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The Global Warming Debate: A Review of the State of Science

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Abstract—A review of the present status of the global warming science is presented in this paper. The term global warming is now popularly used to refer to the recent reported increase in the mean surface temperature of the earth; this increase being attributed to increasing human activity and in particular to the increased concentration of greenhouse gases (carbon dioxide, methane and nitrous oxide) in the atmosphere. Since the mid to late 1980s there has been an intense and often emotional debate on this topic. The various climate change reports (1996, 2001) prepared by the IPCC (Intergovernmental Panel on Climate Change), have provided the scientific framework that ultimately led to the Kyoto protocol on the reduction of greenhouse gas emissions (particularly carbon dioxide) due to the burning of fossil fuels. Numerous peer-reviewed studies reported in recent literature have attempted to verify several of the projections on climate change that have been detailed by the IPCC reports.

The global warming debate as presented by the media usually focuses on the increasing mean temperature of the earth, associated extreme weather events and future climate projections *of increasing frequency of extreme weather events worldwide*. In reality, the climate change issue is considerably more complex than an increase in the earth's mean temperature and in extreme weather events. Several recent studies have questioned many of the projections of climate change made by the IPCC reports and at present there is an emerging dissenting view of the global warming science which is at odds with the IPCC view of the cause and consequence of global warming. Our review suggests that the dissenting view offered by the skeptics or opponents of global warming appears substantially more credible than the supporting view put forth by the proponents of global warming. Further, the projections of future climate change over the next fifty to one hundred years is based on insufficiently verified climate models and are therefore not considered reliable at this point in time.

Key words: Carbon dioxide, global warming, land use effects, sea level, extreme weather events, solar influence.

1. Introduction

Studies and discussions of global warming as well as initiation of ice ages remained mainly as a scientific problem in the 19^{th} century and most of the 20^{th} century. Starting in the mid to late 1980s, this debate has spilled over into the media, the public and in the political arena as well. The debate has become

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emotionally charged with the proponents and opponents of global warming dug in their rigid stance.

The present global warming debate appears to have been accelerated following the publication of the IPCC (1996) report on the science of climate change which included a phrase that *the balance of evidence suggests a discernible human influence on climate*. This sacramental phrase has caused considerable controversy among atmospheric scientists, environmentalists and policymakers, as evidenced in a number of scientific commentaries and articles (AVERY *et al.*, 1996; MASOOD, 1996; SEITZ, 1996; SINGER *et al.*, 1997; KONDRATYEV, 1997) that appeared soon after publication of the IPCC 1996 report. These commentaries and articles questioned the link between the observed warming of the earth's surface and the increasing concentration of greenhouse gases in the atmosphere. The global warming debate has also sparked publication of a number of books and monographs in the last five years; noteworthy among the recent books are *The Satanic Gases* by MICHAELS and BALLING (2000), *Global Warming: The Hard Science* by HARVEY (2000), *Taken by Storm* by ESSEX and MCKITRICK (2002) and *The Greenhouse Delusion* by GRAY (2002). The book by Harvey presents a supporting view of the global warming science while the other three present a dissenting view of the science.

The present manuscript is arranged as follows: Evolution of the earth's atmosphere, the natural greenhouse effect, the case for global warming, the case against global warming, earth's temperature variation in geological and historical times, urbanization and land-use change, impact of solar variability and sun's brightness, sea-level variations, extreme weather events and finally summary and conclusions.

2. *Evolution of the Earth's Atmosphere*

It is generally believed that when the earth evolved about 5 billion years ago (BY), all materials that made up the atmosphere and the oceans were contained inside the earth. The atmosphere began about 4.5 BY ago, as a mixture of water vapor, hydrogen, hydrogen chloride, carbon monoxide, carbon dioxide and nitrogen (GRAY, 2002). Through interaction with surface rocks and living organisms, it gradually reached its present composition, some 280 million years (MY) ago and has remained, more or less, unchanged. During the past 4.5 BY to 280 MY, the most important transformation was the conversion of much of the carbon dioxide (CO_2) into oxygen by abundant plant life, particularly during the carboniferous period, when most of our coal and oil deposits were formed (GRAY, 2002).

The following Table 1 lists four principal gases of the dry atmosphere and their proportional amounts in a well-mixed atmosphere. Besides these four gases, there are several other trace gases like Helium, Methane (CH_4), Nitrous Oxide (N_2O), Krypton Hydrogen, etc., whose proportion by volume is too small to be of any significance in the present discussion. The gases methane and nitrous oxide along with carbon dioxide are referred to as the greenhouse gases (GHG) whose radiative properties are a subject of intense study at present.

In Table 1, we have not considered the highly variable component of the atmosphere, namely the water vapor which is the most important greenhouse gas and can influence the earth's mean temperature structure significantly. There is an upper limit to the quantity of water the atmosphere can hold in gaseous (vapor) form at any temperature. Theoretically, water vapor could increase to a maximum of 5% of the total atmosphere (by volume) at the highest temperature measured near the earth's surface; however, in reality a value of 2% of water vapor in the atmosphere is considered a high value representative of a very humid atmosphere. As we discuss below, the presence of water vapor in the atmosphere produces a greenhouse effect, making the earth-atmosphere system warm and comfortable enough for animal and plant life.

3. The Natural Greenhouse Effect

Sun's radiation is mostly in short wavelengths and passes through the atmosphere without much absorption, except the ultraviolet part of the solar radiation which is absorbed by ozone in the stratosphere. Solar radiation heats the earth and the oceans and they in turn emit radiation back to space in longer wavelengths, hence known as longwave radiation. Some of the gases in the atmosphere, including water vapor and CO_2 absorb this longwave radiation from the earth (and oceans) and in this process, maintain an annual global surface temperature of about 14 °C to 15 °C. Since this phenomenon is somewhat similar to keeping plants warm in a greenhouse, is generally referred to as the greenhouse effect. In the actual greenhouse, vertical mixing is limited by the glass panes, whereas the atmospheric greenhouse gas effect reduces radiative loss to space through the absorption and then reemission downward for longwave radiation by CO_2, O_3 and water vapor. Without this natural greenhouse warming, the earth's annual average surface temperature would

Table 1

The four principal gases of the dry atmosphere, below 25 km (Pettersen, 1958)

Gas	Symbol	Percent by Volume
Nitrogen	N_2	78.09
Oxygen	O_2	20.95
Argon	A	0.93
Carbon Dioxide	CO_2	0.03

be about −18 °C to −19 °C. Thus the natural greenhouse effect contributes about 33 °C to the earth's annual average surface temperature. The greenhouse effect extends through the troposphere and stratosphere.

Figure 1a adapted from RAMANATHAN (1998) shows the global energy balance for annual mean conditions. Here, the earth receives 343 units ($W.m^{-2}$) at the top of the atmosphere, while globally averaged longwave emission by the earth's surface is 395 ± 5 units. At the top of the atmosphere, a total of 237 ± 3 units are lost to space (often identified as OLR—Outgoing Longwave Radiation). Thus the intervening atmosphere and clouds cause a reduction of (395–237) = 158 ± 7 units of energy which is the *Greenhouse Effect*. It is this natural greenhouse effect that keeps the earth's mean temperature a comfortable 289 K (15 °C), or about 33 °C warmer than it would be without this greenhouse blanket. Figure 1b shows global average clear-sky vs. average cloudy-sky radiation budget based on ERBE (Earth Radiation Budget Experiment) data from earth-orbiting satellites. The ERBE data separated the clear-sky radiation from average cloudy-sky radiation based on a five-year period (1985–1989) and the difference, about $-18\ W/m^2$, is attributed to cloud radiative forcing by RAMANATHAN *et al.* (1989a). This average "cloudy-sky" forcing is considerably larger than the $2.45\ W/m^2$ forcing due to increased concentration of GHGs (IPCC, 2001) and, as we shall discuss later, this can be a significant source of uncertainty in the hypothesis on greenhouse gas-induced climate change.

