The Scientific Impact

Brian Tucker
Institute of Public Affairs

Paper to Kyoto the Impact on Australia Conference
Organised by the Australian APEC Study Centre

Hotel Sofitel
Melbourne
12-13 February 1998

The scientific impact

Brian Tucker

Institute of Public Affairs

Abstract

Two broad scientific implications of the Kyoto agreement are identified : the need for improved climate modelling skills if we are to progress to climate prediction, and a better understanding of basic processes associated with emission reductions and sources and sinks of greenhouse gases.

Examples of ongoing climate research focus on the poor correspondence between model simulations of regional climate change and observed change, strong negative forcing from indirect effects of aerosols, not yet included in climate models, and a recent study showing little change in model results of El Nino type droughts in a 2xCO_2 world but with indications of heavier La Nina rainfall.

Examples of ongoing gas research include a new determination of global oceanic and terrestrial uptake of CO_2, and seasonal variation of oceanic uptake in the Southern Ocean SW of Tasmania.

These results demonstrate the ongoing importance of both types of research on greenhouse topics.

1. Introduction

As we now know, a list of agreed targets for Annex I countries was somewhat painfully obtained at Kyoto but with no effective commitments from the remaining countries of the World. Of course the scientific rationale for such reductions was not discussed, politics and policy-making now having overtaken scientific justification.

A little over a year earlier, in Geneva (July 1996), a 1995 update of scientific understanding of the greenhouse gas - climate change connection was prepared for the Intergovernmental Panel on Climate Change (IPCC). Its most important component was the report of the Scientific Working Group (IPCC, 1996a) because, in any logical progression, its other two components (estimating impacts and devising strategies to cope) should be based on sound climate change predictions. These predictions, in turn, should rest on a firm understanding of how Greenhouse gases get into the atmosphere and what happens once they do.

Background information and the first drafts of documentation for this update were provided by many hundreds of scientists who had gathered in different locations around the World to articulate and document the results of their research. An executive group edited the detailed material, prepared summary findings, and published both - which were then sharply criticised from within the ranks of both science and industry. It was asserted that bias and exaggeration were apparent in the final policymakers' summaries; certainly some of the equivocations and caveats in the background scientific documentation (IPCC, 1996b) were omitted from the Policymakers Summary.

Yet despite these concerns the greenhouse gas - climate connection as set out in the Policymakers Summary, including its speculative extrapolations regarding extreme weather, appear to have been accepted without question at Kyoto. Moreover in some instances the science may have been misinterpreted. Two examples of such misinterpretation are (a) the widespread assumption that regional scenarios are predictions, and (b) the equally pervasive confusion between emissions and concentrations of gases. The latter features in Senator Hill's media release of 11 December 1997, this refers to "Australia's consistent and reasoned commitment to reduce global warming". This may well be a slip of the tongue, on the other hand it may reflect a confusion between a reduction in greenhouse gas *emissions* with a reduction in global *concentrations* and hence, theoretically, in global warming.

Just for the record let me make the theory clear on this point. A stabilisation of ambient gas concentrations in the atmosphere will lead to a stabilisation of their influence on climate - whatever this may be. To achieve this, an eventual reduction of more than 60% in current world-wide emissions is required. Thus, on the basis of accepted theory, reductions of less than this will not "reduce global warming" but may slow its rate of increase.

The Kyoto emission reduction targets average somewhat less than an 8% decrease on 1990 emission levels, but for Annex I nations alone, with no commitments from other nations. For reasons given later in this paper, even if achieved this decrease will have an effect difficult to detect in global concentrations - and certainly not in any climatic statistic. Indeed it is evident from proceedings at the Conference that it will be a very long time indeed before a global emission reduction approaching 60% will be achieved. Whether we like it or not, this means that if any climate change is caused by the inevitable continuing increase in ambient gas concentrations, we are going to have to adapt to it. For such adaptation to be planned efficiently, we need confident estimates of the future climate. This will require an assessment of the effects not only of greenhouse gases but of other influences on climate too, most notably particulate matter in the atmosphere and land use changes. Thus the first major scientific implication from Kyoto is the need for much improved climate simulation in order to progress to climate prediction; only thus can we estimate the effect of climate change on sources and sinks of greenhouse gases themselves. Such predictions are explicitly not obtained from current climate 'scenarios'. An improvement in climate modelling is in any case required to remove the many uncertainties associated with the concepts of 'global warming' and 'climate change'. It is not generally realised by those on the periphery of the subject that the underlying science is neither as "settled" nor as "compelling" as is sometimes proclaimed.

