Submission to the

Commonwealth Joint Standing Committee on Treaties

Inquiry into The Kyoto Protocol

Greenhouse Science

Prepared by CSIRO

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CSIRO

Submission Contents

Executive Summary

Climate change

Greenhouse gases

Climate change science shows that greenhouse *gases continue to increase in concentration* in the world's atmosphere. In the case of most of these, and in particular the important greenhouse gas, carbon dioxide, most of the increase can be clearly *attributed to human activity*.

Carbon dioxide *concentrations will continue to grow through this century*. Globally, stabilising the concentration of this gas at approximately double pre-industrial levels would require emissions to be reduced to about a third of their current rate. This is unlikely given population growth, investment and technological dependence on fossil fuels as the prime source of energy and driver of global industrialisation.

The global *atmosphere, ocean and biosphere have limited capacity to absorb future emissions* of carbon dioxide. The complete combustion of known fossil fuel resources over the next centuries would raise carbon dioxide concentration in the atmosphere to almost 1000 per cent above pre-industrial levels, or at any time in at the least the last 400,000 years.

The *growth rate of methane is slowing*, and if this trend continues, the concentration of methane will have stabilised by the first Kyoto commitment period. Similarly the growth rates of CFC gases are slowing in response to the Montreal Protocol on Ozone Depleting Substances.

Observed climate change

The *surface of the earth warmed* by between a half and one degree during the twentieth century. This warming is evidenced in a wide variety of observations.

Predictions of climate change made in the late 1980s and early 1990s are broadly consistent with changes now being observed.

Predictions of future climate

Climate has always varied and will continue to vary for a number of reasons. On the time-scale of this century, most mechanisms for causing such variations are either highly improbable, or cause changes that will impact for short periods or with small magnitude. The *most likely sustained and significant climate change of this century will be human induced* and due to the emissions of greenhouse gases.

Confidence in projections of future climate have improved over the past five years due to better understanding of important climate processes and to improvements in climate models. Nonetheless, *gaps in our understanding remain* and these translate to uncertainties, *particularly in projections of regional climate.*

Investigations into regional climate change continue to suggest that *changes in climatic extremes will produce more significant impacts* than changes in averages. Changes in climatic extremes, by definition, are difficult to detect and attribute to specific causes.

Given the difficulty in reducing greenhouse-gas emissions both nationally and globally it appears inevitable that the concentrations of greenhouse gases will continue to rise and *global climate will continue to change*. However, the rate of warming will be influenced by the changes in growth rates of *all* greenhouse gases and in aerosol emissions.

Responding to Climate Change

Scientific and technological understanding does not suggest a single or best solution to addressing climate-change, *only sets of solutions*.

There are *no short-term solutions*, and some focus needs to be retained on the longer term, beyond the first Kyoto Protocol commitment period.

Global warming will occur, so we must pay *early attention to issues of impacts and of adaptation*.

While Australia is unusual in being a developed country with significant (and uncertain) emissions associated with land management, *most of Australia's emissions come from the use of energy*. Successful greenhouse mitigation will require interventions in the energy cycle. Such interventions may relate to the *reduction of the use of fossil fuels and/or the capture of the emissions* resulting from that use.

There are *many energy technologies* that might be employed to mitigate greenhouse. These technologies include using *renewable forms of energy* (biomass, solar, wind and other processes); *high-efficiency gas-based utilisation technologies* for power, heating, and cooling including fuel cells, microturbines, engines and hydrogen-based systems; *hybrid fossil/renewable* approaches; *energy end-use efficiency*; and *capture and sequestration* of carbon dioxide and methane.

In terms of biospheric sequestration, there are opportunities to gain greenhouse benefits from *tailoring activities with other objectives* – such as tree planting to counter salinity; and measures to prevent problems from acid-sulfate soils.

Any system of carbon or *emissions trading will depend heavily on measurement and accountability*.

Further *measures will be required beyond the first Kyoto commitment period*: we must identify and conduct the long-term science and consider the policy and response implications of future requirements stemming from the United Nations Framework Convention on Climate Change and the inevitable evolution of the agreements under that Convention.

Innovation

The responses listed above represents parts of a comprehensive approach to management of the greenhouse issue. Science and Technology do not provide all of the answers, but need to be an integral part of the collaboration between Government, Industry, Commerce and the public in seeking innovative ways of ensuring economic, environmentally and socially acceptable solutions.

Background to this Submission

'The Parliament of Australia's Joint Standing Committee on Treaties, *Inquiry into the Kyoto Protocol* shall inquire into and report on:

- the implication for Australia proceeding with ratification of the Protocol,
- the veracity of conflicting scientific theories on global warming and any solutions proposed for it,
- definitions and criteria Australia should develop and actively pursue with regard to mechanisms for meeting emission targets, and
- the economic, environmental and social implications of a domestic regulation of emissions.'

This submission has been prepared with the objective of addressing primarily the second of these Terms of Reference by providing background material on the science underpinning the Climate Change issue. However, Australia's capacity and readiness to respond to the challenge of emissions limitation depend on:

- the confidence that we hold with respect to the likelihood of climate change occurring,
- the magnitude and impact of that change on human and natural ecosystem function,
- options (economic, environmental and social) for adaptation; and
- options (economic, environmental and social) for mitigation.

Scientific and technological information can contribute to understanding all of these issues and is addressed to some extent in this submission.

The Intergovermental Panel for Climate Change, an international gathering of several thousand scientists, periodically assesses the progress of international science that underpins our understanding of the global warming issue. The intention of this submission is not to repeat or summarise material that was included within previous assessments, the First Assessment Report in 1992 and the Second Assessment Report in 1996.

CSIRO scientists actively participate in the Intergovernmental Panel for Climate Change and believe that at the time, the Second Assessment Report represented the best available overall assessment in terms of the consideration of all scientific view points, the comprehensiveness of its coverage and its balance between peer reviewed input and currently active research.

In this submission CSIRO aims to provide information that has become available since the Intergovernmental Panel on Climate Change's Second Assessment Report:

- through its own research
- through that of the international science community as appraised by active participation in that community and through the formal publication process and

- formally in the preparation of the draft of the Third Assessment Report which will be released early next year.

In this sense, this submission is an attempt to provide a window on the global research outcomes as they relate to the policy development process.

Substantively, the material in this submission does not differ from a submission by CSIRO to the Senate Environment, Communications, Information Technology and the Arts Reference Committee Inquiry into Australia's Response to Global Warming. The reason for this is that the science underpinning the climate change issue has not changed substantially since the previous submission. Nonetheless we have elaborated upon some issues, including reference to very recent work (available since March 2000) and slightly reworded some material for clarification.

