Subject Area 3: Atmospheric Chemistry and Physics

Commentary

The IPCC Fourth Assessment Report and the Fiftieth Anniversary of Sputnik

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Introduction

The connection between the two items in our title may not be immediately obvious to the reader, but we hope in this article to establish the relationship between them.

In Paris, on 2 February 2007, the Working Group I of the Intergovernmental Panel on Climate Change (IPCC) adopted the Summary for Policymakers of the first volume of 'Climate Change 2007', also known as the Fourth Assessment Report (AR4). This Summary for Policymakers, which describes estimations of projected future climate change, is based on the past IPCC assessments and the new findings in relevant understanding that have been achieved in the past six years of research (since the Third Assessment Report). Among its basic conclusions are (verbatim) the following:

"1. Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

2. At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.

3. For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES (Special Report on Emission Scenarios) emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.

4. Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized."

The report was produced by some 600 authors from 40 countries, reviewed and revised by over 620 experts and a large number of government reviewers as well as representatives from 113 governments.

1 Reliability and Consensus in Climate Prediction

Much has been made of the idea of consensus in the development of the IPCC's role since it was set up in 1988 by WMO, the World Meteorological Oganisation, and UNEP, the United Nations Environment Progamme. The IPCC's scientific assessment involves studying the output from various climate models as well as various historical records of atmospheric and marine data. It is well known that the chaotic character of the atmospheric dynamics [e.g. 1–3] limits the validity of long-term weather forecasts to one or two weeks. However, it is possible to consider climate projections, that is, to develop scenarios of probable climate changes due to the predicted continuing growth of the concentrations of greenhouse gases (GHGs) in the atmosphere. The basic method to make such scenarios tangible involves the use of numerical climate models that simulate interactive processes in the climatic system 'atmosphere-ocean-land surface-cryosphere-biosphere'. Because there are many such models, the serious difficulty arises as to which is the best model to choose and the IPCC attempts to draw the most reliable conclusions from the outputs of all the available models. This difficulty becomes much more serious when taking into account the fact that big uncertainties in fundamental climate-forming factors (e.g. melting of the ice sheets, carbon-cycle feedbacks, the role of clouds, biogeochemical cycles) still remain. In order to reduce the level of existing uncertainties, the modeling of nature-society interaction is urgently required with long-term, non-linear changes in climate system taken into account [4].

In a succession of reports over the period since 1990 the IPCC has come more and more firmly to the view that human activities are contributing significantly to global warming and the statements in the Fourth Assessment Report, published in February 2007, which we have quoted above are the IPCC's strongest statements to date. There has been a considerable emphasis on 'consensus' throughout the history of the IPCC. We should, perhaps, distinguish between two different types of consensus. One can think, on the one hand, of a consensus obtained from the 'good and the great', i.e. relying on their status and authority, and on the other hand, a consensus based on the assessment of the evidence by scientific workers in the field. The IPCC has steadfastly followed the second of these and in consequence has been criticized by some people as being over-cautious in its conclusions. There are, of course, some reputable scientists whose assessment of the evidence does not agree with the IPCC's view that the observed global warming is occurring as a result of human activities. Prominent among these is Richard Lindzen, a professor of atmospheric science from MIT, who has recently written some persuasive articles in the *Wall Street Journal* [5,6].

The situation with regard to the first type of consensus, that among the good and the great, i.e. governments, the media and the general public, has clearly changed since the time of the first IPCC report in 1990. At that time there was a strong lobby, backed discreetly by large oil companies, seeking to discredit the idea of human-induced global warming. But now there is widespread acceptance of the existence of human-induced global warming in political circles, in the media and by the public at large. This was expressed succinctly in a recent Editorial entitled "Light at the end of the tunnel" in *Nature* [7] which commented on the IPCC's Fourth Assessment Report as follows: "The IPCC report has served a useful purpose in removing the last ground from under the sceptics' feet, leaving them looking marooned and ridiculous." The oil companies are beginning to recognize that the resources of oil and gas are not unlimited and they are beginning to think positively about their future role as purveyors of energy from alternative sources. A great deal of the credit for this change in the general attitude to, and acceptance of, the existence of human-induced global warming must go to the IPCC for its relentless pursuance of the scientific evidence, digesting it and presenting it, but without overstating its case. However, there is a downside to this success of the IPCC due to two components. The first is that it leads people to think that the emission of greenhouse gases and the consequent global warming is the major threat, or even the only threat, to the continuation of human life, or at least of our highly sophisticated society, on the planet. This is not the case. One person responsible for labouring this point was the late and very prominent Russian scientist Academician Kirill Kondratyev [8,9]. Another approach is that of Diamond [10], which is to consider some ancient civilisations, some of which collapsed and some of which survived and to see what lessons can be learned from their history. The second component of the downside to the IPCC's success is the fact that there are genuine scientific concerns about the climate models that are currently in use and on which the IPCC relies so heavily. We take these two points in turn.

