Questioning the Global Warming Science:
An Annotated bibliography of recent peer-reviewed papers

Prepared By
Madhav L Khandekar
Environmental Consultant
52 Montrose Crescent
Unionville, ON, L3R 7Z5
e-mail: mkhandekar@rogers.com

Document Prepared For
FRIENDS OF SCIENCE
Calgary, Alberta

January 2007

Table of Contents

Scope & Purpose of the Document..... 3

1. Temperature reconstruction using proxy data: The Hockey-Stick Graph..... 5

2.Impact of solar variability on the earth's climate..... 8

3. Sea-level rise, ocean surface warming/cooling etc. 11

4. Arctic & Antarctic temperatures: from Holocene to present..... 14

5. Impact of large-scale circulation patterns;..... 17

6. Extraneous influence on mean temperature trends: urbanization, land-use change etc. 19

7. Uncertainties in climate model simulations of regional & global features 22

8. Miscellaneous Studies..... 25

Summary & Conclusions..... 28

Glossary and Terms..... 30

Scope & Purpose of the Document

The phrase Global Warming (GW) is now popularly used to refer to the warming of the earth's surface (land-ocean combined) in recent years due to increasing concentration of greenhouse gases (GHG) in the atmosphere as a result of world-wide human activity and industrialization. Of the three GHG (carbon dioxide, methane and nitrous oxide), carbon dioxide is considered to be the most important since its concentration in the atmosphere has steadily increased in last fifty years due to world-wide use of fossil fuels. The earth's mean temperature has increased by about 0.6C in the last one hundred years and most state-of-the-art General Circulation Models (GCM) of the atmosphere-ocean system suggest that the earth's mean temperature may increase further by 3^0C (or higher) by 2100 and this temperature increase may trigger catastrophic events (ex. floods, droughts, sea-level rise, Greenland and Antarctic ice sheets melt-down etc) endangering human societies world-wide.

The Intergovernmental Panel on Climate Change (IPCC), a UN Body of scientists (primarily working with various nations' meteorological & environmental Agencies) was established in 1988 and has been assessing the state of world climate through the publication of periodic reports. A UN Framework Convention on Climate Change (UNFCCC) was established in 1992 and in a meeting held in Kyoto (Japan) in December 1997, it was agreed by all participating countries to reduce GHG emissions to the 1990 level and to help stabilize the earth's climate. The first phase of the Kyoto Agreement came into force in February 2005 and all participating nations of the industrialized world agreed to reduce their GHG emissions by 2012. The developing nations like India, China, Brazil etc, which are exempt from the Kyoto Agreement at this point in time, will be encouraged to come on board after 2012, so as to develop a world-wide strategy to 'combat' GW and associated climate change. The UNFCC has been holding annual meetings to review the progress of GHG emission targets and urging some of the industrialized countries notably the USA and Australia (which are not yet part of the Kyoto Agreement) to join the Kyoto Agreement.

As the debate on climate change and GHG emission targets continues unabated, a large number of studies questioning the GW science have appeared in peer-reviewed International scientific Journals. These studies

have seriously questioned many aspects of the GW science and at present there is an emerging view among many scientists that the present climate change may be more due to natural variability rather than due to human-added CO_2. The impact of solar variability and changes in large-scale atmospheric circulation patterns are now considered as providing significant impact on the earth's climate in historical as well as in geological times.

This Document presents an annotated bibliography of selected peer-reviewed papers which question the current state of the GW science. Seven major areas of the GW science are identified and in each of these seven areas present understanding is briefly reviewed followed by a list of key papers questioning the present assessment. A category entitled *Miscellaneous* lists several papers which question one or more aspects of the GW science and also includes other papers which are not covered elsewhere. The following is the list of various areas and categories:

1. Temperature reconstruction using proxy data; the Hockey Stick Graph
2. Impact of solar variability on the earth's climate
3. Sea-level rise, ocean surface warming/cooling etc.
4. Arctic and Antarctic temperatures: from Holocene to present
5. Impact of large-scale circulation patterns.
6. Extraneous influence on mean temperature trends: urbanization, land-use change etc.
7. Uncertainties in climate model simulations
8. Miscellaneous studies

1. Temperature reconstruction using proxy data: The Hockey-Stick Graph

The IPCC 2001 Document asserted that the present warming of the earth's surface was unprecedented by prominently displaying the earth's mean temperature history over last two millennia using a graph now popularly known as the Hockey-Stick Graph [see Figure 1(a)]. This graph shows the mean temperature of the earth varying only slightly below a zero reference line (this part of the graph representing 'stick' of the Hockey) till about 1850 after which the temperature curve shows a steep rise upwards ('blade' of the Hockey Stick) suggesting a rapid warming of the earth's surface in last 150 years or so. This Hockey-Stick representation of the earth's temperature history was based on a paper published in the prestigious Journal *Nature* by Prof. M Mann and coworkers (Mann et al, Nature, Vol.392, 1998). The authors (Mann et al) used available tree-ring data over the Northern Hemisphere and using a mathematical analysis obtained the Hockey-stick graph. This graph has been used prominently by the IPCC and its advocates to emphasize how human activity and GHG forcing have been pushing the earth's temperature to an unprecedented level.

In 2003, two Canadian scientists (Steve McIntyre & Ross McKitrick) re-analyzed the Mann et al Hockey-stick graph by a careful audit of available tree-ring data and found several errors re: obsolete data, geographical locations, collation of data etc. This led McIntyre & McKitrick to re-analyze the tree-ring data to produce a curve which was able to show the MWP (Medieval Warm Period) during 1400-1550 AD as well as the LIA (Little Ice Age) during 1650-1750 AD. The MWP & LIA were more or less smoothed out in the original Hockey-stick curve of Mann et al. With the publication of the McIntyre/McKitrick paper (Energy & Environment, 2003), an intense debate about the validity of the earth's temperature history has ensued and a re-analysis of the tree-ring data by another group of climate scientists (Moberg et al, Nature 2005) has now led to a new curve which clearly shows the MWP around 1000 AD and the LIA from about 1600 AD to about 1850 AD [Figure 1 (b)]. This curve does not at all resemble the original Hockey-stick curve of Mann et al. In short, the well-publicized Hockey-stick curve is now discarded as being unrepresentative of the earth's temperature history.

