Trans. Nat. Aca. Sci. Tech. Philippines 22: 11-36 (2000).
ISSN 0115-8848

THE DETECTION OF CLIMATE AND ENVIRONMENTAL CHANGES FROM SATELLITE AND IN SITU OBSERVATIONS

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ABSTRACT

The observed positive trends of anthropogenic CO_2 and other greenhouse gases in the atmosphere has been linked to human activities and may cause a profound influence on climate. Global surface temperatures, as observed by meteorological stations, have been increasing at the rate of 0.4 K per decade during the last century. Surface and satellite data show that warming actually accelerated during the last century. Surface and satellite data show that warming actually accelerated during the recent decade providing evidence that the greenhouse induced change may already be occurring. This phenomenon is studied in detail in the polar regions where climate change signal is expected to be amplified due to feedback effects associated with the high albedo of ice and snow. The 50- to 100-year data records from polar stations show consistently higher warming trends in both regions than global trends. The 20 year satellite record and corresponding in situ data, however, show symmetric effects: a warming and a sea ice retreat in the Arctic but a slight cooling and a sea ice cover advance in the Antarctic. This counter-intuitive observations are actually supported by a previous simulation study of greenhouse warming effects using a global circulation model. Satellite data also reveal large regional variability countries. Ensuing changes in the environment and associated impacts on society may be drastic and costly depending on location. The strategy to mitigate the impacts must include a good understanding of the Earths climate system.

Key words: climate change, environment, warming, trends, sea ice,

1. INTRODUCTION

Throughout history, the way of life of human societies has been profoundly influenced by climatic events. Some civilizations have greatly benefited from occurrences of favorable climates while some others have even disappeared because of failure to adjust to adverse climatic conditions. There have been major ones such as the ice ages, that kept the northern hemisphere in deep freeze for a long time, and relatively minor ones, such as the El Nino, that have relatively short durations but can be difficult to cope with. The El Nino of 1997 to 1998, for example, came out as a very damaging climatic event since it caused the lost of many lives and billions of dollars in property damages.

Climatic events have been regarded as part of natural cycles that are driven by external forces such as changes in the luminosity of the sun and the orbital parameters of the Earth. The discovery of increasing levels of CO_2 in the atmosphere at Mauna Loa, Hawaii in 1980, however, started a big debate on the possible influence of human activities on climate. CO_2 is on the greenhouse gases in the atmosphere that keeps radiation from escaping the Earth and thereby causes surface warming (Daly, 1989). It has been postulated that the observed acceleration in the rate of increase in temperature in recent years is caused by such greenhouse warming (Hansen et al., 1984). Recent reports about the retreat and thinning of sea ice, the disappearance of glaciers, the rising sea level, and the calving of big icebergs (Parkinson et al., 1999 Rothrock et al., 1999; Williams et al., 1993) only serve to reinforce the credibility of this hypothesis. The unusual intensity of the 1997 to 1998 El Nino has also been cited by some as a consequence of such an anthropogenic driven climatic influence.

The industrial revolution and the energy needs of an ever increasing global population have been regarded as the culprit for the observed increases in CO2 and other greenhouse gases in the atmosphere. Although the burning of fossil fuels has been identified as the key reason for the increase, there has been a strong resistance against cutting the practice because it has become an integral part of modern society and is currently the most viable source of energy for our factories, motor vehicles, home heating and air conditioning. To compound the problem, global population has been increasing at a high rate and in addition to the demand for more energy, there is the demand for more residential and agriculture lands that may involve the clearing and/or burning of forests and the elimination of wetlands. The accounting of all the sources and sinks of greenhouses and the study of the global carbon cycle have become a serious endeavor for both scientists and policy makers who are anxious to find an amenable resolution to the problem.

The atmospheric increase in CO_2 is not the only issue, however, in terms of human impact. The same factories, facilities, and motor vehicles also cause the introduction of pollutants to the atmosphere and the environment and substantially degrade the overall quality of the latter. Pollution also threatens the health and well being not only of human beings but also of plants and animals that we all depend on. Some of our lakes and rivers have become toxic on account of improper disposal of waste, fertilizers and pesticides. The elimination of swamps and wetlands have also altered the ecology and caused devastating impacts on birds and marine life. Air pollution, a big health threat, has also grown to be a huge problem in big cities where traffic jam is part of daily activities. Moreover, the innocent release of some chemicals unsuspectingly led to the depletion of the ozone layer in the stratosphere (Schoeberl, 1993) and caused what is now popularly known as the ozone hole, the consequences of which are yet to be completely understood.

The direct impact of human activities on climate and environment has been studied but results have been controversial and subject to intense scrutiny because the solutions to the problem are expensive and unpopular. While there are observed indicators of a global warming that are convincing, the link of such warming to human activities has not been established beyond reasonable doubt. Sorting out the anthropogenic effects from those of natural cycles has been a problem because the Earth system is such a complex system the study of which requires the availability of a comprehensive global data set and a sophisticated model of the interactions and feedback effects of so many variables. In this paper, we will review the issues, present new insights on the issues, and discuss short as well as long term impacts of a climate change on the environment and society.

2. NATURAL CLIMATE CYCLES AND CHANGES

The task of making climate predictions has been difficult and could benefit enormously from accurate identification and characterization of the natural cycles of climate. A dependable prediction capability would enable society to be better prepared for changes and to implement an affective utilization of climate as a natural resource. The biblical account on "seven years of plenty and seven years of famine," as cited in the Book of Genesis, is a good example of how knowledge of climate cycles can be utilized for the good of mankind. However, historical records have indicated that man rarely utilized climate in this same way because generally, climate has not been so predictable.

Since the sun is the primary source of energy that drives the Earth's climate, studies of the cycles have been focused on changes in the net input of solar energy on the Earth. Such changes in solar energy input can come from changes in orbital parameters of the Earth with respect to the Sun and/or changes in the luminosity of the Sun itself. While in search for explanation for ice ages, Milankovitch postulated in the early 19th century three climate cycles related to changes in the Earth's orbital parameter: (a) 100,000 to 413,000 years associated with changes in the shape of the elliptical orbit (eccentricity) of the Earth; (b) 19,000 to 23,000 years due to the wobble (precession) of the Earth's axis; (c) 41,000 years, associated with changes in the tilt of the Earth's axis. The concept for these three cycles is illustrated schematically in the top three panels of Figure 1. Since the Sun is such a powerful source of energy, even the small change in orbital parameter can make a big difference. Historical records of the Earth's climate over the past hundreds of thousand of years have been preserved in ice sheets, glaciers and bedrock. Studies of cores from these places have confirmed that such cycles in the climate indeed existed. The last panel in Figure 1 shows a comparison of modeled overall effect of the three cycles (black line) and inferred temperature data indicating

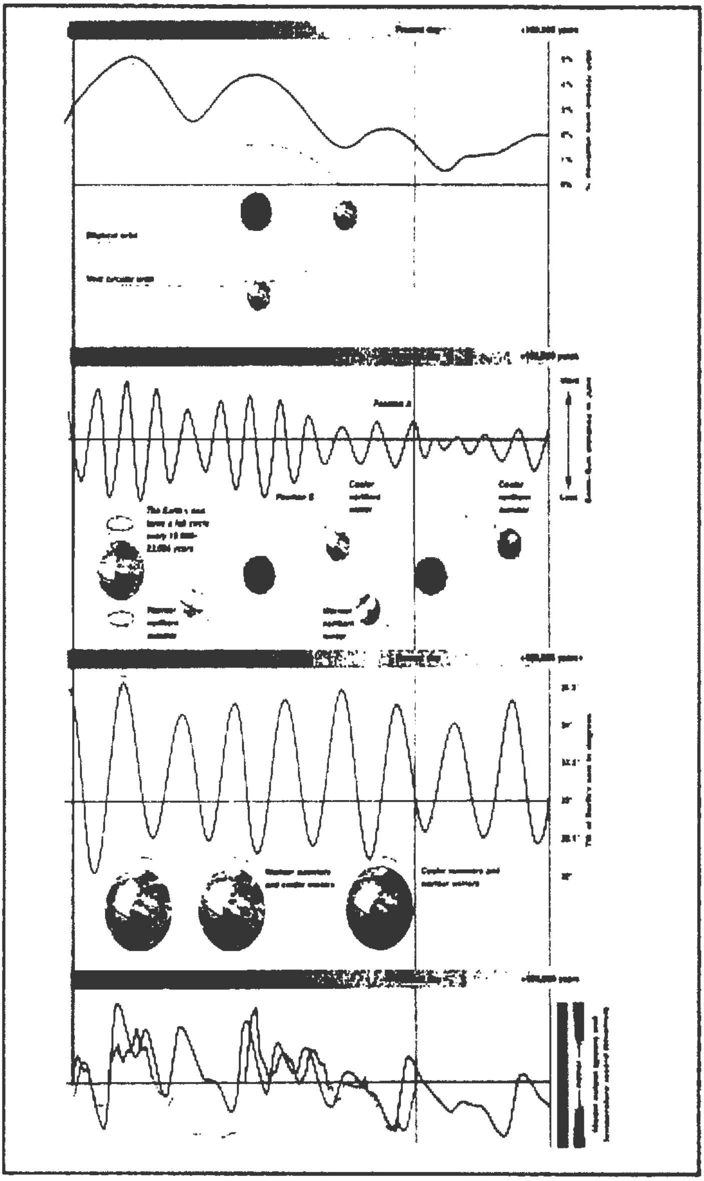

Figure 1. Schematic of the Melankovitch cycles for (a) orbital eccentricity, (b) wobble on the axis, (c) tilt on the axis (that rocks back and forth), and (d) the temperature predictions with the bold line being the model output and the gray being the observed temperatures. (from Burroughs, 1999)

