary between the troposphere and stratosphere located at approximately 10-15km. It is an absolute measure of the strength of a greenhouse gas on a per volume basis. Also radiative forcing can be explained as a simple measure of changes in the energy available to the earth-atmosphere system.

Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiations, or the emission and absorption of terrestrial radiation (IPCC, 1996).

The earth's surface temperature is primarily determined by the balance between the absorption and emission of radiation. A change in this radiative balance is termed radiative forcing which is measured in Watts per square meter. Holding everything else constant, increase in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e. a net increase in the absorption of energy by the earth) (EPA, 2002). The radiative forcing based on the 1992 values of CH_4 and N_2O are $0.47Wm^{-2}$ and $0.14Wm^{-2}$ respectively. These values are significantly smaller as compared to $1.56Wm^{-2}$ for CO_2 (Khandekar, 2000).

Increases in greenhouse gas concentrations since pre-industrial times (i.e. since about 1750) have led to a positive radiative forcing of climate, tending to warm the surface and produce other changes of climate. Many greenhouse gases (e.g. CO_2 and N_2O) had remained in the atmosphere for a long time up to decades and centuries; hence they affect radiative forcing on long time scales. Since pre-industrial times the amount of CO_2 in the atmosphere has increased from 278ppm to 370ppm and resulted in a radiative forcing change of approximately $1.56\ Wm^{-2}$. The amount of CH_4 in the atmosphere has increased from 700ppb (i.e. pre-industrial times) to 1700ppb at present and has resulted in a radiative forcing change of $0.47Wm^{-2}$ (Wallington et al., 2004). To evaluate the long-term impact of emission of greenhouse gases information is required about the residence (i.e. life) times of greenhouse gases emitted on account of human activities. A gas with a long residence time will have a greater impact on future climate than a gas with a short

residence time even if the radiative forcing of the two gases is the same. The atmospheric lifetime of CO_2 is around 100 years, while that of CH_4 and N_2O is around 12 years and 114 years respectively (Wallington et al., 2004).

2.7 Controls of Temperature

The main factors that cause variations in temperature from one place to another are called the controls of temperature. The main controls of temperature are latitude, land and water, ocean currents, atmospheric circulation and elevation (Ahrens, 1998).

Global temperature is an important indicator of global climate. The natural causes of global temperature change or fluctuations include ENSO, volcanic activity and solar flux variability (Folland and Colman, 2000).

Temperature is the best documented of the weather parameters and the easiest to infer from other evidence. Climatic change is not, however, a matter of temperature fluctuation alone; a change in the nature of the general circulation is implied and therefore, also in the distribution of rainfall (McIntosh and Thom, 1973).

2.8 Climate Models

The primary tools for predicting future climate are global climate models (GCM), which are fully coupled, mathematical, computer based models of the physics, chemistry, and biology of the atmosphere, land surface, oceans and cryosphere, and their interactions with each other and with the sun and other influences (such as volcanic eruptions) (Karl and Trenberth, 2003).

Climate models are mathematically based models that attempt to calculate the climate, its variability and its systematic changes on a first principle basis. The fundamental equations solved are the conservation equations of mass, momentum and energy (Schneider and Dickinson, 1974; Mahlman, 1997).

The climate system is too complex for the human brain to grasp with simple insight. Thus, formulating reasonable hypothesis regarding climate change requires physical insight and ingenuity, but subsequently testing this hypothesis demands quantitative computation. Models currently in use generally predict only the atmosphere, and pre-specify the state of its environment (oceans, land surfaces, sun,

etc). The problem of climate change is that it is highly conducive to speculations, and hypotheses easily outnumber established results (Lorentz, 1970).

Modelers look at climate in many different ways, but they all employ one standard calculation so that their results can be compared with those from other groups. They first calculate weather conditions for a simulated time of ten years or more, long enough so that average temperatures, rainfalls, and other quantities can be obtained. The first calculation is made with a standard atmosphere – one with the current amount of CO_2 or with some nominal earlier amount, say 300ppm. Then a second calculation is made with twice as much CO_2, 600ppm. The two results can be compared and the impact of the extra CO_2 estimated. All the models showed the heating to be greater at higher latitudes than near the equator (Firor, 1990).

A number of published model studies have examined the climatic effects of increased atmospheric CO_2 concentrations. These studies have employed a hierarchy of climate models, including the one – dimensional radiative – convective models, the two dimensional zonal model, and the three – dimensional general circulation model. Model studies are usually subjected to caveats i.e. particular things need to be considered before something can be done e.g. which aspects of the atmosphere and its environment are relevant or irrelevant in order to disregard complexity (Ramanathan et al., 1979).

Models have projected a warmer climate due to increasing concentration of greenhouse gases. The uncertainty in this estimate of global surface temperature rise arises from the use of models with differing sensitivity to greenhouse gas concentrations and the use of differing estimates of future greenhouse gas emissions (Weart, 2008; Global warming, 2009). Models project that if current trends in anthropogenic greenhouse gases emissions continue through 2030, the earth will experience an average rise in temperature ranging from 34.7^{o} to 40^{o}F (19.3^{o} to 22.2^{o}C) (Porter and Brown, 1991). The projected impact of this on environmental stability and life on earth will be so great and better imagined than experienced. They include changes in the global climate and the consequent disruption in the temporal and spatial distribution of temperature, precipitation, evaporation, clouds and air currents as well as the consequent shift in the vegetational belts; melting of the polar ice-caps, rise in sea level which could adversely affect low-lying areas, and the synergy among these discrete effects. Some or all of the above have implications for fresh water sources, agriculture and food supply, natural ecosystems, biodiversity and human health (Ayres and Walter, 1991; IPCC, 1996).

CHAPTER THREE

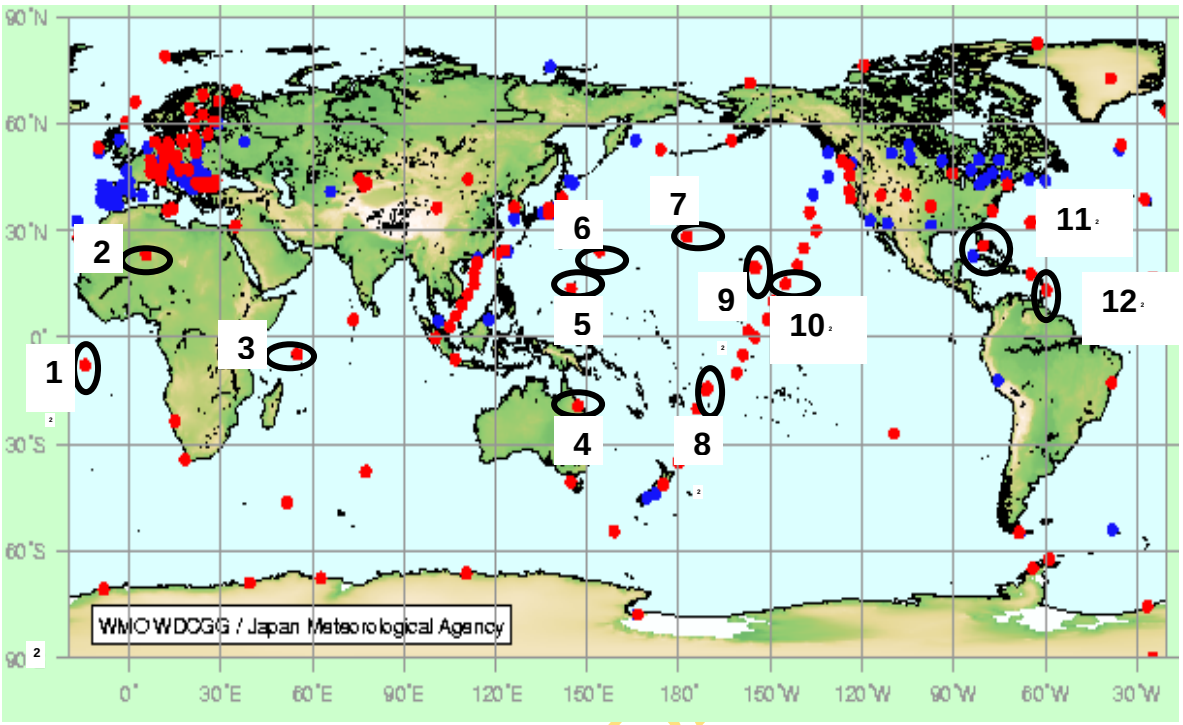
METHODOLOGY

3.1 Data Acquisition

Instrumental and documentary data (Wigley et al., 1981) were acquired from World Data Centre for Greenhouse Gases maintained by Japan Meteorological Agency in cooperation with World Meteorological Organisation for both CO_2 and CH_4. These ground based data were sourced mainly from National Oceanographic and Atmospheric Administration, Commonwealth Scientific and Industrial Research Organisation and Japan Meteorological Agency stations (Fig. 3.1).

The data file obtained employs an ASCII format, and not an MS-Excel or MS-Word in order to prevent computer viruses and also to ensure computer security. The hourly data are generated by arithmetic means from the per-minute data while the arithmetic means of hourly data are adopted as daily data. Likewise, the arithmetic means of daily data are adopted as monthly data and the arithmetic means of monthly data also adopted as yearly data

In this work it is only CO_2 and CH_4 that shall be considered among the gases which cause greenhouse effect in the atmosphere, and are anthropogenically produced, based on their major strength in terms of the magnitude of their concentration, residence (or life) time and contribution to global warming amidst other greenhouse gases in the atmosphere. Their climatological data were collected on the basis of samples taken from 12 available observation sites of Tropical regions which are ground-base stations. The period for data acquired is January 1996 to December 2008 (Table 3.1).



Legend:

1: Ascension Island, 2: Assekrem, 3: Mahe Island, 4: Cape Ferguson, 5: Guam, 6: Minamitorishima, 7: Sand Island, 8: Tutuila, 9: Cape Kumukahi, 10: Mauna Loa, 11: Key Biscayne, 12: Ragged Point

Fig 3.1 Sites from which CO_2 and CH_4 data were collected

Table 3.1 List of Stations/Observation Sites used for this study

S/N	Observation Sites/Territory	Latitudinal and Longitudinal Locations	Tropical Region	Altitude (asl)/m
1	Ascension Island(U.K)	Lat.7º55'S,Long.14º25'W	Africa	54
2	Assekrem(Algeria)	Lat.23º10'N,Long.5º25'E	Africa	2728
3	Mahe Island(Seychelles)	Lat.4º40'S,Long.55º10'E	Africa	7
4	Cape Ferguson(Australia)	Lat.19º17'S,Long.147º3'E	Pacific Ocean	2
5	Guam(U.S.A)	Lat.13º26'N,Long.144º47'E	Pacific Ocean	2
6	Minamitorishima(Japan)	Lat.24º17'N,Long.153º59'E	Asia	8
7	Sand Island(U.S.A)	Lat.28º12'N,Long.17722'W	Pacific Ocean	7.7
8	Tutuila(U.S.A)	Lat.14º15'S,Long.170º34'W	Pacific Ocean	42
9	Cape Kumukahi(U.S.A)	Lat.19º31'N,Long.154º49'W	Pacific Ocean	3
10	Mauna Loa(U.S.A)	Lat.19º32'N,Long.155º35'W	Pacific Ocean	3397
11	Key Biscayne(U.S.A)	Lat.25º40'N,Long.80º12'W	America	3
12	Ragged Point(Barbados)	Lat.13º10'N,Long.59º25'W	America	45

*asl=above sea level

The data acquired for this study lies within the region of latitudes 30^{o}N and 30^{o}S. McGregor and Nieuwolt (1998) have delineated the tropics of cancer and Capricorn as boundaries of tropical climates. However, Barry and Chorley (1992) had earlier explained that latitudinal limits of tropical weather conditions may reach well beyond the tropics of cancer (i.e. 23½^{o}N) and Capricorn (i.e.23½^{o}S) during periods of strong variations.

The tropics occupy four main areas: Tropical Africa, Tropical America, Tropical Asia and Tropical Oceans (including Oceanic Islands). For the various Tropical areas considered, data were obtained for Tropical Africa (3), Tropical America (2), Tropical Asia (1) and Tropical oceans (including oceanic islands) (6).

3.2 **Analyzing climatic data**

The various observations sites from which data were obtained from are Tropical Africa : Ascension Island (UK), Assekrem (Algeria) and Mahe Island (Seychelles); Tropical America: Ragged point (Barbados) and key Biscayne (USA); Tropical Asia: Minamitorishima (Japan), and Tropical oceans including oceanic islands: Tutuila (USA), Mauna Loa (Hawaii, U.S.A), Cape Kumukahi, (USA), Guam (USA), Cape Ferguson (Australia) and Sand island (USA).

The analysis of climatic data was made on the basis of samples taken based on the number of observed values for the element being considered (Day and Sternes, 1970).

The plots of these observation sites' greenhouse gas concentrations with those of time variations including their latitudinal or longitudinal variations shall be considered in order to be able to obtain climatic variability trends and fluctuations. Also, the correlation of the variations of these greenhouse gases with climatic trends shall be considered.

The processing of these climatic data shall be by the use of statistical model similar to the Box-Jenkins model (or Autoregressive moving average). Also other standard statistical methods used in analysing or processing of climatic data shall be considered such as mean, moving average, cumulative distribution and standard deviation (Day and Sternes, 1970).

3.3 Trend analysis

A trend indicates the general direction in which a particular parameter is changing or developing. This is usually obtained through smoothing (i.e. moving average) and then by fitting a function which suits the change or development.

Many data can be adequately approximated by a linear function with the multiple linear regressions used to make predictions in time (Folland and Colman, 2000). Likewise, the trend could be determined by computing the standard deviation for the 12 month anomaly distribution for each year (Stang, 2009). However, in this work the standard deviation is used in determining the warming pattern over the years.

The statistical parameters used to measure or estimate the centre of distribution is called the central tendency, and include the moving average, arithmetic mean, the median and the mode. While those for measurements of dispersion are standard deviation, variance, mean deviation, standardized anomalies, standard error, coefficient of variation, correlation coefficient and coefficient of determination.

3.3.1 The moving average

The moving average (MA) is frequently used in analysing climatic data for possible trends e.g. in determining whether temperatures are increasing or not. Evidence of trends may be concealed from year to year fluctuations of climatic components or from one type of regime towards another, but by smoothing out the fluctuations using moving average the trends may become apparent. Generally, the effect of the short term irregularities can be removed by various statistical techniques of which the simplest is the moving average. The moving average enables us to average out seasonal variations in both the CO_2 and CH_4 concentrations utilised in this work and to minimise their perturbations.

3.3.2 Arithmetic mean (Average)

The arithmetic mean is an important statistical parameter used to measure or estimate the centre of a distribution. The arithmetic mean of a set of N values generally referred to as the mean is obtained by adding them all together and dividing by N (Mulholland and Jones, 1983). Thus

$$\bar{X} = \frac{\sum_{i=1}^{N} xi}{N} \qquad \text{.....3.1}$$

If the x_i's are repeated with frequencies f_i, we have

$$N = \sum_{i=1}^{n} fi \qquad \text{..... 3.2}$$

and

$$\bar{X} = \frac{\sum_{i=1}^{n} fi\ xi}{N} \qquad \text{.....3.3}$$

The arithmetic mean was utilised in determining the mean of both CO_2 and CH_4 concentrations on monthly and annual basis in this work.

3.3.3 The median

The median is the value of the variate which divides a given set of discrete variates arranged in order of magnitude into two numerically equal groups. If there are even numbers of members in the set, the median is taken as half the sum of the values of the variates ascribed to the two middle members.

3.3.4 The mode

The mode of a distribution is the value of the variate with the largest frequency. It was used in this work to indicate the year with the number of greatest occurrence for the highest standard deviation values.

3.3.5 Standard deviation

The standard deviation (SD) which is the most satisfactory and widely used measure of dispersion takes into account all members of the population and can be manipulated algebraically. It tells us how much the measurement differs from the average. Also, standard deviation is the root mean square deviation of the measurement which is calculated by summing the square of the deviation of each value from the mean, dividing by the number of cases and then taking the square root.

$$SD = \sqrt{\frac{\sum(x_i - \bar{x})^2}{N}} \qquad \text{……..3.4}$$

When x_is are represented with frequencies

$$S.D. = \sqrt{\frac{\sum_{i=1}^{n} fi(x_i - \bar{x})^2}{\sum_{i=1}^{n} fi}} \qquad \text{…….3.5}$$

The standard deviation is the square root of variance and it measures the dispersion or spread, of a variable around the mean. The larger the standard deviation, the more variable is the distribution. Most weather statistics are not normally distributed; rather they are skewed toward either upper or lower values.

The square of standard deviation is called the variance. Likewise, both variance and standard deviation measures variability (Variance, 2010). The variance of a data set is calculated by taking the arithmetic mean of the squared differences between each value and the mean i.e.

$$SD^2 = \frac{\sum_{i=1}^{n} f_i(x_i - \bar{x})^2}{\sum_{i=1}^{n} f_i} \qquad \text{…….. 3.6}$$

Both the variance and standard deviation are used as indices of warming in this work because they show good correlation with global temperature trend.

3.3.6 **The mean deviation**

The mean deviation (MD) is another measure of dispersion of a set of variates sometimes used where the standard deviation is not available. It is represented by the equation.

$$MD = \frac{\sum|x_i - \bar{x}|}{N} \qquad \text{…….. 3.7}$$

If the x_is are represented with frequencies f_i, we have

$$MD = \frac{\sum_{i=1}^{n} f_i|x_i - \bar{x}|}{\sum_{i=1}^{n} f_i} \qquad \text{…….. 3.8}$$

3.3.7 **Standardized anomaly**

The standardized anomaly, Z, is computed simply by subtracting the sample mean $\overline{X}$ from the raw data X, and dividing by the corresponding sample standard deviation, σ_X i.e.

$$Z = \frac{X - \overline{X}}{\sigma_X} \qquad \text{.....3.9}$$

This can also be explained as dividing the anomaly $\overline{X_i}$ in the numerator by the corresponding standard deviation i.e.

$$Z = \frac{\overline{X_i}}{\sigma_X} \qquad \text{.....3.10}$$

This transformation is sometimes referred to as normalization.

The standardized anomaly showed seasonal variations in both CO_2 and CH_4 concentrations.

3.3.8 **Standard error**

The standard error (SE) which is also known as the standard deviation of the mean is expressed as:

$$\text{SE} = \frac{SD}{\sqrt{N}} \qquad \text{..... 3.11}$$

$$\text{i.e. SE} = \sqrt{\frac{\sum(x_i - \bar{x})^2}{N^2}} \qquad \text{..... 3.12}$$

Likewise,

$$\text{SE} = \frac{\sqrt{\sum(x_i - \bar{x})^2}}{N} \qquad \text{..... 3.13}$$

Thus, when x_is are represented with frequencies

$$\text{SE} = \frac{\sqrt{\left(\sum_{i=1}^{n} f_i(x_i - \bar{x})\right)^2}}{\sum_{i=1}^{n} f_i} \qquad \text{..... 3.14}$$

The standard error in a similar way as the standard deviation was used in indicating anomalies (i.e. warming) in this work.

3.3.9 The coefficient of variation

The coefficient of variation (CV) can be used to give some measure of the relative importance of the standard deviation to the mean. It is expressed mathematically as:

$$\text{Coefficient of variation} = \frac{standard\ deviation}{Mean} \qquad \ldots\ldots\ldots\ldots\ldots 3.15$$

$$\text{i.e.} \quad CV = \frac{SD}{\overline{X}} \qquad \ldots\ldots\ldots\ldots\ldots 3.16$$

$$CV = \frac{\sqrt{\sum(x_i - \bar{x})^2}}{\sum_{i=1}^{n} xi \Big/ N} \qquad \ldots\ldots\ldots\ldots 3.17$$

where $x_i s$ *are* represented with frequencies

3.3.10 Correlation Coefficient

Suppose we have a problem in which we do not wish to estimate one variable from another and we cannot assume one variable is more likely than the other to contain the error. However, we are interested in any association between the variables, that is, we are interested in interdependence and not in dependence (Mulholland and Jones, 1983).

The linear regression equations of y on x and x on y can be written respectively as:

$$y - \bar{y} = \frac{\sigma_{x,y}(x - \bar{x})}{\sigma_x^2} \qquad \ldots\ldots 3.18$$

Also,

$$x - \bar{x} = \frac{\sigma_{x,y}(y - \bar{y})}{\sigma_y^2} \qquad \ldots\ldots 3.19$$

These equations may be arranged by dividing the LHS and RHS of equation 3.18 by σ_y to obtain

$$\frac{y-\bar{y}}{\sigma_y} = \frac{\sigma_{x,y}}{\sigma_x\sigma_y}\frac{(x-\bar{x})}{\sigma_x} \qquad \text{.....3.20}$$

Also, dividing LHS and RHS of equation 3.19, by σ_x, we obtain

$$\frac{x-\bar{x}}{\sigma_x} = \frac{\sigma_{x,y}}{\sigma_x\sigma_y}\frac{(y-\bar{y})}{\sigma_y} \qquad \text{.....3.21}$$

If we let r which is known as the product moment correlation coefficient to be

$$r = \frac{\sigma_{x,y}}{\sigma_x\sigma_y} \qquad \text{.....3.22}$$

and substituting into equation 3.20 and 3.21 we obtain

$$\frac{y-\bar{y}}{\sigma_y} = r\frac{(x-\bar{x})}{\sigma_x} \qquad \text{..... 3.23}$$

And

$$\frac{x-\bar{x}}{\sigma_x} = r\frac{(y-\bar{y})}{\sigma_y} \qquad \text{..... 3.24}$$

For r = + 1 or -1, both equations 3.23 and 3.24 are identical and we have a perfect positive or negative correlation respectively.

By the Cauchy – Schwarz inequality.

$$\sigma_{x,y}^2 = \left[\frac{\Sigma(x-\bar{x})(y-\bar{y})}{n-1}\right]^2 \le \frac{\Sigma(x-\bar{x})^2}{(n-1)}\frac{\Sigma(y-\bar{y})^2}{n-1}$$

$$= \sigma_x^2\sigma_y^2 \qquad \text{..... 3.25}$$

$$\therefore \frac{\sigma_{x,y}^2}{\sigma_x^2\sigma_y^2} \le 1 \text{ i.e. } r^2 \le 1 \qquad \text{..... 3.26}$$

$$\therefore -1 \le r \le +1 \qquad \text{..... 3.27}$$

If we denote by β_x the regression coefficient of y on x, and by β_y the regression coefficient of x on y, then

$$r^2 = \frac{\sigma^2_{x,y}}{\sigma_x^2\sigma_y^2} = \frac{\sigma_{x,y}}{\sigma_x^2} \text{ x } \frac{\sigma_{x,y}}{\sigma_y^2} = \beta_x . \beta_y \qquad \text{.....3.28}$$

$$\therefore r = \sqrt{(\beta_x \cdot \beta_y)} \qquad \text{.....3.29}$$

If we take the sign of $\sigma_{x,y}$ as +ve or –ve, then the values of correlation coefficient lies between -1 and + 1 i.e. $-1 \leq r \leq +1$.

In this work the correlation coefficient is used in determining the goodness of fit between measured and predicted CO_2 and CH_4 concentrations.

3.3.11 **Coefficient of determination**

In statistics, the coefficient of determination, r^2, is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information. It is the proportion of variability in a data set that is accounted for by the statistical model. It provides a measure of how well future outcomes are likely to be predicted by the model (i.e. the goodness of fit of a model).

In linear regression, r^2 is simply the square of the sample correlation coefficient, r, between the outcomes and their predicted values which vary from 0 to 1 (Coefficient of determination, 2010).

The coefficient of determination is utilised in a similar way as the correlation coefficient in determining the goodness of fit between the measured and predicted CO_2 and CH_4 concentrations in this work.

3.4 **Modelling**

Scientific models are defined as approximate representations or simulations of a real system. They are classified as conceptual, graphical, physical or numerical models (Moran and Morgan, 1991).

Climate models are empirical data augmented with mathematical studies (Schneider and Dickinson, 1974). In climate prediction models, one looks for trends in the time series of climatic variables and correlations between them which help specify the model (Rangarajan and Sant, 1997). The autocorrelation function (i.e. time lags) is the correlation coefficient between two values of the same variable at times X_i and X_{i+k}.This collection of autocorrelations computed for various lags are often displayed graphically with the autocorrelations plotted as a function of lag. If the autocorrelation function did not decay to zero after a few periods of

measurements, making reasonably accurate forecasts at that range would be very easy. This was used to determine how accurate the predictions of CO_2 and CH_4 concentrations were in this work.

3.4.1 **Time Series**

Time series is a set of observations taken at different times, usually at equal intervals. The observations can be plotted against time which could be on seasonal basis. Obtained time series models can be viewed as a generating process, or algorithm that could have produced the data. A mathematical model for the time variations of data set can allow compact representation of characteristics of that data in terms of a few parameters (Wilks, 2006). There are two fundamental approaches to time series analysis: time domain analysis and frequency domain analysis.

Time-domain methods seek to characterise data series in the same terms i.e. time scale in which they are observed and reported. A primary tool for characterization of relationship between data values in the time-domain approach is autocorrelation function.

Frequency-domain analysis represents data series in terms of contributions occurring at different time scales, or characteristic frequencies. Each time scale is represented by a pair of sine and cosine functions.

3.4.2 **Autoregressive moving average**

For time domain with continuous data, autoregressive approach is used. The autoregressive moving average (ARMA) model which is sometimes called the Box-Jenkins model because of its being modeled after the iterative Box-Jenkins methodology is typically applied to time series data (Box and Jenkins, 1994). The ARMA model is a tool for understanding and perhaps, predicting future values in a given time series data. The model consists of two parts, an autoregressive (AR) part and a moving average (MA) part (Wilks, 2006; Autoregressive model, 2009; Autoregressive moving average model, 2009).

Generally, it can be written as:

$$\mathbf{Y}_t = c + \varepsilon_t + \sum_{i=1}^{p} \varphi_i Y_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \quad \text{.....3.30}$$

where Y_t and Y_{t-i} are the observed time series; c is a constant, ε_t and ε_{t-1} are error terms; p and q are the order of the model; φ_i and θ_i are parameters of the model.

The moving average part is written as:

$$\mathbf{Y}_t = c + \varepsilon_t^{'} + \sum_{i=1}^{p} \varphi_i Y_{t-i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.31$$

where $\varepsilon_t^{'}$ is the error term.

Also, the auto-regression part is written as:

$$\mathbf{Y}_t = \varepsilon_t^{''} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.32$$

with $\varepsilon_t^{''}$ used to represent its error term.

Likewise, the ARMA model is usually re-written in a linear model form (i.e. order one) as:

$$Y_t = a + bX_t + e \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.33$$

While the model in quadratic form is re-written as:

$$Y_t = a + bX_t + cX_t^2 + e \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.34$$

where Y_t is the total concentration of greenhouse gases (i.e. the monthly or annual variation), X_t is the specific concentration of greenhouse gases at any particular time, a is the intercept, b is the coefficient of the linear term, c is the coefficient of the quadratic term and e is the standard deviation (i.e. error). (Wayne and Gray, 1993; Chandler, 2005).

In this work 12 months was used in determining the moving average in order to minimise perturbations of greenhouse gases on annual basis so that predictions of these gases could be made. The type of model used was determined based on the values of the correlation coefficient. The higher the value of correlation coefficient obtained the better the model. Also, the standard deviation (i.e. error) was used as index of warming and in determining the warming at any location. Thus, it was also used in comparing warming from one location to another.

The auto regression was used to fit the appropriate model used in predicting the concentrations of both CO_2 and CH_4 after minimising their perturbations by the use of moving average.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Concentration and variation of greenhouse gases in the tropics

There has been a substantial growth in atmospheric CO_2 since the industrial revolution. This is evident in the measurement of its concentration in the atmosphere, ice cores, or at marine sea surface sites. Likewise, the concentration of CH_4, the most abundant organic trace gas in the atmosphere, has increased dramatically over the last centuries, more than doubling its concentration. The increasing concentrations of CO_2 and CH_4 are of special concern because of their effects on climate and atmospheric chemistry. On a per molecule basis, additional CH_4 is much more effective as a greenhouse gas than additional CO_2 but is less effective on climate change because of its smaller atmospheric concentration. The warming effect of CH_4 over a period of 100 years is 25 times stronger than that of CO_2. Fortunately, CH_4 appears in lower concentrations and disappears faster from the atmosphere than CO_2. After about seven years, half of all CH_4 emissions would have transformed into H_2O and CO_2 (Stang, 2009; Methane- a ticking bomb, 2009).

The greenhouse gases vary in both time and space latitudinally, as well as longitudinally in the tropics for the locations considered. The various plots of concentration of these greenhouse gases (CO_2 and CH_4) with time for all the locations considered in terms of their spatial distribution shows that CO_2 and CH_4 fluctuates, but on the average also shows increment with time. This phenomenon is in agreement with the long-term monitoring of atmospheric CO_2 and other greenhouse gases at other non-tropical stations since the launching of an accelerated international research program on the potential human influence on the climate system (Roger Revelle, 2010).

4.2 Concentration of greenhouse gases in the tropics

The values of mean annual concentration of greenhouse gases (CO_2 and CH_4) for each station considered in the northern and southern hemisphere shows that Key Biscayne in tropical America has the highest concentration of both CO_2 and CH_4 gases (Table 4.1).

Table 4.1: Values of mean annual concentration of CO_2 and CH_4 (1996-2005) for each station in the northern and southern hemisphere

Observation sites/ territory (Tropical region)	Mean CO_2 conc. (ppm)	Ranking mean CO_2 conc. by position	Mean CH_4 conc. (ppb)	Ranking mean CH_4 conc. by position
Ascension Island, U.K(Africa)	369.3 ±0.5	10	1732.5 ±0.9	10
Assekrem, Algeria(Africa)	370.8 ±0.5	5	1796.3 ±0.9	4
Mahe Island, Seychelles(Africa)	369.5 ±0.5	9	1745.5±0.8	9
Cape Ferguson ,Australia(Ocean)	369.0 ±0.5	12	1727.6 ±0.8	12
Guam ,U.S.A (Ocean)	370.8 ±0.5	5	1777.2 ±0.8	8
Minamitorishima, Japan(Asia)	371.0 ±0.5	2	1793.9 ±1.0	5
Sand Island, U.S.A(Ocean)	371.0 ±0.5	2	1819.9 ±0.8	1
Tutuila, U.S.A(Ocean)	369.2 ±0.5	11	1728.2 ±0.9	11
Cape Kumukahi , U.S.A(Ocean)	371.0 ±0.5	2	1796.9 ±0.8	3
Mauna Loa ,U.S.A (Ocean)	370.7 ±0.5	7	1782.3 ±0.8	7
Key Biscayne, U.S.A(America)	372.0 ±0.5	1	1812.4 ±1.0	2
Ragged Point, Barbados(America)	370.4 ±0.5	8	1786.9 ±0.7	6

The table further showed that the concentrations of these greenhouse gases were mainly in the territory of the industrialized nations of the world especially USA and Japan. Following hard after these industrialized nations is Algeria, a member of OPEC and is an indication of flares, waste and effluent from the oil industry rather than an industrial development.

The cumulative mean concentration of CO_2 in both the northern and southern hemisphere of the tropics for each stations considered show fluctuations with a progressive rise on year to year basis in the northern hemisphere, while those of CH_4 also shows a fluctuation, which on the average, indicate an increment on yearly basis (Table 4.2). These fluctuations showed monotonic trend in its increment for both CO_2 and CH_4, with CH_4 showing more chaotic pattern than CO_2. Also the standard deviation which indicates abnormality, has highest value in the year 1998 for both CO_2 and CH_4, and is in agreement with average global temperature and tropical temperature anomaly trends (Figs. 4.1 and 4.2), and serves as an indicator of warming. Furthermore, it was observed that El Nino years showed corresponding high values in terms of standard deviations such as the years: 1998, 2002, 2003, 2004 and 2005. This was due to the fact that El Nino causes more heat to be released from the oceans into the atmosphere, thus, resulting in the availability of more heat absorption by greenhouse gases. The El Nino years for the period considered in this work (1996 to 2005) had been documented to be 1997-1998, 2002-2003, and 2004-2005.

In the southern hemisphere of the tropics cumulative mean of both CO_2 and CH_4 concentrations fluctuates for stations considered and show yearly increment on the average in a similar pattern to that of the northern hemisphere of the tropics (Table 4.3). The standard deviation was highest in the year 1998 for CH_4; while it was highest in 2002 for CO_2. Likewise, the years known for El Nino still features prominently among the years having high values of standard deviation for both CO_2 and CH_4 gases as it was in the northern hemisphere.

Table 4.2: The annual concentration of CO_2 and CH_4 concentration for northern hemisphere stations in the tropics

Year	Mean annual CO_2 conc. (ppm)	Standard deviation (SD) of CO_2	Standard error (SE) of CO_2	Ranking of CO_2 SD by position	Mean annual CH_4 conc. (ppb)	Standard deviation (SD) of CH_4	Standard error (SE) of CH_4	Ranking of CH_4 SD by position
1996	362.5	0.41	0.12	9	1776.3	0.70	0.20	6
1997	363.9	0.56	0.16	5	1781.6	2.30	0.66	2
1998	366.5	0.88	0.26	1	1769.7	3.27	0.95	1
1999	368.3	0.32	0.09	10	1796.0	0.59	0.17	8
2000	369.7	0.53	0.15	7	1796.6	0.49	0.10	9
2001	371.4	0.46	0.13	8	1796.7	0.48	0.14	10
2002	373.4	0.74	0.21	2	1798.1	1.59	0.46	5
2003	376.0	0.74	0.21	2	1805.1	1.80	0.52	3
2004	377.9	0.55	0.16	6	1803.4	1.61	0.47	4
2005	380.0	0.66	0.19	4	1801.5	0.72	0.21	6

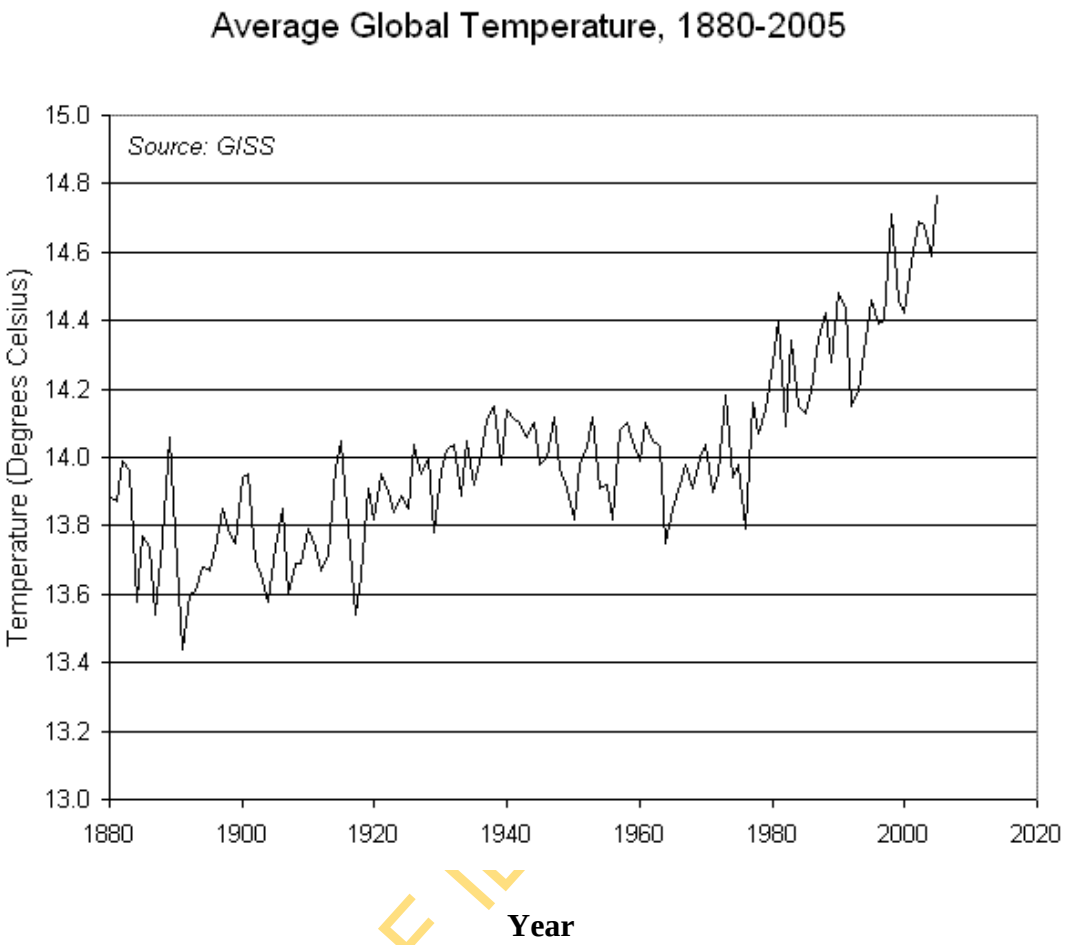


Fig. 4.1: Average global temperature trend

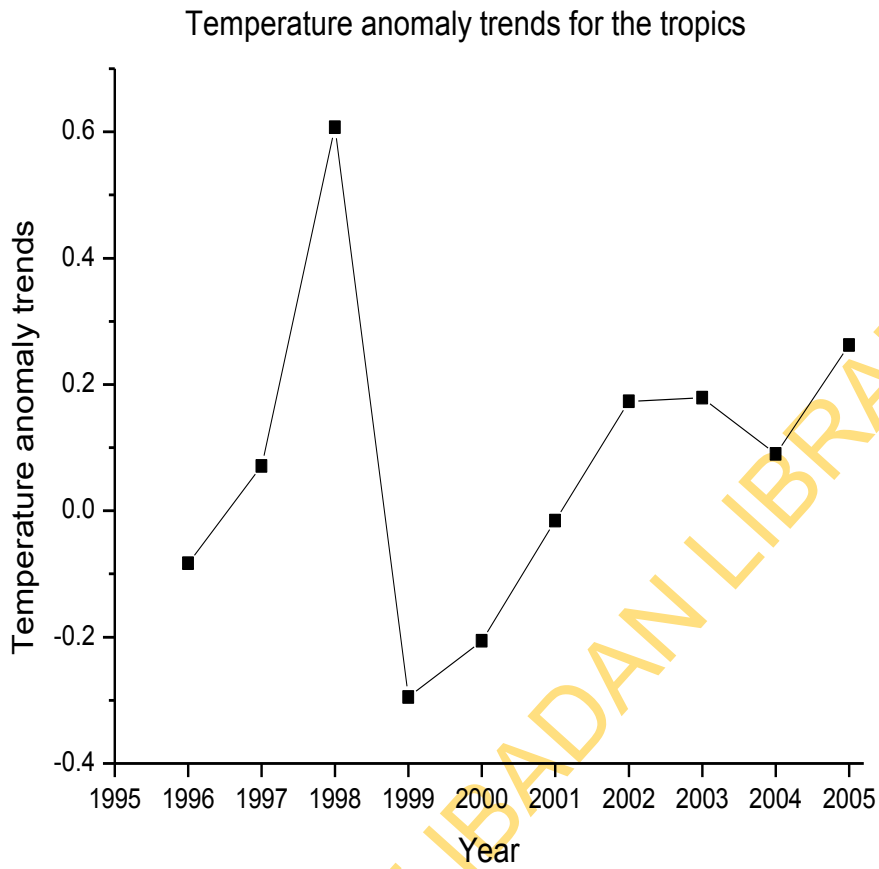


Fig. 4.2: Temperature anomaly trends in the tropics

Table 4.3: The annual concentrations of CO_2 and CH_4 for southern hemisphere stations in the tropics

Year	Mean annual CO_2 conc. (ppm)	Standard deviation (SD) of CO_2	Standard error (SE) of CO_2	Ranking of CO_2 SD by position	Mean annual CH_4 conc. (ppb)	Standard deviation (SD) of CH_4	Standard error (SE) of CH_4	Ranking of CH_4 SD by position
1996	360.7	0.39	0.11	9	1715.4	1.82	0.53	3
1997	362.3	0.66	0.19	4	1719.9	0.95	0.27	6
1998	365.0	0.72	0.21	2	1728.0	4.16	1.20	1
1999	366.6	0.39	0.11	9	1737.2	0.96	0.28	5
2000	368.0	0.45	0.13	8	1738.5	0.18	0.05	10
2001	369.7	0.62	0.18	5	1737.3	0.50	0.14	8
2002	372.0	0.74	0.22	1	1738.5	0.40	0.12	9
2003	374.2	0.57	0.17	6	1740.4	0.94	0.27	7
2004	376.0	0.50	0.14	7	1740.0	1.48	0.43	4
2005	378.1	0.70	0.20	3	1739.6	2.25	0.65	2

Generally, in the tropics (i.e. northern and southern hemisphere) CO_2 showed fluctuations with a progressive rise of concentration from year to year for stations considered, while those of CH_4 also showed fluctuations which on the average indicate an increment on yearly basis (Table 4.4). This trend was similar to what was obtained separately for the northern and southern hemisphere of the tropics. Furthermore, the year 1998 has the highest standard deviation both for CO_2 and CH_4. Similarly, the years of El Nino and its southern oscillation counterpart also showed significant variation for the values of standard deviation.

4.2.1 Variational trends of greenhouse gas concentrations on annual basis

Standard deviation is the most satisfactory and widely used measure of dispersion to account for variable distribution of both CO_2 and CH_4 in each observation sites / stations. It was observed that most of the years with high standard deviation correspond to the warmest years in global warming in accordance with WMO (2006) report. The mean concentration of these gases especially CO_2 increases on the average from year to year. Also, the mean concentration of CH_4 despite having much fluctuation than CO_2 also increases from year to year. The higher standard deviation values obtained for CH_4 which was more than that of CO_2 signifies that there is a higher departure from the true mean in the case of CH_4 than CO_2. It also signifies that on a per molecule basis additional CH_4 is much more effective as a greenhouse gas than additional CO_2. These high values of standard deviations corresponding to warmest years are indications that these warming are anomalous.

The ranking of warm years in accordance with CO_2 and CH_4 concentrations for the locations considered in the northern hemisphere stations show that generally 1998 is the warmest year (Table 4.5). Likewise, the southern hemisphere stations also show that generally 1998 is the warmest year (Table 4.6). WMO (2005 and 2006) had earlier outlined five of the warmest years in decreasing order as 1998, 2005, 2002, 2003 and 2004 which is in good agreement with tropical temperature anomaly trends (Fig. 4.2) and the summary of warmest years obtained in this work according to CO_2 and CH_4 concentrations obtained for stations generally in the tropics (Table 4.7).

Table 4.4: The annual concentration of CO_2 and CH_4 for northern and southern hemisphere stations in the tropics

Year	Mean annual CO_2 conc. (ppm)	Standard deviation (SD) of CO_2	Standard error (SE) of CO_2	Ranking of CO_2 SD by position	Mean annual CH_4 conc. (ppb)	Standard deviation (SD) of CH_4	Standard error (SE) of CH_4	Ranking of CH_4 SD by position
1996	361.9	0.40	0.12	9	1756.0	0.87	0.25	7
1997	363.4	0.59	0.17	5	1761.0	1.79	0.52	2
1998	366.0	0.83	0.24	1	1769.7	3.27	0.95	1
1999	367.7	0.34	0.10	10	1776.4	0.68	0.20	8
2000	369.2	0.51	0.15	7	1777.3	0.28	0.08	10
2001	370.8	0.51	0.15	7	1776.3	0.40	0.12	9
2002	372.9	0.74	0.21	2	1778.2	1.18	0.34	5
2003	375.4	0.68	0.20	3	1783.5	1.48	0.43	4
2004	377.3	0.54	0.16	6	1782.3	1.55	0.45	3
2005	379.4	0.67	0.19	4	1780.9	1.18	0.34	5

Table 4.5: Ranking of warm years according to CO_2 and CH_4 concentrations for northern hemisphere stations in the tropics

Station	Warm years in decreasing order according to CO_2 concentration	Warm years in decreasing order according to CH_4 concentration
Assekrem	1998,2005,2003,2002,1997	1998,1997,2003,2004,1999
Guam	2004,1998,2003,2002,2005	2003,2004,1997,2005,2002
Minamitorishima	2005,1998,2003,1996,2002	1997,2004,1996,2000,2003
Sand Island	1998,2002,2003,2005,2000	2002,2004,2003,1998,2000
Cape Kumukahi	1998,2002,2003,1997,2004	1997,1998,2004,2003,2002
Mauna Loa	1998,2002,2003,2005,1997	1998,2003,1997,1999,2004
Key Biscayne	1998,2002,2003,2000,2005	2003,2004,1997,1998,2005
Ragged Point	1998,2003,2005,2000,2002	1998,1996,2004,2003,2001

Table 4.6: Ranking of warm years according to CO_2 and CH_4 concentrations for southern hemisphere stations in the tropics

Station	Warm years in decreasing order according to CO_2 concentration	Warm years in decreasing order according to CH_4 concentration
Ascension Island	2002,1998,2001,1997,2005	1998,2001,1997,1999,2004
Mahe Island	1996,2002,2005,1997,2001	2005,1996,1998,1997,2004
Cape Ferguson	1997,2005,2002,2001,1998	1998,1997,2001,2004,2000
Tutuila	1998,2005,2002,2003,2001	1998,2005,1999,2004,2003

Table 4.7: Summary of warmest years according to CO_2 and CH_4 concentrations for stations generally in the tropics

Station	Warmest years according to CO_2 and CH_4 concentrations
Ascension Island	2002
Assekrem	1998
Mahe Island	1996
Cape Ferguson	1997
Guam	2004
Minamitorishima	2005
Sand Island	1998
Tutuila	1998
Cape Kumukahi	1998
Mauna Loa	1998
Key Biscayne	1998
Ragged Point	1998

The following are the summary of what was obtained for each of the observation sites considered.

4.2.1.1 **Variational trends of greenhouse gases in the northern hemisphere Stations based on their annual concentrations**

The plots of CO_2 and CH_4 gases' annual concentration show perturbation with time in this region with CH_4 showing higher degree of fluctuation than CO_2. These fluctuations give a trend that shows increment with time.

The patterns obtained for the mean monthly CO_2 concentration in the northern hemisphere showed generally a sinusoidal pattern, while those obtained for CH_4 generally are like that of a syncline.

(i) **Assekrem Station**

Assekrem is located in the mountainous region of southern Algeria in the northern part of Africa.

