GLOBAL CLIMATE CHANGE:

A BRIEF REVIEW OF THE CONSIDERATIONS AND IMPLICATIONS OF THE KNOWN AND UNKNOWN

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PREFACE

THOUGHTS ON A UNIVERSITY COURSE ON

PHYSICAL, BIOLOGICAL, AND SOCIAL IMPLICATIONS OF GLOBAL CHANGE

The disciplinary distinctions of Western human thought, science and technology,
as manifested and exemplified within the University,
have lead to significant changes in the way human beings interact
with each other and their environment.
While many of these changes may be considered
to be improvements to the human condition,
the insularity and narrow focus of the disciplinary approach
also appears to have resulted in a
lack of understanding and appreciation for the
more holistic effects of these changes
within the earthly biosphere upon which all life is based.
While there has been unarguable value in the
practice and pursuit of the specific disciplines,
there now appears to be a growing recognition that many of the
greater problems involved with sustainable human existence on earth
need to be addressed across traditional disciplinary lines.
This trend may be epitomized by a course entitled
"Physical, Biological, and Social Implications of Global Change"
—a "topic" to be covered in one semester
which involves a synthesis of much of the knowledge gained from
all disciplines—from elementary physics to philosophy.
Concern for Biogeochemical Cycles exemplifies the
multidisciplinarity implicit within the topic.
While any thoughts at complete coverage of such a topic are certainly absurd,
the inestimatable value of such courses which
lies in their direction of participants toward
increased awareness of the interconnectedness of all things,
the uncertainty and complexity of scientific inquiry
and the dangers of narrow interpretation.

As with the course itself, a brief synopsis may only touch lightly
upon the major considerations and implications.
While this synopsis is drawn primarily from the course references
following the text, specific citations have been kept to a minimum due
the complexity and interrelationships among the information presented and
inherent in the subject itself.

Like nearly all good science the course has resulted
in the asking of more questions than have been resolved.

INTRODUCTION TO GLOBAL CLIMATE CHANGE AND MODELING

An understanding of the complexities of global change perhaps begins with a review of some elementary physics. Everything so far recognized in the universe with a temperature above 0^{0} K (-273.15^{0} C) radiates electromagnetic energy and that radiation flowing through space which encounters a body may be either transmitted, absorbed or reflected. An understanding of the situation can be gained by the simplifying assumptions involved with a "blackbody"—a body in space which absorbs all incident radiation and emits the maximum possible amount of radiation for any given temperature. The thermodynamic properties of such entities are quantitatively understood and explained by Plank's Law and the Stefan-Boltzmann Law which relate emitted wavelengths to incident wavelengths and temperature. Expansion of the Stefan-Boltzmann Law and the addition of Wein's Displacement Law and Kirchoff's Law permit application to real bodies which are selective along the electromagnetic spectrum in their reflection, absorption and emission.

The earth must maintain a radiative balance between the solar radiation incident upon it and the energy radiated back to space. The composition of the earth's atmosphere and surface features are such that the overall planetary albedo results in the direct reflection of about 30% of the incoming shortwave radiation. Much of the incoming ultraviolet radiation is absorbed in the upper atmosphere by ozone (O_3)—a process which has recently come under great anthropogenic stress. The rest of the incoming shortwave radiation is transmitted to the earth's surface. The energy which is radiated by the earth's surface is of longer wavelength and encounters a much higher level of absorptivity in the atmosphere—primarily due to trace gases such as water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), tropospheric ozone and chloroflourocarbons (CFC's)—collectively termed the "greenhouse gases" (GG).

At the top of the atmosphere, there is a balance between incoming, shortwave solar radiation and outgoing, longwave radiation from the earth's atmosphere and surface. However, the atmosphere itself exhibits a net loss in radiation while the surface shows a net gain with the necessary balance resulting from the transfer of sensible heat and, much more importantly, evaporated water into the atmosphere. Thus, the atmosphere gets most of its energy [70% (Henderson-Sellers, 1991)] from the process of surface absorption and reradiation. While the earth's surface receives more radiation from the atmosphere than it receives from direct and diffuse solar radiation, it radiates more longwave radiation than it receives and most—about 96%—of this radiation is absorbed in the atmosphere.