credibility of the hypothesis. The schematics also show where we stand today in terms of these cycles and what to expect in the next 100,000 years. Because of the long term periodicity, the impacts within a human lifetime are usually minimal.

Another possible source of a cycle would be a changing Sun which incidentally has been observed to be indeed changing. The periodicity of these changes are more short term and are therefore more relevant to present day problems. The discovery of the presence of sunspots came as a big surprise when Galileo turned his telescope towards the Sun in the 17^{th} century. It turns out that the Sun gets in energy from nuclear fusion and that the sunspots are areas on the surface that are active with flares, coronal mass ejections, and other forms of activity. It was also discovered that the number of sunspots changes in a cyclic manner with a period of about 11.2 years (Figure 2). Such periodicity were soon observed in many proxy records including those of tree rings and oxygen isotopes from ice sheet cores. The separation of the tree rings provide a means to interpret growth rates which changes from one year to another because of changes in annual temperature and amount of rain. Tree rings record goes back 9000 years and yield periodic fluctuations similar to solar activity. The isotopic ratio of O^{18} to O^{16} from ice cores also provides a means to obtain proxy temperatures and studies of this ratio have revealed that the Earth's surface temperature has been changing with the same periodicity as the sunspots over time. Using data from space probes that started in 1980, there is now a direct confirmation of solar energy variability and the existence of an 11.2 year cycle.

Along with the 11.2-year cycle associated with the Sun is the "Gleissberg" cycle which has a time scale variation of approximately 90 to 100 years (Gleissberg, 1966). This variation would cause longer term climatic changes on the surface of the Earth than the sunspot cycle. Evidence of this cycle was also found in oxygen isotopes (Danggaard et al., 1971) and in tree rings (Moseley, 1940).

There are many other cycles that have been discovered over the years. Examples are the North Atlantic Oscillation and the Arctic Oscillation that have decadal variability (Maysak et al., 1999) and hence have been associated with the sunspot cycle. There is also the Southern Oscillation with a period of about 5 years, associated with the periodic occurrences of the El Niño. Furthermore, there is the quasi-biennial oscillation which occurs every 27 months or so associated with the periodic reversal of winds in the lower stratosphere over the equatorial region. We should also mention the seasonal and diurnal cycles that we are all familiar with.

The cycles are sometimes not so easy to recognize because there are so many of them and the net effect of some cycles is suppressed by other cycles. There are also other effects, like volcanic eruptions, that affect the overall influence of the natural cycles. During volcanic eruptions, tons of sulfur dioxide and dust are emitted to the mid-atmosphere where they stay for a few years and are spread out around the globe. The sulfur dioxide turns to tiny sulfuric acid droplets which together with the dust particles form a veil that absorb sunlight in the stratosphere thereby reducing the amount of solar radiation reaching the Earth's surface. It was Benjamin Franklin who first recognized the impact of volcanic eruption to weather

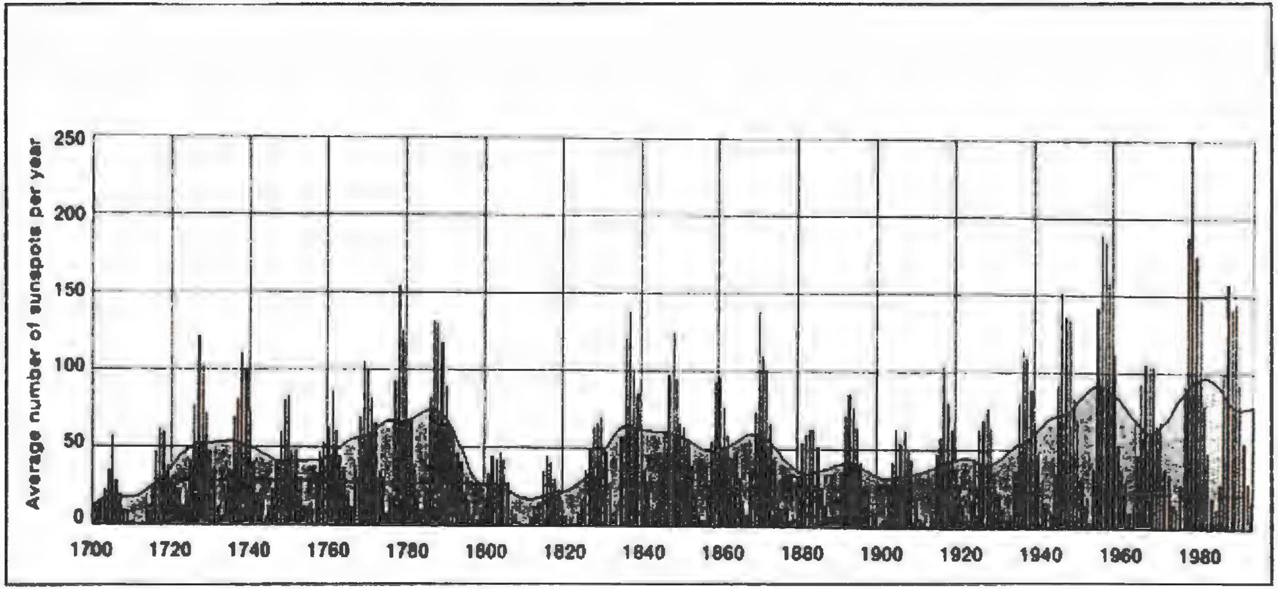

Figure 2. Number of sunspots per year from 1700 to 1990.

when he accurately interpreted the cooling in northern Europe in the winter of 1783 to 1784 as due to dust clouds from the eruption of Laki in Iceland in July 1783. The eruption of Mount Pinatubo in 1991 provided the clearest evidence yet of how volcanoes affect the climate since the impact was well documented and monitored by sophisticated satellite systems.

3. ANTHROPOGENIC IMPACTS AND GLOBAL MODELING

The possible impact of atmospheric CO_2 on the climate of the Earth due to greenhouse effects was first postulated in 1896 by Arrhenius. When radiation from the Sun hits the surface of the Earth, longwave radiation is emitted back to the atmosphere where it is absorbed and re-emitted back to Earth. Much of the radiation is thus trapped between the Earth and the atmosphere by these so-called greenhouse gases. The time series of CO_2 concentrations in the atmosphere at Maona Loa, Hawaii (Figure 3), shows a 30% increase since the industrial revolution and started the big concern that greenhouse gases might cause significant warming effect on the planet Earth.

Other trace gases are also known to cause greenhouse warming as well, including methane, ozone, CFCs (chlorofluorocarbons) and nitrous oxide (released by nitrogen-based fertilizers). Of these, methane is the most important since its concentration in the atmosphere has more than doubled since the pre-industrial period. The sources for the latter include the biological activity of bacteria in paddy fields and the guts of cattle, as well as the release of natural gas from commercial oil and gas fields and landfills. While not as concentrated in the atmosphere are CO_2, the effectiveness of these gases as greenhouse gases on molecule by molecule basis can be much more potent. For example, a molecule from the two most common CFCs has the same greenhouse warming effect as 10,000 molecules of CO_2.

