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Research Article

Impact of solar variation and greenhouse gases on the Earth's climate

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Abstract: The Earth's climate has warmed over the last century. It is very likely that the primary cause of this global warming is the emission of greenhouse gases due to a range of human activities and the resulting increase in the concentrations of greenhouse gases in the atmosphere. Climate models indicate that the global warming and other climate changes will continue and accelerate through the coming century if emissions of greenhouse gases continue to increase. There are two well-known causes that affect the global warming and other climate changes. One of them is solar variation (mainly TSI) and other is increase in greenhouse gases (mainly increases of carbon dioxide, Co_2 after industrial revolution). Solar impact on the Earth's climate in the upper atmosphere interacts most directly with the radiation, particles and magnetic fields emitted by the Sun. Solar activities follow the approximately 11-year solar activity cycle. We have analysed long-term correlative behaviour total solar irradiance (TSI) and sunspot number (SSN) for a long period 1976 onwards and find they are strongly correlated (r=0.928). We find very poor correlation(r=.036) between TSI and global surface temperature (GSTemp) but a strong correlation (r=0.875) have been found between increase in Co_2 and GSTemp. These results indicate that effect of solar variation in change of global temperature is less than increase in greenhouses gases (mainly Co_2) during aforesaid period. It is social need to awareness of maintain emission of greenhouse gases in present time; otherwise our future is very dangerous. Adverse impacts of climate change and challenges in near future have also been discussed.

Keywords: TSI, SSN, GSTemp, GHGs, Climte change.

SOLAR VARIATION AND ULTRAVIOLET IRRADIANCE

The long-term and short-term variations in solar activity are hypothesized to affect global climate. There are three suggested mechanisms by which solar variations may have an effect on climate: (a) solar irradiance changes directly affecting the climate (b) variations in the ultraviolet (UV) component that might explain a larger solar signal in climate (c) effects mediated by changes in cosmic rays such as changes in cloud cover. The external change may involve a variation in the solar outputs that are associated with variations in total solar irradiance (TSI). Proxies of the TSI based on sunspot observations, tree ring records, ice cores, and cosmogenic isotopes have given estimates of the solar influence on the Earth that extend back thousands of years, and correlate with major climatic events on the Earth. This extrapolation is important for understanding the relationship between TSI and the Earth's climate. The state of near-Earth space environment is governed by the Sun and is very dynamic on all spatial and temporal scales.

Energy changes in the UV wavelengths involved in production and loss of ozone have atmospheric effects. Ozone is the main gas involved in radiative heating of the stratosphere. Solar-induced variations in ozone can therefore directly affect the radiative balance of the stratosphere with indirect effects on circulation. Solar-induced ozone variations are possible through: (a) changes in solar ultraviolet (UV) spectral solar irradiance, which modifies the ozone production rate through photolysis of molecular oxygen, primarily in the mid-to-upper stratosphere at low latitudes[1], and (b) changes in the precipitation rate of energetic charged particles, which can indirectly modify ozone concentrations through changes in the abundance of trace species that catalytically destroy ozone, primarily at polar latitudes[2]. In addition, transport-induced changes in ozone can occur[3-6] as a consequence of indirect effects on circulation caused by the above two processes. Solar UV radiation directly influence stratospheric temperatures and the dynamical response to this heating extends the solar influence both poleward and downwards to the lower stratosphere and tropopause region. Evidence that this influence can also penetrate into the underlying troposphere is accruing from a number of different sources. One consequence of these solar perturbations is to complicate the detection of human-induced depletion of the protective ozone layer; another may be to perturb the temperature at the Earth's surface, through connections that link the upper and lower parts of the atmosphere.