A number of key papers re: the Hockey-Stick graph are listed below:

a. **"**Corrections to Mann et al (1998) proxy data base and northern hemisphere average temperature series" S McIntyre & R McKitrick *Energy & Environment Vol. 14 (2003) p. 751-777*

b. **"**Reconstructing past climate from noisy data" H von Storch et al *Science Vol. 306 (2004) p. 679-682*

c. "Hockey sticks, principal components and spurious significance" S McIntyre & R McKitrick *Geophysical Research Letters, Vol. 32 (2005) L03710*

d. "Highly variable northern hemisphere temperatures reconstructed from low- and high-resolution proxy data" A Moberg et al *Nature Vol. 433 (2005) p. 613-617*

e. Wegman Edward, Scott D W and Said Yasmin H 2006: Ad Hoc Committee Report to Chairman of the House Committee on Energy & Commerce and to the Chairman of the House sub-committee on Oversight & Investigations on the Hockey-stick global climate reconstructions. US House of Representatives, Washington USA. Available for download from *ITTP://energycommerce.house.gov/108/home/07142006 Wegman Report.pdf*

f. "Reconstruction of temperature in the central Alps during the past 2000 yr from a delta^{18}O stalagmite record" A Mangini, C Spotl & P Verdes *Earth & Planetary Science Letters, 235 (2005)p. 741-751*

The above studies demonstrate conclusively that the highly publicized Hockey-stick graph was based on several erroneous calculations and assumptions. The graph is now abandoned in favor of a more recent reconstruction of the earth's temperature by Moberg et al (2005) as shown below [Figure 1(b)]. An investigation on the Hockey-stick graph was conducted by the US House Committee on Energy & Commerce which appointed a panel of three well-known mathematicians to look into the mathematical aspects of the Hockey-stick graph. Their findings are available in the Wegman Report which has severely criticized the methodology used by Mann et al. in their reconstruction of earth's mean temperature for the past six centuries. A US National Research Council Panel, chaired by Prof. G North (Texas A & M University USA) confirmed in a public meeting in Washington (*EOS Vol. 87, No. 27, 4 July 2006)* that "the late twentieth century was the warmest in at least the last 400 years and likely in the last

millennium". The NRC Panel further added that the evidence from further past is murky and therefore not conclusive.

In summary the well publicized Hockey-stick representation of the earth's mean temperature is now discarded. The question of whether the MWP was indeed warmer than the present remains open, however the paper listed under (f) presents isotopic analysis of stalagmites from Spannagel Cave in the Central Alps and concludes that during the MWP from about 800 and 1300 AD, temperature maxima was about 1.7C higher than during the LIA and this temperature maxima is similar to the present value. It is now generally accepted that the MWP was at least as warm as the present mean temperature of the earth. What is of interest here is that the earth's mean temperature changed significantly from the MWP to LIA and back to the warm period in the first half of the twentieth century during which the atmospheric concentration of carbon dioxide has remained essentially unchanged. The earth's temperature history of the last 600 years appears to be driven more by natural variability than by anthropogenic GHG variations. The next section provides more evidence of natural variability of the earth's climate through changes in solar irradiance.

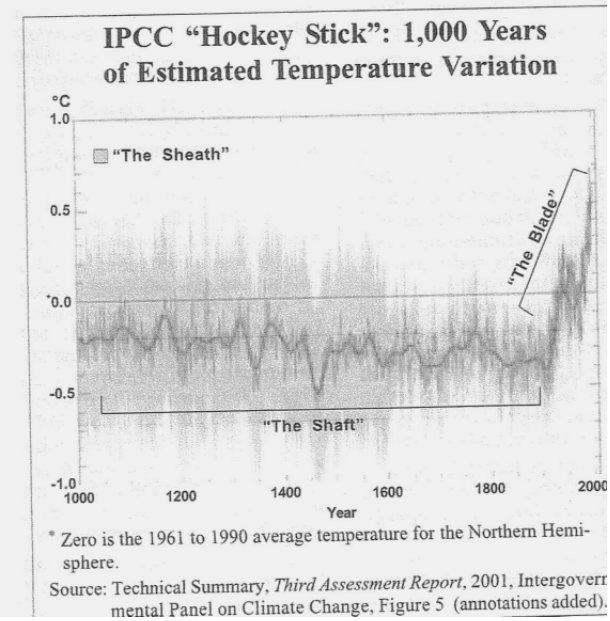
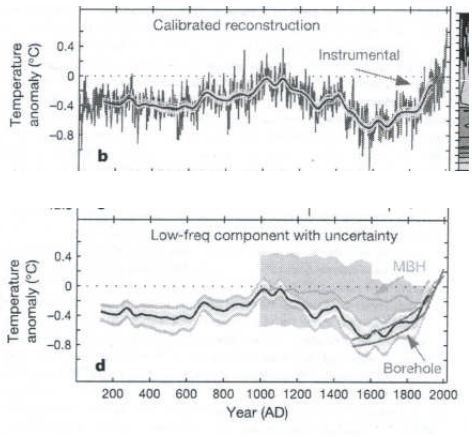


Figure 1 (a)



Moberg et.al. (2005)

Figure 1 (b)

2.Impact of solar variability on the *earth's climate*

The IPCC Climate Change Documents of 1996 and 2001 did consider the solar irradiance change over the last 100 years and its possible impact on the temperature change, however in both the IPCC review cycles (2nd and 3rd) it was concluded that the solar irradiance variations of the past century are likely to have been smaller than the GHG forcing. Based on this argument, the IPCC discounted any possible impact of solar variability on the earth's climate and in particular on the recent warming. Since the publication of IPCC 2001, a number of excellent papers have appeared which conclusively document significant impact of solar variability on the earth's climate. The mechanism by which solar variability can affect the earth's mean temperature trend remains complex and not fully understood. However these papers bring out an important new dimension to the present GW and climate change debate, namely that the present climate change may be more due to natural variability rather than due to human-added CO_2. Some of the key papers on solar variability and linkage to earth's mean temperature and climate are listed below:

a. "Solar variability and the earth's climate: introduction and overview" George Reid *Space Science Reviews 94 (2000) p.1-11*

b. "Low cloud properties influenced by cosmic rays" N D Marsh & H Svensmark *Physical Review Letters 85 (2000) p. 5004-5007*

c. "Global temperature forced by solar irradiation and greenhouse gases?" Wibjorn Karlen *Ambio, Vol. 30 (2001)p. 349-350*

d. "The sun's role in climate variations" D Rind *Science Vol. 296 (2002) p. 673-677*

e. "Solar influence on the spatial structure of the NAO during the winter 1900-1999" Kunihiko Kodera *Geophysical Research Letters, Vol. 30 (2003) 1175 doi:10.1029/2002GL016584*

f. "Can slow variations in solar luminosity provide missing link between the sun and the climate?" Peter Fokul *EOS, Vol. 84, No. 22 (2003)p.205&208*

g. "Celestial driver of phanerozoic climate?" N Shaviv & J Veizer *Geological Society of America 13 (2003) p.4-10*

h. "Variable solar irradiance as a plausible agent for multidecadal variations in the Arctic-wide surface air temperature record for

the past 130 years" Willie W-H Soon *Geophysical Research Letters Vol. 32 (2005) L16712*

i. "solar forcing of the polar atmosphere" P A Mayewski et al *Annals of Glaciology Vol. 41 (2005) p. 147-154*

j. "The influence of the 11-yr solar cycle on the interannual-centennial climate variability" Hengyi Weng *J of Atmosphere and solar-terrestrial physics Vol. 67 (2005) p. 793-805*

k. "Living with a variable sun" Judith Lean *Physics Today (2005) Vol 58, No. 6 p. 32-37 American Inst. Of Physics USA*

l. "Phenomenological solar contribution to the 1900-2000 global surface warming" N Scafetta & B J West *Geophysical Research Letters Vol. 33 (2006) L05708*

m. "Phenomenological solar signature in 400 years of reconstructed northern hemisphere temperature record" N Scafetta & B J West *Geophysical Research Letters Vol. 33 (2006) L17718*

n. "Empirical evidence for a nonlinear effect of galactic cosmic rays on clouds" R G Harrison & D B Stephenson *Proceedings of the Royal Society A (UK): 10.1098/rspa.2005.1628 (2006)*