2 Other Threats to Our Way of Life

Apart from releasing greenhouse gases into the atmosphere we are polluting the atmosphere in other ways. We are polluting the water supplies, we are degrading the soil, we are destroying the forests and other natural habitats and we are causing many species of animals, birds and plants to become extinct. We are creating potential ecological disasters in many ways. We are consuming non-renewable resources at a rapid rate. There has been much attention given to the fact that our supplies of energy from gas, oil and coal are finite [11–13]. However, much less attention has been paid to the fact that resources of uranium (as a fuel for nuclear power stations) and various non-fuel minerals, principally metals and metallic ores, are also finite (one of the few discussions of this problem is given by Tanzer [14], though some aspects of the discussion in that book are now somewhat out of date).

What comes out of the various climate model calculations and the IPCC analysis of the results obtained from these models is that the likely climate change will vary a great deal from place to place. Nevertheless a number of general conclusions can be drawn. Quite a good source for the discussion of the consequences of global warming is the book 'Global Warming – the Complete Briefing' by Sir John Houghton [15]. The main questions he posed are concerned with (a) the magnitude of the expected rise of sea level and the effect that it will have, (b) the effect on water resources, (c) the impact on agriculture and the food supply, (d) the damage that we can expect to be suffered by natural ecosystems, and (e) the effect on human health. Attempts have been made in Houghton's book [15] and in the Stern Review [16] to estimate the cost of global warming and the impression that is presented is that we might be able to buy our way out of the problem.

3 Scientific Problems with the Climate Models

One problem of global circulation models (GCMs), both weather forecast and climate models, lies in the spacing of the grid points or the size of the grid cell that is used, e.g. 1° by 1° or 0.5° by 0.5° in the horizontal plane and 100 or 50 mbars in the vertical direction. Inevitably average values of the various parameters over these grid cells have to be used, e.g. for cloud cover, land surface albedo, sea surface temperature, etc. The variations within a unit cell (due to small clouds, small parcel sizes of the land, etc.) are not able to be taken into account.

There is also a different, and perhaps more fundamental, problem with climate models. What the IPCC does, and most of what has been published on the consequences of human-induced global warming, is based on the idea of slow gradual responses in the climate and that any change in the climate would be gradual and could be predicted by the models. However, one of the problems with the assumption of gradual change and the use of computer models to predict the future climate is the inability to predict sudden changes and this has recently become an active topic of discussion [17,18]. In the conclusion to his book 'The Last Generation: How Nature Will Take Her Revenge for Climate Change' Pearce [18] says that he "called this book 'The Last Generation', not because I believe we humans are about to become extinct, but because we are in all probability the last generation that can rely on anything close to a stable climate in which to conduct our affairs." What Pearce is saying is that people have been overlooking positive feedback mechanisms that can lead to sudden precipitous swings in the climate. He argues that whereas the IPCC is predicting a rise in global mean surface temperature of 3–4°C in 100 years, it could be far worse than that; it could be 10°C which would take us way beyond the social and economic changes predicted by Houghton [15] and Stern [16]. Without going into all the details, a couple of points worth mentioning are the following:

(a) As the ice melts, whether it is on land or water, the surface uncovered has a much lower albedo (reflectivity) than the ice; it absorbs more heat and therefore makes an extra contributing to the warming, i.e. we have a positive feedback mechanism,

(b) People have tended to assume that a glacier or an ice shelf just melts from absorbing radiation at its surface, i.e. rather slowly. However, cracks develop in the ice, meltwater pours into the cracks and the whole melting process accelerates and the water pressure in the cracks acts like wedges and forces the ice to break up. There are spectacular situations like the break up of the Larsen B ice shelf (about 270 km long and 54 km wide) in Antarctica. While the models – and the IPCC's general approach – can handle this sort of change *after* the event by making adjustments to the parameters in the models, they cannot *predict* such sudden events and Pearce's general thesis is that nature often flips suddenly from one state to another and therefore the consequences of climate change may be quite different from – and much more serious than – rather simple kind of gradual changes assumed, for example, by Houghton [15].