A second implication concerns the relation between emissions and concentrations of different greenhouse gases and the Kyoto targets. One of the main sources of uncertainty in estimating greenhouse gas emissions arises from an inadequate understanding of the basic processes resulting in emissions and the creation of sinks (Commonwealth of Australia, 1997). Many difficulties exist in setting realistic methodologies for assessing individual components of the budgets of each gas; an associated difficulty concerns assessing compliance with target emissions.

Such assessment might conceivably be achieved in two ways : directly, by establishing standard methodologies to estimate emissions and undertaking international inspection of the ways in which they are applied; and indirectly, by careful observations of time profiles of global concentrations of individual gases and the application of inversion techniques to infer changes in emissions consistent with these profiles. A system of inspection would have obvious difficulties - and involve a substantial bureaucracy; while both the establishment of emission methodologies and the inversion of trace gas concentration profiles pose some challenging scientific problems concerning gas exchanges within the atmosphere and between the atmosphere and land and sea reservoirs.

Thus the two main scientific implications of the Kyoto agreement are:
(i) the need for an approach to climate prediction via improved climate change simulations - and the observational studies of air, land and sea required for this, and
(ii) the need for improved estimates of sources and sinks of trace gases, and the inversion of concentration measurements to obtain implied emissions on a global and possibly a regional basis.

2. Climate science.

The following outline of some climate research results focuses on four items selected from the 1995 IPCC update :

- observed global average surface air temperature change,
- observed and modelled regional surface air temperature changes,
- the physics incorporated into climate models, and
- the frequency of El Nino type droughts.

2.1 Global temperature change

There has been much debate in meteorological circles over the past six months or so concerning global surface air temperature trends in the atmosphere since 1979. Christie (1997) discussed this at the 'Countdown to Kyoto' Conference, Canberra, August 1997. The problem essentially is that observed average global surface temperatures over the period 1979-1997 show an increase of approximately 0.2^{o}C whereas downward micro-wave soundings from satellites reveal zero temperature change through the lower atmosphere or perhaps a slight decrease. Both sets of data have their problems but neither result has been conclusively invalidated.

Climate is known to exhibit a combination of deterministic and chaotic (unpredictable) variation. To investigate the relative importance of forcing and chaos, Hansen et al (1997) have used a climate model to simulate atmospheric and oceanic behaviour over the period 1979 to 1996. They employ four different forcing mechanisms, running their model for (a) no forcing, (b) stratospheric aerosol change, (c) b + ozone change, (d) c + greenhouse gas change and (e) d + solar irradiance change. (Note: Neither the direct nor the indirect effects of tropospheric particles was included.) Four different ways were used to represent the oceans. To simulate chaotic behaviour they ran the model 5 to 10 times with slightly altered initial atmospheric temperatures.

The results show that, for middle and high latitudes, year to year atmospheric variation is largely chaotic but in low latitudes much of the year to year variation is due to sea surface temperature fluctuations - which themselves are partly chaotic. Also, over the period, greenhouse gases cause a warming at the surface and in the lower atmosphere of the model but this was offset by cooling from the other mechanisms, principally ozone. The net calculated effect of the four forcing mechanisms investigated is approximately zero, with no change in surface temperature or in heat storage in the ocean for the period 1979-1997. This result appears consistent with that derived from satellite data. However, subsequently the authors found that by introducing an extra forcing of +0.65 W/m^2 at the start of the runs they could obtain a surface warming during the period of 0.2°C. They call this a "disequilibrium force" and assert that it represents "unrealised warming due to changes of atmospheric composition prior to 1979". By this means they can simulate both a surface warming and a near zero change in the lower atmosphere, so reconciling ground based and satellite based temperature trends. Nevertheless it is rather unsatisfactory that the magnitude of the "disequilibrium force" appears to have been chosen to give the right answer, and its physical attribution is unclear and needs to be substantiated.