The above list includes papers which cover several areas of solar/climate link. The papers by Reid (a) and by Rind (d) provide a general overview of the sun's impact on the earth's climate through the LIA as well as through geological times and the complexity in establishing the solar/climate link. The study (j) by Weng re-confirms the solar variability impact on earth's climate by analyzing monthly sunspot numbers in conjunction with global and regional SSTs using a wavelet transform analysis technique. This powerful mathematical technique of wavelet transform is once again used by Willie Soon in study (h) to demonstrate a strong link between Total Solar Irradiance (TSI) and Arctic-wide surface temperature over a long period from 1875-2000. In study (e) the NAO (North Atlantic Oscillation), an important large-scale atmospheric oscillation, is shown to be strongly modulated by high & low solar activity as identified through sunspot cycles. Study (i) analyzes high-resolution calibrated proxies for atmospheric circulation from several Antarctic ice cores which reveal decadal-scale association with solar variability over the last 600 years. The study further demonstrates that changes in solar irradiance can significantly impact the earth's polar atmosphere, thus reinforcing the findings of other studies on solar variability and its linkage to the Arctic and Antarctic climate. Two

other recent studies [(l) & (m)] construct a phenomenological model to include solar forcing and demonstrate its linkage to the earth's temperature change over last 400 years.

In (c) Prof. W Karlen (a well-known paleo-climate expert) argues that the present interglacial has been cooler by about 2C than the previous ones during the last 400,000 thousand years when the atmospheric concentration of CO2 was 100 ppmv less than at present. If the earth's climate is sensitive to CO2 concentration only, then the present interglacial should be warmer than what it is and thus it can be concluded that the earth's climate during previous interglacials has responded more to solar variability than to CO_2 changes. Extending this argument, Prof. Karlen concludes in study (c) that the present warming is more due to solar variability than due to CO_2 concentrations. The studies by Peter Fokul (f) and Judith Lean (k) present additional evidence of recent changes in solar irradiance and make a case for solar impact on the earth's climate via more complex mechanism through changes in ultraviolet radiation, plasmas and fields. In study (g), authors Shaviv & Veizer document using a "sea-shell thermometer" how the earth's temperature over last 500 million years is decoupled with atmospheric CO_2 levels while showing strong correlation with variations in the cosmic ray flux. Two more recent studies (b & n) document how galactic cosmic rays can influence the earth's low cloud cover and how this in turn would impact the mean temperature.

Many more studies on solar/climate link have appeared in recent peer-reviewed literature. When all these studies are carefully scrutinized, a new and irrefutable solar/climate link emerges. The physical mechanism for this link still remains complex and not well understood, however there is now mounting evidence that the present climate change may be driven more by solar variability than by anthropogenic GHG. An experiment at the European Organization for Nuclear Research (CERN) to study the impact of high-energy particles on a prototype reaction chamber to recreate the earth's atmosphere is planned for 2008. This experiment may shed more light on the linkage between cosmic ray flux and changes in the earth's cloud cover.

3. Sea-level rise, ocean surface warming/cooling etc.

Among the most debated impacts of GW on future climate is the escalating sea-level rise (SLR) due to the melting of glaciers and polar ice sheets leading to massive flooding of coastal cities and adjacent towns. The possible disastrous impact of escalating SLR on small islands like the Maldives in the Indian Ocean and the Tuwalu Island in the Pacific were highlighted in many studies and articles during the 1990s. Recent media hype about the melting of Greenland and Antarctic ice sheets as depicted in the publicized movie "An Inconvenient Truth" has created an urgency about 'halting' the GW impact through GHG reduction.

It is instructive to look at the evolution of SLR value in the last ten years or so. The 1996 IPCC Document estimated a SLR of about 50 cm over the next one hundred years. Several papers published in the 1990s obtained SLR estimates which varied from a low of 20 cm/century to a high of 1 m or more. In recently published literature, SLR values have been moderated and the problem of uneven SLR in various ocean basins is being discussed. Some of the important recent papers are:

a. "New perspectives for the future of the Maldives" N-A Morner M Tooley & G Possnert *Global and Planetary Change 40 (2004) p. 177-182*
b. "Estimates of the regional distribution of sea-level rise over the 1950-2000 period" J A Church et al *J of Climate 17 (2004) p. 2609-2625*
c. "Low sea-level rise projections from mountain glaciers and icecaps under global warming" Sarah Raper & Roger Braithwaite *Nature V. 439 (2006) p. 311-313*
d. "Nonlinear trends and multiyear cycles in sea-level records" S Jevrejeva et al *J of Geophysical Research V.111(2006) C09012*
e. "On the decadal rates of sea level changes during the twentieth century" S J Holgate *Geophysical Research Letters 34 (2007) doi:10.1029/2006GL028492*

These and many other papers bring out a number of uncertainties re: SLR in the past and future. Prof. Morner and coworkers demonstrate [study(a)] that in the region of Maldives a general fall in SLR occurred some 30 years ago possibly due to increased evaporation in the central Indian Ocean and intensification of the NE Monsoon. Further, there does not appear to be any

evidence of increasing SLR in the near future. Authors Church and coworkers [study (b)] analyze patterns of regional SLR over the period 1950-2000 and conclude that it is not possible to detect a significant SLR over this period anywhere. These authors obtain global-averaged SLR rise of 1.8 mm +/- 0.3 mm per year over the 1950-2000 period. In study (c) Raper & Braithwaite obtain future projection of SLR from mountain glacier and icecaps (outside of Greenland & Antarctic Ice Sheets) as only about 5.1 cm by 2100, half of previous projections. The recent study (d) obtains global SLR trend of 2.4 mm per year for the period 1993-2000 and further document that over last 100 years the rate of 2.5 mm per year occurred from 1920-1945 and this trend is likely to be as large as the recent trend. This study further documents a nonlinear trend in various ocean regions and a 2 to 14 year variability in sea-level records which appears to be increasing in recent years. The latest study (e) [published January 2007] makes a careful analysis of nine long and continuous records of sea-level changes from 1904 through 2003 and obtains sea-level change of ~2.03 +/-.35 mm/yr from 1904-1953 while for the latter period 1954-2003, sea-level change is found to be lower ~1.45 +/-.34 mm/yr. The study further documents high decadal variability in sea-level changes with the highest decadal rate (~5.3 mm/yr) for the 1980s and the lowest rate (~1.74 mm/yr) for the ten-year period around 1964.

