CLIMATIC CHANGE - AN OVERVIEW

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The theory of the "Greenhouse Effect" has been known for years and is not disputed by scientists. The fact that man, world wide, is discharging compounds into the atmosphere that may cause the atmosphere to warm is also well known. Presently there is insufficient evidence to state that these man made emissions are causing the global atmosphere to warm. However, recent General Circulation Models (GCMs) suggest that warming on the order of 2 to 5 ° C may occur in the next 50 to 100 years. The ramifications of such a warming are immense since a warming of this magnitude is greater than anything experienced in the last 100,000 years. But how certain are we that the models are close to correct? The GCMs are among the most complex physical models developed and they are known to be weak in several areas such as the way they incorporate the clouds and the oceans. The spatial resolution of these global models is poor, with grid squares the size of Colorado, and as a result, they are incapable of providing predictions at a regional scale. The ramifications of the climatic changes being forecast are so significant that they could change global economies and the social order. What is sustainable or is planted as part of a reclamation project today may not be successful 25 or 50 years from now. Therefore we must incorporate the possibility of climatic change into our planning to prepare for this uncertain future.

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Perspective de changement climatique: une revue

par

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La théorie de "l'effet de serre" est connue depuis plusieurs années et elle ne suscite pas de controverse parmi les scientifiques de l'atmosphère. Le fait que l'homme, émette à l'échelle planétaire, des substances dans l'atmosphère qui ont le potentiel de la réchauffer est bien connu. A date, les données, prouvant que ces émissions, produites par l'homme, causent le réchauffement de l'atmosphère terrestre, sont insuffisantes. Cependant, des modèles de circulation globale (MCG) récents suggèrent qu'un réchauffement de l'ordre de 1 à 5^{0}C pourrait se produire dans les 50 ou 100 prochaines années. Les ramifications d'un tel réchauffement sont énormes, car la terre n'en a jamais fait l'expérience au cours des 100,000 dernières années.

Mais, quel niveau de confiance peut-on accorder à ces modèles? Assez peu, semble-t-il... En effet, les MCG comptent parmi les modèles physiques les plus complexes et sont d'une faiblesse reconnue dans certains domaines, en particulier de la façon dont ils tiennent compte des nuages et des océans par exemple. La résolution spatiale de *ces* modèles globaux est assez médiocre et ils sont incapables d'être utilisés à l'échelle régionale. Avec toutes ces incertitudes, pourquoi alors s'inquiéter? C'est que les ramifications du changement climatique prévu sont telles qu'elles pourraient changer l'ordre socio-économique du monde entier. En plus, un projet de réhabilitation, actuellement réalisable, comme l'implantion d'espèce végétale pourrait ne pas l'être dans 25 ou 50 ans. Il nous faut donc incorporer la possibilité d'un changement climatique global à notre analyse et nous préparer à cet avenir incertain.

INTRODUCTION

> "Much has been written about varying amounts of carbon dioxide in the atmosphere as a possible cause of glacial periods............ No probable increase in atmospheric carbon dioxide could materially affect either the amount of insolation reaching the surface or the amount of terrestrial radiation lost to space" (Russell, 1941).

The greenhouse effect, despite all the controversy that surrounds the issue, is actually one of the most well-established theories in atmospheric science (Schneider, 1989). Without the naturally occurring layer of gases in our atmosphere, including water vapour and carbon dioxide (CO_2), our planet would be substantially colder with a mean temperature near -15 °C instead of the current 18 °C. However, the natural makeup of our atmosphere has been changing rapidly in the last 100 years due to man's activities. Contrary to Russell, this has resulted in a rapid increase in the major gases that could contribute to the Earth's warming. These gases include CO_2, chlorofluorocarbons (CFCs), methane, nitrous oxide, methyl chloroform and tropospheric ozone (low level ozone which is produced indirectly from photochemical reactions between NO_X (nitrous oxides) and volatile organic compounds). Currently $C0_2$ accounts for about 49% of the predicted global warming due to the "enhanced" greenhouse effect; the other trace gases account for the remainder. Scientists predict that the rate of rate of increase in CO_2 concentration will decrease and the contribution of the trace gases will become more important. Recent forecasts suggest that the Earth's atmosphere may warm by 1.5 to 5.0 °C in the next 100 years due to the changes in greenhouse gases. Such a change in temperature in such a brief period is unprecedented in the history of our planet! For example, Earth was only 5 °C colder during the last ice age.