The best way to understand the impact of greenhouse gases is through the use of climate simulation numerical models that is usually referred to as Global Circulation Models (GCM). The GCMs incorporate the basic conservation equations and their external factors, namely radiation and other interactive processses, such as the transfer of momentum, heat, and water substance across the Earth's surface as illustrated in Figure 4. These models started basically as global atmospheric models but they have been enhanced to account for interactions with the ocean, land, cryosphere and biosphere. At present, there are around 16 GCMs put together by scientists in climate centers around the globe. It has been predicted by some of these models that a doubling in CO_2 in the atmosphere would cause the global surface temperature to increase by 2^oC (e.g., Manabe et al., 1992). The different models, however, do not always produce consistent results revealing the complexity of the problem and the need to evaluate the different techniques to verify that they formulate the physics of the Earth system in the same manner. Currently, none of them could simulate the occurrence of some distinct climate phenomena, like the

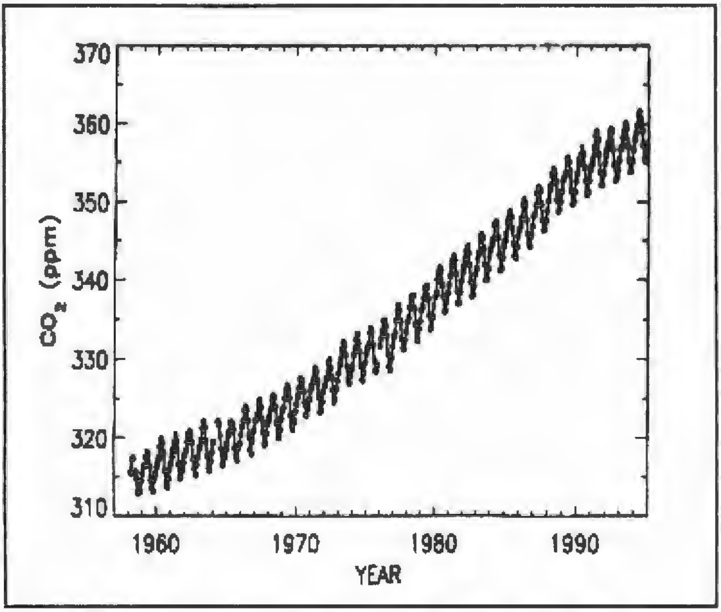

Figure 3. CO_2 time series measured from Mauna Loa, Hawaii from 1958 to 1995.

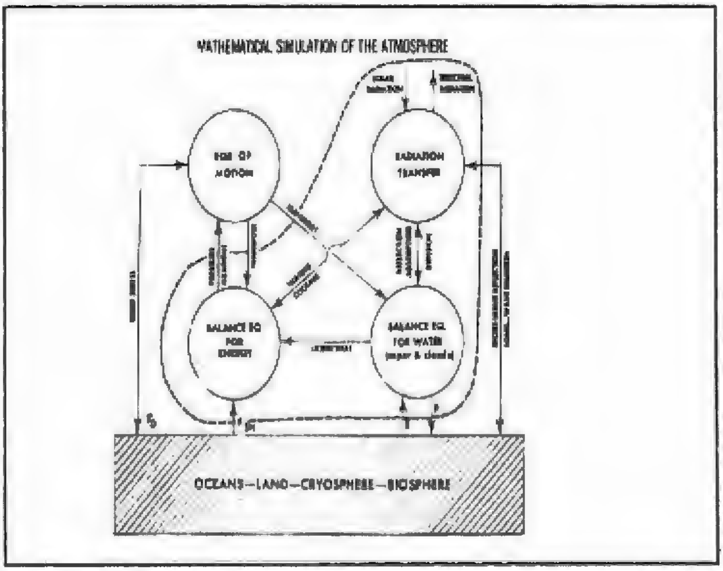

Figure 4. Schematics for the mathematical simulation of climate. The items inside the dash curve correspond to the physics while those outside correspond to the dynamics and other factors. (from Peixoto and Oort, 1992)

El Niño and cannot reproduce the spatial extent of the sea ice cover as observed by satellites. However, they are the only means to evaluate the sensitivity of each geophysical parameter to global change and they are also useful in the interpretation and extrapolation of observational data in time and space. With the advent of more powerful computers and more comprehensive global data sets provided by satellites, these models will only get better.

4. WARMING SIGNALS: IN SITU AND SATELLITE DATA

The temperature of the Earth as observed by meteorological stations around the globe (Jones et al., 1999) has been increasing at the rate of 0.04 K per decade (Figure 5a). More importantly, the record shows accelerated warming during the last few decades. It is such changes in the rate of increase that has been postulated as the potential warming effect of greenhouse gases. If such a rate of warming is sustained during the next few decades, the climate of the Earth would become very different from what we are accustomed with. However, the temperatures go through some cycles as the running average (in bold) indicates and the result from Fourier analyses of the data reveals some periodicities at different periods, one of which is around 12 years that may be associated with the solar (sunspot) cycle (Figure 5b).

The use of long term meteorological station data for climate change studies has been criticized in the past as lacking adequate quality control. It was discovered that there are mismatches of some records from different stations but close to each other. Also, the temperature record from some stations that are located in what used to be outside urban areas did not take into account additional surface temperature changes due to the expansion of the urban area. But even after these temperature data have been enhanced to take care of these problems, the results still yield positive trends in temperatures. It should be noted that when we think of global trends, we usually refer to global averages and because of the paucity of stations, the global station data set does not really provide global average values. The only way that we could come out with real global averages is through the use of satellite data which became available in the 1970s. However, because of the relatively short record length of satellite data, the latter have to be analyzed concurrently with the longer term station data.

To study the warming phenomenon, it is best to start with the polar regions because the latter are expected to provide significantly enhanced signal of a climate change. The high reflectivity of ice and snow, which are dominant in the polar regions, triggers a feedback effect that causes an amplification of a warming signal in the region. The amplification factor has been predicted by some models to be as high as five. This is an important consideration since the average temperature of the West Antarctic Ice Sheet is about -6°C and a 2°C rise globally produced by a doubling in CO_2 would bring the average temperature of the West Antarctic Ice Sheet to melt temperatures. The immediate impact of the melting of the West Antarctic Ice Sheet would be a rise in sea level of about 5 meters.

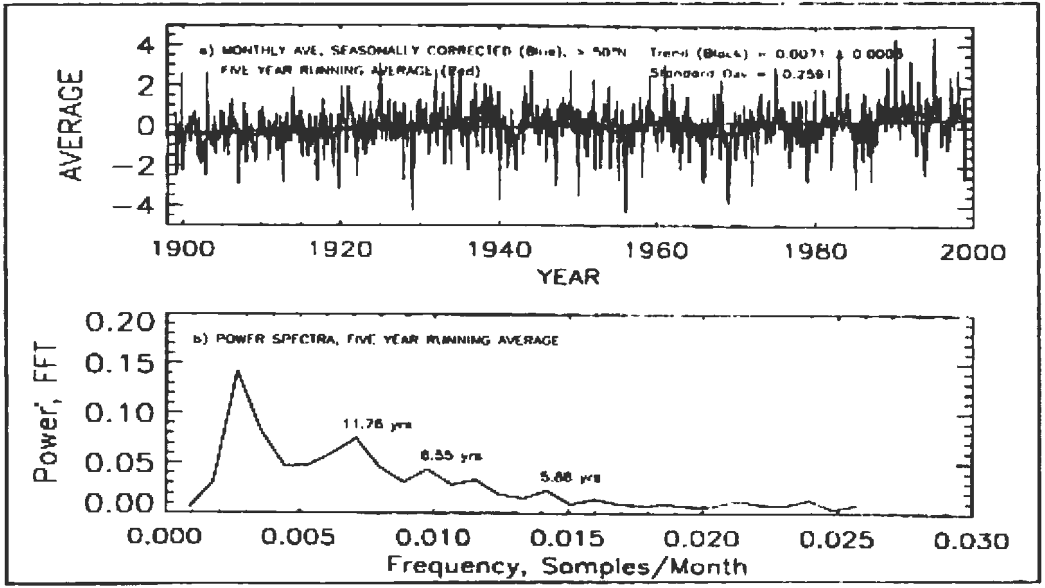

Figure 5. (a) Time series of Arctic temperatures with 5 year running average; and (b) power spectral plot of the 5 year running average data.

Using the same data set used for global studies by Jones et al. (1999), the temperature anomalies derived from the stations north of 50°N for different time periods are shown in Figure 6. The trends as inferred from these anomalies during the last 20, 50, and 100 years (Figures 6a, 6b, and 6c) are 0.0384±0.0119 K, 0.0219±0.0036, and 0.0076±0.0010 per year, respectively. These results show higher trends than the global data for the polar region and that the 20-year trend is about 5 times more positive than the 100 year trend indicating an accelerating rate of temperature increase. The stations from 50°N to the North Pole, especially those with the record lengths of about 50 years or more are located mainly in the Eurasian continent and are only few in numbers.