The warming and cooling of ocean surface as revealed by world-wide SST distribution has become an important topic of research in recent years. The warming of the world oceans by about 0.5^0C from the surface to a depth of ~750 m is now identified as the potential heat storage in the earth's atmosphere-ocean system which could lead to future warming of the earth's temperature. Several recent studies have documented warming as well as cooling of the upper ocean.

a. "The sustained North American warming of 1997 and 1998" A Kumar et al *J of Climate 14 (2001)p.345-353*
b. "Recent cooling of the upper ocean" J Lyman J Willis & G Johnson *Geophysical Research Letters 33 (2006) L18604*
c. "Anomaly of heat content in the northern Atlantic in the last 7 years: Is the ocean warming or cooling?" V Ivchenko N Wells & D Aleynik *Geophysical Research Letters 33 (2006) L22606*
d. "How much is the ocean really warming?" V Gouretski & K P Koltermann *Geophysical Research Letters 34 (2007) L01610*

These studies demonstrate the short-term variability of ocean surface warming & cooling and its significant impact on the earth's temperature structure. The paper by Kumar et al (a) shows how the sustained North American land warming was primarily due to the intense El Nino event of 1997/98 which produced and maintained high SST values over the Pacific basin as well as over other ocean basins through the middle of 1998. The North American warming contributed significantly to make 1998 the warmest year of the twentieth century according to the IPCC. In studies (b) and (c) recent cooling of the upper oceans and in particular of the southern North Atlantic is documented. A net loss of $3.2x10^{22}$ J of heat from the upper ocean between 2003 and 2005 is documented in study (b) and this loss is found to be comparable to the previous rapid cooling of $6x10^{22}$ J in the 0-750m layer from 1980 to 1983. In study (d) data from the Argo profiling buoys are analyzed for the North Atlantic and it is found that the southern North Atlantic has cooled in the last seven years. The latest study (d) [published January 2007] takes a closer look at the global hydrographic data as provided by bathythermographs (XBT) and finds a warming bias when the XBT data are compared against bottle and CTD (current, temperature, density) data. This warming bias is estimated to be between 0.2 to 0.4^0C on average giving an ocean warming artifact by a factor of 0.62. When taken together, the various studies discussed above suggest considerable variability re: ocean surface warming & cooling in recent years. Additionally recent cooling of ocean surface, which is not simulated by climate models, warrants further analysis on ocean heat storage and its long-term variability.

The IPCC 2007 Documents now estimate the total SLR over next one hundred years to be about 29cm +/- 15cm, this estimate being considerably smaller than some of the earlier estimates. The decadal variability of SLR as evidenced in the latest study suggests that future increase in sea level may be subject to considerable uncertainty.

4. Arctic & Antarctic temperatures: from Holocene to present

The climate of the Arctic and the Antarctic is complex and not fully understood at this time. The Arctic basin is especially more complex due to the presence of Arctic ocean and the Arctic pack ice which has varied in its extent and thickness considerably during the entire Holocene period, from about 11000 cal yr BP to the present time. It is now widely accepted that the Arctic Ocean was almost free of ice where there is permanent pack ice at present and that sailing activity was reported in that region during or about 1000 AD. The recent warming of the Arctic region is being widely reported and discussed in media as well as in popular scientific magazines and Journals and has now become a prime example of the disastrous impact of GW on the Arctic ecology and habitat. The IPCC 2007 Documents discuss extensively the possibility of Greenland and Antarctic Ice sheets 'melt-down' leading to an eventual sea-level rise anywhere from 2m to 7m. Several papers in recent literature discuss Arctic and Antarctic temperature changes in recent times and also of the past few thousand years. Some of key papers are listed below:

a. "First survey of Antarctic sub-ice shelf sediment reveals mid-Holocene ice shelf retreat" C J Pudsey & J Evans *Geology 29 (2001) p.787-790*

b. "Antarctic climate cooling and terrestrial ecosystem response" P Doran et al *Nature online 13 January 2002 (DOI:10.1038/nature 710)*

c. "Variability and trends of air temperature and pressure in the maritime Arctic, 1875-2000" I V Polyakov et al *J ournal of Climate 16 (2003) p. 2067-2077*

d. "Holocene climate variability" P A Mayewski et al *Quaternary Research 62 (2004) p. 243-255*

e. Global warming & the Greenland ice sheets" P Chylek J E Box & G Lesins *Climatic Change (2004) 63 p. 201-221*

f. "A multi-proxy lacustrine record of Holocene climate change on northeast Baffin Island, Arctic Canada" *Quaternary Research (2006) 65 p. 431-442*

g. "Greenland warming of 1920-1930 and 1990-2005" P Chylek M K Dubey & G Lesins *Geophysical Research Letters 33 (2006) L11707*

h. "Extending Greenland temperature records into the late eighteenth century" B M Winter et al *J of Geophysical Research 111 (2006) D11105*

i. "Ice shelf history from petrographic and foraminiferal evidence, Northeast Antarctic Peninsula" C J Pudsey et al *Quaternary Science Reviews 25 (2006) p. 2357-2379*

The papers listed above and several others in recent literature now clearly document how the temperatures in the Arctic and Antarctic regions have changed dramatically during the early to mid-Holocene as well as in the recent historical past. The paper by Mayeski et al (d) identifies *Rapid Climate Change* (RCC) throughout the Holocene involving cool polar regions and wet (or dry) tropical regions. Studies (a) and (i) document that the Larsen A & B Ice Shelves in the northeastern Antarctic Peninsula were probably altogether absent about two thousand years ago when the Antarctic temperatures in that region were likely as warm or perhaps warmer than the present-day temperatures. The study (i) further concludes that the CO_2 concentration was about 100 ppm lower than the present so the warming of the Antarctic during the mid-Holocene was due to reasons other than anthropogenic increase in atmospheric CO_2 levels. In study (b) Doran et al document a cooling trend in the Antarctica using recent temperature data. Study (c) presents a long series of temperature and pressure data (1875-2000) over the Arctic basin and document strong multi-decadal variability on a time scale of 50-80 years. These multi-decadal oscillations are identified as LFO (Low Frequency Oscillations) which strongly influence the Arctic (as well as the Antarctic) basin climate. Study (f) analyzes multi-proxy lacustrine records in northeast Baffin Island in the Canadian Arctic to show a pronounced Holocene temperature maximum, about 5C warmer than the present. In studies (e) and (g), it is shown that a rapid warming over all of coastal Greenland occurred in the 1920s when the average annual temperature rose between 2 and 4C in less than ten years. Further, it is shown that Greenland warmed at a faster rate during 1920-1930 than during the recent ten years 1995-2005. Finally study (h) extends Greenland temperature records back to the year 1784, using old records from the Danish Meteorological Institute. A careful analysis of the data shows that the 1930s and the 1940s were the warmest decades with 1941 as the warmest year. The study also documents that the 1810s were the coldest years in Greenland with the possible influence of volcanic eruptions including that of Mt Tambora in 1815.