Cosmic radiation: The Sun's magnetic field and the solar wind modulate the amount of high energy cosmic radiation that the earth receives. The galactic cosmic rays change the amount of C-14 in the atmospheric Co_2, which is best known as the isotope that archeologists use for dating biological archeological artifacts. The change in the C14 concentration in the atmosphere is dominated by variations in solar activity. When the solar activity is high the production of C14 is low, this is due to the shielding effect of the solar wind against cosmic rays. The C-14 content of, for example, annual rings of old trees may reveal something about the Sun's performance during the last few millennia. Some studies have indicated that there is a connection between long term climate change and Sun's activity[7,8]. One possible mechanism operating is that during high activity levels the decreased amount of galactic cosmic rays could lead to reduced cloud formation in the atmosphere, and hence to increased temperatures. The basis of the hypothesis of Svensmark and Friis-Christensen[9] is that weak solar activity causes a weak solar wind, which in turn increases the number of galactic cosmic rays penetrating the Earth's atmosphere. This increases low level cloud formation and the Earth's albedo.

Geomagnetic disturbances: The geomagnetic disturbances, occurrence of auroras at low latitudes, sporadic ionization on high latitudes reduced quality of shortwave radio transmissions all appear to follow the 11-year solar activity cycle. The number of sunspots peaks every 11 years. There is a strong radial magnetic field within a sunspot and the direction of the field reverses in alternate years within the leading sunspots of a group. So the true sunspot cycle is 22 years. During periods of maximum sunspot activity, the Sun's magnetic field is strong. When sunspot activity is low, the Sun's magnetic field weakens. The magnetic field of the Sun also reverses every 22 years, during a sunspot minimum. There are longer cycles than the 11-year sunspot cycle known as Gleissberg cycle (88-year) with variable amplitudes. The cosmogenic radio nuclides confirm the existence of other longer periodicities (e.g. 208-year DeVries or Suess cycle, 2300-year Hallstatt cycle and others) and also the present relatively high level of solar activity, although there is some controversy[10-12]. The Milankovitch theory suggests that normal cyclical variations in three of the Earth's orbital characteristics are probably responsible for some past climatic change. Observations of the Sun, during the middle of the Little Ice Age (1650-1750) indicated that very little sunspot activity was occurring on the Sun's surface[13]. The Little Ice Age was a time of a much cooler global climate and very little sunspot activity occurring on the Sun.

Greenhouse gases and the Earth's climate: Life on Earth depends on the presence of greenhouse gases (GHGs) in the atmosphere. The main GHGs influenced directly by human activities are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and synthetic gases, such as chlorofluorocarbons (CFCs) and hydro fluorocarbons (HFCs). Water vapour is also a major greenhouse gas, but its concentration in the atmosphere is not influenced directly by human activities; rather, it is controlled mainly by the Earth's temperature. **Figure-1** represents the recently concentration of greenhouse gases (GHGs) in the atmosphere. Greenhouse gases influence Earth's climate because they interact with energy flows.