CSIRO does not advocate a policy position with respect to how Australia should respond to the Framework Convention on Climate Change or the Kyoto Protocol, but rather wishes to ensure that policy development proceeds with the best possible scientific and technical underpinning.

Sources and sinks of greenhouse gases

The global perspective

Trends in the concentrations of greenhouse gases are now well known.

Figure 1 shows the record of carbon dioxide in the earth's atmosphere over the past one thousand years. Fossil fuel burning and deforestation are the main contributors to the increases over the past two centuries. Continued emissions combined with the long lifetime of carbon dioxide in the atmosphere means that the concentrations of this gas are expected to increase through this century.

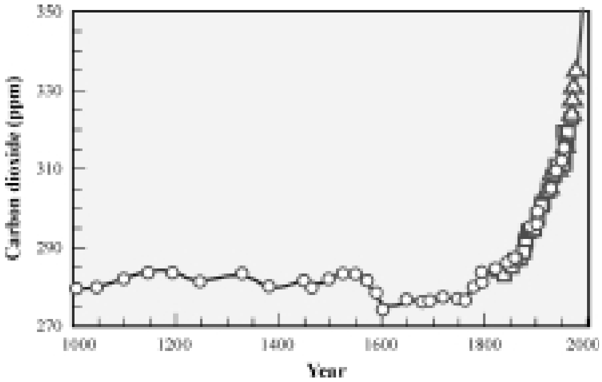

Figure 1. The record of global atmospheric CO_2 concentration (parts per million) over the past one thousand years, as obtained from Antarctic ice cores (circles, squares and triangles) and direct observations (red line). Results from CSIRO research in collaboration with the Australian Antarctic Division and the Bureau of Meteorology at the Australian Baseline Observatory, Cape Grim, Tasmania, (www.dar.csiro.au/res/gac/grim.htm).

The changes in methane emissions and the corresponding change in the *growth rate* of methane in the atmosphere are shown in Figure 2. If the growth rate of methane in the atmosphere continues to fall, the concentration of methane in the atmosphere will have levelled at about the same time as the first Kyoto commitment period. This rapid change in the status of methane in the atmosphere is due to changed emissions combined with the short atmospheric lifetime of this gas.

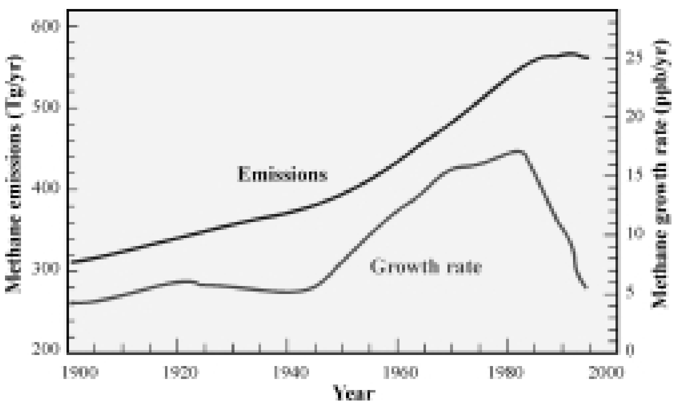

Figure 2. Global methane emissions are stabilising and the growth rate of methane in the atmosphere is falling. If this trend continues, the concentration of methane in the atmosphere will no longer be increasing during the Kyoto Protocol commitment period (2008-2012).

At present the so-called synthetic gases: perfluorcarbons, hydrochlorofluorocarbons, sulfur hexafluoride, while in minute concentrations, are growing rapidly.

With scientists now able to monitor the concentrations of greenhouse gases in the atmosphere very accurately, emphasis in the science has changed markedly since the Intergovernmental Panel on Climate Change Second Assessment Report. Internationally attention is being directed towards independently *verifying* emissions inventories and providing an independent assessment of the effectiveness of global measures to control emissions.

Advances in carbon cycle science, including the development of atmospheric transport (the way gases are transported by the motions of from one part of the earth to the other) and carbon cycle models, allows scientists to calculate a distribution of sources and sinks from measurements of greenhouse gas concentrations. As this science develops it is likely to be used to verify inventories of emissions.

Relationship between emissions and concentrations

The United Nations Framework Convention on Climate Change as a first step with the Kyoto Protocol aims to stabilise *concentrations* of greenhouse gases through exercising control on *emissions* and *sinks*. This Section is intended to illustrate the extent to which current global policy measures contribute to a long-term aim of stabilising greenhouse gas concentrations.

Two key facts with regard to the longer-term climate change issue need to be made. First, the existing fossil fuel resource is huge compared to that which has already been utilised. Since the onset of industrialisation some 273 Gt C (thousand million tonnes of carbon) contained in fossil fuels have been oxidised and released into the atmosphere as carbon dioxide. The resource base[1] is currently taken to be about 4,700 Gt C, meaning that if all of this resource were to be utilised, the impact on the atmospheric levels of the atmosphere would be many times that already observed. Even allowing for disproportionate uptake of carbon by the oceans and biosphere, atmospheric concentrations of almost 1000 percent greater than pre-industrial levels would result.

Second, the capacity is limited for the global reservoirs, the atmosphere, oceans and biosphere to absorb this carbon without substantial concentration changes. This is summarised in the 1999 World Energy Assessment (UN Development Program/UN Department of Economic and Social Affairs/World Energy Council) in the following way. “If the cumulative 273 Gt C emitted to the atmosphere already raise concerns with regard to climate stability, then mankind has the means to add several times that amount during the 21st century. Fossil resource scarcity will not come to the rescue”.

Thus the options for avoiding uncontrolled climate change include setting a long-term target that does not include the combustion of all of the resource, and/or the introduction of methods whereby the combustion occurs but the carbon dioxide produced is trapped and not allowed to enter the atmosphere.

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1 Resources are defined as concentrations of naturally occurring solid, liquid or gaseous material in or on the Earth’s crust. Estimates of resources here are from the World Energy Assessment.

Figure 3 shows two pathways that might result in stabilisation of carbon dioxide in the atmosphere. In one path carbon dioxide stabilises at roughly double pre-industrial concentrations. Another path leads to stabilisation at roughly three times pre-industrial concentrations. The emissions that would meet these requirements are shown in the accompanying panel and are compared with the IPCC IS92a emissions scenario (labelled Business-as-usual).