The plots of CO_2 and CH_4 gases' annual concentration with time at Assekrem showed that CO_2 and CH_4 fluctuate. However, the trend indicated a general increment with time (Fig. 4.3a and b). The maximum and minimum annual concentrations of these gases are depicted in Fig 4.4a and b. These figures showed that the gap between the minimum and maximum annual values is getting narrower which is an indication of "saturation" of these elements in the atmosphere.

Table 4.8 shows the mean concentrations and standard deviation for these gases. With reference to this table, the yearly variation shows that the standard deviation which indicates warming has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2005, 2003, 2002 and 1997 for CO_2, while those of CH_4 are 1998, 1997, 2003, 2004 and 1999 (Fig. 4.5 a and b). Thus, in this location, 1998 is the warmest year and coincides with the SD peak of CO_2 and CH_4. The mean monthly concentrations of these gases are also as indicated in Fig. 4.6a and b. These figures showed that these concentrations are based on seasons with CO_2 being minimum in September and maximum in May, while CH_4 is minimum in June and maximum in December.

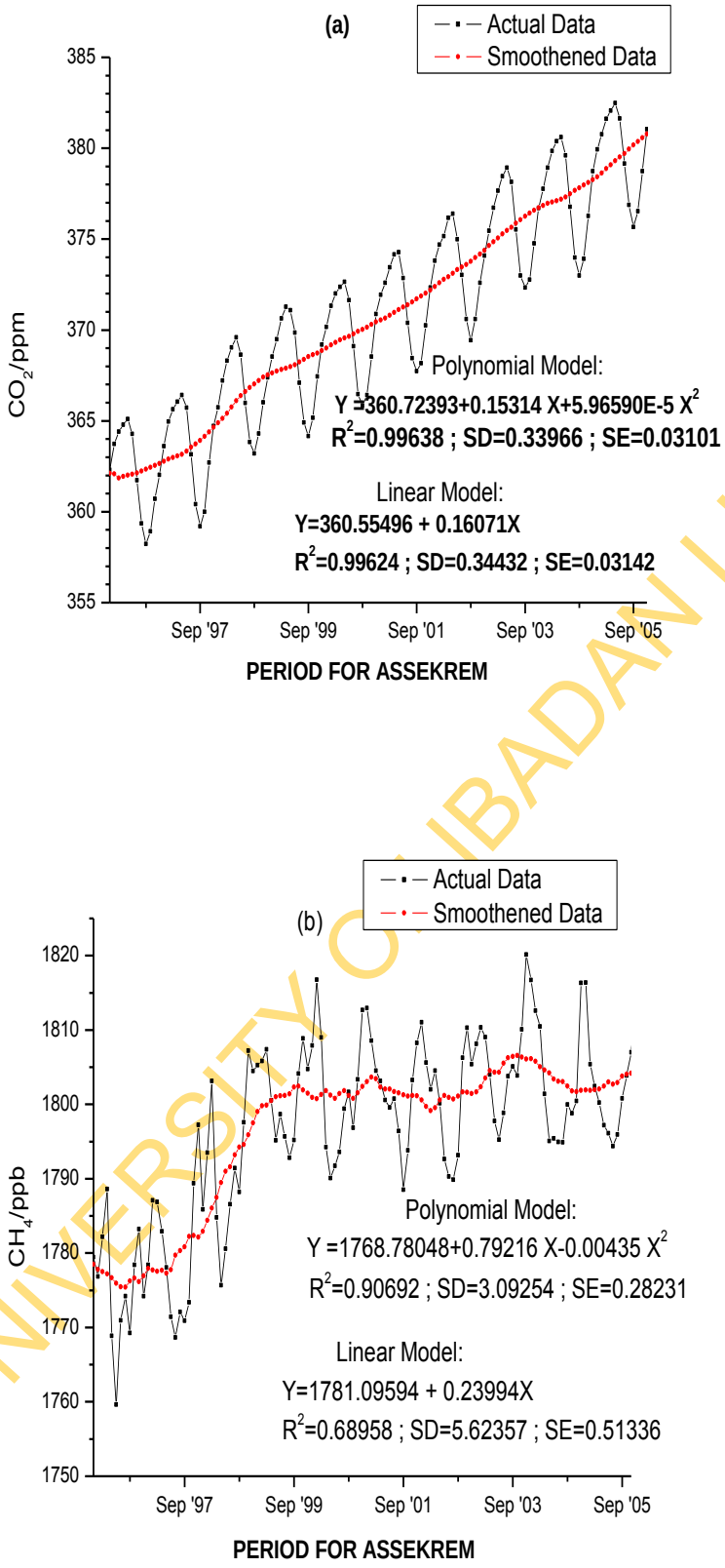


Fig. 4.3(a and b): Plot of annual CO_2 and CH_4 for Assekrem station

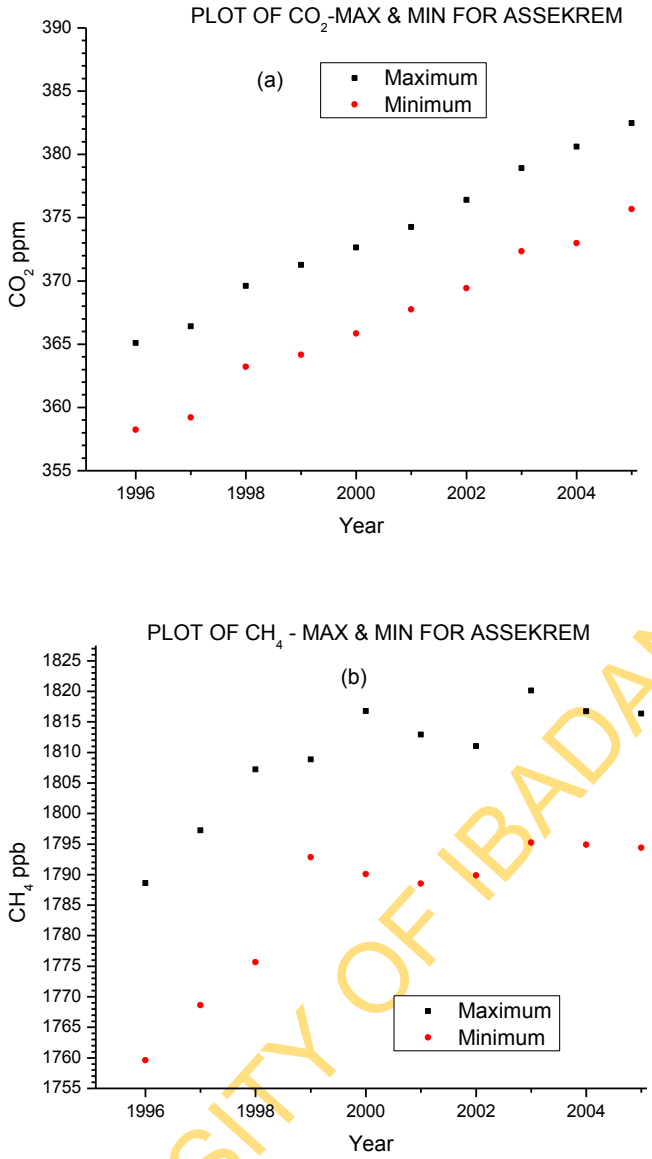
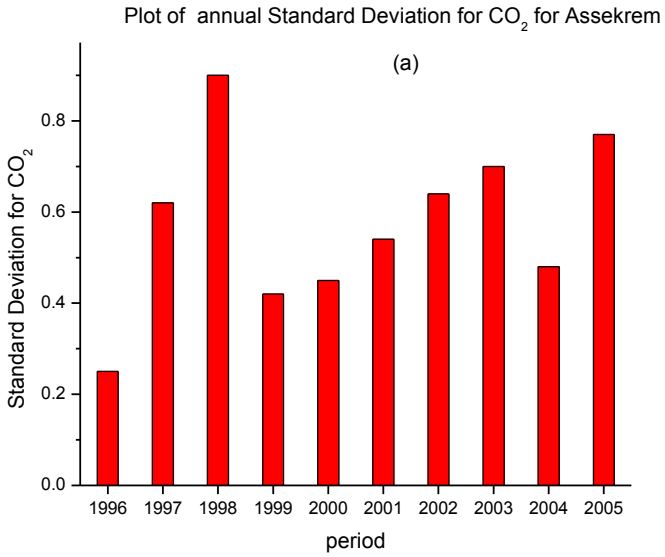


Fig. 4.4(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Assekrem station

Table 4.8: Values of mean annual concentration of CO_2 and CH_4 with both the standard deviation and ranking for Assekrem station

Year	Mean CO_2 conc. (ppm)	CO_2 standard deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 conc. (ppb)	CH_4 standard deviation (SD)	Ranking of CH_4 SD by position
1996	362.2±0.1	0.25	10	1776.7±0.3	0.94	7
1997	363.6±0.2	0.62	5	1779.5±0.6	2.04	2
1998	366.4±0.3	0.90	1	1790.7±1.4	4.69	1
1999	368.2±0.1	0.42	9	1801.0±0.3	1.05	5
2000	369.7±0.1	0.45	8	1801.3±0.2	0.51	10
2001	371.3±0.2	0.54	6	1802.1±0.3	0.91	8
2002	373.4±0.2	0.64	4	1800.7±0.2	0.82	9
2003	375.7±0.2	0.70	3	1804.8±0.5	1.66	3
2004	377.5±0.1	0.48	7	1803.6±0.5	1.55	4
2005	379.6±0.2	0.77	2	1803.0±0.3	0.96	6



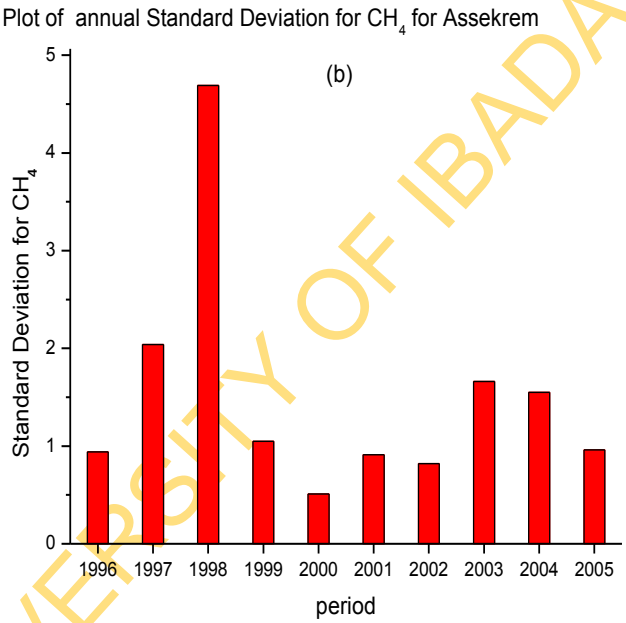


Fig. 4.5(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Assekrem station

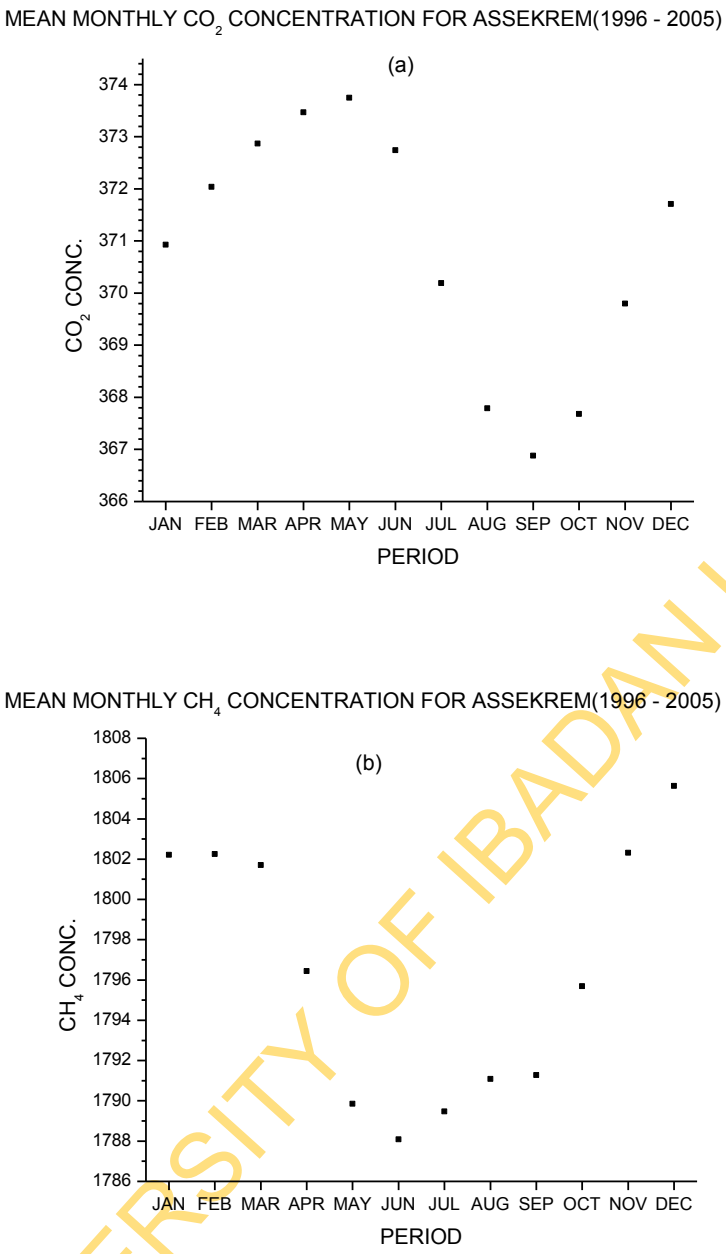


Fig. 4.6(a and b): Mean monthly concentration of CO_2 and CH_4 at Assekrem station

(ii) **Guam station**

Guam is the largest island in the Pacific Ocean between Hawaii and the Philippines, and between Japan and New Guinea. It is an island located within the southern end of the Mariana chains of islands in the western pacific covering an area of approximately 212 square miles, 30 miles long and 4 to 9 miles wide. Its location some 900 miles north of the equator gives it a tropical climate through out the year.

The plots of CO_2 and CH_4 gases' annual concentration with time at Guam are depicted in Fig. 4.7a and b. These plots also show an increasing trend for both CO_2 and CH_4 gases. The maximum concentration of CO_2 is becoming closer to the minimum concentrations which show the same trend towards saturation that was observed for Assekrem station (Fig. 4.8a and b).

Table 4.9 shows the mean concentration and standard deviation for these gases. With reference to this table the yearly variation shows that the standard deviation, which is an index of warming has five of its highest values in terms of position ranking when arranged in decreasing order in 2004, 1998, 2003, 2002 and 2005 for CO_2 , while those for CH_4 are 2003, 2004, 1997, 2005 and 2002 (Fig.4.9a and b). Thus, in this location 2004 and 2003 would be the warmest year in terms of both CO_2 and CH_4 respectively if these gases were the dominant factor of warming. Other years mentioned by WMO amongst others as the warmest also features in the list of years stated above, and showed the combined effects of these gases.

The mean monthly concentration of these gases, including their minimum and maximum concentration for the period considered, shows fluctuations (Fig.4.10a and b). This is due to the difference in the amount of source and sink at various seasons. The maximum and minimum concentrations were observed in May and September respectively for CO_2, while the maximum and minimum concentrations were observed in December and August respectively for CH_4.

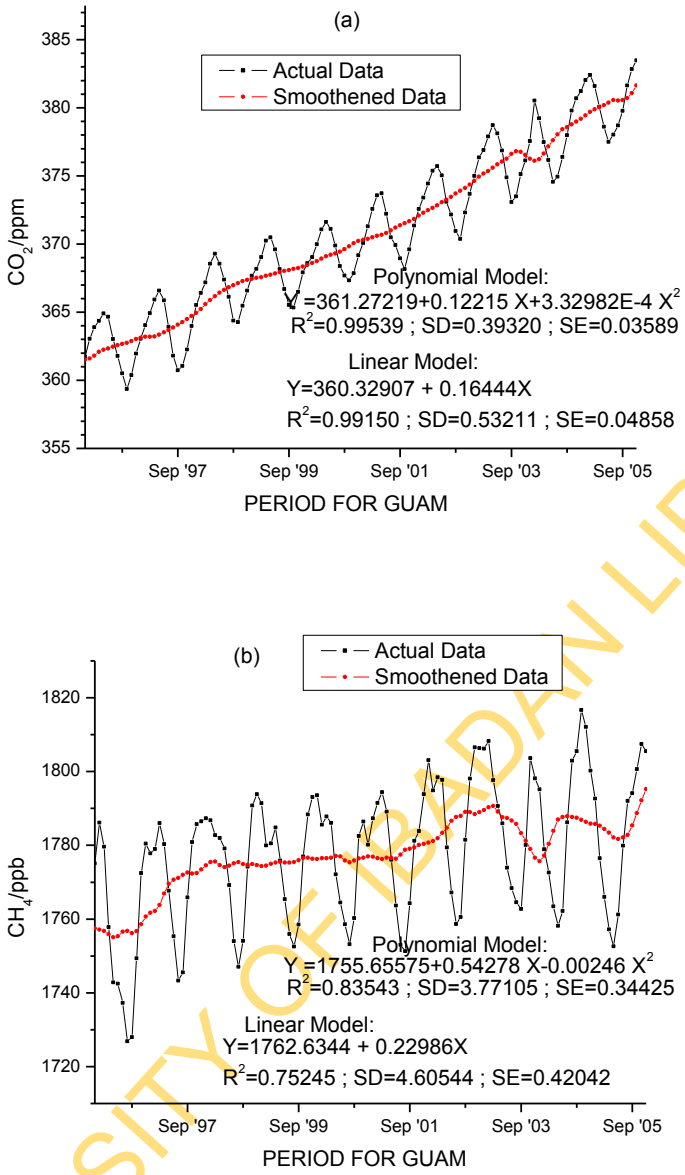


Fig. 4.7(a and b): Plot of annual CO_2 and CH_4 for Guam station

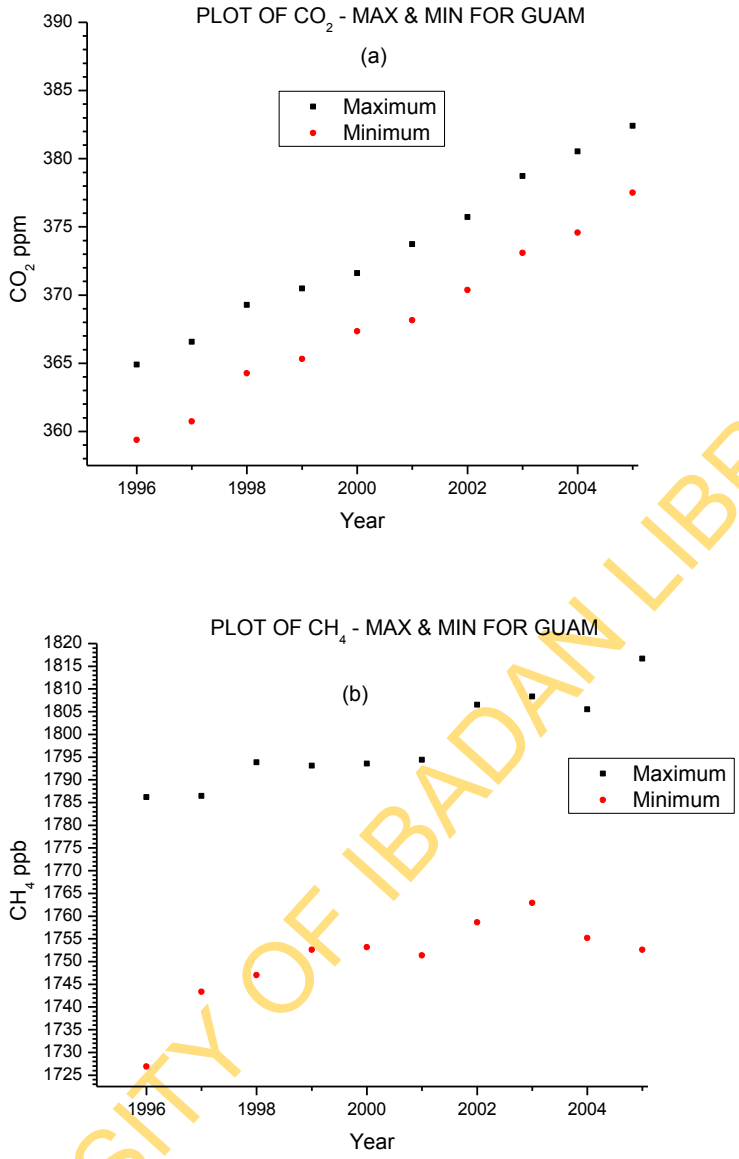


Fig. 4.8(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Guam station

Table 4.9: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Guam station

Year	Mean CO_2 Conc. (ppm)	CO_2 standard deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 standard deviation (SD)	Ranking of CH_4 SD by position
1996	362.3 ±0.1	0.50	9	1756.9 ±0.4	1.50	7
1997	363.7 ±0.2	0.56	6	1769.1 ±1.2	4.30	3
1998	366.4 ±0.2	0.81	2	1774.9 ±0.1	0.46	10
1999	367.9 ±0.1	0.30	10	1775.5 ±0.2	0.74	8
2000	369.3 ±0.2	0.56	6	1776.4 ±0.2	0.52	9
2001	371.0 ±0.2	0.53	8	1777.9 ±0.5	1.57	6
2002	373.2 ±0.2	0.74	4	1785.8 ±0.9	3.25	5
2003	375.9 ±0.2	0.75	3	1785.6 ±1.3	4.60	1
2004	377.7 ±0.3	1.16	1	1784.5 ±1.3	4.33	2
2005	380.4 ±0.2	0.60	5	1785.8 ±1.2	4.25	4

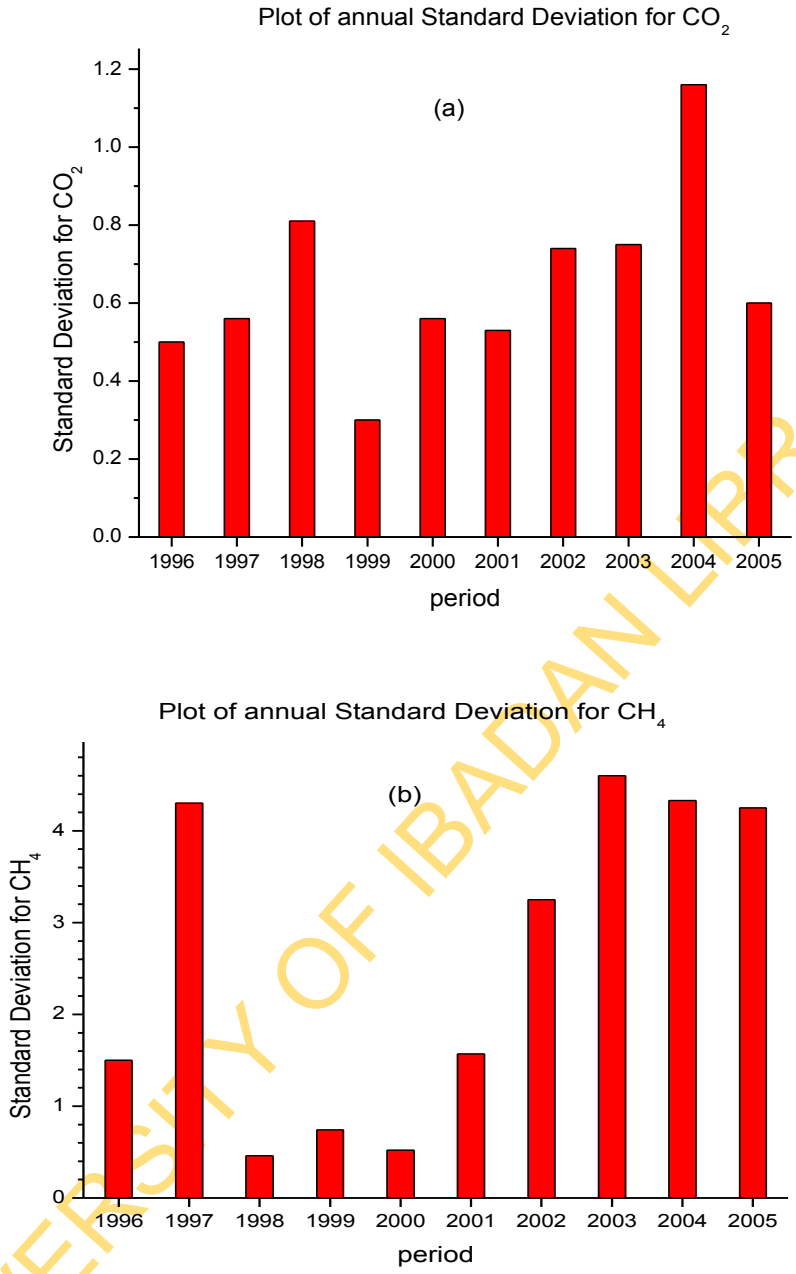


Fig. 4.9(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Guam station

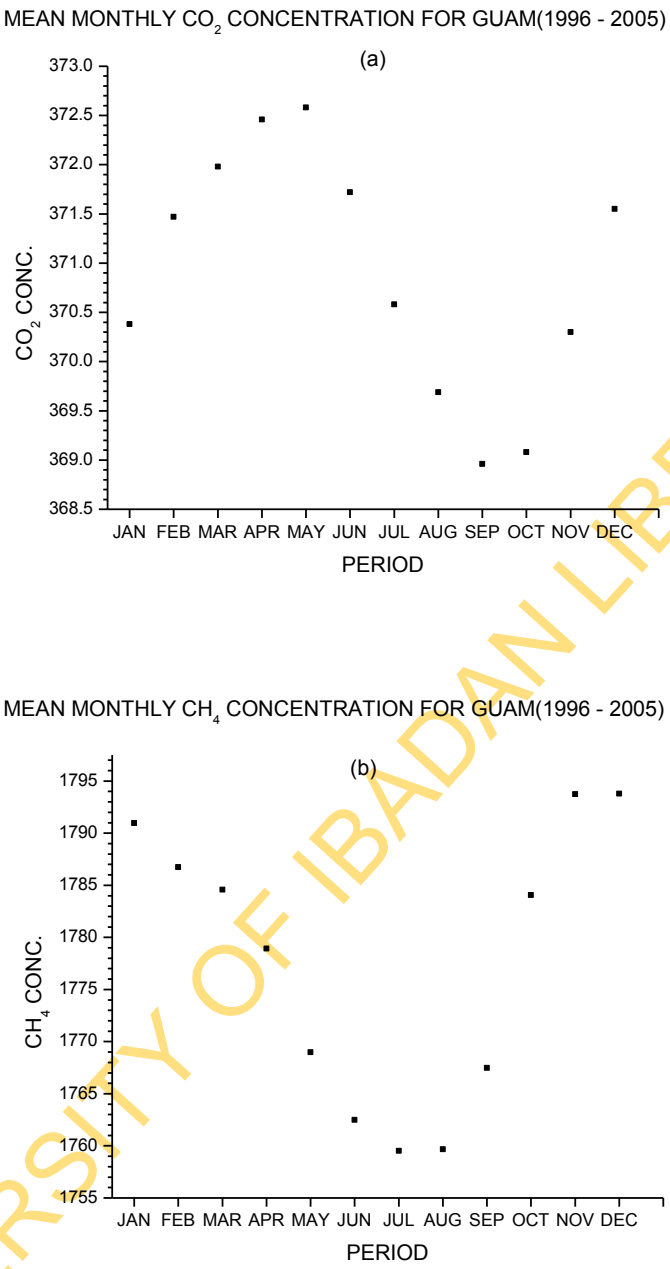


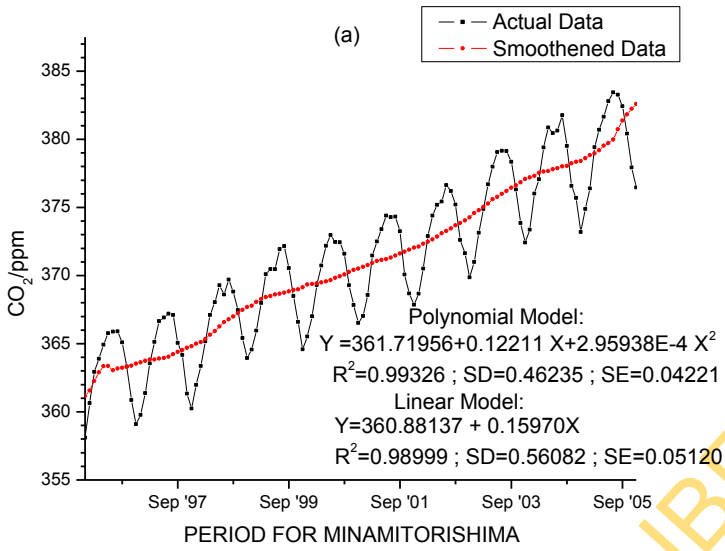
Fig. 4.10(a and b): Mean monthly concentration of CO_2 and CH_4 at Guam station

(iii) Minamitorishima station

Minamitorishima is an isolated island with an area of 1.2 square kilometers in the north western Pacific Ocean. It is the hottest place and easternmost territory belonging to Japan, lying some 1848 kilometers south west of Tokyo, and 1267 kilometers east of the closest Japanese island, South Iwo Jima of the Ogasawara islands, and nearly on a straight line between Tokyo and Wake Island, which is 1415 kilometers east southeast. The meteorological station is located in the central part of the North West coast of the island near the airport.

Fig. 4.11a and b are plots of CO_2 and CH_4 annual concentration with time at Minamitorishima and showed the same trend of increasing concentration with the years. The net concentration is increasing and the amplitude of variation is decreasing as both the maximum and minimum values are increasing with time (Fig. 4.12a and b).

Table 4.10 show the mean concentration and standard deviation for these gases. With reference to this table the yearly variation shows that the standard deviation has five of its highest values in terms of position ranking when arranged in decreasing order in 2005, 1998, 2003, 1996 and 2002 for CO_2, while those for CH_4 are 1997, 2004, 1996, 2003 and 2000 (Fig.4.13a and b). Thus, in this location 2005 and 1997 would be the warmest year in terms of both CO_2 and CH_4 respectively if these gases were the dominant factor of warming. Other years mentioned by WMO amongst other authors as the warmest also features in the list of years stated above, and showed the combined effect of these gases.



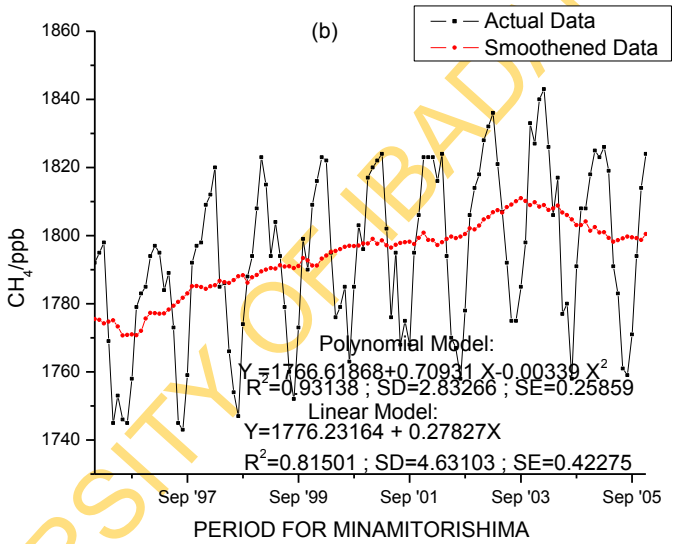


Fig. 4.11(a and b): Plot of annual CO_2 and CH_4 for Minamitorishima station

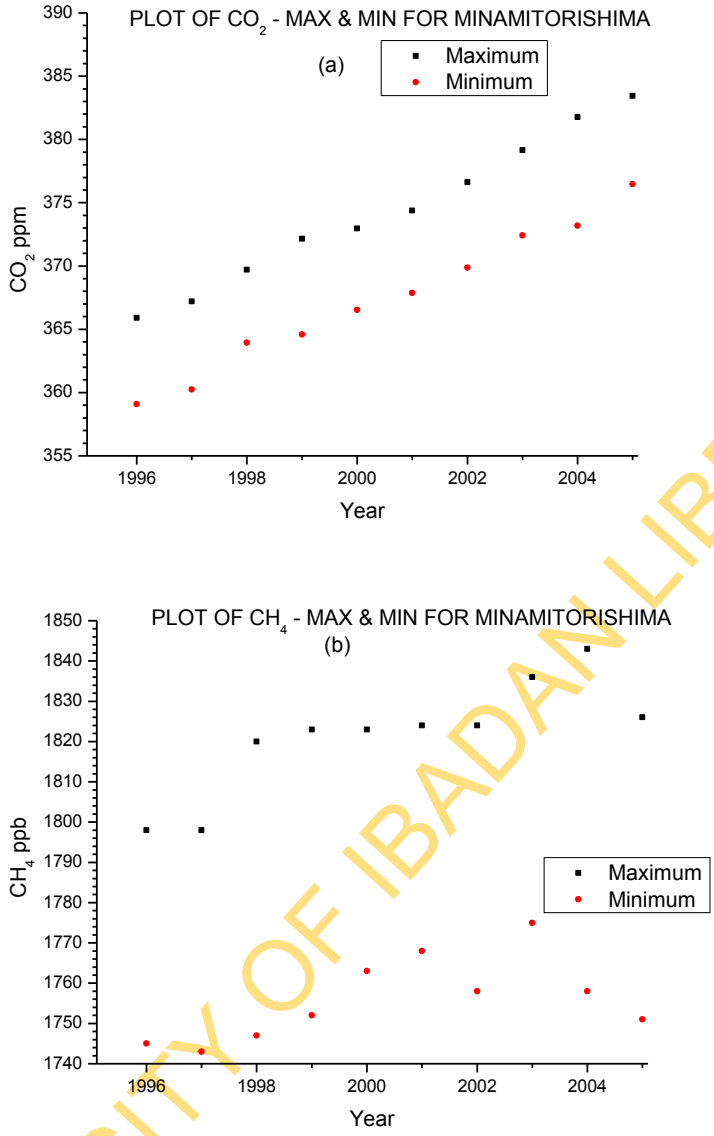
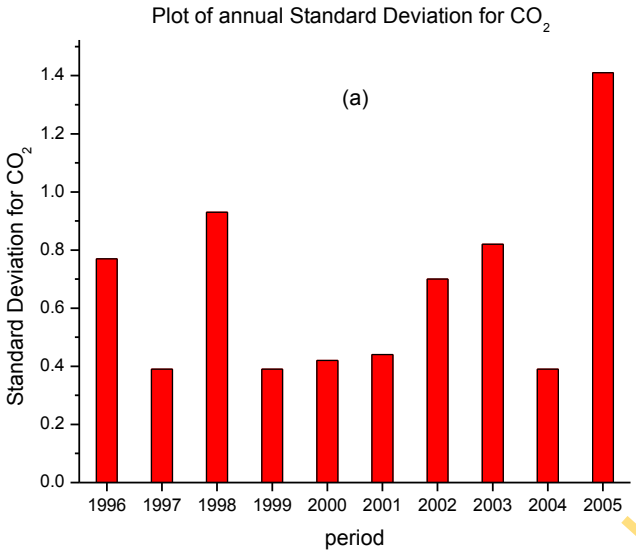


Fig. 4.12 (a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Minamitorishima station

Table 4.10: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Minamitorishima station

Year	Mean CO_2 Conc. (ppm)	CO_2 standard deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 standard deviation (SD)	Ranking of CH_4 SD by position
1996	363.9 ±0.2	0.77	4	1773.3 ±0.6	2.06	3
1997	364.1 ±0.1	0.39	8	1780.6 ±0.9	3.30	1
1998	366.3 ±0.3	0.92	2	1786.6 ±0.4	1.33	7
1999	368.6 ±0.1	0.39	8	1791.0 ±0.3	1.09	10
2000	369.8 ±0.1	0.42	7	1795.7 ±0.6	1.98	4
2001	371.3 ±0.1	0.44	6	1798.2 ±0.3	1.16	9
2002	373.2 ±0.2	0.70	5	1799.8 ±0.5	1.71	6
2003	375.9 ±0.2	0.82	3	1808.2 ±0.6	1.98	4
2004	377.8 ±0.1	0.39	10	1805.9 ±0.7	2.57	2
2005	380.3 ±0.4	1.41	1	1799.8 ±0.4	1.22	8



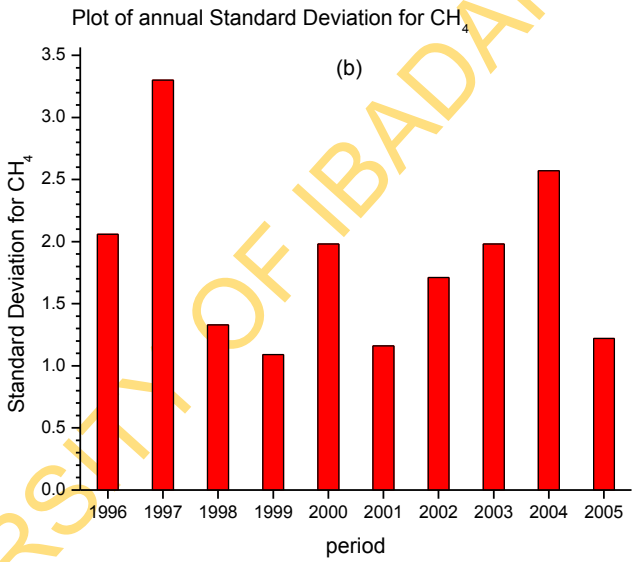


Fig. 4.13(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Minamitorishima station

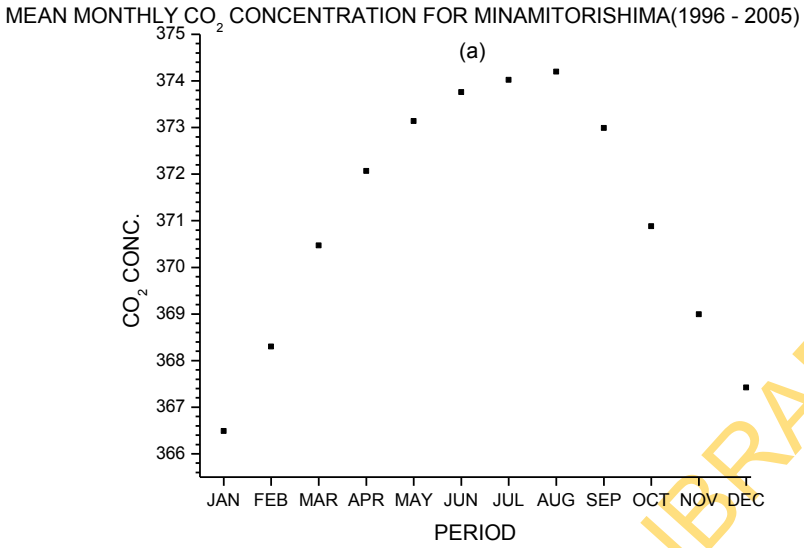
The mean monthly concentration of these gases including their minimum and maximum concentration for the period considered also shows fluctuations (Fig.4.14a and b). These are due to the difference in the amount of source and sink which are season dependent. We note that Fig. 4.14a is different from the earlier ones, and shows local effect on these variations. The maximum and minimum concentrations were observed in August and January respectively for CO_2 in this location which is different from the pattern of CO_2 observed in other locations which were in May and September respectively. Also, the maximum and minimum concentrations for this location were observed in February and August respectively for CH_4.

(iv) Sand Island station

Sand Island is a small Island within the city of Honolulu, Hawaii, United States. The Island is at the entrance to Honolulu Harbor. According to the United States Census Bureau the island has a land area of 203.78 hectare, and a population of 184 persons as of the 2000 census.

The plots of CO_2 and CH_4 gases' concentration with time at Sand Island showed an increasing trend as depicted in Fig. 4.15a and b. The interval between the maximum and minimum concentrations of these gases are getting narrower as was obtained in the earlier stations discussed and the same trend towards saturation was also observed (Fig. 4.16a and b).

Table 4.11 shows the mean concentration and standard deviation for these gases.



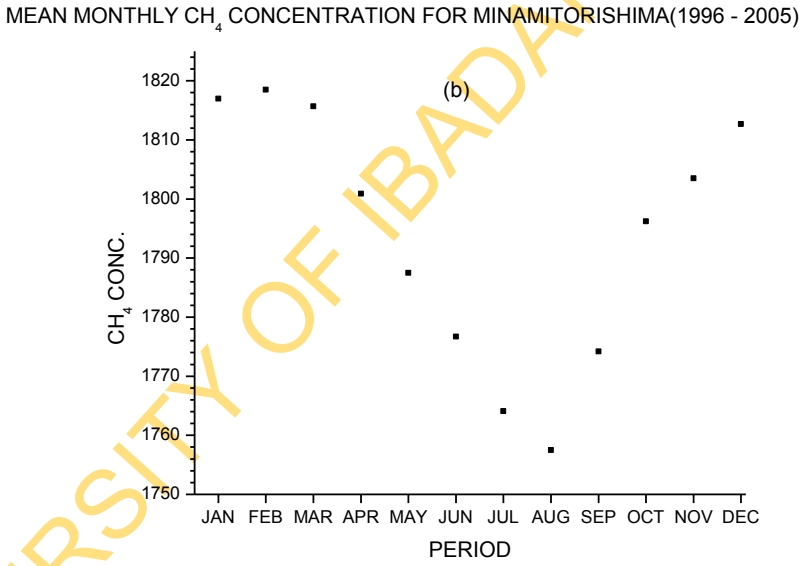


Fig. 4.14(a and b): Mean monthly concentration of CO_2 and CH_4 at Minamitorishima station

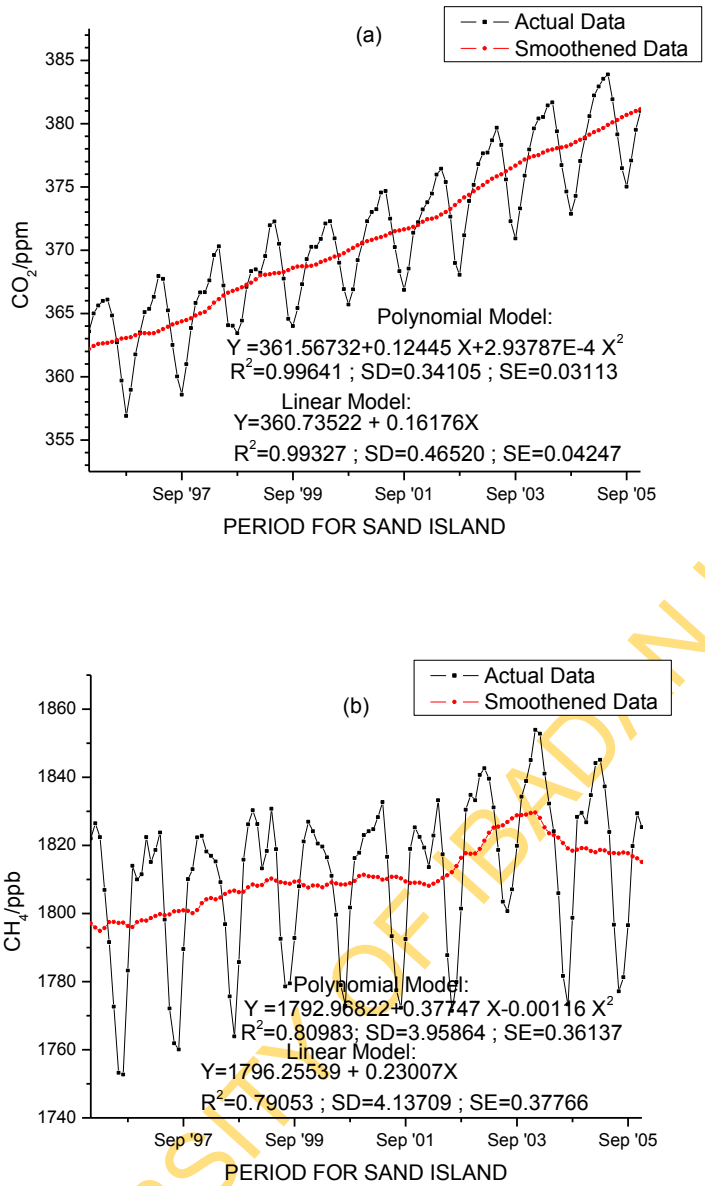


Fig. 4.15(a and b): Plot of annual CO_2 and CH_4 for Sand Island station

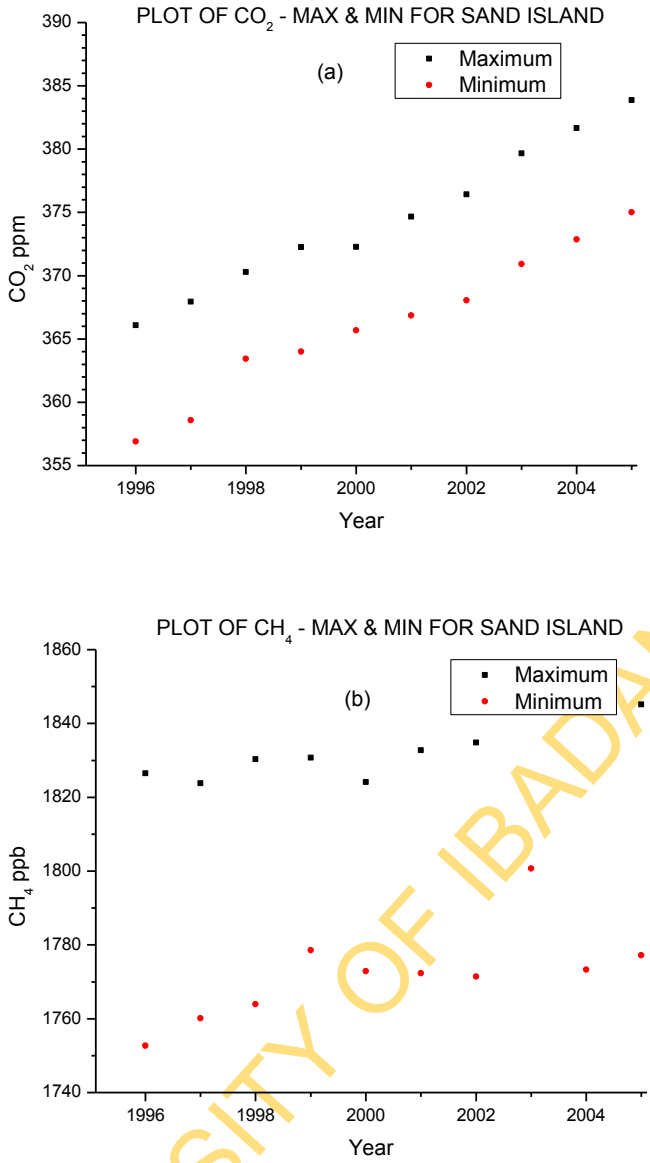


Fig. 4.16(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Sand Island station

Table 4.11: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Sand Island station

Year	Mean CO_2 conc. (ppm)	CO_2 standard deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 standard deviation (SD)	Ranking of CH_4 SD by position
1996	362.8 ±0.1	0.36	9	1796.7 ±0.3	0.94	8
1997	364.0 ±0.1	0.49	6	1799.9 ±0.3	0.96	7
1998	366.3 ±0.2	0.83	1	1805.7 ±0.5	1.61	4
1999	368.3 ±0.1	0.33	10	1809.0 ±0.2	0.77	9
2000	369.6 ±0.2	0.59	5	1809.0 ±0.3	1.12	5
2001	371.3 ±0.1	0.42	8	1810.1 ±0.2	0.76	10
2002	373.3 ±0.2	0.82	2	1812.6 ±1.1	3.80	1
2003	376.1 ±0.2	0.80	3	1826.0 ±1.0	3.29	3
2004	378.1 ±0.1	0.46	7	1822.3 ±1.1	3.80	1
2005	380.2 ±0.2	0.68	4	1817.5 ±0.3	1.02	6

With reference to this table the yearly variation shows that the standard deviation has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2002, 2003, 2005 and 2000 for CO_2, while those for CH_4 are 2002, 2004, 2003, 1998 and 2000 (Fig.4.17a and b). Thus, in this location 1998 and 2002 would be the warmest years in terms of both CO_2 and CH_4 respectively if these gases were the only factor of warming. Other years mentioned by WMO amongst other authors as the warmest also features in the list of years stated above, and showed the combined effects of these gases.