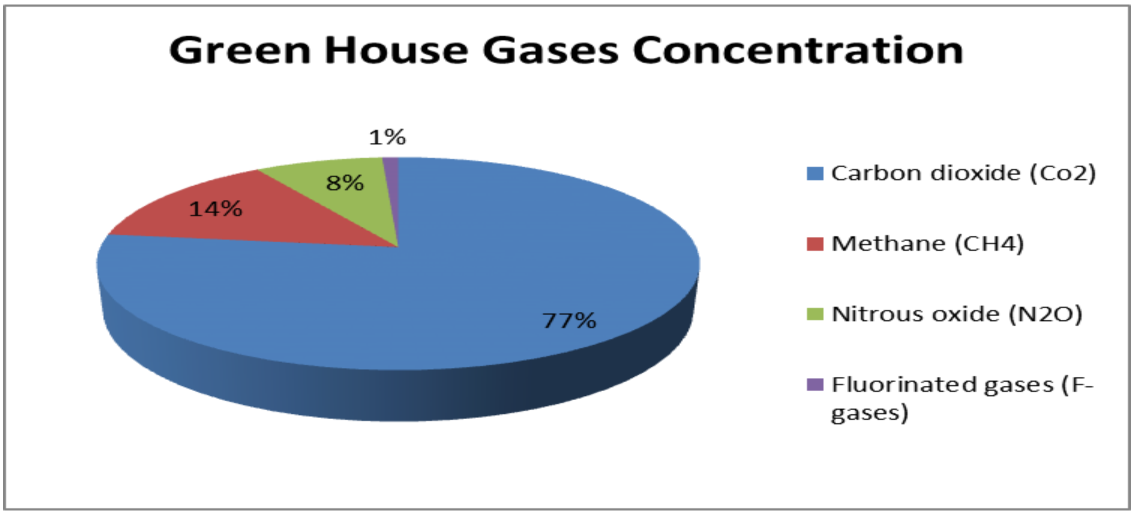

Figure-1: Represents the recently concentration of greenhouse gases (GHGs) in the atmosphere.

The atmosphere is largely transparent to the Sun's energy, most of which arrives in the form of light. At the Earth's surface, this energy is partly reflected and partly absorbed and re-radiated as heat. Poler ice- and snow-covered surfaces of the planet reflect much more energy than darker surfaces, such as forests and oceans. The GHGs in the atmosphere absorb and re-radiate much of the outgoing heat energy. At the same time, minute particles or droplets floating in the atmosphere, known as aerosols, act both to reflect incoming solar radiation (light) and to absorb and re-radiate outgoing heat. The Earth's climate is influenced by all of these factors, which together maintain the planet at about 32ºC warmer than it would otherwise be. Their combined effect is measured by a quantity called net radiative forcing, which is basically the net rate of input of heat energy to the entire planet due to all the processes described above. Extra heat builds up in the atmosphere and oceans when the rate of energy input is positive, causing the planet to warm.

Atmospheric carbon dioxide (Co_2) is an important kind of greenhouse gas which influences global temperature. Its concentration variation could indicate the distribution of human and natural activities in various regions. The amount of Co_2 that can be held in oceans is a function of temperature. Co_2 is released from the oceans when global temperatures become warmer and diffuses into the ocean when temperatures are cooler. Initial changes in global temperature were triggered by changes in received solar radiation by the Earth through the Milankovitch cycles. The increase in Co_2 then amplified the global warming by enhancing the greenhouse effect. The long-term climate change represents a connection between the concentrations of Co_2 in the atmosphere and means global temperature. Co_2 concentrations in the atmosphere have increased from about 280 ppm in pre-industrial times to 395 ppm at present. **Figure-2** represents variation of increase of Co_2 *vs* global surface temperature from 1958 onwards. Increase of main greenhouse gases from pre-industrial level to current level along with radiative forcing are shown in **Table-1**. Human activity since the industrial revolution has increased the amount of greenhouse gases in the atmosphere, leading to increased radiative forcing from Co_2, methane, tropospheric ozone, CFCs and nitrous oxide. The concentrations of Co_2 and methane have increased by 36% and 148% respectively since 1750.

Table-1: Represent increase of main greenhouse gases from pre-industrial level to current level.

S. No.	Main Greenhouse Gases	Pre-industrial level	Current level	Increase since 1750	Radiative forcing
01	Co_2	280 ppm	394.29 ppm	114.29 ppm	1.46
02	Methane	700 ppb	1745 ppb	1045 ppb	0.48
03	Nitrous oxide	270 ppb	314 ppb	44 ppb	0.15
04	Clorofluoro-carbons(CFC-12)	0 ppt	533 ppt	533 ppt	0.17

