A GUIDE TO THE GREENHOUSE EFFECT

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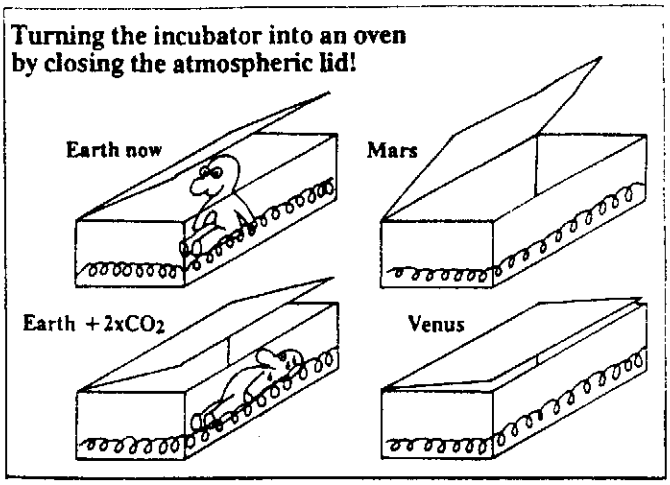
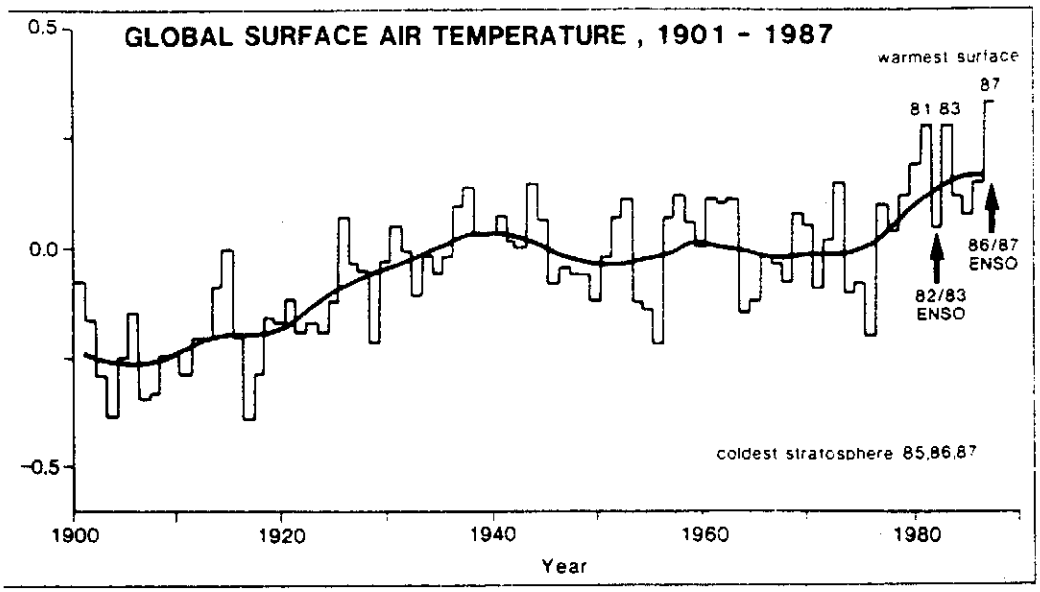
The 'greenhouse effect' is the best, most fully established theory in atmospheric science. It is this well-understood, greenhouse effect that keeps the Venus surface hot enough to bake potatoes out in the open while the lack of all but a very thin greenhouse makes the Martian surface resemble a very effective commercial deep freeze! Scientists predicted these temperatures with models before spacecraft measured them. The same models predict a warming for the Earth of between 3 and 4 degrees C by 2030.





We understand radiative transfer very well. The theory is based on sound physics and as far as we know there is no antidote within the natural Earth system — except of course to remove the gases from the atmosphere again. This is a very costly process; such a costly antidote to warming is not, in my opinion, something which we are likely to see.

There is considerable confusion and debate about temperature trends which have been measured for most of this century. Figure 1 shows the temperature increases this century. These temperature increases are derived from very many measurements of temperatures with thermometers which, whilst they might not have been absolutely accurate, agree and are generally mutually consistent. The general sense is of global surface temperatures (both land and ocean temperatures) increasing in an admittedly, somewhat oscillatory mode. The **important** point to make here is that these increases in temperature have absolutely nothing to do with the **predictions** of the greenhouse effect. They seem to be circumstantial evidence supporting the predictions and, indeed, they may well be the first hints of the greenhouse effect occurring on Earth; but they are not in themselves the basis of any of the greenhouse predictions.