2.2 Regional temperature change: The ability of modern climate models to simulate regional climate change due to increased Greenhouse gases was indicated in the 1995 update, and some 'scenarios' developed for sensitivity studies are based on these. In the Policymakers Summary (and in the background documentation) maps of the surface temperature changes for a $2xCO_2$ climate model run compared with the present are shown for greenhouse gas increases alone and for gas increases plus 'sulphur emissions' (anthropogenic sulphate aerosols). The latter result is declared to be "qualitatively more similar" to observed temperature changes from 1965 to 1985* which are shown several pages earlier, with the implication that this gives more credence to regional temperature simulations. However a careful comparison shows this to be untrue. Certainly the gas plus aerosol result shows large areas of positive and negative surface temperature changes whereas the result for the gas alone is positive every where. But the areas of negative change for the gas plus aerosol model are in quite different locations from those observed, the result being a strongly negative spatial correlation. Thus more correctly this result indicates that regional temperature changes depicted by this climate model are invalid. Yet widely used climate scenarios are based on regional results derived in this way!

2.3 Indirect effect of aerosols: The IPCC estimates of globally and annually averaged anthropogenic forcing show that major negative forcing is estimated to come from the indirect effects of tropospheric aerosols. This refers to their influence on the effective cloud droplet radius used in short-wave and long-wave radiation calculations and the cloud lifetime considered in the derivation of precipitation. Rotstayn (1998) has used a global climate model to investigate the effect of best estimates of indirect radiative forcing due to this modification of liquid-water cloud properties. His results indicate a very large negative indirect forcing (-2.1 Wm^{-2}), significantly larger than indicated in the IPCC update. This forcing results from a 1% increase in cloudiness, a 6% increase

* Actually, in an attempt to smooth out interannual variations, the averages 1955-74 and 1975-94 were used to derive an 'observed' 20 year change.

in liquid water path and a 7% increase in droplet effective radius. He notes that the strongest negative forcing tends to occur over the North Atlantic Ocean and in regions of persistent marine stratus cloud. Since most current models do not include this forcing, it may be a partial explanation of why these models do not depict the *cooling* of near surface air observed to have occurred over some ocean areas in the past few decades; also the possibility arises that, especially in Winter, they underestimate precipitation.

This work and similar studies which give even larger negative indirect forcing from aerosols cast doubt on the accuracy of precipitation results from current models because of the crudity of their representation of cloud physics. Yet, once again, these are the values on which scenarios are based.

2.4   <u>El Nino type drought</u>: Another area of grave doubt in the IPCC update is the indication of more severe droughts and floods in a high CO_2 world.   This conclusion which appears in the Policymakers Summary was based on very slight evidence and appears to have been influenced by the existence at the time it was written of prolonged weather events consistent with a form of El Nino Southern Oscillation (ENSO) phenomenon.   The fact that previous work had found that ENSO under high CO2 conditions continued to occur without substantial change was ignored.

Recently Wilson and Hunt (1997) in a new model designed to study the low latitude Pacific Ocean have confirmed that ENSO is a robust feature of climatic variability. For $2xCO_2$ conditions they find a reduced ENSO amplitude and an increased ENSO frequency from about once every 5 years to about once every 3 years. They also find an increase in mean rainfall over Australia. In this warmer and wetter environment, because of this reduced amplitude, less frequent and less severe droughts occur in the warm El Ni〉o phase of the ENSO cycle, but Wilson and Hunt make the extrapolation: "for north eastern Australia, this increase in rainfall together with the increased frequency, suggests the possibility of more frequent and more severe floods resulting from the cool La Nina phase of the ENSO cycle". These are preliminary inferences and the authors emphasise that they need to be verified by an improved model and ensemble runs of the type undertaken by Hansen et al, as described above.