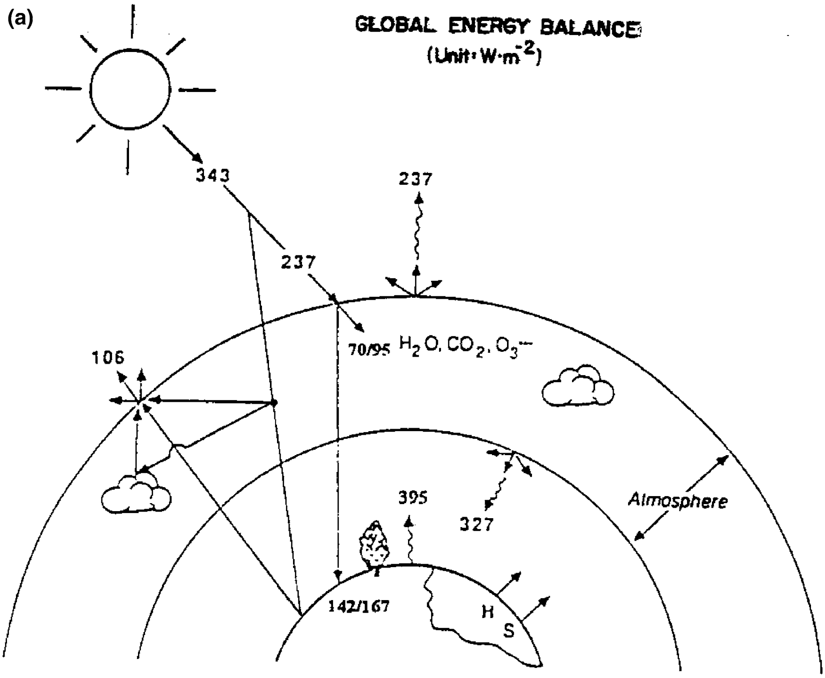
4. *The Case for Global Warming*

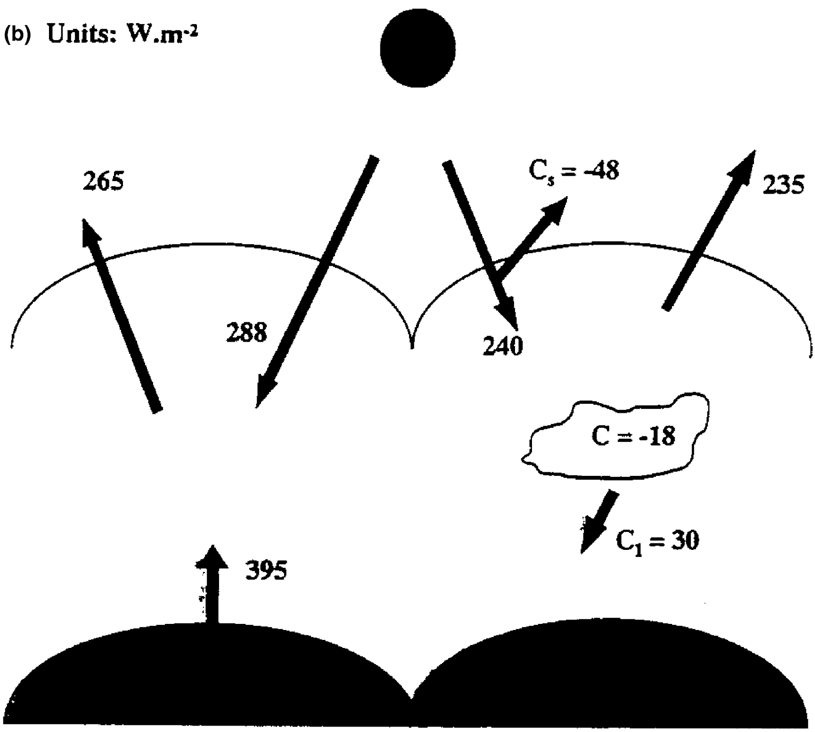
The concept that the earth's atmosphere acts somewhat like the glass of a greenhouse, letting through the sunlight (shortwave light rays) while retaining a portion of the longwave radiation emanating from the earth's surface was first introduced by the French mathematician JOSEPH FOURIER (1827). This concept was further expounded by TYNDALL (1861) who carried out sophisticated experiments to study the infrared radiative properties of water vapor and carbon dioxide and demonstrated that water vapor is the most important greenhouse gas.

▶

Figure 1a
Global energy balance for annual mean conditions. The top-of-the-atmosphere estimates of solar insolation (343 units), reflected solar radiation (106 units) and outgoing longwave radiation (237 units) are obtained using satellite data. Refer to the text for more details (from RAMANATHAN, 1988).

Figure 1b
Global average clear-sky radiation budget (left panel) and average cloudy fluxes and cloud radiative forcing (right panel) from ERBE data. Outgoing arrows denote OLR (Outgoing Longwave Radiation) and incoming arrows denote incoming solar radiation. Values shown are for 5-year averages between 1985 and 1989 with uncertainties in the fluxes of about ± $5\ W/m^2$ (from RAMANTHAN *et al.*, 1989b).


(a)
GLOBAL ENERGY BALANCE
(Unit: W·m^{-2})
343
237
237
106
70/95 H_2O, CO_2, O_3...
395
327
Atmosphere
142/167
H
S


(b) Units: W.m^{-2}
265
288
240
C_s = -48
235
C = -18
C_1 = 30
395

The first estimates of how changes in the global concentration of "carbonic acid" (a primary greenhouse gas, now more commonly referred to as carbon dioxide) might affect mean global surface temperature were made by a Swedish chemist Svante Arrhenius more than 100 years ago. ARRHENIUS (1896) demonstrated that an increase in the atmospheric concentration of CO_2 by a factor of two would lead to a heating of the earth's temperature by 5 to 6 °C. Arrhenius' work was followed by the studies of American geologist CHAMBERLIN (1899) whose work was focused on the role of CO_2 in the formation of glacial periods in geological times. The studies of Arrhenius and Chamberlin received scant support from the atmospheric science community of that time, since there was a general consensus that the absorption of longwave radiation (emanating from the earth) by water vapor was so strong that the absorption by carbon dioxide was considered negligible.

In 1938, British engineer CALLENDAR (1938, 1940) demonstrated through laboratory experiments that CO_2 does indeed have absorption bands outside of those dominated by water vapor and that increased CO_2 concentration could have significant global effects on the surface temperature of the earth. Callendar also speculated for the first time that humans could have a significant influence on the atmospheric CO_2 concentration, but estimated that it would take several centuries of continued industrial emission to achieve a doubling of concentration. In an important paper, the well-known American geophysicist Roger Revelle proposed that "humans are carrying out a large-scale geophysical experiment through worldwide industrial activity that could lead to a build-up of CO_2 larger than the rate of CO_2 production from volcanoes" (REVELLE and SUESS, 1957). Revelle was instrumental in establishing the first station for long-term monitoring of atmospheric CO_2 at Mauna Loa (Hawaii) and in launching an accelerated international research program on the potential human influence on the climate system.

The most direct and visible evidence of global warming is the change of ocean heating, and not the (earth's) surface air temperature record, even though it is the latter that has received the most attention from IPCC and the media. A more appropriate unit to measure warming (or cooling) is Joules, and not degrees Celsius. A recent paper by PIELKE (2003) analyzes the heat storage system in the earth system and points out how the utilization of surface temperature as a monitor of the earth system climate change is not particularly useful in evaluating the heat storage changes to the earth system. However, since surface air temperature is the most commonly used and most easily understood variable in the present global warming debate, we will refer to air temperature record as the basis for our discussion.