The greenhouse is a very poor analogy for the effect which is called the greenhouse effect. In fact, greenhouses, those that are not heated by stoves, stay warm because they shelter the plants. It is a poor name for another, much more important reason: it sounds benign. By contrast, nuclear winter does not sound nice, the ozone hole is obviously a bad thing. The greenhouse analogy is not only a scientific misnomer, it is also an inadequate label because it does not emphasise how much our social and economic systems, and particularly our agricultural and water gathering activities, are going to be affected by the gradual warming and rainfall changes.

A better analogy might be 'turning the incubator of the planet Earth into an oven by closing the atmospheric lid' (Figure 2). The Earth is an efficient incubator. Life, since it first originated at least three and a half billion years ago, within a billion years of the planet being formed, has diversified and spread over all of the planet. At the moment, then, the incubator in which we live has its lid somewhat ajar; some energy from the surface is emitted back to space. The incubator heater can be thought of as the

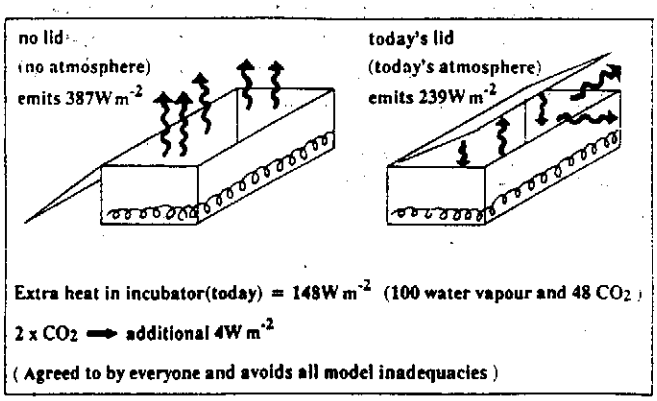


Figure 3: radiation emissions associated with closing incubator lid

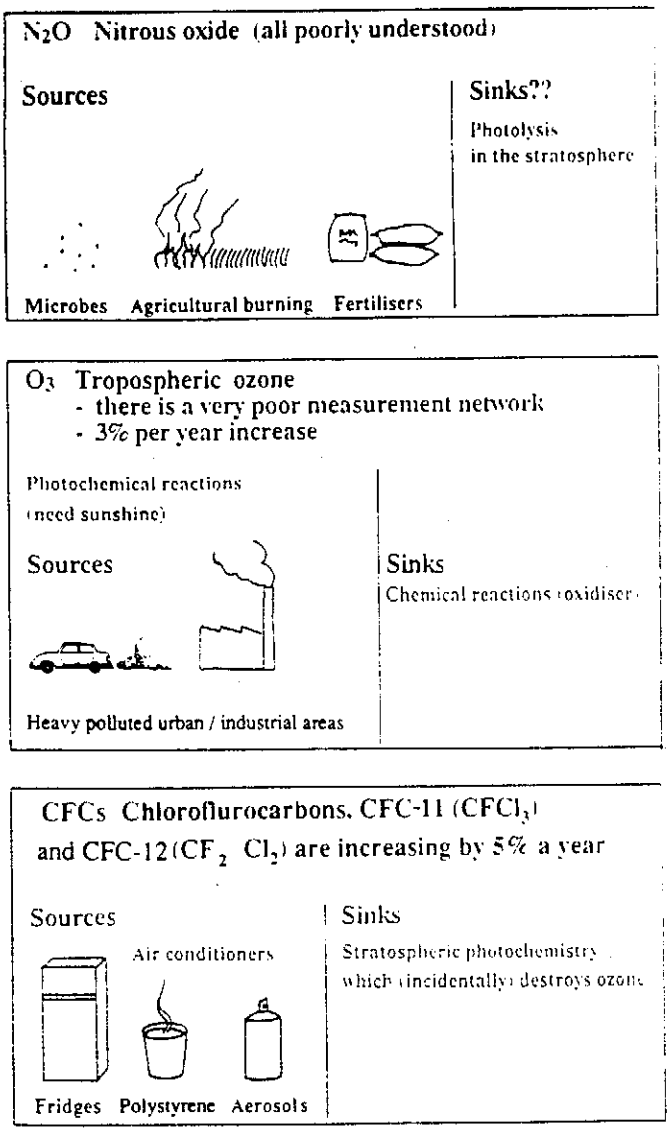


Figure 4: sources and sinks of greenhouse gases

standards will change between now and 2050. It is hard enough to estimate this for the developed countries, where many of us hope that there will be a change in lifestyle to use energy more efficiently, and perhaps even to use less energy, to afforest areas that have been denuded of vegetation and so on. It is much harder to tell how the rest of the world, which is still striving for industrial independence and economic wealth, will change and therefore it is difficult to tell how much of these gases will be added to the atmosphere. By adding all the best estimates that can be made from socio-economic models we discover that by 2050 we will have added to our incubator somewhere between about 2.2 and 7.2 watts per square metre. It is important to recall here that doubling carbon dioxide alone adds four watts per square metre of energy. If the upper estimates in this prediction are right, then we will have almost doubled the doubling of carbon dioxide.