Yearly averages in surface temperature as inferred from satellite AVHRR data from 1981 through 2000 are shown in Figure 7. The yearly averages, which represent the mean of the ice season that starts in August each year, provide a means to compare unique spatial features of temperature distributions from one year to another. The last image in Figure 7 is the average of all available data and is used in calculating the yearly anomalies. The Greenland ice sheet appears to be consistently the coldest region in the yearly maps although this is not always the case in the monthly maps. Also, large interannual variations in the temperature distributions are apparent and for different regions, the year of coldest temperatures is usually different. For example, the coldest year in the Central Arctic appears to be 1987 while that in Greenland appears to be 1992, which was the year right after the Pinatubo eruption and represents a general cooling period that started in 1991 and ended in 1993. Regions of temperature anomalies are better depicted in the anomaly maps for each year as shown in Figure 8. The anomaly maps show many striking features in the temperature distributions, especially when the first half of the record is compared with the second half. The coldest temperature in the Central Arctic and Eurasia occurred in 1987 but for the same year, the temperatures in North America were warmer than the average. In 1992, the temperatures in practically the entire Arctic region was colder than the average. During the period 1995-1998, the temperatures became warmer than usual in most regions. The warmest two years appear to be 1995 and 1998, with the rate of warming being the highest in the Eurasian side in 1995, whereas it was highest in the North American side in 1998. To date 1998 is the warmest year in this century.

Trends in surface temperature over the last 18 years for each satellite pixel are depicted in spatial detail for the entire Arctic in Figure 9a. The trends were inferred using monthly anomalies from 1981 through 1999. Except in Mongolia (top right portion), the rate of warming is shown to be generally positive with the highest in the Central Arctic, Greenland, and Northern Canada. The uncertainties and standard deviations in these trends are shown in Figure 9b and 9c, respectively. It is apparent that there are regional variations in the trends, especially inside the 60 degree latitude.

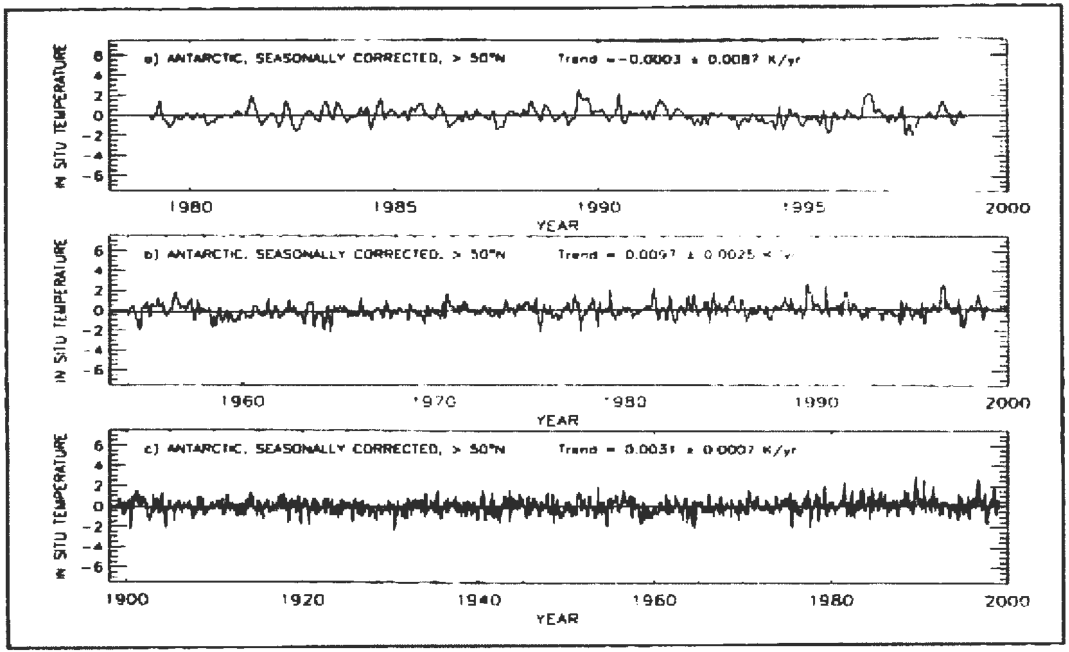

Figure 6. Arctic temperature anomalies and trend lines for (a) 1979 to 1998; (b) to 1955 to 1998; and 1900 to 1998 using meteorological station data.

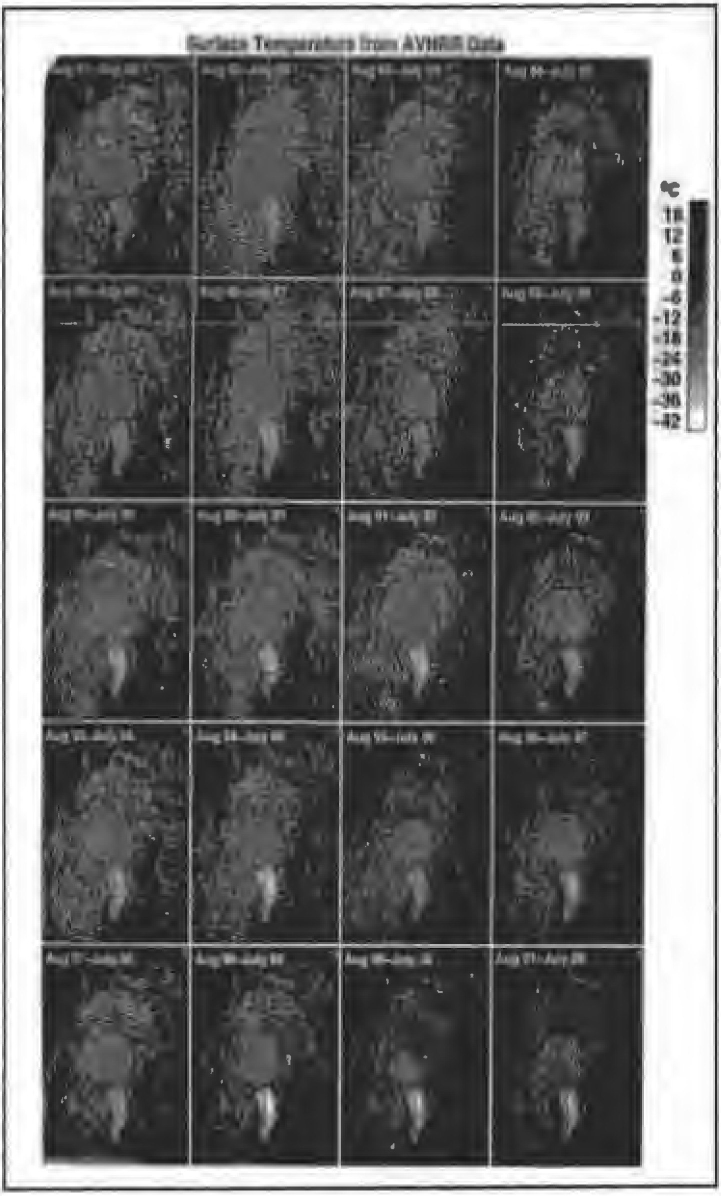

Figure 7. Yearly average of surface temperature data in the Arctic from 1981 to 2000. The averages are from August of one year to July the following year and reflect the average over an ice season. The last image is the climatological yearly average or the average of all data from August 1981 to July 2000.

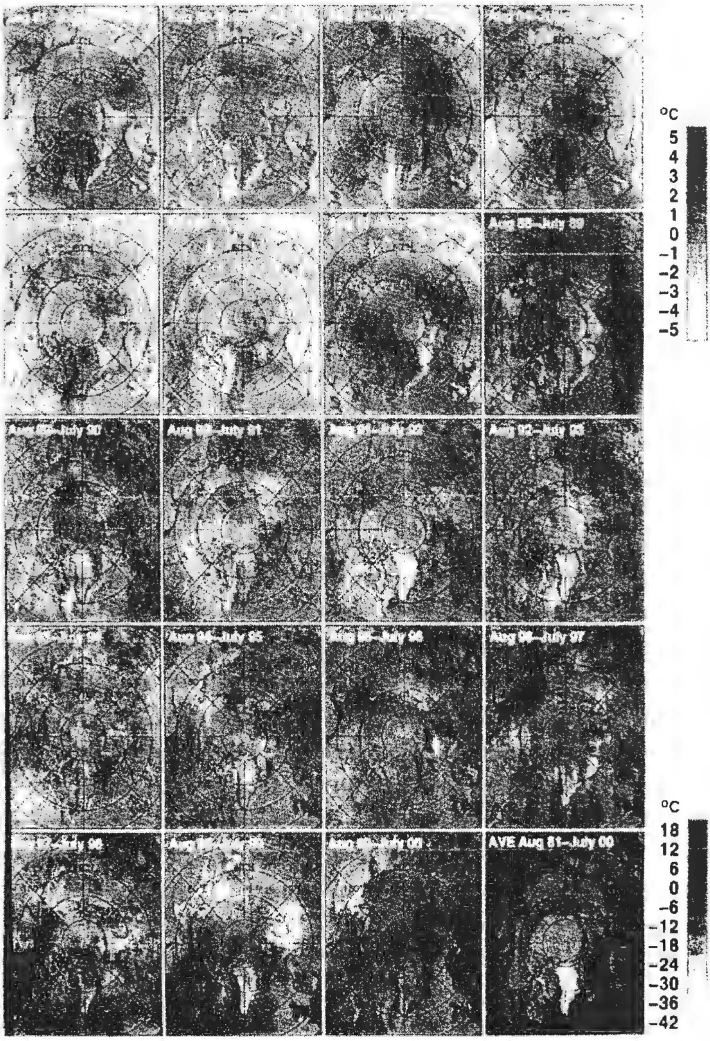

Figure 8. Yearly anomalies of Arctic surface temperatures from 1981 to 2000. The last image is the climatological yearly average used in calculating the anomalies

