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Modelling a meteorological muddle

Media hype has made global warming a hot topic. But the evidence is far from clear. A lot more cool thinking, better climate models, and more reliable methods of data collection are needed.

On 'Earth Day', 22 April, a Doordarshan TV presenter said in a television programme on environment that the average global temperature would go up by 5 to 6°C by the middle of the next century. She went on to say that, with this global warming, sea levels would rise by 30 to 100 cm, inundating our beautiful Lakshadweep archipelago, that the eastern coast of mainland India would suffer storm surges, etc.

Is there any experimental evidence for global warming? The first major scientific effort to assess trends in global warming was made recently (*Science*, 1990. **247**, 1558; see also page 397 of this issue) by a careful analysis of the passive microwave radiometric data obtained through the US National Oceanic and Atmospheric Administration's (NOAA) *TIROS-N* satellites, which have a monthly precision of ±0.01°C. The report states that there was no obvious trend indicating global warming during the ten-year period 1979–1988. This does not however mean that the last word has been said on this subject.

The story starts at the turn of this century, when Arrhenius postulated an increase in atmospheric carbon dioxide due to burning of fuel by man. But the first quantitative measurements, made during the International Geophysical Year (1957–1958), in Hawaii, indicated a decrease of 7 parts per million by volume (ppmv) in the CO_2 content in summer compared to that in winter. This was attributed to the photosynthetic consumption of CO_2. Subsequent measurements revealed that the level of CO_2 in the atmosphere had risen from 315 ppmv in 1958 to 350 ppmv in 1988. Analysis of 'old air' bubbles trapped in the ice of polar regions showed that the CO_2 content was 270 ppmv during the last interglacial period, 180 ppmv at the last glacial maximum, and 270–280 ppmv in 1850 (while it was 315 ppmv in 1958 and 350 ppmv in 1988).

There are four stages in the attempts to understand the phenomenon of global warming. The first is the physics of the so-called greenhouse effect. Any body emits black body radiation corresponding to its temperature, whose wavelength maximum depends on that temperature. The black body radiation from the Sun, whose surface temperature is 6000 K, has a maximum in the visible region (600 nm, i.e. orange-red), while that from the Earth's surface, which has a temperature of nearly 300 K, has its maximum at a longer, infrared, wavelength. Satellite data show that 343 watts per square metre ($W\ m^{-2}$) of solar radiation strike the top of the Earth's atmosphere, 106 $W\ m^{-2}$ of it is reflected back by the atmosphere, 68 $W\ m^{-2}$ is absorbed in the atmosphere, and 169 $W\ m^{-2}$ is absorbed by the Earth's surface. Longwave emission by the Earth's surface is 390 $W\ m^{-2}$, of which 163 $W\ m^{-2}$ is absorbed by the atmosphere and the remaining 237 $W\ m^{-2}$ is radiated back into space. The 163 $W\ m^{-2}$ of longwave radiation that is absorbed is the net greenhouse effect of the atmosphere, and is comparable to the absorbed solar radiation. If CO_2, which is the major greenhouse gas in the atmosphere, were not there, our planet would be a cold one and no life would have been possible on it. It is this so-called greenhouse effect that makes our planet liveable.

The second stage relates to the chemistry of the atmosphere. In the early seventies, the chemical picture we had of the atmosphere changed with our greater understanding of active chemical transformations in it: the nitrogen oxides NO and NO_2 attack stratospheric ozone (O_3), carbon monoxide (CO) and methane (CH_4) are oxidized by the hydroxyl (OH) radical in the troposphere, and the active series of chlorine radicals also play important roles in chemical transformations. The timescales of these reactions vary from minutes to fractions of a second. In many instances the controlling molecules are not the most abundant species nor are they in the most obvious locations. The atmosphere has 21% oxygen and only 0.3 ppmv of ozone, and the OH radical, the most important oxidizing species, is present at a concentration of only 1 in 10^{13} near the surface of the Earth. This understanding of the chemistry of the atmosphere brought in its wake concern over the highaltitude emission of nitrogen oxides by supersonic aircraft, which could affect the ozone content of the stratosphere. Then came the detection of traces of the chlorofluorocarbons CFC-11 and CFC-12 (gases used in refrigerators and aerosol sprays)—40 to 100 parts per trillion by volume (pptv). In terms of radiation absorption potential, one molecule of these gases corresponds to about 10,000 molecules of carbon dioxide. The unprecedented increase of CO_2, CH_4, CO, NO and CFCs, all of which absorb the longwave infrared radiation emitted by the Earth, not only will play a significant role in the control of the Earth's temperature, but also—because, except CO_2, all these molecules are also chemically active—could control the formation and destruction of ozone, hence the absorption of incoming ultraviolet light from the Sun which dictates the temperature structure, and indeed the very existence, of the stratosphere. Obviously, the delicate balance between the absorbed solar energy and the longwave energy emitted into space will strongly influence the overall temperature of the atmosphere. When the concentrations of the 'dirty' gases increase, this radiation balance must seriously be disturbed because the gases will trap more longwave radiation into the system. The system can restore the balance only by warming and emitting more infrared energy. So global warming is the obvious conclusion.