Surface and tropospheric temperatures have been warming throughout this century and stratospheric temperatures have been cooling as the models predict. However, specifying exactly when the planet Earth will catch up with the model predictions is tough because the planet is actually two-thirds ocean (Figure 5). Water takes a lot longer to warm up than air or soil as we all know from outdoor pool or ocean swimming in early summer. Uncertainties about how fast oceans sequester heat easily resolve the differences between observed and predicted temperature trends to date. More importantly oceanic sequestration of heat does **not** reverse or remove the greenhouse effect — it simply slows it down a little.

It is difficult to summarise the consensus view of the climate modelling community because models are being refined continually. Nevertheless it is agreed that there will be an increased gaseous absorption because we are increasing the greenhouse gases. This will lead to a warming. This is unambiguous; it is not open to debate and it is not disputed within the atmospheric modelling community. Trace gases other than carbon dioxide will cause an equivalent or effective doubling of carbon dioxide much faster than carbon dioxide increases alone. We believe now that we will get an effective doubling of carbon dioxide by the year 2020 or perhaps 2030 AD.

There is considerable consensus about what will happen at a global scale. Temperatures are believed to be likely to increase with an effective doubling of carbon dioxide, by somewhere between three and five degrees. Also all of the models agree that doubling carbon dioxide will increase the amount of evaporation and the amount of rainfall. The hydrological cycle, which moves water around the globe by evaporating it from some places and circulating the water vapour to other locations where clouds form and sometimes rain (or snow) falls, will intensify. Precipitation will increase on average around the world although Australia may find its total rainfall decreased.

WE CAN (AND SHOULD) PLAN TO CAPITALIZE ON THE BENEFITS OF GREENHOUSE

There is a growing realisation that the warming of the planet and the intensification of the hydrological cycle could have a marked impact on human society.

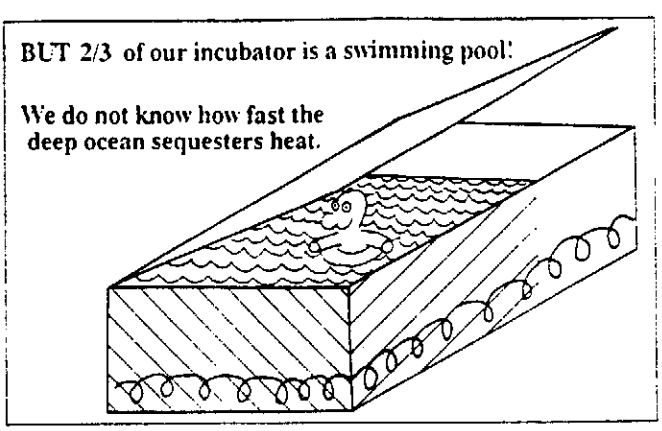


Figure 5: the role of the ocean in the greenhouse effect

Sun but here we've represented it as a heating element around the outside of the incubator.