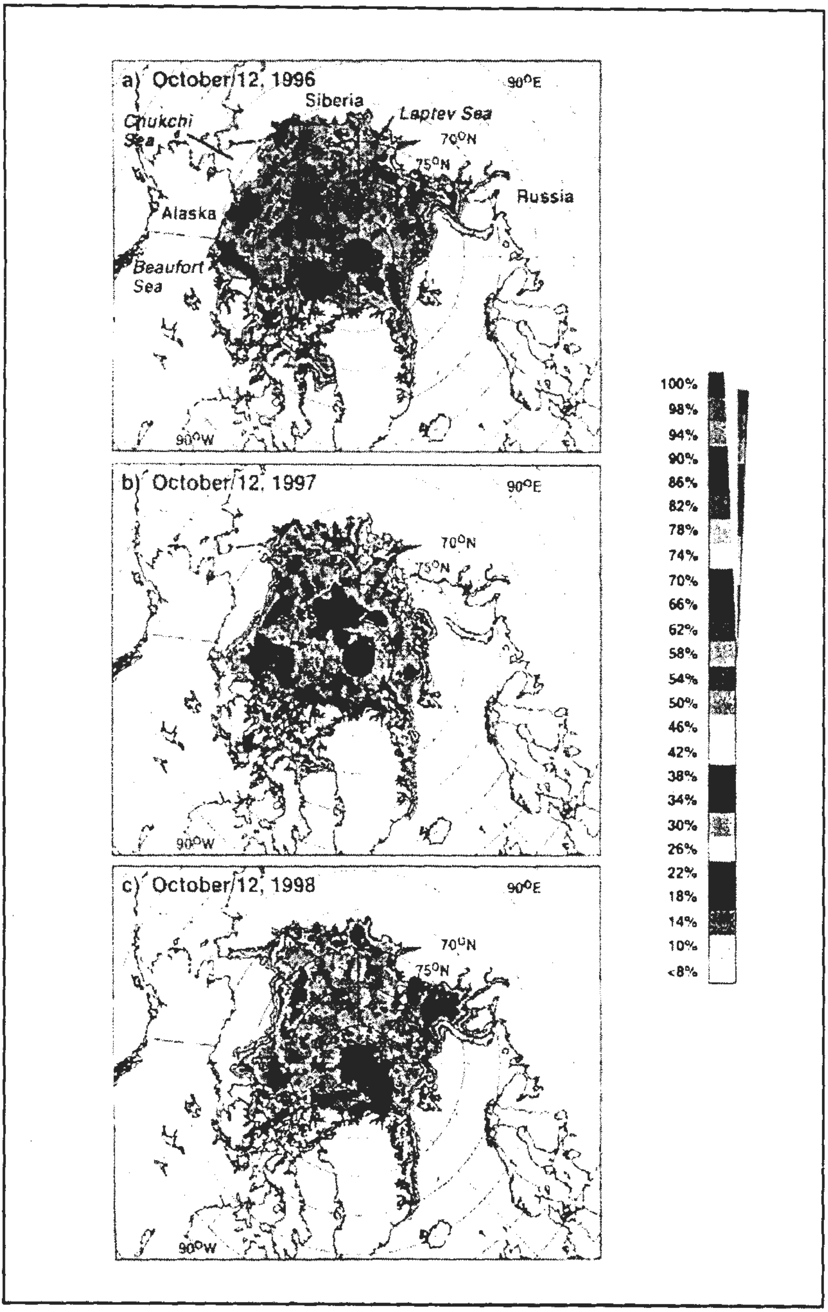

Figure 9. Trends in surface temperature from 1981 to 2000 on a pixel by pixel basis.

The warming scenario is further supported by sea ice cover data. There have been recent reports about thinning of sea ice as observed by submarines (Wadhams et al., 1989, Rothrock et al., 1999). Passive microwave satellite data also show that the ice have been retreating as illustrated by a sequence of images on October 12 during the years 1996 to 1998 (Figure 10). The coded ice concentration images, correspond to the time when the Arctic basin is almost all frozen up. During this time, the area not covered by ice in the Beaufort Sea Region (left side) has an areal extent of 300,000, 700,000, and 970,000 km^2, in 1996, 1997, and 1998, respectively. This reduction in the ice cover is highly correlated with the warming anomalies shown in Figure 8. Such a reduction can also impact the circulation of the underlying ocean which is a big component of the climate system. Analysis of 18 to 20 years of ice concentration data also reveals a trend in ice extent of about 3% per decade (Bjorgo et al., 1997; Parkinson et al., 1999). Also, a 7% per decade decrease in the multiyear ice cover has been reported (Johannessen et al., 1999).

In the Antarctic region, the eighteen to twenty year record shows either no trend or a slight positive trend for the entire region (Bjorgo et al., 1997; Cavalieri et al., 1997). Regionally, it turns out that while the Bellingshausen and Amundsen Seas have been losing sea ice cover as reported by Jacobs and Comiso (1997), the Ross Sea ice cover has been increasing and those from other regions show practically no change. These regions have been the site of big iceberg calving in recent years and the Antarctic Peninsula has been regarded as climatologically changing region (King, 1994). An updated version of the ice extent and ice area anomalies with trend lines superimposed are shown in Figure 11. The results show a trend of 0.4 ± 0.2 %/decade for the entire hemisphere and general consistency with previous results.

Surface temperature data derived from satellite AVHRR infrared data actually provided useful insights into this Antarctic phenomenon. The observed slightly positive trend in ice extent during the last 20 years is coherent with a slight negative trend in surface temperature in the continental region as reported by Comiso (2000). The 20-, 50-, and 100-year records are shown in Figures 12a, 12b and 12c, respectively, and the only negative trend is the first case. The longer term records show significant warming which is also consistent with the observed decline in the ice cover from the 1940s to the 1980s, as reported using whaling data by de la Mare (1997).

Evidences of warming are also observed in other parts of the globe. The Greenland ice sheet has recently been observed to be thinning in some areas by Krabill et al. (1999), using an aircraft laser mapping instrument. Permafrost in the northern hemisphere has also been observed to be thawing and decreasing in area. In the high mountains, the glaciers are generally retreating. Figure 13 shows images of the Horn and Waxeggkees glaciers in the Austrian Tyrol for 1921 and 1994 and depicts huge recession of the glaciers. It should be pointed out that while a direct relationship to global warming is evident in the observables, the interpretation of data may not be straightforward. For example, in some areas