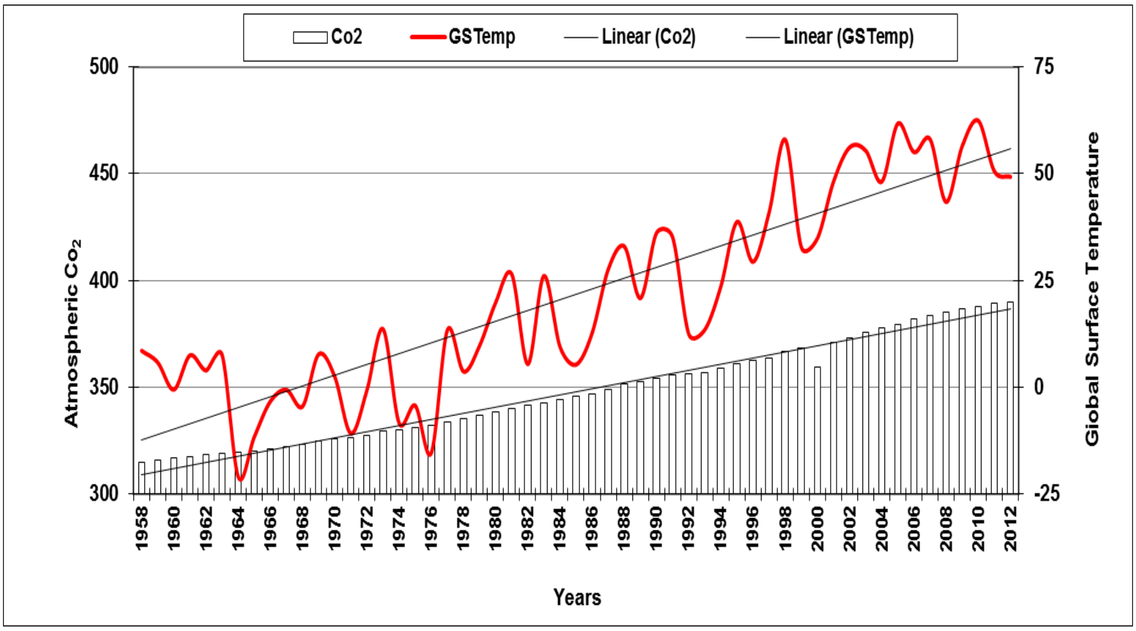

Figure-2: Represents variation of increase of Co_2 *vs* global surface temperature from 1958 onwards.

DATA ANALYSIS

The data of the sunspot numbers (SSN) were taken from the National Geophysical Data Center (NGDC). TSI has been monitored from 1978 by several satellites, e.g. Nimbus 7, Solar Maximum Mission (SMM), the NASA, Earth Radiation Budget Satellite (ERBS), NOAA9, NOAA 10, Eureca and the UARS (Upper Atmospheric Research Satellite) etc. The historical reconstruction of more recently accepted TSI absolute value is described by Kopp and Lean[14] based on new calibration and diagnostic measurements by using TIM V.12 data on 19th January 2012, and is updated annually. The data of global surface temperature (GSTemp) have been taken from National Aeronautics and Space Administration, Goddard Institute for Space Studies. The data of atmospheric carbon dioxide (in ppm) collected at Mauna Loa, Hawaii.

Total solar irradiance (TSI) and sunspot number (SSN): The total solar irradiance (TSI) is integrated solar energy flux over the entire spectrum which arrives at the top of the atmosphere at the mean Sun-Earth distance. TSI are known to be linked to Earth climate and temperature. Accurate TSI measurements from the last 25 years are correlated with sunspots and faculae. These correlations can then be used to extrapolate the TSI to time periods prior to accurate space-borne measurements, since the solar records extend back 100 years for faculae and 400 years for sunspots. The TSI observations show variations ranging from a few days up to the 11-year sunspot cycle and longer timescales[15]. Recent research indicates that variability in TSI associated with the 11-year sunspot cycle arises almost entirely from the distribution of sizes of the patches where magnetic field threads through the visible surface of the Sun. Solar variability on time scales of centuries to millennia can be reconstructed using cosmogenic radio nuclides such as ^{10}Be and ^{14}C whose production rate in the atmosphere is modulated by solar activity. In this way, at least the past 10,000 years can be reconstructed[16], although the temporal resolution is poorer, signal to noise ratio is lower and the record must be corrected for variations in the geomagnetic field. In the present section, we investigate the correlation between yearly average value of TSI and SSN for the period 1976 onwards that are scatter plotted in **Figure-3**. We find a strong correlation (r=0.928) between them.