The mean monthly concentration of these gases including their minimum and maximum concentration for the period considered, shows fluctuations (Fig. 4.18a and b). This is due to the difference in the amount of source and sink. The maximum and minimum concentrations were observed in May and September respectively for CO_2, while the maximum and minimum concentrations were observed in January and August respectively for CH_4.

(v) Cape Kumukahi Station

Cape Kumukahi is located on the easternmost point of the Big Island, twenty five miles southeast of the city called Hilo on the Hawaiian Islands in the Pacific Ocean.

The plots of CO_2 and CH_4 concentration at Cape Kumukahi with time (Fig. 4.19 a and b) showed the same trend of increment as that of Guam. These figures showed that their maximum concentration especially that of CO_2, is getting closer to the minimum concentration. This is also an indication of the saturation of these elements in the atmosphere (Fig. 4.20a and b).

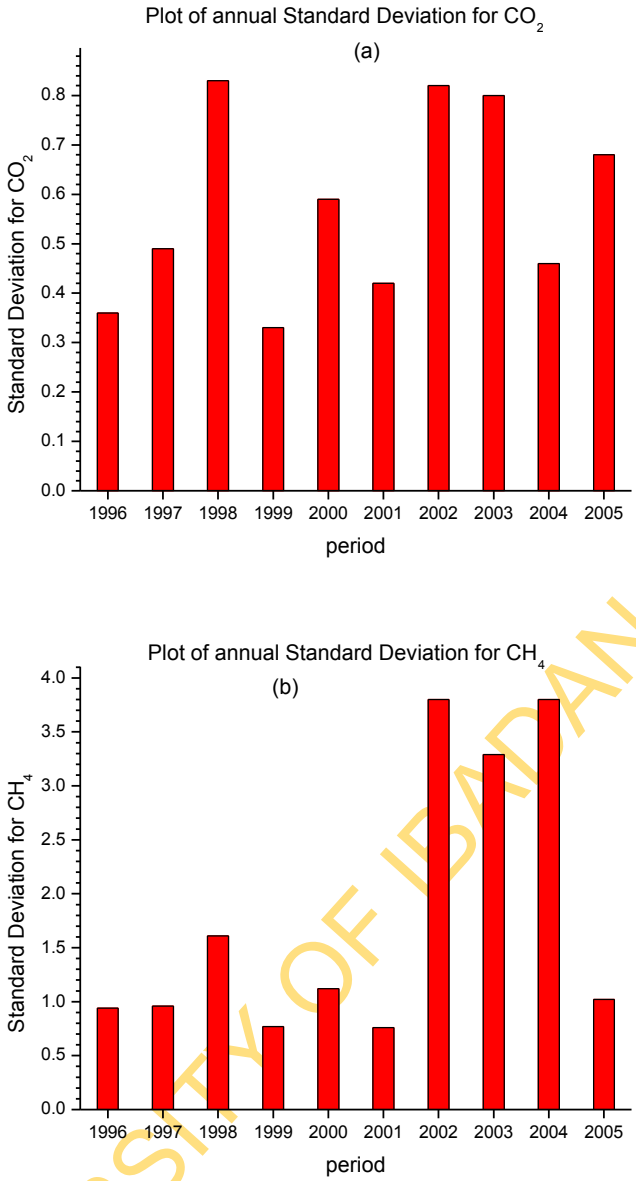
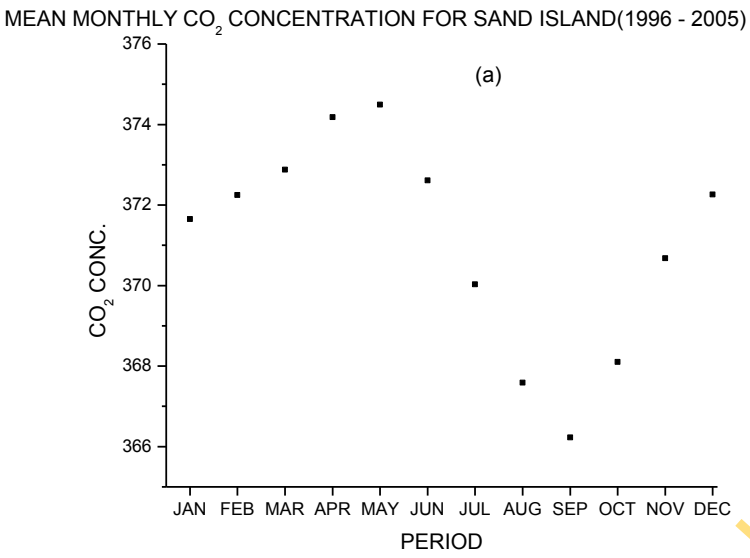


Fig. 4.17(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Sand Island station



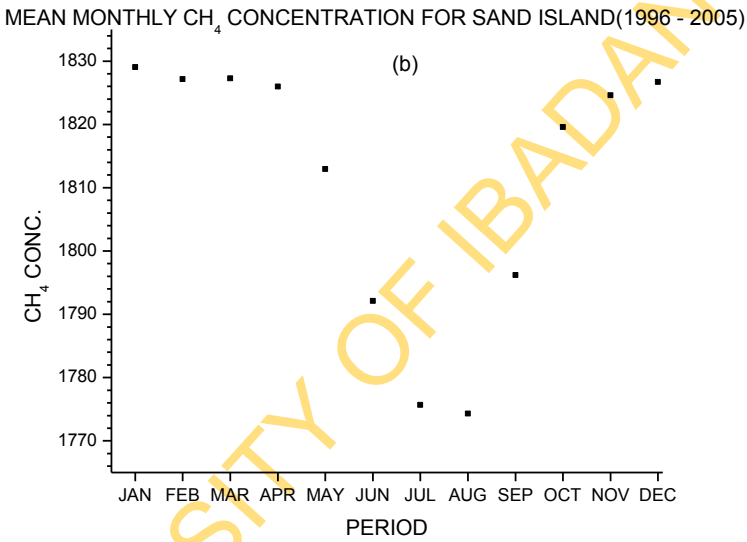
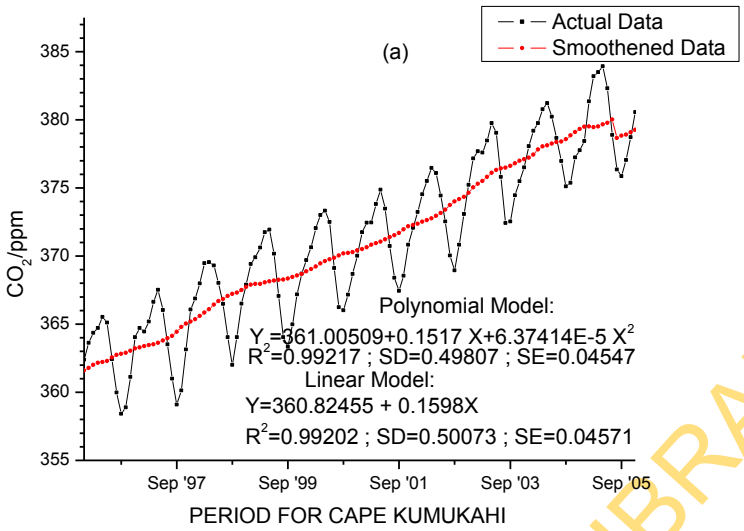


Fig. 4.18(a and b): Mean monthly concentration of CO_2 and CH_4 at Sand Island station



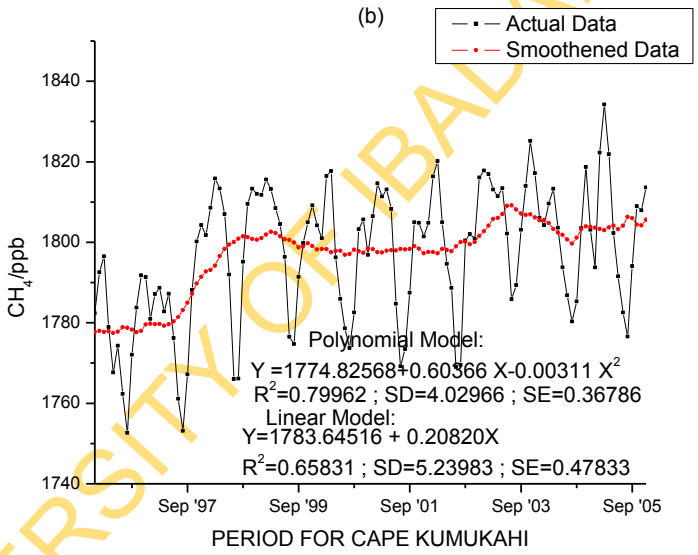


Fig. 4.19(a and b): Plot of annual CO_2 and CH_4 for Cape Kumukahi station

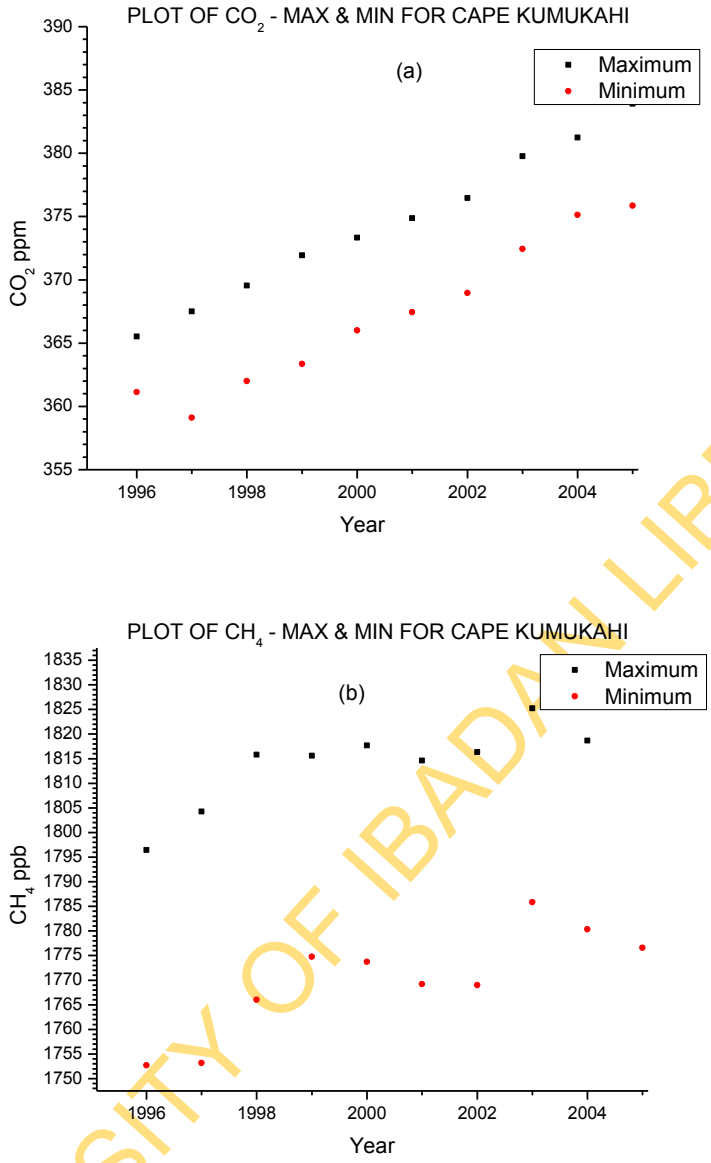


Fig. 4.20(a and b): Plot of maximum and minimum annual CO_2 and CH_4 for cape kumukahi station

Table 4.12 shows the mean concentration and standard deviation for these years. With reference to this table, the yearly variation shows that the standard deviation has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2002, 2003, 1997 and 2004 for CO_2, while those for CH_4 are 1997, 1998, 2004, 2003 and 2002 (Fig.4.21a and b). Thus in this location 1998 and 1997 would be the warmest years in terms of both CO_2 and CH_4 respectively.

The mean monthly concentration of these gases including their minimum and maximum concentration for the period considered also shows fluctuations (Fig.4.22a and b). The maximum and minimum concentrations were observed in May and September respectively for CO_2, while the maximum and minimum concentrations were observed in March and August respectively for CH_4. This was due to the difference in the amount of source and sink which is season dependent.

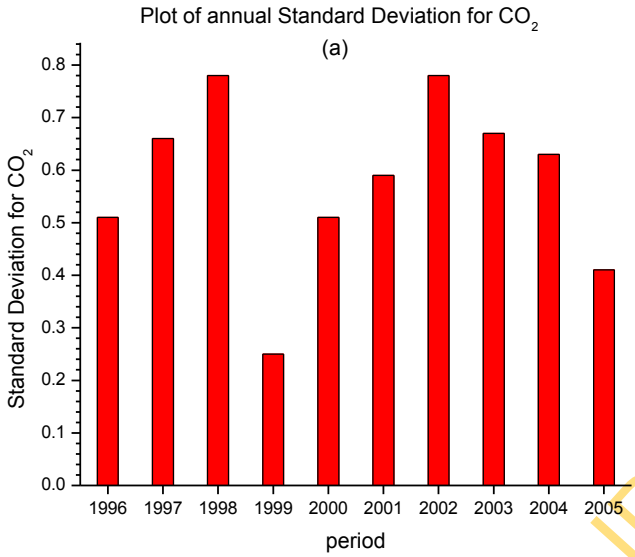
(vi) Mauna Loa Station

Mauna Loa is shaped as a shield and located in the Island of Hawaii in the U.S. state of Hawaii in the Pacific Ocean. Trade winds blow from east to west across the Hawaiian Island, and the presence of Mauna Loa strongly affects the local climate. At low elevations, the eastern (windward) side of Mauna Loa usually receives heavy rainfall making the city of Hilo to be the wettest in the United States. The western (leeward) side has a much drier climate. At higher elevations, the amount of precipitation decreases, and skies are very often clear. Very low temperatures mean that precipitation often occurs in the form of snow.

The plots of CO_2 and CH_4 concentration with time at Mauna Loa showed an increasing trend with the years (Fig. 4.23a and b). The maximum concentration of CO_2, for previous years is becoming closer to the minimum concentrations which indicate trends toward saturation (Fig. 4.24a and b).

Table 4.12: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Cape Kumukahi station

Year	Mean CO_2 conc. (ppm)	CO_2 standard deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 conc. (ppb)	CH_4 standard deviation (SD)	Ranking of CH_4 SD by position
1996	362.5 ±0.2	0.51	7	1778.1 ±0.2	0.62	8
1997	364.1 ±0.2	0.66	4	1783.0 ±1.3	4.32	1
1998	366.6 ±0.2	0.78	1	1798.3 ±1.0	3.30	2
1999	368.2 ±0.1	0.25	10	1800.6 ±0.4	1.33	6
2000	369.8 ±0.2	0.51	7	1797.8 ±0.2	0.51	9
2001	371.4 ±0.2	0.59	6	1798.1 ±0.1	0.50	10
2002	373.4 ±0.2	0.78	1	1798.9 ±0.4	1.36	5
2003	376.2 ±0.2	0.67	3	1806.6 ±0.5	1.85	4
2004	378.3 ±0.2	0.63	5	1803.0 ±0.5	1.87	3
2005	379.4 ±0.1	0.41	9	1804.3 ±0.3	1.09	7



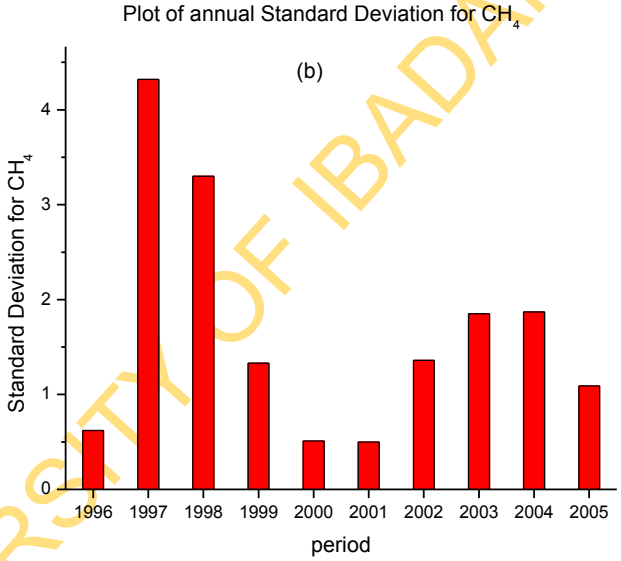
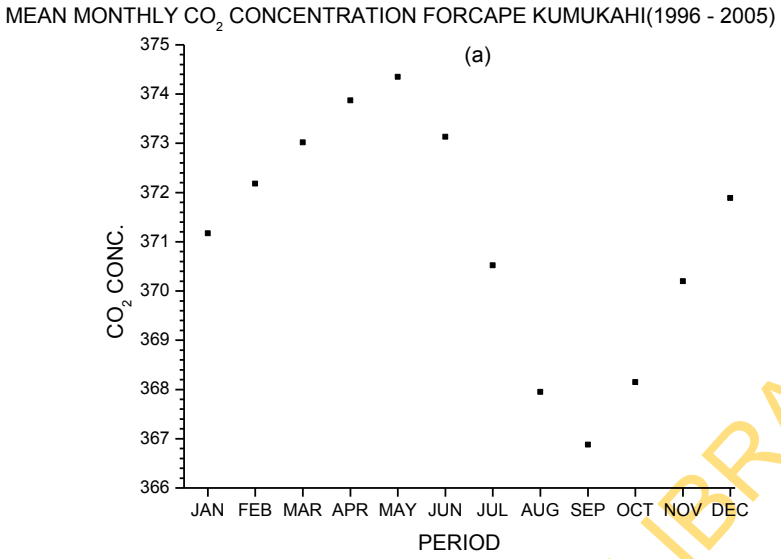


Fig. 4.21(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Cape Kumukahi station



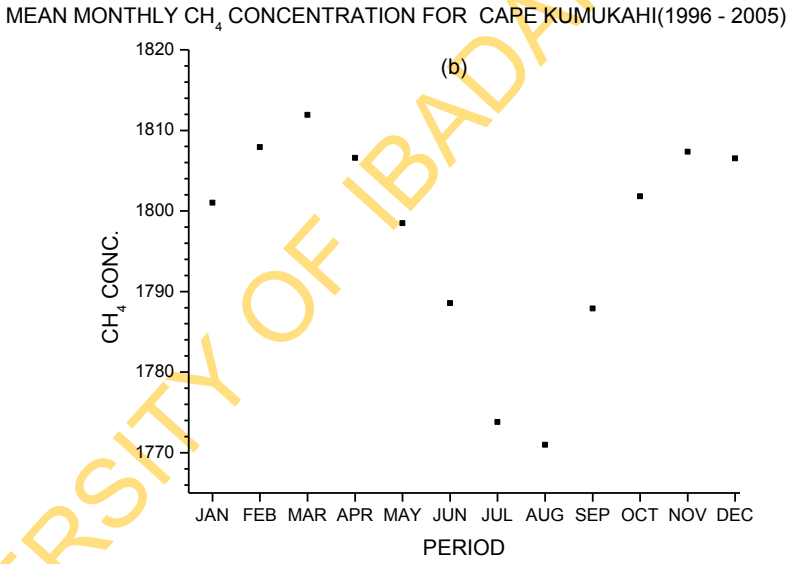
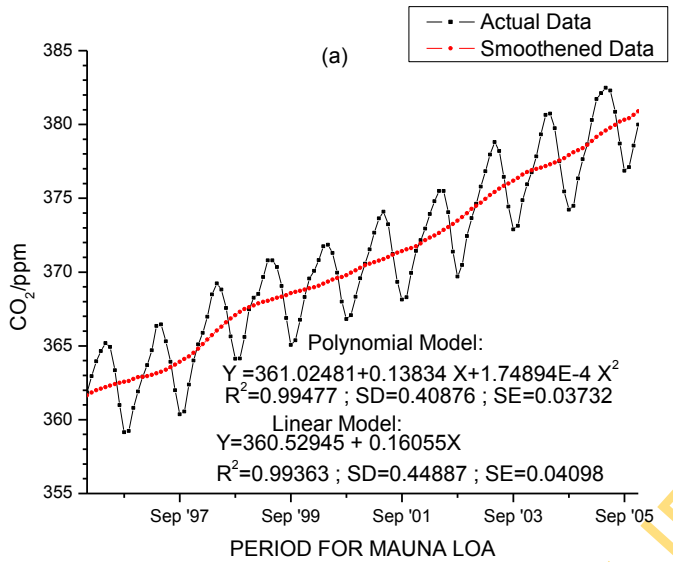


Fig. 4.22(a and b): Mean monthly concentration of CO_2 and CH_4 at Cape Kumukahi station



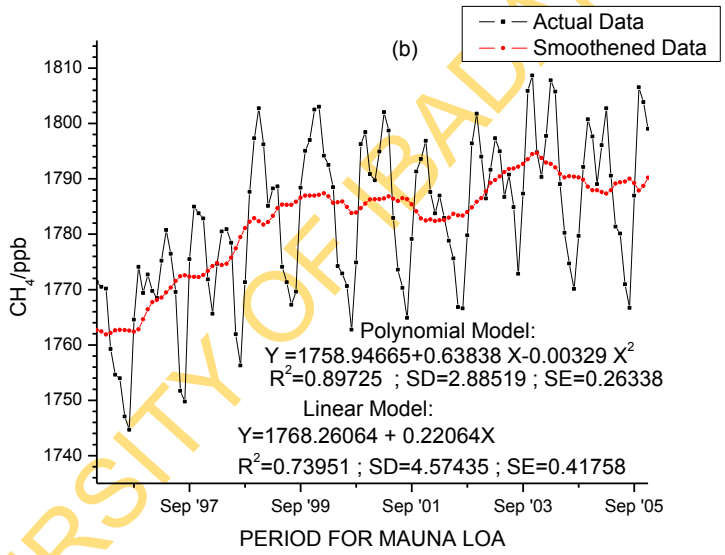
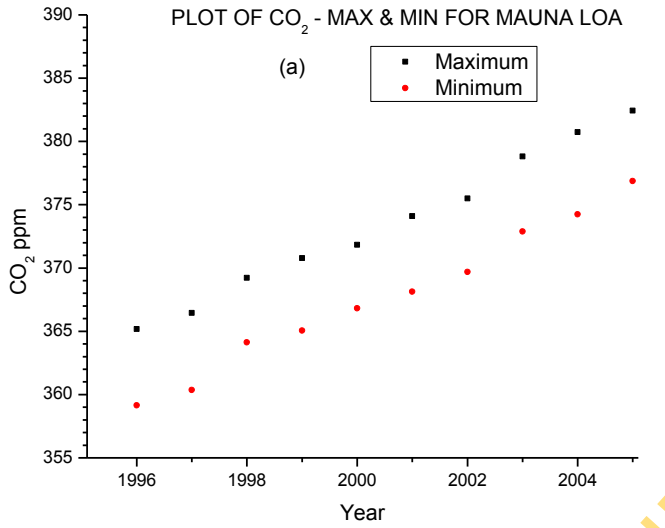


Fig. 4.23(a and b): Plot of annual CO_2 and CH_4 for Mauna Loa station



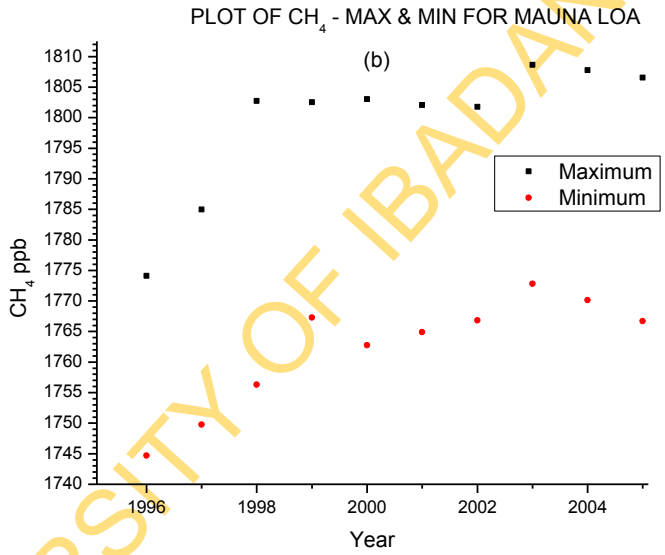


Fig. 4.24(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Mauna Loa station

Table 4.13 shows the mean concentration and standard deviation for these years. With reference to this table the yearly variation shows that the standard deviation, has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2002, 2003, 2005 and 1997 for CO_2 , while those for CH_4 are 1998, 2003, 1997, 1999 and 2004 (Fig.4.25a and b). Thus, in this location 1998 is the warmest year and coincides with the SD peak of CO_2 and CH_4.

The mean monthly concentration of these gases, including their minimum and maximum annual concentration for the period considered, shows fluctuations (Fig.4.26a and b). This is due to the difference in the amount of source and sink. The maximum and minimum concentrations were observed in May and September respectively for CO_2, while the maximum and minimum concentrations were observed in November and August respectively for CH_4.

(vii) Key Biscayne Station

Key Biscayne is a low elevation village with a total area of 3.6 square kilometer located in Miami-Dade County, Florida, United States on the Island of Key Biscayne in the Atlantic Ocean. The population was 10,507 at the 2004 census.

The plots of CO_2 and CH_4 gases' concentration with time at Key Biscayne showed a trend of general increment with time (Fig. 4.27a and b). The maximum and minimum concentrations of these gases are as depicted in Fig. 4.28a and b.

Table 4.14 shows the mean concentration and standard deviation for these gases. With reference to this table, the yearly variation shows that the standard deviation, has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2002, 2003, 2000 and 2005 for CO_2 , while those for CH_4 are 2003, 2004, 1997, 1998 and 2005 (Fig.4.29a and b).

Table 4.13: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Mauna Loa station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	362.3 ±0.1	0.38	9	1763.0 ±0.4	1.27	8
1997	363.6 ±0.2	0.55	5	1770.9 ±0.6	1.91	3
1998	366.4 ±0.3	0.95	1	1777.7 ±1.1	3.65	1
1999	368.3 ±0.1	0.35	10	1785.1 ± 0.5	1.82	4
2000	369.5 ±0.1	0.45	7	1785.7 ±0.3	1.16	9
2001	371.1 ±0.1	0.43	8	1785.5±0.4	1.50	6
2002	373.0 ±0.2	0.75	2	1783.7 ±0.4	1.36	7
2003	375.7 ±0.2	0.75	2	1791.6 ±0.6	2.08	2
2004	377.6 ±0.2	0.51	6	1790.8 ±0.5	1.75	5
2005	379.8 ±0.2	0.72	4	1788.7 ±0.3	0.98	10

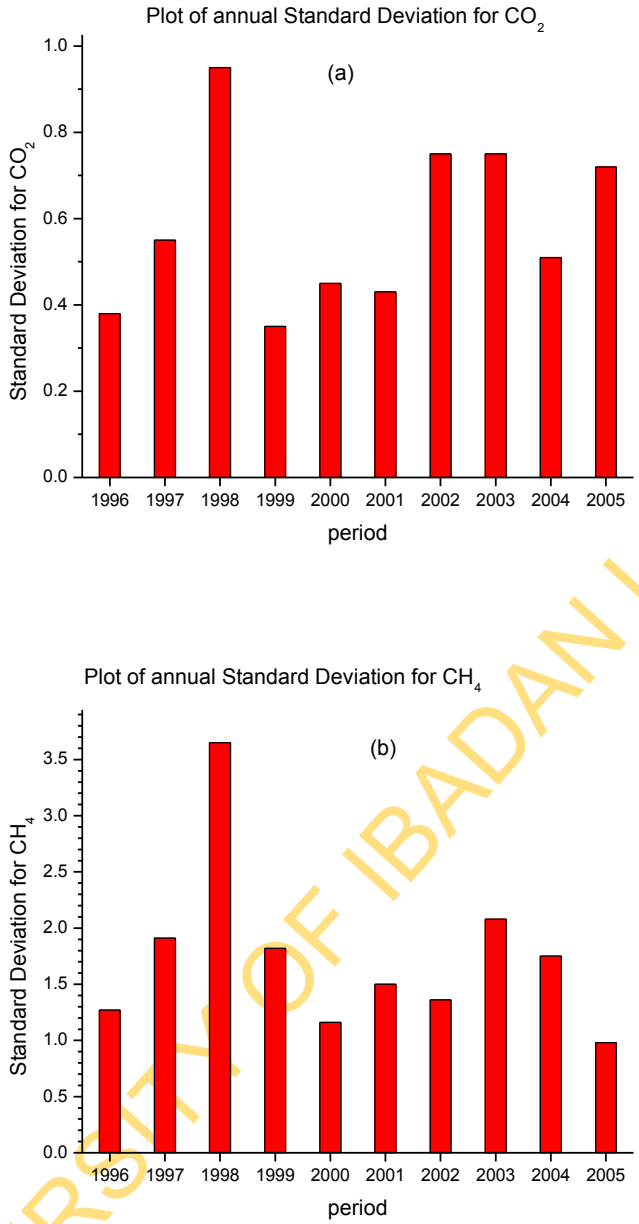
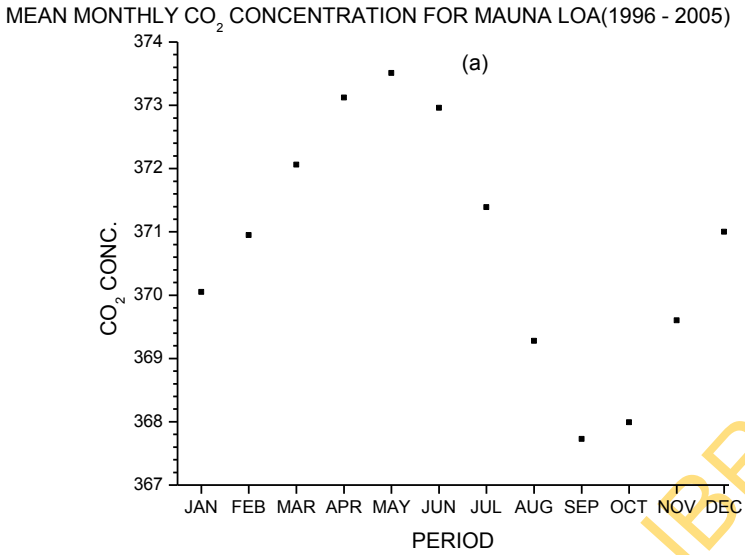


Fig. 4.25(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Mauna Loa station



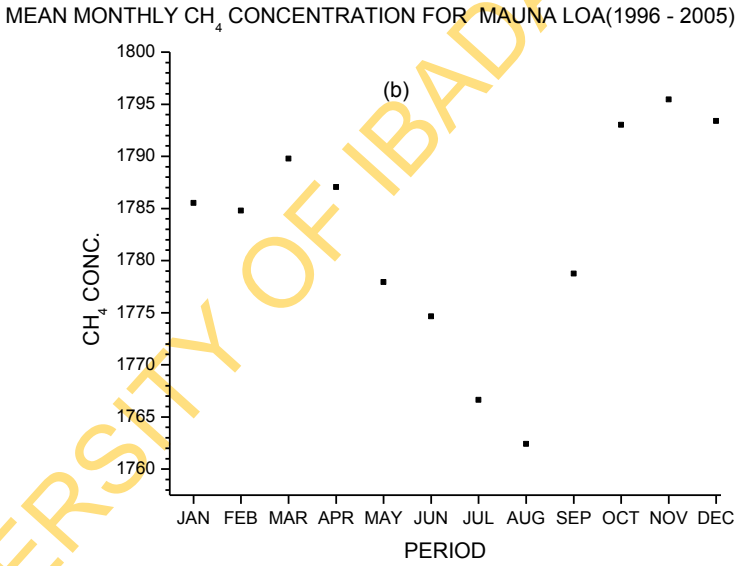


Fig. 4.26(a and b): Mean monthly concentration of CO_2 and CH_4 at Mauna Loa station

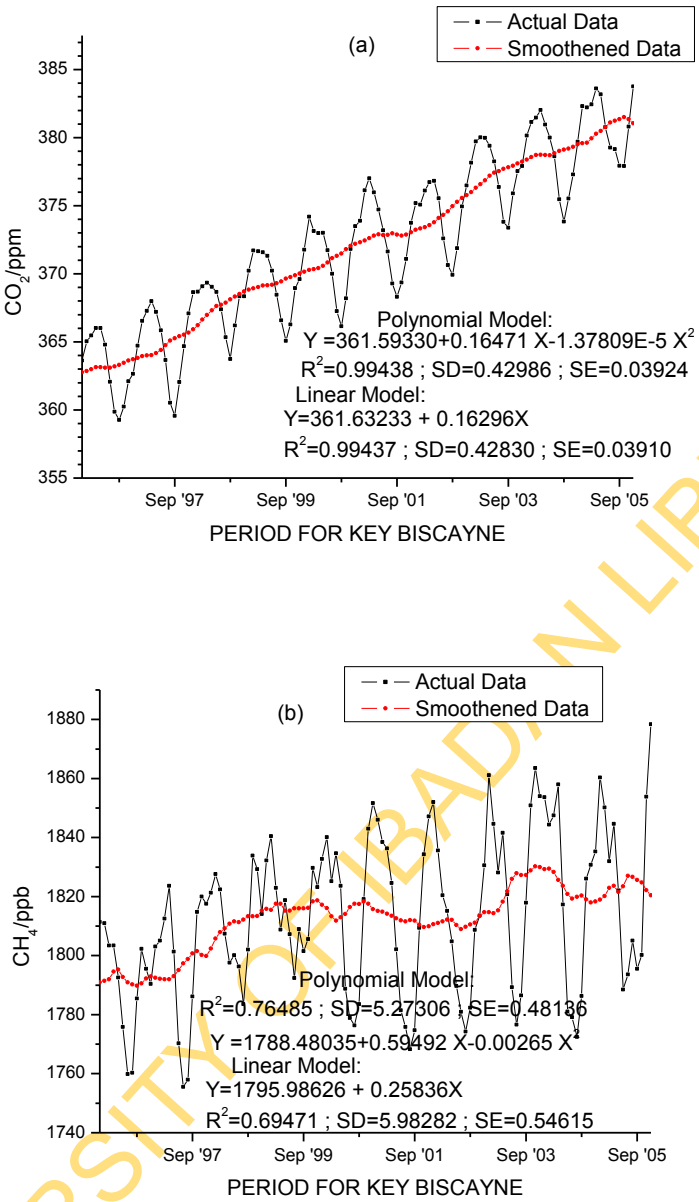


Fig. 4.27(a and b): Plot of annual CO_2 and CH_4 for Key Biscayne station

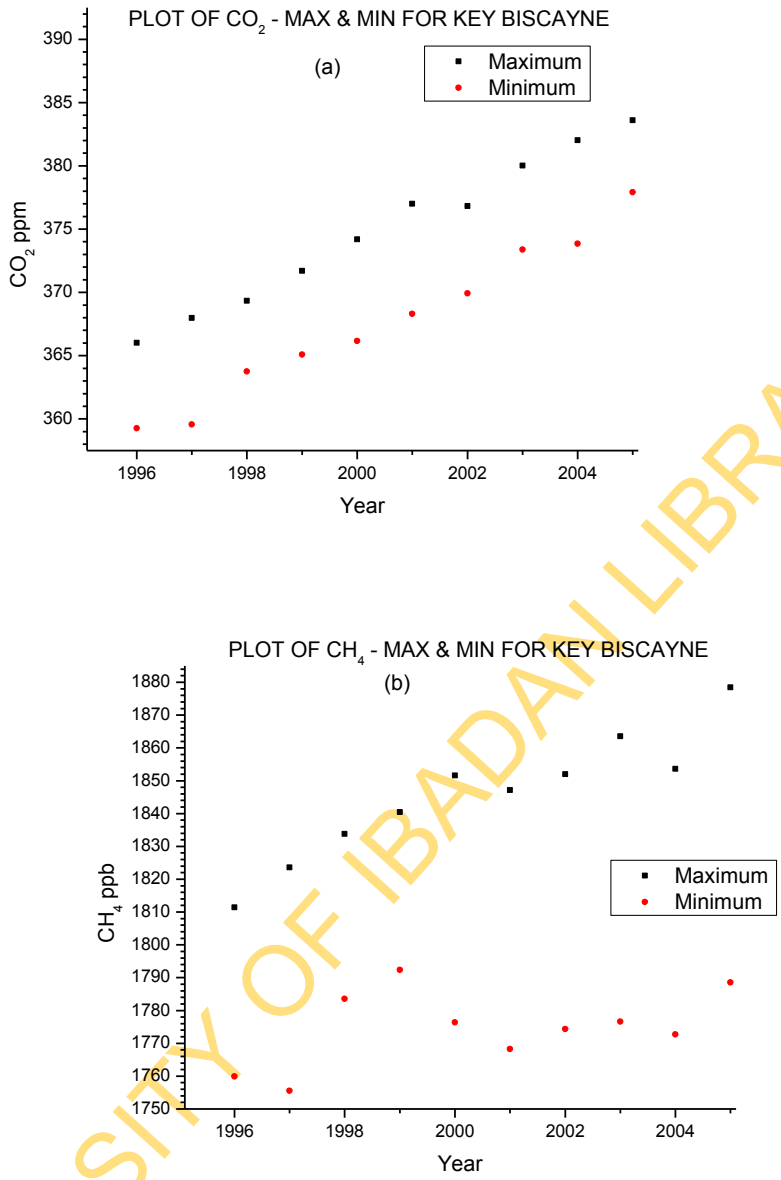


Fig. 4.28(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Key Biscayne station

Table 4.14: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Key Biscayne station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	363.2 ±0.1	0.29	9	1792.0 ±0.5	1.68	8
1997	364.7 ±0.2	0.69	6	1796.3 ±1.1	3.86	3
1998	367.5 ±0.3	0.90	1	1810.5 ±1.1	3.68	4
1999	369.4 ±0.1	0.39	7	1816.5 ±0.4	1.22	10
2000	371.1 ±0.2	0.72	4	1815.7 ±0.6	2.14	6
2001	372.8 ±0.1	0.21	10	1812.3 ±0.5	1.82	7
2002	374.3 ±0.3	0.90	1	1811.4 ±0.5	1.56	9
2003	377.3 ±0.2	0.73	3	1823.5 ±1.8	6.25	1
2004	378.9 ±0.1	0.33	8	1822.7 ±1.3	4.40	2
2005	380.7 ±0.2	0.70	5	1821.1 ±0.8	2.59	5

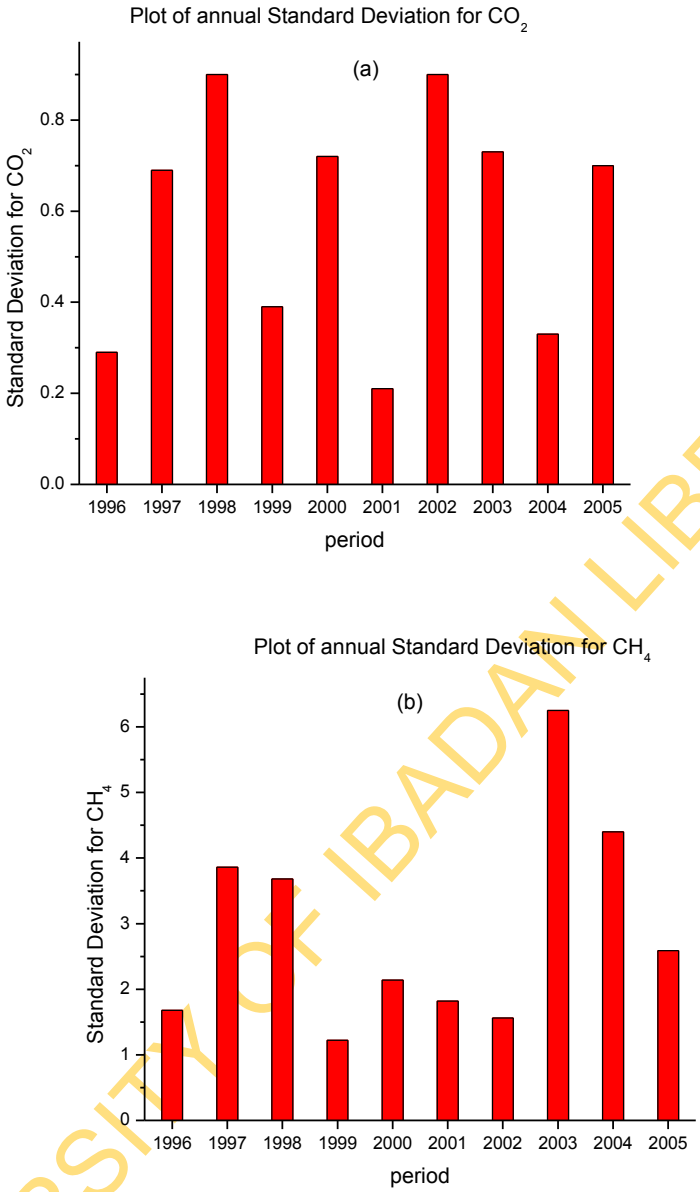


Fig. 4.29(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Key Biscayne station

Thus, in this location 1998 and 2003 would be the warmest year in terms of both CO_2 and CH_4 respectively if these gases were the dominant factor of warming. Other years mentioned by WMO amongst other authors as the warmest also features in the list of years stated above, and showed the combined effects of these gases.

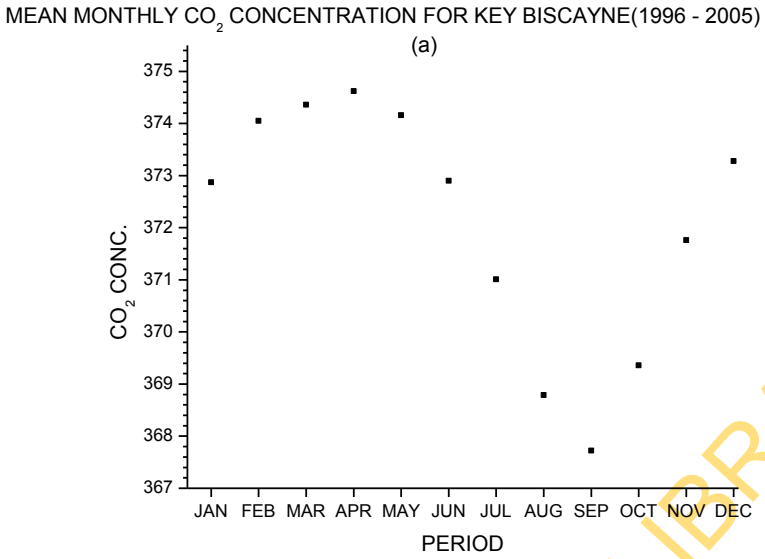
The mean monthly concentration of these gases, including their minimum and maximum annual concentration for the period considered shows fluctuations (Fig. 4.30a and b). The maximum and minimum concentrations were observed in April and September respectively for CO_2, while the maximum and minimum concentrations were observed in January and August respectively for CH_4. This is due to the difference in the amount of source and sink.

(viii) **Ragged Point Station**

Ragged Point is located in the most easterly point of the Island of Barbados, in the Atlantic Ocean. The gentle trade winds blow with a constant speed of 5-6 m/s to keep the surf rolling in and the sky clear of clouds.

The plots of CO_2 and CH_4 gases' concentration with time at Ragged Point which showed an increasing trend is as depicted in Fig. 4.31a and b. The maximum concentration of these gases is becoming closer to minimum concentration especially for CO_2 (Fig. 4.32a and b).

Table 4.15 shows the mean concentration and standard deviation for these gases. With reference to this table, the yearly variation shows that the standard deviation which indicates warming has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2003, 2005, 2000 and 2002 for CO_2 , while those for CH_4 are 1998, 1996, 2004, 2003 and 2001 (Fig. 4.33a and b). Thus, in this location 1998 is the warmest year and coincides with the SD peak of CO_2 and CH_4.