Apart from possible human-induced rises that may very much exceed the 3–4°C rise in the next 100 years predicted by the climate models there is also the possibility of a substantial *decrease* in the temperature that would correspond, as a result of natural causes, to a return to a new ice age. Until recently and in the absence of any evidence to the contrary, geologists and palaeoclimatologists had assumed that climate changes in the past had always been slow. Therefore, in relation to human-induced global warming, the opposite effect, namely a natural cooling leading to a new ice age, has been assumed to be on a much longer timescale. However, it has recently emerged that rather than slow and gradual transitions between ice ages and inter-glacial periods there have been many abrupt changes in the climate. A general discussion is given, for instance by Cox [17] and, to some extent by Pearce [18]. Evidence of past climate variations have been obtained from ice cores drilled from the Greenland ice sheet, supported by some other ice cores from elsewhere, and from ocean sediment cores from various parts of the world. A historical temperature record has been obtained from the ratio of the ^{18}O istotope to ^{16}O, the common isotope, in the ice cores and in cores from marine sediments in the ocean floor. Ice cores from Greenland have provided records for more than the last 100,000 years and the marine sediments cores give even longer records of several hundred thousand years covering several past ice ages and intervening inter-glacial periods. The general conclusion, from the ^{18}O to ^{16}O ratio measurements and from some other newer more sophisticated techniques, is that large changes in climate marking the difference between an ice age and a warmer period have occurred suddenly in the past, over a few years or perhaps a decade or two and certainly on a different timescale from the 3 or 4 degrees per century predicted by climate models. While the evidence for abrupt changes is quite clear, the mechanisms driving these changes is less clear and they are still the subject of very active research. Even if the causes of these changes were known it seems unlikely that computer models would be able to predict sudden changes. It is ironic that the sudden changes of the kind considered on the basis of the climatic record in the ice and sediment cores would be a change from our present climate to a much colder ice-age type of climate, which is of course the opposite of the warming that is being predicted from the climate model studies based on the emissions of greenhouse gases from human activities.

4 The Stability of the Earth's Atmosphere

We have already noted the limit to the reliability of long-term weather forecasting to a couple of weeks or thereabouts. There is no doubt that the Earth's atmosphere can be considered as a system with an unstable potential energy, which is stabilized with gyroscopic forces (like the Lagrange top or the rotating shaft). However, according to the fundamental classical stability theorem of Thomson-Tait-Chetayev, this stability is lost after the addition of arbitrarily small dissipation, a phenomenon that was known to William Thomson (Lord Kelvin), since 1879, but its understanding remains to be clarified as yet. In fact, when the relative equilibrium is not maintained by an external source of energy, then the nonconservative forces (e.g. dissipative and positional forces that are, among others, proportional to velocities and displacements, respectively) cause instabilities. It should be kept in mind that there is a differentiation of positional forces into dissipative and nondissipative, depending on whether or not the particular physical system is closed or open.

It is worth mentioning that the lack of theoretical understanding of dissipation-induced instabilities led to the flight failure of the first American satellite – *Explorer I* – launched on 31 January 1958 shortly after Russian *Sputniks* (launched on 4 October and 3 November 1957). Specifically *Explorer I* was long and narrow like a pencil, spinning around its long axis (axis of minimum moment of inertia) at 750 revolutions per minute, and not around the axis of maximum moment of inertia (despite the suggestion of the Stanford University astronomer Ronald Bracewell). Thus, an instability caused by a flexing of its antennae, dissipated a small amount of rotational energy, with the result that once *Explorer I* had made just one Earth orbit, it flipped over and from then on it windmilled. By the way, the satellite *Sputnik I* (a 55 cm diameter sphere that weighed 83 kg with four antennae coming off it) was spinning in its maximum moment of inertia mode [19].

It is not just the example of the stability or instability of the earliest Earth-orbiting spacecraft that led to the inclusion of the 50th anniversary of *Sputnik* in the title of this article. It is principally because the launch of *Sputniks* 1 and 2 fifty years ago marked the beginning of a long period of successful launches of a large number of Earth-orbiting unmanned spacecraft for environmental observation, or remote sensing as it has come to be known. Earth-orbiting satellites now play a vital role in weather forecasting, in climate modelling and in studying the effects of climate change. They generate input data on winds, cloud cover, atmospheric profiles, Earth surface temperature and albedo, etc., for the weather forecast and climate computer models. They also generate data to provide evidence of climate change in terms of temperature, ice cover, desertification, etc.

It is notable that the instability develops due to the withdrawal of energy from the state of the relative equilibrium and the total energy of the whole physical system would decay, if the relative equilibrium is not maintained, while the energy of the perturbation may grow. As an example, the baroclinic instability is a type of dissipation-induced instability. Very recently Krechetnikov and Marsden [20] have come to the conclusion that if one is predicting the appearance of a baroclinic instability, the error of predicting the critical bifurcation parameter will be around 10%. Though this difference is probably within the accuracy of meteorological forecasts, it is still of physical and mathematical importance. In this regard Krechetnikov and Marsden [20] stated that "this phenomenon is more frequent than rare and its prominence may vary depending upon a particular problem at hand".

5 Conclusion

Undoubtedly, significant progress has been achieved in studying the atmospheric variability and the consequences of its changes. However, quite a number of related problems remain unsolved so far and there is a necessity for a more comprehensive and integrative consideration of all problems of atmospheric chemistry and physics in their full complexity, taking also into account the long-memory effect that the physico-chemical dynamics of the atmosphere displays [2,21–24]. In order to reduce the level of existing uncertainties in climate forecasts, the improved modelling of atmosphere-ocean-land surface-cryosphere-biosphere interactions is urgently required with long-term, non-linear changes in the climate system taken into account [4,25–28].

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