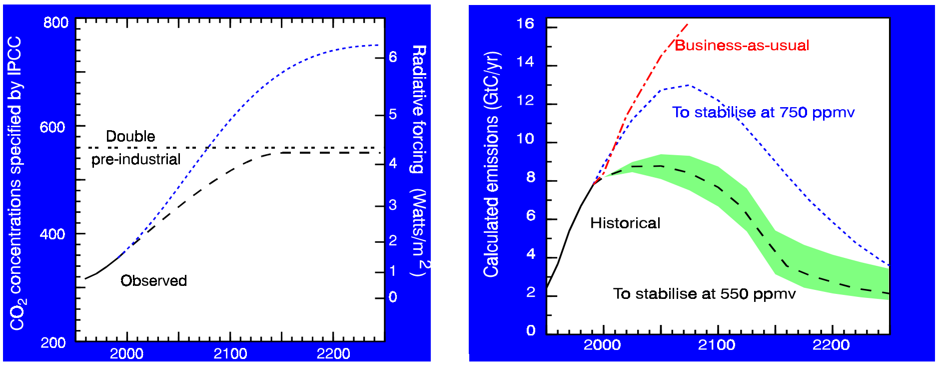

Figure 3. The left panel shows two pathways for stabilising atmospheric carbon dioxide concentrations. The right panel shows the emissions that would be required to meet these stabilisation pathways.

These provide two strong messages:

1. Ultimately, to stabilise atmospheric concentrations, be it at double or triple pre-industrial levels, global emissions would need to be reduced to significantly less than current emissions.
2. If we are to ultimately stabilise carbon dioxide concentrations at 550 ppmv, or twice pre-industrial concentrations, global emissions must not rise above current levels. To stabilise carbon dioxide concentrations at 750 ppmv, three-times pre-industrial concentrations, emissions must be restricted to less than double current levels. Both of these strategies present a challenge, as global population and energy demand are likely to continue to rise in future.

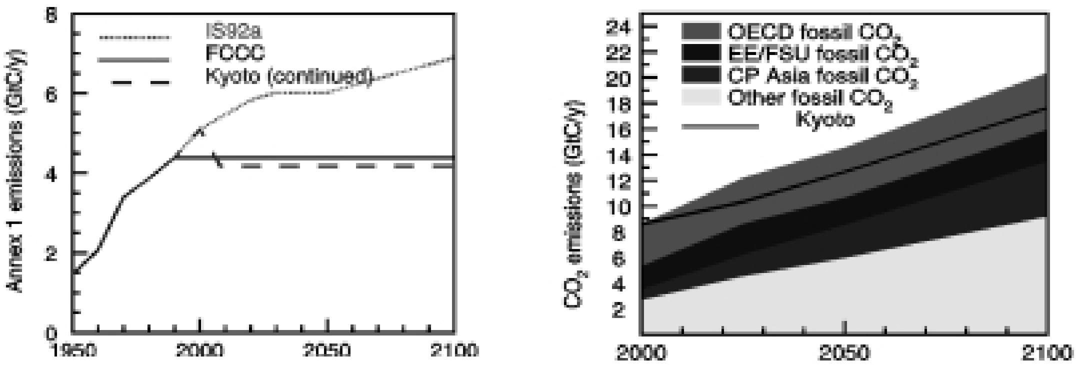

Figure 4. The left panel shows three scenarios for Annex 1 developed country carbon emissions: (1) the IS92a emissions scenario (an example of no climate change policy; red line), (2) developed countries meet the implied UNFCCC commitment and hold emissions constant (black line) and (3) emissions meet the Kyoto Protocol and are held constant thereafter. The right panel shows the contribution from different country blocks to fossil fuel emissions under the IPCC IS92a scenario, with the black line indicating the effect that meeting the Kyoto Protocol and developed countries then holding their emissions constant would have on global carbon dioxide emissions.

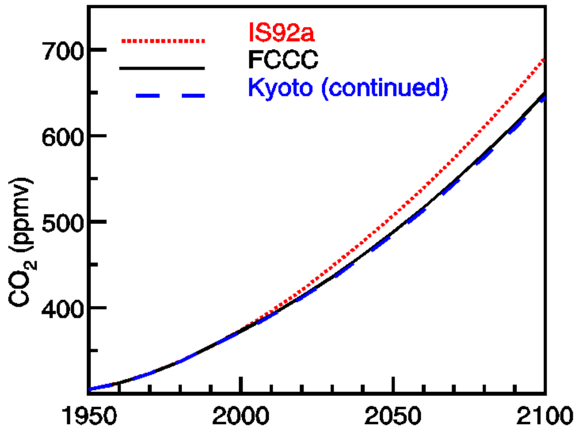

Figure 5. Future global concentrations of CO_2 under three scenarios: the IPCC IS92a scenario (red line), developed countries meet the implied commitment under the UNFCC and hold emissions constant thereafter, while developing countries have no commitments (black line); and the Kyoto obligations are met and Annex B parties do not increase emissions thereafter.

There are several conclusions we draw from Figures 4 and 5:

1. Greater commitments to reduce emissions beyond those currently in place under the Kyoto Protocol are required if the global concentration of carbon dioxide is to be stabilised.
2. Future commitments need to extend to developing countries at some stage.
3. Given the genuine difficulty being experienced by developed countries in reducing their emissions, it is inevitable that carbon dioxide concentrations will continue to rise.
4. Since there is increasing evidence of climate change already (see next Section of this submission) climate change will continue. Communities will need to *adapt* to climate change (either consciously in a planned way, or in an entirely responsive mode).
5. There will be new measures required beyond the first Kyoto commitment period; we must identify and conduct the long-term science and consider the policy and response implications of future requirements stemming from the FCCC.

Observed climate change

Global Temperature

During the late 1980's and early 1990's climatologists and other scientists produced a series of predictions concerning the way in which increased greenhouse gases in the global atmosphere might affect climate. One such prediction was that, given the natural variability of planetary temperature, it would be around 2000 before the greenhouse-warming trend appeared distinctly in the global temperature record.

A record of global temperature from 1856 to 1999, as compiled by the Climatic Research Unit at the University of East Anglia (Figure 6). It shows the temperature deviations from the 1961–1990 global average. The last decade of the 20th Century was the warmest since the modern instrumental record started in the 1860s.

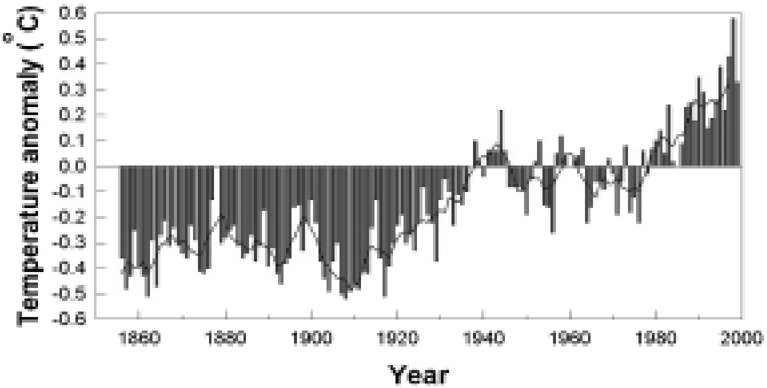

Figure 6. Global mean temperature (land + sea). 1856–1999 (anomalies relative to 1961–90).