These and many other recent studies now demonstrate the existence of RCC over the Arctic and the Antarctic during the entire Holocene. As the lead author Mayewski of study (d) and also of study (h) in section 4 concludes "*Bipolar expansion of high latitude atmospheric circulation systems and subsequent redistribution of low latitude atmospheric circulation begs a symmetrical forcing such as solar variability*". The present warming of the Arctic basin thus appears to be part of this natural variability and not a consequence of the GHG increase.

5. Impact of large-scale circulation patterns

The IPCC refers to a large number of recent studies on inter-annual variability of large-scale circulation patterns of the global atmosphere-ocean system and their impact on regional, hemispheric and global weather and climate anomalies. Among the important large-scale circulations that are discussed at present are: El Nino-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO), Arctic & Antarctic Oscillation (AO & AAO) and Pacific North American (PNA) flow pattern. Some of these atmospheric oscillations like SO (Southern Oscillation) and NAO were discovered by Sir Gilbert Walker in the early part of the twentieth century while the AO and the PNA have been identified in the 1980s through the insightful research of Prof. John Wallace and coworkers at the University of Washington (USA). The ENSO which is a combination of the El Nino event in the equatorial Pacific in conjunction with the SO has been the subject of large number of studies published in last 25 years. It is now generally accepted that an El Nino event (warming of the waters off the equatorial South American coast) produces milder winter weather for western Canada while its world-wide impact varies depending on the development and evolution of the event. The NAO and its possible impact of winter temperatures in eastern Canada and over Europe has been the subject of an intense study in recent years. The following list provides some key papers appearing in literature in last five years which document significant impact of these oscillations on mean temperature trends.

a. "A study of NAO variability and its possible non-linear influences on European surface temperatures" D Pozo-Vazquez et al *Climate Dynamics, Vol. 17 (2001) p. 701-715*

b. "Impacts of low frequency variability modes on Canadian winter temperature" B Bonsal, A Shabbar & K Higuchi *Int'l journal of Climatology, Vol. 21 (2001) p. 95-108*

c. "Are stronger North-Atlantic southwesterlies the forcing to the late-winter warming in Europe?" J Ottermann et al *Int'l J of Climatology, Vol. 22 (2002) p. 743-750*

d. "Variability of extreme temperature events in south-central Europe during the twentieth century and its relationship with large-scale circulation" P Domonkos et al *Int'l J of Climatology, Vol. 23 (2003) p. 987-1010*

e. "January Northern Hemisphere circumpolar vortex variability and its relationship with hemispheric temperature and regional teleconnection" R Rohli, K Wrona & M McHugh *Int'l J of Climatology, Vol. 25 (2005) p. 1421-1436*

The studies referenced above demonstrate the significant impact of large-scale circulation patterns on regional and hemispheric temperature trends. Studies (a) and (d) show that a positive value of the NAO index can produce winter season warming in Europe, while study (b) shows how an El Nino event together with positive values of the PDO index can provide strong positive winter temperature anomalies over most of Canada. In study (c), it is suggested that stronger southwesterlies in the North Atlantic may be producing early spring-like conditions in parts of Europe. In study (e) the circumpolar vortex and its linkage to AO variability as well as to the PNA pattern is discussed. It is hypothesized that the GW signal in surface temperature would cause a size reduction in the Northern Hemisphere circumpolar vortex as the cold pool of air over the poles would shrink. The study analyzes January data over a period from 1951-2001 and shows no change in the circumpolar vortex, thus suggesting no GW signal in the circumpolar vortex variability.

Several other studies now suggest a definite role of large-scale circulation patterns and their inter-annual or decadal variability on temperature trends over Europe and North America. These circulation changes are not directly affected by observed GW at this point in time. Some of the recent studies (listed in earlier sections) suggest a definite impact of solar variability on large-scale circulation patterns like NAO. Thus it can be argued here that the large-scale circulation changes are driven primarily by natural climate variability and there is no evidence of GHG-induced forcing on these circulation patterns at this point in time.

Most climate models do not fully simulate the natural variability of these large-scale circulation patterns. Consequently, future projections of climate change based on present climate models have little reliability.

6. Extraneous influence on mean temperature trends: urbanization, land-use change etc.

Assessing the influence of urbanization, land-use change and other extraneous influences like economic activity in and around city centers is a challenging and a difficult task. Several classical studies published in the 1970s and 1980s (e.g. 'City size and the urban heat island' T R Oke, *Atmospheric Environment, 1973,* H Landsberg's book 'The Urban Climate' 1981, Academic Press) have documented urban-rural temperature differences to be as large as 8 to 10^0C on a given day. The IPCC Climate Change Documents of 1996 & 2001 assert that the urbanization impact, when averaged over all land stations, contributes to no more than 0.06C for the mean temperature trend over 100 years. This value appears too small per several recent studies. Some of the key papers appearing in recent literature are listed below:

a. **"**The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases" R A Pielke sr et al *Phil. Trans. R soc. London UK (2002)360 p.1705-1719*

b. "Impact of urbanization and land-use change on climate" E. Kalnay & M Cai, *Nature, Vol. 423, 29 May 2003, p. 528-531*

c. "The urban heat island in winter at Barrow, Alaska" K Hinkel et al *International J of Climatology, Vol. 23, 2003, p. 1889-1905*

d. "Impacts of anthropogenic heat on regional climate patterns" A Block, K Keuler & E Schaller *Geophysical Research Letters, Vol 31, L12211, 2004*

e. "A test of correction for extraneous signals in gridded surface temperature data" R McKitrick & P Michaels, *Climate Research, Vol. 26, 2004, p. 159-173*

f. "Evidence for a significant urbanization effect on climate in China" L Zhou et al *Proc. National Academy of Science(USA) V. 101 (2004) p.9540-9544*

g. "Evidence for influence of anthropogenic surface processes on lower tropospheric and surface temperature trends" A T J De Laat & A N Maurellis, *International J of Climatology, 26, 2006, p. 897-913*

h. "Urban heat island effect analysis for San Juan, Puerto Rico" A Velazquez-Lozada, J E Gonzalez & A Winter, *Atmospheric Environment, 40, 2006, p. 1731-1741*