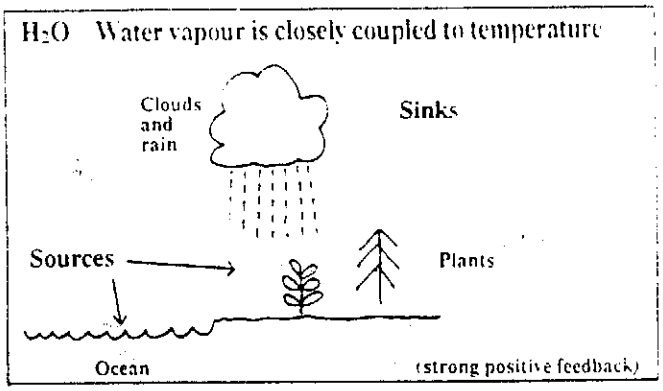
Continuing the incubator analogy we can consider the situation if the Earth had no greenhouse gases in its atmosphere, that is if the incubator lid were open completely. The amount of radiant energy emitted would be 387 watts per square metre (Figure 3). Actually at present the incubator lid is closed so that the amount of energy emitted is only 239 watts per square metre. What that means is that the incubator lid serves to keep in an extra amount of heat equal to 148 watts per square metre. It happens that about 100 of those 148 is due to water vapour which is the largest greenhouse gas in the Earth's atmosphere; and the other 48 is due to carbon dioxide.

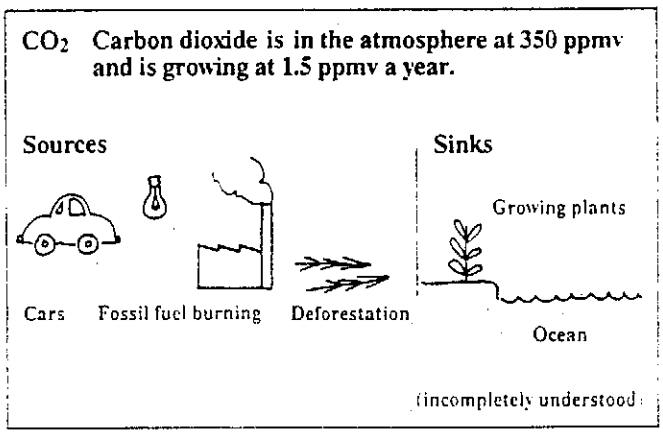
It is important to recognise here that doubling carbon dioxide, which is what is usually meant by the greenhouse effect, adds only an additional four watts per square metre. This additional energy is about the equivalent of the heat you obtain from a 40 watt light bulb burning 24 hours a day in a small single bedroom. Mankind's greenhouse does not totally reorganise the heat balance of the planet nor does it boil off the oceans or melt all the icecaps but it will modify temperatures and rainfall, and possibly winds and the extent of cyclone tracks. The other important point to notice is that all the climate modellers around the world agree about this number of four watts per square metre. There is still some discussion about exactly what the temperature change will be and there is a great deal of debate about the impact on rainfall and on soil moisture and agricultural productivity; but all modellers agree about the radiative forcing. This is, as I indicated before, because we understand the theory behind the greenhouse effect rather well.

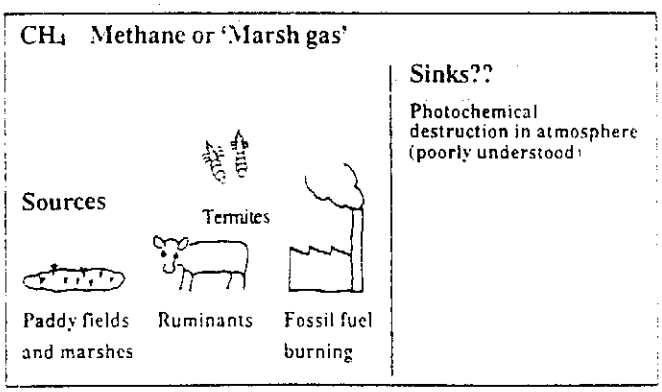
HOW MUCH WARMING AND HOW SOON?

Only the trace gases (<1% of the atmosphere) are associated with the Earth's greenhouse. The largest, water vapour, is coupled to temperature and must increase as temperature increases. The others are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), tropospheric ozone (O_3) and the chlorofluorocarbons (CFCs) all of which are being increased by mankind (Figure 4). Fossil fuel burning adds 5000 million tonnes of CO_2 to the atmosphere each year. Land clearance in Latin America alone adds 700 million tonnes.

CO_2 is increasing at 5 per cent per decade, CH_4 is increasing at 10 per cent per decade, CFCs are increasing at 100 per cent per decade.