Satellite and ground-based records of temperature

Figure 6 shows the record obtained from the earth's surface. At about the time the Intergovernmental Panel on Climate Change's Second Assessment Report was published, differences between temperature records obtained from satellite and the ground-based records were identified. These differences have attracted significant attention. Since then substantial work internationally has led to the following results:

- Surface temperatures (usually taken at about 2 m above the earth surface) and satellite temperature records differ, because the satellite responds to the varying temperature profile of the troposphere and lower stratosphere (1,500–10,000 m above the Earth's surface). In particular, the satellite temperature is sensitive to the atmospheric lapse rate (temperature change with height; O'Brien, 2000, *J. Quant. Spectrosc. Radiat. Transfer*, in press), which in turn is affected by factors such as emission of greenhouse gases, thinning of the ozone layer and emissions of both natural (such as volcanic) and man-made aerosols.
- Satellite temperature record has undergone several significant revisions in its short history (as did the surface temperature record in earlier years). Examples include adjustments for the effects upon the satellite orbit caused by atmospheric drag (Wentz and Schabel, 1998, *Nature*, **394**, 661-664) and corrections for an incorrect calibration of the NOAA-12 Microwave Sounding Unit (Christy et al., 2000, *J. Atmos. Oceanic Technol.,* in press).
- Controversy that has surrounded the small difference between satellite and surface temperature records has arisen because climate models suggest that the two temperature records should increase or decrease at similar rates. However, this prediction is one of the less robust of the model predictions, in the sense that it depends sensitively on the way that models represent the complex processes of the lower atmosphere. Consequently, it is both unwise and unscientific to place too much emphasis upon the discrepancy. More important are the robust predictions of models, such as the surface temperature and lower stratospheric temperature, for which the predictions agree well with observations.
- Finally, there is almost unanimous agreement that the satellite temperature record is too short. As an illustration, the record from 1979-1997 shows a decrease of -

0.04 °C/decade, while the record from 1979-1998, longer by only one year, shows an increase of +0.06 °C/decade. In this case, the El Niño event of 1998 biases the trend of the temperature record, but it is equally true that exceptional events in other years of the record may cause similar biases.

The ground-based record of temperature has been corrected to take into account local heating arising from the urban heat island effect. Other inconsistencies in the record due to changes in instrumentation, observing sites, personnel and practices are also taken into account when preparing consistent global data sets such as that shown in Figure 6.

Solar variations

The influence that variations in solar output may have on global climate has also received attention. It is CSIRO's view that it is important to identify all potential causes of climate variation. But that what is more important is to establish the probability of any one of these causes might bring about changes in the relatively near future of the planet. The following material is included to provide some background on the issue of solar influences on climate variability.

One aspect of the current discussion stems from a paper by Lockwood et al., (1999; *Nature*, **399,** 437-439) asserting that solar changes may have caused virtually all the warming that occurred between 1860 and 1930. The amount of radiation emitted by the sun fluctuates, with an 11-year cycle of sunspots as well as longer-term changes to radiation emissions. But, according to this paper, since 1970, when the rate of warming began to increase, the sun has been the source of less than a third of global warming.

One commentary on this paper (Parker, 1999, *Nature*, **399**, 416-417) used this work to diminish the role of greenhouse gases as a factor that would account for the warming shown in Figure 6. News reports of work of the United States Global Change Research Program suggest that that the sun may have played a dominant role in pre-industrial climate change (from 1600-1800; see http://www.enn.com/enn-news-archive/1999/11/112399/seminar_7523.asp) but it has not played a significant part in long-term climate change during the past few decades. It is unlikely that the sun accounted for more than half, at most, of climate change from 1900-1970.

Such a conclusion is supported by the recent analysis of Crowley (2000, *Science*, **289**, 270-277). He says "that as much as 41-64% of preanthropogenic (pre-1850) decadal-scale temperature variations was due to changes in solar irradiance and volcanism". Further he concludes that a "21st-century global warming projection far exceeds the natural variability of the past 1,000 year and is greater than the best estimate of global temperature change for the last interglacial".

In summary:

- It is most likely that solar variation can contribute to climatic changes.
- Prior to global industrialisation these solar variations, during particular times, may have played a major role in decade-to-decade changes in global temperature.
- Taking solar variations into account in climate models provides a 'better fit' between observed and modelled temperature changes.
- However, solar variations cannot account for the warming observed during the latter part of the 20th Century.
- The most probable cause of significant and sustained climate change in the 21st century will be due to changing levels of greenhouse gases in the atmosphere.

More details on global temperatures since the 19th Century can be found in a CSIRO position paper published at: http://www.dar.csiro.au/publications/Holper_1999a.htm. The National Climate Centre at the Bureau of Meteorology regularly evaluates Australia's temperatures and each year updates the record. CSIRO anticipates the Inquiry receiving information from the Bureau of Meteorology on the Australian climate record. However, it is possible to examine the Australian warming trend at http://www.bom.gov.au/climate/change/amtemp.shtml.

Other observations related to climate

Apart from observations of global surface temperature, changes to other aspects of global climate have been observed. These include:

- Three ocean basins (the Atlantic, the Pacific and the Indian) now show warming over the past twenty years to depths of about 1000 m.
- The upper atmosphere (lower stratosphere) is showing a cooling trend, consistent with a 'greenhouse' signal.
- There is a widespread retreat of glaciers in the tropics and mid-latitude regions.
- A record published in 1998 shows the recent temperature record in the context of the past 1000 years (Figure 7) in which the 20th century warming counters a millennial-scale cooling trend due to gradual changes in the Earth's orbit.
- Precipitation (measured over land) has increased about 1% since the beginning of the 20th century – this is statically significant.
- Consistent with the increase in precipitation is an increase in cloud cover and a decrease in the difference between day and night temperatures.
- Heavy extreme precipitation has generally increased in areas where average precipitation has risen.
- The pressure at high altitude observations is increasing consistent with surface warming.
- The temperature profiles down bore-holes in the earth's crust indicate recent global warming.