It is these last processes which are commonly referred to as the "Greenhouse Effect." Without the presence of the longwave absorbing compounds in the earth's atmosphere, the average temperature would be about -18^{0} C instead of the current 15^{0} C. Thus, there is no doubt as to the reality of its existence. What is of more interest and concern are the increasing anthropogenic effects on the levels of the GG's and whether these are resulting or will result in changes in the global climate.

It must first be recognized that change in the global climate is inevitable. The earth's climate is in a constant state of flux due to various cycles in its orbit and wobble. Collectively known as the Milankovich Cycles, these include the 100,000 year cycle of variation in orbital eccentricity, the

41,000 year cycle of axial tilt between 21.5 and 24.5 degrees and the 22-23,000 year procession of the equinoxes. MacKenzie (1991) suggests that these cycles would lead to the expectation of the onset of a period of glaciation within the next several hundred years and that it appears that there is a certain level of atmospheric CO_2 which is necessary for the cycles to be fully manifested in the climate.

The field of Paleoclimatology—the study of previous climate on earth—has expanded greatly in recent decades and now offers much evidence for wide variability of climate over the past couple million years. Proxy measurements such as differential levels of O^{16} and O^{18} in ocean basin cores indicate the occurrence of 18-26 different ice ages over the past million years. Differential levels of C^{12} and C^{14} in coral rings showing changes in the solar magnetic field, pollen types and levels in peat bogs, and for most recent, accurate and direct information, air bubbles in ice cores all have contributed to current under-standing of these cycles of change.

Since, with the exception of water vapor and minorly important NO_2, all of the major GG's are compounds containing carbon, perhaps the first information requirement for gaining an understanding of the situation is a quantitative balance of the earths's carbon budget. While MacKenzie (1991) suggests that global CO_2 and temperature levels are primarily driven by the level of plate tectonics—more activity correlating to higher levels—and that we are in a period of low activity, the evidence does show that CO_2 levels have increased from about 280 ppm in pre-industrial times to over 350 ppm today—as high as have ever existed within the paleoclimatic record—with most of the increase attributed to the combustion of fossil fuels and anthropogenic land use change.

Unfortunately, it has not even been possible to obtain a scientific consensus on the carbon budget. The atmosphere is said to generally contain 700-750 gigatons (GT) of carbon, terrestrial systems 1,800-2,000 GT, and the ocean around 38,000 GT with between 1,200 and 4,000 GT stored in fossil fuels. Part of the problem lies in the relatively low levels of flux when compared to total contents—56-150 GT per year between the land and atmosphere with another 5 GT input to the atmosphere from the burning of fossil fuels; 90-115 GT per year between the oceans and atmosphere with a net uptake by the oceans of 0.6-2.6 GT by the oceans. Peng (1991) suggests that, between 1800 and 1980, land use changes resulted in the emission to the atmosphere of 90-120 GT, that fossil fuel use added another 150-190 GT, and that the oceans removed between 40-78 GT. Thus, the total increase to the atmosphere would be expected to be between 162 and 270 GT while the observed increase is only 150 GT. [See also Oceanic Interactions and Biotic Interactions.]

In spite of the uncertainty in even the basic carbon budget, an increasing amount of effort over the past two decades has been going into the development of computer models. These range from a simple rotating annulus, through one-dimensional radiative/convective models and two-dimensional energy balance, statistical-dynamic and box diffusion models to three-dimensional ocean and atmosphere general circulation models (GCM). The more complicated the model, the more expensive and time consuming to "run," with the GCM's requiring significant time on supercomputers [which distracts from the much more important tasks of modeling for the military in an attempt to gain real security].

The real situation is infinitely complex and chaotic due to the non-linearity of almost all interrelationships and both positive and negative feedbacks. The models thus require significant mathematical simplification in an attempt to isolate a few of the most important variables. While there is much to be learned from the simpler models, it is the GCM's which attempt to present a picture of the overall results of change. One potential aide in the simplification process is "convolution mathematics" which attempts to develop simplified computer algorithms for the GCM's from many runs of more complicated smaller programs focusing on specific areas of interest (Warrick, 1991). This author might suggest that, while the development of simplified algorithms is certainly necessary, great care must be taken so as to not factor out essential interactions which may only come into play when the modules are incorporated into more complete models.