It can be seen from the above examples that the direction of current climate modelling research continues to provide results that significantly modify previous model simulations and inferences from these about the characteristics of our future climate.

3. Greenhouse gas studies.

3.1 Inventory methodology: The greenhouse gases targeted in Kyoto are six in number : carbon dioxide, methane, nitrous oxides, chloro-fluorocarbons, per-fluorocarbons and sulfur hexafluoride*. National inventories will be required for the 5 year period 2008 - 2012. These will be subject to three broad classes of possible error:

- the exclusion of one or more significant source or sinks, ie. there will be a need for uniform definition of components relevant to each specific gas,
- errors in the determination of algorithms by means of which the net emissions are estimated,
- sampling errors particularly in areas that are sparsely populated or have difficult or heterogeneous geography.

Galbally (1997) has noted the uncertainty that besets national inventories and has advocated international comparison not only of inventories but also of trends in component sources and sinks. He has shown how scaling factors applied to individual nations can aid comparisons.

3.2 Compliance: To illustrate the problems in assessing compliance the examples used here refer to carbon dioxide because in the atmosphere it is an approximately conservative tracer and is perhaps the most studies greenhouse gas.

The atmospheric global budget of carbon dioxide adopted by the IPCC (1996a&b), in units of Gt/year is:

Anthropogenic Sources	5.5 ±0.5	fossil fuel combustion and cement production
	1.6 ±1.0	tropical land-use changes
Sinks	3.3 ±0.2	atmospheric storage
	2.0 ±0.8	ocean uptake
	0.5 ±1.0	Northern Hemisphere forest regrowth
	1.3 ±1.5	required for balance.

---

*At Kyoto the base year for these last three named gases was changed to 1995, but for the first three 1990 remains the base year. It is a reasonable to assume that the European Union would never agree to this change applying to all gases because then, particularly for the United Kingdom and Germany, large emission reductions that occurred in the period 1990-1995 for reasons that had nothing to do with notional climate change could not be credited.

The residual balance requirement of +1.3 Gt/year is deemed consistent with the sum of 0.5 ±1.0 from nitrogen fertilisation and 0 -2 from CO_2 fertilisation and climatic effects.

It has been known for several years (eg. Francey et al, 1995) that changes in the carbon isotope ratio of atmospheric CO_2 can be used in global carbon models to distinguish the relative roles of oceanic and terrestrial uptake of fossil fuel CO_2. If the anthropogenic source over a 5 year period is to be estimated (checked) by independent measurements of the other terms in the budget, it will be necessary to know the variability of these surface fluxes in order to assess the precision of the calculations. Recently Rayner et al (1998) have used an inversion technique to recover oceanic and terrestrial fluxes from concentration levels and isotopic measurements of CO_2 in the atmosphere for the 15 year period 1981-1995.

They calculate long term mean ocean and terrestrial sinks as 2.1 ±0.3 and 0.7 ± 0.3 Gt/year. Thus their ocean uptake is similar to that in the IPCC Report but the terrestrial uptake is larger. The technique also allows annual figures to be derived and also a crude latitudinal breakdown into northern hemisphere, tropical and southern hemisphere values. The standard deviation of five year averages of oceanic uptake and of terrestrial uptake were 0.4 and 0.5 Gt/year. However if a 7 - 8% emission reduction is achieved by Annex I nations, after taking account of a conservative 2% per annum increase from non-Annex I nations, world wide *increases* of some 6% will occur, ie. of magnitude 0.4 Gt/year. Therefore, over the 5 year commitment period of 2008-2012, there is some prospect of at least World emissions of CO_2 being cross checked via the other components of the budget. But it will not be possible to distinguish Annex I contributions by this method.