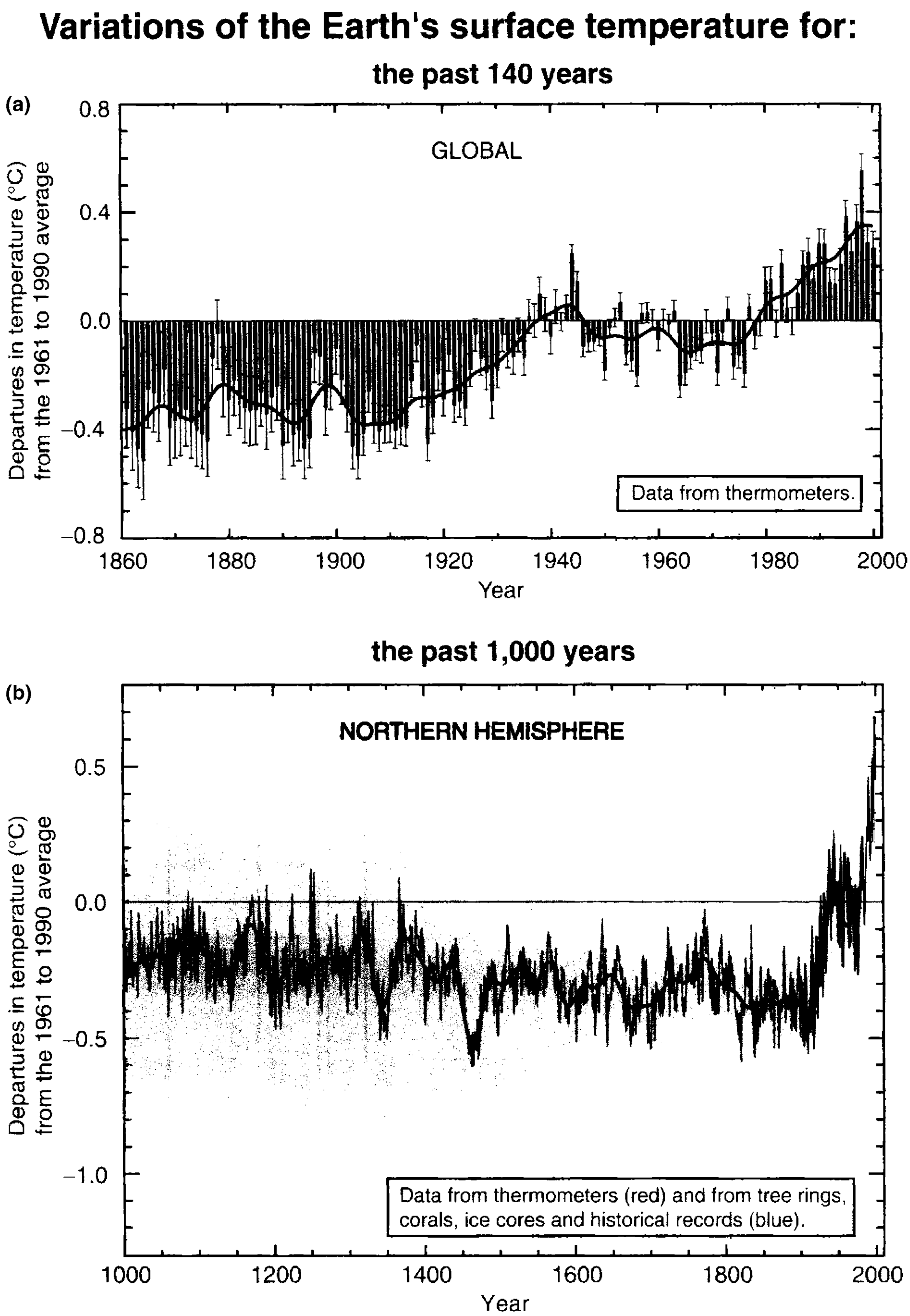
Through a careful analysis of a vast amount of land-ocean surface data, mean temperature variation of the earth's surface over a long period (1860–2000) has been prepared by JONES *et al.* (1999, 2001) and this temperature variation as shown in Fig. 2 has become the benchmark for the present global warming debate. For the present discussion here, we focus our attention on the 20^{th}

century temperature variation: During the last 100 years, the earth's temperature increased rather steeply (by ~0.5 °C) from 1910 through 1945, then decreased (by ~0.2 °C) from 1945 through 1975 and since about 1977 the mean temperature has increased by about 0.3 °C. It is this recent temperature increase of about 0.3 °C or more that has become the focus of the present global warming debate. The bottom part of Fig. 2 shows earth's temperature changes for the last millennium, based on MANN *et al.* (1998, 1999). This temperature variation is estimated using a number of proxy data like tree-ring widths, ice core data from Greenland, etc. Mann *et al.* conclude recent warming of the Northern Hemisphere as unprecedented and the 1990s are likely the warmest decades in 1000 years. As we shall discuss later, this temperature variation of the last millennium has become a subject of vigorous debate at present.

The most recent IPCC report on the climate change (IPCC, 2001) states that *the atmospheric concentration of carbon dioxide has increased from 280 ppm (parts per million) from 1750 to 367 ppm in 1999 (31% increase). Today's carbon dioxide concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years*. The IPCC also refers to a substantial recent increase in other greenhouse gases (GHG) namely, methane and nitrous oxide which have increased by 145% and 15%, respectively in the last 250 years. These greenhouse gases have added a total direct radiative forcing of about 2.45 $W.m^{-2}$ which, according to IPCC, has led to an increase in the mean surface temperature of the earth. Further, the recent steep increase (~ 0.16 °C per decade) in the mean surface temperature is being *directly linked* to the increased greenhouse gas emission of the last 25/30 years.

A number of climate models developed at various national and international institutions in North America, Europe and elsewhere have simulated the mean surface temperature increase and its intimate link to the increasing concentrations of greenhouse gas emissions. Noteworthy among the climate modeling studies are those reported by BOER *et al.* (1992, 2000), HANSEN *et al.* (2001), MANABE *et al.* (1990), MANABE and STOUFFER, (1996), MEEHL *et al.* (2003) and MITCHELL *et al.* (1995). These modeling studies have simulated the earth's temperature change over the twentieth century and in particular the recent temperature increase, using gradually increasing levels of greenhouse gases.

The case for global warming and its link to GHG resides in the claim (by IPCC) that the increase in the mean surface temperature of the earth cannot be explained by the natural variability of the atmosphere-ocean system alone. Further, the recent increase in the mean temperature is unprecedented and can be explained (only) through climate model simulations which demonstrate the purported link between mean temperature and the increasing concentrations of GHG in the atmosphere.


Variations of the Earth's surface temperature for:
the past 140 years
(a)
GLOBAL
Data from thermometers.
Departures in temperature (°C) from the 1961 to 1990 average
0.8
0.4
0.0
−0.4
−0.8
1860
1880
1900
1920
1940
1960
1980
2000
Year
the past 1,000 years
(b)
NORTHERN HEMISPHERE
Data from thermometers (red) and from tree rings, corals, ice cores and historical records (blue).
Departures in temperature (°C) from the 1961 to 1990 average
0.5
0.0
−0.5
−1.0
1000
1200
1400
1600
1800
2000
Year

5. *The Case against Global Warming*

The case for global warming as presented above appears convincing and seemingly governed by a simple but attractive physical argument that more CO_2 in the atmosphere will trap more outgoing longwave radiation and thus the earth's surface will eventually become warm enough to make a case for "global warming." As mentioned before, the global warming and associated climate change issues are governed by many complex mechanisms and it is imperative to more closely examine these mechanisms before making definitive conclusions about cause and consequence of global warming.

Among the important issues that we discuss here are: **1.** Mean temperature calculation and the impact of urbanization and land-use change; mean temperature changes on regional and hemispheric scale and their variation in the context of large-scale atmospheric circulation patterns and other mechanisms. **2.** The impact of solar variability on climate change (and global warming) in geological times as well as on shorter time scales of a few hundred to a few thousand years and **3.** Consequences of global warming in terms of the "increase in mean sea-level and in extreme weather events world-wide." Within each of these three main issues there are numerous related other issues which make the simple warming/CO_2 link questionable, and consequently the warming/extreme weather link becomes tenuous at best.

In the last few years, several studies have brought into sharper focus some of the issues mentioned above: The urbanization and land-use change impact is now considered as providing a climate forcing which may be equal to or even stronger than the GHG forcing. The solar variability on geological as well as on shorter time scales appears to provide a significant influence on the mean temperature change. Further, the large-scale atmospheric circulation patterns and their decadal changes appear to provide significant impact on the mean temperature calculation. Finally the consequence of global warming in terms of increasing the frequency of extreme weather events and sea-level rise is fraught with considerable uncertainty due to the lack of good data on extreme weather events over a long period of time and due to other reasons of natural variability. When all these issues are taken together, a strongly dissenting view of the global warming science appears to emerge.

Figure 3 shows mean monthly temperature anomalies over global, Northern and Southern Hemisphere land-areas from January 1990 through January 2004. These temperature anomalies are obtained as departures from the 1971–2000 base period

◄

Figure 2
(a) Earth's mean temperature variation from 1860 to 2000, with respect to 1961–1990 average. (b) Mean temperature variation over the Northern Hemisphere for the past 1000 years with respect to 1961–1990 average (from IPCC, 2001).