In the above, the paper (a) by Pielke sr et al is considered a landmark paper in the present GW debate, as this paper brings out an important aspect of land-use change and its dominating impact which could overwhelm the GHG forcing of the climate system in future. Study (b) uses the NCAR (National Centre for Atmospheric Research, USA) re-analysis of upper-air data and an extrapolation to the surface to obtain the urbanization impact on mean temperature trend to be about 0.28^0C over 100 years and about 0.18^0C over the recent 30 years. Study (c) obtains the urban-rural temperature difference of over 2^0C during the winter months at Barrow, Alaska, while study (d) shows how anthropogenic heat release from highly industrialized and populated areas can produce a permanent warming from 0.15 to 0.5^0C with additional heat flux between 2 to 20 Wm^{-2} over affected areas. In study (e), the impact of economic activity (e.g, per capita income, growth rate, coal use etc) on mean temperature trend (1979-2000) measured at over 200 locations in 93 countries was estimated using a linear regression analysis. The study documented a definite warm bias in the temperature trend as a result of non-climatic impact of local (and regional) economic activity. Study (f) uses an integrated modeling approach to delineate urban influence on the mean temperature and obtains urbanization impact over China to be more than the estimated 0.27^0C in the USA during the twentieth century. In study (g), the influence of anthropogenic surface processes on mean temperature trends were estimated using GHG emission world-wide database as proxy for industrial activity. The mean temperature trends at highly industrial regions and locations were found to be higher than elsewhere, thus confirming the impact of non-GHG anthropogenic processes on surface temperature changes. Finally the study (h) documents a strong urban heat island effect at San Juan, Capital city of Puerto Rico. The urban heat island effect is estimated to be increasing at a rate of about 0.06^0C per year over last forty years and it is estimated that the urban-rural temperature difference could increase to about 8^0C by the year 2050 at the present urbanization growth rate in and around San Juan.

These and several other recent studies confirm that urbanization and land-use change impact on the earth's climate system is much larger than what the IPCC and its supporting scientists have assessed so far. The upcoming IPCC Document on Climate Change to be published in early 2007

recognizes urban influences but discounts its impact on mean temperature trend as small and insignificant. The papers listed above clearly demonstrate significant non-GHG impact which must be removed from the mean temperature trend so as to determine the mean temperature rise *due to human-added CO2 only*. Removing the urban influence may reduce the mean temperature rise to just about 0.10^0C per decade over recent 25 to 30 years which is not of major concern.

A careful assessment of the mean temperature trend in recent 25 to 30 years is needed to confirm if the recent increase in earth's mean temperature is primarily due to human-added GHG or is a combination of a number of other parameters that are being debated in peer-reviewed literature at present.

7. Uncertainties in climate model simulations of regional & global features

There are literally hundreds of peer-reviewed papers on climate models in many international Journals that it is impossible to summarize their findings and projections in this section. Here we have selected several key papers on climate model simulations of regional and global features like Asian Monsoon, El Nino and its global impacts etc and have briefly summarized the uncertainties associated these simulations. Also listed are global model simulations which document the inclusion of processes not included in the present suite of GCM used for projecting the earth's climate over next fifty to one hundred years:

a. "Potential role of solar variability as an agent for climate change" C Bertrand & J Van Ypersele *Climatic Change V 43 (1999) p.387-411*

b. "Simulated impacts of historical land-cover changes on global climate in northern winter" T N Chase et al *Climate Dynamics V 16 (2000) p. 93-10*

c. "Monsoon prediction-why yet another failure?" S Gadgil M Rajeevan & R Nanjundiah *Current Science(India) V 88 (2005) P.1389-1400*

d. "Detection and attribution of twentieth-century northern & southern African rainfall change" M Hoerling et al *J of Climate V 19 (2006) p. 3989-4008*

e. "ENSO evolution and teleconnections in IPCC's twentieth-century climate simulations: realistic representation?" R Joseph & S Nigam *J of Climate V 19 (2006) p.4360-4377*

f. "Precipitation characteristics in eighteen coupled climate models" Aiguo Dai *J of Climate V 19 (2006) p.4605*

g. "Is the thermohaline circulation changing?" M Latif et al *J of Climate V 19 (2006) p.4631-4637*

These and many other recent papers bring out several uncertainties in climate model simulations. In study (a) a two-dimensional model is used to assess the potential impact of solar variability on the earth's surface temperature from 1700 to 1992. It is shown that although total solar irradiance reconstruction is insufficient to reproduce observed warming of the 20th century, the model response suggests that the Gleissberg cycle (~88

yr) solar forcing should not be neglected in explaining the century-scale time variations. In study (b) the authors examined ten years of modeled equilibrium January climate differences between simulations which were forced at the surface by spatially realistic depiction of current land surface and an estimate of natural potential vegetation in equilibrium with current climate. The simulations suggest that anthropogenic land cover changes can produce teleconnection patterns affecting global temperature and precipitation distributions.

In study (c) the authors examine prediction of the Indian monsoon for 2004 made by empirical as well as by dynamical models and conclude that the skill in forecasting the Indian summer monsoon variability has not improved in the last fifty years or so when some of the empirical models were introduced. The skill of dynamical models was found to be even worse. In comparing observed monsoon rainfall totals with simulated values from 20 state-of-the-art GCM, the authors found that none of the dynamical models were able to "*simulate correctly the interannual variation of the summer monsoon rainfall over the Indian region"* The authors lament the fact that after so many years of climate model development, the models are still not able to simulate one of the largest and regionally the most important atmospheric phenomena, the tropical monsoon and further question the validity of many GCM for simulating the impact of anthropogenic GHG forcing on future projections of the earth's climate. In study (d) the impact of Atlantic and global SST patterns on African rainfall changes for the twentieth century is investigated using five coupled GCM as part of the IPCC fourth (2007) assessment project and it is found that the Sahel region drought from 1950-2000 period was not influenced by the GHG forcing, indicating that the Sahel drought conditions were likely of natural origin. The same study further concludes that natural variability will continue to be the primary driver of Sahel region's low frequency rainfall variations during the next century. In another similar model inter-comparison study (f), precipitation characteristics of eighteen coupled climate models were examined by analyzing monthly and 3-hourly precipitation output and it is found that most models produce too much convective and too little stratiform precipitation over most of the low latitude regions. The same study further concludes that considerable improvements in precipitation simulations are still desirable for the latest generation of the world's coupled climate models.