Although GCM's have advanced tremendously over their flat-land, no-surface-interaction beginnings, there is still quite far to go. While current GCM's generally use a 5-7^0 grid, Henderson-Sellers (1991) suggests that the next generation which is now being developed will have a 2-3^0 resolution. The important, basic ocean interactions have only recently begun to be included and, while the base state, i.e. the current climate, for the northern hemisphere is predicted fairly well, the southern hemisphere remains problematic—the mean location of the Intertropical Convergence Zone is predicted to lie below the equator while this is never the observable situation.

GCM's have also been run primarily as equilibrium models, i.e. they are started-up, allowed to run until a "steady state" is reached and then the results in the final state are observed. The runs have usually involved a conversion of all 's into CO_2-equivalents and a doubling of the total concentration. The level of accuracy in current GCM's is illustrated by their prediction that there should have been a 1.3^0 C increase since 1800 while the observed increase is only 0.5^0 C. It is only recently that the time has been available to observe the time-dependent, annual effects of various changes in the model's predictions (Henderson-Sellers, 1991).

The GCM's require "parameterization" of the various components and interactions within the cells of the models. Parameterization is greatly complicated by the fact that most of the processes of interest and relevance to the models are characterized by incompletely understood non-linearity. The process, while progressing, is still at a fairly rudimentary level, especially for chemical feedbacks, vegetation and land surface interactions and clouds. While the global cloud cover results in increased albedo and a negative feedback in relation to surface temperature, is currently estimated to be about 50% and might be expected to increase with higher temperatures, all current parameterizations are recognized as being inadequate (Henderson-Sellers, 1991).

While the topic of global change is inherently holistic, the following discussion attempts to deal with some of the major factors as they impact upon the primary classes of earthly systems—the atmosphere, the oceans, the biosphere, and human society.

ATMOSPHERIC INTERACTION CONSIDERATIONS

Of primary interest for consideration of the atmosphere in regard to global change are its composition and chemical reactivity, levels of radiative exchange and patterns of circulation. As mentioned previously, the primary compound of concern are the longwave-radiation-absorbing water vapor, CO_2, CH_4, NO_2, tropospheric ozone and CFC's. Water vapor, by far the most common of these compounds comprising about 1% of the atmosphere, might be expected to increase with any eustatic global warming but is not generally directly considered in GCM's. The rest of the 's are far less common, comprising about 353 parts per million for CO_2, and 1717 parts per billion for CH_4 and 310 for NO_2, and a few parts per trillion for CFC's. It is these compounds which intercept and reradiated energy from the earth's surface and maintain the earth's temperature at a livable level. Complicating the problems of predicting global climatic change is the fact that the atmospheric chemistry and lifetimes of all of the 's is difficult to determine and is still under debate within the scientific community.

One of the few "knowns" in regard to global climate change is that the concentration of CO_2 has increased from about 280 ppm in 1800 to over 350 ppm today. This increase is continuing and growing and is primarily attributed to the combustion of fossil fuels by human beings. The level of contribution to increased CO_2 levels by anthropogenic land use changes is quite problematic and is currently reported to be anywhere from slightly negative to a 2.6 GT addition annually. Also complicating the situation is that seasonal variations in CO_2 levels increase with in higher latitudes, especially in the northern hemisphere. The current level of increase is around 1.5% per year.

Methane is the primary component of most natural gas and is also a major product of the bacteriological anaerobic breakdown of organic materials. The currently recognized primary sources include releases from land surfaces with water cover including swamps and rice fields, the flatulence of incomplete digestion by a growing worldwide ruminant livestock population [and other large animals such as human beings] and release due to fossil fuel exploration and transportation. The current concentration of 1717 ppb is increasing at a rate of around 1% per year.

Nitrous oxide is currently thought to be emitted to the atmosphere primarily by agricultural changes in soil use and utilization of chemical fertilizers. The current state of [lack of] knowledge in the field is exemplified by a very recent report that nylon production has been found to be a major contributing factor (Blume, 1991). The current level of 310 ppb is increasing at a rate of 0.5% per year.