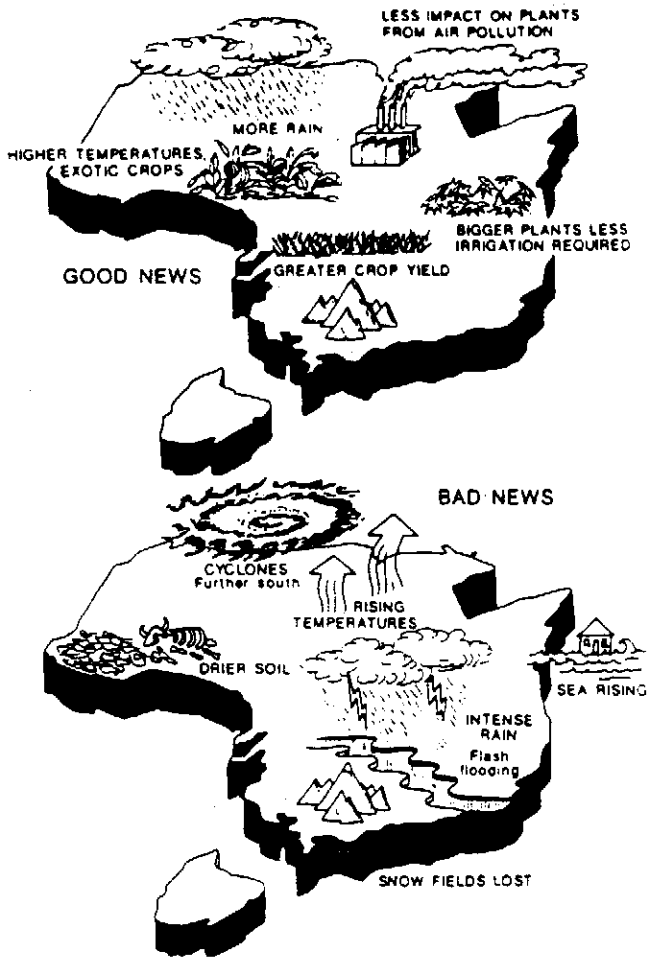






CO_2 has increased by 25 per cent since the industrial revolution. The Earth must warm by approximately 1.5 degrees C even if we stopped adding all greenhouse gases to the atmosphere right now. It is important to recognise that the Montreal protocol agreement on CFCs does not buy us very much time. The pre-protocol estimate was that all of the greenhouse gases together would produce an effective doubling of carbon dioxide by 2019. With the protocol in place, if it is ratified by all the signatory nations, the post-protocol estimation is that all of the trace gases together would produce an effective doubling of CO_2 by 2027. By this international agreement which took a great deal of political skill to contrive, we have managed to buy ourselves only eight years.

We can calculate, let us say for the year 2050, how much extra heat there will be in our incubator. For each of the greenhouse gases, we can calculate, or rather we can estimate, how much of the gas there will be by 2050. These estimates range widely because they are dependent on other models such as those which predict how social and economic



Even in an agreed global warming there are regional 'winners' and 'losers' (Figure 6) but without effective planning both the bad and the good news become costly and perhaps catastrophic.

Temperature rise will cause thermal expansion of the oceans by between 20 cm and one metre, perhaps inundating some low-lying coastal areas. Nearly one third of all human beings live within 60 km of a coastline. A one metre rise could displace 15 million people in Bangladesh, up to 10 million in Egypt. Deltas in Europe and North America and islands in the tropical seas are also vulnerable. Conservative estimates of coastal protection costs against a one metre sea level rise run into tens of billions of dollars.

I believe that the atmospheric scientist's task is to advise on the predictions, on their theoretical basis and on how they relate to observations. This I have done here. I do not believe that policies can be determined by climatic scientists but I list some possible actions which follow directly from this review:

- reduce contaminant emissions now and pursue further reductions urgently and aggressively (but recognize this will not save us from at least some warming and the associated changes in circulation and the hydrological cycle).

- plan to modify land use and industrial development now in ways that will benefit us whenever the warming occurs. Obvious examples are to become more energy efficient and conserve and recycle resources. Because agriculture will be affected, farmers need advice and support.

- recognise that unambiguously detected thresholds may come too late to be useful. It is not true to say that we have until the end of the century.

We know that mankind is slowly closing the heat-retaining lid of our planetary incubator. The regional and local consequences are very difficult to predict but our policy makers must recognise that "not to decide, is to decide". ■