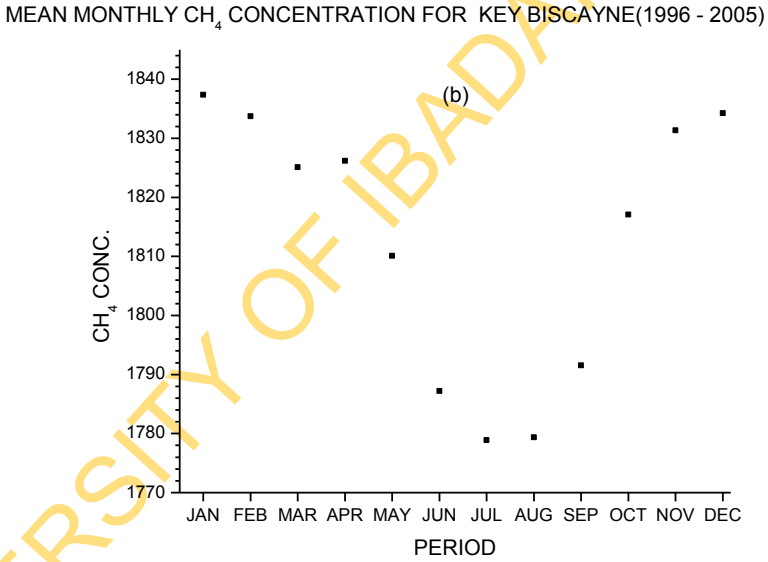
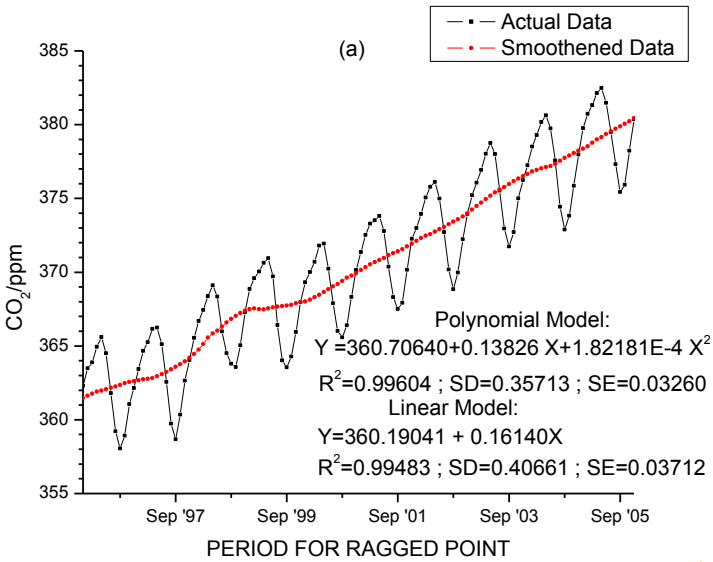


Fig. 4.30(a and b): Mean monthly concentration of CO_2 and CH_4 at Key Biscayne station



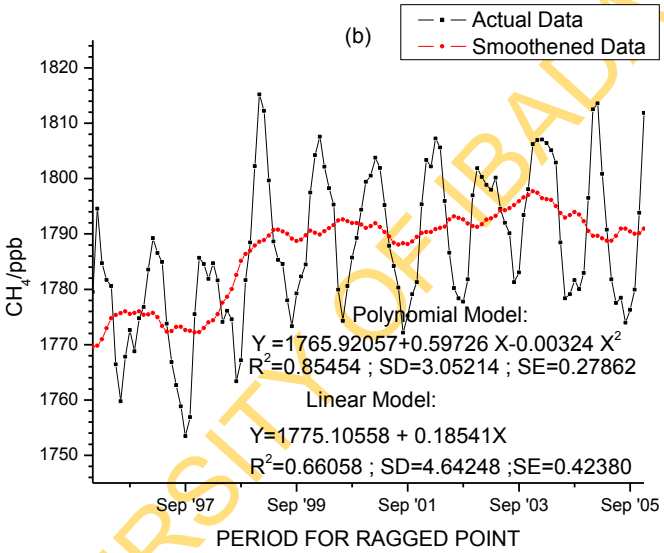


Fig. 4.31(a and b): Plot of annual CO_2 and CH_4 for Ragged Point station

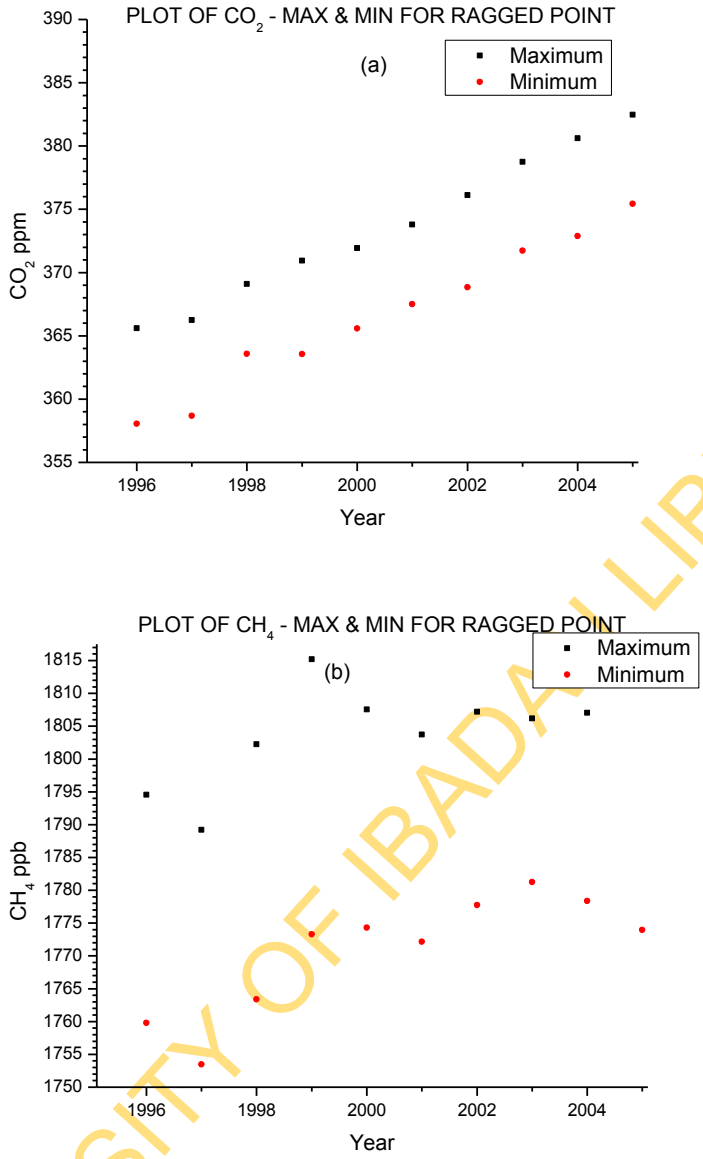


Fig. 4.32(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Ragged Point station

Table 4.15: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Ragged Point station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	362.1 ±0.1	0.37	9	1774.0 ±0.7	2.48	2
1997	363.3 ±0.2	0.52	7	1773.4 ±0.4	1.29	6
1998	366.1 ±0.3	0.97	1	1780.2 ±1.6	5.46	1
1999	367.7 ±0.1	0.16	10	1789.7 ±0.2	0.82	9
2000	369.0 ±0.2	0.65	4	1791.4 ±0.3	0.90	8
2001	371.1 ±0.2	0.56	6	1789.6 ±0.4	1.37	5
2002	373.0 ±0.2	0.60	5	1791.7 ±0.3	0.97	7
2003	375.4 ±0.2	0.75	2	1794.7 ±0.6	1.89	4
2004	377.4 ±0.2	0.51	8	1794.3 ±0.6	1.99	3
2005	379.4 ±0.2	0.67	3	1789.9 ±0.2	0.80	10

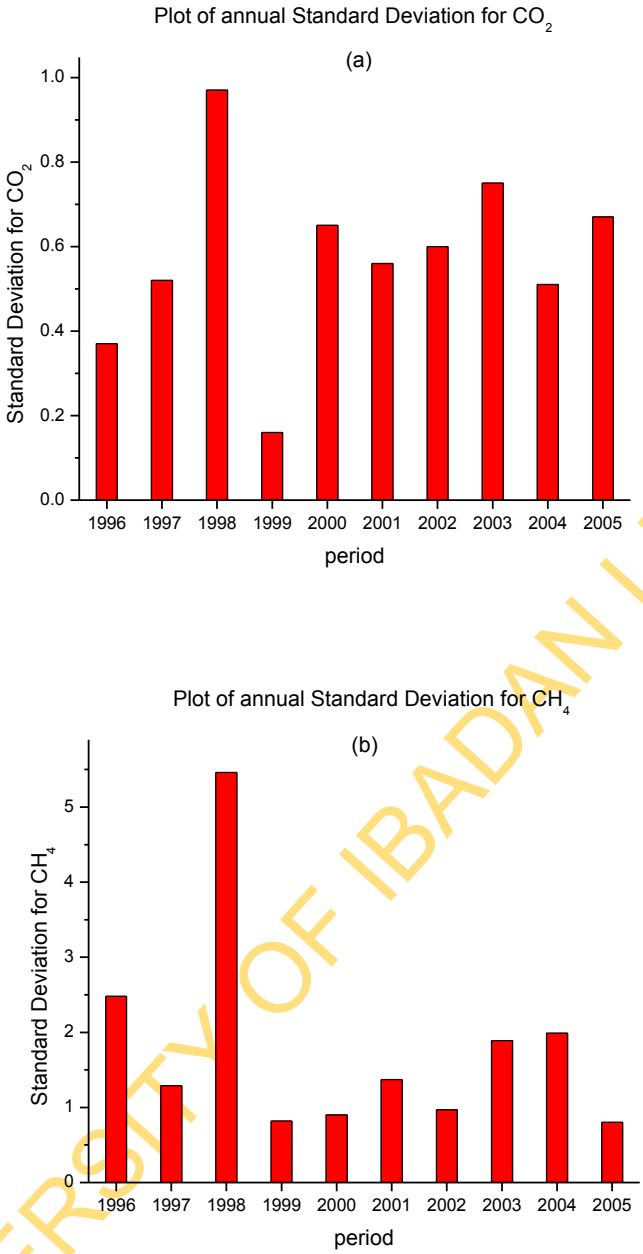


Fig. 4.33(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Ragged Point station

The mean monthly concentration of these gases including their minimum and maximum annual concentration for the period considered also shows fluctuations (Fig.4.34a and b). The maximum and minimum concentrations were observed in May and September respectively for CO_2, while the maximum and minimum concentrations were observed in February and August respectively for CH_4.

4.2.1.2 **Variational trends of greenhouse gases in the southern hemisphere stations based on their annual concentrations.**

The plots of CO_2 and CH_4 gases' annual concentration with time show a general increment pattern in trend. It was also observed that higher degree of fluctuation occurred in CH_4 than CO_2.

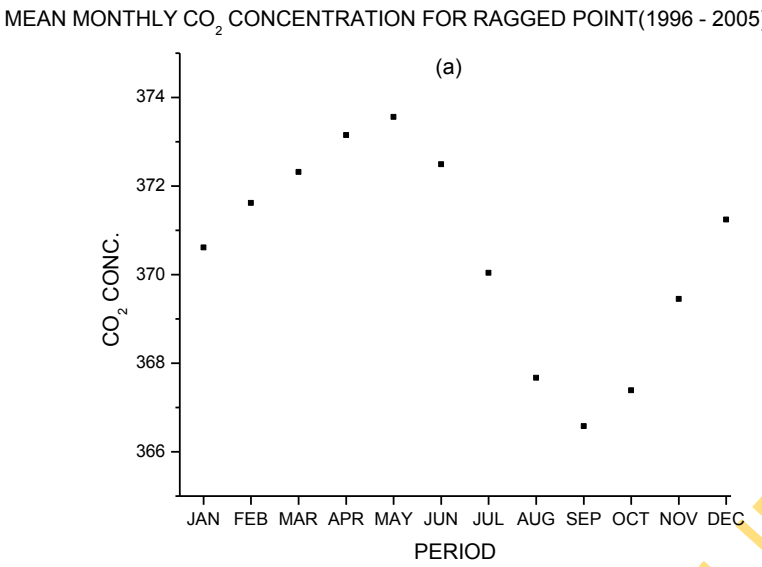
The patterns obtained for the mean monthly CO_2 concentration in the southern hemisphere showed generally a linear pattern, while those obtained for CH_4 generally showed an anticline pattern.

(i) **Ascension island station**

Ascension Island is a remote, rugged, dry, barren and inhospitable Island with an area of 98 square kilometer lying almost exactly in the middle of the South Atlantic Ocean.

Fig. 4.35a and b showed the plots of CO_2 and CH_4 concentration with time at Ascension Island. These trends showed increment with time. Fig 4.36a and b depicts the increasing net concentration of these gases which indicates a decrease in the amplitude of variation with time as both the maximum and minimum values are increasing.

Table 4.16 shows the mean concentration and standard deviation for these gases. With reference to this table the yearly variation shows that the standard deviation has five of its highest values in terms of position ranking when arranged in decreasing order in 2002, 1998, 2001, 1997 and 2005 for CO_2 , while those for CH_4 are 1998, 2001, 1997, 1999 and 2004 (Fig.4.37a and b).



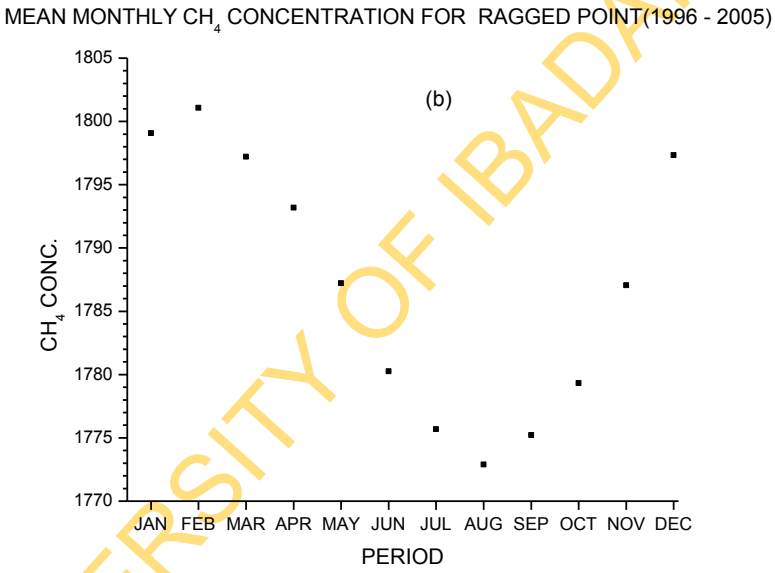


Fig. 4.34(a and b): Mean monthly concentration of CO_2 and CH_4 at Ragged Point station

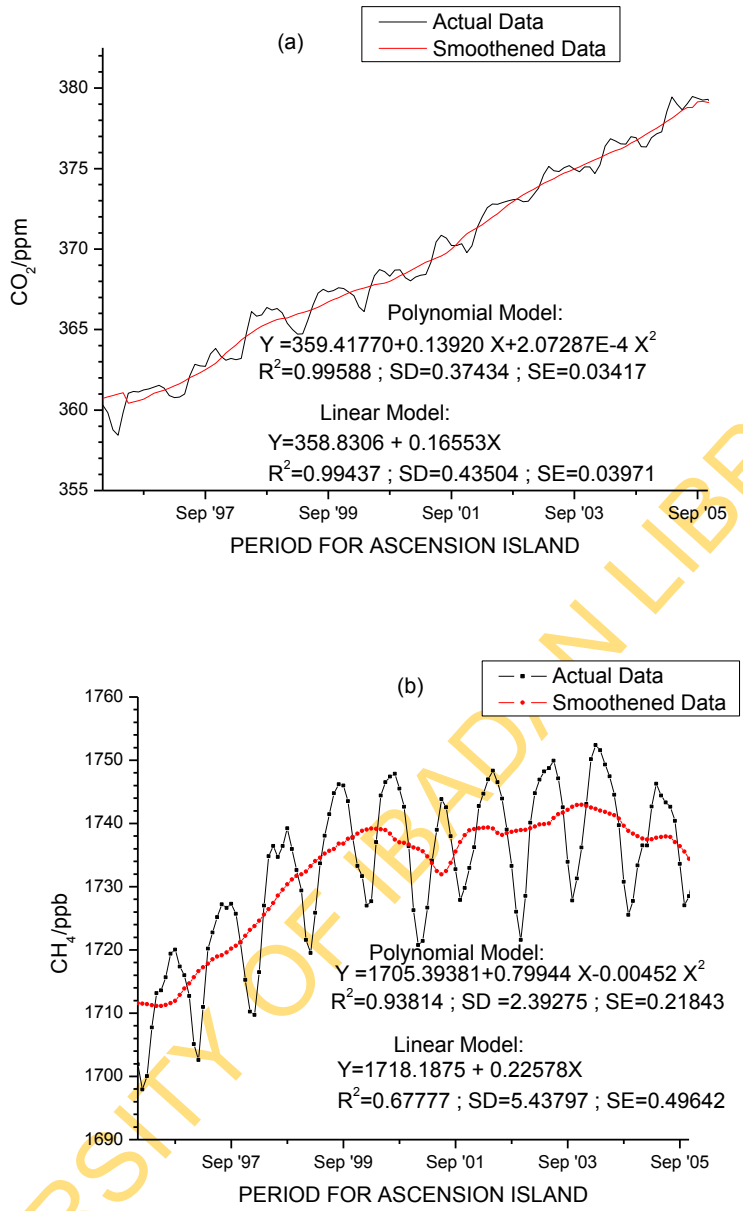


Fig. 4.35(a and b): Plot of annual CO_2 and CH_4 for Ascension Island station

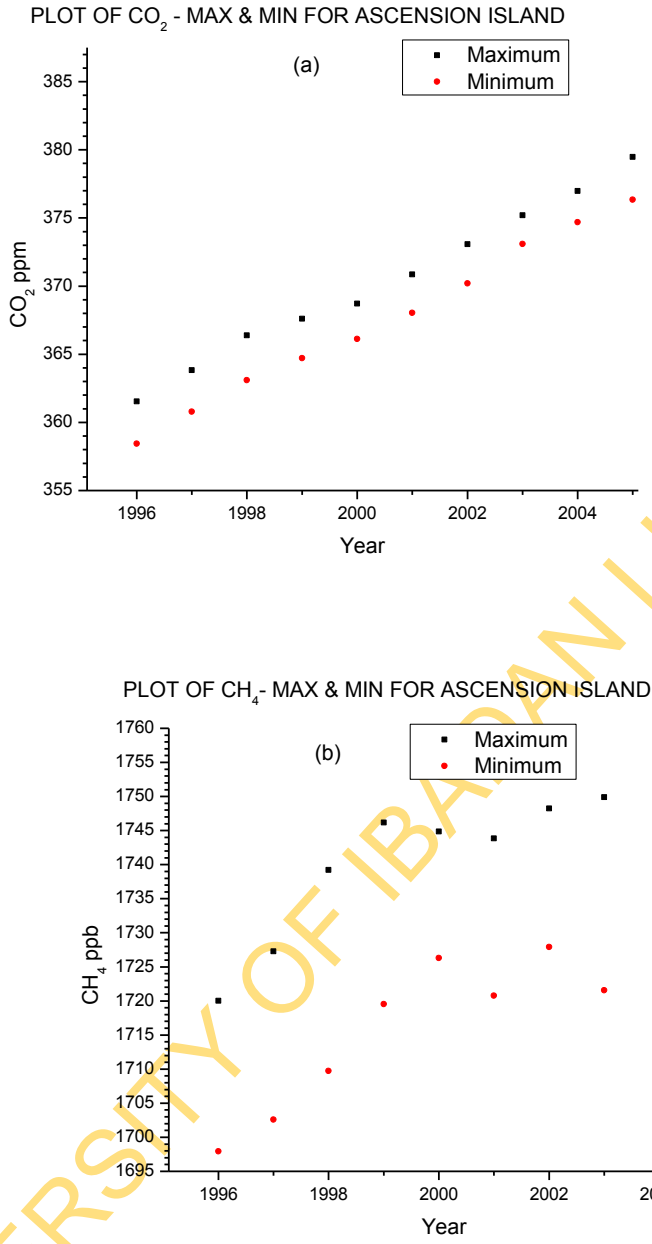


Fig. 4.36(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Ascension Island station

Table 4.16: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Ascension Island station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	360.8±0.1	0.23	10	1712.0±0.3	1.17	8
1997	362.1±0.2	0.63	4	1719.0±0.6	1.94	3
1998	364.8±0.2	0.73	2	1727.9±0.9	3.14	1
1999	366.4±0.1	0.46	8	1735.7±0.6	1.90	4
2000	367.8±0.1	0.37	9	1738.1±0.3	1.13	9
2001	369.6±0.2	0.72	3	1735.0±0.7	2.26	2
2002	372.3±0.2	0.82	1	1738.9±0.1	0.38	10
2003	374.6±0.2	0.55	7	1741.1±0.4	1.38	7
2004	376.4±0.2	0.58	6	1740.8±0.5	1.70	5
2005	378.5±0.2	0.59	5	1736.8±0.4	1.45	6

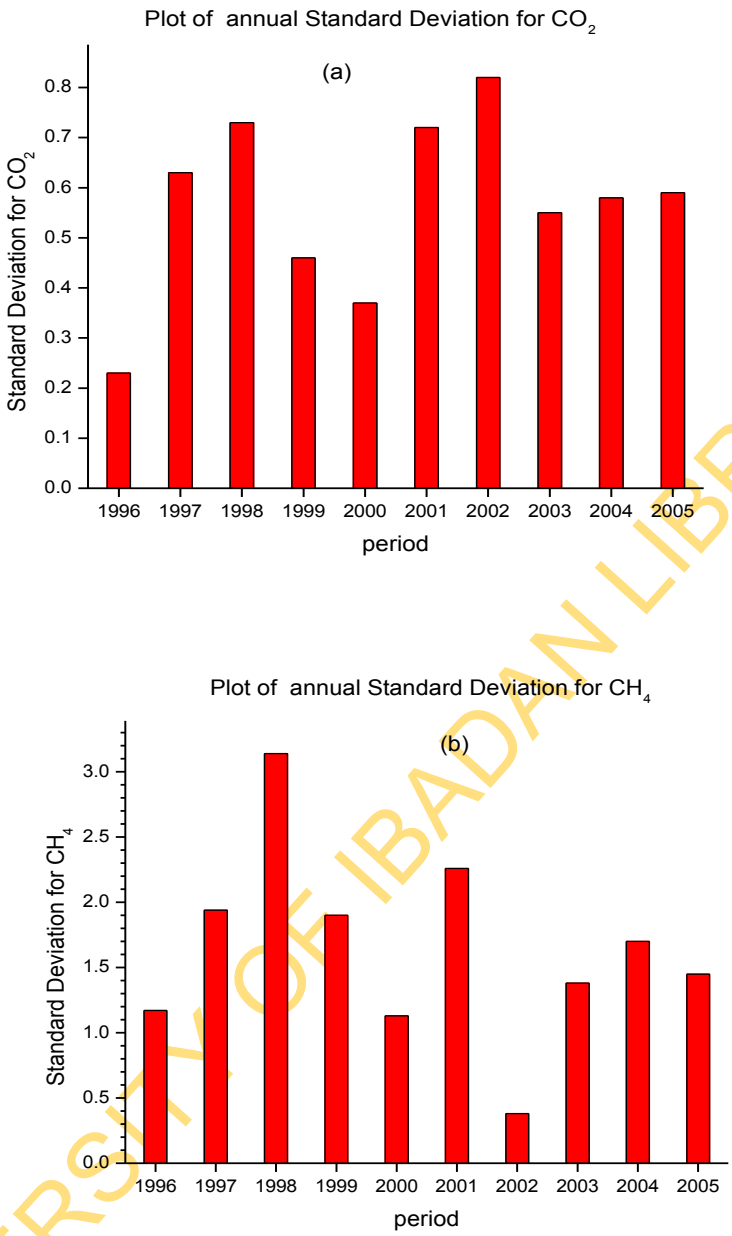


Fig. 4.37(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Ascension Island station

Thus, in this location 2002 and 1998 would be the warmest year in terms of both CO_2 and CH_4 respectively if these gases were the dominant factor of warming. Other years mentioned by WMO amongst other authors as the warmest also features in the list of years stated above, and showed the combined effects of these gases.

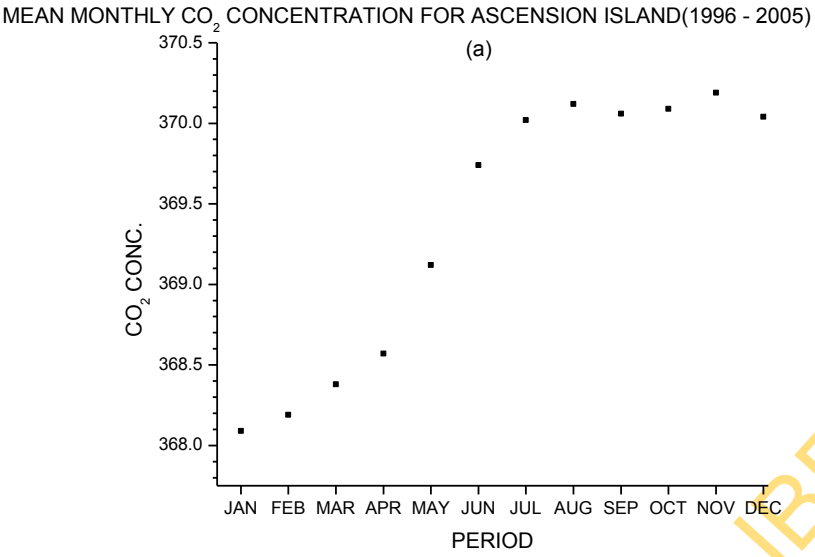
Fig. 4.38 (a and b) showed the mean monthly concentration of these gases. The maximum and minimum concentrations were observed in November and January respectively for CO_2, while the maximum and minimum concentrations were observed in June and January respectively for CH_4.

(ii) **Mahe Island**

Mahe is the largest Island with an area of about 155 square kilometers in Seychelles, lying north east of the nation within the Indian Ocean and having a population of 80,000 inhabitants.

The plots of CO_2 and CH_4 gases' concentration with time at Island are as shown in Fig.4.39 (a and b). These plots showed an increasing trend Likewise, the maximum and minimum concentrations of CO_2 are getting closer to each other, an indication of saturation (Fig 4.40a and b).

Table 4.17 shows the mean concentration and standard deviation for these gases. With reference to this table the yearly variation shows that the standard deviation, has five of its highest values in terms of position ranking when arranged in decreasing order in 1996, 2002, 2005, 1997 and 2001 for CO_2 , while those for CH_4 are 2005, 1996, 1998, 1997 and 2004 (Fig.4.41a and b). Thus, in this location 1996 and 2005 would be the warmest year in terms of both CO_2 and CH_4 respectively if these gases were the dominant factor of warming. Other years mentioned by WMO amongst other authors as the warmest also features in the list of years stated above, and showed the combined effect of these gases.



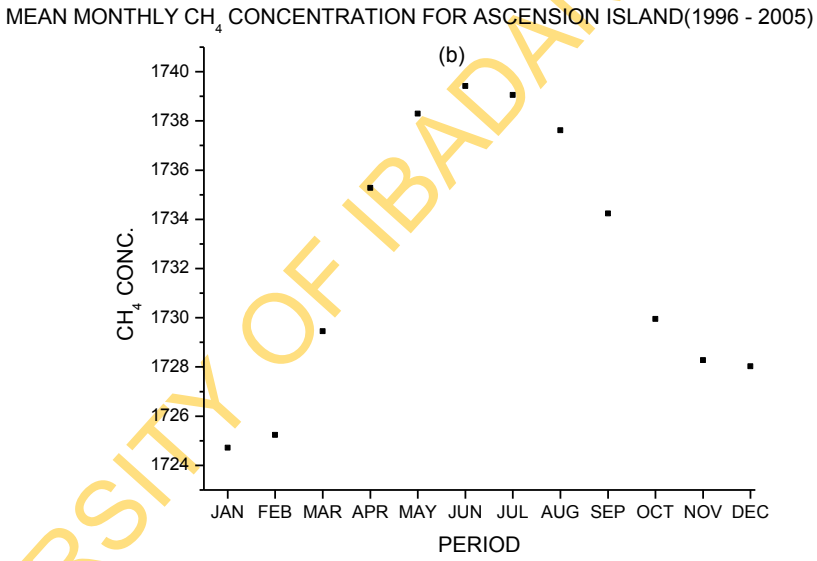


Fig. 4.38(a and b): Mean monthly concentration of CO_2 and CH_4 at Ascension Island station

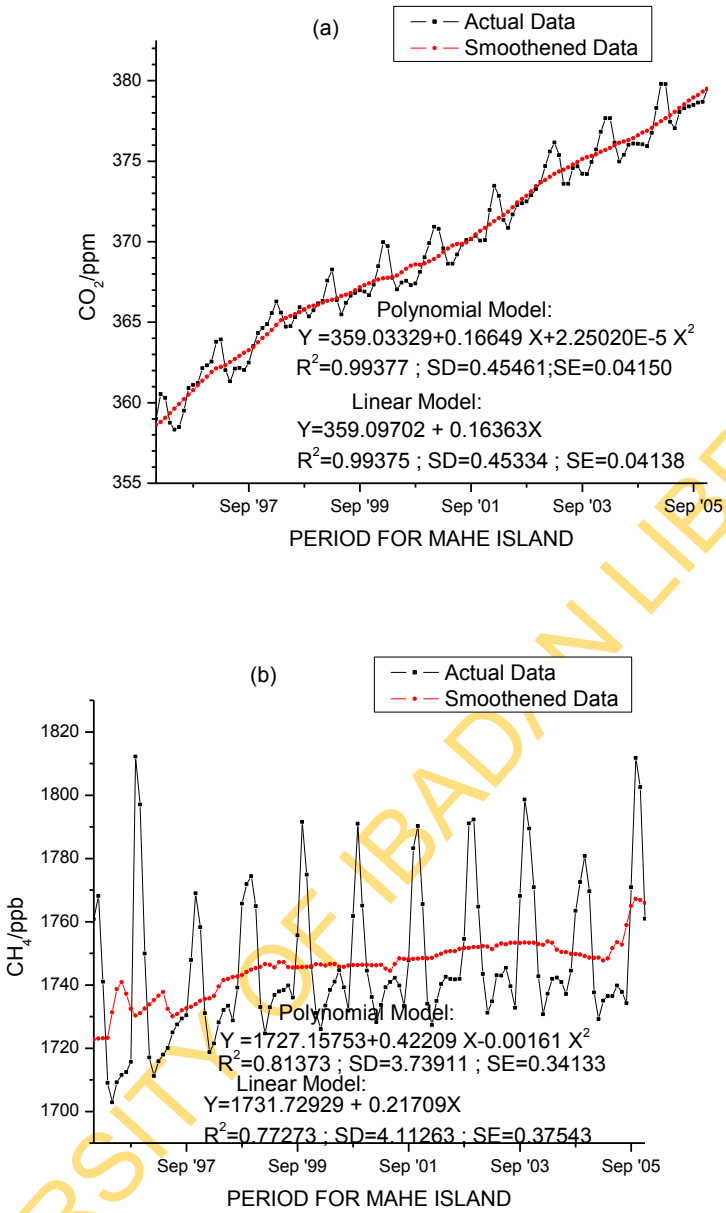


Fig. 4.39(a and b): Plot of annual CO_2 and CH_4 for Mahe Island station

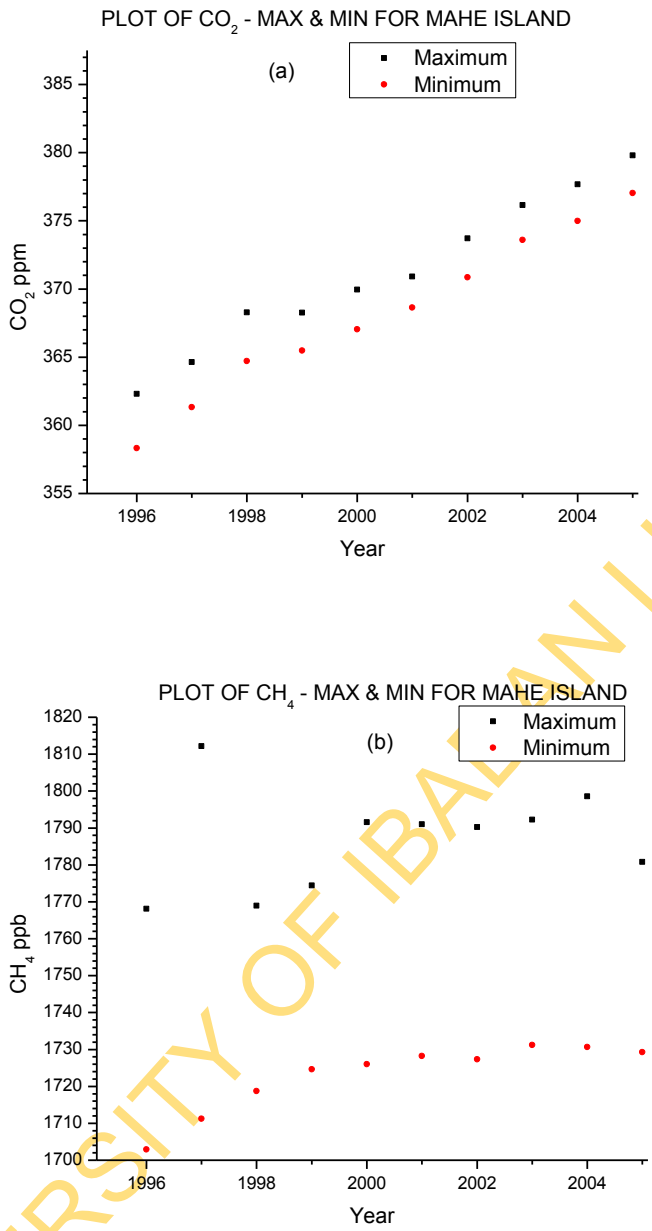


Fig. 4.40(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Mahe Island station

Table 4.17: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Mahe Island station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	360.9±0.3	1.01	1	1730.5±1.9	6.40	2
1997	362.9±0.2	0.67	4	1733.6±0.7	2.26	4
1998	365.4±0.2	0.60	5	1741.1±1.0	3.47	3
1999	366.8±0.1	0.45	9	1746.0±0.2	0.64	9
2000	368.2±0.1	0.42	10	1746.3±0.1	0.30	10
2001	369.9±0.2	0.60	5	1747.0±0.4	1.39	6
2002	372.3±0.3	0.87	2	1750.6±0.4	1.28	7
2003	374.7±0.2	0.53	7	1752.8±0.2	0.67	8
2004	376.3±0.1	0.48	8	1751.0±0.5	1.76	5
2005	378.4±0.2	0.75	3	1756.3±2.3	8.01	1

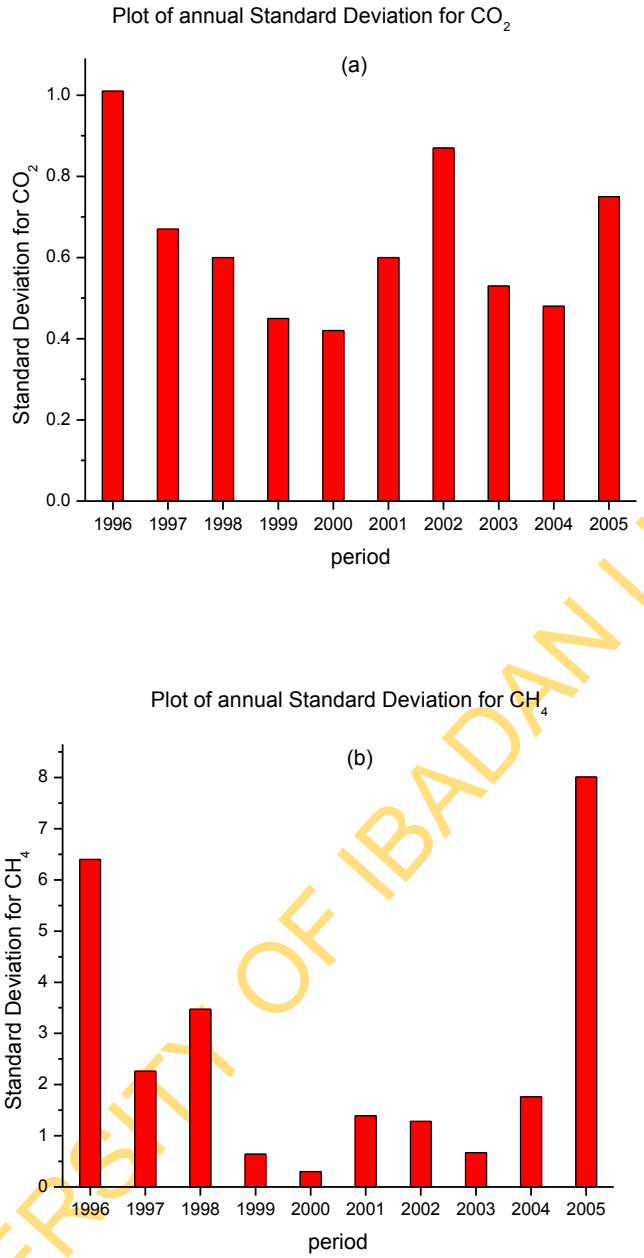


Fig. 4.41(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Mahe Island station

The mean monthly concentration of these gases, including their minimum and maximum annual concentration for the period considered, shows fluctuations (Fig.4.42a and b). This is due to the difference in the amount of source and sink. The maximum and minimum concentrations were observed in December and May respectively for CO_2, while the maximum and minimum concentrations were observed in October and February respectively for CH_4.

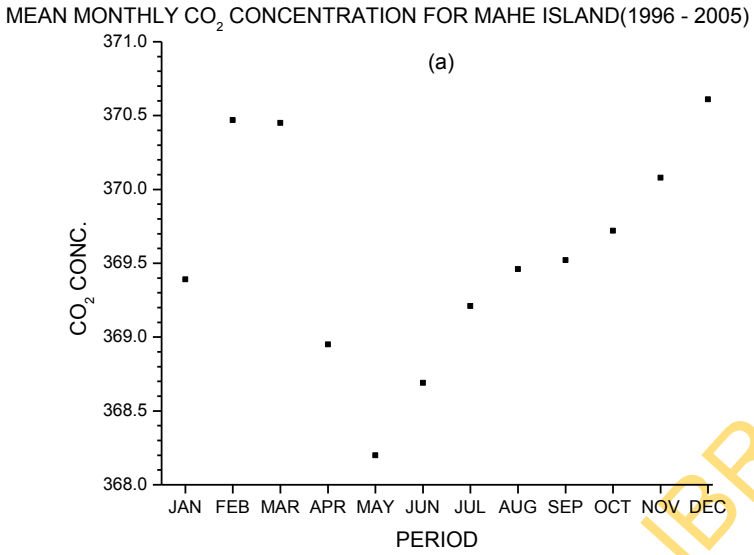
(iii) **Cape Ferguson station**

Cape Ferguson is located in the North Eastern part of the Queensland region in Australia, in the Pacific Ocean.

Fig. 4.43a and b are plots of CO_2 and CH_4 concentration with time at Cape Ferguson which showed increasing trend with time over the years. The net concentration is increasing and the amplitude of variation is decreasing as both the maximum and minimum values are increasing with time (Fig. 4.44a and b).

Table 4.18 shows the mean concentration and standard deviation for these gases. With reference to this table the yearly variation shows that the standard deviation, has five of its highest values in terms of position ranking when arranged in decreasing order in 1997, 2005, 2001, 2002 and 1998 for CO_2 , while those for CH_4 are 1998, 1997, 2001, 2004 and 2000 (Fig 4.45a and b). Thus, in this location 1997 and 1998 would be the warmest year in terms of both CO_2 and CH_4 respectively if these gases were the dominant factor of warming. Other years mentioned by WMO amongst other authors as the warmest also features in the list of years stated above, and showed the combined effects of these gases.

The mean monthly concentration of these gases, including their minimum and maximum concentration for the period considered, shows fluctuations (Fig.4.46a and b). The maximum and minimum concentrations were observed in December and March respectively for CO_2, while the maximum and minimum concentrations were observed in August and February respectively for CH_4.



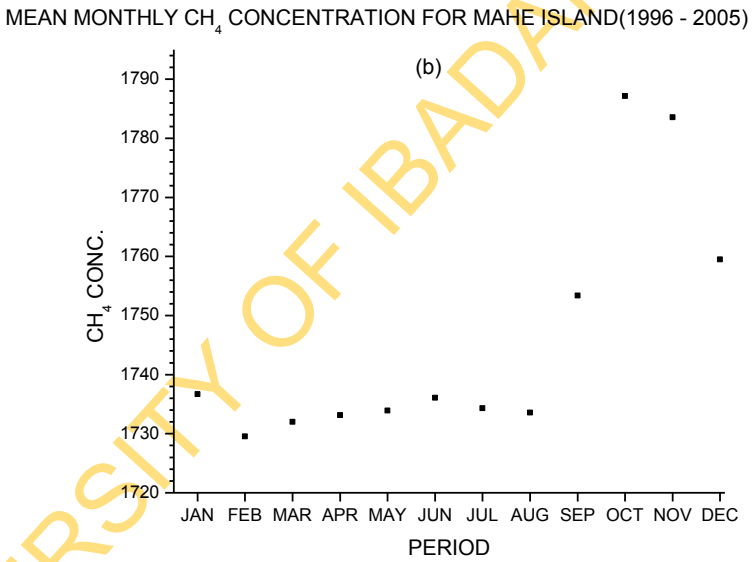


Fig. 4.42(a and b): Mean monthly concentration of CO_2 and CH_4 at Mahe Island station

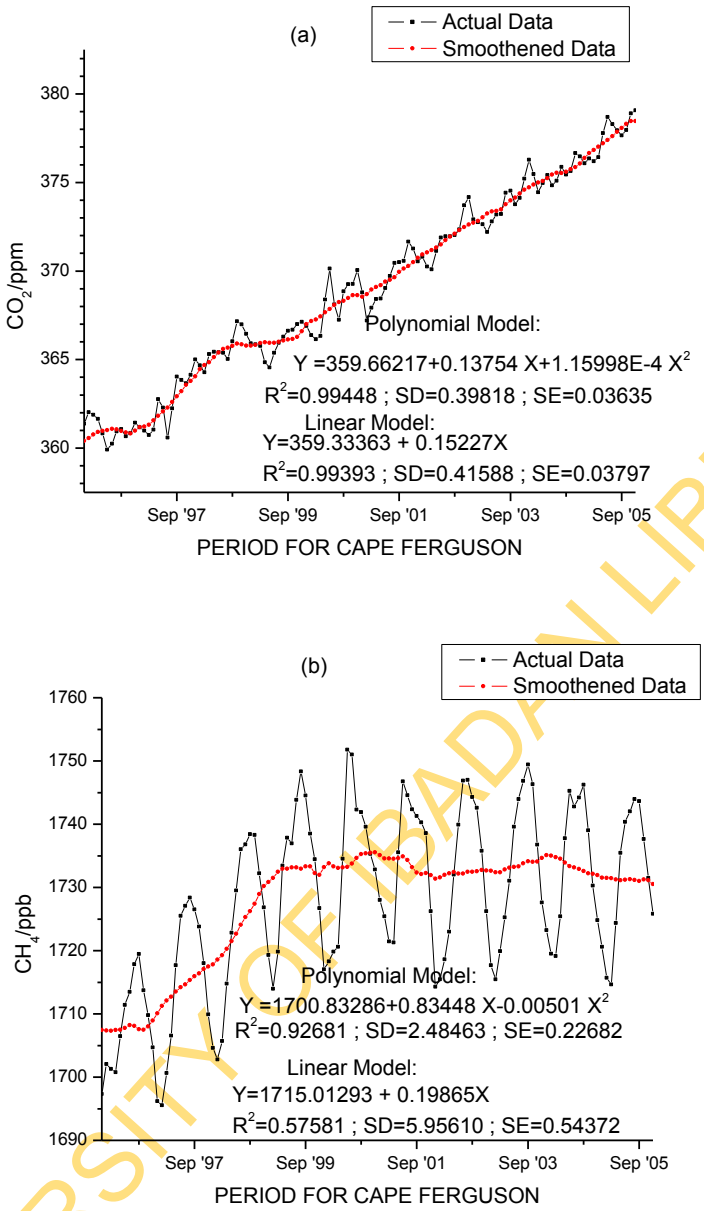


Fig. 4.43(a and b): Plot of annual CO_2 and CH_4 for Cape Ferguson station

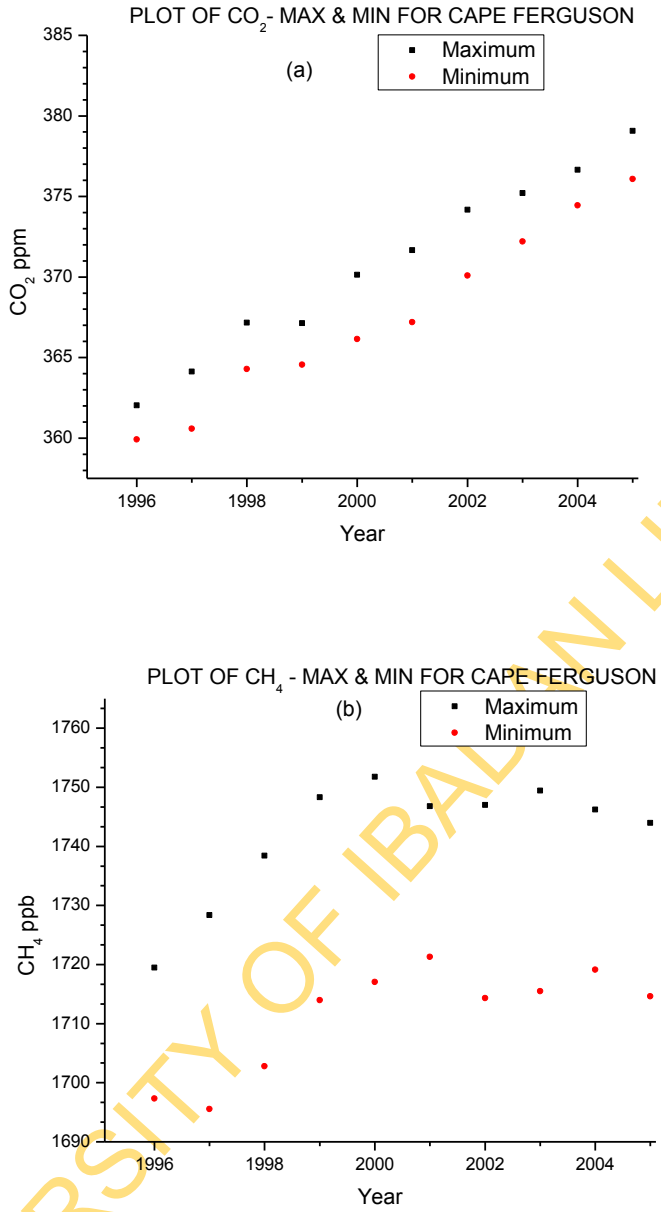
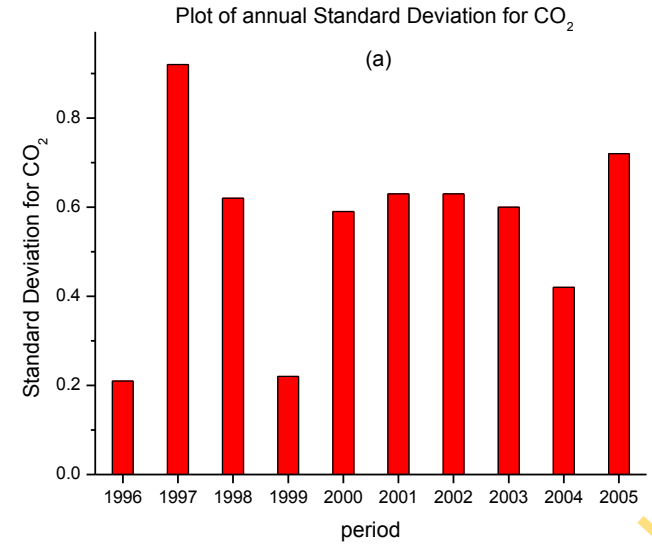


Fig. 4.44(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Cape Ferguson station

Table 4.18: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Cape Ferguson station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	360.9 ±0.1	0.21	10	1707.8 ±0.1	0.47	8
1997	362.3 ±0.3	0.92	1	1714.2 ±0.7	2.36	2
1998	365.3 ±0.2	0.62	5	1723.5 ±1.2	4.16	1
1999	366.1 ±0.1	0.22	9	1732.6 ±0.2	0.79	6
2000	367.7 ±0.2	0.59	7	1734.2 ±0.3	1.02	5
2001	369.5 ±0.2	0.63	3	1733.7 ±0.4	1.23	3
2002	371.7 ±0.2	0.63	3	1732.2 ±0.1	0.42	9
2003	373.6 ±0.2	0.60	6	1733.4 ±0.2	0.75	7
2004	375.4 ±0.1	0.42	8	1733.5 ±0.3	1.16	4
2005	377.5 ±0.2	0.72	2	1731.2 ±0.1	0.27	10



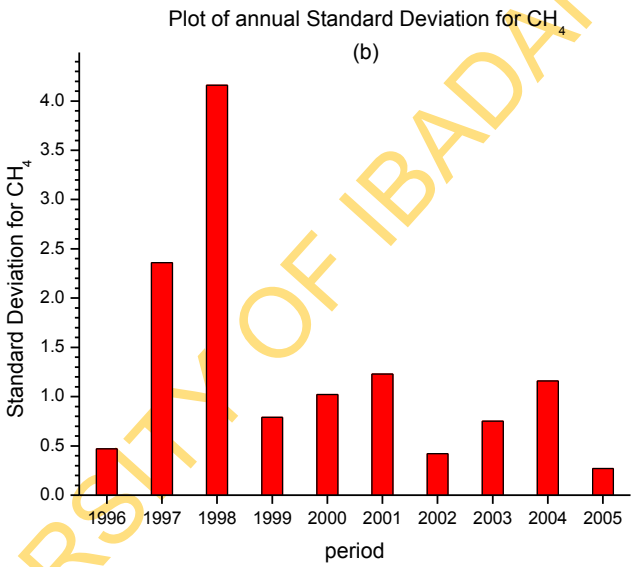
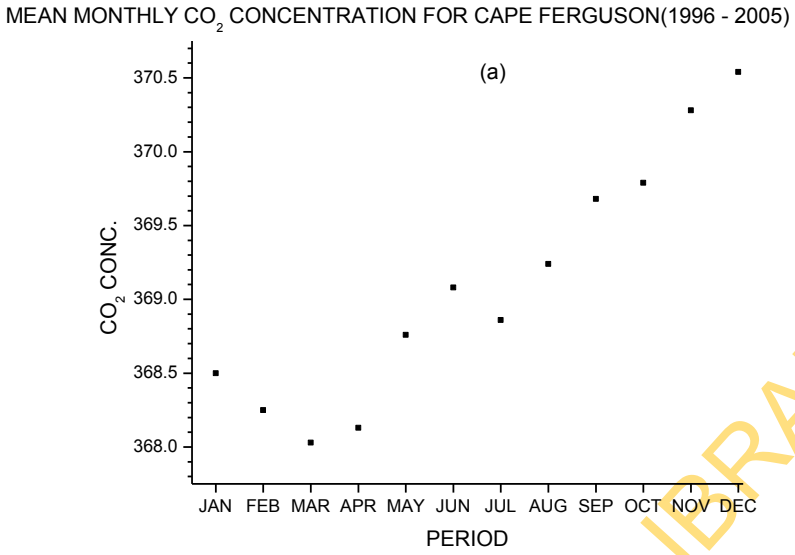


Fig. 4.45(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Cape Ferguson station



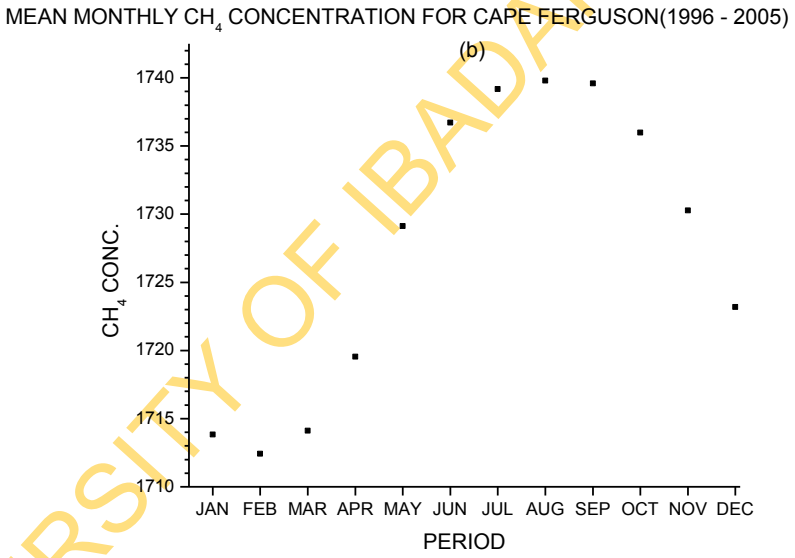


Fig. 4.46(a and b): Mean monthly concentration of CO_2 and CH_4 at Cape Ferguson station

(iv) **Tutuila Station**

Tutuila is the third largest Island in the Samoan archipelago in the heart of the South Pacific Ocean. It has a total land area of 142 square kilometer and the trade winds blow predominantly from the east.