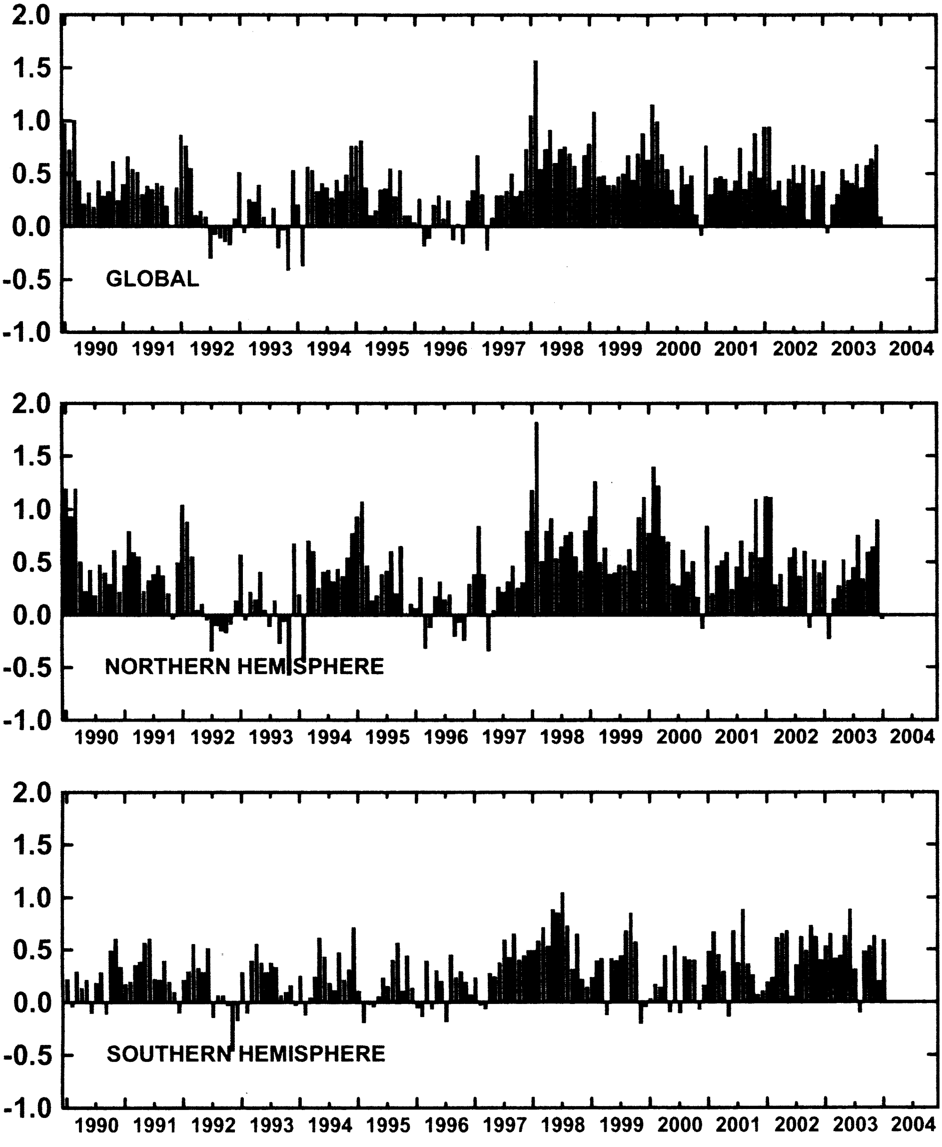


Figure 3
Monthly global (top), Northern Hemisphere (middle) and Southern Hemisphere (bottom) surface temperature anomalies in °C (land areas only) from January 1990-present, computed as departures from the 1971–2000 base period means. (from CLIMATE DIAGNOSTICS BULLETIN, January 2004).

means and show how the global temperature anomaly (land-areas) which peaked in 1998 after the 1997 El Niño, has steadily declined in recent years. Similar decrease in mean temperature anomalies for northern and southern land-areas is also seen in the same Figure. These temperature anomalies show how mean temperature calculation can be significantly influenced by natural climatic events like El Niño (KUMAR *et al.*, 2001).

6. *Earth's Temperature Variation in Geological and Historical Times*

Earth's temperature does not change monotonically. It rises and falls in highly irregular cycles and the amplitude of the change is highly variable. Earth's climate has been changing in geological as well as in historical times due to natural processes and it is instructive to take a closer look at the earth's temperature variation. While there is no universal agreement on the earth's climate history, there is some consensus on the following temperature history, which is based on a variety of data sources, mostly proxy records for the geologic past, with weather diaries for the past few centuries and instrumental records for the 20^{th} century and part of the 19^{th} century. The following is a partial list of proxy records: boreholes, glaciers, coral reefs, tree rings, sediments, pollen, insects, sea organisms, river flow, dune migration, stalactites, crop amounts, etc. The list provided here is in random order and does not reflect the order of importance of various proxy records.

The earth's temperature history reverting to 500 MY (Million Years) is given below:‘

- Earth was warmer than now at −500 MY, −390 MY, −250 MY, and −100 MY and colder than now at −445 MY, −310 MY, −170 MY and −35 MY (VIEZER *et al.*, 2000; KUMP, 2000).
- −490 to −443 MY (Ordovician glaciation). Colder than present (SHAVIV and VIEZER, 2003).
- −145 MY (Cretaceous). Very warm. Speculation that there was no ice on the planet, even at the poles (ENVIRONMENT CANADA, 2003).
- −43 MY (Eocene). Very warm. CO_2 levels then were less than during the glaciation at –114,000 years (ENVIROTRUTH, 2003).
- −17 MY (Miocene) very warm. CO_2 levels then were less than present levels (ENVIROTRUTH, 2003).
- −2 MY very warm. Forests almost extended towards the North Pole (ENVIROTRUTH, 2003).
- −1.6 MY to now. Thirty-three glacial advances (ice ages) and retreats; earth was much colder than at −2 MY (ENVIROTRUTH, 2003). Periodic and rapid fluctuations from cooler to warmer periods are referred to as interglaciations. Reasons cited are: continental drift, changes in ocean configurations, changes in atmospheric and ocean circulations, natural wobbles in earth's orbit (called Milankovich cycles) and variations in solar energy.
- −125,000 years. Very warm in Europe. Hippopotami and other animals, now confined mainly to Africa in natural habitat, existed in Northern Europe (ENVIROTRUTH, 2003).

- −114,000 years. Beginning of the most recent glacial period. Very cold. High CO_2 levels (Envirotruth, 2003).
- −50,000 years. Very cold. Most of North America was covered by ice, some places up to 1.5 km thick (Environment Canada, 2003).
- −15,000 years. Earth was emerging from the last ice age. Temperatures in Greenland rose by 9 °C in 50 years (Weart, 2003).
- −12,000 years. In Europe, temperatures varied from warmer than present to the coldest during the ice age in a few decades and then bounced back. In Greenland, temperatures rose by 8 °C in a single decade (Weart, 2003).
- −11,000 years. Last ice age ended. Since then temperatures have been fluctuating (Environment Canada, 2003).
- −7,000 to −4,000 years. 1 to 3°F warmer than now (Environment Canada, 2003; Briffa, 2000).
- −5,000 years. Cooling of 2 °C globally. 6 °C cooling in the Arctic and only 0.5 °C in lower latitudes (Envirotruth, 2003).
- −2,000 years. Tree-ring records from Siberia suggest no temperature change except three episodes (i) Medieval Warm Period (MWP), (ii) Little Ice Age (LIA) and (iii) high temperatures of 20^{th} Century with peak in 1940 (Center for the Study of Carbon Dioxide and Global Change, 2003).
- 800 to 1300 A.D. MWP (Medieval Warm Period): 1 to 2 °C warmer than present. Warmest period was during 900 to 1100 A.D (Soon and Baliunas, 2003; Villalba, 1990, 1994).
- 1000 A.D. Very warm in the Arctic. Sailing activity reported where there is a permanent ice pack now (Thompson *et al.*, 2000; Briffa, 2000 and also Lamb, 1972a, b; Villalba, 1990, 1994).
- 1350 – 1800 A.D. LIA (Little Ice Age): Average temperature dropped by 1.5 °C in 100 years. Coldest period of the LIA was during 1550 to 1700 (Jones *et al.*, 1998; Villalba, 1990, 1994).
- 1860 – to present time: This period of instrument data has provided the most detailed description of the earth's climate with a steep temperature increase between 1910–1940, a moderate decrease from 1945 to 1970 and the present warming from about 1975 (Lamb, 1972a, b; DeGaetano and Allen, 2003; Gray, 2002.

In the context of the earth's climate through the last 500 million years, the recent (1975–2000) increase in the earth's mean temperature does not appear to be unusual or unprecedented as claimed by IPCC and many supporters of the global warming hypothesis. According to Mann *et al.* (1998, 1999), *the 20^{th} century is likely the warmest century in the Northern Hemisphere and the 1900s were the warmest decades with 1998 as the warmest year in the last 1000 years.*

Several recent studies have questioned the conclusion of Mann *et al.*, which has become the pivotal issue in the global warming debate at present. A paper by Soon and BALIUNAS (2003) examines a large number of proxy records and concludes that the 20th Century is probably not the warmest or a uniquely extreme climatic period of the last millennium. Another recent paper by MCINTYRE and MCKITRICK (2003) recalculates and reconstructs the Mann *et al.* temperature curve of the last 1000 years shown in Fig. 2 (this curve has been dubbed "the Hockey Stick Curve") using all available data and improved quality control. The recalculated curve by McIntyre and McKitrick is shown in Fig. 4. This Figure suggests that the 20th century is unexceptional when compared to the 15th century (1400–1500 A.D.) which according to McIntyre and McKitrick, could be warmer than the 20th century. Several other studies (e.g., LAMB, 1965; GROVE, 1996, 2001; OGILVIE and JONSSON, 2001) have suggested that the MWP (Medieval Warm Period) and the LIA (Little Ice Age) were global scale climatic anomalies and not just regional phenomena as concluded by IPCC (2001). The debate concerning the scale and extent of MWP and LIA continues at present.