Chloroflourocarbons and other halogenated hydrocarbons did not exist in the atmosphere before the advent of anthropogenic production. While the primary problem with CFC's is their destruction of the UV reflecting ozone layer of the stratosphere, they are about 1000 times more effective than CO_2 as a greenhouse gas. While there has been unprecedented international agreement on the reduction of CFC's, they are still being produced at a rate of nearly 13 kilotons per year and the backlog of the compounds currently contained in innumerable refrigeration and air conditioning units around the world would seem to assure that the current rate of atmospheric increase of 5% per year will continue for some time. The technological substitute, hydrogenated CFC's, which will come into increasing use, still have an anticipated lifetime of 22 years in the atmosphere.

Also of relevance to the long term study of atmospheric composition is work done on the effect of volcanic eruptions on climate. While it appears most ash and dust fall out of the atmosphere fairly quickly, it is the sulfuric aerosols and volatile compounds reaching the stratosphere which are more long lasting and more important to the climate.

The most complex computer modeling of the atmosphere has come from the GCM's and has generally involved equilibrium runs with a doubling of the CO_2-equivalent concentration in the atmosphere. Equilibrium runs of a variety of GCM's with varying climatic sensitivity to CO_2 increase indicate that this doubling would result in a reduction of the heat escaping the lower atmosphere by 4.4 W/m^2 from its current level of 240 W/m^2 leading to a resultant temperature increase of around 2.5^0 C as a "best guess" (Warrick, 1991). As mentioned previously, clouds and chemical feedbacks are still not well handled in these models.

What is of perhaps even more interest and relevance to planners, decision makers and individual human beings is how a global climate change might be manifested regionally in terms of the spatial and temporal distribution of precipitation and temperature variation. While it has been possible to "average" the results of the various GCM's in an attempt to predict regional effects as Warrick, et al. (1990) have done for Europe, there appears to be a consensus among researchers involved with the modeling efforts that any but the most broad regional conclusions are unjustified at this point.

OCEANIC INTERACTION CONSIDERATIONS

Since over two-thirds of the earth's surface is covered by oceans and other bodies of water, atmospheric and terrestrial interactions with this area is overwhelmingly important to climate change considerations. The thousand year circulation time and huge temperature inertia of the oceans is hoped to be a significant mitigating influence on any changes.

Unfortunately, the current level of understanding of ocean currents, especially in Antarctic regions, and more-especially in Southern winter, is rather limited. It is only in the past thirty years that systematic, scientific investigations of deep sea currents have taken place and the data sites are still extremely few and far between. The atmospheric explosion of nuclear bombs has been quite useful in providing a "tracer" to scientists attempting to map the currents. Changes in ocean currents and surface temperatures are addressed as "anomalies," there is a poor understanding of the Eastern Pacific El Nino in spite of considerable attention devoted to it over the past decade and the media still report things like "Odd [i.e. unexplained] ocean change in currents in Greenland Sea (Cooke, 1991).

One of the main considerations in relation to 's is the ocean's ability to remove CO_2 from the atmosphere. Whereas the oceans were a source of CO_2 in pre-industrial times, increased atmospheric levels have now produced a situation in which the atmospheric partial pressure of CO_2 is higher than the ocean's and they have now become a sink. The primary process of CO_2 uptake by the oceans is through dissolution which must progress from the ocean surface. While wind and the partial pressure of CO_2 appear to be the most important variables in the process, the facts that the "skin layer" of the ocean heats rapidly when in sunlight and that an increase in water temperature correlates with a decreased level of dissolved gases may provide for a feedback mechanism which was not addressed during the course.

Dissolution is the only CO_2 up-take process which is included in the few GCM's which have begun to incorporate ocean circulation modules. MacKenzie (1991) has suggested that the global carbon budget could actually be balanced if consideration were to be taken of several other less important processes such as the changes in ocean alkalinity, the reaction of dissolved CO_2 with calcium carbonate in marine animals, the enhanced fluxes of nutrients and inorganic carbon to the oceans and the resultant increased settling of organic matter.