Attempts are currently being made to estimate the regional uptake of some gases. Two possible methods are : using the best available numerical weather analyses to calculate horizontal fluxes and hence flux divergence across regional boundaries, and using aircraft measurements along the perimeter of the chosen area to do the same.

Wang et al (1998) have used such a model to estimate lateral transport and have derived estimates of the seasonal variation of ocean uptake in the region south-west of Cape Grim, Tasmania (35 to 60 S and 80 to 144 E). They obtain quite strong interannual variation, monthly variation in the years 1990, 1991 and 1992 being of the same magnitude as the monthly uptake. The annual carbon uptake by this south-west sector of the southern ocean is 0.21, 0.12 and 0.20 GtC/year for each year respectively but the authors argue that this may be an underestimate. But attempts to extend this type of study to estimate indirectly Australia's emission rates have yet to be made.

Aircraft observations around the periphery of the United Kingdom are reported to have been used along with surface flux estimates for comparison for a number of greenhouse gases with observed changes in atmospheric concentration, but no results are currently available.

4. Conclusion.

In the two years since preparation of the 1995 update there has been a progressive improvement in the science associated with both climate and greenhouse gases in the atmosphere. Results from the small sample of ongoing studies described above illustrate problems that remain to be solved and indicate the importance of maintaining the momentum of the variety of scientific research on greenhouse topics.

It is unrealistic to believe that the Kyoto protocol will achieve anything more than a slight slowing of the rate of increase in levels of greenhouse gases accumulating in the atmosphere. Therefore, if indeed higher levels of greenhouse gases induce some change in climate, this will occur. The preparation of adaptation policies received little attention at Kyoto; yet they require a much better idea of the climate to which we will have to adapt than we have at present.

More directly related to the policy of reducing greenhouse gas emissions is the accuracy and precision with which we will be able to assess compliance. Methods for accomplishing these are far from clear but they are fundamentally necessary if the Kyoto protocol is to have any credibility.

References.

Christie, John,1997, *The role of satellite measurements*, Conf. Proc.'Countdown to Kyoto', Canberra,19-21 August 1997, Australian APEC Study Centre, p133-149.

Francey, R J, P P Tans, C E Allison, I G Enting, J W C White and M Troller, 1995, *Changes in oceanic and terrestrial carbon uptake since 1982*, Nature, 373, 26 January 1995, p326-330.

Galbally, I, 1997, *Greenhouse gas sources and sinks -- the globe, developed countries and projections*, Abstract IM22U, IAMAP/IAPSO Joint Assemblies Abstracts, T Beer and D Jasper (Eds).

Hansen, J et al (44 co-authors), 1997, *Forcings and chaos in interannual to decadal climate change*, J.Geophys.Res., **102**, D22, p25,679-25,720.

IPCC, 1996a, *Climate Change 1995: The Science of Climate Change. Summary for Policymakers and Technical Summary for the Working Group 1 Report*, WMO/UNEP Intergovernmental Panel on Climate Change, 56pp.

IPCC, 1996b, *Climate Change 1995: The Science of Climate Change. Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, J T Houghton, L G Meira Filho, B A Callendar, N Harris, A Kaltenberg and K Masjell (Eds), Camb.Univ.Press, 572pp.

Rayner, P J, I G Enting, R J Francey and R Langenfelds, 1998, *Reconstructing the Recent Carbon Cycle from Trace Gas Observations*, to be published.

Rotstayn, Leon.D, 1998, *A physically based scheme for the treatment of stratiform clouds and precipitation in large-scale models. I: Description and evaluation of the microphysical processes*, Q.J.R.Meteor.Soc.**123**, p1227-1282.

Wang, Y-P, E A Kowalczyk, I G Enting, G I Pearman and J L McGregor, *Seasonal variation of CO2 fluxes in the Southern Ocean from 1990 to 1992*, to be published.

Wilson, S G and B G Hunt, 1997, *Impact of Greenhouse warming on El Nino/Southern Oscillation behaviour in a high resolution Coupled Global Climate Model*, A Research Project commissioned by the federal Department of Environment, Sport and Territories, Australia, 19pp.