The plots of CO_2 and CH_4 gases' concentration with time at Tutuila showed fluctuations which are not periodic, but the trend showed a general increment with time (Fig. 4.47a and b). Fig. 4.48a and b showed that the interval between the minimum and maximum monthly concentrations of these gases is getting narrower, an indication of their becoming saturated in the atmosphere.

Table 4.19 shows the mean concentration and standard deviation for these gases. With reference to this table, the yearly variation shows that the standard deviation has five of its highest values in terms of position ranking when arranged in decreasing order in 1998, 2005, 2002, 2003, and 2001 for CO_2 , while those for CH_4 are 1998, 2005, 1999, 2004, and 2003 (Fig.4.49a and b). Thus, in this location 1998 is the warmest year and coincides with the SD peak of CO_2 and CH_4.

The mean monthly concentration of these gases, including their minimum and maximum concentration for the period considered, shows fluctuations (Fig. 4.50a and b). This is due to the difference in the amount of source and sink. The maximum and minimum concentrations were observed in December and May respectively for CO_2, while the maximum and minimum concentrations were observed in August and April respectively for CH_4.

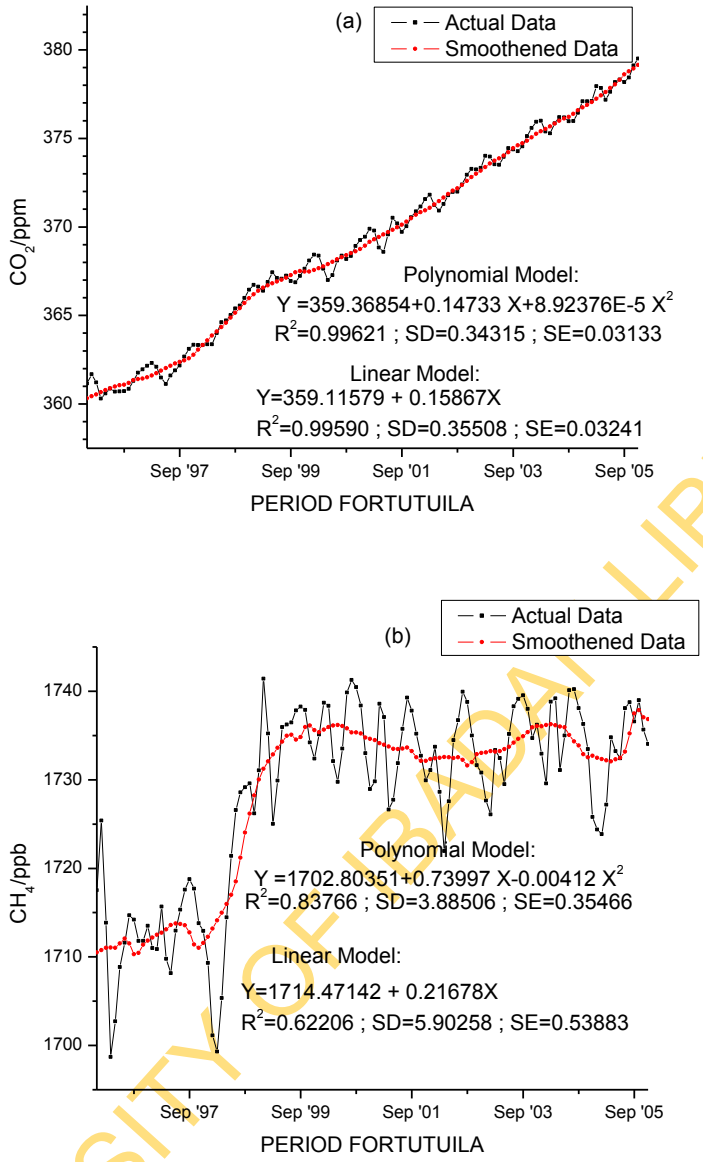
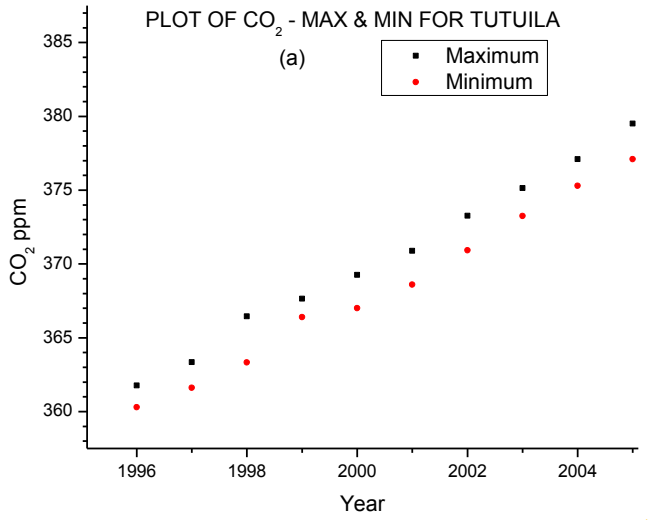


Fig. 4.47(a and b): Plot of annual CO_2 and CH_4 for Tutuila station



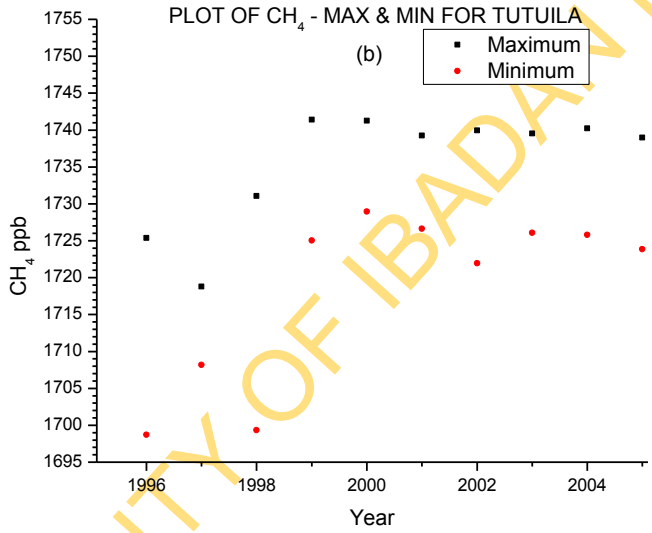


Fig. 4.48(a and b): Plot of maximum and minimum annual CO_2 and CH_4 concentration for Tutuila station

Table 4.19: Values of mean concentration of CO_2 and CH_4 with both the standard deviation and ranking for Tutuila station

Year	Mean CO_2 Conc. (ppm)	CO_2 Standard Deviation (SD)	Ranking of CO_2 SD by position	Mean CH_4 Conc. (ppb)	CH_4 Standard Deviation (SD)	Ranking of CH_4 SD by position
1996	360.9 ±0.1	0.35	10	1711.1 ±0.2	0.56	8
1997	362.1 ±0.1	0.44	7	1712.7 ±0.3	0.98	6
1998	364.5 ±0.3	0.95	1	1719.6 ±1.8	6.15	1
1999	367.0 ±0.1	0.44	7	1734.3 ±0.4	1.54	3
2000	368.1 ±0.1	0.43	9	1735.5 ±0.2	0.52	9
2001	369.8 ±0.2	0.54	5	1733.4 ±0.2	0.75	7
2002	371.8 ±0.2	0.66	3	1732.4 ±0.1	0.37	10
2003	374.0 ±0.2	0.62	4	1734.2 ±0.3	1.11	5
2004	375.9 ±0.2	0.53	6	1734.8 ±0.4	1.49	4
2005	377.9 ±0.2	0.77	2	1732.3 ±0.7	2.39	2

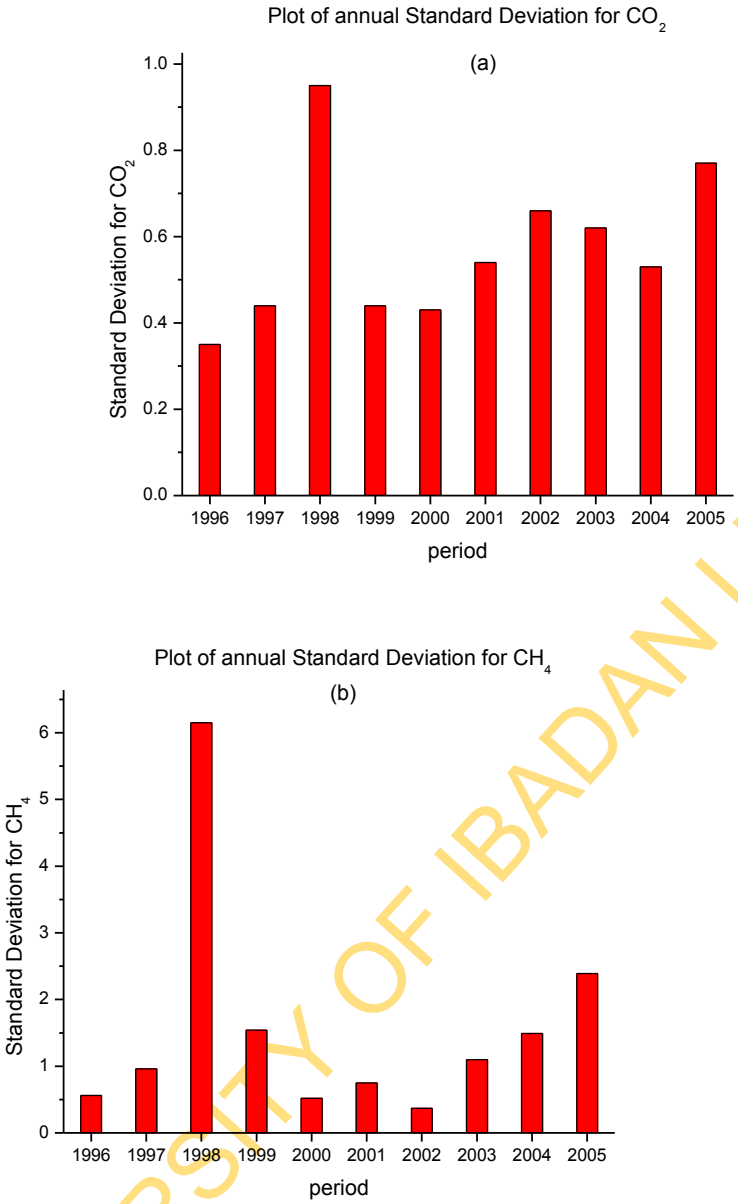
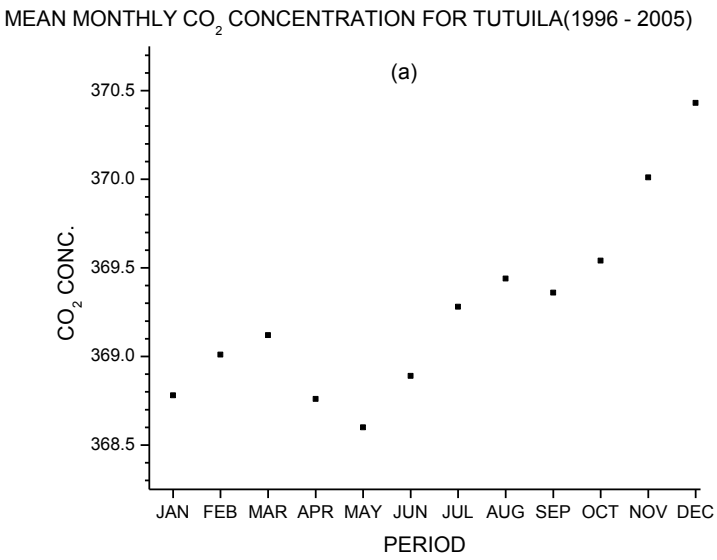


Fig. 4.49(a and b): Plot of annual standard deviation for CO_2 and CH_4 at Tutuila station



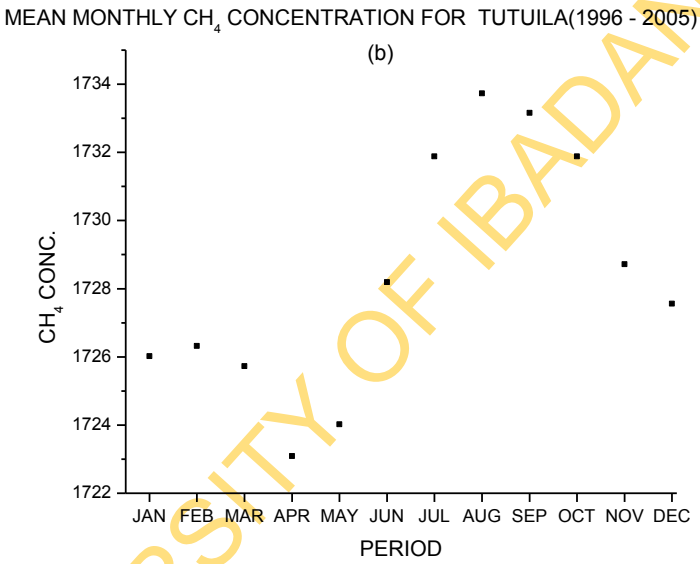


Fig. 4.50(a and b): Mean monthly concentration of CO_2 and CH_4 at Tutuila station

4.2.2 Variational trends of greenhouse gases concentration on spatial distribution basis

The spatial distributions of greenhouse gases were considered in the Tropics both latitudinally and longitudinally in the Northern and Southern hemisphere in order to ascertain the spatial variation of these gases, and it was observed that CO_2 has more correlation than CH_4 in each of the stations considered. Likewise, systematic cross plots were made for stations approximately 5^o interval to each other and also for those with more than 5^o interval to each other for both the Northern and Southern hemisphere.

4.2.2.1 Latitudinal variation of CO_2 and CH_4 for stations approximately 5^o interval to each other in the northern hemisphere

The comparisons of CO_2 and CH_4 gas' concentrations made for stations within 5^o interval to each other latitudinally in the northern hemisphere and the summary of the values of both the square of correlation coefficient (i.e. interdependence) and standard deviation, used in indicating warming of these gases are as shown in Table 4.20. Also, Fig. 4.51 was used to represent one of these numerous plots. The values of the square of correlation coefficient (R^2) for CO_2 concentration in these stations lie between 0.993 and 0.999, while those of CH_4 lie between 0.586 and 0.942. Similarly, the standard deviations for CO_2 concentration in these stations lie between 0.15 and 0.61, while those of CH_4 lie between 2.17 and 5.15. Thus, it can be concluded that CO_2 has better correlation with minimal deviation than CH_4 in this hemisphere because of its higher R^2 values and lower SD values in comparison with that of CH_4.

Table 4.20: Comparisons of latitudinal plots of CO_2 and CH_4 concentrations for Northern Hemisphere stations approximately 5º interval to each other

Cross Plots of Stations	Latitudinal Locations	Square of Correlation Coefficient (R^2) for CO_2	Standard Deviation (SD) for CO_2	Square of Correlation Coefficient (R^2) for CH_4	Standard Deviation (SD) for CH_4
Assekrem vs. Minamitorishima	Lat.23º10'N vs. Lat.24º17'N	0.997	0.33	0.867	3.95
Assekrem vs. Sand Island	Lat.23º10'N vs. Lat.28º12'N	0.999	0.20	0.791	4.15
Assekrem vs. Cape Kumukahi	Lat.23º10'N vs. Lat.19º31'N	0.993	0.47	0.889	3.00
Assekrem vs. Mauna Loa	Lat.23º10'N vs. Lat.19º32'N	0.999	0.15	0.942	2.17
Assekrem vs. Key Biscayne	Lat.23º10'N vs. Lat,25º40'N	0.998	0.27	0.857	4.11
Guam vs. Ragged Point	Lat.13º26'N vs. Lat.13º10'N	0.998	0.27	0.586	5.15
Minamitorishima vs. Sand Island	Lat.24º17'N vs. Lat.28º12'N	0.996	0.39	0.930	2.41
Minamitorishima vs. Cape Kumukahi	Lat.24º17'N vs. Lat.19º31'N	0.988	0.61	0.849	3.50
Minamitorishima vs. Mauna Loa	Lat.24º17'N vs. Lat.19º32'N	0.997	0.30	0.918	2.57
Minamitorishima vs. Key Biscayne	Lat.24º17'N vs. Lat,25º40'N	0.995	0.41	0.808	4.77
Sand Island vs. Key Biscayne	Lat.28º12'N vs. Lat,25º40'N	0.999	0.21	0.871	3.91
Cape Kumukahi vs. Mauna Loa	Lat.19º31'N vs. Lat.19º32'N	0.993	0.46	0.885	3.05

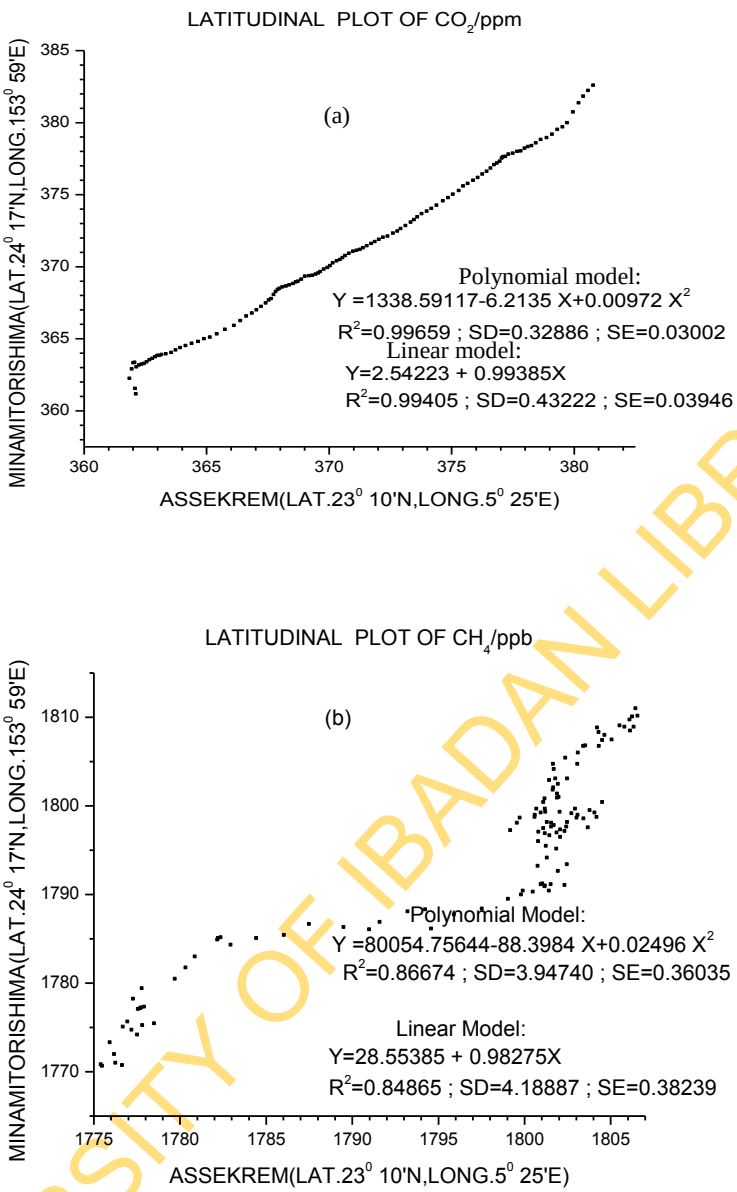


Fig. 4.51 (a and b) Comparisons of latitudinal plots of CO_2 and CH_4 concentration for Assekrem vs. Minamitorishima

4.2.2.2 **Latitudinal variation of CO_2 and CH_4 for stations approximately 5^o interval to each other in the southern hemisphere**

The comparisons of CO_2 and CH_4 gas' concentrations made for stations within 5^o interval to each other latitudinally in the southern hemisphere and the values of both the R^2 and SD of these gases are as shown in Table 4.21. Fig. 4.52 was used to indicate the representation of one of these plots. The value R^2 of CO_2 concentration for these stations is 0.993, while those of CH_4 lie between 0.716 and 0.956. Similarly, SD of CO_2 concentrations for these stations lie between 0.46 and 0.48, while those of CH_4 lie between 2.56 and 4.61. It was observed that there was a better correlation for CO_2 in the northern hemisphere than in the southern hemisphere for stations approximately 5^o interval to each other. Also the value of deviation for CH_4 is higher in the northern hemisphere than in the southern hemisphere. These SD values were used as indicators of warming because they correlate well with global temperature. Thus, due to the higher SD values obtained it can be concluded that there is much warming in the northern hemisphere than in the southern hemisphere for stations approximately 5^o interval to each other.

4.2.2.3 **Latitudinal variation of CO_2 and CH_4 for stations with more than 5^o interval to each other in the northern hemisphere**

The comparisons of CO_2 and CH_4 gas' concentrations made for stations beyond 5^o interval to each other latitudinally in the northern hemisphere and the values of both the R^2 and SD of these gases are as shown in Table 4.22. Also, Fig. 4.53 was used to represent one of these numerous plots. The values R^2 for CO_2 concentrations in these stations lie between 0.994 and 0.999, while those of CH_4 lie between 0.644 and 0.942. Similarly, the SD for CO_2 concentrations in these stations lies between 0.18 and 0.45, while those of CH_4 lie between 1.92 and 6.45.

Table 4.21: Comparisons of latitudinal plots of CO_2 and CH_4 concentrations for Southern Hemisphere stations approximately 5º interval to each other

Cross Plots of Stations	Latitudinal Locations	Square of Correlation Coefficient (R^2) for CO_2	Standard Deviation (SD) For CO_2	Square of Correlation Coefficient (R^2) For CH_4	Standard Deviation (SD) For CH_4
Ascension Island vs. Mahe Island	Lat. 7º55'S vs.Lat.4º40'S	0.993	0.48	0.716	4.61
Cape Ferguson vs. Tutuila	Lat.19º17'S vs.Lat.14º15'S	0.993	0.46	0.956	2.56

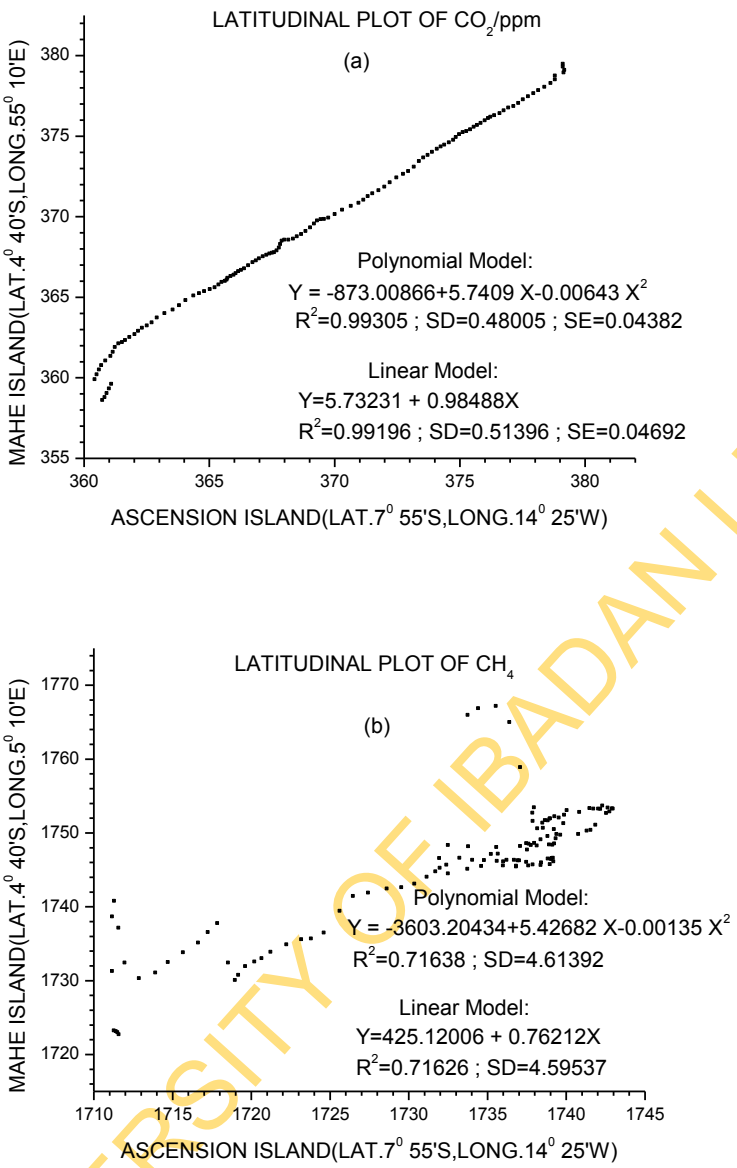
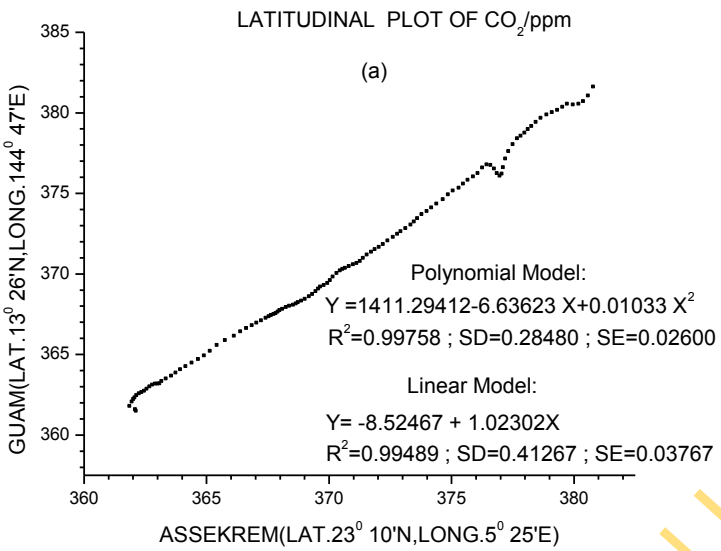


Fig. 4.52 (a and b) Comparisons of latitudinal plots of CO_2 and CH_4 concentration for Ascension Island vs. Mahe Island

Table 4.22: Comparisons of latitudinal plots of CO_2 and CH_4 concentrations for Northern Hemisphere stations with more than 5º interval to each other

Cross Plots of Stations	Latitudinal Locations	Square of Correlation Coefficient (R^2) for CO_2	Standard Deviation (SD) For CO_2	Square of Correlation Coefficient (R^2) for CH_4	Standard Deviation (SD) for CH_4
Assekrem vs. Guam	Lat.23º10'N vs. Lat.13º26'N	0.998	0.29	0.696	5.13
Assekrem vs. Ragged Point	Lat.23º10'N vs. Lat.13º10'N	0.999	0.20	0.942	1.92
Guam vs. Minamitorishima	Lat.13º26'N vs. Lat.24º17'N	0.994	0.45	0.785	5.02
Guam vs. Sand Island	Lat.13º26'N vs. Lat.28º12'N	0.997	0.31	0.644	5.42
Guam vs. Cape Kumukahi	Lat.13º26'N vs. Lat.19º31'N	0.995	0.41	0.781	4.21
Guam vs. Mauna Loa	Lat.13º26'N vs. Lat.19º32'N	0.998	0.26	0.783	4.19
Guam vs. Key Biscayne	Lat.13º26'N vs. Lat.25º40'N	0.996	0.37	0.649	6.45
Minamitorishima vs. . Ragged Point	Lat.24º17'N vs. Lat.13º10'N.	0.995	0.40	0.820	3.39
Sand Island vs. Cape Kumukahi	Lat.28º12'N vs. Lat,1º31'N	0.996	0.37	0.904	2.79
Sand Island vs. Mauna Loa	Lat.28º12'N vs. Lat,19º32'N	0.999	0.18	0.938	2.24
Sand Island vs. Ragged Point	Lat.28º12'N vs. Lat,13º10'N	0.999	0.20	0.831	3.29
Cape Kumukahi vs. Key Biscayne	Lat.19º31'N vs. Lat.25º40'N	0.994	0.43	0.912	3.23
Cape Kumukahi vs. .Ragged Point	Lat.19º31'N vs. Lat.13º10'N	0.994	0.43	0.748	4.02
Mauna Loa vs. Key Biscayne	Lat.19º32'N vs. Lat.25º40'N	0.998	0.26	0.910	3.27
Mauna Loa vs. Ragged Point	Lat.19º32'N vs. Lat.13º10'N	0.998	0.23	0.872	2.86
Key Biscayne vs. Ragged Point	Lat.25º40'N vs. Lat.13º10'N	0.997	0.30	0.780	3.76



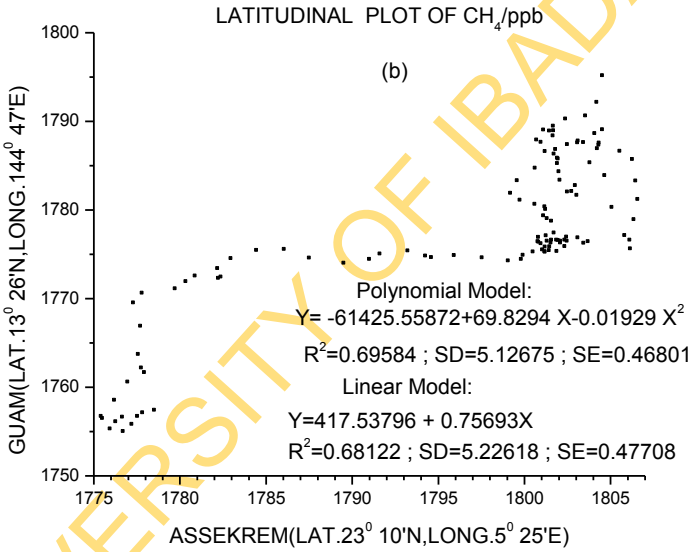


Fig. 4.53 (a and b) Comparisons of latitudinal plots of CO_2 and CH_4 concentration for Assekrem vs. Guam

It was observed that there was a higher value of SD for CH_4 in the northern hemisphere for stations beyond 5^o interval to each other than for those approximately 5^o interval to each other latitudinally.

4.2.2.4 Latitudinal variation of CO_2 and CH_4 for stations with more than 5^o interval to each other in the southern hemisphere

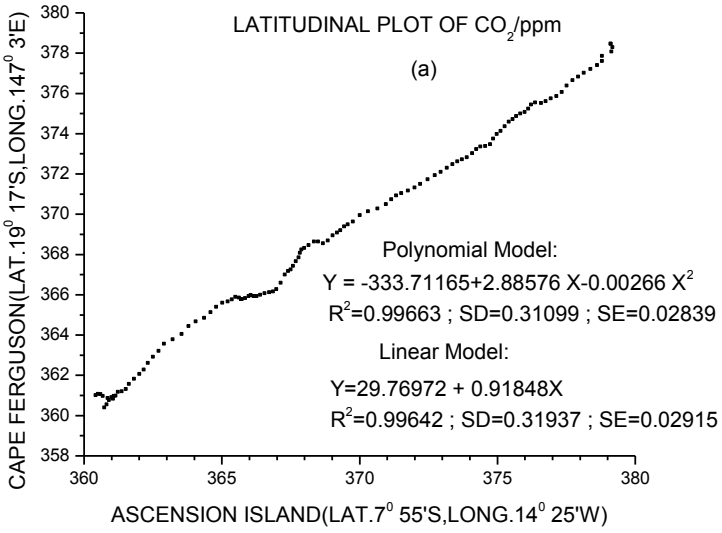
The comparisons of CO_2 and CH_4 gas' concentrations made for stations beyond 5^o interval to each other latitudinally in the southern hemisphere and the values of both R^2 and SD of these gases are as shown in Table 4.23. Fig. 4.54 was used to represent one of these gases. The values of R^2 for CO_2 concentrations in these stations lie between 0.992 and 0.997, while those of CH_4 lie between 0.776 and 0.958. Similarly, the SD of CO_2 concentrations in these stations lie between 0.31 and 0.49, while those of CH_4 lie between 0.19 and 4.57. It was observed that the standard deviation for CH_4 in the southern hemisphere has a lower value for stations beyond 5^o interval to each other than for those approximately 5^o interval to each other.

4.2.2.5 Longitudinal variation of CO_2 and CH_4 for stations approximately 5^o interval to each other for both the northern and southern hemisphere

The comparisons of CO_2 and CH_4 gas' concentrations made for stations within 5^o interval to each other longitudinally in the northern and southern hemisphere and the values of both R^2 and SD of these gases are as shown in Table 4.24. Fig. 4.55 was used to represent one of these plots.

Table 4.23: Comparisons of latitudinal plots of CO_2 and CH_4 concentrations for Southern Hemisphere stations with more than 5° interval to each other

Cross Plots of Stations	Latitudinal Locations	Square of Correlation Coefficient (R^2) for CO_2	Standard Deviation (SD) for CO_2	Square of Correlation Coefficient (R^2) for CH_4	Standard Deviation (SD) for CH_4
Ascension Island vs. Cape Ferguson	Lat. 7°55'S vs.Lat.19°17'S	0.997	0.31	0.958	0.19
Ascension Island vs. Tutuila	Lat.7°55'S vs.Lat.14°15'S	0.996	0.35	0.889	3.21
Mahe Island Vs. Cape Ferguson	Lat.4°40'S vs.Lat.19°17'S	0.994	0.41	0.791	4.20
Mahe Island Vs. Tutuila	Lat.4°40'S vs.Lat.14°15'S	0.992	0.49	0.776	4.57



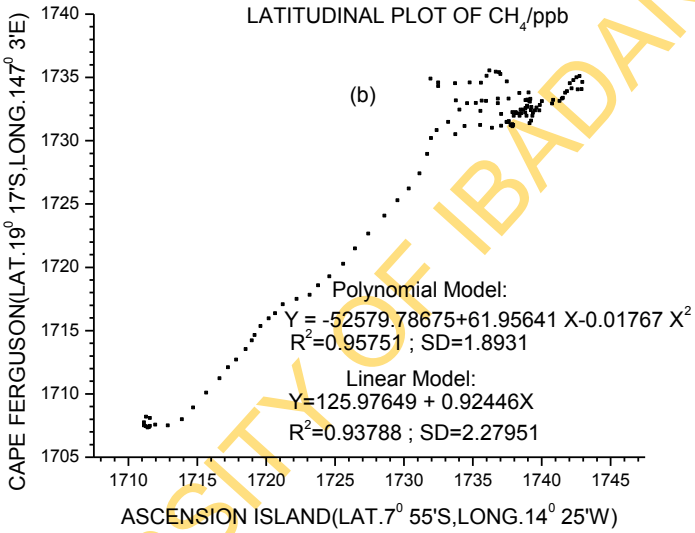
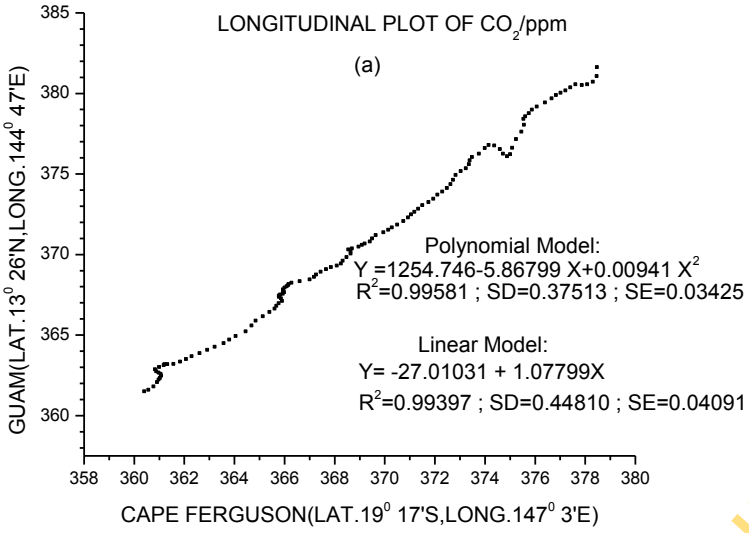


Fig. 4.54 (a and b) Comparisons of latitudinal plots of CO_2 and CH_4 concentration for Ascension Island vs. Cape Ferguson

Table 4.24: Comparisons of longitudinal plots of CO_2 and CH_4 concentrations for both Northern and Southern Hemisphere stations approximately 5 º intervals to each other

Cross Plots of Stations	Latitudinal Locations	Square of Correlation Coefficient (R^2) for CO_2	Standard Deviation (SD) for CO_2	Square of Correlation Coefficient (R^2) for CH_4	Standard Deviation (SD) for CH_4
Cape Ferguson Vs. Guam	Long.147º3'E vs.Long.144º47'E	0.996	0.38	0.744	4.71
Cape Kumukahi Vs. Key Biscayne	Long.154º49'W s.Long.80º12'W	0.994	0.43	0.912	3.23
Cape Kumukahi Vs. Ragged Point	Long.154º49'W s.Long.59º25'W	0.994	0.43	0.746	4.01



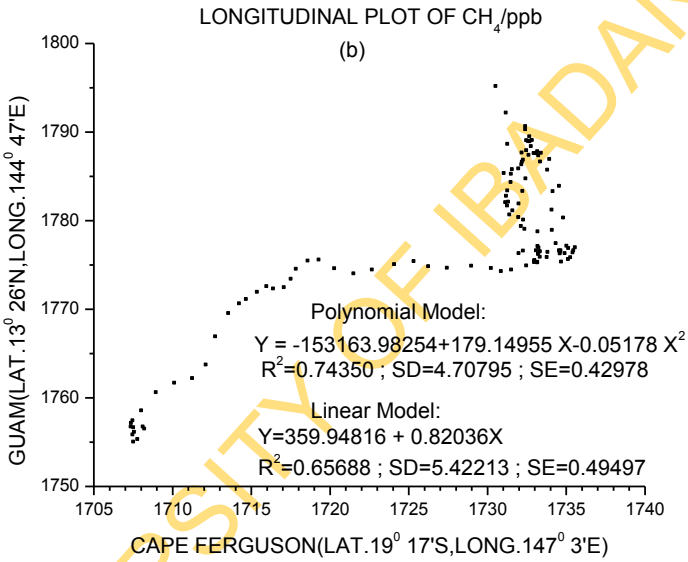


Fig. 4.55 (a and b) Comparisons of longitudinal plots of CO_2 and CH_4 concentration for Cape Ferguson vs. Guam

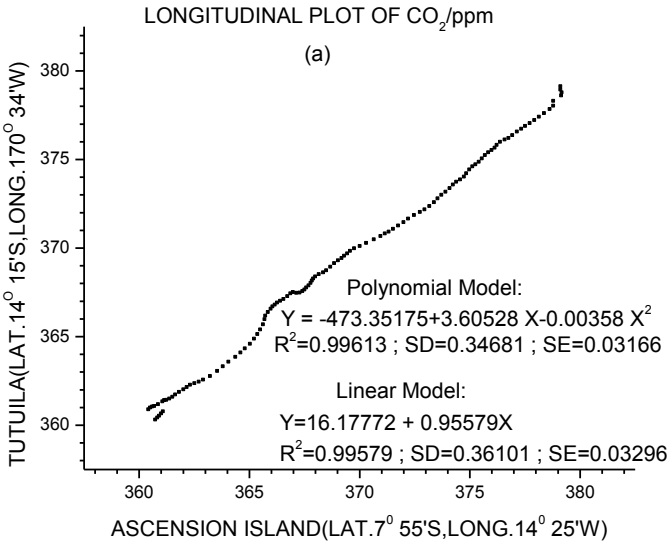
The values of R^2 for CO_2 concentrations in these stations lie between 0.994 and 0.996, while those of CH_4 lie between 0.744 and 0.912. Similarly, SD for CO_2 concentrations in these stations lie between 0.38 and 0.43, while those of CH_4 lie between 3.23 and 4.71. It was observed that the values of both R^2 and SD in the longitudinal limits are not as high as those for the latitudinal limits for the same interval. It seems latitude has more impact on the variation of greenhouse gases than longitude, as a result of meridional circulation.

4.2.2.6 Longitudinal variation of CO_2 and CH_4 for location more than 5^o interval to each other for both the northern and southern hemisphere stations

Table 4.25 shows the values of both R^2 and SD for the comparisons of both CO_2 and CH_4 gas' concentrations made for stations beyond 5^o interval to each other longitudinally in the northern and southern hemisphere. Also, Fig. 4.56 represents one of the numerous plots of these gases. The values of R^2 for CO_2 concentrations for these stations lie between 0.992 and 0.999, while those of CH_4 lie between 0.696 and 0.904. Similarly, the values of SD for CO_2 concentrations in these stations lie between 0.20 and 0.51, while those of CH_4 lie between 2.79 and 5.13. It was observed that the values for both R^2 and SD for the longitudinal limits are not as high as those for the latitudinal limits for the interval. However these values obtained for locations beyond 5^o interval to each other longitudinally in both hemisphere are more than for those approximately 5^o interval to each other longitudinally in both hemisphere. Thus, it can be concluded that latitude is more important than longitude in terms of variation of greenhouse gases.

Table 4.25: Comparisons of longitudinal plots of CO_2 and CH_4 concentrations for both Northern and Southern Hemisphere stations more than 5º interval to each other

Cross Plots of Stations	Latitudinal Locations	Square of Correlation Coefficient (R^2) for CO_2	Standard Deviation (SD) for CO_2	Square of Correlation Coefficient (R^2) for CH_4	Standard Deviation (SD) for CH_4
Ascension Island Vs Tutuila	Long.14º25'Wvs.Long. 170º34'W	0.996	0.35	0.889	3.21
Assekrem Vs Mahe Island	Long.5º25'E vs.Long.55º10'E	0.994	0.46	0.778	4.09
Assekrem Vs Guam	Long.5º25'E vs. Long.144º47'E	0.998	0.29	0.696	5.13
Assekrem Vs Minamitorishima.	Long.5º25'E vs. Long.153º59E'	0.997	0.33	0.867	3.95
Mahe Island Vs. Cape Ferguson	Long.55º10'E vs.Long.147º3'E	0.994	0.41	0.791	4.20
Cape Ferguson Vs. Minamitorishima	Long.147º3'E vs. Long.153º59E'	0.992	0.51	0.788	4.98
Guam Vs. Minamitorishima.	Long.144º47'E vs.Long.153º59E'	0.994	0.45	0.785	5.02
Sand Island Vs. Tutuila	Long.177º22'W vs.Long.170º34'W	0.993	0.30	0.822	4.07
Sand Island Vs Cape Kumukahi	Long.177º22'W vs. Long.154º49'W	0.996	0.37	0.904	2.79
Sand Island Vs. Key Biscayne	Long.177º22'W vs. Long.80º12'W	0.999	0.21	0.871	3.91
Sand Island Vs Ragged Point	Long.177º22'W vs. Long.59º25'W	0.999	0.20	0.831	3.29
Tutuila Vs. Cape Kumukahi	Long.170º34'W vs.Long.154º49'W	0.992	0.51	0.789	4.13



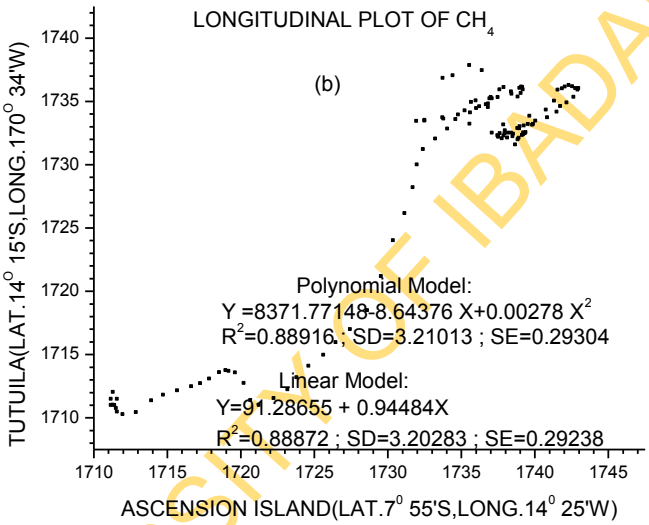


Fig. 4.56 (a and b) Comparisons of longitudinal plots of CO_2 and CH_4 concentration for Ascension Island vs. Guam

4.3 Modelling of greenhouse gas concentration in the tropics

The methodology used for modelling the greenhouse gas concentration and their impacts for the period 1996 to 2005 combines both the moving average and auto regression in a similar way to the iterative Box-Jenkins methodology. Thus, the developed model for the 10-year period (i.e. 120 months) for CO_2 and CH_4 respectively is expressed as:

$$\psi = a + bt + ct^2 + \varepsilon \quad \text{.....4.1}$$

and

$$\psi = a + bt - ct^2 - \varepsilon \quad \text{.....4.2}$$

Where:

ψ =concentration of modeled greenhouse gases

t= total number of months utilized in modelling

ε=environmental determining factor

a, b, and c represents concentration of greenhouse gases as time progresses during the 10 year period (i.e. 120 months) used for modelling and are location dependent.

In order to be able to predict the future concentration of greenhouse gases that falls outside the 10-year period (i.e. 1996-2005) used for modelling, the equation that gives best fit is the quadratic form rather than the linear form for CO_2 and CH_4 respectively as:

$$\psi = a' + bt' + ct'^2 + \sigma \quad \text{.....4.3}$$

and

$$\psi = a' + bt' - ct'^2 - \sigma \quad \text{.....4.4}$$

Where:

$a' = a - 1$

$t' = t + n$

n = integer representing the additional month to be predicted

σ = standard deviation which is the same as the environmental determining factor

The environmental determining factor is dependent on factors which include circulation, lifetime and recombination processes taking place in the atmosphere.

The quadratic form gives better fit than the linear form because it gives higher correlation coefficient value.

Thus, for CO_2 equation 4.3 becomes:

$$\psi = (a-1) + b(t+n) + c(t+n)^2 + \sigma \quad \text{.....4.5}$$

However, for CH_4 equation 4.4 becomes:

$$\psi = (a-1+n) + b(t+n) - c(t+n)^2 - \sigma \quad \text{.....4.6}$$

The a term on the right hand side of equations 4.5 and 4.6 represents the intercept (i.e. initial concentration of gases) obtained during the 10 year period of modelling. However, since these initial concentrations of gases precede the concentrations for those of additional months to be modeled the value -1 was deducted in order to make the initial concentration of these gases to converge with the time additional concentration of gases to be modeled commenced.

Additional term, n was added to the first terms in the case of CH_4 because its life time (12 years) was less than that of CO_2 (100 years). Thus, n was added in order to compensate for the difference in life time. Also, the 3rd and 4th terms were deducted in equation 4.6 rather than been added as in equation 4.5 because after 7 years most of CH_4 would have been transformed into CO_2 and water since the period used in modelling was 10 years. Both CO_2 and water were removed so as to ensure it was only CH_4 that was considered. In essence, the prediction of CH_4 beyond the modelled period (i.e. 10 years) will be ascertained.

This model was tested by comparing predicted and measured monthly concentration of these gases for the period 2006 to 2008.

4.3.1 Model fitting for mean monthly concentration of CO_2 and CH_4 for each station considered in the tropics

Both linear and polynomial equations were fitted to the monthly CO_2 and CH_4 gas concentrations for each station considered in the tropics. However, the polynomial fit i.e. quadratic formula provides the best fit for both CO_2 and CH_4 gas' monthly concentrations for all the stations considered in this work because of higher values of coefficient of determination(Table 4.26).

Table 4.26 Empirical equations that fit monthly concentration of CO_2 and CH_4 for the period Jan. 1996 to Dec. 2005 for each station in the tropics

Observation Sites/Territory and best Equation of fit	Square of Correlation Coefficient(R^2) of CO_2	Standard Deviation (SD) of CO_2	Standard error (SE) of CO_2	Square of Correlation Coefficient (R^2) of CH_4	Standard Deviation (SD) of CH_4	Standard error (SE) of CH_4
Ascension Island(U.K)	0.9959	0.37	0.03	0.9381	2.39	0.22
CO_2: Y=359.42 + 0.14X + 2.07E-4 X^2 + SD CH_4: Y=1705.39 + 0.80X – 0.0045X^2 - SD						
Assekrem(Algeria)	0.9964	0.34	0.03	0.9069	3.09	0.28
CO_2: Y=360.72 + 0.15X + 5.97E-5 X^2 + SD CH_4: Y=1768.78 + 0.79X – 0.0044 X^2 – SD						
Mahe Island(Seychelles)	0.9938	0.46	0.04	0.8137	3.74	0.34
CO_2: Y=359.03 + 0.17X + 2.25E-5 X^2 + SD CH_4: Y=1727.16 + 0.42X – 0.0016 X^2 – SD						
Cape Ferguson(Australia)	0.9945	0.40	0.04	0.9268	2.49	0.23
CO_2: Y=359.66 + 0.14X + 1.16E-4 X^2 + SD CH_4: Y=1700.83 + 0.84X – 0.0050 X^2 – SD						
Guam(U.S.A)	0.9954	0.39	0.04	0.8354	3.77	0.34
CO_2: Y=361.27 + 0.12X + 3.33E-4 X^2 + SD CH_4:1755.66 + 0.54X – 0.0025 X^2 – SD						
Minamitorishima(Japan)	0.9933	0.46	0.04	0.9314	2.83	0.26
CO_2: Y=361.72 + 0.12X + 2.96E-4X^2 + SD CH_4: Y=1766.62 + 0.71X – 0.0034 X^2 - SD						

Sand Island(U.S.A)	0.9964	0.34	0.03	0.8098	3.96	0.36
CO_2: Y= 361.57 + 0.13X + 2.94E-4 X^2 + SD CH_4: Y=1792.97 + 0.38X – 0.0012 X^2 – SD Tutuila(U.S.A)	0.9962	0.34	0.03	0.8377	3.89	0.36
CO_2: Y=359.37 + 0.15X + 8.92E-5 X^2 + SD CH_4: Y=1702.80 + 0.74X – 0.0041 X^2 – SD Cape Kumukahi(U.S.A)	0.9922	0.50	0.05	0.7996	4.03	0.37
CO_2: Y=361.01 + 0.15X + 6.37E-5 X^2 + SD CH_4: Y=1774.83 + 0.60X – 0.0031 X^2 – SD Mauna Loa(U.S.A)	0.9948	0.41	0.04	0.8973	2.89	0.26
CO_2: Y=361.03 + 0.14X + 1.75E-4 X^2 + SD CH_4: Y=1758.95 + 0.64X – 0.0033 X^2 – SD Key Biscayne(U.S.A)	0.9944	0.43	0.04	0.7649	5.27	0.48
CO_2: Y=361.59 + 0.17X + 1.38E-5 X^2 + SD CH_4: Y=1788.48 + 0.60X – 0.0027 X^2 – SD Ragged Point(Barbados)	0.9960	0.36	0.03	0.8545	3.05	0.28
CO_2: Y=360.71 + 0.14X + 1.82E-4 X^2 + SD CH_4: Y=1765.92 + 0.60X – 0.0032 X^2 – SD						

4.4 Prediction of greenhouse gases concentrations

The model equations 4.5 and 4.6 were used to predict the concentrations of CH_4 and CO_2 gases for the period January 2006 to December 2008 and then compared with the available observed data for the same period for:

(i) Stations individually in the Northern Hemisphere

(ii) Stations individually in the Southern Hemisphere

4.4.1 Model fit test for individual station in the Northern Hemisphere

The predicted and observed concentrations of both CO_2 and CH_4 gases for the period 2006 to 2008 in the Northern Hemisphere shows a very good correlation, with CO_2 having higher correlation than CH_4 in each of the stations considered (Table 4.27). The corresponding values for the predicted and observed concentrations of these gases (Table 4.28 to 4.43) and their plots for the individual stations are as shown in Figure 4.57 to 4.72.

4.4.2 Model fit test for individual station in the Southern Hemisphere

The predicted and observed concentration of both CO_2 and CH_4 in the Southern Hemisphere shows a very good correlation with CO_2 having higher correlation than CH_4 in each of the stations considered (Table 4.44). The corresponding values for the predicted and observed concentrations of these gases (Table 4.45 to 4.52) and their plots of the individual stations are as shown in Figure 4.73 to 4.80.

4.5 Temperature anomaly model for CO_2 and CH_4 in the tropics

Correlating the annual mean standard deviation of CO_2 and CH_4 concentration with the tropical temperature anomaly data provides empirical relationships that predict warming effectively in the tropics.

(i) For CO_2:

$$T = -0.27 - 0.49\sigma + 1.72\sigma^2 \quad (R=0.93) \qquad \ldots\ldots\ldots\ldots\ldots\ldots 4.7$$

(ii) For CH_4:

$$T = -0.32 + 0.13\sigma + 0.04\sigma^2 \quad (R=0.86) \qquad \ldots\ldots\ldots\ldots\ldots\ldots 4.8$$

Where, T = temperature anomaly; σ = standard deviation and R = correlation coefficient

Table 4.27: Correlation of observed and predicted monthly concentrations for individual stations in the Tropical Northern Hemisphere for both CO_2 and CH_4

Observation Sites/ Territory	Square of correlation coefficient (R^2) for CO_2 Observed	Square of correlation coefficient (R^2) for CO_2 Predicted Vs Observed	Square of correlation coefficient (R^2) for CH_4 Observed	Square of correlation coefficient (R^2) for CH_4 Predicted Vs Observed
Assekrem ,Algeria(Africa)	0.990	0.987	0.970	0.792
Guam ,U.S.A (Ocean)	0.975	0.975	0.262	0.161
Minamitorishima, Japan(Asia)	0.945	0.959	0.863	0.757
Sand Island, U.S.A(Ocean)	0.987	0.987	0.979	0.980
Cape Kumukahi , U.S.A(Ocean)	0.996	0.996	0.956	0.904
Mauna Loa ,U.S.A (Ocean)	1.000	0.998	0.893	0.856
Key Biscayne, U.S.A(America)	0.988	0.988	0.566	0.581
Ragged Point, Barbados(America)	0.989	0.987	0.948	0.938

Table 4.28: Modelling of monthly CO_2 concentration at Assekrem:

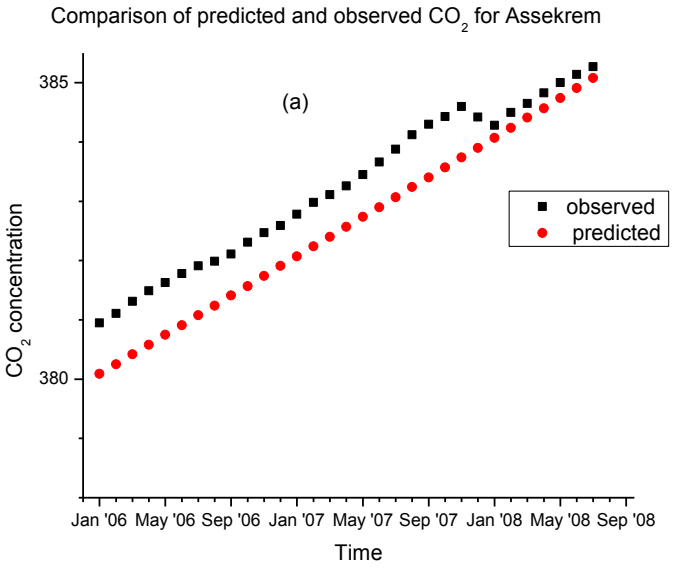
$$\psi = 359.72 + 0.15(120+n) + 5.97E\text{-}5(120+n)^2 + 0.34$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	379.08	380.95	-1.87
2	379.25	381.11	-1.86
3	379.41	381.31	-1.90
4	379.58	381.49	-1.91
5	379.74	381.63	-1.89
6	379.91	381.78	-1.87
7	380.07	381.91	-1.84
8	380.24	381.99	-1.75
9	380.40	382.11	-1.71
10	380.57	382.31	-1.74
11	380.73	382.47	-1.74
12	380.90	382.59	-1.69
13	381.07	382.78	-1.71
14	381.23	382.98	-1.75
15	381.40	383.11	-1.71
16	381.56	383.26	-1.70
17	381.73	383.45	-1.72
18	381.90	383.66	-1.76
19	382.06	383.88	-1.82
20	382.23	384.12	-1.89
21	382.40	384.30	-1.90
22	382.56	384.43	-1.87
23	382.73	384.60	-1.87
24	382.90	384.42	-1.52
25	383.07	384.28	-1.21
26	383.23	384.50	-1.27
27	383.40	384.65	-1.25
28	383.57	384.83	-1.26
29	383.74	385.00	-1.26
30	383.90	385.14	-1.24

Table 4.29: Modelling of monthly CH_4 concentration at Assekrem:

$$\psi = (1767.78+n) + 0.79(120+n) - 4.35E\text{-}3(120+n)^2 - 3.09$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	1797.59	1804.81	-7.22
2	1798.32	1805.26	-6.94
3	1799.05	1805.36	-6.31
4	1799.76	1805.08	-5.32
5	1800.47	1805.06	-4.59
6	1801.17	1805.29	-4.12
7	1801.86	1805.18	-3.32
8	1802.54	1804.11	-1.57
9	1803.21	1803.76	-0.55
10	1803.88	1804.58	-0.70
11	1804.53	1804.85	-0.32
12	1805.18	1804.85	0.33
13	1805.81	1804.72	1.09
14	1806.44	1804.70	1.74
15	1807.06	1805.43	1.63
16	1807.67	1806.09	1.58
17	1808.27	1806.22	2.05
18	1808.87	1806.51	2.36
19	1809.45	1807.45	2.00
20	1819.03	1809.29	9.74
21	1810.60	1810.39	0.21
22	1811.16	1810.61	0.55
23	1811.71	1811.23	0.48
24	1812.25	1811.40	0.85
25	1812.78	1811.61	1.17
26	1813.31	1812.21	1.10
27	1813.82	1812.82	1.00
28	1814.33	1813.45	0.88
29	1814.83	1814.46	0.37
30	1815.32	1815.50	-0.18



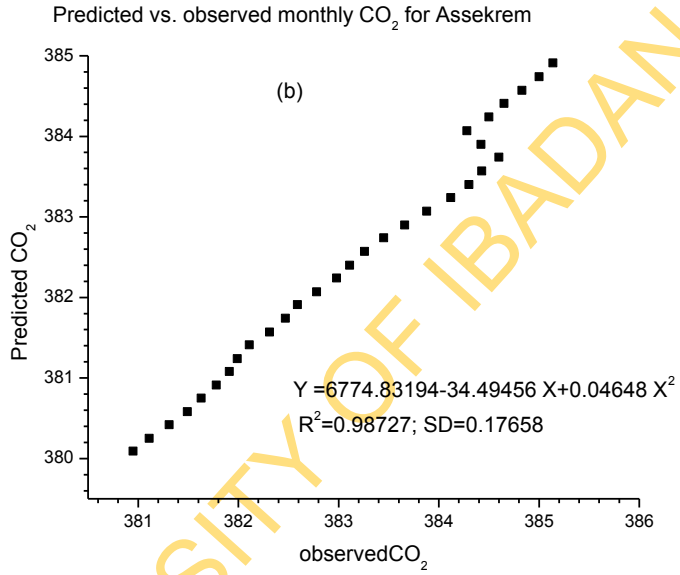


Fig. 4.57(a and b): Predicted vs. observed monthly CO_2 for Assekrem

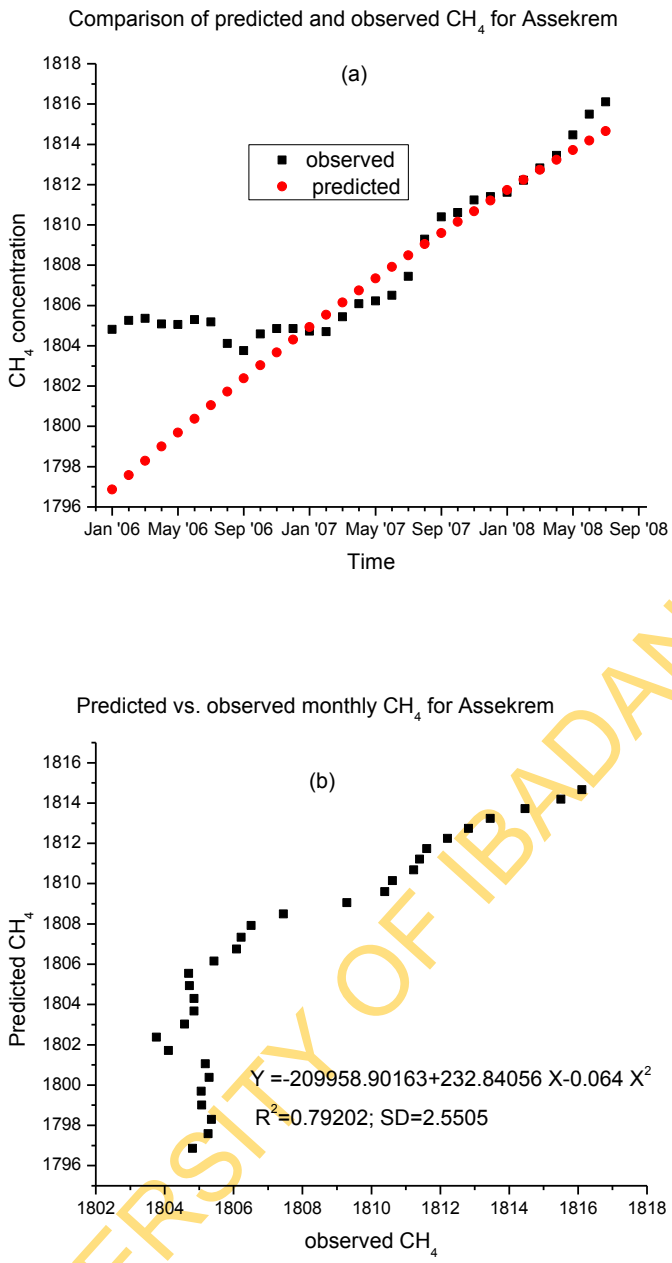


Fig 4.58 (a and b): Predicted vs. observed monthly CH_4 for Assekrem

Table 4.30: Modelling of monthly CO_2 concentration at Guam:

$$\psi = 360.27 + 0.12(120+n) + 3.33E\text{-}4(120+n)^2 + 0.39$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	380.06	381.22	-1.16
2	380.26	381.42	-1.16
3	380.46	381.56	-1.10
4	380.66	381.68	-1.02
5	380.86	381.81	-0.95
6	381.07	382.04	-0.97
7	381.27	382.30	-1.03
8	381.48	382.45	-0.97
9	381.68	382.60	-0.92
10	381.89	382.52	-0.63
11	382.09	382.33	-0.24
12	382.30	382.42	-0.12
13	382.51	382.59	-0.08
14	382.72	382.82	-0.10
15	382.93	383.09	-0.16
16	383.14	383.34	-0.20
17	383.35	383.50	-0.15
18	383.56	383.63	-0.07
19	383.77	383.71	0.06
20	383.99	383.74	0.25
21	384.20	383.62	0.58
22	384.41	383.62	0.79
23	384.63	383.62	1.01
24	384.85	384.03	0.82
25	385.06	384.31	0.75
26	385.28	384.53	0.75
27	385.50	384.68	0.82
28	385.71	384.79	0.92
29	385.93	384.99	0.94
30	386.15	385.25	0.90

Table 4.31: Modelling of monthly CH_4 concentration at Guam:

$$\psi = (1754.66+n) + 0.54(120+n) - 2.46E\text{-}3(120+n)^2 - 3.77$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	1781.21	1784.53	-3.32
2	1782.16	1787.02	-4.86
3	1783.09	1790.46	-7.37
4	1784.03	1793.71	-9.68
5	1784.95	1794.85	-9.90
6	1785.88	1796.23	-10.35
7	1786.79	1797.39	-10.60
8	1787.71	1797.36	-9.65
9	1788.61	1796.11	-7.50
10	1789.52	1794.77	-5.25
11	1790.41	1793.99	-3.58
12	1791.31	1795.04	-3.73
13	1792.20	1794.33	-2.13
14	1793.08	1788.47	4.61
15	1793.96	1783.33	10.63
16	1794.83	1781.18	13.65
17	1795.70	1781.03	14.67
18	1796.56	1781.19	15.37
19	1797.42	1777.86	19.56
20	1807.27	1774.10	33.17
21	1799.12	1774.10	25.02
22	1799.97	1774.10	25.87
23	1800.81	1779.08	21.73
24	1801.64	1781.42	20.22
25	1802.47	1783.18	19.29
26	1803.29	1784.69	18.60
27	1804.11	1786.64	17.47
28	1804.93	1788.67	16.26
29	1805.74	1790.92	14.82
30	1806.54	1792.30	14.24

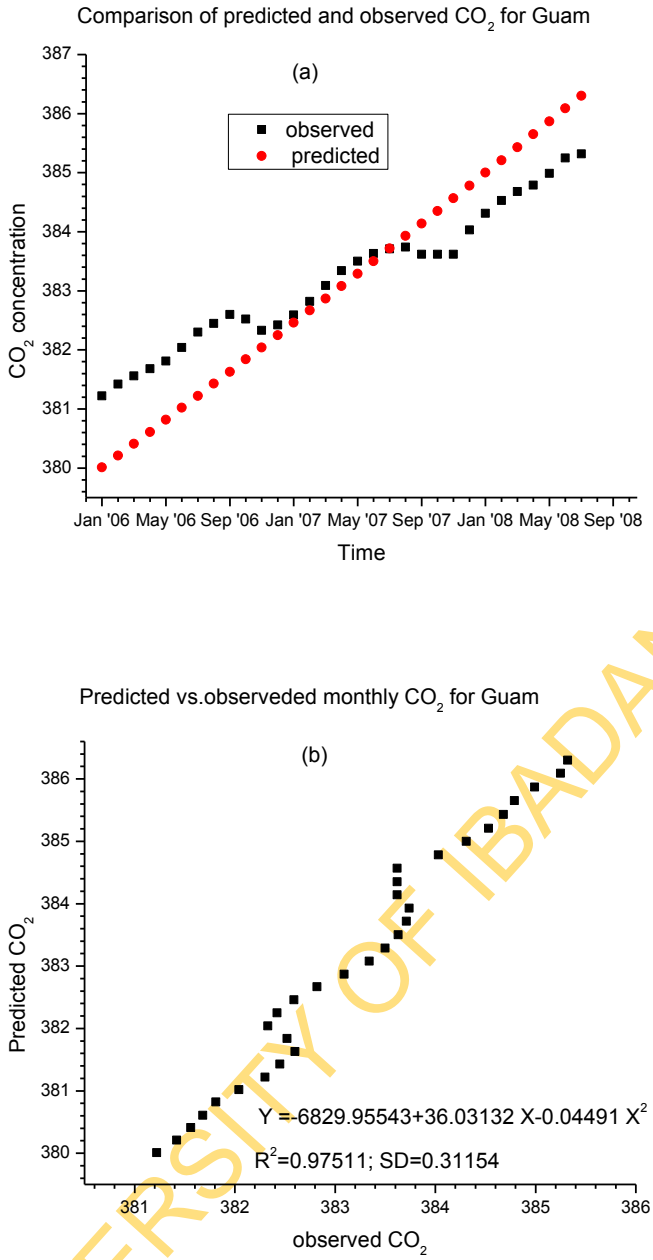


Fig. 4.59(a and b): Predicted vs. observed monthly CO_2 for Guam

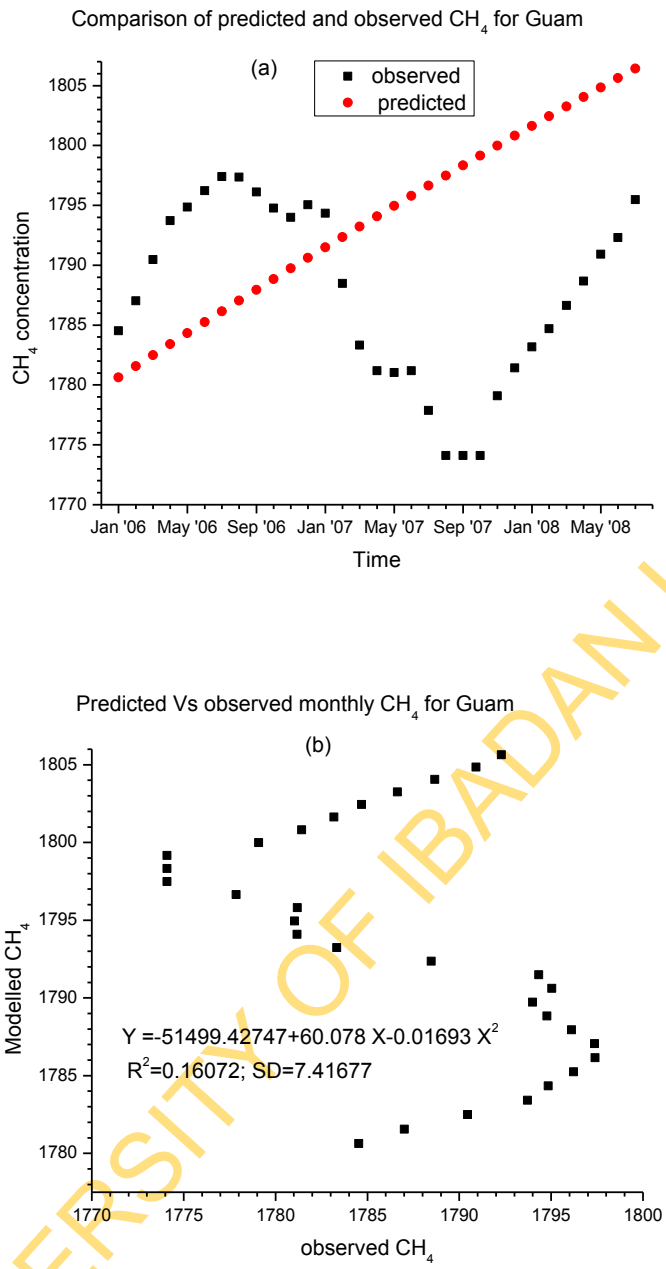


Fig. 4.60: Predicted vs. observed monthly CH_4 for Guam

Table 4.32: Modelling of monthlyCO_2 concentration at Minamitorishima:

$$\psi = 360.72 + 0.12(120+n) + 2.96E\text{-}4(120+n)^2 + 0.46$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	380.03	381.89	-1.86
2	380.23	382.03	-1.80
3	380.42	382.20	-1.78
4	380.61	382.72	-2.11
5	380.81	383.28	-2.47
6	381.00	383.55	-2.55
7	381.19	383.67	-2.48
8	381.39	383.79	-2.40
9	381.59	384.06	-2.47
10	381.78	384.29	-2.51
11	381.98	384.45	-2.47
12	382.18	384.60	-2.42
13	382.38	384.73	-2.35
14	382.57	384.93	-2.36
15	382.77	385.11	-2.34
16	382.97	384.69	-1.72
17	383.18	384.43	-1.25
18	383.38	384.44	-1.06
19	383.58	384.62	-1.04
20	383.78	384.82	-1.04
21	383.98	385.02	-1.04
22	384.19	385.19	-1.00
23	384.39	385.40	-1.01
24	384.60	385.53	-0.93
25	384.80	385.74	-0.94
26	385.01	385.82	-0.81
27	385.22	386.03	-0.81
28	385.42	386.15	-0.73
29	385.63	386.27	-0.64
30	385.84	386.45	-0.61

Table 4.33: Modelling of monthly CH_4 concentration at Minamitorishima:

$$\psi = (1765.62+n) + 0.71(120+n) - 3.39E\text{-}3(120+n)^2 - 2.83$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	1800.07	1801.00	-0.93
2	1800.95	1801.75	-0.80
3	1801.83	1802.17	-0.34
4	1802.71	1805.00	-2.29
5	1803.57	1806.10	-2.53
6	1804.43	1806.80	-2.37
7	1805.28	1805.00	0.28
8	1806.13	1804.50	1.63
9	1806.97	1805.80	1.17
10	1807.80	1806.80	1.00
11	1808.62	1807.40	1.22
12	1809.44	1807.10	2.34
13	1810.25	1806.20	4.05
14	1811.06	1806.30	4.76
15	1811.86	1806.90	4.96
16	1812.65	1804.82	7.83
17	1813.43	1804.67	8.76
18	1814.21	1804.00	10.21
19	1814.98	1805.00	9.98
20	1824.75	1805.83	18.92
21	1816.50	1806.75	9.75
22	1817.25	1807.25	10.00
23	1818.00	1807.67	10.33
24	1818.73	1806.58	12.15
25	1819.47	1808.00	11.47
26	1820.19	1809.25	10.94
27	1820.91	1809.58	11.33
28	1821.62	1810.25	11.37
29	1822.32	1811.25	11.07
30	1823.02	1812.25	10.77

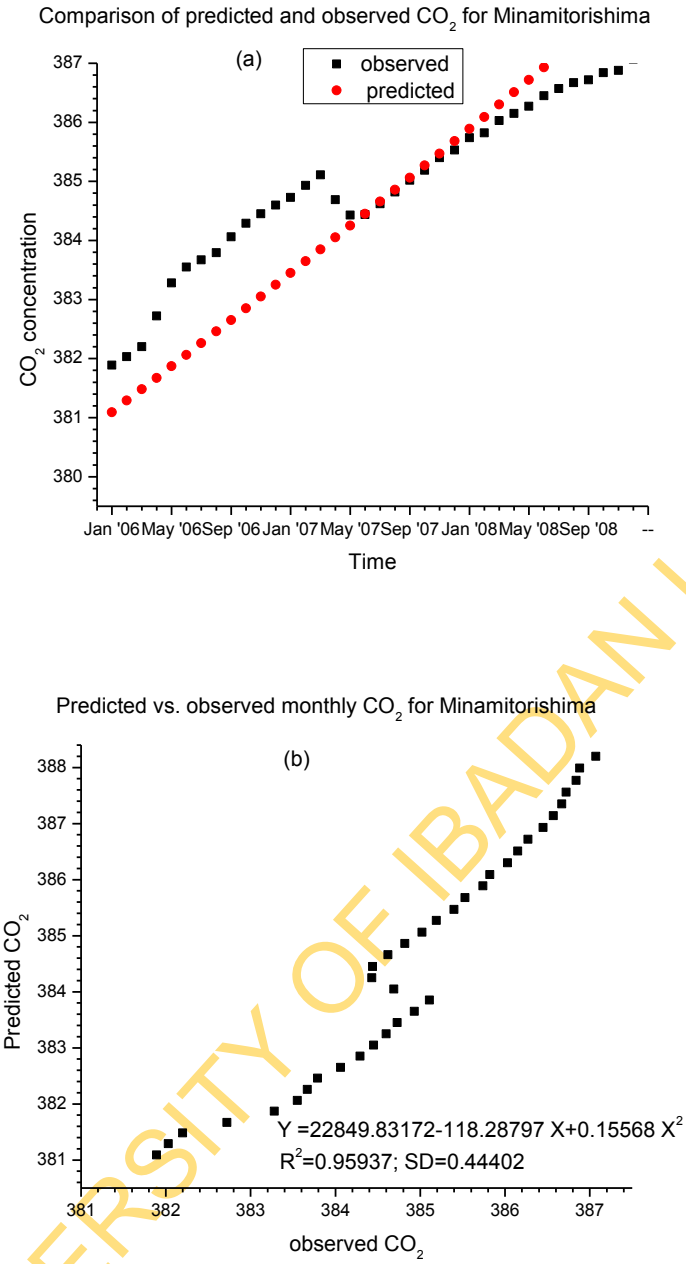


Fig. 4.61(a and b): Predicted vs. observed monthly CO_2 for Minamitorishima

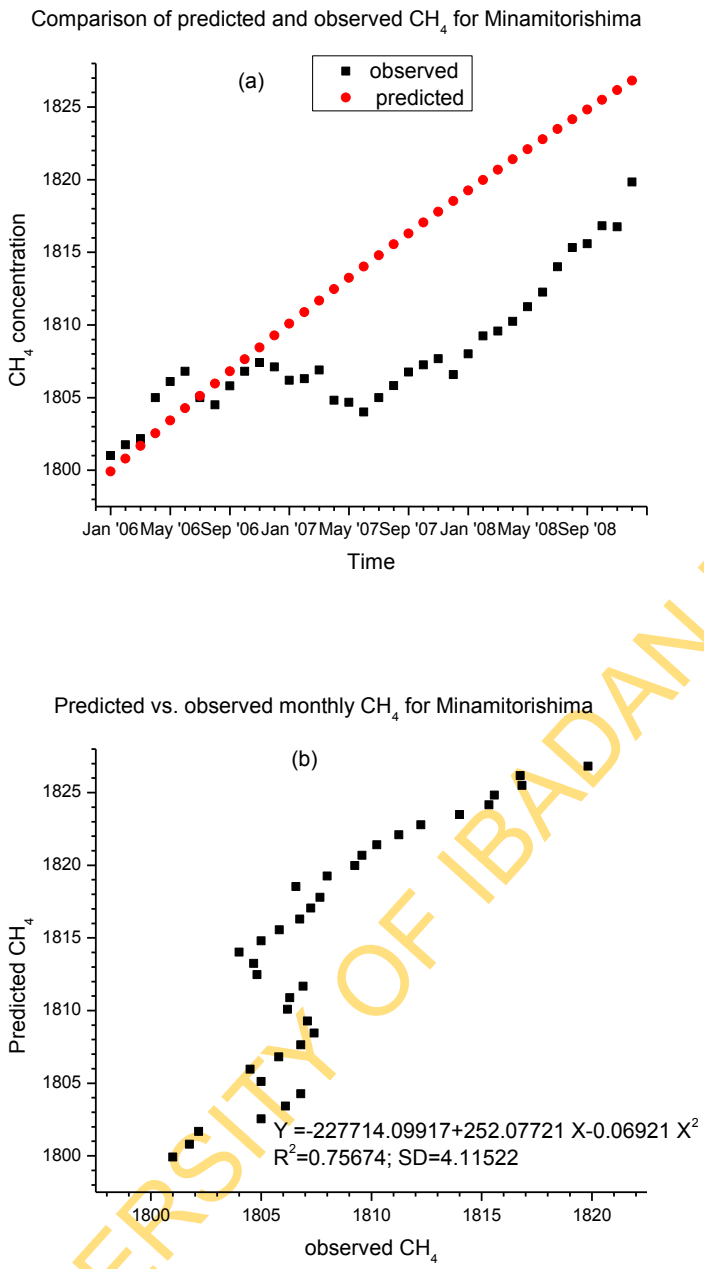


Fig. 4.62(a and b): Predicted vs. observed monthly CH_4 for Minamitorishima

Table 4.34: Modelling of monthly CO_2 concentration at Sand Island:

$$\psi = 360.57 + 0.13(120+n) + 2.94E\text{-}4(120+n)^2 + 0.34$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	380.94	381.29	-0.35
2	381.15	381.51	-0.36
3	381.35	381.66	-0.31
4	381.55	381.80	-0.25
5	381.75	382.00	-0.25
6	381.96	382.21	-0.25
7	382.16	382.45	-0.29
8	382.37	382.67	-0.30
9	382.57	382.79	-0.22
10	382.78	382.90	-0.12
11	382.99	383.01	-0.02
12	383.19	383.10	0.09
13	383.40	383.15	0.25
14	383.61	383.17	0.44
15	383.82	383.27	0.55
16	384.03	383.43	0.60
17	384.24	383.55	0.69
18	384.45	383.70	0.75
19	384.66	383.81	0.85
20	384.87	383.91	0.96
21	385.09	384.13	0.96
22	385.30	384.38	0.92
23	385.51	384.61	0.90
24	385.73	384.87	0.86
25	385.94	385.16	0.78
26	386.16	385.38	0.78
27	386.37	385.57	0.80
28	386.59	385.75	0.84
29	386.81	385.87	0.94
30	387.03	386.02	1.01

Table 4.35: Modelling of monthly CH_4 concentration at Sand Island:

$$\psi = (1791.97+n) + 0.38(120+n) - 1.16E\text{-}3(120+n)^2 - 3.96$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	1818.01	1814.35	3.66
2	1819.10	1814.37	4.73
3	1820.20	1814.13	6.07
4	1821.29	1815.20	6.09
5	1822.39	1816.53	5.86
6	1823.47	1816.62	6.85
7	1824.56	1817.27	7.29
8	1825.64	1817.74	7.90
9	1826.73	1817.30	9.43
10	1827.81	1817.64	10.17
11	1828.88	1818.40	10.48
12	1829.96	1819.25	10.71
13	1831.03	1820.61	10.42
14	1832.10	1822.03	10.07
15	1833.17	1823.37	9.80
16	1834.23	1823.20	11.03
17	1835.30	1822.58	12.72
18	1836.36	1823.46	12.90
19	1837.42	1823.89	13.53
20	1847.47	1823.88	23.59
21	1839.53	1824.82	14.71
22	1840.58	1825.12	15.46
23	1841.63	1824.91	16.72
24	1842.68	1825.63	17.05
25	1843.72	1826.56	17.16
26	1844.76	1827.14	17.62
27	1845.80	1827.99	17.81
28	1846.84	1829.30	17.54
29	1847.88	1830.47	17.41
30	1848.91	1831.23	17.68

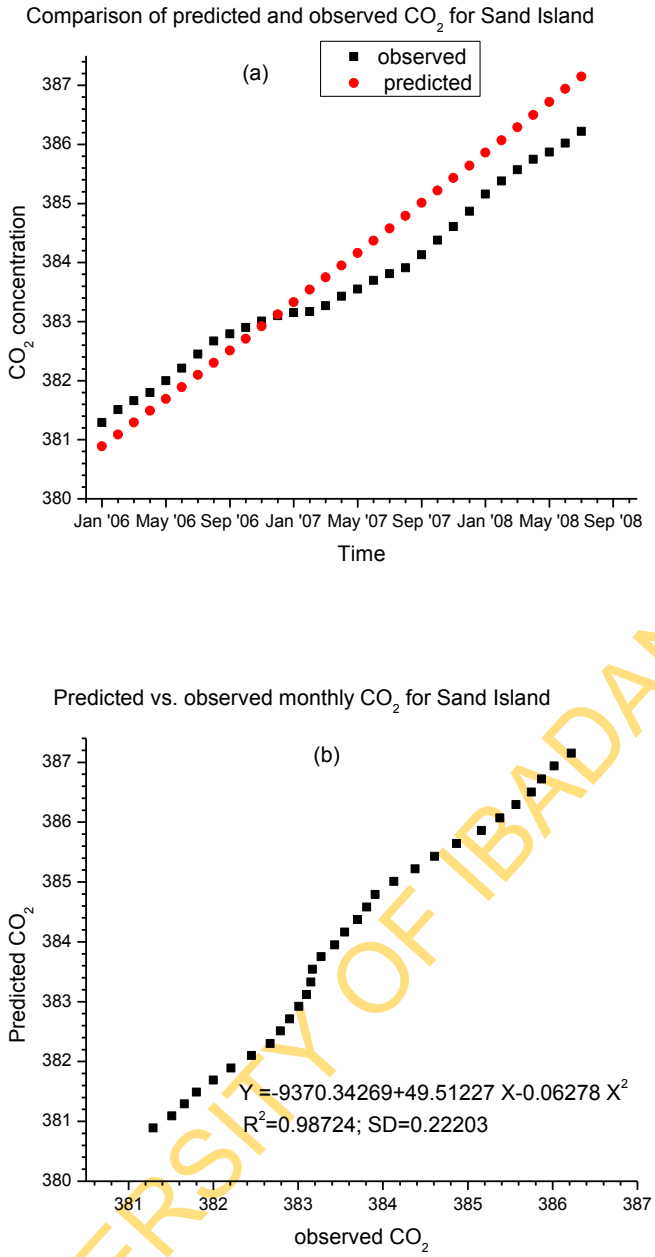


Fig. 4.63(a and b): Predicted vs. observed monthly CO_2 for Sand Island

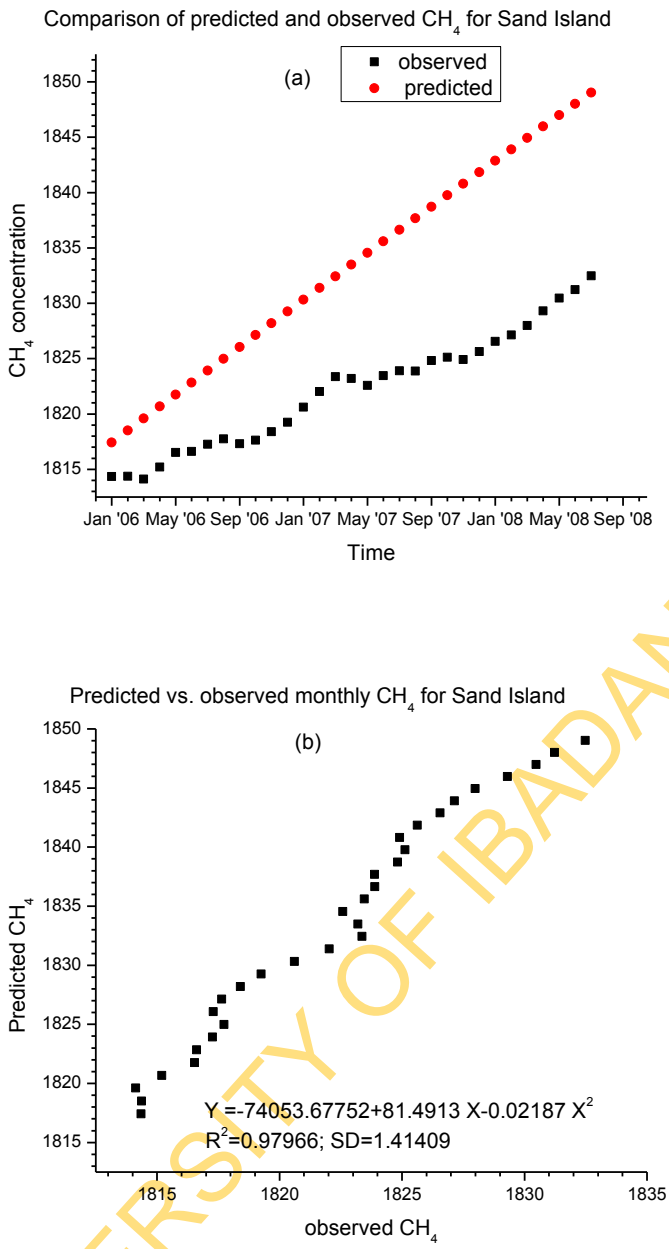


Fig 4.64(a and b): Predicted vs. observed monthly CH_4 for Sand Island

Table 4.36: Modelling of monthly CO_2 concentration at Cape Kumukahi:

$$\psi = 360.01 + 0.15(120+n) + 6.37E\text{-}5(120+n)^2 + 0.50$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	379.59	381.18	-1.59
2	379.76	381.48	-1.72
3	379.92	381.67	-1.75
4	380.09	381.80	-1.71
5	380.26	381.95	-1.69
6	380.42	382.17	-1.75
7	380.59	382.36	-1.77
8	380.75	382.52	-1.77
9	380.92	382.70	-1.78
10	381.09	382.84	-1.75
11	381.25	382.92	-1.67
12	381.42	383.00	-1.58
13	381.59	383.06	-1.47
14	381.75	383.15	-1.40
15	381.92	383.38	-1.46
16	382.09	383.69	-1.60
17	382.26	383.94	-1.68
18	382.42	384.05	-1.63
19	382.59	384.16	-1.57
20	382.76	384.33	-1.57
21	382.93	384.50	-1.57
22	383.09	384.71	-1.62
23	383.26	384.98	-1.72
24	383.43	385.27	-1.84
25	383.60	385.51	-1.91
26	383.77	385.70	-1.93
27	383.94	385.90	-1.96
28	384.11	386.03	-1.92
29	384.27	386.14	-1.87
30	384.44	386.30	-1.86

Table 4.37 Modelling of monthly CH_4 concentration at Cape Kumukahi:

$\psi = (1773.83+n) + 0.60(120+n) - 3.11E\text{-}3(120+n)^2 - 4.03$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	1797.87	1805.53	-7.66
2	1798.71	1804.74	-6.03
3	1799.55	1805.14	-5.59
4	1800.38	1805.09	-4.71
5	1801.21	1804.36	-3.15
6	1802.03	1804.53	-2.50
7	1802.84	1805.11	-2.27
8	1803.65	1805.52	-1.87
9	1804.45	1805.74	-1.29
10	1805.24	1805.79	-0.55
11	1806.03	1805.76	0.27
12	1806.81	1804.93	1.88
13	1807.59	1805.47	2.12
14	1808.36	1806.59	1.77
15	1809.12	1806.67	2.45
16	1809.88	1808.01	1.87
17	1810.63	1810.11	0.52
18	1811.37	1810.24	1.13
19	1812.11	1810.12	1.99
20	1821.84	1810.70	11.14
21	1813.57	1810.40	3.17
22	1814.29	1809.90	4.39
23	1815.00	1809.98	5.02
24	1815.71	1810.67	5.04
25	1816.41	1811.95	4.46
26	1817.11	1813.16	3.95
27	1817.80	1814.22	3.58
28	1818.48	1814.63	3.85
29	1819.15	1814.66	4.49
30	1819.83	1815.66	4.17

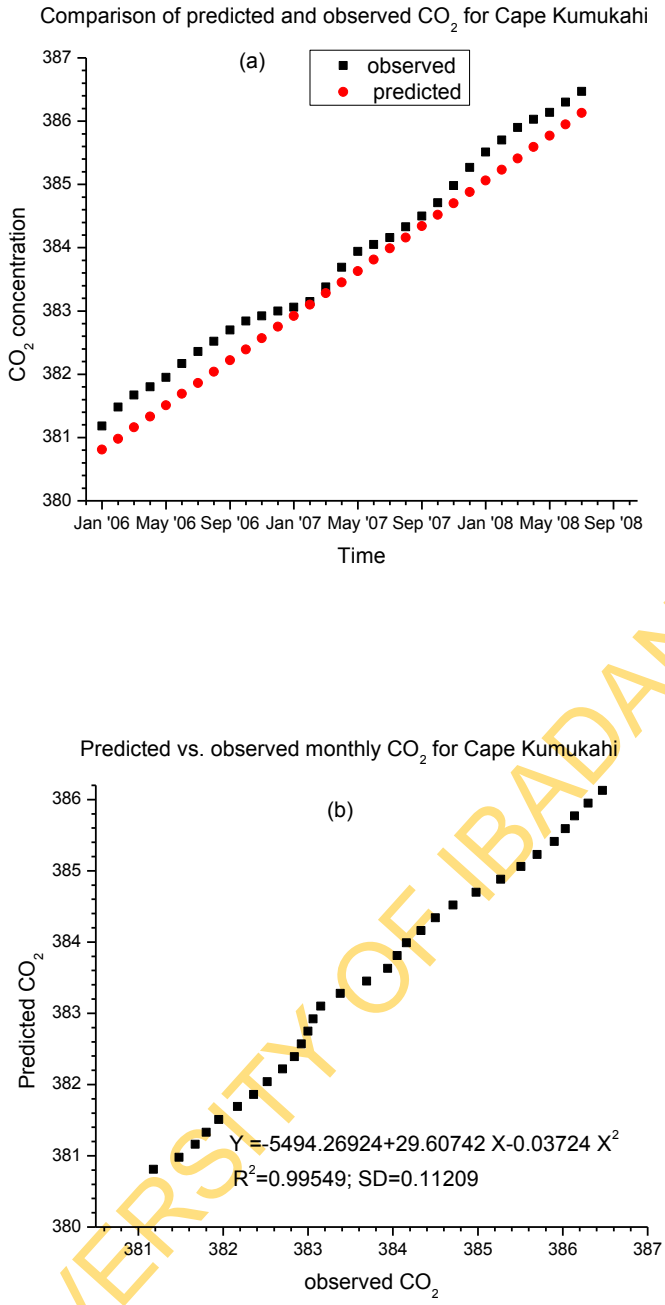


Fig 4.65(a and b): Predicted vs. observed monthly CO_2 for Cape Kumukahi

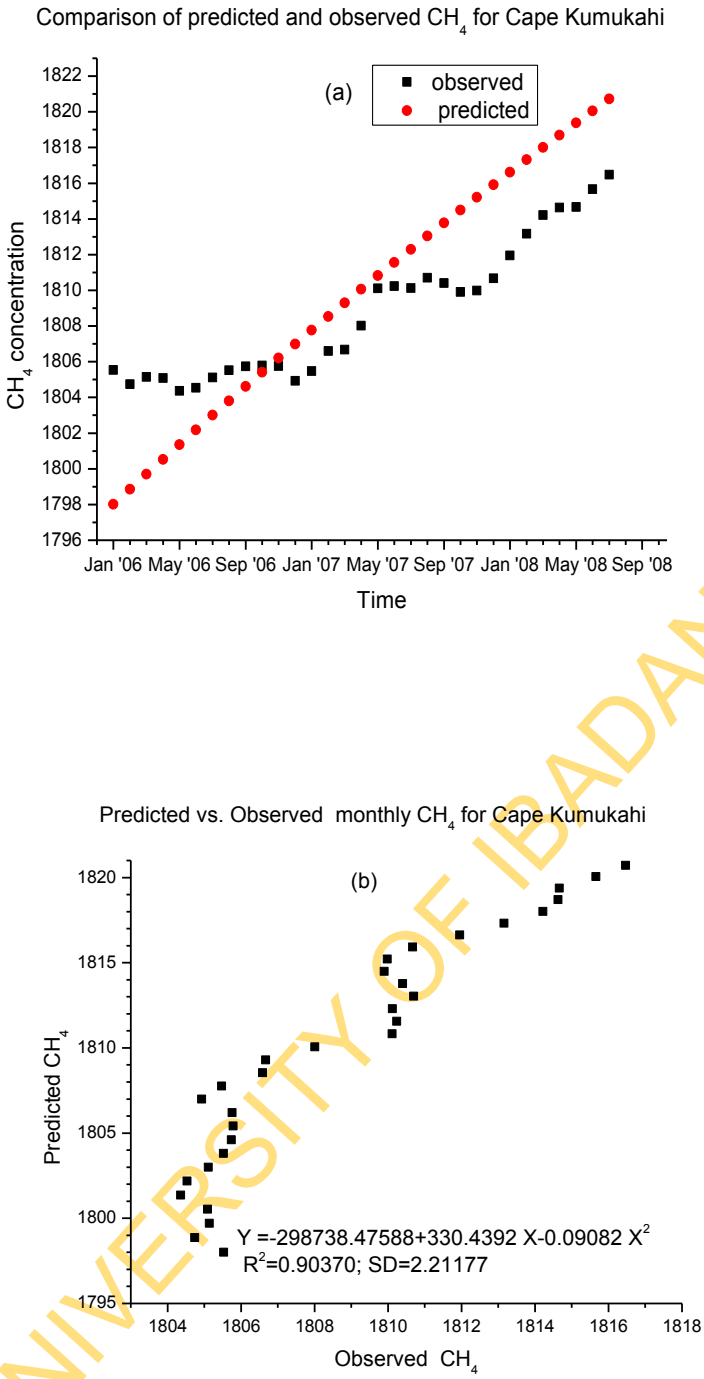


Fig 4.66(a and b): Predicted vs. observed monthly CH_4 for Cape Kumukahi

Table 4.38: Modelling of monthly CO_2 concentration at Mauna Loa:

$$\psi = 360.03 + 0.14(120+n) + 1.75E\text{-}4(120+n)^2 + 0.41$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	379.94	381.04	-1.10
2	380.12	381.15	-1.03
3	380.31	381.26	-0.95
4	380.49	381.42	-0.93
5	380.67	381.60	-0.93
6	380.86	381.74	-0.88
7	381.04	381.89	-0.85
8	381.23	382.05	-0.82
9	381.41	382.25	-0.84
10	381.60	382.45	-0.85
11	381.78	382.60	-0.82
12	381.97	382.72	-0.75
13	382.16	382.90	-0.74
14	382.34	383.09	-0.75
15	382.53	383.21	-0.68
16	382.72	383.34	-0.62
17	382.90	383.49	-0.59
18	383.09	383.68	-0.59
19	383.28	383.88	-0.60
20	383.47	384.08	-0.61
21	383.66	384.20	-0.54
22	383.85	384.22	-0.37
23	384.04	384.25	-0.21
24	384.23	384.40	-0.17
25	384.42	384.57	-0.15
26	384.61	384.76	-0.15
27	384.80	385.00	-0.20
28	384.99	385.20	-0.21
29	385.19	385.34	-0.15
30	385.38	385.47	-0.09

Table 4.39: Modelling of monthly CH_4 concentration at Mauna Loa:

$$\psi = (1757.95+n) + 0.64(120+n) - 3.29E\text{-}3(120+n)^2 - 2.89$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	1785.33	1790.62	-5.29
2	1786.17	1790.48	-4.31
3	1787.01	1790.39	-3.38
4	1787.83	1789.63	-1.80
5	1788.65	1788.60	0.05
6	1789.47	1787.69	1.78
7	1790.28	1787.61	2.67
8	1791.08	1787.60	3.48
9	1791.87	1788.29	3.58
10	1792.66	1789.35	3.31
11	1793.44	1789.57	3.87
12	1794.22	1789.60	4.62
13	1794.98	1790.27	4.71
14	1795.74	1791.08	4.66
15	1796.50	1791.99	4.51
16	1797.25	1792.96	4.29
17	1797.99	1794.26	3.73
18	1798.73	1795.57	3.16
19	1799.45	1795.95	3.50
20	1809.18	1796.97	12.21
21	1800.89	1797.22	3.67
22	1801.60	1796.61	4.99
23	1802.30	1796.09	6.21
24	1803.00	1796.35	6.65
25	1803.69	1797.13	6.56
26	1804.37	1797.68	6.69
27	1805.05	1798.23	6.82
28	1805.72	1798.89	6.83
29	1806.38	1799.43	6.95
30	1807.04	1799.78	7.26

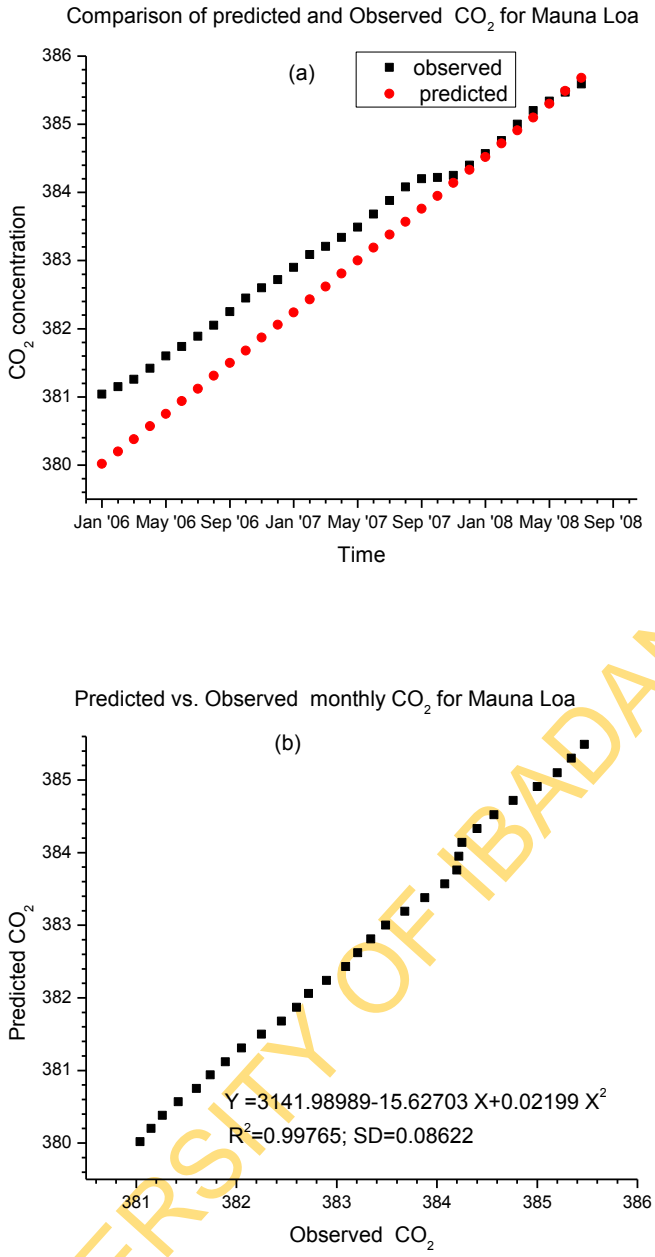


Fig. 4.67(a and b): Predicted vs. observed monthly CO_2 for Mauna Loa

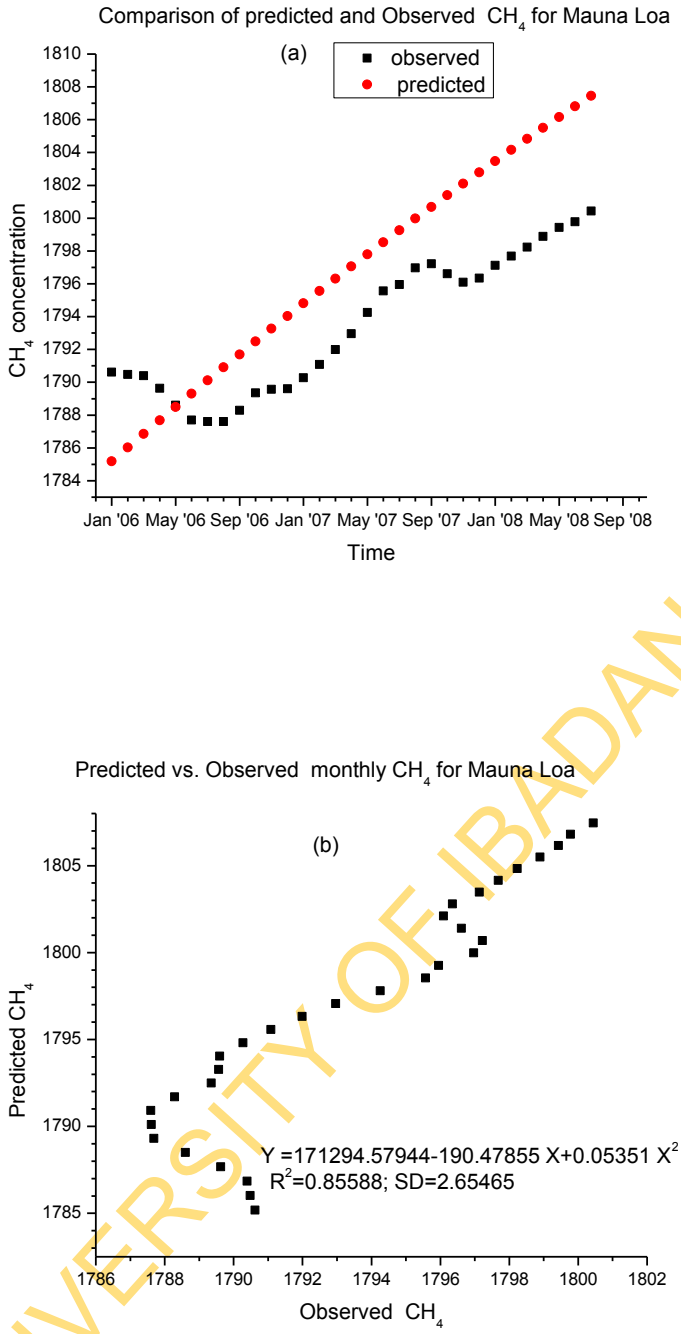


Fig. 4.68: (a and b) Predicted vs. observed monthly CH_4 for Mauna Loa

Table 4.40: Modelling of monthly CO_2 concentration at Key Biscayne:

$\psi = 360.59 + 0.17(120+n) + 1.38E\text{-}5(120+n)^2 + 0.43$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	381.79	381.18	0.61
2	381.97	381.46	0.51
3	382.14	381.49	0.65
4	382.31	381.56	0.75
5	382.49	381.82	0.67
6	382.66	381.98	0.68
7	382.83	381.91	0.92
8	383.01	381.97	1.04
9	383.18	382.30	0.88
10	383.35	382.90	0.45
11	383.53	383.36	0.17
12	383.70	383.64	0.06
13	383.87	383.74	0.13
14	384.05	383.89	0.16
15	384.22	384.02	0.20
16	384.40	384.14	0.26
17	384.57	384.23	0.34
18	384.74	384.31	0.43
19	384.92	384.53	0.39
20	385.09	384.85	0.24
21	385.26	385.02	0.24
22	385.44	385.07	0.37
23	385.61	385.23	0.38
24	385.79	385.46	0.33
25	385.96	385.65	0.31
26	386.13	385.92	0.21
27	386.31	386.26	0.05
28	386.48	386.46	0.02
29	386.66	386.66	0.00
30	386.83	386.95	-0.12

Table 4.41: Modeling of monthly CH_4 concentration at Key Biscayne:

$$\psi = (1787.48+n) + 0.60(120+n) - 2.65E\text{-}3(120+n)^2 - 5.27$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	1817.01	1820.23	-3.22
2	1817.97	1819.27	-1.30
3	1818.92	1817.07	1.85
4	1819.86	1818.57	1.29
5	1820.80	1821.41	-0.61
6	1821.74	1818.24	3.50
7	1822.67	1813.82	8.85
8	1823.59	1812.60	10.99
9	1824.51	1813.25	11.26
10	1825.43	1815.68	9.74
11	1826.33	1818.65	7.68
12	1827.24	1822.22	5.02
13	1828.13	1825.63	2.50
14	1829.03	1827.10	1.93
15	1829.91	1828.21	1.70
16	1830.80	1827.27	3.53
17	1831.67	1825.70	5.97
18	1832.54	1826.76	5.78
19	1833.41	1828.46	4.95
20	1843.27	1829.94	13.33
21	1835.13	1829.32	5.81
22	1835.98	1827.80	8.18
23	1836.82	1827.91	8.91
24	1837.66	1827.18	10.48
25	1838.49	1824.63	13.86
26	1839.32	1823.78	15.54
27	1840.15	1824.32	15.83
28	1840.96	1824.68	16.28
29	1841.78	1826.91	14.87
30	1842.59	1830.83	11.76

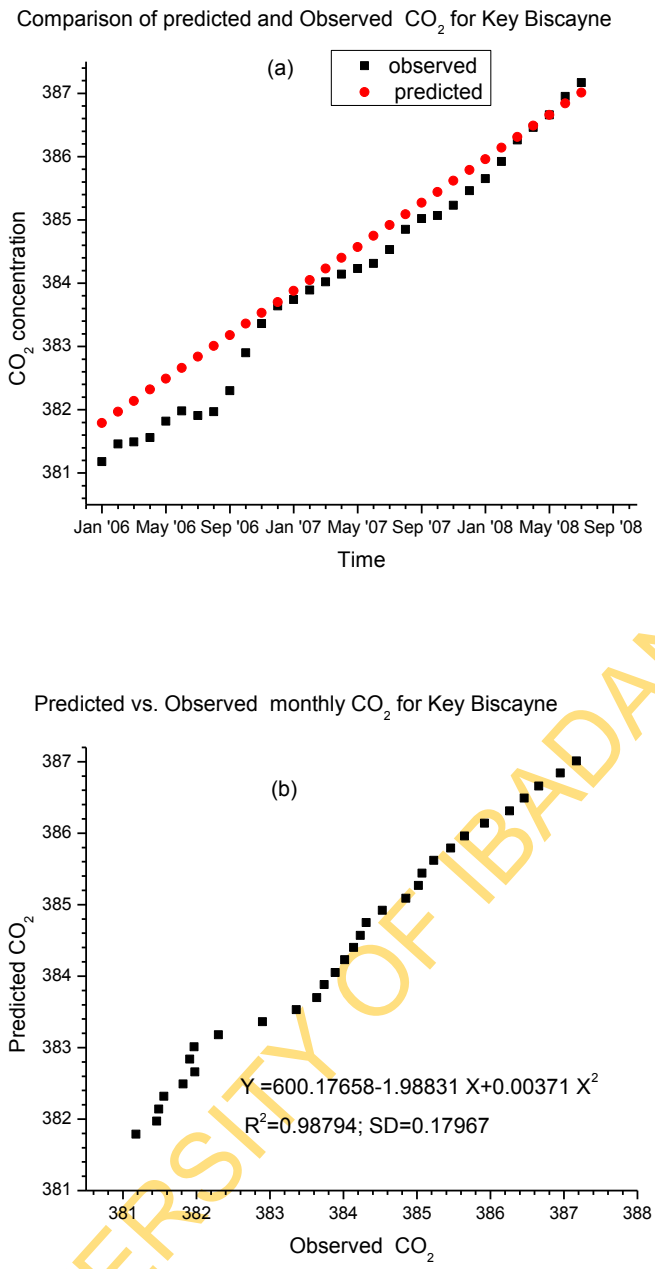
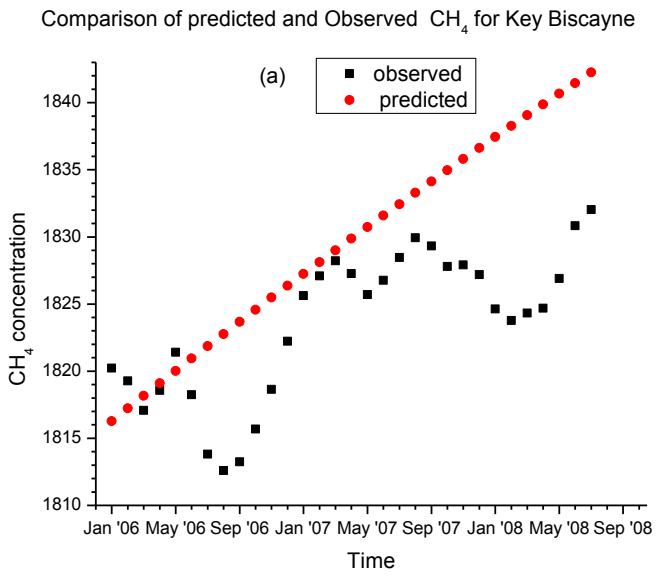


Fig. 4.69(a and b): Predicted vs. observed monthly CO_2 for Key Biscayne



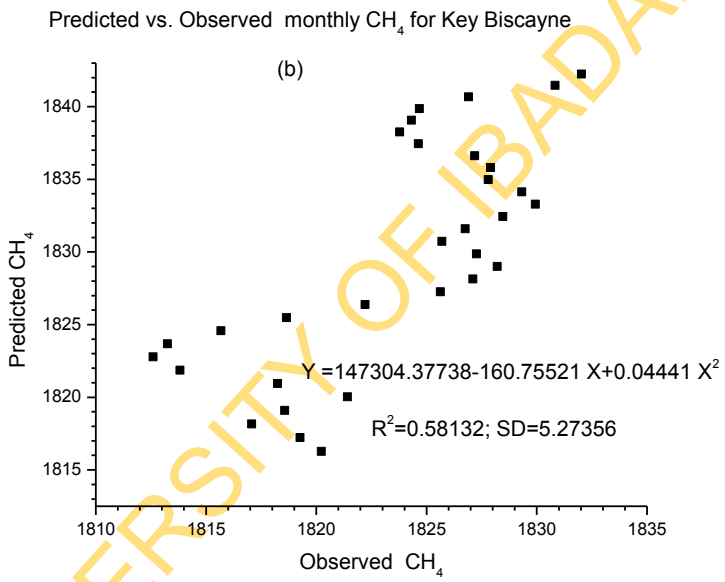


Fig. 4.70(a and b): Predicted vs. observed monthly CH_4 for Key Biscayne

Table 4.42: Modelling of monthly CO_2 concentration at Ragged Point:

$$\psi = 359.71 + 0.14(120+n) + 1.82E\text{-}4(120+n)^2 + 0.36$$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	379.67	380.62	-0.95
2	379.86	380.76	-0.90
3	380.04	380.90	-0.86
4	380.23	381.13	-0.90
5	380.41	381.38	-0.97
6	380.60	381.58	-0.98
7	380.79	381.73	-0.94
8	380.97	381.88	-0.91
9	381.16	382.03	-0.87
10	381.35	382.24	-0.89
11	381.53	382.42	-0.89
12	381.72	382.54	-0.82
13	381.91	382.68	-0.77
14	382.10	382.82	-0.72
15	382.29	382.91	-0.62
16	382.48	383.04	-0.56
17	382.67	383.16	-0.49
18	382.86	383.29	-0.43
19	383.05	383.45	-0.40
20	383.24	383.63	-0.39
21	383.43	383.85	-0.42
22	383.62	384.05	-0.43
23	383.81	384.24	-0.43
24	384.00	384.06	-0.06
25	384.20	383.92	0.28
26	384.39	384.04	0.35
27	384.58	384.32	0.26
28	384.78	384.57	0.21
29	384.97	384.82	0.15
30	385.17	385.06	0.11

Table 4.43: Modelling of monthly CH_4 concentration at Ragged Point:

$\psi = (1764.92+n) + 0.60(120+n) - 3.24E\text{-}3(120+n)^2 - 3.05$

n	Modelled data(ψ)	Observed data	Modelled data – observed data
1	1788.03	1791.66	-3.63
2	1788.85	1791.99	-3.14
3	1789.65	1792.59	-2.94
4	1790.45	1792.78	-2.33
5	1791.25	1792.96	-1.71
6	1792.03	1793.09	-1.06
7	1792.81	1792.64	0.17
8	1793.59	1792.13	1.46
9	1794.35	1791.89	2.46
10	1795.11	1793.12	1.99
11	1795.87	1794.38	1.49
12	1796.62	1795.04	1.58
13	1797.36	1795.99	1.37
14	1798.09	1797.05	1.04
15	1798.82	1798.34	0.48
16	1799.54	1800.06	-0.52
17	1800.26	1801.89	-1.63
18	1800.97	1802.73	-1.76
19	1801.67	1802.72	-1.05
20	1811.37	1803.36	8.01
21	1803.06	1805.20	-2.14
22	1803.74	1807.09	-3.35
23	1804.42	1808.18	-3.76
24	1805.09	1808.92	-3.83
25	1805.75	1810.09	-4.34
26	1806.41	1811.75	-5.34
27	1807.06	1810.94	-3.88
28	1807.70	1809.72	-2.02
29	1808.34	1809.24	-0.90
30	1808.97	1810.42	-1.45

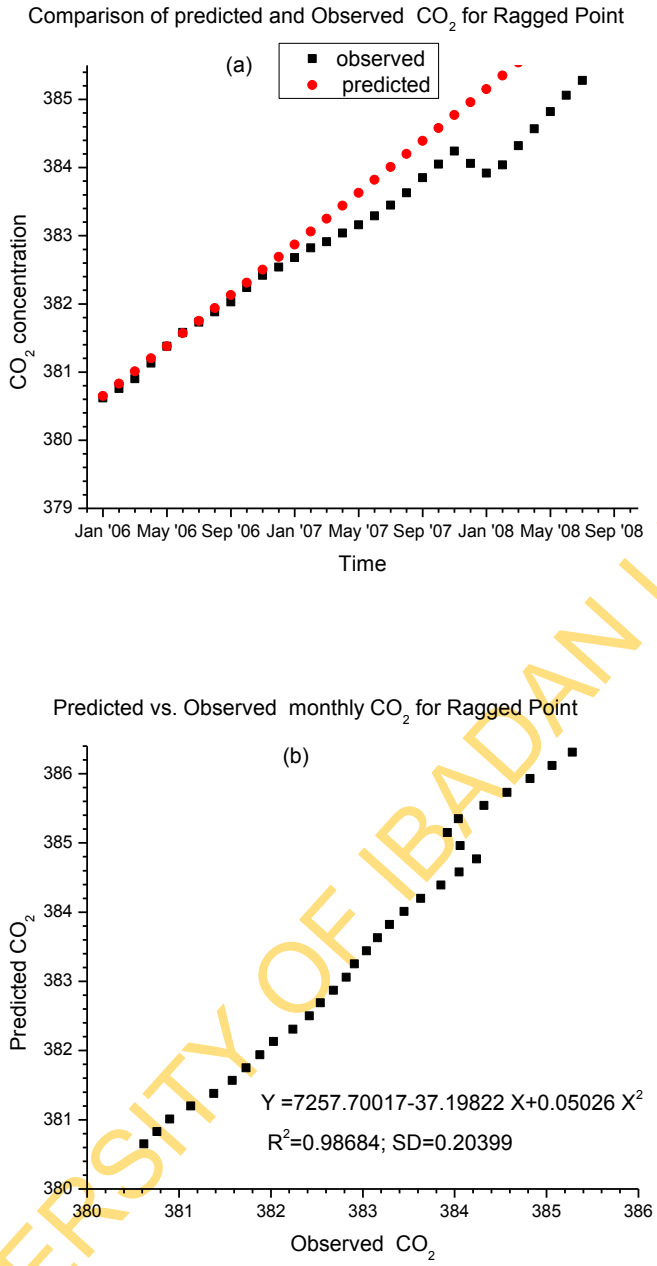


Fig. 4.71(a and b): Predicted vs. observed monthly CO_2 for Ragged Point

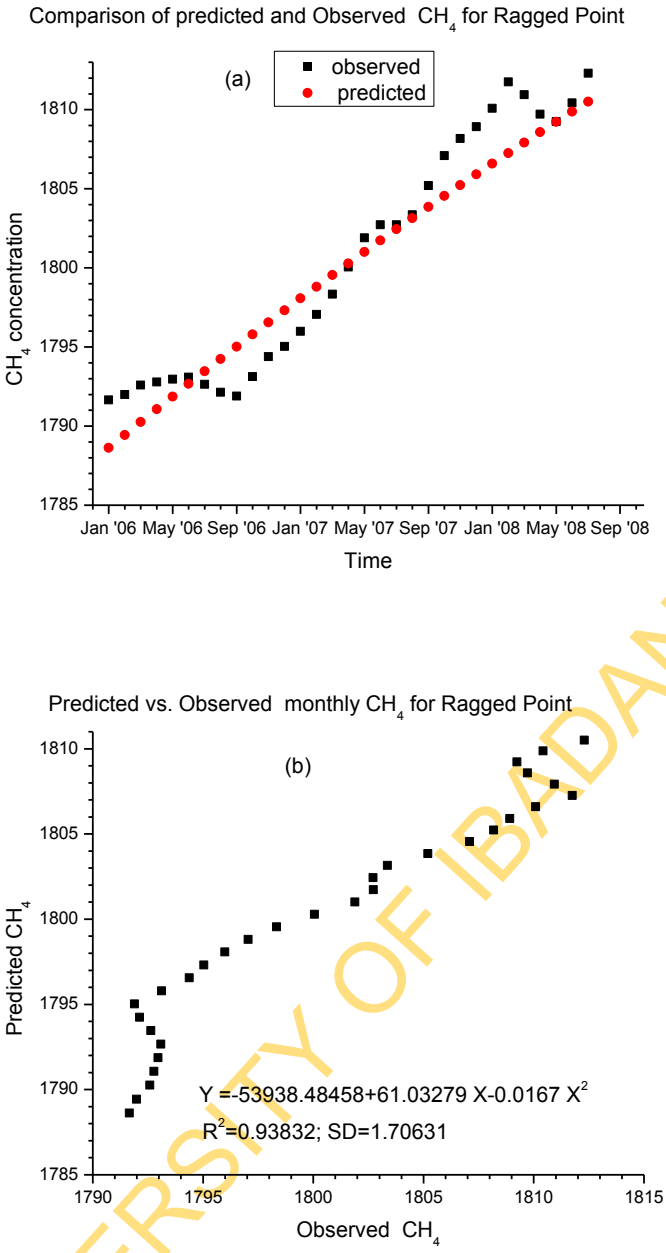


Fig. 4.72(a and b): Predicted vs. observed monthly CH_4 for Ragged Point

Table 4.44: Comparisons of R^2 for Observed and predicted against observed monthly concentrations of individual stations in the Southern Hemisphere of the Tropics for both CO_2 and CH_4

Observation Sites/ Territory	Square of correlation coefficient (R^2) for CO_2 observed	Square of correlation coefficient (R^2) for CO_2 predicted Vs observed	Square of correlation coefficient (R^2) for CH_4 observed	Square of correlation coefficient (R^2) for CH_4 predicted Vs observed
Ascension Island, U.K(Africa)	0.992	0.992	0.977	0.944
Mahe Island, Seychelles(Africa)	0.991	0.990	0.986	0.919
Cape Ferguson ,Australia(Ocean)	0.986	0.986	0.938	0.915
Tutuila, U.S.A(Ocean)	0.996	0.996	0.915	0.790

Table 4.45: Modeling of monthly CO_2 concentration at Ascension Island:

$$\psi = 358.42 + 0.14(120+n) + 2.07E\text{-}4(120+n)^2 + 0.37$$

n	Modelled data(ψ)	Observed data	Modeled data - observed data
1	378.76	379.17	-0.41
2	378.95	379.23	-0.28
3	379.14	379.37	-0.23
4	379.33	379.57	-0.24
5	379.52	379.74	-0.22
6	379.72	379.85	-0.13
7	379.91	379.93	-0.02
8	380.10	380.02	0.08
9	380.29	380.12	0.17
10	380.49	380.23	0.26
11	380.68	380.37	0.31
12	380.88	380.55	0.33
13	381.07	380.73	0.34
14	381.27	380.94	0.33
15	381.46	381.15	0.31
16	381.66	381.34	0.32
17	381.86	381.54	0.32
18	382.05	381.77	0.28
19	382.25	382.00	0.25
20	382.45	382.21	0.24
21	382.65	382.36	0.29
22	382.84	382.48	0.36
23	383.04	382.57	0.47
24	383.24	382.66	0.58
25	383.44	382.79	0.65
26	383.64	382.95	0.69
27	383.84	383.09	0.75
28	384.04	383.21	0.83
29	384.25	383.31	0.94
30	384.45	383.40	1.05

Table 4.46: Modeling of monthly CH_4 concentration at Ascension Island:

$$\psi = (1704.39 + n) + 0.80(120+n) - 4.52E\text{-}3(120+n)^2 - 2.39$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	1733.62	1737.57	-3.95
2	1734.32	1737.45	-3.13
3	1735.02	1737.67	-2.65
4	1735.70	1738.03	-2.33
5	1736.38	1738.11	-1.73
6	1737.04	1737.91	-0.87
7	1737.70	1737.64	0.06
8	1738.34	1737.63	0.71
9	1738.98	1737.70	1.28
10	1739.61	1738.02	1.59
11	1740.23	1739.06	1.17
12	1740.84	1739.90	0.94
13	1741.45	1740.39	1.06
14	1742.04	1741.19	0.85
15	1742.62	1741.74	0.88
16	1743.20	1742.36	0.84
17	1743.76	1743.17	0.59
18	1744.32	1743.78	0.54
19	1744.87	1744.82	0.05
20	1754.41	1746.12	8.29
21	1745.94	1747.18	-1.24
22	1746.46	1748.03	-1.57
23	1746.97	1748.63	-1.66
24	1747.47	1749.04	-1.57
25	1747.97	1749.42	-1.45
26	1748.45	1749.94	-1.49
27	1748.93	1750.75	-1.82
28	1749.39	1751.33	-1.94
29	1749.85	1751.67	-1.82
30	1750.30	1752.38	-2.08

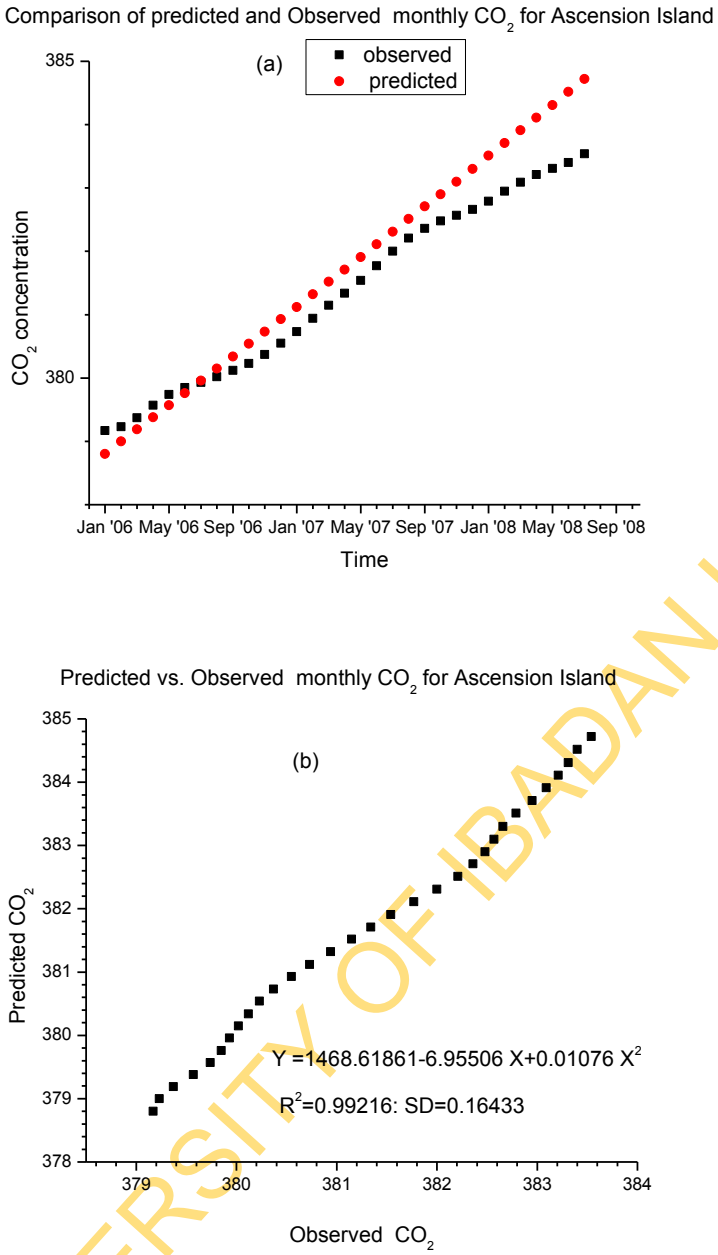


Fig. 4.73(a and b): Predicted vs. observed monthly CO_2 for Ascension Island

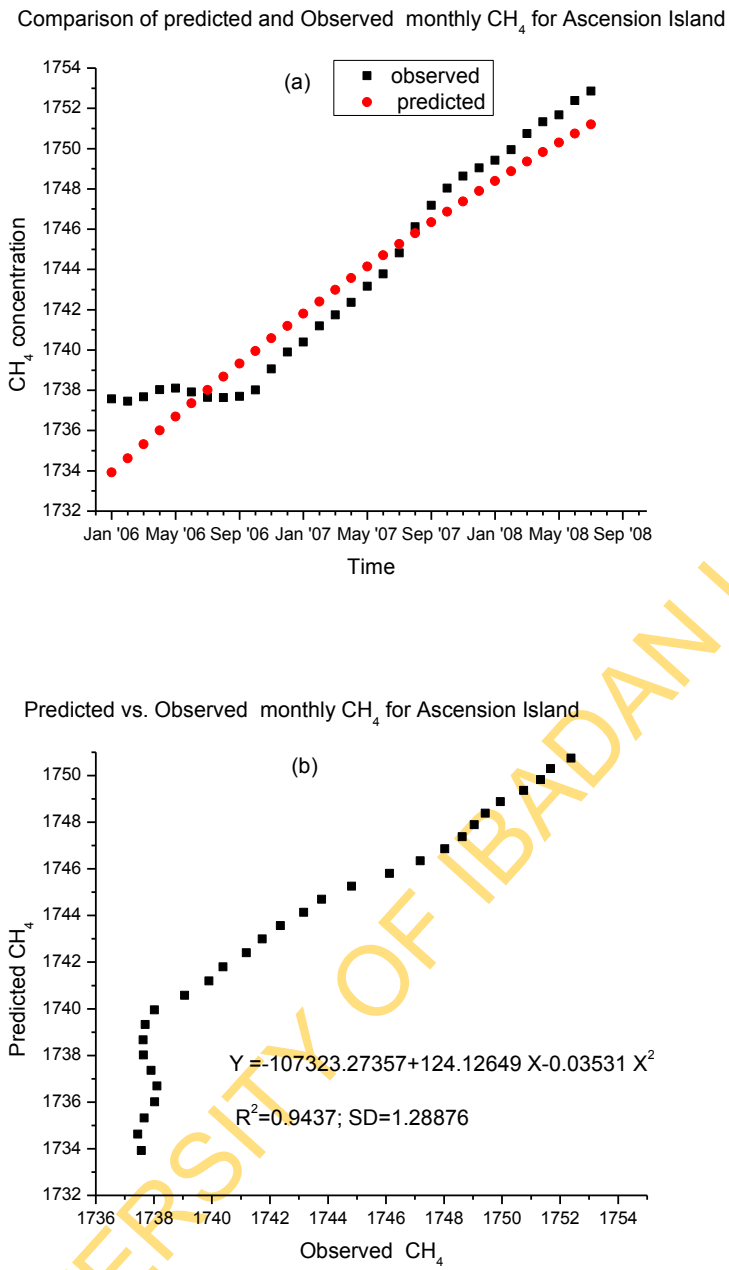


Fig. 4.74(a and b): Predicted vs. observed monthly CH_4 for Ascension Island

Table 4.47: Modeling of monthly CO_2 concentration at Mahe Island:

$$\psi = 358.03 + 0.17(120+n) + 2.25E\text{-}5(120+n)^2 + 0.46$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	379.39	379.59	-0.20
2	379.56	379.71	-0.15
3	379.74	379.85	-0.11
4	379.92	379.99	-0.07
5	380.09	380.12	-0.03
6	380.27	380.26	0.01
7	380.44	380.41	0.03
8	380.62	380.51	0.11
9	380.79	380.57	0.22
10	380.97	380.56	0.41
11	381.15	380.61	0.54
12	381.32	380.81	0.51
13	381.50	381.03	0.47
14	381.67	381.22	0.45
15	381.85	381.40	0.45
16	382.03	381.56	0.47
17	382.20	381.73	0.47
18	382.38	381.91	0.47
19	382.55	382.12	0.43
20	382.73	382.38	0.35
21	382.91	382.69	0.22
22	383.08	383.05	0.03
23	383.26	383.30	-0.04
24	383.44	383.40	0.04
25	383.61	383.52	0.09
26	383.79	383.66	0.13
27	383.97	383.81	0.16
28	384.14	383.98	0.16
29	384.32	384.12	0.20
30	384.50	384.26	0.24

Table 4.48: Modeling of monthly CH_4 concentration at Mahe Island:

$\psi = (1726.16 + n) + 0.42(120+n) - 1.61E\text{-}3(120+n)^2 - 3.74$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	1750.67	1751.77	-1.10
2	1751.70	1751.77	-0.07
3	1752.72	1751.88	0.84
4	1753.74	1751.84	1.90
5	1754.76	1752.09	2.67
6	1755.78	1752.89	2.89
7	1756.79	1752.81	3.98
8	1757.80	1752.41	5.39
9	1758.81	1751.74	7.07
10	1759.81	1751.34	8.47
11	1760.81	1751.59	9.22
12	1761.81	1752.52	9.29
13	1762.80	1753.28	9.52
14	1763.79	1754.02	9.77
15	1764.78	1754.71	10.07
16	1765.76	1755.22	10.54
17	1766.74	1755.68	11.06
18	1767.72	1755.98	11.74
19	1768.69	1756.69	12.00
20	1778.66	1757.47	21.19
21	1770.63	1758.37	12.26
22	1771.60	1759.88	11.72
23	1772.56	1760.97	11.59
24	1773.52	1761.68	11.84
25	1774.47	1762.40	12.07
26	1775.42	1762.92	12.50
27	1776.37	1763.67	12.70
28	1777.31	1764.46	12.85
29	1778.26	1764.88	13.38
30	1779.20	1766.30	12.90

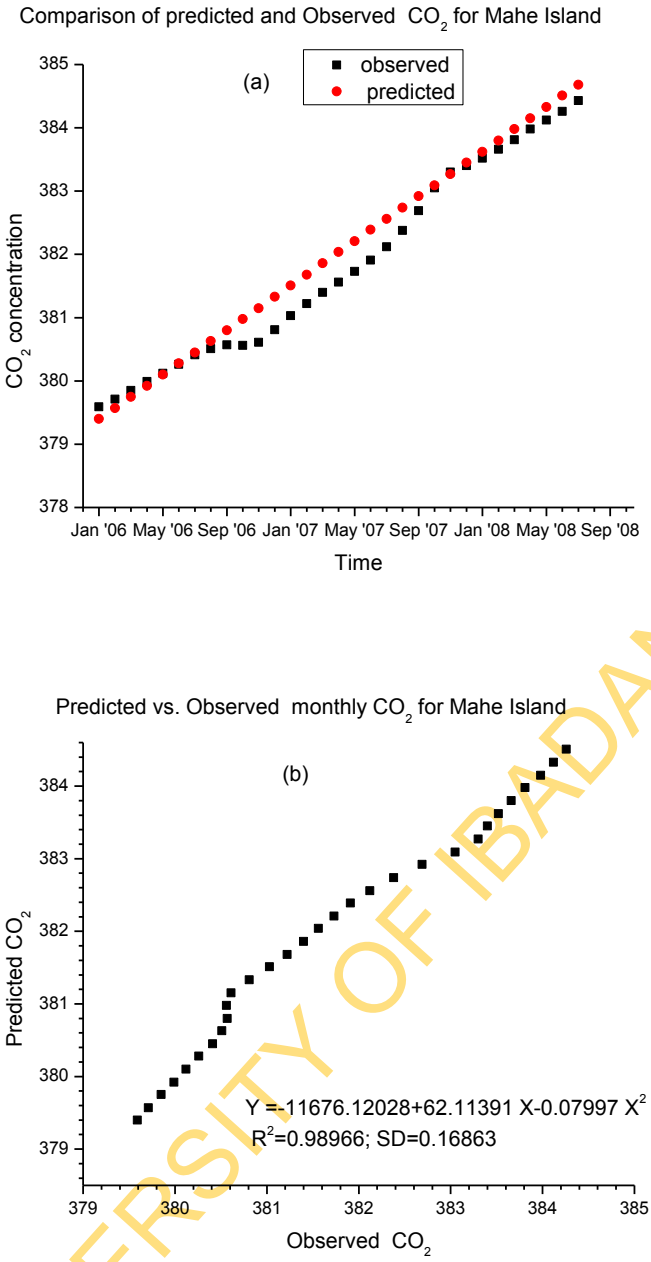


Fig. 4.75(a and b): Predicted vs. observed monthly CO_2 for Mahe Island

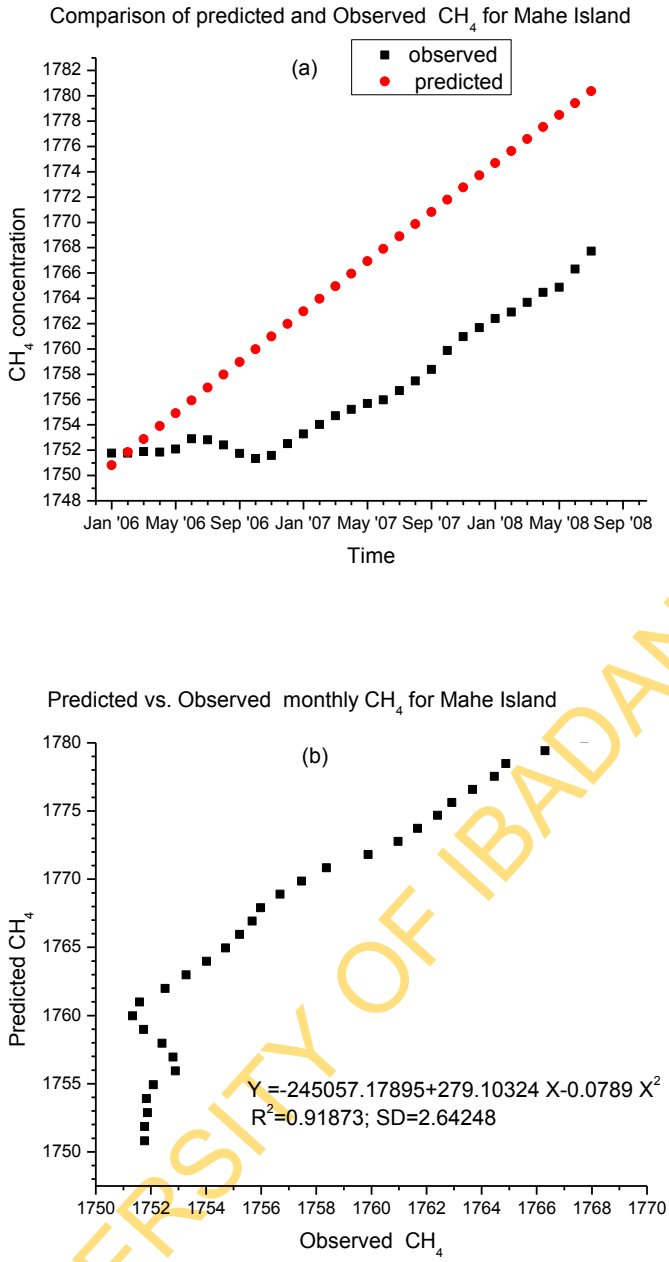


Fig. 4.76(a and b): Predicted vs. observed monthly CH_4 for Mahe Island

Table 4.49: Modeling of monthly CO_2 concentration at Cape Ferguson:

$$\psi = 358.66 + 0.14(120+n) + 1.16E\text{-}4(120+n)^2 + 0.40$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	377.70	378.43	-0.73
2	377.87	378.51	-0.64
3	378.03	378.65	-0.62
4	378.20	378.80	-0.60
5	378.37	378.93	-0.56
6	378.54	379.02	-0.48
7	378.71	379.11	-0.40
8	378.88	379.20	-0.32
9	379.05	379.35	-0.30
10	379.22	379.51	-0.29
11	379.39	379.80	-0.41
12	379.56	380.17	-0.61
13	379.73	380.36	-0.63
14	379.90	380.44	-0.54
15	380.07	380.65	-0.58
16	380.25	380.97	-0.72
17	380.42	381.26	-0.84
18	380.59	381.48	-0.89
19	380.76	381.69	-0.93
20	380.93	381.90	-0.97
21	381.11	382.06	-0.95
22	381.28	382.18	-0.90
23	381.45	382.21	-0.76
24	381.63	382.25	-0.62
25	381.80	382.45	-0.65
26	381.97	382.61	-0.64
27	382.15	382.70	-0.55
28	382.32	382.79	-0.47
29	382.50	382.88	-0.38
30	382.67	383.01	-0.34

Table 4.50: Modeling of monthly CH_4 concentration at Cape Ferguson:

$$\psi = (1699.83 + n) + 0.84(120+n) - 5.01E\text{-}3(120+n)^2 - 2.49$$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	1726.64	1729.99	-3.35
2	1727.26	1729.68	-2.42
3	1727.87	1729.50	-1.63
4	1728.48	1729.44	-0.96
5	1729.07	1729.59	-0.52
6	1729.65	1729.74	-0.09
7	1730.22	1729.61	0.61
8	1730.79	1729.24	1.55
9	1731.34	1729.30	2.04
10	1731.88	1729.86	2.02
11	1732.41	1730.66	1.75
12	1732.94	1731.54	1.40
13	1733.45	1732.64	0.81
14	1733.95	1733.60	0.35
15	1734.44	1734.53	-0.09
16	1734.93	1735.84	-0.91
17	1735.40	1736.93	-1.53
18	1735.86	1737.90	-2.04
19	1736.31	1738.92	-2.61
20	1745.75	1740.19	5.56
21	1737.19	1741.70	-4.51
22	1737.61	1742.85	-5.24
23	1738.02	1743.29	-5.27
24	1738.42	1743.58	-5.16
25	1738.81	1743.80	-4.99
26	1739.20	1744.11	-4.91
27	1739.57	1744.38	-4.81
28	1739.93	1744.05	-4.12
29	1740.28	1744.30	-4.02
30	1740.63	1744.94	-4.32

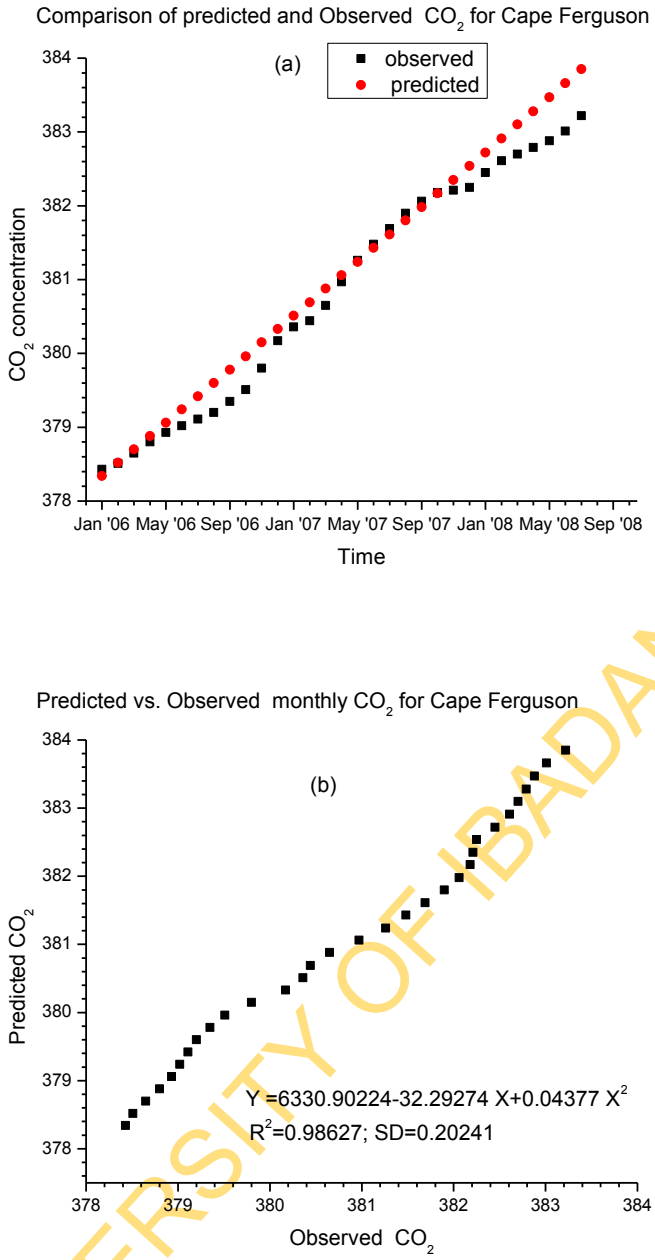


Fig. 4.77(a and b): Predicted vs. observed monthly CO_2 for Cape Ferguson

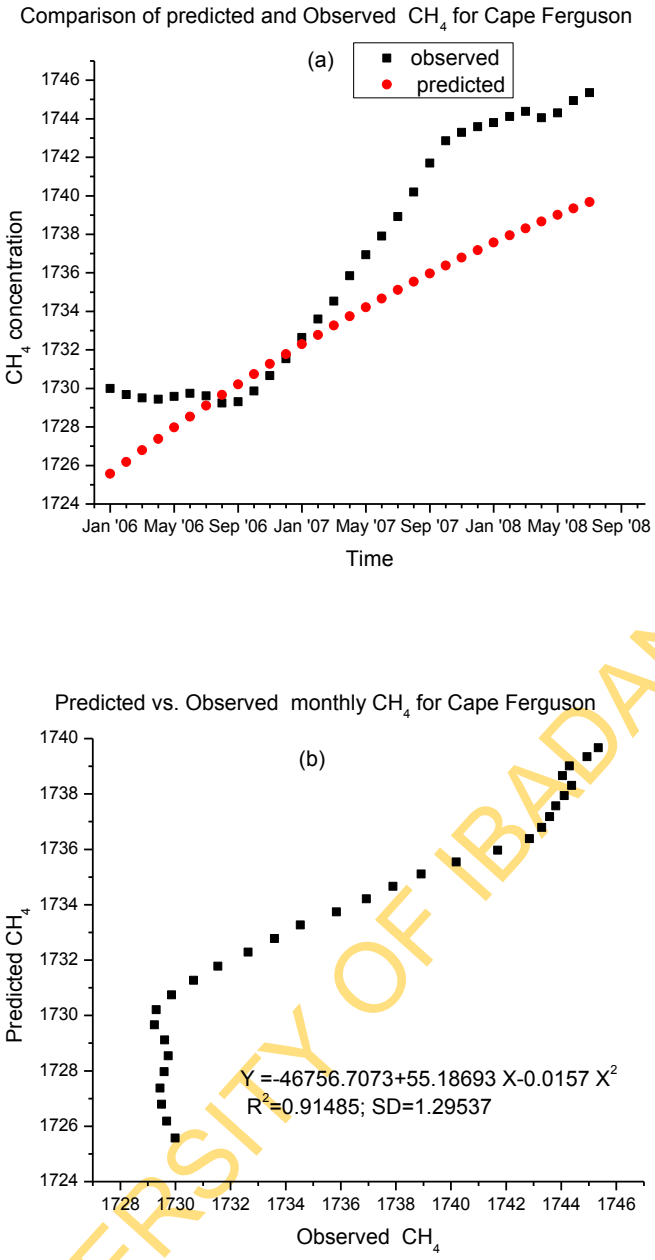


Fig. 4.78(a and b): Predicted vs. observed monthly CH_4 for Cape Ferguson

Table 4.51: Modeling of monthly CO_2 concentration at Tutuila:

$\psi = 358.37 + 0.15(120+n) + 8.92E\text{-}5(120+n)^2 + 0.34$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	378.17	379.29	-1.12
2	378.34	379.42	-1.08
3	378.51	379.53	-1.02
4	378.68	379.67	-0.99
5	378.85	379.79	-0.94
6	379.03	379.91	-0.88
7	379.20	380.05	-0.85
8	379.37	380.12	-0.75
9	379.54	380.22	-0.68
10	379.72	380.42	-0.70
11	379.89	380.59	-0.70
12	380.06	380.76	-0.70
13	380.24	380.97	-0.73
14	380.41	381.17	-0.76
15	380.59	381.36	-0.77
16	380.76	381.53	-0.77
17	380.93	381.75	-0.82
18	381.11	381.96	-0.85
19	381.28	382.15	-0.87
20	381.46	382.39	-0.93
21	381.63	382.58	-0.95
22	381.81	382.69	-0.88
23	381.98	382.85	-0.87
24	382.16	383.07	-0.91
25	382.34	383.25	-0.91
26	382.51	383.38	-0.87
27	382.69	383.52	-0.83
28	382.86	383.68	-0.82
29	383.04	383.81	-0.77
30	383.22	383.94	-0.72

Table 4.52: Modeling of monthly CH_4 concentration at Tutuila:

$\psi = (1701.80 + n) + 0.74(120+n) - 4.12E\text{-}3(120+n)^2 - 3.89$

n	Modelled data(ψ)	Observed data	Modelled data - observed data
1	1728.13	1736.99	-8.86
2	1728.87	1736.84	-7.97
3	1729.60	1736.64	-7.04
4	1730.32	1736.79	-6.47
5	1731.04	1736.75	-5.72
6	1731.74	1736.67	-4.93
7	1732.44	1736.32	-3.88
8	1733.13	1734.65	-1.52
9	1733.81	1733.87	-0.06
10	1734.48	1734.85	-0.37
11	1735.15	1735.38	-0.23
12	1735.80	1735.59	0.21
13	1736.45	1736.21	0.24
14	1737.09	1736.76	0.33
15	1737.72	1737.38	0.34
16	1738.35	1737.83	0.52
17	1738.96	1738.38	0.58
18	1739.57	1739.58	-0.01
19	1740.17	1741.24	-1.07
20	1749.76	1743.31	6.45
21	1741.34	1743.91	-2.57
22	1741.91	1743.41	-1.50
23	1742.48	1744.07	-1.59
24	1743.04	1745.04	-2.00
25	1743.59	1745.65	-2.06
26	1744.13	1746.36	-2.23
27	1744.66	1747.05	-2.39
28	1745.19	1747.47	-2.28
29	1745.70	1747.59	-1.89
30	1746.21	1747.37	-1.16

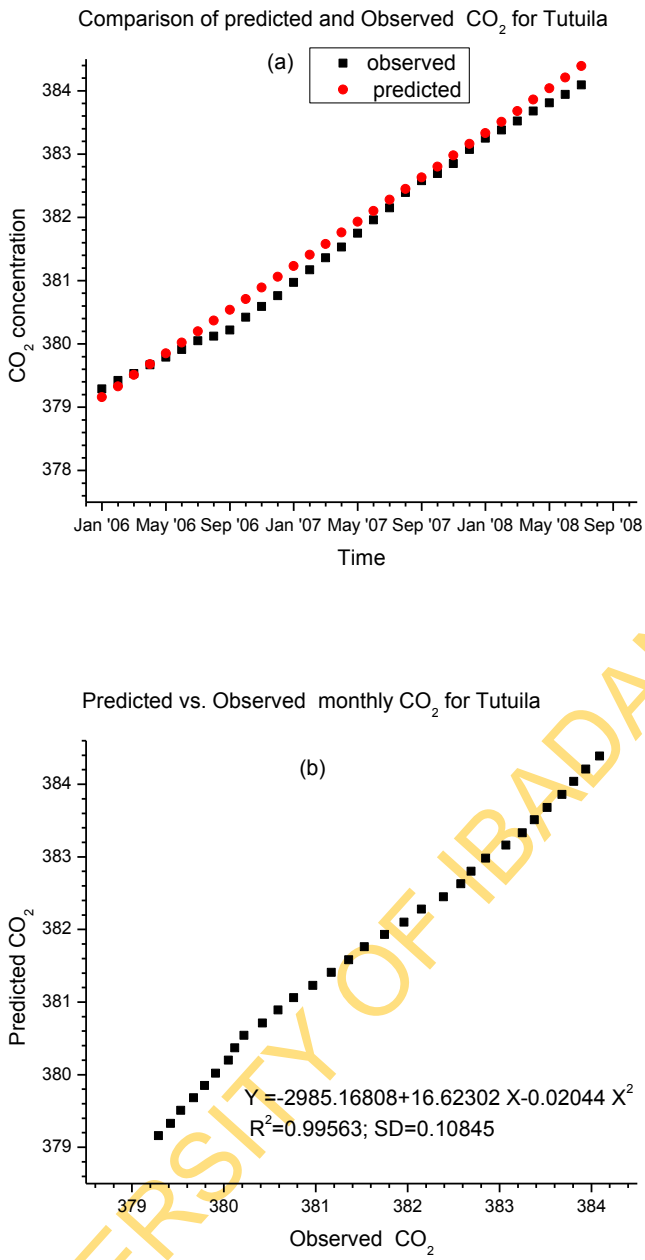
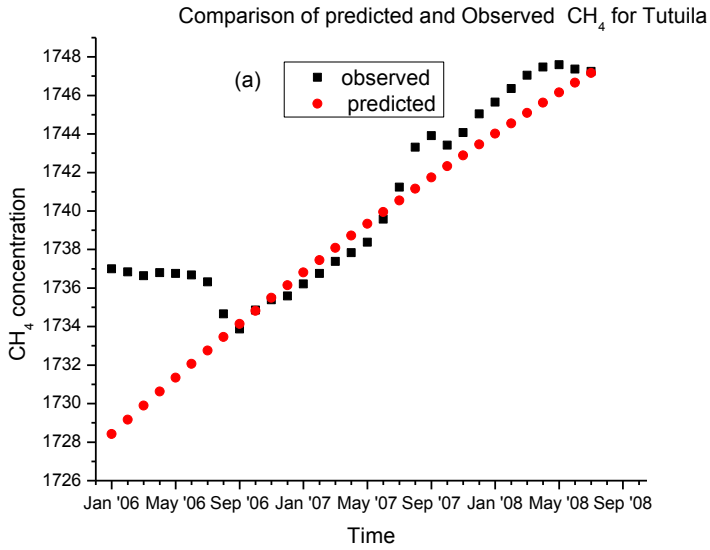


Fig. 4.79(a and b): Predicted vs. observed monthly CO_2 for Tutuila



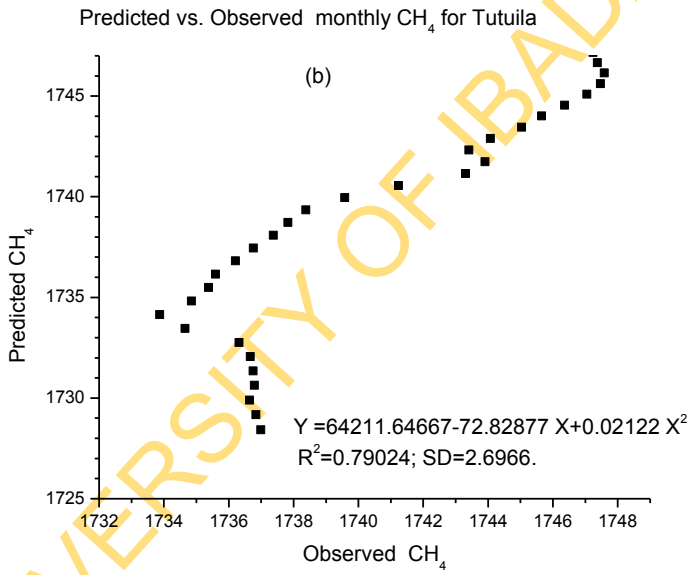


Fig. 4.80(a and b): Predicted vs. observed monthly CH_4 for Tutuila

CHAPTER FIVE

CONCLUSION

5.1 Observations and conclusion on concentration and time variation of CO_2 and CH_4 gases in the tropics

Based on the study carried out within the tropics it was observed that the greenhouse gas (CO_2 and CH_4) concentrations varies with time and space both latitudinally and longitudinally for the stations considered.

The time variation shows that the mean concentration for both CO_2 and CH_4 was highest in Key Biscayne station, U.S.A. (America) which is a territory within one of the industrialized nations of the world. Also, the mean concentration of CO_2 was least in Cape Ferguson, Australia (Ocean), while the mean concentration of CH_4 was least in Tutuila, U.S.A (Ocean). Thus, tropical America has highest CO_2 and CH_4 concentration, while tropical Ocean including oceanic islands has least CO_2 and CH_4 concentrations among the tropical main areas for the stations considered.

For the concentration of CO_2 and CH_4 gases for stations considered in the tropics, key Biscayne station has the highest mean CO_2 concentration of 372.0 ± 0.5 ppm, and highest mean CH_4 concentration of 1812.4 ± 1.0ppb, while Cape Ferguson station has the least mean CO_2 concentration of 369.0 ± 0.5ppm with Tutuila station having least mean CH_4 concentration of 1728.2 ± 0.9ppb. It was also observed that stations in the southern hemisphere have lower concentrations of both CO_2 and CH_4 when compared to those in the northern hemisphere. Thus, it can be said that the southern hemisphere seems to be cleaner than the northern hemisphere in terms of both CO_2 and CH_4 pollution.

5.2 Conclusion on model fit for CO_2 and CH_4 concentrations for stations in the tropics

The model that best fit both the mean concentration of CO_2 and CH_4 gases for stations generally in the tropics is a polynomial fit (i.e. quadratic formula) since the gases fluctuates slightly on daily, weekly, monthly and yearly basis. Moreover,

the changes in concentration of these gases vary non-linearly, especially on daily, weekly, monthly and yearly basis for each station considered (i.e. from location to location).

5.3 Implications of model fit for CO_2 and CH_4 concentration in the tropics

The models obtained could be used in determining specifically the monthly concentrations of both the CO_2 and CH_4 gases for each station in the northern hemisphere and the southern hemisphere of the tropics. Likewise, the standard deviation which is used as an index of warming could also be obtained for both the CO_2 and CH_4 gases on annual basis for each station in the tropics. This could be used in comparing warming on yearly basis from one station to another (i.e. locations) in the tropics.

The correlation of the variation of both the CO_2 and CH_4 with global warming shows that for stations considered in the northern hemisphere, the year 1998 was the warmest; this is the same for the tropical southern hemisphere.

The increase in CO_2 and CH_4 concentrations which has direct correlation with global warming, are responsible for the increase in temperature of the lower atmosphere. These greenhouse gases are on the increase thereby causing anomalous climatic conditions which also has an indirect effect on the hydrologic cycle. Likewise, warming which is an aspect of climatic variability brings about changes in precipitation variability which results in either floods or drought throughout the world depending on atmospheric circulation, thus resulting in devastating effect on the people and the environment such as famine, and increasing vulnerability to disease, and ecological damage. If the annual standard deviation, which is an indication of warming for any particular location, is calculated for a particular year and compared to that of year 1998 which thus far has been the year with the warmest contribution by these greenhouse gases for this study, then the warming and anticipated climate variability for that location can be deduced. This will also allow for opportunities involved with climate variability to be utilized and the risks minimized for that particular location.

5.4 Conclusion on latitudinal and longitudinal variation of CO_2 and CH_4 Concentrations in the tropics

The latitudinal variation in the concentrations of CO_2 and CH_4 within the northern and southern hemisphere location in the tropics showed that the values of R^2 for CO_2 are higher than those of CH_4 in both hemispheres. Also, the values of SD obtained for the concentration of these gases at stations within intervals beyond 5^o are higher than those within 5^o interval. The values of R^2 obtained for CO_2 at stations both within 5^o interval and beyond, to each other latitudinally in the northern hemisphere stations are more than those in this interval for the southern hemisphere stations, while for the CH_4 concentrations the values of R^2 obtained at southern hemisphere stations within interval beyond 5^o to each other latitudinally are more than those in the northern hemisphere stations for this same interval. The longitudinal variation shows that the values of R^2 obtained for CO_2 concentrations are more than those obtained for CH_4 in both hemispheres with the values of R^2 obtained for these gases at interval beyond 5^o more than those within 5^o interval.

5.5 Recommendation for policy and practice

Since increment in concentration of greenhouse gases has been shown to be causing warming which has also been causing much devastating effect globally, especially in the tropics, it would be advisable that the sources of these gases such as fossil fuel consumption, natural gas flaring, bush burning and deforestation be mitigated, so as to reduce their concentrations due to the fact that the sink for these gases such as afforestation are also continually on the decline. Moreover, alternative sources of clean energy to fossil energy should be utilised including renewable sources of energy such as wind, solar and hydro power generation.

5.6 **Recommendation for further research**

This work could be further enhanced if the period for data collection is increased (say, about 30 years which is not available now). Moreover, more stations and more greenhouse gases that are anthropogenicaly produced such as N_2O and CFCs could also be included as parameters used in doing the same analysis performed in this work with the individual contribution of these greenhouse gases to global warming also aimed at in further work.

REFERENCES

Ahrens, C.D. 1998. *Essentials of meteorology-An invitation to the atmosphere*. Wadsworth publishing company. London. 443pp.

Arrhenius, S. 1896. On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophy magazine* 41: 237-277.

Autoregressive model. 2009. In: *Wikipedia, The Free Encyclopedia*. Retrieved 02:46, April 12, 2009, from http://en.wikipedia.org/w/index.php?title= Autoregressive_model&oldid=283294788

Autoregressive moving average model. 2009. In: *Wikipedia, The Free Encyclopedia*. Retrieved 11:20, April 15, 2009, from http://en.wikipedia.org/w/index.php?title=Autoregressive_moving _average_ model & oldid =28397588

Ayres, R.U. and Walter, J. 1991. The Greenhouse Effect: Damages, costs and abatement, *Environmental and Resource Economic*. 1: 237 – 270.

Barry, R.G. and Chorley, R. J. 1992. *Atmosphere, weather and climate*. 6th ed. Routlegde Publisher. NY. 392pp.

Bolin, B. and McElroy, M.B. 1985. A Geosphere-Biosphere research program in *Global change* (The proceedings of a symposium sponsored by the international council of scientific unions (ICSU) during its 20th general assembly in Ottawa, Canada on Sept. 25, 1984. (Edited by T.E. Malone and J.G. Roederer), published on behalf of the ICSU press by Cambridge Univ. Press. 53-66.

Box, G.E.P. and G.M. Jenkins, 1994. Time Series Analysis: Forecasting and Control. Prentice-Hall. 598pp.

Bradley, R.S. 1999. *Paleoclimatology: Reconstructing climate of the Quaternary*. 2nd ed. Academic press

Brimblecombe, P. 1986. *Air composition and chemistry*. Cambridge University Press. 165 – 169.

Bryson, R. 1974. A perspective on climate change. *Science* 1.84: 753-760.

Budyko, M.I. 1974. Climate and Life in D.H. Miller. (English Edition Editor). *international Geophysics series*.18: 290 – 316. Academic Press. NY.

Busallachi, A., Legler, D., Cattle, H., Palmer, T. and Gould, J. 2005. Climate change and variability – what can we predict? *WMO Bull*.54 (2): 51 – 57.

Callendar, G.S. 1938. The artificial production of carbon dioxide and its effect on temperature. *Quart. Journal of Royal meteor. Soc*. 64: 223 – 240.

Callendar, G.S. 1940. Variations of the amount of carbon dioxide in different air currents. *Quart. J. Roy. meteor. Soc*. 66: 395 – 400.

Callendar, G.S. 1949. Can carbon dioxide influence climate? *Weather* 4: 310 – 314.

Callendar, G.S. 1958. On the amount of carbon dioxide in the atmosphere. *Tell Us* 10: 243 – 248.

Cess, R.D., Zhang, M.H., Potter, G.L., Barker, H.W. and Colman, R.A. 1993. Uncertainties in CO_2 radiative forcing in atmospheric GCMs. *Science* 262: 1252 – 1255.

Chamberlain, T.C. 1899. An attempt to frame a working hypothesis of the cause of glacial periods on an atmospheric basis. *J. of Geology* 7: 751-787.

Chandler, R.E. 2005. On the use of generalized linear models for interpreting climate variability. *Environmetrics* 16: 699-715, DOI:10.1002/env.731

Cicerone, R.J. and Oremland, R. 1988. Biogeochemical aspects of atmospheric methane. *Global Biogeochem. cycles* 2: 299 – 328

Clayton, K. 1996. The threat of global warming in T. O'Riordan (Ed.). *Environmental science for environmental management*. Longman Group Ltd. England. 110 – 130.

Climate Change. 2009. *In: Wikipedia, the Free Encyclopedia*. Retrieved 21:16, May25, 2009, from http://en.wikipedia.org/w/index.php?titleclimate_change &oldid=292298974

Climate Change Information Center of Armenia. 2007. In: Causes of Climate Change. Retrieved 10:42, September 11, 2008, from http://www.nature-ic.am/ccarmenia/en/climate literature/causes of climate change information center.html

Coefficient of determination. 2010. In: wikipedia, The Free Encyclopedia. Retrieved 08:21, December 14, 2010, from http://en.wikipedia.org/w/ index.php? title=coefficient_of_determination&oldid=40134318.

Crane, A.J. 1981. Comment on recent doubts about the CO_2 greenhouse effect. *Journ. of Appl. Meteor*. 20: 1547 – 1549.

Day, J.A. and Sternes, G.L. 1970. *Climate and weather*. Addison Wesley.

DeLong, K.L., Quinn, T.M. and Taylor, F.W. 2007. Reconstructing twentieth – century sea surface temperature variability in the South west Pacific: A replication study using multiple coral Sr/Ca records from New Caledonia, Paleoceanography.22,PA 4212,doi:10.1029/2007PA001444

Dickerson, R.E. and Cicerone, R.J. 1986. Future global warming from atmospheric trace gases. *Nature* 319: 109 – 115.

Easterling, D.R., Evans J.L., Grossman, P.Y., Karl, T.R., Kunkel, K.E. and Ambege, P. 2000. Observed variability and trends in extreme climatic events: A brief review. *Bulletin of American Meteorological Society* 81: 417 – 425.

Edge, G. and Tovey, K. 1996. Energy: Hard choices ahead in T. O'Riordan (Ed.). *Environment science for Environmental management*. Longman Group Ltd. England. 317 – 334.

El Nino-Southern Oscillation. 2009. In: *Wikipedia, The Free Encyclopedia*. Retrieved 16:08, January20, 2009, from http://en.wikipedia.org/w/index.php?title=El_Ni%C3%B1o_Southern_Oscillation&oldid=265303343

EPA. 2002. Inventory of U.S Greenhouse gas emission and sinks: (1990 – 2000). *U.S. Environmental Protection Agency*. Office of Atmospheric Programs. EPA 430 – R – 02 – 003, April 2002 <www.epa.gov/globalwarming/publication/emissions>

Firor, J. 1990. *The Changing atmosphere – A global change*. Yale Univ. Press. London.

Folland, C.K. and Colman, A.W. 2000. Empirical prediction of the global temperature anomaly for 2000. *Experimental long lead forecast*. Bulletin 9 (published by COLA, U.S.A, www.iges.org/ellfb)

Fourier, J.B. 1827. 569 – 604: moircsur les tempereatures du globe terrestre et des espaces planetaires, *mem. Acad. Sci. Fr*. 7: 569 – 604.

Fraisse, C.W., Breuer, N.E., Zierden, D. and Ingam, K.T. 2009. From climate variability to change: challenges and opportunities to extension. *Journal of extension* 47(2). Feature articles. 2FEA9.

Ge, Y. and Xiankun, K. 2002. Reconstructing of the past 1000-a temperature in Canada based on pollen data. *Chinese Science Bulletin* 47(17):14 70 – 1473

Global warming. 2009. In: *Wikipedia, The Free Encyclopedia*. Retrieved 12: 25, June 10, 2009, from http://en.wikipedia.org/w/index.php?title=Global warming & oldid=29556712.

Greenberg, J.P., Helming, D. and Zimmerman, P.R. 1996. Seasonal measurements of non-methane hydrocarbons and carbon monoxide at the Mauna Loa observatory during the Mauna Loa observatory photo-chemistry Experiment 2. *Journal of Geophysical Research* 101(D9): 581- 598.

Greenhouse effect. 2009. In: wikipedia, The Free Encyclopedia. Retrieved 11:53, February 8, 2009, from http://en.wikipedia.org/w/index.php?title= Greenhouse_effects&oldid=26931231.

Greenhouse gas. 2009. In: wikipedia, The Free Encyclopedia. Retrieved 08:07, February 20, 2009, from http://en.wikipedia.org/e/index.php?title= Greenhouse_gas&oldid=27202696.

Griffiths, J.F. 1985. Controls of climate in D.D. Houghton (Ed). *Handbook of Applied Meteorology*. John Wiley and sons. NY. 62 – 132.

Haltiner, G.J. and Martin, F.L. 1957. *Dynamical and physical Meteorology*. McGraw – Hill Book Company. NY.

Hamilton, C. 1999. Justice, the market and climate change *Global ethnics and environment*. N. Low. Ed. Routledge. London. 90 – 105.

Holdren, J.P. 1992. The energy predicament in perspective *Confronting climate change: Risks, implications and responses*. I. Mintzer. Ed. Cambridge Univ. Press. 163 – 170.

Houghton, J. 1998. *Global warming: The complete briefing*. Cambridge Univ. Press.

Houghton, J.T. 1977. *The physics of Atmospheres*. Cambridge Univ. Press. 203pp.

Houghton, J.T. 1979. Greenhouse effects of some Atmospheric constituents. *Phil. Trans*. 290: 515-521

Houghton, J.T. 2004. *Global Warming-The Complete Briefing*. Cambridge University Press. 216-241

Hutchinson Encyclopedia. 2008. *Anthropogenic global warming, the free dictionary*. Farlix inc. (http://www.thefreedictionary.com/about.htm)

Ice Core. 2008. In: *Wikipedia, The Free Encyclopedia*. Retrieved 16:15, October 29, 2008, from http://en.wikipedia.org/w/index.php?title=1ce_core&oldid =248426065

Ikeme, J. 2005. Assessing the future of Nigeria's economy: ignored threats from the global climate change debacle. *Africa economic analysis*. (www.Africa Economic Analysis.org).

International Arctic Science Committee. 2010. Tree rings and past climate in the Artic in C.J. Cleveland (Ed.). *Encyclopedia of Earth*. [First published in the Encyclopedia of Earth February 9, 2010 < http//www.eoearth.org/article /Tree_rings_and_past_climate_in_the_Artic >]

International council of scientific union. 1985. Global change. *Proceedings of International council of scientific union (ICSU).* T.F. Malone and R.G. Roederer. Eds. Cambridge University Press.

IPCC 1990. Scientific Assessment of Climate change. *Intergovernmental panel on climate change (IPCC) report. WMO – UNEP*. Cambridge University Press. Cambridge. 366pp.

IPCC. 1992. The supplementary part to the intergovernmental panel on climate change (1990) scientific assessment. *Intergovernmental panel on climate change (IPCC) report. WMO – UNEP*. Cambridge University Press. Cambridge. 200pp.

IPCC. 1996. *Climate change (1995): Impacts, Adaptations and Mitigation of climate change*. Cambridge Univ. Press.

IPCC. 2001. *The third Assessment report on climate change: Impacts, adaptation and vulnerability*. Cambridge University Press.

IPCC. 2007. *The fourth Assessment report on scientific aspects of climate change: for researchers, students and policymakers.* Cambridge University Press.

Kandikar, M. and Sagar, A. 1979. Climate change research and analysis in India: An integrated assessment of a South-North divide. *Global Environment change* 9: 119 – 138.

Karl, T.R. and Trenberth, K.E. 2003. Science: modern global climate change. *Science magazine* 302(5051): 1719 – 1723 (www.sciencemag.org science vol. 302, 5 Dec 2003).

Keeling, C.D. and Bacastow, R.B. 1977. Energy and climate. *National Academies of Sciences.* Washington D.C.

Kellert, S.R. (Ed.). 1997. *Macmillan Encyclopedia of the Environment.* vol. 1. Macmillan. N.Y.

Kerski, J. and Ross, S. 2005. *The essential of the environment*. Hodder Arnold

Khandekar, M.L. 2000. Uncertainties in greenhouse gas induced climate change. *Report prepared for Science and Technology Branch, Alberta Environment*. ISBN 0-7785-1051-4, Edmonton, Alberta.

Lamb, H.H, and Johnson, A.I. 1959. Climatic variations and observed changes in the General Circulation. *Geofrafiska Annaler* 41(2-3): 94-134

Langley, S.P. 1890. The temperature of the moon. *Mem. of the Nat. Acad. Of Sci.* iv: 193.

Lashof, D.A. 1989. The dynamic greenhouse: Feedback processes that may influence future concentrations of Atmospheric trace gases and climatic change. *Climatic change* 14: 213.

Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., Peterson, T., and Prather, M. 2007. Historical overview of climate change. In :*climate change (2007): The physical basis*. Contribution of working group 1 to the fourth assessment report of the intergovernmental panel on climate change (Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avergt K.B, Tiguor M, and Miller H.L (Eds.)). Cambridge University Press. U.K. and U.S.A.

Liss, P.S. and Crane, A. J. 1983. *Man-made carbon dioxide and climatic change – A review of scientific problems*. Geo Books. England. 127pp.

Lorenz, E.N. 1970. Climate change as a mathematical problem. *J. Appl. Meteor*. 9: 325 – 329.

Lutgens, F.K. and Tarbuck, E.J. 1986. *The Atmosphere – An introduction to meteorology*. Prentice Hall. N.J. 422pp

Machta, L. 1971. The role of the oceans and the biosphere in the carbon dioxide cycle. *Nobel Symposium 20*. Gothenburg, Sweden.

Madden R.A. and Ramanathan, V. 1980. Detecting climate change due to increasing carbon dioxide. *Science* 209: 763 – 768.

Mahlman, J.D. 1997. Uncertainties in projections of human caused climate warming. *Science*. 278(5342): 1416 – 1417. (DOI: 10. 1126/science 278.5342 pp 1416).

Manabe, S. and Wetherald, R.T. 1967. Thermal equilibrium of the atmosphere with a given distribution of relative humidity. *Journal of the Atmospheric Sciences* 24: 241 – 259.

Manabe, S. and Wetherald, R.T. 1980. On the distribution of climate change resulting from an increase in CO_2 content of the atmosphere. *Journal of the Atmospheric sciences* 37: 99 – 118.

McGregor, G.R. and Nieuwolt, S. 1998. *Tropical Climatology*. John Wiley and Sons. England. 339pp.

McIntosh, D.H. and Thom, A.S. 1973. *Essentials of Meteorology*. Wykeham publishing Ltd. London.

Methane – a ticking bomb. 2009. In: *Allianz*. Retrieved 09:48, July 16, 2009, from http://knowledge.allianz.com/en/globalissues/climate_change/global_warming_basics/global_warming_greenhouise_effect.html.

Mitchell, J.M. 1970. A preliminary evaluation of atmospheric pollution as a cause of the global temperature fluctuation of the past century. *Proc. AAAS 1969 symposium on global effects of environmental pollution.*

Moran, J.M. and Morgan M.D. 1991. *Meteorology–The atmosphere and the science of weather*. 3rd ed. Macmillan. N.Y.

Mulholland, H. and Jones, C.R. 1983. Fundamentals of statistics, ELBS ed. Butterworths. London, 291pp

Nakazawa, F. and Fujita, K. 2006. Use of ice cores from glaciers with melting for reconstructing mean summer temperature variations. *Annals of Glaciology* 43: 167-171.

National Academy of Science. 2005. *Understanding and responding to climate change (Highlights of National Academics report)*. <http://dels.nas.edu/ccgc, http://www.nationalacademics.org/basc.>

National Oceanographic and Atmospheric Administration (NOAA) Paleoclimatology program. 2002. In: Introduction to paleoclimatology. Retrieved 08: 15. May 26, 2009, from http://www.ncdc.noaa.gov/paleo /paleo.proxy data.html

Newell, R.E. and Dopplick, T.G. 1979. Questions concerning the possible influence of anthropogenic CO_2 on atmospheric temperature. *Journal of Applied Meteorology* 18: 822 – 825.

Novelli, P.C., Conway, T.J., Dhigokencky, E.J. and Tans, P.P. 1995. Recent changes in carbon dioxide, carbon monoxide and methane and the implications for global climate change. *WMO Bulletin* 44(1): 32 – 38.

Oeschger, H., Siegenthaler, U., Schotterer, U., and Gugelmann A. 1975. A box diffusion model to study the carbon dioxide exchange in nature. *Tell Us* 27: 168 – 192.

Oxford Dictionary of Scientists. 2003. *A Dictionary of Scientists: Roger Revelle*. Oxford University Press.

Plass, G.N. 1956. The Carbon dioxide Theory of Climatic change. *Tell Us* 8: 140 – 154.

Porter, G. and Brown, J.W. 1991. *Global Environmental Politics: Dilemmas in World Politics*. Colorado: Washington.

Poullet, C. 1837. Memoire Sur la Chaleur Solaire, sur les pouvoirs rayonnants et absorbants d'lair atmospherique, et sur la temperature de lespace. *Compte rendus hebdomadaires des seances de 1, academie des sciences* 7: 24 – 65.

Ramanathan, V. 1975. Greenhouse effect due to chlorofluorocarbons: Climatic implications. *Science* 190: 50-52.

Ramanathan, V., Lian, M.S., and Cess, R.D. 1979. Increased atmospheric CO_2: zonal and seasonal estimates of the effect on the radiation energy balance and surface temperature. *Journal of Geophysical Research* 84.C8

Rangarajan, G. and Sant, D.A. 1997. A climate predictability index and its applications. *Geophysical Research letters*. 24.10: 1239 – 1242.

Rasool, S.I. and Schneider, S.H. 1971. Atmosphere CO_2 and aerosols: Effects of large increases on Global Climate. *Science* 173: 138 – 141.

Revelle, R. and Suess, H.E. 1957. Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades. *Tell Us* 9: 18 – 27.

Roger Revelle. 2010. In: *wikipedia, The Free Encyclopedia*. Retrieved 08:23, December 10, 2010, from http://en.wikipedia.org/w/index.php?title=Roger_Revelle&oldid=394732841.

Schneider, S.H., and Dickinson, R.E. 1974. Climate modeling. *Review of geophysics and space physics* 12.3: 447 - 494.

Sellers, W.D. 1965. *Physical Climatology*. Univ. of Chicago Press.

Shaw, N. 1926. *Manual of meteorology* I: 84.

Solow, A. and Huppert, A. 2004. Optimal multiproxy reconstruction reconstruction of sea surface temperature from Corals. *Paleoceanography*. (19, PA4004, doi: 10.1029/2003PA000980)

Stang, D.R. 2009. Trends in atmospheric methane. In: *zipcodezoo.com the Bay Science foundation Inc*. (http://zipcode.com/Trends/Trends in atmosperic methane)

Strong, M.F. 1992. Energy, Environment and Development Energy policy 20.6: 490-494.

Taylor, J.R. 1982. *An introduction to Error Analysis – The study of Uncertainties in physical measurements.* Univ. Science Books. CA. 270pp.

Trenberth, K.E. 1997. ‘‘The definition of El Nino” (pdf). *Bulletin of the American Meteorological Society*. (78(12): 2771-2777.doi:10.1175/1520-0477 (1977)078 <2771: TDOEN>2.0.CO; 2).

Tyndall, J. 1861. On the absorption and radiation of heat by gases and vapours and the physical connection of radiation, absorption and conduction. *Phil. Magazine* 22: 169 – 194.

United State agency for International development. 2007. *Adapting to Climate Variability and Change – A Guidance Manual for development planning (United State agency for International development (USAID))* in Duane Muller (Ed.). *(EGAT/ESP/GCC) cc_vamanual.pdfadobereader.*

Variance.2010. In: wikipedia, Free Encyclopedia. Retrieved 08:28, December 14, 2010, from http://en.wikipedia.org/w/indexphp?title=variance&oldid=399 73536.

Wallington, T.J., Srinivasan, J., Nielsen, O.J., Highwood, E.J. 2004. Greenhouse gases and global warming. In: *Environmental and Ecological Chemistry*. (Ed. Aleksandar Sablyic) In Encyclopedia of Life support systems (EOLSS), Developed Under The Auspices of the UNESCO, Eolss publishers, Oxford, U.K (http://www.eolss.net)

Wang, W.C., Yung, Y.L., Lacis, A.A., Mo, T. and Dansen, J.E. 1976. Greenhouse effects due to man-made perturbations of trace gases. *Science* 194: 685 – 690. (dois 10.1126/science. 194. 4266.685)

Wayne, A.W. and Gray, H.L. 1993. Global Warming and the problem of Testing for Trend in Time Series Data. *Journal of Climate*. 6(5): 953-962. (DOI: 10.1175/1520-0442(19930006<0953.GWATPO>2.0.CO; 2)

Weart, S. 2008. *The Discovery of Global Warming*. Retrieved March 25, 2009, from http://www.aip.org/history/climate/xwiring.html.

Wesler, H. 1953. Radiation balance of the Earth as a factor of climate changes in Shapley, H. (Ed.). *Climate change: Evidence, Causes and Effects*. Harvard Univ. press. Cambridge and Massachusetts.

Wigley, T.M., Ingram, M.J., and Farmer, G. (Ed.). 1981. *Climate and History – studies in past climates and their impact on man.* Cambridge Univ. press.

Wilks, D.S. 2006. *Statistical methods in the atmospheric sciences*. 3rd ed. Elsevier Academic press.

World Bank Atlas. 1992. The United State of the World Atlas in M. Kidron and R. Segal (Eds.). *World Bank Atlas*. 25th ed. Washington DC.

World Meteorological Organisation. 2005. The global climate system in (2004). *WMO statement on status of the global climate in 2004.* (WMO – No 983. Annual statement on the state of global climate). <www.wmo.int/pages /prog/dpm/publications.html>

World Meteorological Organisation. 2006. The global climate system in 2005. *WMO statement on status of the global climate in 2005*. (WMO No 998, ISBN: 92 – 63 – 10998 – 2).

Yamaguchi, D.K. 1986. Interpretation of cross-correlation between tree-ring series. *Tree Ring Bulletin* 46: 47-54

Yeh, T. and Fu, C. 1985. Climatic change – A Global multidisciplinary theme in T.F. Malone and J.G. Roederer (Eds.). *ICSU: Global change*. Cambridge University press. 127 – 145.