THE GREENHOUSE EFFECT

What happens to the gases that are suspected of causing global warming after they enter the atmosphere is an uncertain and complex process. Their contribution depends both on the chemical characteristics of the gas and its atmospheric lifetime. The average carbon atom spends its life being shunted from one place to another from fossil fuel to the air, from the air to the oceans (in the form of dissolved carbonates), from the oceans to fish and other marine organisms, from them to the sea bed, from there to the surface again, then to the atmosphere where it can be used by plants, enters the soil and may eventually end up again in fossil fuel. This is known as the global carbon cycle and its exact workings are not completely understood. Most carbon cycle models assume that approximately one half of the carbon dioxide released by burning fossil fuel to the atmosphere stays there, the other half being absorbed by the oceans and plant life.

A simplified carbon cycle is presented in figure 1 (UNGMP, 1987). At any one time approximately 725 gigatonnes (109 tonnes) of carbon are present in the atmosphere, 37000 gigatonnes in the oceans, 5000 to 10000 gigatonnes stored as fossil fuels, 1300 to 1400 gigatonnes in the soil and surface litter and approximately 560 gigatonnes in the biomass. These values, however, are not static and there is a continuous interchange between the various carbon storage zones. On an annual basis approximately 93 gigatonnes of carbon flow from the atmosphere to the ocean and about 90 megatonnes (10^6 tonnes) from the ocean to the atmosphere. The biomass releases 60 megatonnes to the atmosphere while absorbing double that amount. As the biomass decays it gives up a further 60 megatonnes of carbon to the soil and litter at the surface. Finally the consumption of fossil fuels releases 6 megatonnes of carbon to the atmosphere. Although small in the entire carbon budget, this component is rapidly increasing. Approximately 3 megatonnes are unaccounted for in the carbon cycle and indicate our lack of understanding of this complex equation.

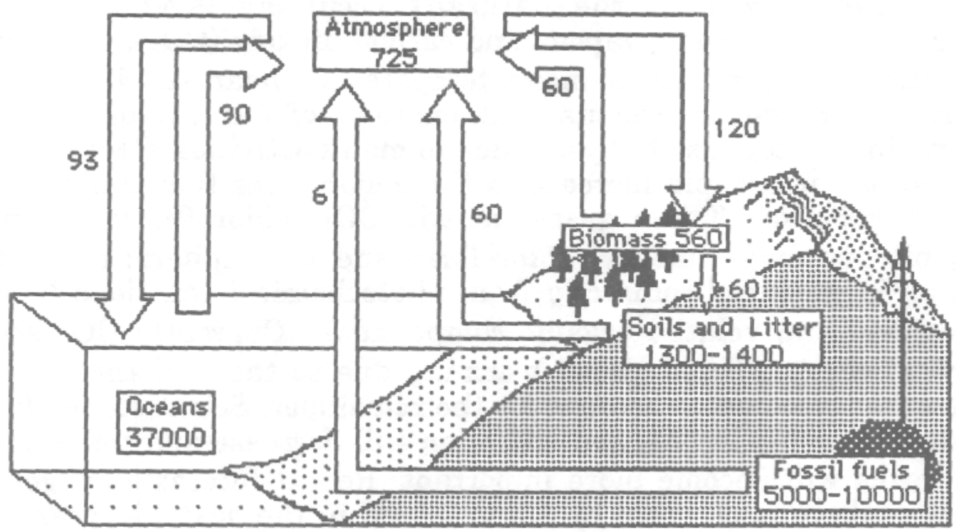


Fig. 1 **Carbon Cycle** Values in boxes show stored carbon in gigatonnes (10^9); values on arrows show flux of carbon in megatonnes of carbon/year

Further examination of figure 1 demonstrates the serious ramifications of man's activities. If we increase fossil fuel consumption *and/or* remove biomass, the atmospheric carbon will rise rapidly, unfortunately, the remainder of the sinks for carbon are unable to absorb this increase. Carbon dioxide measurements, conducted at Mauna Loa observatory in Hawaii since 1958 (Figure 2), show a gradual and exponential increase in the level of C02 in the atmosphere (Harrington, 1987).