Two other studies listed above relate to simulation of two important large-scale features of the earth-atmosphere system, namely the El Nino-Southern Oscillation (ENSO) and the Thermohaline Circulation (THC) in the North Atlantic. In study (e), the authors examined ENSO simulations by a suite of coupled models as part of IPCC Fourth (AR4) assessment project and conclude that climate models *are still unable to simulate many features of ENSO variability, its circulation and hydroclimatic teleconnections. Further the climate system models are not quite ready for making projections of regional-to-continental scale hydroclimatic variability and change.* The final study (g) in this section examines the THC in the North Atlantic which is responsible for large amounts of heat and freshwater transport by the Gulf Stream and the North Atlantic current. Analyses of ocean observations and model simulations suggest that the changes in the THC during the twentieth century are likely to be the result of natural multidecadal climate variability and are driven by low-frequency variations of the NAO (North Atlantic Oscillation). The study further concludes that there is no evidence of sustained weakening of the Meridional Overturning Circulation (MOC) as reported in several recent studies.

In summary the present suite of climate models cannot as yet provide reliable projection of the earth's climate over the next fifty to one hundred years. In a recent paper "*Will our ride into the greenhouse future be a smooth one?"* GSA Today (2007), Prof. Wallace Broecker, recipient of the 2006 Craaford Prize (Sweden) succinctly summarizes the present state of the earth's climate and climate models as follows:

"My lifetime study of Earth's climate system has humbled me. I am convinced that we have greatly underestimated the complexity of this system. Global climate change predictions are mostly mental masturbation in the final analysis"

8. Miscellaneous Studies

This section includes papers which question one or more of the GW science issues (e.g. review papers) and also papers which deal with GW impacts like extreme weather events, economic losses etc. The section also lists papers which discuss other issues not covered earlier. A total of ten papers published in last five years are listed here:

a. "Reconciling observations of global temperature change" Richard Lindzen & Constantine Giannitsis *Geophysical Research Letters V 29 (2002) No 12 10.1029/2001GL014074*

b. "Compilation and discussion of trends in severe storms in the United States: Popular perception vs climate reality" Robert Balling Jr & Randall Cerveny *Natural Hazards V 29 (2003) p. 103-112*

c. "On destructive Canadian Prairie windstorms and severe winters: A climatological assessment in the context of global warming" Keith Hage *Natural Hazards V 29 (2003) p. 207-228*

d. "Shifting economic impacts from weather extremes in the Unites States: a result of societal changes, not global warming" Stanley Changnon *Natural Hazards V 29 (2003) p. 273-290*

e. "The global warming debate: A review of the present state of science" M L Khandekar T S Murty & P Chittibabu *Pure & Applied Geophysics V 162 (2005) p. 1557-1586*

f. "Extreme weather trends vs dangerous climate change: A need for a critical reassessment" M L Khandekar *Energy & Environment V 16 (2005) p.327-331*

g. "The interaction of climate change and the carbon dioxide cycle" A Rorsch R S Courtney & D Thoenes *Energy & Environment V 16 (2005) p. 217-238*

h. "Can we detect trends in extreme tropical cyclones?" Christopher Landsea et al *Science V 313 (2006)p.452-454*

i. "Trends in western North Pacific tropical cyclone intensity" M-C Wu K-H Yeung & W-L Chang *EOS Transactions AGU V 87 (2006) No 48 28 November 2006*

j. "On global forces of nature driving the earth's climate: Are humans involved?" L F Khilyuk & G V Chilinger *Environmental Geology V 50 (2006) p. 899-910*

Three of the studies (b, c & f) listed above discuss the GW impacts in terms of extreme weather (EW) events and their trends in recent years. Recent media reports and popular scientific articles often discuss about increasing trends in EW events and its linkage to rising temperature of the earth's surface in response to increasing GHG in the atmosphere. The three studies listed above carefully analyze available data on EW events in the USA, Canada and elsewhere and discount any possible link between EW & GW. Study (b) documents the mismatch between popular perception as created by media reports and climate reality which does not show EW as increasing in the USA. Study (c) makes a painstaking analysis of large amount of data extracted from Canadian Prairie farm news letters and other sources over a long period 1880-1984. Based on a detailed analysis of these data, the author (Emeritus Prof. Keith Hage, University of Alberta) documents a temporal frequency peak in severe windstorms and associated tornadoes during the Dust Bowl years of 1920s and 1930s. The windstorm frequency shows a steady decline since 1940 through 1980s. A steep rise in tornado frequency since 1970 is attributed to increasing awareness and reporting of tornado activity in recent years and NOT due to change in tornado climatology. In study (f) the EW events over Canada and elsewhere are carefully analyzed and it is shown that EW events like heat waves, winter blizzards, rainstorms, droughts etc are not increasing anywhere in Canada, USA or elsewhere where sufficient data are available for adequate analysis; some of the EW events like winter blizzards are definitely on the decline on the Canadian Prairies in the last 40 years. In study (d) the author (Stanley Changnon, a respected US climatologist) documents that *increasing economic impacts of EW events in the USA is a result of societal change and NOT global warming*.

In study (a) the authors Lindzen & Giannitsis analyze the discrepancy between global mean temperature trends obtained by satellite microwave data and surface temperature measurements. The authors argue that the warming of the troposphere in recent 25 years is likely associated with tropospheric jump and atmospheric regime change occurring around 1976/77. The authors further argue that the troposphere/surface temperature discrepancy can be reconciled if the earth's climate sensitivity (earth's mean temperature rise due to doubling of carbon dioxide) is assumed small, just

about 1C or so. The paper (e) is a review paper in which the authors (Khandekar et al) conclude that the recent warming of the earth's surface is primarily due to urbanization, land-use change etc and not due to increasing GHG in the atmosphere. The authors further document the possible role of solar variability on the mean temperature increase and discuss the SLR in and around the Maldive Islands as a regional change not associated with any global change in SLR. In study (g) the authors develop a mathematical model for atmospheric carbon cycle and argue that the relatively large rise of carbon dioxide in the twentieth century was caused by the increase in the mean temperature that preceded it. The rise in the carbon dioxide was possibly due to disorption (release of CO_2) from the oceans with an observed time lag of half a century or about. The authors further argue that a rigorous mathematical analysis cannot be made to prove that the recent rise in the atmospheric CO_2 can be attributed solely to anthropogenic emission. Other processes such as microbiological activity cannot be discounted as possible source for the recent rise of CO_2 .

The next two studies (h) & (i) deal with the issue of strengthening of tropical cyclones/hurricanes due to GW and in particular due to warming of the oceans. The lead author (Chris Landsea, a leading hurricane expert) in study (h) suggests that the Dvorak technique developed to estimate hurricane strength was not available in the early 1970s or before when some of the hurricanes & tropical cyclones [e.g. Bay of Bengal cyclone 1970; hurricane Camille (USA) 1969] may have been stronger than estimated then. The recent paper from EOS [study (i)] suggests that the western North Pacific tropical cyclone climatology does not reveal increasing strength for typhoon records from 1965 till 2004. These two studies (h) & (i) demonstrate the uncertainty in establishing a definitive link between GW and hurricane strength.