The structure of the observed warming has become another point of debate in recent years. According to MICHAELS *et al.* (2000), the observed warming of the last fifty (1950–2000) years is mostly confined to the dry, cold anticyclones of Siberia and northwestern North America during the winter season. Further, on a seasonally weighted basis, a relatively small area (12.8%) contributed over half of the annual warming, while in the winter season of the Northern Hemisphere, 26% of the area

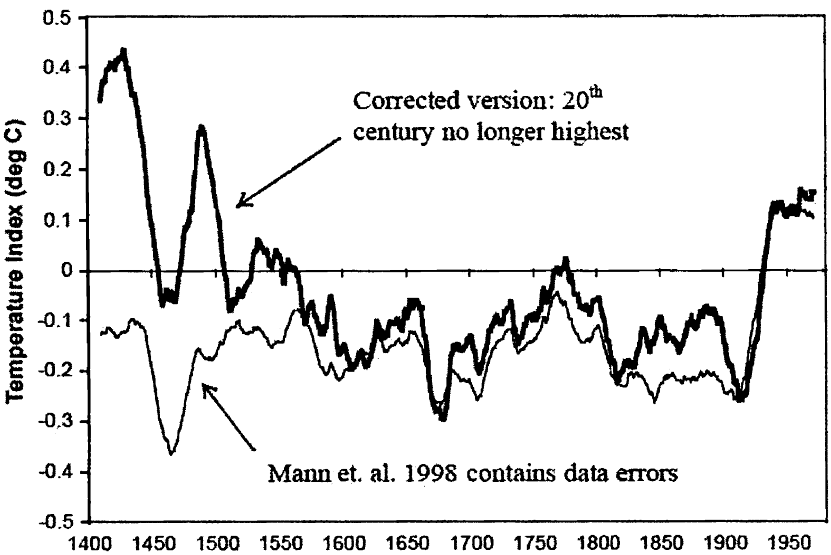


Figure 4

Temperature change (with respect to present mean temperature) over the last six centuries by Mann *et al.* (thin line) and as recalculated by McIntyre and McKitrick (thick line). See text for further discussion (from MCINTYRE and MCKITRICK, 2003).

accounts for 78% of the warming. The spatial patterns of observed warming, according to Michaels *et al.* (2000) are not consistent with that projected by many of the climate models as reported in the IPCC documents (e.g., IPCC, 1996). In another recent paper by Jones and Moberg (2003), the observed warming of the 20^{th} century is identified as having occurred during two distinct periods, 1920–1945 and 1975–2000. Jones and Moberg further document that the recent (1975–2000) warming is statistically significant only at 19% of the grid locations; these grid locations being predominantly distributed over heavily populated and industrial areas of the earth. Thus it can be argued that the recent warming could be due to land use change and related economic activity and need not be linked to the atmospheric GHGs.

Finally, the warming that is being debated at present appears to be restricted to the lowest layer of the earth's atmosphere, approximately 1.5 km atmospheric layer above the earth's surface. Extensive analysis of satellite-derived surface-temperature data of the recent 22 years (1978–1999) by Christy *et al.*, (1995, 1998, 2000) shows that in the troposphere (850–200 hPa layer), temperature trends range from −0.03 to +0.04 °C per decade (see Fig. 5), too small to be statistically significant from zero. Thus the troposphere has not warmed appreciably with respect to the earth's surface, as documented by Christy and coworkers. The tropospheric temperature changes have been recalculated in a recent paper by Santer *et al.* (2003). A commentary by Pielke Sr. and Chase (2004) discusses these calculations in additional details. These and other papers suggest that the

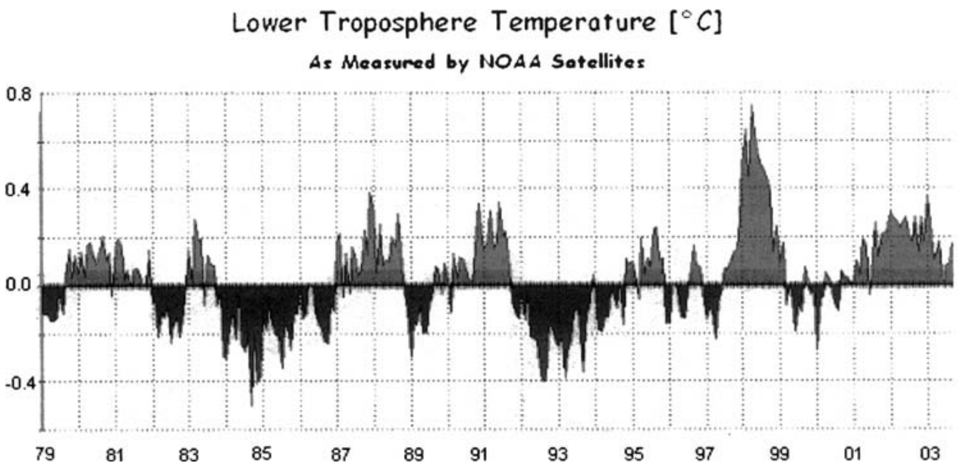


Figure 5
Lower tropospheric temperature as measured by NOAA satellite. The abscissa is years and the ordinate is temperature. The average trend in temperature change over 22 years (1979–2000) is estimated to be between −0.03°C to +0.04°C per decade. Note the high positive spike in temperature change during the strong El Niño years of 1997/98.

troposphere has warmed in the recent 25 years, however the warming remains significantly less than the modeled warming of the lower-to-mid troposphere. (CHASE *et al.*, 2004).

7. *Urbanization and Land-Use Change*

Assessing the impact of urbanization and land-use change on the mean temperature calculation is a challenging task. The classical studies of MITCHELL (1961) and OKE (1973) suggest that an urban heat island effect could be significant even for towns with a population of a few thousand people. For large cities, the urban heat island effect has been shown to be as high as 10 °C (temperature difference between the city center and a remote suburban location) in studies by OKE (1973) and others. The IPCC (1990) identified the urban heat island and its potential impact on surface air temperature as the most serious source of systematic error in the mean temperature calculation. In the context of the present global warming debate, the urbanization impact has been assessed as about 0.05 to 0.06 °C over one hundred years (JONES *et al.*, 1990; IPCC, 2001). This value appears too small in view of similar calculations for individual large cities or local regions.

Several recent studies (FUJIBE, 1995; GALLO *et al.*, 1996, 1999; HANSEN *et al.*, 2000, DEGAETANO and ALLEN, 2002; KALNEY and CAI, 2003) have taken a closer look at the land-use change impact on mean temperature calculations and these and other studies strongly suggest the impact to be significantly more than the value 0.06 °C used by IPCC (2001). The study by Fujibe shows trends in mean temperature at several Japanese stations (where long-term temperature data of 100 years or longer are available) of between 2 to 5 °C per hundred years at large cities and about 1 °C per hundred years at medium-sized cities. Another study by HINGANE (1996) estimates rising temperature trends of 0.84 °C and 1.39 °C per hundred years in the mean surface temperature calculated for Bombay (Mumbai) and Calcutta (Kolkata), two of the largest cities in India. Hingane used mean temperature data from Mumbai and Kolkata in conjunction with two neighboring stations to estimate the temperature trend due to urbanization as shown in Figure 6. Figure 6 shows how urbanization impact on temperature can gradually grow with time as two of the largest cities in India have grown in population and industrial development over 100 years.