Other Radiatively Active Gases

Five other trace gases occur in sufficient quantity in the atmosphere, to absorb radiation in the far infrared region of the spectrum strongly enough to be considered significant greenhouse gases (Wuebbles and Edmonds, 1988). They are chlorofluorocarbons (CFC 11 and 12), methane, nitrous oxide, and ozone. Although present in much smaller quantities than CO_2, on a molecule for molecule basis these gases absorb infrared radiation much more effectively.

Methane concentration in the atmosphere has doubled in the last 100 years and its effect as a greenhouse gas is about 30 times greater than CO_2. The

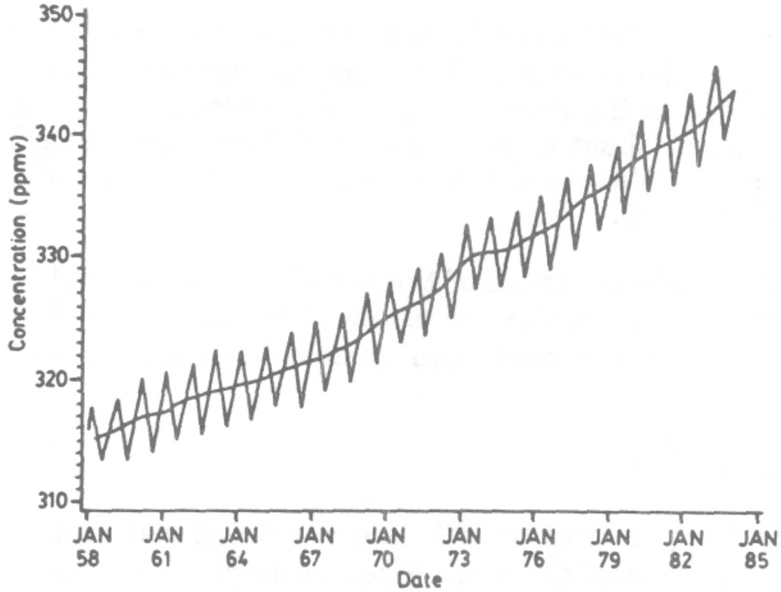


Fig. 2: Monthly mean values of C02 Concentration (Harrington, 1987)

atmospheric lifetime of methane is estimated at about 10 years. This gas is produced naturally through the decay of vegetation, and through the activities of man such as coal mining, burning of fossil fuel, agriculture and landfills.

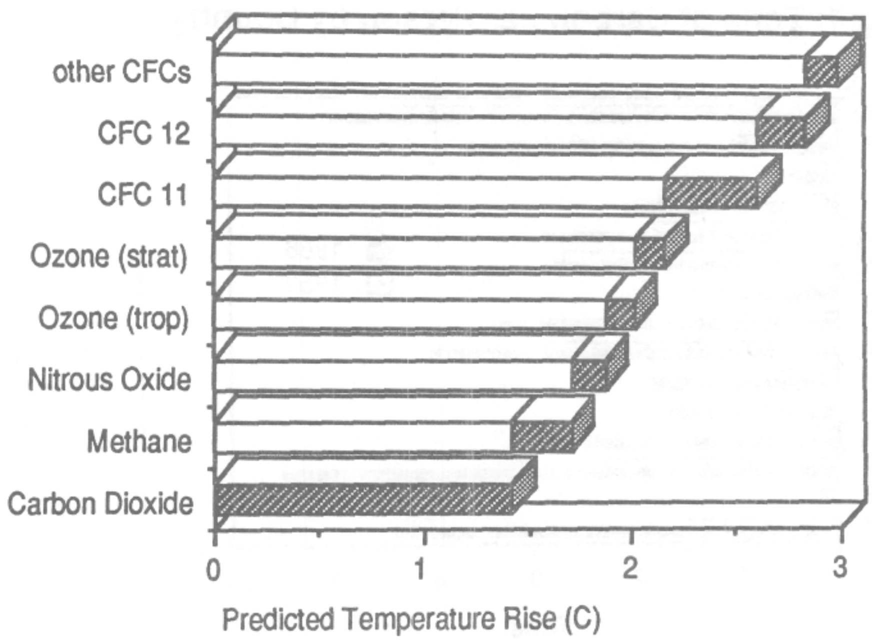


Fig. 3: **Relative Contribution of Greenhouse** Gases (Anonymous, 1987)