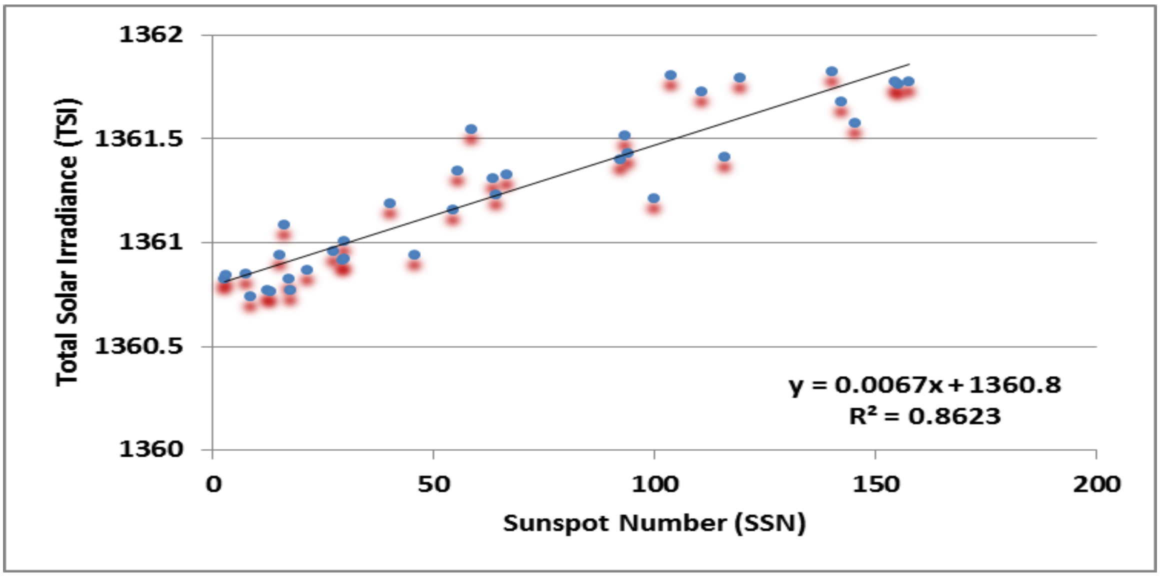

Figure-3: Scatter plot between yearly average value of total solar irradiance (TSI) and sunspot number (SSN), observed during the period 1976 onwards.

Total solar irradiance (TSI) and global surface temperature (GSTemp): The effect of global surface temperature is increasing the average temperature of the Earth. The basic components that influence the Earth's climatic system can occur externally (from extraterrestrial systems) and internally (from ocean, atmosphere and land systems).The external change may involve a variation in the Sun's output. Internal variations in the Earth's climatic system may be caused by changes in the concentrations of atmospheric gases, mountain building, volcanic activity, and changes in surface or atmospheric albedo. The basic causes of increase in global temperature can occur from variation in TSI and human made activities (mainly emission of Co_2). We have calculated correlation between total solar irradiance (TSI) and global surface temperature (GSTemp) during 1976 onwards is scatter plotted in **Figure 4**. We find a poor correlation (r=0.036) between them. Since 1978, the Sun has shown a slight cooling trend but global temperatures have been warmed up continuously. It is indication for a dangerous period and high awareness about global warming is most essential, otherwise we left our Earth as flame of burning for next generation.