Based on the study by KARL (1993) and others, it is now recognized that urbanization and land-use change influence minimum temperature, which in the last 100 years has risen faster than the maximum temperature at most locations, and this has led to a decrease in the DTR (Diurnal Temperature Trend). The recent study by GALLO *et al.* (1999) developed an innovative approach to identify rural vs. urban locations over the conterminous USA by using a night-light index from a satellite-based device. Their study (GALLO *et al.*, 1999) found that the

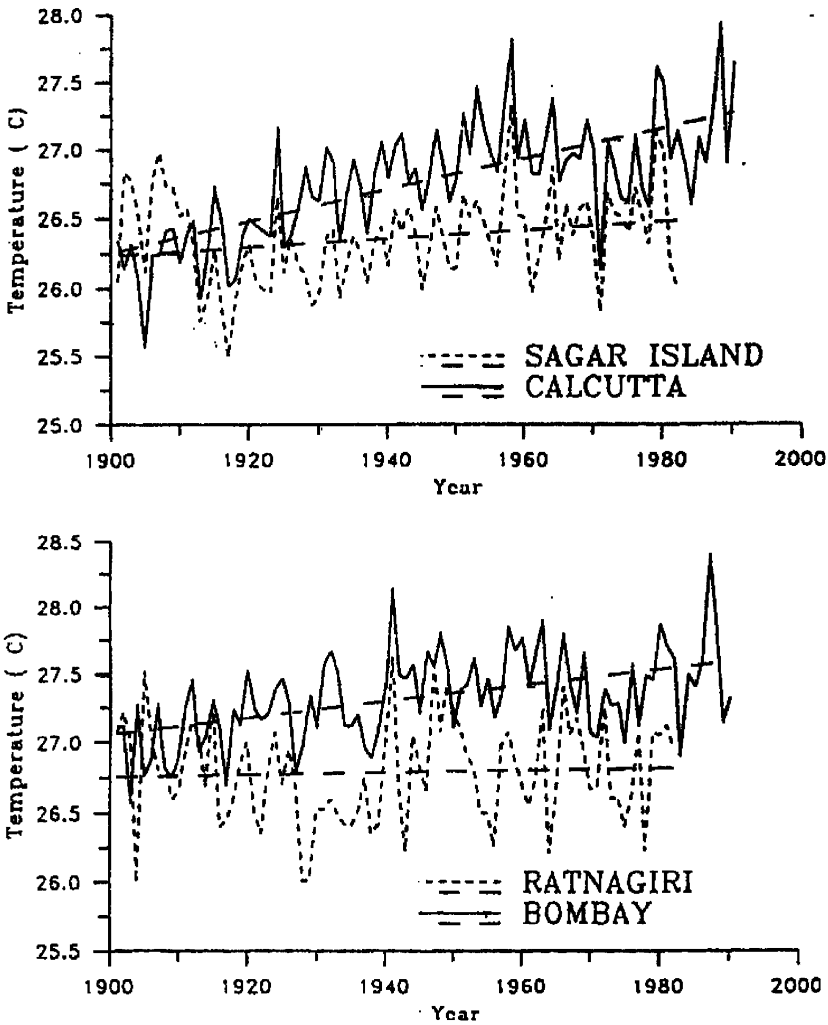


Figure 6
Long-term variation of surface-air temperature at two industrialized cities in India in relation to temperature variation at adjacent nonindustrial towns. **Top:** Calcutta vs. Sagar Island. **Bottom:** Bombay vs. Ratnagiri (from HINGANE, 1996).

decreasing trend in the DTR was smaller at rural stations than at urban stations by about 0.45 °C per 100 years. The study by HANSEN *et al.* (1997) suggests the urbanization impact of at least 0.1 °C on the earth's mean temperature calculations over a 100-year period. A more recent study by HANSEN *et al.* (2001) concludes that *local human effect (urban warming) can be identified even in suburban and small-town surface air temperature records*. Another recent study by KALNEY and CAI (2003) used the NCAR (National Center for Atmospheric

Research, Boulder, USA) reanalysis for the 1950–2000 period and reconstructed the surface temperature by extrapolating the various tropospheric level data to the surface level. Kalney and Cai obtained the urbanization and land-use change impact of 0.27 °C per century and about 0.18 °C for the recent 25-year period; this value (0.18 °C) being highly significant.

In another recent study by OOKA (2002), the urbanization impact on the temperature variation over Metropolitan Tokyo is documented using a network of stations in and around Tokyo for which data are available from 1870 through 2002. It is of interest to note that the temperature has risen by about 4 °C in the central part of Tokyo from its surroundings during the 150-year period. This increase of about 4 °C in the central part of Tokyo can most assuredly be attributed to urbanization and land-use change impact in and around Tokyo. Another recent study by DEGAETANO and ALLEN (2002) makes a detailed analysis of temperature structure at many locations in the USA and obtains trends in the occurrence of maximum and minimum temperatures which are significantly influenced by urbanization. In the most recent study, PETERSON (2003) carefully analyzes rural/urban temperature differences for several clusters of stations in the USA and demonstrates that the differences between rural and urban sites are insignificant when homogeneity and other corrections are applied. Peterson's analysis is, however, based on only three years' data (1989–1991) and may not apply over longer durations as shown by Hingane, Fujibe and Ooka for locations in India and Japan, respectively.

Since urbanization is decidedly linked to economic activity, another recent study (MCKITRICK and MICHAELS, 2004) has investigated the global temperature histories at over 200 individual stations in 93 countries, to identify the impact of local economic activity like income, GDP (Gross Domestic Produce) growth rates, coal use, etc. McKitrick and Michaels find that the recent (1979–2000) temperature trends are influenced by economic activity and sociopolitical characteristics of the region surrounding individual stations.

Besides the urban/rural influence, the impact of land-use change and landscape dynamics on the climate system is being increasingly recognized and studied. In a landmark paper by PIELKE *et al.* (2002), the impact of land-use change and associated landscape dynamics on the climate system has been documented. It is further concluded that a more complete indication of human contribution to climate change will require the climatic influence of land-surface conditions and other processes to be included. Many of these processes will have strong regional effects that are not represented in a globally averaged metric. The study by PIELKE *et al.* brings out an important 'climate forcing' in the radiation budget of the earth-atmosphere climate system. Pielke has further suggested (PIELKE, 2002) that the climate forcing by land-use change and landscape dynamics can overwhelm the GHG forcing in the future. Other related studies reported in recent literature (CHASE *et al.*, 1996; RADDATZ, 2003a,b) suggest how land-cover changes in terms of agricultural practices over various regions and subsequent leaf-area index can influence the global climate system. These and related papers have added a new dimension to the global warming debate.

In summary, the impact of urbanization and land-use change on the mean temperature calculation appears considerably more significant than that which has been assumed to date. There is a definite need to reanalyze the mean surface temperature calculation and to determine the "true warming" due to GHG (CO_2–induced) forcing only. The above discussion also points to a need for adequately incorporating the impact of land-use/land-cover change in present and future climate models, as pointed out by PIELKE *et al.* (2002).

8. The Impact of Solar variability and Sun's Brightness

The IPCC 1996 report did consider solar irradiance change over the last 100 years (and earlier) and its possible impact on global warming. However, it was concluded that the solar irradiance variation in the past century is likely to have been considerably smaller than the anthropogenic radiative forcing, and consequently its impact on global warming and climate change was considered to be insignificant. Several studies (e.g., HOYT and SCHATTEN, 1993; LEAN *et al.*, 1995; LEAN and RIND, 1998; SOLANKI and FLIGGE, 1998) published in the last ten years have attempted to reconstruct solar irradiance variations over the last 300 years or more and these reconstructed solar irradiance values have been examined in conjunction with earth's mean temperature changes. These studies now suggest that solar forcing can be significant and may have contributed significantly to the observed warming of the earth's surface. According to LEAN *et al.* (1995) and LEAN and RIND (1998), solar forcing may have contributed to about half of the observed warming of 0.55 °C since 1860 and about one third of the warming since 1970. Lean and Rind further state that since 1970, GHG forcing has been significantly larger than solar forcing and consequently the solar forcing signal in the global warming data cannot be easily isolated. Other studies, notably by RIND and OVERPECK (1993), SOON *et al.* (1996) and POSMENTIER *et al.* (1998) have suggested that up to 78% of earth's warming between 1885 and 1987 can be accounted for by an increase in the sun's irradiance.

A few other studies reported in recent literature have attempted to analyze the solar brightness through geological times and have strongly suggested the dominant role of the sun in driving the earth's climate over geological times. Notable among these studies are by VIEZER *et al.* (2000) and SHAVIV and VIEZER (2003). These studies now suggest that increased CO_2 levels in geological times were not linked with increased temperature. The earth's climate history listed earlier (section 6) suggests no correlation between warmer periods in earth's climate and CO_2 levels. For more than 90% of earth's history the mean temperature of the earth was warmer than present (ENVIROTRUTH, 2003). According to SHAVIV and VIEZER (2003) the earth's temperature fluctuated from slightly below –3 °C to slightly less than + 3 °C from the present mean temperature over the last 500 million years (see Fig. 7). Their study which is based on the so-called "sea shell thermometer" also establishes that (Fig. 7) there is absolutely no correlation between atmospheric CO_2 levels and temperature. Shaviv and Viezer further show that the earth's temperature correlates well (Fig. 7) with changes in cosmic ray flux.