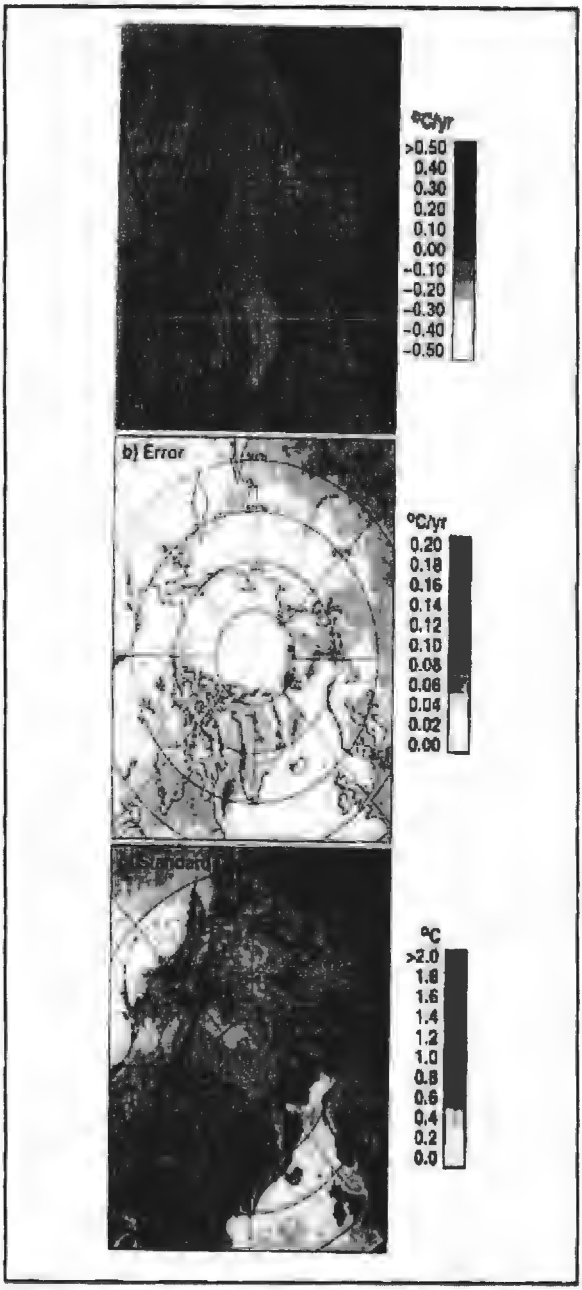

Figure 10. Coded ice-concentration maps in the Arctic for (a) October 15, 1996; (b) October 15, 1997; and (c) October 15, 1998, using the Bootstrap Algorithm.

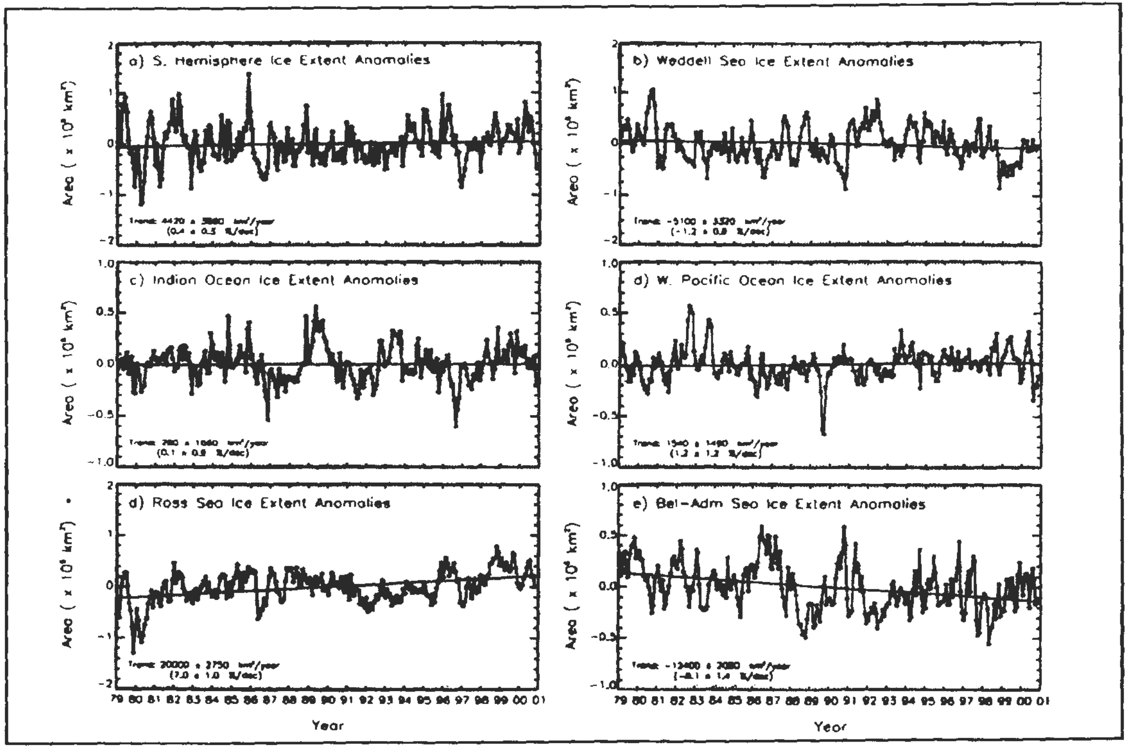

Figure 11. Monthly average ice extent anomalies from satellite data fpr 1979-2000 in (a) the entire Antarctic region; (b) Weddell Sea Region; (c) Indian Ocean; (d) Western Pacific; (e) Ross Sea; and (f) Bellingshausen-Amundsen Seas.

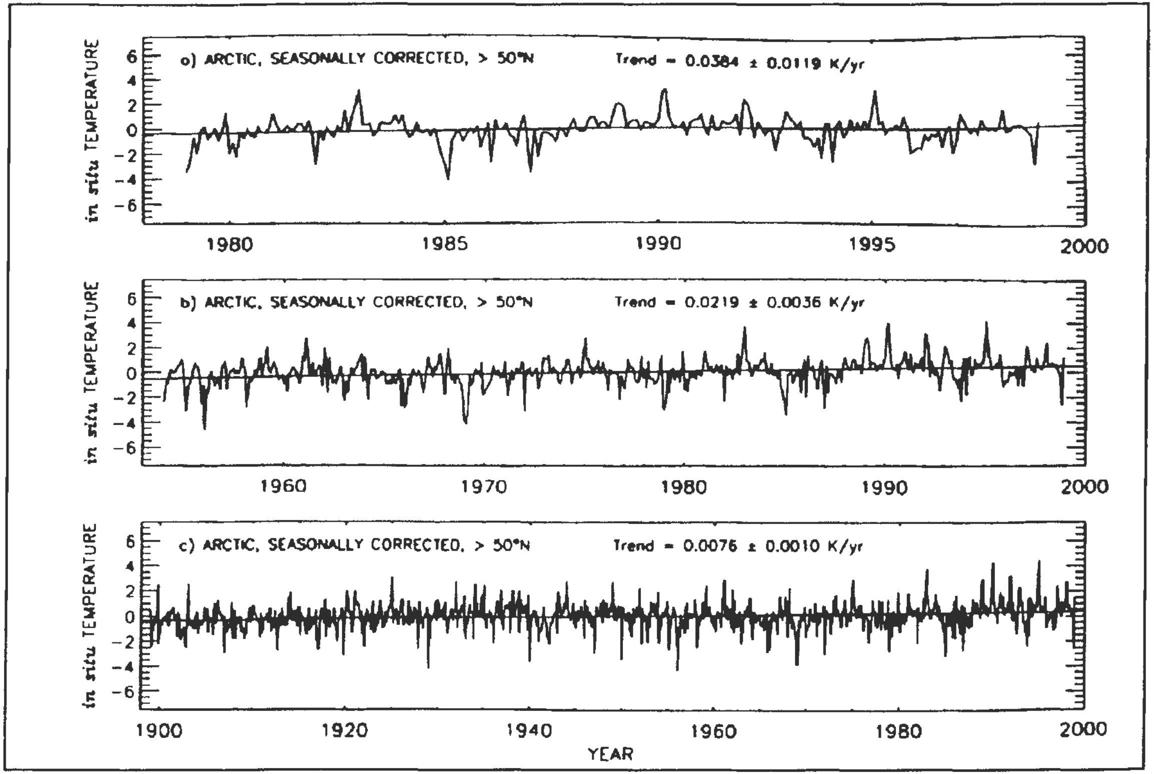

Figure 12. Trends in surface temperature in the Antarctic using meteorological station data for the periods (a) 1979 to 1998; (b) 1955 to 1998; and *c(1900 to 1998.