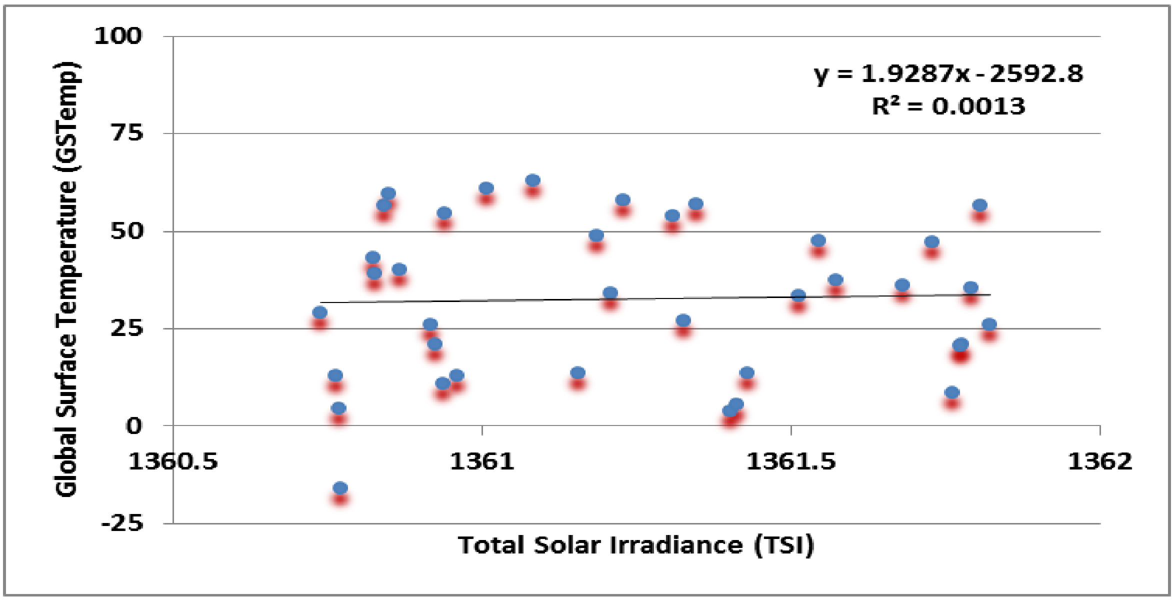

Figure-4: Scatter plot between yearly average value of total solar irradiance (TSI) and global surface temperature (GSTemp) during 1976 onwards.

Atmosphere Co_2 and global surface temperature (GSTemp): The world's most current data available for the atmospheric Co_2 is from measurements at the Mauna Loa Observatory in Hawaii. Monthly mean Co_2 concentrations are determined from daily averages for the number of Co_2 molecules in every one million molecules of dried air and without considering the water vapor in air. Annual mean Co_2 concentrations are the arithmetic mean of the monthly averages for the year. The annual mean rate of growth would represent the sum of all Co_2 added to, and removed from, the atmosphere during the year by human activities and by natural processes. There is a small amount of month-to-month variability in the Co_2 concentration that may be caused by anomalies of the winds or weather systems arriving at Mauna Loa. This variability would not be representative of the underlying trend for the northern hemisphere which Mauna Loa is intended to represent. The estimated uncertainty in the Mauna Loa annual mean growth rate is 0.11 ppm/yr.

The correlation between yearly average value of concentrations of atmospheric carbon dioxide (in ppm) and global surface temperature (GSTemp) during 1976 onwards is scatter plotted in **Figure 5**. We find a strong correlation (r=0.875) between them. The higher concentrations of Co_2 in the atmosphere will enhance the greenhouse effect making the planet warmer. According to computer climate models, if the globe will warm up by 1.5 - 4.5 °C then Co_2 concentration can reaches the of 600 ppm by the year 2050.