According to BENESTAD (2002) it is inappropriate to claim that response to solar activity can explain all the 20th century warming, as it is to dismiss it as making a negligible contribution. Any mechanism, linking solar activity and climate, must involve a forcing agent that penetrates at least into the stratosphere, if not into the

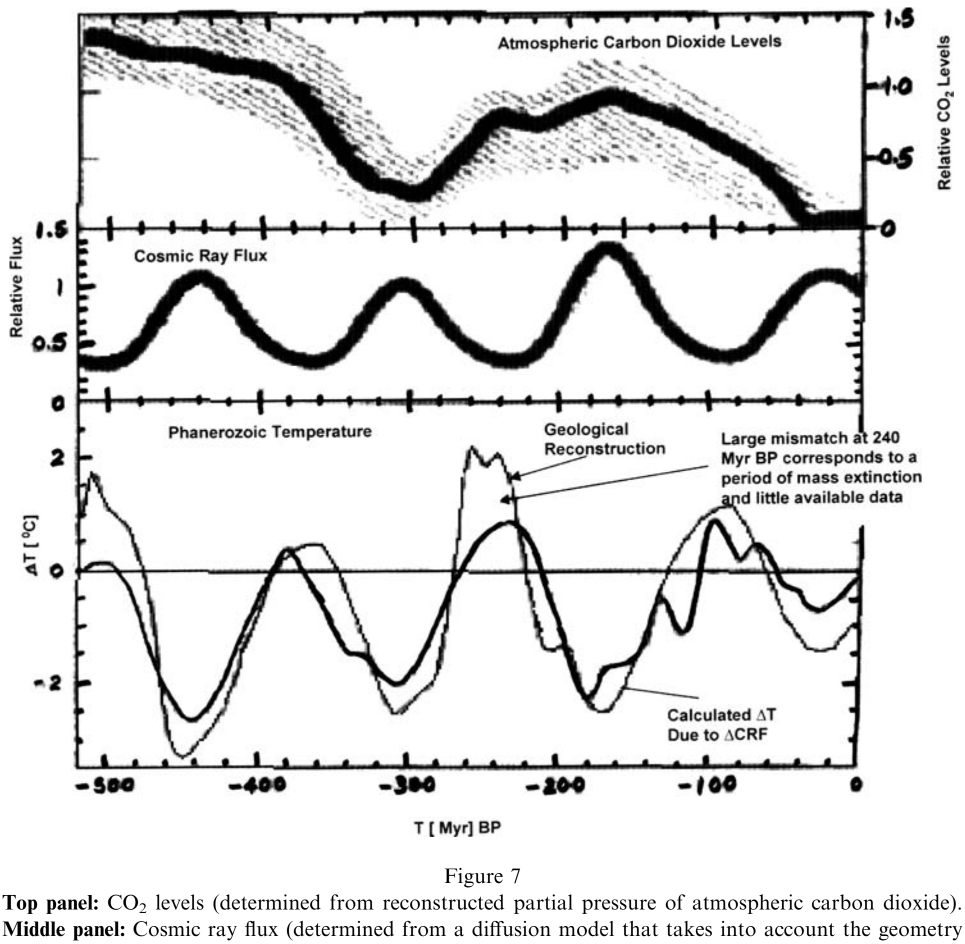


Figure 7

Top panel: CO_2 levels (determined from reconstructed partial pressure of atmospheric carbon dioxide). **Middle panel:** Cosmic ray flux (determined from a diffusion model that takes into account the geometry and dynamics of the spiral arms of the galaxy). **Bottom panel:** Temperature anomaly (determined from reconstructed sea-water temperatures based on various proxy records). The abscissa is years (in millions) BP (Before Present). (Simplified from SHAVIV and VEIZER, 2003 and PATTERSON, 2003).

troposphere. Benestad further proposes that solar ultraviolet irradiance can provide forcing which can influence the earth's climate. Observations show that this forcing does affect the climate at the 30 hPa (~25 km) level. The question then is: Can this forcing somehow affect the dynamics and climate at the 1000 hPa level? However, there are two other solar agents that appear more promising, in view of their ability to produce changes in atmospheric ionization. These two agents are solar wind and galactic cosmic ray flux affecting clouds. These two (solar) forcing mechanisms are present in the stratosphere as well as the troposphere with modulation amplitudes of about 10%. SVENSMARK and FRIIS-CHRISTENSEN (1997) demonstrate that there is a direct connection between earth's cloud cover and cosmic ray flux and this can influence earth's climate more effectively than increasing CO_2 levels.

It has been argued by LANDSBERG (1974) and RANDALL *et al.* (1984) that merely one to four percent increases in marine stratocumulus cloud cover can offset any warming due to a doubling of CO_2. Svensmark and Friis-Christensen further document an increase in solar irradiance of about 1.5 W/m^2 over a short period from 1986 to 1990. Further, studies by BARLOW and LATHAM (1983) and by DICKINSON (1975) show that secondary ions produced by cosmic rays can provide condensation nuclei which can enhance cloud cover. Thus solar irradiance change can influence earth's climate far more effectively over a short period of time than increased CO_2 forcing over a considerably longer period as claimed by IPCC.

Finally, two new studies deserve attention here: A statistical analysis of satellite-derived tropospheric (and stratospheric) temperature anomaly and solar irradiance has been carried out by KARNER (2002) in an attempt to identify solar influence on the tropospheric temperature trends. Karner's study demonstrates that global average tropospheric temperature anomaly and solar irradiance anomaly behave similarly and show antipersistency for scales longer than two months. A precise definition of "antipersistency" is provided by KARNER (2002). Karner's study suggests a cumulative negative feedback in the earth's climate system, contrary to the suggestion by MITCHELL (1989) of a positive feedback. The study further emphasizes the dominant role of solar irradiance variability and lends no support to the hypothesis of anthropogenic climate change. In a more recent investigation, FOUKAL (2003) suggests that slow variation in solar luminosity can provide a missing link between sun and climate. Foukal's study suggests that solar impact on the earth's climate may be driven by variable output of ultraviolet radiation or plasmas and fields via more complex mechanisms than direct forcing of tropospheric temperature.

In summary, the impact of solar variability and sun's brightness on the earth's climate has been brought into sharper focus in several recent studies. These studies further suggest a much stronger solar impact on earth's climate than previously believed. Some of the recent studies (e.g., SHAVIV and VIEZER, 2003; BENESTAD, 2002) suggest a definite link between solar variability and cloud cover which can significantly influence earth's mean temperature. The role of solar variability and the sun's brightness on earth's climate has not been fully incorporated in most climate modeling studies at present.

9. *Sea-level Variations*

This is not a review of sea-level variation, but rather an evaluation of the suggestion that global warming may be causing (accelerated) sea-level rise currently and in the future.

Sea-level measurements are even more biased than weather stations (GRAY, 2002). They are mainly near Northern Hemisphere ports, and are subject to local and short and long-term geological changes which are difficult to allow for. Sites in remote, low population places, such as the smaller Pacific Islands, show no evidence of recent sea-level changes.

Figure 8 shows that the sea level is more or less steady in Tuvalu, one of the small atolls in South Pacific. According to the National Tidal Facility (NTF) of Australia, the historical record shows no visual evidence of any acceleration in the sea level trends. They suggest that coastal degradation and sinking islets in Funa Futi were the result of environmental conditions, and not due to sea-level rise.

Other Pacific islands showing no detectable change in sea level are:

Tarawa, Kribati for 24 years
Kanton Island for 28 years

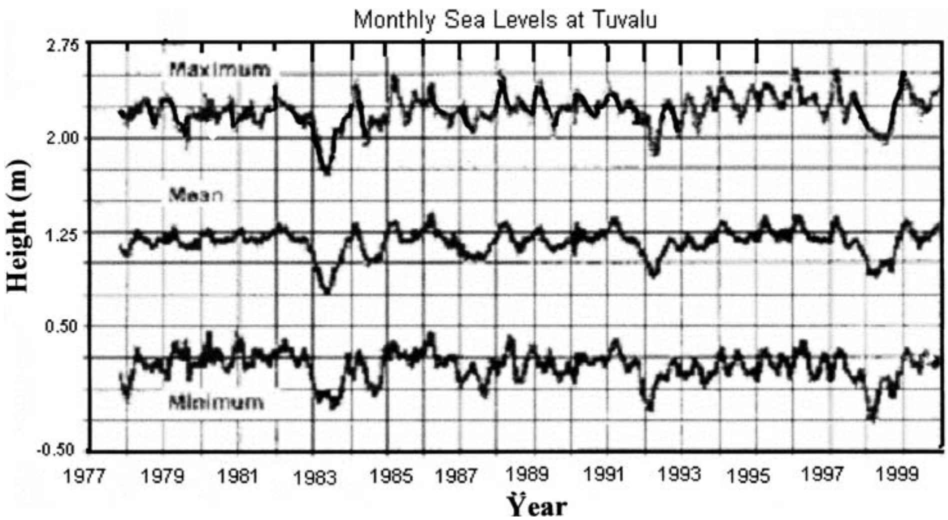


Figure 8
Sea levels at Tuvalu in the South Pacific as measured by tide gauges for the period 1978 to 2000 (from the National Tidal Facility of Australia)

Nauru for 26 years
Johnston Island for 50 years
Honiara, Solomons, for 26 years
Saipan for 22 years

Many others exhibit a stable period followed by a sudden jump, most likely due to hotel or airport construction, or a hurricane. Most of them also show no mean temperature increase over the period. The El Niño events of 1983 and 1998 show low readings.