Since the oceans cover so much area and they contain so much dissolved nutrient material, they are a significant contributor to the world's total net primary production. It has been suggested that one means for increasing ocean uptake of carbon would be to increase biological activity in the Antarctic Ocean by additions of iron which appears to be the limiting nutrient in the area (Martin, 1990). While this plan has been scientifically addressed by Peng (1991) and others, this author would suggest that a more crucial consideration is that to respond to problems created by humanity's current experiment with global climate change with another experiment with further unknown and potentially global consequences based on reductionist's expectations of one specific result is imprudent at best.

Another issue of intense interest, especially to inhabitants of the world's islands, coastlines and vast agriculturally productive deltas, is the potential for changes in sea level due to eustatic temperature change. While normal variations, tides and the rise and fall of land surfaces create much "noise," it does appear that mean sea level has risen by 1-1.5 mm per year for the past hundred years. Over 50% of this rise is attributed to the expansion of the ocean due to temperature increase with the rest coming from retreat or melting of mountain glaciers. These two processes are also expected to be responsible for the "best guess" sea level rise of 17-25 cm by 2030, since any net loss to the Greenland Ice Sheet is expected to be balanced by increased snowfall and accumulation in Antarctica.

BIOTIC INTERACTION CONSIDERATIONS

While incorporation of realistic ocean interactions into GCM's is extremely difficult, it is comparatively simple in relation to the immense problems which need to be faced when considering the far wider diversity of interaction which exists on the land surface. Among the primary reasons for this diversity are variations in elevation; anthropogenic and other natural variations and changes in land use and albedo, soil and vegetative cover, and photosynthetic and evapotransporative activity; and variations and concentrations in innumerable other anthropogenic activity.

One of the primary problems for incorporation of land use variations into GCM's is the necessity for developing "averages" for the 5^0 grids currently common in the models. Even the most recent "big leaf" models loose important factors in the fluxes resulting from spatial and temporal variations in rainfall and evapotransporation. Also, most models continue to treat the soil as merely a 15 cm deep bucket for hydrological purposes and to treat soil organisms only implicitly in spite of the fact that they comprise the most massive portion of land biomass.

Another of the problems in modeling the land for GCM's lies in the difficulty of obtaining reliable data for construction of even the base case. Shuttelworth, et al. (1984), show the huge effort required to get information on the energy and moisture fluxes among the soil, biomass and air in just one data point. Certainly the only way to monitor global changes will be to utilize satellite data but the development of accurate proxies continues to be quite problematic.

Certainly the land use change affecting the global climate which has received the most media attention is the destruction of rainforests. It must be recognized that deforestation of various areas of the earth by human beings has been occurring for several thousand of years. While attention has largely focused on deforestation in the Amazon and Asia, United Nations Food and Agriculture Organization figures show that the largest change in forest area between 1949 and 1984 occurred in North America!

Another data problem cited by Henderson-Sellers (1991) is the sparse data available with which to extrapolate trends, e.g. two temporal points from all of Brazil. (This author has experienced similar problems. In 1986, when involved with the production of a national energy balance for Nepal, the two primary sources for information on forest cover were an FAO report from 1979 and a World Bank report from 1983 which, in spite of all "anecdotal" and local evidence, combined to indicated a significant increase in Nepal's forested areas.)

While Henderson-Sellers (1984) has suggested that albedo change from rainforest destruction will have a rather insignificant effect on global temperatures, she suggests (1991) that the concomitant changes in energy and moisture flux will have significant regional consequences. It is these regional changes which are perhaps most important in regard to potential losses in ecological habitats and diversity.

The current level of scientific uncertainty surrounding the entire area of global change is perhaps greatest in regard to trends in land use change and effects on the global carbon budget. Ocean modelers have generally concluded that net CO_2 emissions from land use change peaked in the 1920's and have fallen since then while land modelers maintain that the net level of emissions continues to increase (Peng, 1991; Post, 1990).