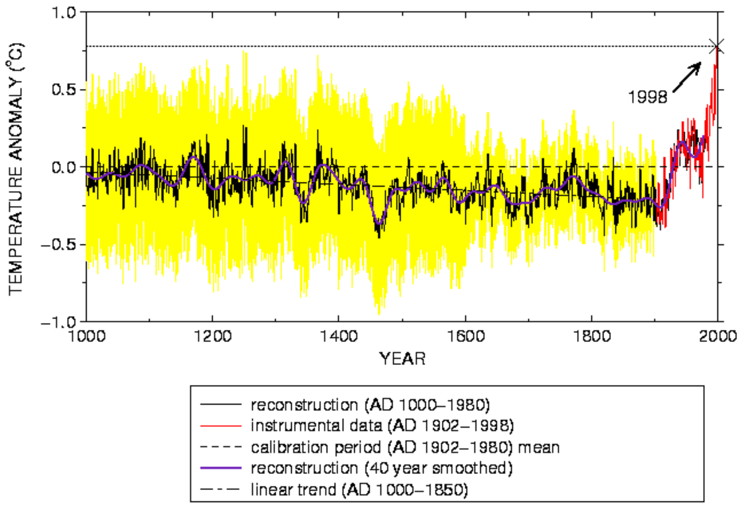

Figure 7. A proxy record of temperature for the past 1000 years compared with the modern temperature record (Mann et al., 1998). *Geophysical Research Letters*, 26(6), 759-762). The yellow area represents the likely range of uncertainty.

Projected climate change

Climate models

From the scientific perspective it is clear that since industrialisation there have been rapid increases in the levels of greenhouse gases in the global atmosphere. Given that this is now uncontested, the question arises: 'What effect will such continued changes have on global climate?'

In principle, there are four ways in which a projection of climate can be made:

1. guess work.
2. predictions made on the basis of the past (use of analogues).
3. extrapolations from recent trends (that is, assuming a recent trend will continue and using this to forecast).
4. climate models.

Clearly policy-making based on guesswork is unacceptable. The use of climatic analogues finds some favour, but in reality there are no precedents for today's circumstances with a large human population driving large-scale atmospheric changes. While rapid changes in greenhouse gases have occurred in the past and have changed climate, these changes occurred in the absence of a human population potentially vulnerable to them. Extrapolations from the past to the future do not adequately address the *non-linear* nature of the global climate system. In other words, small changes can sometimes produce larger than expected effects due to feedbacks within the global climate system. Feedbacks cannot be adequately incorporated into such extrapolations. Therefore, climate models, imperfect as they are, emerge as the most valuable method for projecting future climate changes.

The major processes that need to be included in a climate model are illustrated in Figure 8. Unlike some other prediction systems, climate models that are used to assess climate change do not require *observations of climate as input*. Observations of real climate are used to assess the extent to which the climate model mimics, or reproduces the observed behaviour of the climate system. Thus it is important to realise, global warming anticipated through the use of climate models, is not dependent on the observational data of warming shown in the previous Section.

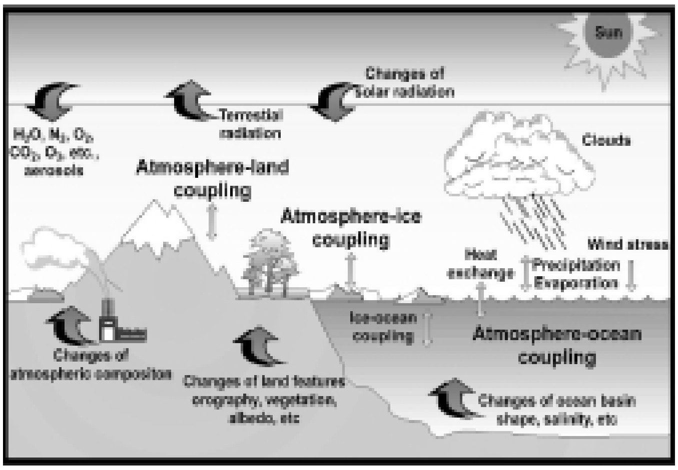

Figure 8. Major features of the global climate system.

The computer programs used to simulate climate — climate models — have improved substantially since the Intergovernmental Panel for Climate Change reported in 1995.

These advances can be summarised as a) *model developments*, leading to a more complete or realistic incorporation of processes known to be important in climate and, b) *demonstrated improvements* in the ability of a model to simulate features of climate that have actually been observed.

Major developments that have been implemented in the past five years include:

- The effects of sulfate and other aerosols (airborne particles). These are included with varying levels of sophistication within models and many simulations have been completed (at the time of the Second Assessment Report only two simulations had been completed that addressed the issue of sulfate aerosol and their cooling effect).
- The way in which the land surface including vegetation is represented within the models is more comprehensive; for example:
    - soil moisture is calculated in more detail and across more soil types
    - calculations of snow and ice (including permafrost) are more realistic
    - more detailed vegetation types are included, with improved exchanges of moisture and heat between vegetation, soil and atmosphere.
- All the major models now include a model of the global oceans coupled to an atmospheric model.
- The methods for coupling these two components are demonstrably better, with less need for artificial adjustments between the two (known as flux adjustments).
- The vertical and horizontal resolution of climate models has increased, meaning that the climatic variables calculated by the model (e.g air and sea temperature, air

pressure, relative humidity, wind speed and direction) are calculated on a horizontal distances of less than 500 km, giving better regional detail.

- Processes of cloud formation, the influence clouds have on radiation are more realistically included.

Model intercomparison studies represent the other major area where the science has advanced since the Second Assessment Report. Figure 9 shows an example where error in the simulation of rainfall is analysed, between many of the models being developed around the world (including the Australian models CSIRO and BMRC). Information such as this allows close comparison between different models and also clearly identifies where model performance needs most improvement.

CSIRO is now completing the final testing of a new global coupled ocean–atmosphere climate model. This model, known as CSIRO Mark 3 will be a high resolution model comparable to that run at the Hadley Centre in the UK and the Max Planck Institute in Germany.

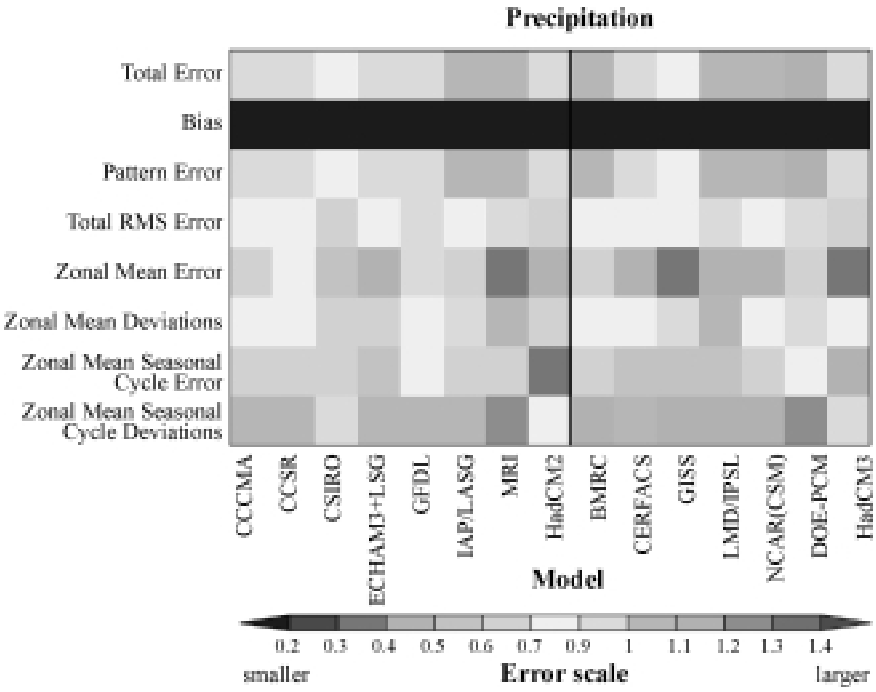

Figure 9. An example of the evaluation of error in fifteen global climate models. Precipitation is evaluated against observed measures of rainfall variability. Figure courtesy PCMDI, USA.