According to IPCC (2001), *''the sea level rise in the 20th century is in the range of 1.0 to 2.0 mm per year with a central value of 1.5 mm per year. No significant acceleration in the rate of sea-level rise during the 20th century has been detected.* The study by BALTUCK *et al.* (1996) concludes that *it is very probable that the rising sea level is due to natural causes and not due to man's contribution to the greenhouse effect.*

Sea level has been rising naturally since the end of the last ice age and this has not accelerated recently. The total rise has been over 120 meters and is still proceeding at a rate of about 18 cm per century. An inspection of sea-level data does not show accelerated rise during the last fifty years, when the mean temperature of the earth increased by about 0.5 °C (ENVIROTRUTH, 2003).

Ongoing sea-level rise is due to the slow melting of Antarctic ice sheets that have been gradually disappearing for about 18,000 years; the date of the last glacial maximum. As far as we can tell from geological data, only temperature variations on a millennial time scale can affect this rate. Climate fluctuations lasting decades or even centuries are too short to affect appreciably this rate of melting. So unless another ice age commences in the meantime, sea level is bound to continue rising at about the same rate as present.

It is also important to understand that just as the melting of ice cubes in a glass of water does not cause the glass to overflow, the melting of polar sea ice will not result in ocean level changes. Only if massive quantities of inland Antarctic and Greenland glaciers melted, would sea levels raise enough to submerge coastal settlements. This did not happen 5,500 years ago, when the earth was three degrees warmer. Sea level was only two meters higher than now at 120,000 yeas ago, when temperatures were almost six degrees warmer than now.

Ordinarily, small island nations like the Maldives and Barbados are not threatened by such a rise. This is because these island countries are built entirely on coral and coral fragments. This coral is continually and quickly growing upwards and, unless something disastrous happens to the natural environment in a region, no sea-level rise is fast enough to get ahead of coral growth. The Maldivian reefs have been coping with increasing sea level for the past few thousand years and were able to keep up even when the ocean was rising ten times faster than it is now, about 10,000 years ago.

10. Extreme Weather Events

An important consequence of global warming is the possibility of increased incidences of extreme weather events worldwide. The most recent document on climate change (IPCC, 2001) has identified a number of extreme weather events which are expected to be observed with increased frequency during the 21st century. Increased incidences of some of the extreme weather events (e.g., frequent heavy precipitation, increased hot spells in summer, increased summer continental drying and associated risk of drought) are purported to have been observed and detected during the latter half of the 20th century. The earlier climate change document (IPCC, 1996) summarizes that *warmer temperature will lead to a more vigorous hydrologic cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events.*

The global warming/extreme weather link has been investigated in numerous studies in recent years. Besides scientific studies, a number of informal articles and commentaries have appeared in news and print media (popular science magazines, etc.). Also, news treating extreme weather events worldwide (e.g., hurricane landfalling, outbreak of tornadoes, summer heat waves, large forest fires) is reported on television and in newspapers with suggestions of a possible link to global warming. According to UNGER (1999), American television viewers are three times more likely to see a story on severe weather today than they were only thirty years ago. The growing news coverage of extreme weather events and their socio-economic impact has created a perception that extreme weather events are on the rise at present and are due to the increasing mean temperature of earth.

When carefully analyzed, the link between global warming and extreme weather is more a perception than reality. A number of peer-reviewed studies cited in IPCC (2001) appear to suggest global warming/extreme weather link, however a close inspection of available data does not provide any evidence of such a link at this point in time. In a survey article, BALLING and ÇERVÉNY (2003) analyze a number of severe weather events in the conterminous USA and find no upward trend in their frequency in recent years. Balling and Çervény further analyze damage from severe weather which has increased in recent years in the USA, however, when the damage in terms of loss of human life and property is adjusted to inflation, population growth and wealth, this upward trend in damage disappears. A similar conclusion is arrived at in another comprehensive study by CHANGNON (2003) who has documented that *shifting economic impact from weather extremes in the United States is a result of societal change and not global warming*. Elsewhere in North America, KHANDEKAR (2000, 2002) has analyzed some of the synoptic scale events such as Atlantic and Pacific hurricanes and (USA/Canada) East Coast winter storms. Khandekar has also examined other extreme weather events like heat waves, intense thunderstorms/

tornadoes, ice storms in eastern Canada and winter blizzards on the Prairies. Based on a careful assessment of available data over Canada and the Canadian Prairies, Khandekar concludes that extreme weather events are not increasing in Canada or on the Prairies (south of 70°N) at this point in time. Some of the extreme weather events like Prairie winter blizzards are definitely on the decline (LAWSON, 2003) in frequency as well as in intensity. KHANDEKAR (2002) has further examined available data in the Arctic and sub-Arctic regions of Canada and found evidence of an increase in ''heavy precipitation'' events in the Canadian Arctic. However, the present database in the Canadian Arctic is limited in terms of length of time as well as in spatial coverage; consequently, a definitive conclusion regarding an increasing/decreasing trend cannot be made currently. In another paper by KUNKEL (2003a), extreme precipitation trends are analyzed over North America and it is concluded that there is a definite increase in extreme precipitation trends in some regions of the USA (e.g., Great Lakes and Northeast) but not over Canada. In a subsequent paper KUNKEL (2003b) analyzes newly available data on rainstorms and concludes that the recent increase in extreme precipitation events in USA may be similar to what was observed more than 100 years ago and could thus be related to natural variability and not necessarily due to anthropogenic influence.

Elsewhere, extreme rainfall analysis has been made by ZHAI *et al.* (1999) for China and by RAKHECHA and SOMAN (1994) for summer Monsoon rains over India. Both these studies conclude no significant increasing trend in extreme rainfall events of 1-to-3-day duration. For southeast Asia, interannual rainfall variability is primarily governed by the ENSO (El Niño-Southern Oscillation) phase and does not reveal an increasing/decreasing tendency in recent years (KHANDEKAR *et al.*, 2000; KRIPLANI and KULKARNI, 1997). A comprehensive analysis by GROISMAN *et al.* (1999) finds a 20% increase in the probability of summer daily precipitation amount of over 25.4 mm (1 inch) in a few northern European countries like Norway and Poland, but such increasing trend has not been reported elsewhere in Europe. Over Australia, heavy rainfall events have increased in some areas, although this increase is not significant. For South Africa, a recent study by FAUCHEREAU *et al.* (2003) concludes that some regions have experienced a shift toward more extreme rainfall events in recent decades; however this increasing trend appears to be due to a closer link to ENSO phase in recent years and not due to anthropogenic influence.

In summary, the global warming/extreme weather link appears to be tenuous at best at this point in time. As pointed out by KHANDEKAR (2003), there is a definite need to closely examine this link using all available data in different parts of the world. A recent review paper by KARL and TRENBERTH (2003) states that *human influences are large enough to exceed the bounds of natural climate variability*. This statement and many other examples of ''extreme weather'' events given by Karl and Trenberth are debatable and require close examination.

11. Summary and Conclusions

During the long geological history of the earth, there was no correlation between global temperature and atmospheric CO_2 levels. Earth has been warming and cooling at highly irregular intervals and the amplitudes of temperature change were also irregular. The warming of about 0.3 °C in recent years has prompted suggestions about anthropogenic influence on the earth's climate due to increasing human activity worldwide. However, a close examination of the earth's temperature change suggests that the recent warming may be primarily due to urbanization and land-use change impact and not due to increased levels of CO_2 and other greenhouse gases.

Besides land-use change, solar variability and the sun's brightness appear to provide a more significant forcing on earth's climate than previously believed. Recent studies suggest solar influence as a primary driver of the earth's climate in geological times. Even on a shorter time scale, solar irradiance and its variability may have contributed to more than sixty percent of the total warming of the 20^{th} century. The impact of solar activity like cosmic ray flux on the earth's cloud cover has not been fully explored and may provide an additional forcing to the earth's mean temperature change.

There appears to be no intimate link between global warming and worldwide extreme weather events to date. Increasing economic impact due to extreme weather events in the conterminous USA appears to be a result of societal change in wealth and population and not due to global warming. Outside of USA, very few studies have been reported thus far which make a meaningful analysis of economic impact of extreme weather events. There has been no accelerated sea-level rise anywhere during the 20^{th} century.

Our review suggests that the present state of global warming science is at an important cross road. There is a definite need to reassess the science and examine various issues that have been discussed and analyzed here.

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