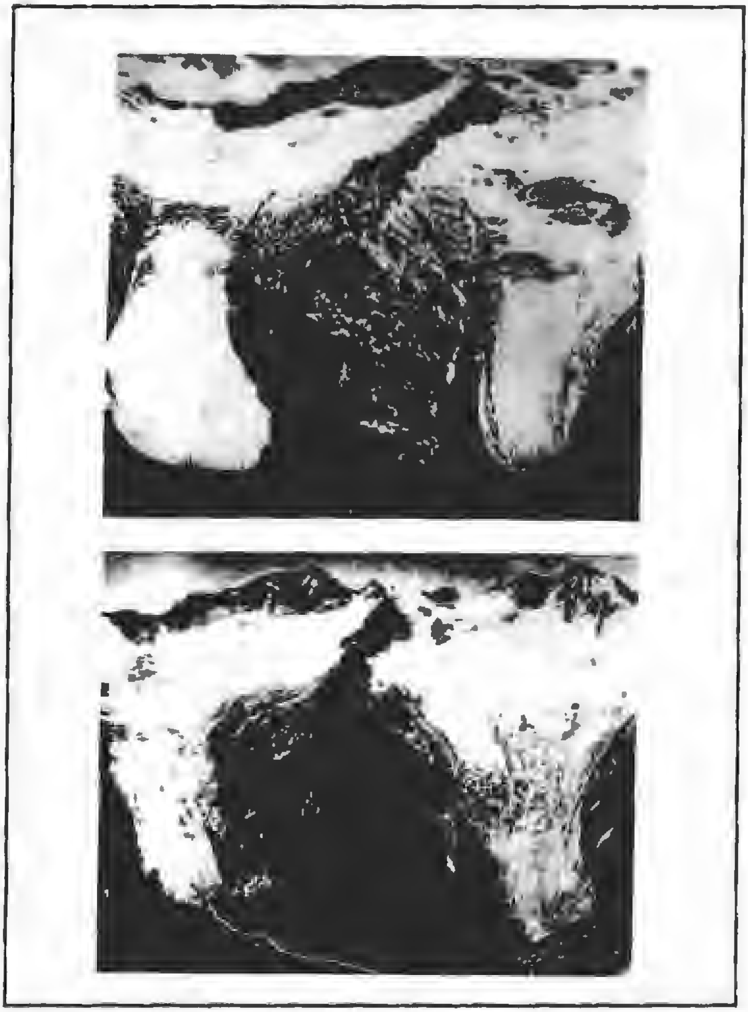

Figure 13. Images glacial retreat at the Horn and Waxeggkees glaciers in the Austrian Tyrol for 1921 and 1994 period. (from Burroughs, 1999).

of Europe, glaciers have been advancing but this has been interpreted as caused by increased precipitation due to more evaporation in the ocean caused by warming during the same period.

5. ENVIRONMENTAL CHANGES AND IMPACTS ON HUMANS

Although it is not yet certain that the observed global warming is associated with the influence of greenhouse gases, modeling results point to the need for an aggressive plan in response to what may happen in the foreseeable future. The Arctic sea ice has been retreating significantly and may be thinning, glaciers are receding and the rise in surface temperatures has been accelerating. Pending sudden changes in these trends, which are not likely, it would not be a good strategy to just wait and do nothing until all the problems of sorting out the different effects from a complex climate system are all resolved.

A panel of experts was assembled through a mandate by the US congress in 1990 to study what the climate will be like in the 21st Century. The key projections by the panel have just been released and summarized as follows: (a) The average global temperature will rise by about 3-6°C prompting more summer heat waves and gentler winter; (b) Agricultural production will likely surge and forest will likely flourish because of the fertilizing effect of more carbon dioxide in air. (c) Snowpack will probably diminish by 50% on the average, while winter rains are likely to increase, bringing 60 to 100 percent more showers to much of Southern California and the parched southwest; and (d) Total precipitation nationwide which rose to 5 to 10 percent during the 20th century, will probably increase another 10 percent by 2100, chiefly in the form of extreme storms, exacerbating runoff pollution in places like the Chesapeake Bay and other sensitive areas. The study also points out that many long-suffering ecosystems, such as alpine meadows, coral reefs, coastal wetlands and Alaskan permafrost, will likely deteriorate further or disappear altogether. Also, the threat of drought will rise and the water levels could drop by as much as five feet in the Great Lakes because hotter conditions will enhance evaporation. As for health effects, a doubling or tripling of heat-related deaths in big cities are expected while there would be substantial shift in the habitat of disease-bearing mosquitoes and other animals.

Although the report is meant for the United States, much of it is likely relevant worldwide. Some of these projections are familiar and have been published as a scientific report. Many of them are based on sensitivity studies using two of the most established GCMs. Where the two GCMs disagree the average of the results is taken. But the two models have significant disagreements in some derived parameters and this may be an indication that they are not mature enough to be reliable. Assuming that they are correct, it appears that human beings will be able to adjust and adapt to most of the impacts.

It should be pointed out that the economic impact will vary regionally and should be assessed on a case by case basis. For example, a 50 cm rise in sea level is projected for the next century on the assumption that the trends from the last century will continue. Such a rise in sea level is primarily from thermal expansion of the ocean and is ready considered to cause a very serious impact on many countries (Schneider,1997). However, a rise of 3° C to 6° C in surface temperature would cause the disappearance of the West Antarctic Ice Sheet which in turn would cause the sea level to rise by about 5 m. A comparison of current shoreline with that corresponding to a 5 m sea level rise is shown in Figure 14. It is apparent that such change in sea level would cause a large fractions of Florida and Vietnam to be underwater. Large amount of occupied lands worldwide, including big cities, are expected to be suffer the same fate as well.

The consequence of the projected change in climate is not all negative and can positive in some areas. Higher levels of CO_2 is expected to cause an enhanced forest and an increase timber production by 8 to 25%. Also, agriculture yields for most commercial crops are expected to increase 15 to 50%. Moreover, a warmer and accelerated growing season may reduce the need for crop irrigation by 30 to 40% which will be a big relief to water resources. But even such positives could lead to negatives. For example, higher agricultural yields would require the use of 5 to 20% more pesticides that would raise the threat of more nitrogen fertilizer runoff into bays and estuaries.

It should also be pointed out that man has enormous capacity to overcome some of the problem. For example, the rapid expansion of the Sahara desert (50 km per year) became such a big concern that in 1977 the United Nations decided to launched on a $6 billion project to prevent desertification over the next 15 years. The result is favorable as indicated in two images of the same region in 1984 and 1991 in Figure 15. During the period, the northern border of the desert retreated and the area of the desert declined by about 695,000 km^2. The successful implementation of such a huge activity is promising and is a strong manifestation of the ability of man to counteract adverse trends.

6. DISCUSSION AND CONCLUSIONS

Changes in climate and environment have been occurring throughout history but it is only in recent times that human activities may be causing an alternation in the climate. The advent of the industrial revolution had caused a substantial increase in the emission of greenhouse gases into the atmosphere and a likely consequence is an enhanced warming of the Earth's surface. Historical records from a global network of meteorological stations reveal that surface temperatures have indeed been on the rise during the last century and that the rate of increase has been accelerating during the last few decades. Meteorological station data do not provide the long term record needed to analyze trends and periodic cycles and where there is overlap, they are generally consistent with satellite data. The latter on the other hand show for the first time spatially detailed observations that reveal locations and persistence of anomalies in both temperature and sea ice cover. The

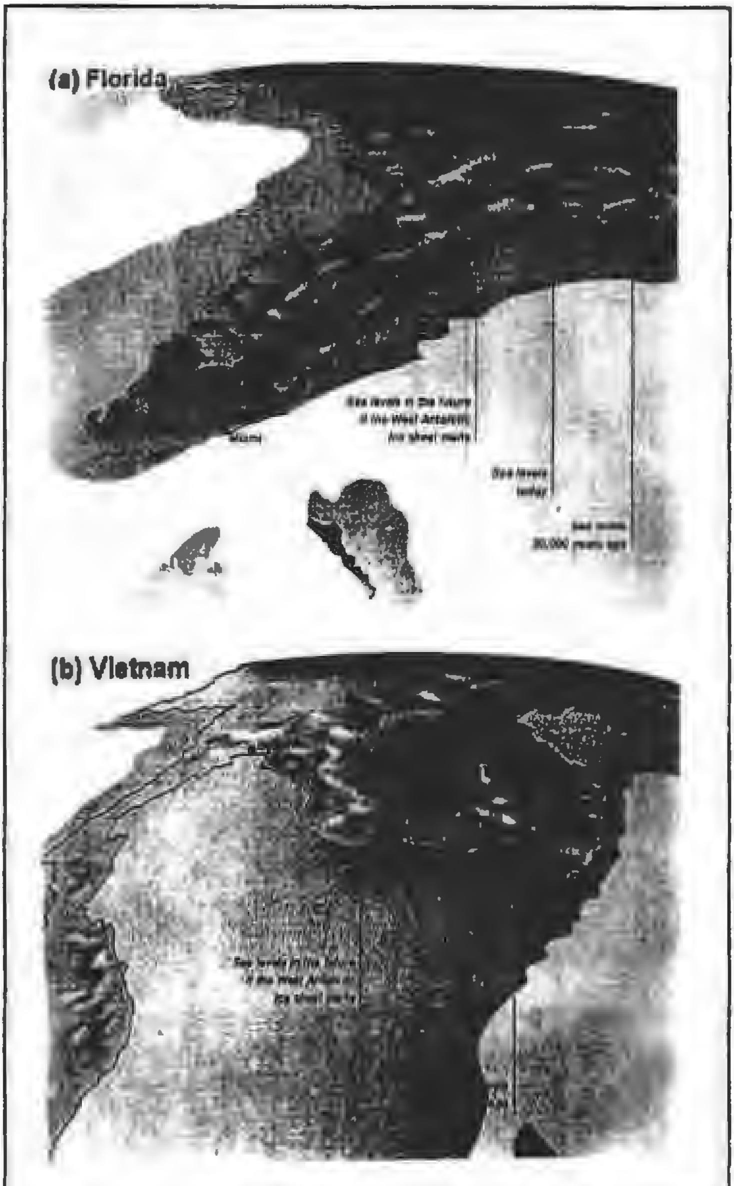

Figure 14. Sea level rise if the west Antarctic ice sheet collapse in (a) Florida and (b) Vietnam. (from Burroughs, 1999).