Projections

Projections of future climate are typically produced by *specifying* changes to the concentrations of greenhouse gases in the model atmosphere. The model then adjusts to this ‘climate forcing’. In order for scientists to compare the results from different models, a standard set of *concentration scenarios* tends to be used. These are often derived from the Intergovernmental Panel on Climate Change’s *emissions scenarios*. The IS92a scenario of *emissions* has been the most commonly used since 1996 and is shown in Figure 10. The scenario does not include the effect of policies intended to abate emissions.

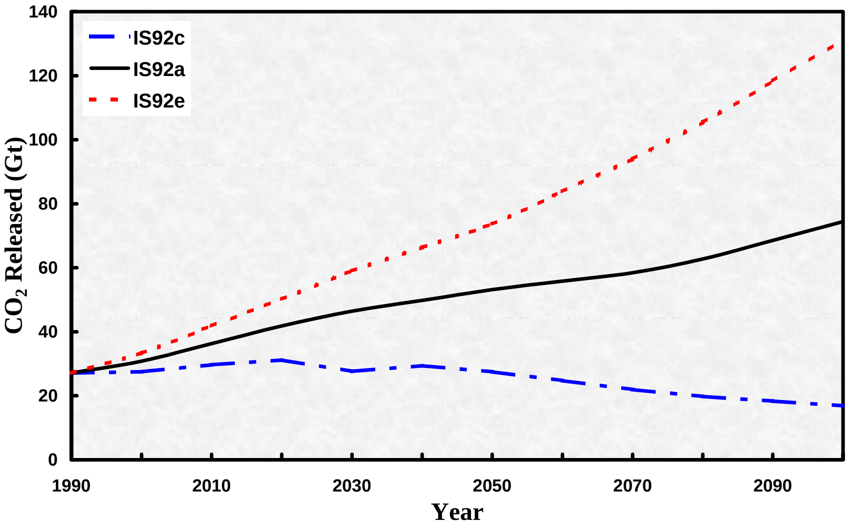

Figure 10 The Intergovernmental Panel on Climate Change ‘IS92’ global emissions scenarios.

The Intergovernmental Panel on Climate Change emissions scenarios are being revised now. Until climate models are using the new Intergovernmental Panel on Climate Change emissions scenarios, we are continuing to use the projections of global temperature rise published in the Second Assessment Report.

The broadest spread of potential temperature change cited in the Second Assessment report was an increase (from a 1990 base) of 0.8–4.5ºC, by 2100. **It is expected that new projections of global temperature change using the revised IPCC scenarios (known as the SRES scenarios) will fall within this range.**

In broad terms about half the uncertainty associated with projections of temperature to 2100 derives from differences between models (which we interpret as scientific uncertainty about the behaviour of the climate system) and about half is due to differing views about future emissions of greenhouse gas and sulfate aerosol (which we interpret as the uncertainty related to what societies will do).

Figure 11 shows two simulations from the CSIRO coupled ocean-atmosphere global climate model (Mark2). The red line shows the temperature increase simulated by the model, as a consequence of greenhouse-gas concentrations rising in accordance with the IS92a emissions scenario. The blue line shows the temperature increase simulated as a result of the IS92a emissions scenario *and* the effect of sulfate aerosol. The black line shows the temperature change observed during the past century. Including the effect of sulfate aerosol results in closer correspondence between the observed and modelled temperature.

In addition to global warming, patterns of rainfall are also expected to change next century. Figure 12 shows the changes in daily rainfall as simulated by the CSIRO global climate model. Different climate models show different patterns of rainfall change. However, all climate models show an increase in global average rainfall and extreme rainfall increases in many regions.

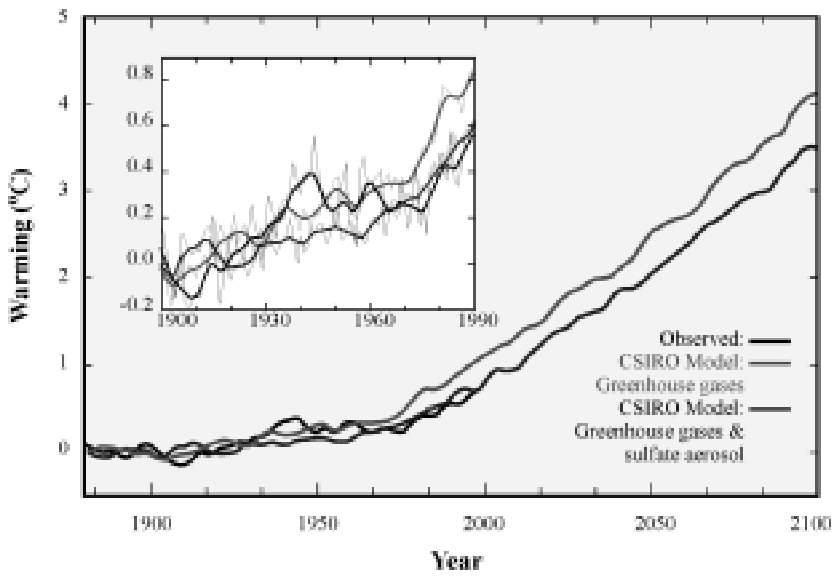

Figure 11. Modelled global temperature increases resulting from the IS92a emissions scenario (red line). Inclusion of sulfate aerosol within the model reduces future warming (blue line) and fits better with observations.