Chlorofluorocarbons, unlike other greenhouse gases, are not produced naturally and they are approximately 1000 times more active than C02- The major sources of CFCs are refrigerants and halogen-based propellants. The action of

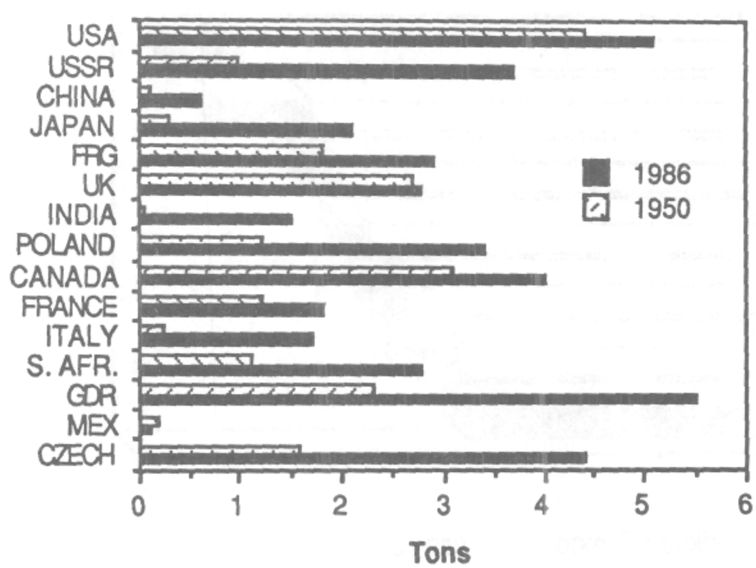
3FCs as a destroyer of stratospheric O_3 is well known. New substitutes to replace CFCs are coming on the market and it is hoped that new emissions of CFCs will be all but eliminated in the near future. The reduction and eventual elimination CFCs is being brought about through intense international cooperation developed in such forums as the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol.

In total the combined effect of these trace gases is roughly equal to that of CO£ itself. Figure 3 demonstrates the potential net warming effect produced by the various gases taking into account their chemical characteristics and atmospheric lifetime.

<u>Global Emissions of CO_2</u>

For discussion purposes we will examine the global growth in CO_2 with the understanding that most of the other greenhouse gases are increasing at an even more rapid rate. The pattern in CO_2 emissions globally has seen the North American and Western European portion of the pie diminishing with respect to other parts of the globe. Unfortunately, though our relative portion of the pie is diminishing, the total pie is getting larger! On a per capita basis, Canada is currently ranked fourth, better than our number 2 ranking in 1950 (figure 4). As we can see, our ranking is dropping but our per capita use of carbon is increasing (CDIAC, 1989).

Fig 4: Tons of Carbon per Person by Country



The scientific evidence is irrefutable: emissions of greenhouse gases are rapidly increasing and these increases can be traced - without ambiguity - to human activities (American Meteorological Society, 1991). The question that poses the most uncertainty, however, is what effect will these changes in the composition of our atmosphere have on the global and regional climate? Scientific procedures would suggest that we design an experiment to determine the impact of these emissions on a second group of planets similar to our own, run the experiment to completion, statistically examine the results and publish the conclusions. Unfortunately, without companion planets, such an experiment is impossible and we are forced to conduct the experiment on ourselves and attempt to model the consequences.

MODELLING THE GREENHOUSE

Modelling the complexities of Earth's atmosphere is an exceedingly difficult task requiring a thorough understanding of both atmospheric and oceanic processes. Our understanding of these processes is far from complete and major areas of uncertainty include the manner in which clouds and the oceans are represented by General Circulation Models (GCMs).