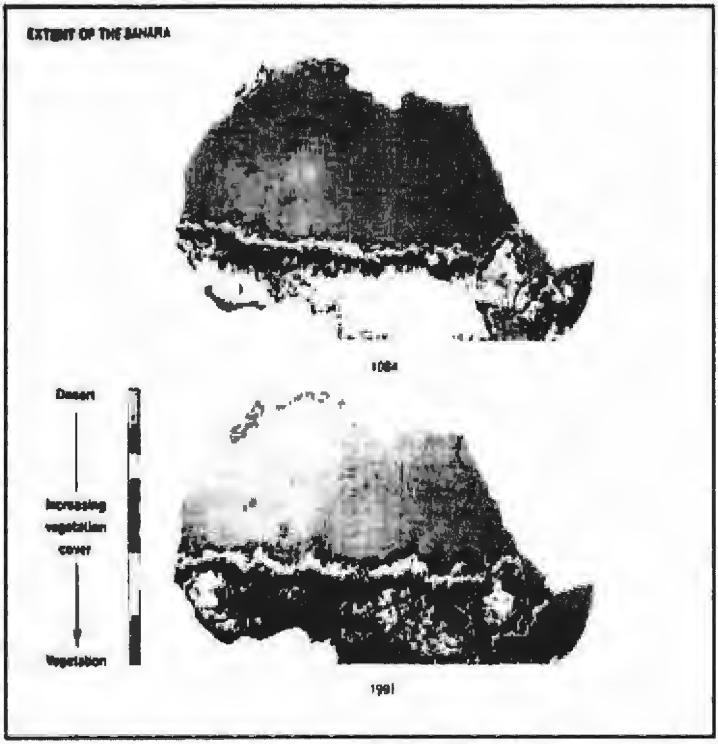

Figure 15. Change in the Sahara desert from 1984 to 1991 after intervention by the United Nations to restore the desert. During this period, the desert has declined by about 695,000 km^2. (from Burroughs, 1999)

satellite data also indicate that the influence of climate change can be very regional, e.g., anomalously warm in some areas and cold in other areas during the same year. Trends in temperature also varies from one region to another but a predominance of a warming trend is observed. The warming trend is reflected in other areas of the globe and rare manifested in terms of retreating glaciers, thawing permafrosts, expanding deserts, more stormy weather and increasing sea level. The consequence of a climate change can be far reaching and should be studied in detail. The key question is whether currently observed changes are indeed caused by greenhouse warming and if so whether there is anything that man can do minimize the change. The answer to the question requires a good strategy.

The strategy should begin with a careful analysis of the problem and an evaluation of the steps needed to mitigate or minimize the problem. Since it is a global problem, a global solution is required, which means that the participation of all countries around the world is needed. It is important that a good understanding of the Earth climate system is acquired before policy decisions are made. This includes the acquisition of a comprehensive global data sets of geophysical parameters with the proper temporal and spatial coverage. Such venture involves the design, and implementation of expensive satellite and field programs that may take years to execute. Such data are already collected but more are needed to improve our understanding of the climate system and to be able to confidently predict changes in the climate through the use of sophisticated and reliable models. The regional and global consequences of such predictions have to be analyzed and evaluated and key information have to be managed and reduced into a format that is useful for policy makers. The solutions to the problem may require big sacrifices and enormous efforts. This makes it imperative that mitigation policies are based on well founded and carefully executed studies. There should also be a strategy that addresses short term changes observed in recent years. A warming trend could cause a demise of the Arctic perennial ice cover in the next century whether or not the warming is associated with greenhouse gases.

REFERENCES:

Bjorgo E, Johannessen, OM, and Miles MW. 1997. Analysis of merged SSMR-SSMI time series of Arctic and Antarctic sea ice parameters 1978-1995. Geophys. Res. Lett. 24(4):413-416.

Burroughs, WJ. 1999. The Climate Revealed. Cambridge: Cambridge University Press. 192 p.

Cavalieri DJ, Gloersen P, Parkinson CL, Comiso JC, and Zwally HJ. 1997. Observed hemispheric asymmetry in global sea ice changes, Science 287: 1104-1106.

Comiso JC. 2000. Variability and trends in Antarctic surface temperatures from in situ and satellite infrared measurements, J. Climate, 13(10): 1674-1696.

Daly, JL 1989. The Greenhouse Trap. Sydney: Bantam. 192p.

Dansgaard W, Johnsen SJ, Clausen HB, and Langway, CC Jr. 1971. Climate record revealed the Camp Century Core. In: Turekian KK, editor. The Late Cenozoi Glacial Ages. New Haven: Yale University Press. p37-56.

dela Mare WK 1998. Abrupt mid-twentieth-century decline in Antarctic sea ice extent from whaling records, Nature 389 57-60.

Gleissberg W.1966. Ascent and descent in the eighty-year cycles of solar activity, J. British Astron. Soc. 76: 265-270.

Hansen JA. Lacis, Rind D, Russel G, Stone, P, Fung I, Ruedy R, and Lerner J. 1984. Climate sensitivity: Analysis of feedback mechanisms. In: Climate Processes and Climate Sensitivity: Geophysical Monograph 29, Washington DC: American Geophysical Union. p130-163.

Jacobs SS., and Comiso JC. 1997. A climate anomaly in the Amundsen and Bellingshausen Seas. J.Climate, 10(4):697-709. Johannessen, O.M., E.V. Shalina, and M.W. Miles, 1999. Satellite evidence for an Arctic sea ice cover in transformation, Science, 286: 1937-1939.

Jones PD, New M, Parker DE, Martin, and Rigor IG. 1999. Surface air temperature and its changes over the past 150 years. Rev. Geophys., 37:173-199.

King JC. 1994. Recent climate variability in vicinity of the Antarctic peninsula. Int. J. Climatol. 14:357-369.

Krabill WC, Frederick E, Manizade S, Martin C, Sonntag J, Swift R, Thomas R, Writhe W, Yungel J.1999. Rapid thinning of parts of the Southern Greenland Ice Sheet, Science. 283:1522-1524.

Manabe S, Spelman MJ, and Stoufer RJ. 1992. Transient responses of a coupled ocean -atmosphere model to gradual changes of atmospheric CO2. Part II: Seasonal response. J. Climate. 5:105-126.

Moseley EL. 1944. Recurrence of floods and droughts after intervals of about 90.4 years. Popular Astronomy. 52:73-84.

Mysak LA.1999. Interdecadal varibility at northern high latitudes. 1999. In: Beyond El Nino: Decadal and interdecadal climate variability, A. Navarra, editor. Berlin: Springer-Verlag. p 1-24.

Parkinson CL., Cavalieri DJ, Gloersen P, Zwally HJ, and Comiso JC. 1999. Arctic Sea ice extents, areas, and trends, 1978-1996. J. Geophys. Res. 104(C9): 20837-20856.

Peixoto JP., and Oort AH 1992. Physics of the Climate: American Institute of Physics. New York, N.Y., 520 p.

Rothrock DA, Yu Y, and Maykut GA. 1999. Thinning of the Arctic sea-ice cover. Geophys. Res. Letters. 26 (23):3469-3472.

Schoeberl MR. 1993. Stratospheric Ozone Depletion. In: Atlas of Satellite Observations related to Global Change. Gurney RJ, Foster JL, Parkinson CL, editors. Cambridge: Cambridge University Press. p 59-66.

Schneider, D. 1997: The rising seas, Scientific American, 112-117.

Wadhams P. 1988. Evidence of thinning of the Arctic ice cover north of Greenland. Nature, 345(6279):795-797.

Williams RS Jr. and Hall DK, Glaciers, 1993: In: Atlas of Satellite Observations related to Global Change. Gurney RJ, Foster JL, and Parkinson CL, editors. Cambridge: Cambridge University Press. p401-424.