The last study (j) is a comprehensive review of the global forces driving the earth's climate over geological times going back to two billion years and argues that the present warming of the last 150 years is a short warming episode in the earth's geologic history. The authors further argue that the earth's temperature history of last 1000 years suggest that we are in a cooling geologic epoch and further the human activity (anthropogenic GHG emission) may be responsible for only 0.01^0C of approximately 0.56^0C warming of the twentieth century.

Summary & Conclusions

This Document has examined 69 peer-reviewed papers out of a much larger number that have appeared in various international Journals in the last six years. These papers cover a wide range of topics pertaining to the present debate on the GW science. Most of the papers listed above have questioned the present view of the GW science and when taken together, these papers and many others not listed here provide an emerging view of the science of global warming & climate change which is at odds with the prevailing view. The emerging view can be briefly summarized as follows:

1. The recent warming of the earth's surface (~0.4^0C) is significantly influenced by human activity on ground like urbanization, land-use change etc. The warming due solely to human-added CO_2 appears to be a smaller part of the total recent warming.
2. Solar variability and changes in large-scale atmospheric flow patterns in recent years have also contributed to some of the recent warming of the earth's surface.
3. The Arctic Basin temperature changes of the last 125 years appear to be intimately linked to the Total Soar Irradiance (TSI) while showing a weak correlation with atmospheric CO_2 concentrations.
4. The earth's climate experienced *Rapid Climate Change* during the entire Holocene period and in particular during the last 5000 years or so. Ice core and other proxy data document mid-Holocene warming of the Arctic as well as of the Antarctic. This Holocene warming appears to be strongly linked to solar variability and not to the greenhouse gas forcing.
5. There does not appear any discernible link between Global Warming and recent increase in extreme weather events world-wide. The apparent increase in extreme weather events is more a perception than reality, this perception being created due to increased media attention and publicity of extreme weather events.
6. North Atlantic hurricanes appear to have strengthened in recent years; however typhoons and tropical cyclones in other ocean basins do not show consistent increase in strength in recent years.
7. The SLR (Sea Level Rise) of the twentieth century is influenced significantly by inter-decadal variability. The most recent study

(published January 2007) shows that the sea-level change in the last fifty years were smaller than those in the early part of the twentieth century. There is no evidence of accelerated sea-level change in recent years.

8. Present state-of-the-art coupled climate models still cannot simulate many important features of major climate events like ENSO and tropical and/or Asian Monsoon at this time. The climate models do not simulate many features of convective or large-scale precipitation characteristics.

9. The Thermohaline Circulation (THC) in the North Atlantic has exhibited considerable variability in the twentieth century; however this variability appears to be part of natural multi-decadal climate variability and does not appear to be linked to Global Warming.

10. Future projections of earth's climate using present climate models do not have sufficient reliability for climate policy decisions.

Glossary of acronyms & t*erms*

1. AO: Arctic Oscillation; a circumpolar slow-moving circulation pattern whose strength and intensity controls northern hemisphere winter weather through occasional outbreaks of cold Arctic air. Similar circulation pattern for southern hemisphere is identified as AAO (Antarctic Oscillation).
2. CTD: current, temperature and density values for world oceans; these oceanic parameters are measured through a network of suitable instruments.
3. ENSO: El Nino-Southern Oscillation. El Nino refers to the warming of the equatorial eastern Pacific surface waters with an irregular 3 to 7 year cycle. Southern Oscillation (SO) is a slow varying equatorial surface pressure oscillation and is a measure of exchange of air between eastern & western hemisphere. The SO was first discovered by Sir Gilbert Walker in 1932.
4. EW: Extreme Weather (events)
5. GW: Global Warming (of the earth's surface, land-ocean combined)
6. GCM: General Circulation Models (of the atmosphere-ocean system)
7. GHG: Greenhouse Gases (CO_2 , methane & nitrous oxide)
8. IPCC: Intergovernmental Panel on Climate Change (a United Nations Body established 1988 by two UN Agencies WMO & UNDP)
9. LIA: Little Ice Age (approx from 1600 till 1900)
10. MOC: Meridional Overturning Circulation (referred to the North Atlantic circulation carrying warm waters from the tropics to high latitudes and contributes to the warming of Northern Europe)
11. MWP: Medieval Warm Period (approx from 8^{th} thru 13^{th} century)
12. NAO: North Atlantic Oscillation, a slow varying pressure oscillation over the North Atlantic and measured by sea-level pressure difference between two locations, Lisbon (Portugal) & Reykjavik (Iceland).
13. PDO: Pacific Decadal Oscillation is an ENSO-like oscillation exhibiting inter-decadal variability over the North Pacific. It is derived as the leading principal component of monthly SST anomalies over the North Pacific, north of 20^0N.
14. PNA: Pacific North American atmospheric flow pattern, first defined by Wallace & Gutzler in 1981. It is a characteristic & persistent flow pattern that controls weather & climate of North America especially during the winter season. It is defined in terms 70-kPa height anomalies and is a representative measure of mid-tropospheric

atmospheric over the central and eastern North pacific and North America.

15. ppm/ppmv: parts per million by volume (the atmospheric concentration of carbon dioxide is measured by ppm or ppmv. In real atmosphere, carbon dioxide represents only about 0.03% of the total atmospheric gases)
16. RCC: Rapid Climate Change; this refers to rapid change in the earth's climate during the Holocene, the change in the earth's climate taking place in a matter of few decades
17. SST: Sea Surface Temperature
18. THC: Thermohaline Circulation (it is a global three-dimensional belt of ocean currents that transport large amounts of heat *(thermo)* and fresh water and is driven by density *(haline)* stratification)
19. TSI: Total Solar Irradiance (measured in W/m^2; TSI values going back to the solar Maunder Minimum of 1645-1715 have been reconstructed using solar cycles and other proxy data)
20. UNFCC: United Nations Framework Convention on Climate Change (established 1992 to monitor greenhouse gas emission targets of world Nations)

Author information:

Dr Madhav L Khandekar is a former Research Scientist from Environment Canada where he worked for about 25 years. Khandekar holds M.Sc degree in Statistics from India and M.S. and Ph.D. degrees in Meteorology from USA. Khandekar has been in the fields of atmosphere/ocean/climate for over 49 years and has published over 120 papers, reports, book reviews, scientific commentaries etc. He has published over 40 peer-reviewed papers in various international Journals and authored a book on ocean surface wave analysis and modeling, published by Springer-Verlag in 1989.

Khandekar is presently on the editorial board of the Journal *Natural Hazards (Netherlands)* and is a former editor of the Journal *Climate Research (Germany*). He is also an expert reviewer for the IPCC (Intergovernmental Panel on Climate Change) Climate Change Documents (AR4) to be published in 2007.