For the most part GCMs treat the globe as simple terrain. They account for the major interfaces such as where the oceans meet the land and the location of the major mountain ranges, however the less-than-major terrain is all but ignored. The GCMs use a network of grid points to model the surface of the earth, with resolution varying from 80 latitude x 10° longitude (Goddard Institute of Space Studies) to 4° x 5° (Oregon State Univ.). This produces a grid square (within which changes in the climate and the surface are assumed to be uniform) that is typically the size of the state of Colorado (AAAS, 1988). In addition, several layers in the vertical are incorporated, with the OSU model using only 2 and the United Kingdom Meteorological Office model using 11. The models can incorporate 2000 or more grid points at each level and solution of the appropriate equations require an immense amount of high speed computer time. Harrington (1987) estimates that 1 day of simulation using a 10 level model at a resolution of 500 km takes approximately 2 minutes of CPU time on a Cray super computer! These are among the most complex models developed and the extreme cost limits their use.

The question that arises is "how accurate" are these models? The ocean contains more than 50 times as much CO_2 as the atmosphere, therefore a small change in the ocean can cause large changes in the atmosphere. In addition, the representation of clouds will affect how incoming solar radiation is reflected back into space and how much water vapour, a powerful greenhouse gas, is in the atmosphere. These processes are know as feedback mechanisms and they can be positive, contributing to climatic warming, or negative, decreasing climatic warming. The design of GCMs involves the quantification of several of these feedback mechanisms based on our current understanding of the science. Recent research (Mitchell et al., 1989) suggests that slight modifications to the complexity of standard cloud models can have dramatic effects on the both the magnitude and the sign of cloud feedbacks reducing predicted global warming by a factor of three.

Additional model errors occur due to simplifications that must be incorporated into the GCMs to make them workable. These include, for example, the number of layers used by the model, the complexity with which we represent the oceans and the clouds, and density of the grid. In some cases cost of computer time and the lack of adequate speed in today's computers may be the limiting factors, **but** in others it is simply lack of understanding of the physical processes involved.

Some daring scientists have seen fit to use GCMs to predict future climates on the regional and local scale. This provides excellent material for newspapers, however by the time the interpretations reach that level any caveats attached explaining the potential errors in the models have long since disappeared. These models were never intended and cannot properly be used for such detailed applications and it will be at least several decades before the science catches up to the requirement for local and regional predictions.

Summary

The consensus among most of the scientific community is that the anthropogenic input to our atmosphere of gases such as carbon dioxide, CFCs and methane will likely cause global warming (IPCC, 1990). When that warming will occur and how quickly it will proceed is unknown. Needless to say there are several well known scientists who are not convinced that climate warming due to the *greenhouse effect* is upon us. The question of model "accuracy" has resulted in a recent surge of papers suggesting that we proceed with caution before undertaking any major changes to our society. Others argue that many of the necessary actions will help solve other problems such as local air quality and the waste of fossil fuel reserves. As Ellsaesser (1988) has said "Our climate models, which provide the basis for most of this attribution of cause and effect, are not merely unverified - they are unverifiable". So with these precautions in mind we can now proceed to examine some possible scenarios.

GREENHOUSE SCENARIOS

In the previous section we have examined how complex, yet tenuous, the GCMs are and how risky it may be to use them to predict regional or local climate. However, the possible ramifications of global climatic change, above and beyond normal climatic fluctuations, are well worth considering. The temperature change predicted for the next 50 to 100 years may be equal in magnitude to the temperature change we have gone through in the several thousand years since the last ice age. Changes of this magnitude in this brief period are, as mentioned earlier, ***unprecedented*** in Earth's history. Astronomical variations in Earth's climate account for less than 0.1 °C cooling per 100 years. Volcanic activity can account for up to 0.4 °C cooling and variations in the solar constant, the output of the sun itself, may account for a temperature variation ranging from -0.2 to +0.4 °C. The temperature and precipitation patterns that we know today may be vastly different from those future generations will experience in the next century. If the predictions are close to correct then it is well worth our while to consider some of the possible scenarios that may occur.

Current GCMs predict an extremely different climate for parts of North America by the middle of the next century. Forecast temperature changes are least near the equator, increasing rapidly in polar regions while the reliability of temperature estimates is questionable, the precipitation scenarios are even more tenuous, with some models predicting increased seasonal precipitation and others showing some seasons with reduced precipitation. Although the precipitation and temperature changes we will encounter in the next century are at best uncertain, it is likely that patterns will be highly modified from those we encounter today.