HUMAN SOCIETAL INTERACTION CONSIDERATIONS

Of interest here are the human influence on the global environment and the resultant influence of climate changes on human beings. Humans have now become a significant and relatively instantaneous event in the geological history of earth. Due to anthropogenic activity, many material fluxes have been significantly changed from those of earth's "pristine" state. In addition to the previously mentioned effects on the carbon cycle, the atmospheric input from fossil fuel combustion is now the single largest flux in the sulfur cycle. Largely due to agricultural activities, the flow of nitrogen and phosphorus to the oceans is over twice the likely pristine flows. The anthropogenically induced fluxes of mercury, lead and other heavy metals are orders of magnitude greater than "pristine" flows. That changes in human "habits" can have a positive result is seen in the recent reduction in ocean surface lead levels following quickly after a ban on leaded gasoline in the United States (MacKenzie, 1991).

While the overall growth of the human population has resulted in significant land use changes, it is the level of affluence and lifestyle which appear to be more important in the production of most GG's. The average citizen of the United States is responsible for the yearly atmospheric input of over 100 times as much CO_2 as the average Indian. While energy use in developing countries is likely to increase as they strive to meet their basic needs, there are huge opportunities in developed countries to increase the efficiency of energy use.

Many of the expected results of a global temperature increase on human society are related to potential sea level rise and its effects on low-lying delta areas and islands in regard to both habitability and fresh water supplies. Other considerations involve temperature-induced habitat shifts for both flora and fauna, especially in relation to types of agricultural production and pest populations. Also of great importance to agriculture are spatial and temporal shifts in rainfall patterns. While global models are very weak in determining regional changes, one widely accepted prediction is for a general increase in both the strength and occurrence of extreme climatic events. While historical data is problematic, there does appear to be some evidence that this trend is already occurring (Smith, J.B., 1990).

CONCLUSIONS: SCIENCE AND GOVERNMENT POLICY IN THE FACE OF GLOBAL UNCERTAINTY

Perhaps the greatest value in the study of global change is that it teaches one how little is really known about where we live and the support systems which make life possible. This is all the more striking when contrasted to our vast knowledge and recently demonstrated expertise with anthropogenic destruction of these systems.

The controversies surrounding anthropogenically induced global change and the enhanced greenhouse effect present scientists with a dilemma. Although good science always recognizes some level of uncertainty and never gives firm answers (Schroeder, 1991), the unprecedented risks posed by global change, the growing consensus of those scientists most closely involved with the research and the fact that seven of the ten hottest years on record have occurred since 1980 all combine to make it increasingly difficult for concerned individuals not to recommend some level of prudent action. The experience of Dr. James Hansen, director of Goddard Institute's GCM project, certainly demonstrates that extreme care must be taken in dealings with the media. However, as Henderson-Sellers (1991) has suggested, to do nothing to change current trends is actually to concur with the status quo.

The potential for global change presents government policy makers with apparently unwelcomed and unprecedented challenges at local, national and international levels. Unfortunately, while mention of the uncertainty of the situation is required for proper scientific presentation, this is often taken by recalcitrant "leaders" as an excuse for continuing the status quo. The complexity of the situation permits the introduction of "evidence" of "no observable change" such as Spencer and Christy's study (1990) of a mere ten years of satellite data focused at the level in the atmosphere where the transition from lower warming to upper heating might be expected to occur. While relevant "further study" is obviously warranted, the growing weight of the evidence would appear to recommend some level of prudent action, especially when there are available numerous win-win options such as energy conservation.

The primary interest of most policy makers currently appears to be the effect of governmental actions on economic conditions. Unfortunately, the current, dominant economic paradigms are extremely weak in regard to valuation of the environment and myopic in regard to the future. Of extreme importance in mitigating global climate change is the distribution of national responsibility. Smith (K.R., 1989, 1991) has suggested the concept of a "Natural Debt" which would take into account the past production of GG gases.

Responsibility is especially relevant to the United States which, with a mere 6% of the world's population, continues to be responsible for over 25% of the world's annual resource use. This country appears to be increasingly viewed as a major impediment to prudent international action. The recent "National Energy Plan," purged of incentives for energy conservation and focusing only on increased production and the dilatory and poor job done on the Policy section of the Intergovernmental Panel on Climate Change report are indicative of the current attitude of presented by the nation's policy makers.

There is little doubt that the issues involved with global change mill require international cooperation. The recent agreements concerning the reduction of CFC production do offer some hope. However, further progress will require further unprecedented cooperation and awareness of the holistic nature of life on earth.

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