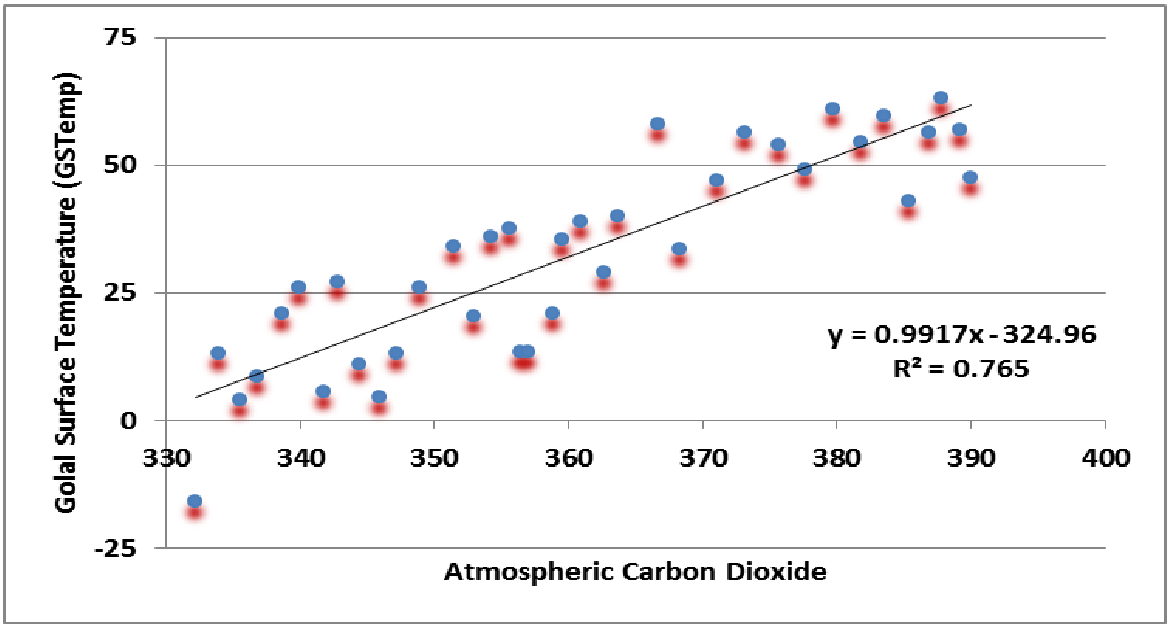

Figure-5: Scatter plot between yearly average value of concentrations of atmospheric Co_2 and global surface temperature (GSTemp) during 1976 onwards.

A rise in Earth's global temperatures may boost the occurrence and concentration of severe climate events, such as floods, famines, heat waves, tornados, and twisters. Other consequences may comprise of higher or lower agricultural outputs, glacier melting, lesser summer stream flows, genus extinctions and rise in the ranges of disease vectors. As an effect of increase in global surface temperature species like golden toad, harlequin frog of Costa Rica has already become extinct. There are number of species that have a threat of disappearing soon and various new diseases have emerged lately. The increase in global surface temperature is extending the distribution of mosquitoes due to the increase in humidity levels and their frequent growth in warmer atmosphere. Various diseases due to ebola, hanta and machupo virus are expected due to warmer climates. The effect of increase in global surface temperature will definitely be seen on some species in the water. The increase in global surface temperature is expected to cause irreversible changes in the ecosystem and the behavior of animals. Based on the study on past climate shifts and computer simulations, many climate scientists say that lacking of big curbs in greenhouse gas discharges, the 21st century might see temperatures rise of about 3 to 8^{o} C, climate patterns piercingly shift, ice sheets contract and seas rise several feet. Climate change will exert unprecedented stress on the coastal and marine environment too. Increase in ocean temperature cause sea level rise and will have impact on ocean circulation patterns, ice cover, fresh water run-off, salinity, oxygen levels and water acidity. Sea level is rising around the world. In the last century, sea level rose 5 to 6 inches more than the global average along the Mid-Atlantic and Gulf Coasts, because coastal lands there are subsiding. Due to global warming, higher temperatures are expected to further raise sea level by expanding ocean water, melting mountain glaciers and small ice caps, and causing portions of Greenland and the Antarctic ice sheets to melt. The IPCC[17] suggests that if sea level rise could convert as much as 33% of the world's coastal wetlands to open water by 21st century. Forecasts of climate extremes can improve awareness and reduce adverse effects. Focusing attention on extreme events also may help countries to develop better means of dealing with the longer-term impacts of global climate change. Conversely, the pressures on the biosphere that drive climate change may cause critical thresholds to be breached, leading to shifts in natural systems that are unforeseen and rapid. Studying historical extremes of climate cannot forewarn on the consequences of such events. Rapid changes in climate during extreme events may be more stressful than slowly developing changes due to the greenhouse effect.

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