If the predictions are correct, we could see radical changes in agriculture, but the effects may be even more dramatic on unmanaged ecosystems. Crops requiring a long rotation, such as forests, and natural ecosystems may be unable to react to the rapid changes in climate that are forecast. Some models predict that North American forest climate boundaries may move northward in excess of 200 km by the end of the next century. (The natural migration rate of a Douglas fir ecosystem is between 4 and 30 km over the same period). It is likely that some species would be incapable of adapting genetically to cope with such rapid changes in the climate. The soil develops over a time frame of centuries and it is possible that as ecosystems, capable of adapting to a modified climate, move poleward a suitable rooting medium may not exist.

Increased temperatures will result in increased evaporation with more atmospheric water vapour and clouds. The effects are anticipated to be most pronounced at middle and higher latitudes (ie. north of the Canada-US border). Most current GCMs suggest that winter precipitation will increase and, when combined with the warmer temperatures, will result in higher and earlier runoff. The predicted increase in the summer precipitation is expected to be offset by higher evapotranspiration, resulting in more severe and perhaps more frequent drought. Such a scenario will affect forestry, agriculture, fisheries, wildlife habitat, recreation, domestic water supplies, hydro electric power generation, dam design and safety, and waste disposal - in short, our entire socio-economic structure. The distribution and timing of water availability in the future may be one of the most serious consequences we have to face.

Elevated CO_2 levels could increase the yield of numerous plant species. For example, doubling the atmospheric CO_2 may increase wheat yield by as much as 38%. Weeds as well as beneficial plants may become more vigorous resulting in an increased need for fertilizers and herbicides. Also, water use-efficiency of some plants is expected to improve, but at this time our understanding of these reactions is based on laboratory data as opposed to long-term field experiments (Mooney et al., 1991).

Increased global temperatures will result in a rise in sea level. The cause is not anticipated to be the melting of land-based ice or glaciers but the inevitable expansion of the world's oceans as they warm up. A global warming estimated at 1.5 to 5.5 °C is likely to cause a sea level rise of between 20 and 165 cm. Nearly one-third of all human beings live within 60 km of a coastline; a sea level rise of eve: one metre could have profound impacts.

Of course, these predictions are based on GCMs that we know may be incorrect. The difficulty in adequately incorporating the contribution of the oceans, clouds and other important controlling factors into the models is an obvious shortcoming. However, the seriousness of the potential impacts of these predictions dictates that we must examine the most likely scenarios. If all emissions of greenhouse gases ceased today, global temperatures would continue to increase during most of the next century. Even the lowest estimated temperature change of 1.5 °C will produce a climate that is beyond the range of any climate that has existed in recent history. We must ***PLAN*** for the possible climatic changes on the horizon.

RECLAMATION CONSIDERATIONS

Society is fast becoming aware of the need to reduce, reuse and recycle those products entering the waste stream. In addition, industry too has begun to take advantage of what was once considered waste and to use it as a resource. Examples of this are the recovery of methane fuel from landfills and the use of wood waste for the co-generation of electricity. A new spirit of cooperation has begun to replace the once difficult relations between business and environmental groups. Multinational corporations have excellent economic and political reasons to work with environmental organizations; they depend on resources threatened by major problems such as the greenhouse effect.

With this in mind we must consider what the possible impacts of climatic change may be on sites that are subject to reclamation. As scientists involved in the restoration and reclamation of various land sites, it is imperative that you consider the possible climatic changes forecast for the next 50 to 100 years most seriously. The plant species that currently flourish at the site in question may not survive if the climatic change scenarios come about.

Consideration should be given to selecting plant species based on the possibility that changes may occur. This does not mean that you should be considering the use of cactus where you are now using bunch grasses. It may, however, be prudent to look at the possibility of using more drought tolerant varieties of bunch grass.

Unfortunately, climatologists cannot, at this time, advise you if and when climatic change will occur. It is up to you to weigh the current evidence, determine the potential risks that may occur at the reclamation site and proceed. Please consider that waiting for scientific certainty may result in a substantial increase in the cost of adaptation and the potential difficulty of site reclamation.

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