Up to this point the concepts are simple. After this one has to grapple with the realities of the Earth's atmosphere and its circulation. The planet receives more solar energy per unit area in the tropics than in the polar regions because of its spherical shape. The emitted longwave radiation is unable to offset completely this equator-to-pole heat gradient, which becomes the fundamental driving force for atmospheric and oceanic circulation patterns, jet streams, monsoonal circulation, polar deep-water circulation, etc. One has also to take into consideration the effects of the rotation of the Earth.

The problem of meteorology is how to deal with the heat and mass flows in this huge system which we call the atmosphere, in which the incoming solar radiation, the heating of the surface of the Earth—which is part land and part water—, the evaporation of the seawater, the condensation of the clouds and the consequent absorption and release of latent heat, and other processes are in constant, dynamic interaction. Each phenomenon in itself may be understood but their interactions appear to be of immense complexity. The pioneers who grasped the basic principles of these interactions were men like George Simpson, Gilbert Walker (see *Current Science*, 1990, **59**, 121) and others who worked in India. But the real advance was made by the visionary Lewis Fry Richardson, the father of numerical meteorology. His grand dream is now becoming a reality. The idea, simply stated, is to divide the surface of the Earth into small squares bounded by latitudes and longitudes; treat the air over each square as a stack of layers which change according to the known physical rules, taking into consideration the radiation entering and leaving the stack, the evaporation and condensation of water, the dynamics of the flow of air, and indeed all the factors that could influence the air in the stack; and then take into account the effect of the neighbouring squares. The input data are the measured values of temperature, humidity and wind velocities at various heights. With the coming of giant computers, which solve the complex mathematical equations that factor these inputs into weather-prediction models, numerical prediction of weather is becoming a reality, and even successful in predicting weather over short periods, i.e. day-to-day changes. It has been quite unsatisfactory in forecasting gales, blizzards and other catastrophic changes. Improvements are continually being made to predict more long-term effects. Some efforts are being made in India to model and predict the monsoons.

It is in this backdrop that we come to the fourth stage, where meteorologists are trying to compute the effects of the increase of greenhouse gases. The heat gradient over the surface of the Earth controls many meteorological phenomena. Altered greenhouse effects can alter the important radiative heating gradient in many ways. The effects being looked for are very small (a few degrees), and the time periods very large (a few decades). The weather/climate predictions themselves are uncertain. Hence the task is a difficult one. There are, at present, at least two dozen models for these calculations. Unfortunately no two models give the same results. The results are so conflicting that one is sometimes tempted to believe that the models give the results that the modellers subconsciously want. Indeed, one comment that is made is that these models 'are marvels of mathematics and computer science, but rather crude imitators of reality'. Most models show a warmer world. Some models predict a warming-up of 5°C by the middle of the next century. Others reduce the increase in temperature to 1.5°C. Extreme scenarios of coastal flooding from melting ice-caps and rising inland droughts have been predicted. But the figures should be viewed as estimates from evolving computer models and not as reliable predictions.

There is a completely opposite view. The major weakness of the models is their assumption that CO_2 build-up is the only significant climate variable. According to some, the cloud cover, which is the other important variable, is at least 100 times more powerful in affecting temperatures than greenhouse gases. V. Ramanathan of the University of Chicago states that 'clouds appear to cool Earth's climate', and could offset the atmospheric greenhouse effect.

A strong view is emerging that all the models completely ignore the thermostatic effects of the hydrological cycle of evaporation and condensation. Two-thirds of the predicted global warming is due not directly to the radiative power of CO_2 but due to an indirect effect. This is the increase, caused by CO_2 warming, of water vapour evaporation into the atmospheric blanket. But in the warmer, tropical latitudes, where the temperature change from sea level upward is rapid, there is an opposite effect: The water vapour rises by deep convection and in turn leads to more rapid condensation and precipitation, which then causes a drying and thinning of the upper atmosphere in a process called subsidence. In these lower latitudes a rise in CO_2 emission will produce a three-to-one rise in greenhouse blanket thinning due to condensation—exactly the opposite of what the models predict. According to Sir James Lovelock, the hydrological process is comparable in magnitude with that of the CO_2 greenhouse effect, but in opposition to it. Others say: As CO_2 speeds up the hydrological cycle, more convection creates more clouds and more cooling, so the greenhouse effect should turn out to be minimal or even benign. Correcting for deep convection alone could lower the global warming estimates by a factor of six and it is unlikely that we will see more than a few tenths of a degree increase over the next century.

All this is very confusing to the layman and even to the scientific mind. The modellers gather every year and exchange views. They usually 'publish' their results in the media. There is a rift even amongst the scientists who study global warming. There are many able scientists on both sides. We shall end this essay with a few quotations from them.

'The records of the last 150,000 years found in ice cores and marine deposits scream to us that carbon dioxide and temperature are closely correlated.' (This correlation is much lower in the last 100 years.)

'Sixteen meteorological stations in the Antarctic have shown an average warming of 0.022°C per year, i.e. 2°C by 2080, and a sea-level rise of 2 mm per year. The coral nations of the tropical oceans face inundation as the warming seas begin to rise. Small island nations must begin to map out their strategies on a long-term basis.'

'There is a suggestion that governments nervous of the enormous investments that are to be made to prevent global warming are slowly propagating the idea that the greenhouse effect need not be taken seriously and the scientists and the common man must beware!'

'It appears that no possible policies are likely to prevent the world from warming a degree or two. I see a positive aspect that the possibility of a slight but manifest global warming coupled with a larger-threat forecast may catalyse international co-operation to achieve environmentally sustainable development.'

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