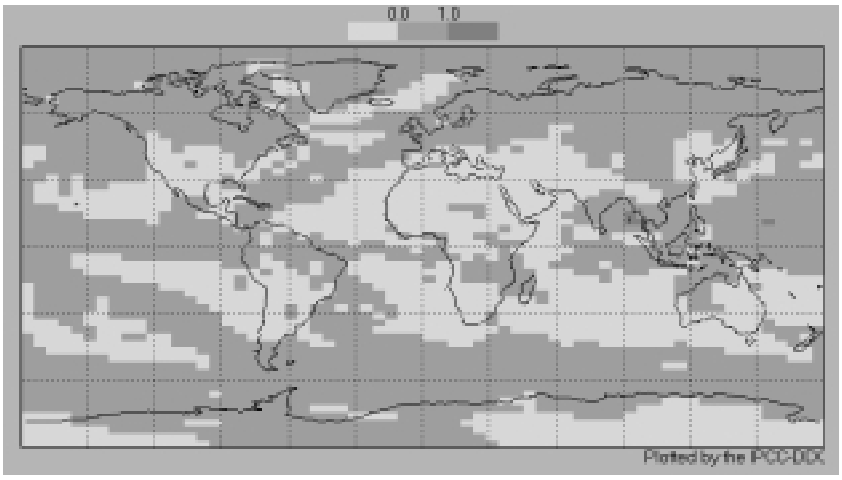

Figure 12. CSIRO Mark 2 model simulation of annual precipitation change (mm/day) for the 2050s relative to 1961-90. Yellow regions are drier, green regions are wetter.

Climate change over Australia

There is substantive agreement within the scientific community on the broad global features of the climate changes that we can anticipate throughout the course of this century. But there is less consistency when attempting to describe future climate at a regional scale. By regional scale, we mean geographic regions that are the size of the major continents or smaller.

Australia's climate is subject to large year-to-year variations in rainfall. What scientists call 'climate variability' and 'climatic extremes', ordinary Australians think of as droughts, floods, tropical cyclones, heat waves, frosts and severe storms. Understanding the nature of these variations and how climate change may influence them is key to providing useful information on how climate change might affect us.

Extreme events cause much of the impact of climate on agricultural enterprises, mining operations, transport, health, and natural ecosystems.

As well as examining changes on temperature and rainfall, CSIRO research is focussing on a limited number of issues that we regard as key to making more reliable our projections of climate in Australia. These are:

- The impact of global warming on the El Nino–Southern Oscillation (ENSO)
- The implications of climate change for tropical cyclones
- Extreme rainfall events.

Changes associated with the ENSO are still far from clear. There is some indication from a number of climate model experiments that global warming will lead to an ‘average’ climate that resembles an El Nino-like state. This suggests that regions that currently experience droughts during El Nino years would experience these conditions more often, and areas where rainfall increases during El Nino years would become wetter. Year-to-year changes associated with ENSO variability will continue under climate change, but there is little consensus about the nature of this change.

Several global climate model experiments have shown an increase in the maximum intensity of tropical cyclones (as measured by minimum central pressure or maximum wind speed) under enhanced greenhouse warming. Similar results are found in diagnostic studies, so an increase in intensity is considered likely. The number of extreme tropical cyclones would consequently increase. Other measures of changes in cyclone behaviour (e.g. total cyclone numbers, formation regions and tracks) exhibit variable results between models.

In order to assist with planning for climate change, Australian state governments have used CSIRO to investigate potential climate change in relation to specific States. In this work CSIRO has used a regional climate model ‘nested’ within the global climate model to produce simulations of climate change with a spectral resolution of about 60 km.

The major finding from this work is that within a relatively small *average* change, there exists the potential for significant changes in the frequency of extreme climatic events. Figure 13 illustrates this finding by showing modelled temperature changes in NSW. The left-hand side of the Figure shows the number of summer days in the northwest of the State that exceeds a 35°C maximum. The right hand side of the Figure shows a decline in the number of nights where the temperature falls below 0°C. By the year 2050, hot days occur 20% more often, and frosty nights occur 40% less often, but the *average temperature* has risen by only 1.7°C. Note the significant inter-annual variability.

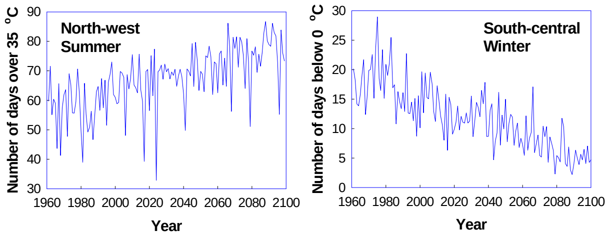

Figure 13. Number of hot summer days in north-west NSW (left panel) and number of frosty winter days in south-central NSW (right panel) as simulated by the CSIRO regional climate model in which greenhouse gas concentrations were increased according to the IS92a emissions scenario.

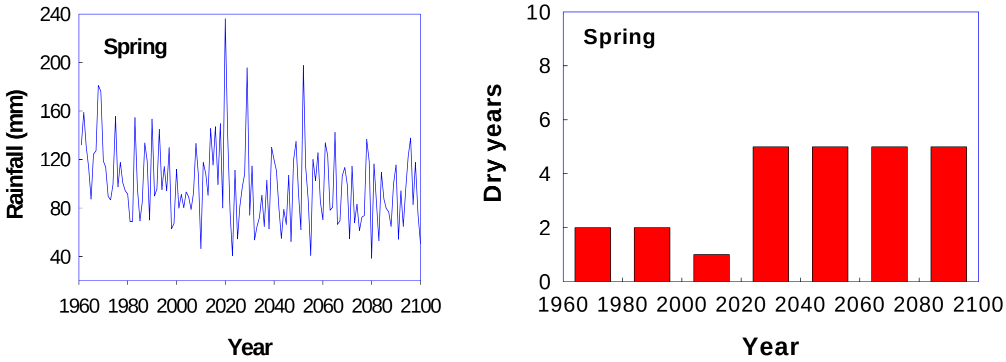

Figure 14. Simulated spring rainfall over south-western New South Wales (left panel) and the number of dry spring seasons experienced per 20 years (right panel). 'Dry' is defined as a spring season where rainfall is below that of the 4th driest year in the period 1961-2000.

Similar analyses have been done for rainfall. Figure 14 illustrates the way in which natural variations can obscure a small overall trend, which in turn masks substantial changes in the number of extremes. As described in the caption, the panel on the right indicates that from the middle of this century there is an increased chance that south-western NSW will receive an amount of spring rainfall that was regarded as 'dry' in the latter part of the twentieth century.

The problem for policymakers is that while these results are plausible, they are from a single experiment from a regional climate model. Different models are likely to show quantitatively different changes over the same regions.

Sea-level rise

The prospect of *average* sea levels rising as a result of global warming has been a continuing feature of public discussions about global warming.

In terms of assessing the potential impacts of climate change on coastal environments it is necessary to keep in mind that a trend in average sea level is only one factor that is likely to impinge on the coast.

The Intergovernmental Panel on Climate Change Second Assessment report noted that there are many factors leading to sea-level changes. These are:

- thermal expansion of the oceans (+ regional variations)
- polar ice caps
  - precipitation, evaporation (accumulation)
  - discharge (long-term responses)
- non-polar ice melt
- extraction of groundwater
- increased water storage
- local processes: subsidence, uplift, reef processes, erosion etc.

The Intergovernmental Panel on Climate Change reviews what is known about these processes to produce estimates of future sea-level rise. This has led to revisions in our expectations and understanding of sea-level rise.

In summary:

- There has been a consistent narrowing of the range of potential sea-level rise over the past decade
- The extreme upper estimates have been reduced but the lower estimates have changed little
- The Second Assessment Report gives a sea-level rise of 13-94 cm by the year 2100 (from a 1990 base). It is expected that revised estimates using the updated emission scenarios will fall within this range.
- An *acceleration* in the rate of sea-level rise has not been observed, but is expected over the course of this century
- There is a greater appreciation of the lag between sea-level rise and global surface temperature increases
- Sea-level rise will not be globally uniform
- Over the next one hundred years it is expected that ocean thermal expansion, glaciers and the Greenland ice sheet will all contribute to sea-level rise, whereas precipitation over Antarctica is expected to increase resulting in a small growth of the Antarctic ice sheet thereby off-setting sea-level rise slightly.

Options for greenhouse gas mitigation

From a scientific perspective, the increased levels of carbon dioxide in the global atmosphere reflect a change to the global carbon cycle. That change is driven through the release of carbon, formerly stored within the earth’s crust as fossil fuels (coal, oil and gas), to the atmosphere; and through carbon stored in vegetation being released to the atmosphere as a result of land-use change.

The global carbon cycle responds through:

- enhanced growth of vegetation (‘vegetation sinks’)
- increased uptake of carbon dioxide by the oceans (the ‘ocean sink’) and
- increased levels of carbon dioxide in the atmosphere.

In the event that elevated rate of emissions to the atmosphere ceases, a new equilibrium is eventually (after thousands of years) established.

If we wish to avoid the atmospheric increases in greenhouse gases that lead to climate change, then there is a limited set of strategies that can be adopted. These strategies may translate to many different policy measures.

The four underlying mitigation strategies are:

1. ***Improved Efficiencies from Carbon Fuels*** — efficiency improvement of primary energy conversion through its life cycle from extracting the fuel, through to power generation so that fewer units of fossil fuel energy are required to provide the same converted energy output.
2. ***Carbon Sequestration***—the removal and utilisation or storage of greenhouse gas that would otherwise be emitted to the atmosphere.
3. ***Fuel Switching***—the use of lower-carbon or carbon-free energy sources that will reduce emissions of greenhouse gas. Fuel switching may involve a structural change in the energy supply system, and specifically includes *decarbonisation*.
4. ***Transmission and End Use Efficiencies***—efficiency improvements that lead to reduced energy demand, which can be transmitted up through the energy chain.

CSIRO conducts research relevant to all four strategies. A compendium of CSIRO's research into greenhouse and which covers many of the research areas can be found in *CSIRO Solutions for Greenhouse*.

Each of these strategies is potentially legitimate in technical terms and each strategy will be associated with a series of consequences — some potentially undesirable from an economic, social or environmental point of view.

The range of energy technologies potentially encapsulated within these strategies is enormous and includes using renewable forms of energy (biomass, solar, wind and other processes); high efficiency gas-based utilisation technologies for power, heating, and cooling including fuel cells, microturbines, engines and hydrogen-based systems; hybrid fossil/renewable approaches; energy end-use efficiency; and capture and sequestration of carbon dioxide and methane.

In the short term, the three approaches that appear to have the smallest costs revolve around:

- energy efficiency
- fuel switching to less carbon intensive fuels
- utilisation of biomass for energy and waste gas for energy.

Existing government programs employ each of these strategies, but many potential greenhouse-gas savings are very difficult to capture. From a research perspective potential technological solutions have to be conceived and developed in close relationship to their social, economic and institutional context.

In this submission, we have elected to provide somewhat more detailed information on strategies involving sequestration. We have chosen to do this because:

- carbon sequestration arises only in the context of a response to greenhouse
- some of the issues have received relatively little attention in Australia
- the inquiry is likely to receive submissions relating to mitigation in a variety of sectors and sequestration (apart from tree planting programs and Bush for Greenhouse) is still almost entirely within the research domain.

Given the close relationship between energy derived from fossil fuels and greenhouse response, we have included, as an attachment to this submission, a broad overview paper on energy sustainability and greenhouse. The paper is a pre-print prepared for a recent international conference.

Sequestration

If carbon is not to remain in the atmosphere, then it can be stored (sequestered) in:

- vegetation and the soil (biospheric sequestration)
- the earth's crust (geological sequestration)
- the oceans (marine sequestration).

Biospheric sequestration and emission reduction

As part of its response to this inquiry a number of CSIRO scientists assessed the potential for biological sequestration in Australia. This assessment identified eight potential strategies that could enhance sequestration in the Australian biosphere through changes in land use and land management.

The strategies identified are:

1. reducing methane emissions from livestock
2. reducing nitrous oxide emissions from cropping and pasture systems
3. management to increase soil carbon stocks in agricultural systems
4. management to increase soil carbon stocks in rangeland systems
5. increases in plantation forestry
6. increases in agroforestry
7. reductions in rates of land clearing
8. woody thickening in rangelands.

Six criteria were developed against which these strategies could be evaluated. Three criteria relate to the nature and admissibility of the proposed strategy:

1. is the strategy biophysically realistic?
2. is it measurable (verifiable)?
3. is it admissible within the framework of the Kyoto Protocol?

The other three relate to its 'practicality':

1. what is its magnitude in the Australian context?
1. what are its costs and benefits?
2. what policy drivers are available, or are required, to bring about change?

A summary of the assessment is shown in Table 1.

Strategy	Bio – physically realistic?	Certainty of verification	Admissible under Kyoto Protocol?	Magnitude (Mt CO_2e per year)	Main additional benefits (+) or costs (-)
(a) Reduce methane from livestock	Yes	Medium	Yes	7 to 33	(+) Increased livestock production
(b) Reduce nitrous oxide emissions in agricultural systems	Yes	Medium	Yes	0.1 to 1	(+) Increased efficiency of fertiliser use
(c) Increase soil carbon in agricultural systems	Yes	Low	Under review	1 to 18	(+) Improved soil organic matter content
(d) Increase soil carbon in rangeland systems	Yes	Low	Under review	2 to 37	(+) Retirement of unproductive land
(e) Increase commercial forestry	Yes	Medium	Yes	2 to 24	(+) