Journal of the Nigerian Association of Mathematical Physics
Volume28, No. 1, (*November, 2014*), pp281 – 294

Empirical Prediction of Temperature Anomalies Over Tropical Pacific Ocean Using Greenhouse Gas Concentrations

Ogunsola, O.E and Oladiran, E.O.

Department of Physics, University of Ibadan, Ibadan, Nigeria.

Abstract

Temperature is the best and easiest of all documented weather parameters to show that climate is changing. However, temperature anomaly is more representative of a particular location than its absolute temperature. The accumulation of greenhouse gases results in accelerated warming of the atmosphere due to changes in the earth's radiation balance. The Pacific Ocean which covers a very large area of the equatorial region is a major contributor to the transfer of heat across the globe and is very important to warming.

Greenhouse gases data obtained from World Data Centre for Greenhouse Gases were analyzed using standardized anomalies, moving average and autocorrelation methods for the tropical Pacific Ocean region of the earth. The multiple regression approach was used to fit the relationship between the standard deviations of these greenhouse gases concentrations within the tropical Pacific Ocean and Roy Spencer's tropical temperature anomaly data in order to obtain a relationship between the standard deviation and temperature anomaly.

The obtained empirical relationship was used in determining the temperature anomaly pattern for each of the stations within this particular region of the earth in order to be able to compare warming on yearly basis from the predicted monthly concentrations of these gases.

Keywords: Temperature anomaly, greenhouse gases, standard deviation

1.0 Introduction

Climate change is best deciphered from temperature. However, it is not a matter of temperature fluctuation alone but a change in the nature of the general circulation is implied and therefore, also in the distribution of rainfall [1]. Other factors on which climate are dependent includes latitude, air circulation, ocean currents, and the local physical geography of an area [2, 3].

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). Thus, based on the aforementioned it was concluded that the five warmest years in decreasing order are: 1998, 2002, 2003, 2004 and 2001 [4]. In addition, WMO (2006), it was 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 10 years (1996-2005), with the exception of 1996 and 2000, are the warmest on record [5].

The temperature anomaly is the temperature difference between the temperature of the year in question and an averaged reference period, which is deemed to be normal [6]. It can be simply explained as a departure from a reference value or long term average.

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, just as high temperature during flowering may lower the grain number, size and quality [7].

The natural causes of global temperature change or fluctuations include El Nino and its Southern Oscillation (ENSO), volcanic activity and solar flux variability [8]. In addition, the enhancing global atmospheric pollution due to greenhouse gas emissions which is contributing to temperature rise is also causing climate change.

Corresponding author:Ogunsola, O.EE-mail: seyiogunsola22@yahoo.com, Tel.: +2348050253416

Climate change is usually studied using General Circulation models (GCMs) and Empirical models. Empirical models are preferred because the solutions of GCMs are complex and imprecise due to parameterizations of microprocesses embedded in them [9]. Climate models are empirical data augmented with mathematical studies [10]. In climate prediction models, one looks for trends in the time series of climatic variables and correlations between them which help specify the model [11]. 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.

Roy Spencer, a meteorologist and a Senior Scientist for Climate Studies at NASA's Marshall Space Flight Center obtained temperature anomaly data for the different regions of the earth which correlates well with absolute temperature data [12]. His tropical temperature anomaly data was used to fit the relationship between the standard deviations of the concentrations of greenhouse gases within the tropical Pacific Ocean in this work, in order to obtain a relationship between the standard deviation and temperature anomaly. These standard deviations were utilized as proxy data for temperature since 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 [13,14].

2.0 Materials and Methods

Climate change is usually studied using General Circulation models (GCMs) and Empirical models. Empirical models are preferred because the solutions of GCMs are complex and imprecise due to parameterizations of microprocesses embedded in them. In this work the per-minute data of both CO_2 and CH_4 concentrations for the period 1996 to 2005 were obtained from the World Data Centre for Greenhouse Gases (WDCGG). The concentrations were collected for 6 available observation sites from the tropical Pacific Ocean (Table 1).

The processing of these data is by the conversion of the per-minute data to hourly data and subsequently to daily data, monthly data and yearly data using the arithmetic mean approach which is a measure of their central tendency. Other means of processing these data include the use of moving average, auto-regression and standard deviation (σ) [15, 16, 17]. The methodology used for modeling 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 method [18]. The moving average which is frequently used in analyzing climatic data for possible trends, e.g. in determining whether temperatures are increasing or not, was used in smoothening the concentration of the greenhouse gases (ψ) in order to minimize their perturbations and also to determine their trend. The reason being that evidence of trends may be concealed from year to year for 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. Likewise, the auto-regression was used to determine the best equation of fit for the monthly concentrations of these greenhouse gases (Table 2) for the period considered (n=1, 2, 3…120) [19, 20]. Many data can be adequately approximated by a linear function with the multiple linear regressions used to make predictions in time [8, 21]. Both linear and quadratic equations were fitted to the monthly CO_2 and CH_4 gas concentrations for each station considered in the tropics. However, the quadratic fit gives 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 i.e. square of correlation coefficient.

The standard deviation (SD) which is the most satisfactory and widely used measure of dispersion that takes into account all members of the population was used as proxy data since the SD of these gases acts as a proxy for the actual temperature data required. Hence, it was also used to determine the warming pattern over the years since it showed good correlation with the global temperature trend.

Table 1: List of Observation Sites from which greenhouse gases' concentrations were obtained for this study

S/N	Observation Sites/Territory	Latitudinal and Longitudinal Locations	Tropical Region	Altitude(asl)*/m
1	Cape Ferguson(Australia)	Lat.19º17'S,Long.147º3'E	Pacific Ocean	2
2	Guam(U.S.A)	Lat.13º26'N,Long.144º47'E	Pacific Ocean	2
3	Sand Island(U.S.A)	Lat.28º12'N,Long.17722'W	Pacific Ocean	7.7
4	Tutuila(U.S.A)		Pacific Ocean	42
5	CapeKumukahi(U.S.A)	Lat.14º15'S,Long.170º34'W	Pacific Ocean	3
6	Mauna Loa(U.S.A)	Lat.19º31'N,Long.154º49'W Lat.19º32'N,Long.155º35'W	Pacific Ocean	3397

*asl=above sea level

Table 2: Monthly empirical equations for both CO_2 and CH_4 concentrations at each station considered in the Tropical Pacific Ocean (Jan. 1996 to Dec. 2005).

Observation Sites/Territory and best Equation of fit	Square of Correlation Coefficient (R^2) of CO_2	Standard Deviation (σ) of CO_2	Square of Correlation Coefficient (R^2) of CH_4	Standard Deviation (σ) of CH_4
CapeFerguson(Australia) CO_2: $\psi = 359.66 + 0.14n + 1.16\times10^{-4}n^2 + \sigma$ CH_4: $\psi = 1700.83 + 0.84n - 5.01\times10^{-3}n^2 - \sigma$	0.995	0.40	0.927	2.49
Guam(U.S.A) CO_2: $\psi = 361.27 + 0.12n + 3.33\times10^{-4}n^2 + \sigma$ CH_4: $\psi = 1755.66 + 0.54n - 2.5\times10^{-3}n^2 - \sigma$	0.995	0.39	0.835	3.77
Sand Island(U.S.A) CO_2: $\psi = 361.57 + 0.13n + 2.94\times10^{-4}n^2 + \sigma$ CH_4: $\psi = 1792.97 + 0.38n - 1.2\times10^{-3}n^2 - \sigma$	0.996	0.34	0.810	3.96
Tutuila(U.S.A) CO_2: $\psi = 359.37 + 0.15n + 8.92\times10^{-5}n^2 + \sigma$ CH_4: $\psi = 1702.80 + 0.74n - 4.1\times10^{-3}n^2 - \sigma$	0.996	0.34	0.838	3.89
Cape Kumukahi(U.S.A) CO_2: $\psi = 361.01 + 0.15n + 6.37\times10^{-5}n^2 + \sigma$ CH_4: $\psi = 1774.83 + 0.60n - 3.1\times10^{-3}n^2 - \sigma$	0.992	0.50	0.800	4.03
Mauna Loa(U.S.A) CO_2: $\psi = 361.03 + 0.14n + 1.75\times10^{-4}n^2 + \sigma$ CH_4: $\psi = 1758.95 + 0.64n - 3.3\times10^{-3}n^2 - \sigma$	0.995	0.41	0.897	2.89

3.0 Results and Discussion

3.1 Models of Greenhouse Gas Concentrations Within The Tropical Pacific Ocean

The developed model was of the form: $\psi_1 = a_1 + b_1(120+n) + c_1(120+n)^2 + \sigma_1$ for CO_2 and $\psi_2 = a_2 + b_2(120+n) + c_2(120+n)^2 - \sigma_2$ for CH_4,where ψ_i represents concentration of greenhouse gases as a function of time, while, σ_i, a^i , b^i , c^i and n represent the standard deviations, intercept, linear term coefficient, quadratic term coefficient and predicted month of concentrations of modeled gases respectively [22].

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

For additional month beyond December, 2005 the concentration can be determined as:

3.1.1 Modeling of monthly CO_2 and CH_4concentration at Cape Ferguson(Table 3):

$\psi = 358.66 + 0.14(120+n) + 1.16\text{x}10^{-4}(120+n)^2 + 0.40$ for CO_2 ……..... (1)

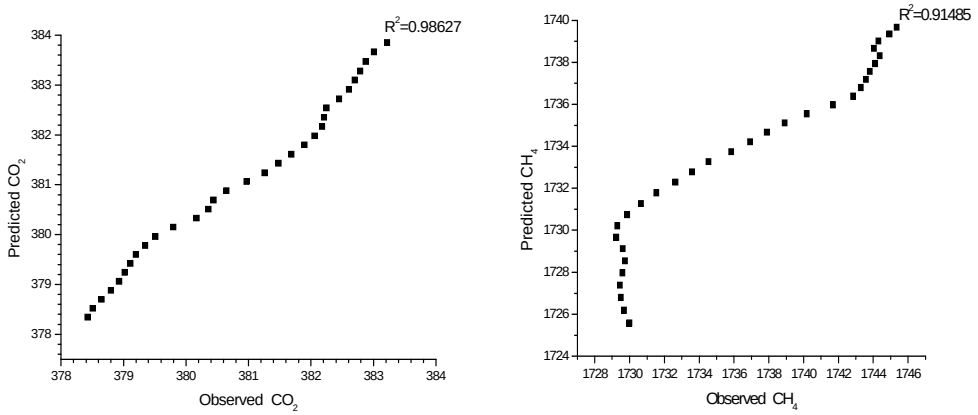
and

$\psi = (1699.83 + n) + 0.84(120+n) - 5.01\text{x}10^{-3}(120+n)^2 - 2.49$ for CH_4 ……. (2)

Table 3: Modeling of monthly CO_2 and CH_4 concentration at Cape Ferguson

Year	n	Modelled CO_2 data(ψ)	Observed CO_2 data	Modelled CH_4 data(ψ)	Observed CH_4 data
Jan 2006	1	377.70	378.43	1726.64	1729.99
Feb 2006	2	377.87	378.51	1727.26	1729.68
Mar 2006	3	378.03	378.65	1727.87	1729.50
Apr 2006	4	378.20	378.80	1728.48	1729.44
May 2006	5	378.37	378.93	1729.07	1729.59
Jun 2006	6	378.54	379.02	1729.65	1729.74
Jul 2006	7	378.71	379.11	1730.22	1729.61
Aug 2006	8	378.88	379.20	1730.79	1729.24
Sep 2006	9	379.05	379.35	1731.34	1729.30
Oct 2006	10	379.22	379.51	1731.88	1729.86
Nov 2006	11	379.39	379.80	1732.41	1730.66
Dec 2006	12	379.56	380.17	1732.94	1731.54
Jan 2007	13	379.73	380.36	1733.45	1732.64
Feb 2007	14	379.90	380.44	1733.95	1733.60
Mar 2007	15	380.07	380.65	1734.44	1734.53
Apr 2007	16	380.25	380.97	1734.93	1735.84
May 2007	17	380.42	381.26	1735.40	1736.93
Jun 2007	18	380.59	381.48	1735.86	1737.90
Jul 2007	19	380.76	381.69	1736.31	1738.92
Aug 2007	20	380.93	381.90	1745.75	1740.19
Sep 2007	21	381.11	382.06	1737.19	1741.70
Oct 2007	22	381.28	382.18	1737.61	1742.85
Nov 2007	23	381.45	382.21	1738.02	1743.29
Dec 2007	24	381.63	382.25	1738.42	1743.58
Jan 2008	25	381.80	382.45	1738.81	1743.80
Feb 2008	26	381.97	382.61	1739.20	1744.11
Mar 2008	27	382.15	382.70	1739.57	1744.38
Apr 2008	28	382.32	382.79	1739.93	1744.05
May 2008	29	382.50	382.88	1740.28	1744.30
Jun 2008	30	382.67	383.01	1740.63	1744.94

Fig. 1a and b showed the comparison between actual and modeled monthly concentrations for CO_2 and CH_4 gases respectively at Cape Ferguson station,



(a) Modeled vs. Actual monthly CO2(b)Modeled vs. Actual monthly CH4

Fig. 1 (a and b): Modeled vs. actual monthly CO_2 and CH_4 concentrations at Cape Ferguson

3.1.2 Modeling of monthly CO_2 concentration at Guam (Table 4):

$\psi = 360.27 + 0.12(120+n) + 3.33x10^{-4}(120+n)^2 + 0.39$ for CO_2 …… (3)

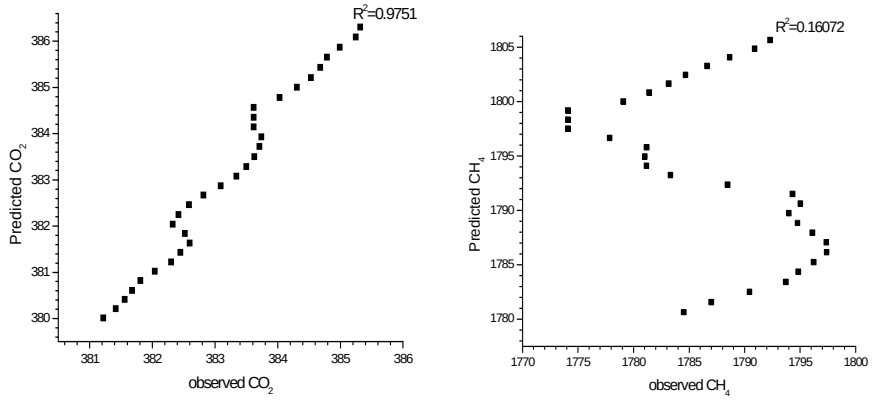
and

$\psi = (1754.66+n) + 0.54(120+n) - 2.46x\ 10^{-3}(120+n)^2 - 3.77$ for CH_4 …… (4)

Table 4: Modeling of monthly CO_2 and CH_4 concentration at Guam

Year	N	Modelled CO_2 data(ψ)	Observed CO_2 data	Modelled CH_4 data(ψ)	Observed CH_4 data
Jan 2006	1	380.06	381.22	1781.21	1784.53
Feb 2006	2	380.26	381.42	1782.16	1787.02
Mar 2006	3	380.46	381.56	1783.09	1790.46
Apr 2006	4	380.66	381.68	1784.03	1793.71
May 2006	5	380.86	381.81	1784.95	1794.85
Jun 2006	6	381.07	382.04	1785.88	1796.23
Jul 2006	7	381.27	382.30	1786.79	1797.39
Aug 2006	8	381.48	382.45	1787.71	1797.36
Sep 2006	9	381.68	382.60	1788.61	1796.11
Oct 2006	10	381.89	382.52	1789.52	1794.77
Nov 2006	11	382.09	382.33	1790.41	1793.99
Dec 2006	12	382.30	382.42	1791.31	1795.04
Jan 2007	13	382.51	382.59	1792.20	1794.33
Feb 2007	14	382.72	382.82	1793.08	1788.47
Mar 2007	15	382.93	383.09	1793.96	1783.33
Apr 2007	16	383.14	383.34	1794.83	1781.18
May 2007	17	383.35	383.50	1795.70	1781.03
Jun 2007	18	383.56	383.63	1796.56	1781.19
Jul 2007	19	383.77	383.71	1797.42	1777.86
Aug 2007	20	383.99	383.74	1807.27	1774.10
Sep 2007	21	384.20	383.62	1799.12	1774.10
Oct 2007	22	384.41	383.62	1799.97	1774.10
Nov 2007	23	384.63	383.62	1800.81	1779.08
Dec 2007	24	384.85	384.03	1801.64	1781.42
Jan 2008	25	385.06	384.31	1802.47	1783.18
Feb 2008	26	385.28	384.53	1803.29	1784.69
Mar 2008	27	385.50	384.68	1804.11	1786.64
Apr 2008	28	385.71	384.79	1804.93	1788.67
May 2008	29	385.93	384.99	1805.74	1790.92
Jun 2008	30	386.15	385.25	1806.54	1792.30

Fig. 2a and b showed the comparison between actual and modeled monthly concentrations for CO_2 and CH_4 gases respectively at Guam station,



(a) Modeled vs. Actual monthly CO2 (b) Modeled vs Actual monthly CH4

Fig. 2 (a and b): Modeled vs. actual monthly CO_2 and CH_4 concentrations at Guam

3.1.3 Modeling of monthly CO_2 concentration at Sand Island (Table 5):

$\psi = 360.57 + 0.13(120+n) + 2.94x\ 10^{-4}(120+n)^2 + 0.34$ for CO_2 …… (5)

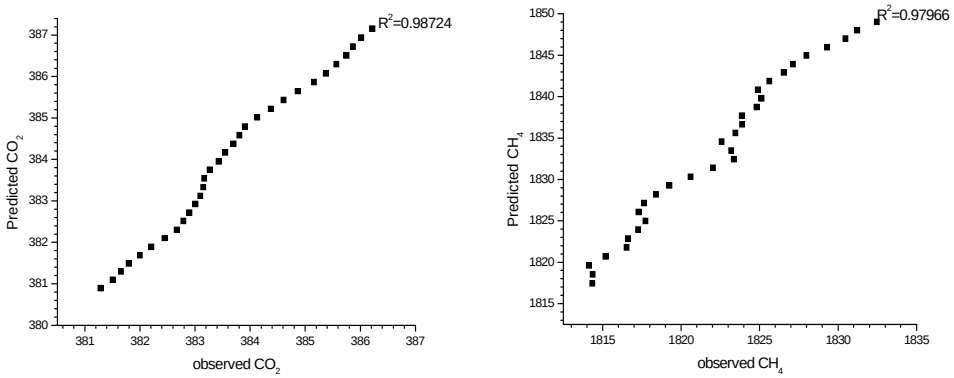
and

$\psi = (1791.97+n) + 0.38(120+n) - 1.16x\ 10^{-3}(120+n)^2 - 3.96$ for CH_4 ……. (6)

Table 5: Modeling of monthly CO_2 and CH_4 concentration at Sand Island

Year	N	Modelled CO_2 data(ψ)	Observed CO_2 data	Modelled CH_4 data(ψ)	Observed CH_4 data
Jan 2006	1	380.94	381.29	1818.01	1814.35
Feb 2006	2	381.15	381.51	1819.10	1814.37
Mar 2006	3	381.35	381.66	1820.20	1814.13
Apr 2006	4	381.55	381.80	1821.29	1815.20
May 2006	5	381.75	382.00	1822.39	1816.53
Jun 2006	6	381.96	382.21	1823.47	1816.62
Jul 2006	7	382.16	382.45	1824.56	1817.27
Aug 2006	8	382.37	382.67	1825.64	1817.74
Sep 2006	9	382.57	382.79	1826.73	1817.30
Oct 2006	10	382.78	382.90	1827.81	1817.64
Nov 2006	11	382.99	383.01	1828.88	1818.40
Dec 2006	12	383.19	383.10	1829.96	1819.25
Jan 2007	13	383.40	383.15	1831.03	1820.61
Feb 2007	14	383.61	383.17	1832.10	1822.03
Mar 2007	15	383.82	383.27	1833.17	1823.37
Apr 2007	16	384.03	383.43	1834.23	1823.20
May 2007	17	384.24	383.55	1835.30	1822.58
Jun 2007	18	384.45	383.70	1836.36	1823.46
Jul 2007	19	384.66	383.81	1837.42	1823.89
Aug 2007	20	384.87	383.91	1847.47	1823.88
Sep 2007	21	385.09	384.13	1839.53	1824.82
Oct 2007	22	385.30	384.38	1840.58	1825.12
Nov 2007	23	385.51	384.61	1841.63	1824.91
Dec 2007	24	385.73	384.87	1842.68	1825.63
Jan 2008	25	385.94	385.16	1843.72	1826.56
Feb 2008	26	386.16	385.38	1844.76	1827.14
Mar 2008	27	386.37	385.57	1845.80	1827.99
Apr 2008	28	386.59	385.75	1846.84	1829.30
May 2008	29	386.81	385.87	1847.88	1830.47
Jun 2008	30	387.03	386.02	1848.91	1831.23

Fig. 3a and b showed the comparison between actual and modeled monthly concentrations for CO_2 and CH_4 gases respectively at Sand Island station,



(a) Modeled vs. Actual monthly CO2 (b) Modeled vs. Actual monthly CH4

Fig. 3 (a and b): Modeled vs. actual monthly CO_2 and CH_4 concentrations at Sand Island

3.1.4 Modeling of monthly CO_2 concentration at Tutuila(Table 6):

$\psi = 358.37 + 0.15(120+n) + 8.92x\ 10^{-5}(120+n)^2 + 0.34$ for CO_2 …….(7)

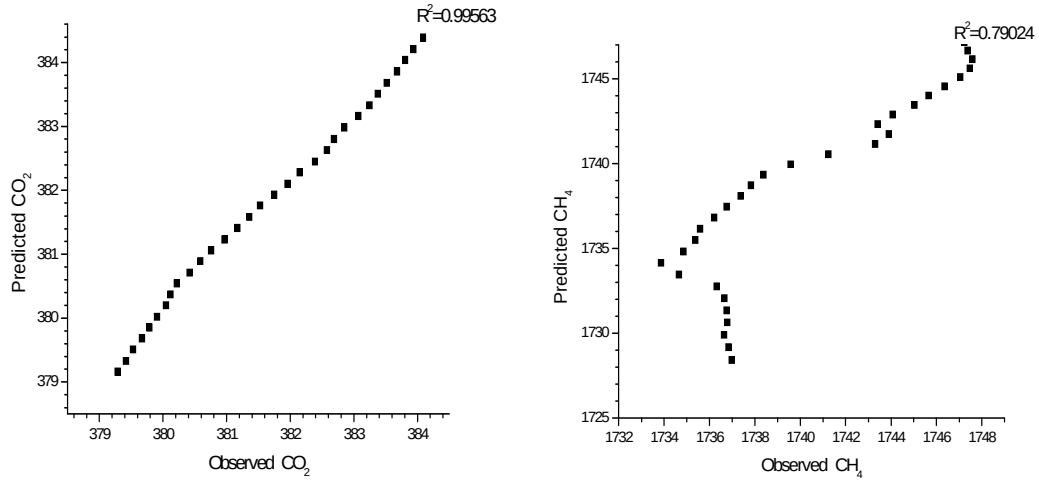
and

$\psi = (1701.80 + n) + 0.74(120+n) - 4.12x\ 10^{-3}(120+n)^2 - 3.89$ fort CH_4 …….. (8)

Table 6: Modeling of monthly CO_2 and CH_4 concentration at Tutuila

Year	N	Modelled CO_2 data(ψ)	Observed CO_2 data	Modelled CH_4 data(ψ)	Observed CH_4 data
Jan 2006	1	378.17	379.29	1728.13	1736.99
Feb 2006	2	378.34	379.42	1728.87	1736.84
Mar 2006	3	378.51	379.53	1729.60	1736.64
Apr 2006	4	378.68	379.67	1730.32	1736.79
May 2006	5	378.85	379.79	1731.04	1736.75
Jun 2006	6	379.03	379.91	1731.74	1736.67
Jul 2006	7	379.20	380.05	1732.44	1736.32
Aug 2006	8	379.37	380.12	1733.13	1734.65
Sep 2006	9	379.54	380.22	1733.81	1733.87
Oct 2006	10	379.72	380.42	1734.48	1734.85
Nov 2006	11	379.89	380.59	1735.15	1735.38
Dec 2006	12	380.06	380.76	1735.80	1735.59
Jan 2007	13	380.24	380.97	1736.45	1736.21
Feb 2007	14	380.41	381.17	1737.09	1736.76
Mar 2007	15	380.59	381.36	1737.72	1737.38
Apr 2007	16	380.76	381.53	1738.35	1737.83
May 2007	17	380.93	381.75	1738.96	1738.38
Jun 2007	18	381.11	381.96	1739.57	1739.58
Jul 2007	19	381.28	382.15	1740.17	1741.24
Aug 2007	20	381.46	382.39	1749.76	1743.31
Sep 2007	21	381.63	382.58	1741.34	1743.91
Oct 2007	22	381.81	382.69	1741.91	1743.41
Nov 2007	23	381.98	382.85	1742.48	1744.07
Dec 2007	24	382.16	383.07	1743.04	1745.04
Jan 2008	25	382.34	383.25	1743.59	1745.65
Feb 2008	26	382.51	383.38	1744.13	1746.36
Mar 2008	27	382.69	383.52	1744.66	1747.05
Apr 2008	28	382.86	383.68	1745.19	1747.47
May 2008	29	383.04	383.81	1745.70	1747.59
Jun 2008	30	383.22	383.94	1746.21	1747.37

Fig. 4a and b showed comparison between the actual and modeled monthly concentrations for CO_2 and CH_4 gases respectively at Tutuila station.



(a) Modeled vs. Actual monthly CO2 (b) Modeled vs. Actual monthly CH4

Fig. 4 (a and b): Modeled vs. actual monthly CO_2 and CH_4 concentrations at Tutuila

3.1.5 Modeling of monthly CO_2 concentration at Cape Kumukahi (Table 7):

$\psi = 360.01 + 0.15(120+n) + 6.37x\ 10^{-5}(120+n)^2 + 0.50$ for CO_2 ……. (9)

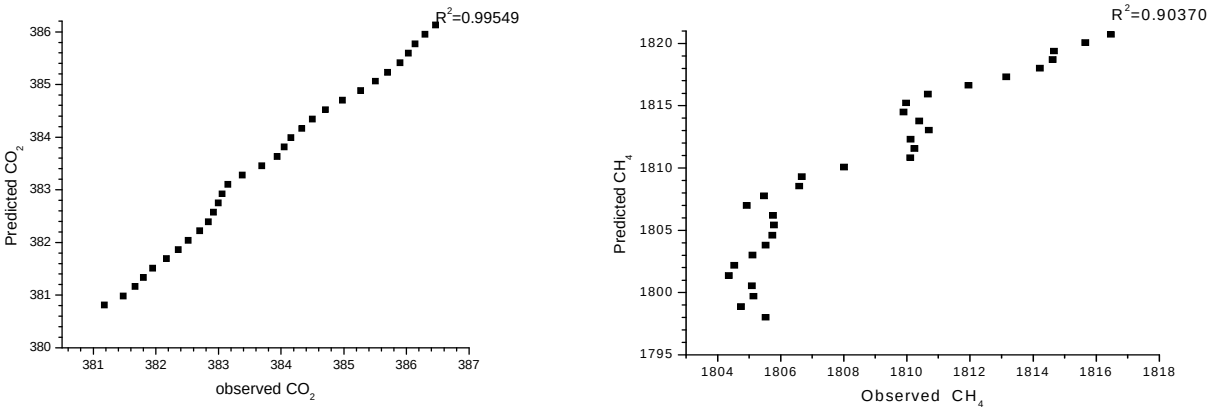
and

$\psi = (1773.83+n) + 0.60(120+n) - 3.11x\ 10^{-3}(120+n)^2 - 4.03$ for CH_4 ……. (10)

Table 7: Modeling of monthly CO_2 and CH_4 concentration at Cape Kumukahi

Year	N	Modelled CO_2 data(ψ)	Observed CO_2 data	Modelled CH_4 data(ψ)	Observed CH_4 data
Jan 2006	1	379.59	381.18	1797.87	1805.53
Feb 2006	2	379.76	381.48	1798.71	1804.74
Mar 2006	3	379.92	381.67	1799.55	1805.14
Apr 2006	4	380.09	381.80	1800.38	1805.09
May 2006	5	380.26	381.95	1801.21	1804.36
Jun 2006	6	380.42	382.17	1802.03	1804.53
Jul 2006	7	380.59	382.36	1802.84	1805.11
Aug 2006	8	380.75	382.52	1803.65	1805.52
Sep 2006	9	380.92	382.70	1804.45	1805.74
Oct 2006	10	381.09	382.84	1805.24	1805.79
Nov 2006	11	381.25	382.92	1806.03	1805.76
Dec 2006	12	381.42	383.00	1806.81	1804.93
Jan 2007	13	381.59	383.06	1807.59	1805.47
Feb 2007	14	381.75	383.15	1808.36	1806.59
Mar 2007	15	381.92	383.38	1809.12	1806.67
Apr 2007	16	382.09	383.69	1809.88	1808.01
May 2007	17	382.26	383.94	1810.63	1810.11
Jun 2007	18	382.42	384.05	1811.37	1810.24
Jul 2007	19	382.59	384.16	1812.11	1810.12
Aug 2007	20	382.76	384.33	1821.84	1810.70
Sep 2007	21	382.93	384.50	1813.57	1810.40
Oct 2007	22	383.09	384.71	1814.29	1809.90
Nov 2007	23	383.26	384.98	1815.00	1809.98
Dec 2007	24	383.43	385.27	1815.71	1810.67
Jan 2008	25	383.60	385.51	1816.41	1811.95
Feb 2008	26	383.77	385.70	1817.11	1813.16
Mar 2008	27	383.94	385.90	1817.80	1814.22
Apr 2008	28	384.11	386.03	1818.48	1814.63
May 2008	29	384.27	386.14	1819.15	1814.66
Jun 2008	30	384.44	386.30	1819.83	1815.66

Fig. 5a and b showed the comparison between actual and modeled monthly concentrations for CO_2 and CH_4 gases respectively at Cape Kumukahi station.



(a) Modeled vs. Actual monthly CO2 (b) Modeled vs. Actual monthly CH4

Fig. 5 (a and b): Modeled vs. actual monthly CO_2 and CH_4 concentrations at CapeKumukahi

3.1.6 Modeling of monthly CO_2 concentration at Mauna Loa (Table 8):

$\psi = 360.03 + 0.14(120+n) + 1.75x\ 10^{-4}(120+n)^2 + 0.41$ for CO_2 …… (11)

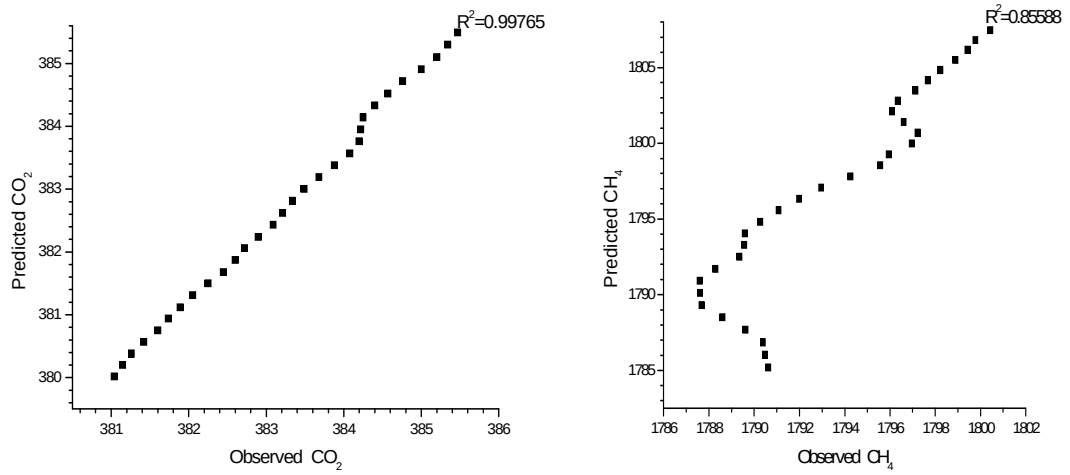
and

$\psi = (1757.95+n) + 0.64(120+n) - 3.29x\ 10^{-3}(120+n)^2 - 2.89$ for CH_4 …….. (12)

Table 8: Modeling of monthly CO_2 and CH_4 concentration at Mauna Loa

Year	N	Modelled CO_2 data(ψ)	Observed CO_2 data	Modelled CH_4 data(ψ)	Observed CH_4 data
Jan 2006	1	379.94	381.04	1785.33	1790.62
Feb 2006	2	380.12	381.15	1786.17	1790.48
Mar 2006	3	380.31	381.26	1787.01	1790.39
Apr 2006	4	380.49	381.42	1787.83	1789.63
May 2006	5	380.67	381.60	1788.65	1788.60
June 2006	6	380.86	381.74	1789.47	1787.69
July 2006	7	381.04	381.89	1790.28	1787.61
Aug 2006	8	381.23	382.05	1791.08	1787.60
Sep 2006	9	381.41	382.25	1791.87	1788.29
Oct 2006	10	381.60	382.45	1792.66	1789.35
Nov 2006	11	381.78	382.60	1793.44	1789.57
Dec 2006	12	381.97	382.72	1794.22	1789.60
Jan 2007	13	382.16	382.90	1794.98	1790.27
Feb 2007	14	382.34	383.09	1795.74	1791.08
Mar 2007	15	382.53	383.21	1796.50	1791.99
Apr 2007	16	382.72	383.34	1797.25	1792.96
May 2007	17	382.90	383.49	1797.99	1794.26
Jun 2007	18	383.09	383.68	1798.73	1795.57
Jul 2007	19	383.28	383.88	1799.45	1795.95
Aug 2007	20	383.47	384.08	1809.18	1796.97
Sep 2007	21	383.66	384.20	1800.89	1797.22
Oct 2007	22	383.85	384.22	1801.60	1796.61
Nov 2007	23	384.04	384.25	1802.30	1796.09
Dec 2007	24	384.23	384.40	1803.00	1796.35
Jan 2008	25	384.42	384.57	1803.69	1797.13
Feb 2008	26	384.61	384.76	1804.37	1797.68
Mar 2008	27	384.80	385.00	1805.05	1798.23
Apr 2008	28	384.99	385.20	1805.72	1798.89
May 2008	29	385.19	385.34	1806.38	1799.43
Jun 2008	30	385.38	385.47	1807.04	1799.78

Fig. 6a and b showed the comparison between actual and modeled monthly concentrations for CO_2 and CH_4 gases respectively at Mauna Loa station.



(a) Modeled vs. Actual monthly CO2 (b) Modeled vs. Actual monthly CH4

Fig. 6 (a and b): Modeled vs. actual monthly CO_2 and CH_4 concentrations at Mauna Loa

The models showed that CO_2 can be predicted with higher accuracy than CH_4. This may be due to the fact that the life time of CO_2 is higher than that of CH_4, thus CO_2 stays longer in the atmosphere than CH_4. Similarly, after the release of CH_4 into the atmosphere and before its total removal due to expiration of its life time, it produces both H_2O and CO_2 due to combustion, thereby leading to increment in CO_2 concentration and a subsequent reduction in CH_4.

3.2 Temperature Anomaly Models for CO_2 AND CH_4in the Tropical Pacific Ocean

Tables 9 – 14 showed the ranking of modeled temperature anomaly and standard deviation values of CO_2 and CH_4. These tables showed that the standard deviations of these greenhouse gases had good correlation with the warmest years. The temperature anomaly models were obtained by correlating the annual mean standard deviations (σ) of CO_2 and CH_4 concentration in the Pacific Ocean with Roy Spencer's tropical temperature anomaly data (Fig. 7). The obtained model for each of these gases is given in equations 13 and 14.

(i) For CO_2:

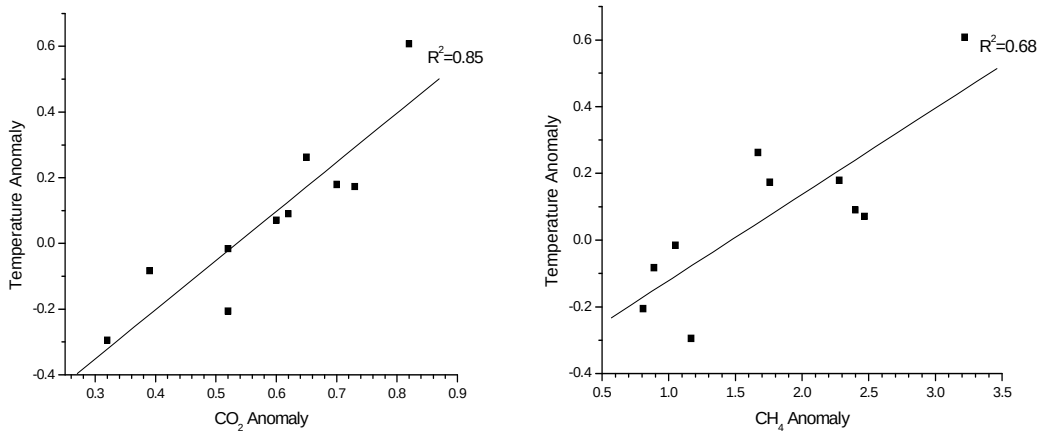
$$T^* = -0.06 - 1.32\sigma + 2.50\sigma^2 \quad \text{……..……} \quad (13)$$

(ii) For CH_4:

$$T^* = -0.22 + 0.05\sigma + 0.05\sigma^2 \quad \text{…….....} \quad (14)$$

Where,

T* = temperature anomaly; σ = standard deviation and R^2 = square of correlation coefficient



(a) Temperature anomaly vs. CO2 anomaly (b) Temperature anomaly vs. CH4 anomaly

Fig. 7(a and b) Temperature anomaly VS. CO_2 and CH_4 anomaly in the Pacific Ocean

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

3.2.1 Cape Ferguson station

Table 9 showed the ranking of Cape Ferguson's greenhouse gases' modeled temperature anomaly with their standard deviations. The ranking of temperature anomaly for the first three years in decreasing order respectively are: 1997, 2005 and 2001/2002 for CO_2 and 1998, 1997 and 2001 for CH_4.

Table 9: Ranking of modeled temperature anomaly and standard deviation values of CO_2 and CH_4 at Cape Ferguson station.

Year	CO_2 SD	Modeled Temperature anomaly (T*) from CO_2 SD	Ranking of T* from CO_2 SD by position	CH_4 SD	Modeled Temperature anomaly (T*) from CH_4 SD	Ranking of T* from CH_4 SD by position
1996	0.21	-0.227	10th	0.47	-0.185	8th
1997	0.92	0.842	1st	2.36	0.176	2nd
1998	0.62	0.083	5th	4.16	0.853	1st
1999	0.22	-0.229	9th	0.79	-0.149	6th
2000	0.59	0.031	7th	1.02	-0.117	5th
2001	0.63	0.101	3rd	1.23	-0.083	3rd
2002	0.63	0.101	3rd	0.42	-0.190	9th
2003	0.60	0.048	6th	0.75	-0.154	7th
2004	0.42	-0.173	8th	1.16	-0.095	4th
2005	0.72	0.286	2nd	0.27	-0.203	10th

3.2.2 Guam station

Table 10 showed the ranking of Guam's greenhouse gases' modeled temperature anomaly with their standard deviations. The ranking of temperature anomaly for the first three years in decreasing order respectively are: 2004, 1998 and 2003 for CO_2 and 2003, 2004 and 1997 for CH_4. It is significant that all these warmest years are El Nino years.

Table 10: Ranking of temperature anomaly and standard deviation values of CO_2 and CH_4 at Guam station.

Year	CO_2 SD	ModeledTemperature anomaly (T*) from CO_2 SD	Ranking of T* from CO_2 SD by position	CH_4 SD	Modeled Temperature anomaly (T*) from CH_4 SD	Ranking of T* from CH_4 SD By position
1996	0.50	-0.095	9th	1.50	-0.033	7th
1997	0.56	-0.015	6th	4.30	0.920	3rd
1998	0.81	0.511	2nd	0.46	-0.186	10th
1999	0.30	-0.231	10th	0.74	-0.156	8th
2000	0.56	-0.015	6th	0.52	-0.180	9th
2001	0.53	-0.057	8th	1.57	-0.018	6th
2002	0.74	0.332	4th	3.25	0.471	5th
2003	0.75	0.356	3rd	4.60	1.068	1st
2004	1.16	1.773	1st	4.33	0.934	2nd
2005	0.60	0.048	5th	4.25	0.896	4th

3.2.3 Sand Island station

Table 11 showed the ranking of Sand Island's greenhouse gases' modeled temperature anomaly with their standard deviations. The ranking of temperature anomaly for the first three years in decreasing order respectively are: 1998, 2002 and 2003 for CO_2 and 2002/2004, 2003 and 1998 for CH_4. It is also significant that all these warmest years are El Nino years.

Table 11: Ranking of temperature anomaly and standard deviation values of CO_2 and CH_4 at Sand Island station.

Year	CO_2 SD	Modeled Temperature anomaly (T*) from CO_2 SD	Ranking of T* from CO_2 SD by position	CH_4 SD	Modeled Temperature anomaly (T*) from CH_4 SD	Ranking of T* from CH_4 SD by position
1996	0.36	-0.211	9th	0.94	-0.129	8th
1997	0.49	-0.107	6th	0.96	-0.125	7th
1998	0.83	0.567	1st	1.61	-0.010	4th
1999	0.33	-0.223	10th	0.77	-0.152	9th
2000	0.59	0.031	5th	1.12	-0.101	5th
2001	0.42	-0.173	8th	0.76	-0.153	10th
2002	0.82	0.539	2nd	3.80	0.692	1st
2003	0.80	0.484	3rd	3.29	0.486	3rd
2004	0.46	-0.138	7th	3.80	0.692	1st
2005	0.68	0.198	4th	1.02	-0.117	6th

3.2.4 Tutuila station

Table 12 showed the ranking of Tutuila's greenhouse gases' modeled temperature anomaly with their standard deviations. The ranking of temperature anomaly for the first three years in decreasing order respectively are: 1998, 2005 and 2002 for CO_2 and 1998, 2005 and 1999 for CH_4. In this station the first two warmest years for both CO_2 and CH_4 correlates and are in agreement with WMO observations.

Table 12: Ranking of temperature anomaly and standard deviation values of CO_2 and CH_4 at Tutuila station.

Year	CO_2 SD	Modeled Temperature anomaly (T*) from CO_2 SD	Ranking of T* from CO_2 SD by position	CH_4 SD	Modeled Temperature anomaly (T*) from CH_4 SD	Ranking of T* from CH_4 SD by position
1996	0.35	-0.216	10th	0.56	-0.176	8th
1997	0.44	-0.157	7th	0.98	-0.123	6th
1998	0.95	0.942	1st	6.15	1.979	1st
1999	0.44	-0.157	7th	1.54	-0.024	3rd
2000	0.43	-0.165	9th	0.52	-0.180	9th
2001	0.54	-0.044	5th	0.75	-0.154	7th
2002	0.66	0.158	3rd	0.37	-0.195	10th
2003	0.62	0.083	4th	1.11	-0.103	5th
2004	0.53	-0.057	6th	1.49	-0.034	4th
2005	0.77	0.406	2nd	2.39	0.185	2nd

3.2.5 Cape Kumukahi station

Table 13 showed the ranking of Cape Kumukahi's greenhouse gases' modeled temperature anomaly with their standard deviations. The ranking of temperature anomaly for the first three years in decreasing order respectively are: 1998/2001and 2005 for CO_2 and 1997, 1998 and 2004 for CH_4.

Table 13: Ranking of temperature anomaly and standard deviation values of CO_2 and CH4 at Cape Kumukahi station.

Year	CO_2 SD	Modeled Temperature anomaly (T*) from CO_2 SD	Ranking of T* from CO_2 SD by position	CH_4 SD	ModeledTemperature anomaly (T*) from CH_4 SD	Ranking of T* from CH_4 SD by position
1996	0.51	-0.083	7th	0.62	-0.170	8th
1997	0.66	0.158	4th	4.32	0.929	1st
1998	0.78	0.431	1st	3.30	0.490	2nd
1999	0.25	-0.234	10th	1.33	-0.065	6th
2000	0.51	-0.083	7th	0.51	-0.181	9th
2001	0.59	0.031	6th	0.50	-0.183	10th
2002	0.78	0.431	1st	1.36	-0.060	5th
2003	0.67	0.178	3rd	1.85	0.044	4th
2004	0.63	0.101	5th	1.87	0.048	3rd
2005	0.41	-0.181	9th	1.09	-0.106	7th

3.2.6 Mauna Loa station

Table 14 showed the ranking of Mauna Loa's greenhouse gases' modeled temperature anomaly with their standard deviation values. The ranking of temperature anomaly for the first three years in decreasing order respectively are: 1998 and 2002/2003 for CO_2 and 1998, 2003 and 1997 for CH_4. The warmest year for both CO_2 and CH_4 are in agreement with WMO observation for this station.

Table 14: Ranking of temperature anomaly and standard deviation values of CO_2 and CH_4 at Mauna Loa station.

Year	CO_2 SD	Modeled Temperature anomaly (T*) from CO_2 SD	Ranking of T* from CO_2 SD by position	CH_4 SD	Modeled Temperature anomaly (T*) from CH_4 SD	Ranking of T* from CH_4 SD By position
1996	0.38	-0.201	9th	1.27	-0.076	8th
1997	0.55	-0.030	5th	1.91	0.058	3rd
1998	0.95	0.942	1st	3.65	0.629	1st
1999	0.35	-0.216	10th	1.82	0.037	4th
2000	0.45	-0.148	7th	1.16	-0.095	9th
2001	0.43	-0.165	8th	1.50	-0.033	6th
2002	0.75	0.356	2nd	1.36	-0.060	7th
2003	0.75	0.356	2nd	2.08	0.100	2nd
2004	0.51	-0.083	6th	1.75	0.021	5th
2005	0.72	0.286	4th	0.98	-0.123	10th

4.0 Conclusion

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 models predicted CO_2 and CH_4 concentrations adequately and could also be used to predict their future concentrations and climate warming effectively in that the greenhouse gases' standard deviations utilized as proxy data correlates well with both the absolute temperature and Roy Spencer's tropical temperature anomaly data. These empirical relationships helped in determining the temperature anomaly pattern for each of the stations within the tropical Pacific Ocean from the obtained standard deviations, and the warmest years obtained are in agreement with WMO observations.

Acknowledgement

The authors wish to acknowledge the World Data Centre for Greenhouse Gases for making the data utilized in this work available.

References

[1]. McIntosh D H, Thom A S (1973) Essentials *of Meteorology*. Wykeham Publishing Ltd., London.

[2]. Kellert S R (ed) (1997) Macmillan *Encyclopedia of the Environment* vol. 1 Macmillan, N.Y.

[3]. Moran J.M, Morgan M. D (1991) Meteorology–*The atmosphere and the science of weather*. Macmillan, N.Y.

[4]. World Meteorological Organization (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> Accessed 23 July, 2009

[5]. World Meteorological Organization (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) http://www.wmo.int. Accessed 23 July, 2009

[6]. The Dictionary of the Climate Debate (2013). In: Temperature Anomaly. www.odlt.org/dcd/ballast/temperature_anomaly.html. Accessed 2 October, 2013

[7]. Fraisse C W, Breuer N E, Zierden D, Ingam K T (2009) From climate variability to change:challenges and opportunities to extension. *Journal of extension 47*(2) Feature articles 2FEA9. www.joe.org. Accessed 1 June, 2009

[8]. Folland C K, Colman A W (2000). Empirical prediction of the global temperature anomaly for 2000. *Experimental long lead forecast*. Bulletin **9** 1 Published by COLA, U.S.A, www.iges.org/ellfb. Accessed 11 June, 2009

[9]. Stull R B (2000). *Meteorology for Scientists and Engineers.* 2E, Brooks/Cole, Cengage learning, USA, 502 pp

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

[11]. Rangarajan G, Sant DA (1997). A climate predictability index and its applications. *Geophysical Research letters*. 24.10: 1239 – 1242.

[12]. Spencer R (2009). In: *latest Global temperatures Anomaly Roy Spencer, Ph_D.* http://www.drroyspencer.com/. Accessed 28 September, 2009

[13]. Wigley TM, Ingram M J, Farmer G (Ed.) (1981). Climate *and History – studies in past climates and their impact on man.* Cambridge University press,

[14]. 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: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Avergt K.B, Tiguor M, and Miller H.L (Eds.) climate *change- the physical basis,* Contribution of working group 1 to the fourth assessment report of the intergovernmental panel on climate change, Cambridge University Press, U.K. and U.S.A. 93-127.

[15]. Mulholland H, Jones C R (1983). Fundamentals of statistics, ELBS ed. Butterworths, London, 291pp

[16]. Wikipedia, TheFree Encyclopedia (2009a). In: *Autoregressive model*.http://en.wikipedia.org/w/index.php?title=Autoregressive_model &oldid=283294788 Accessed2 April, 2009

[17]. Wikipedia, The Free Encyclopedia (2009b). In: *Autoregressive moving average model*http://en.wikipedia.org/w/index.php? title= Autoregressive _moving _average_ model &oldid =28397588. Accessed 5 April, 2009

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

[19]. Wayne A W, 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))

[20]. Chandler R E (2005). On the use of generalized linear models for interpreting climate variability. *Environmetrics.* Published online 20 May 2005 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/env.731. Accessed 24 April 2009

[21]. Stang D R (2009). Trends in Global Temperature. In: zipcode zoo.com the Bay Science foundation inc. http://*zipcodezoo.com /Trends/*Treds%20in%20Global%20 Temperature.asp. Accessed 16 July, 2009

[22]. Ogunsola O E (2012). Effects of CO_2 and CH_4 Emissions on Climate Variability in the Tropics. Unpublished PhD Thesis, University of Ibadan, Nigeria. 210pp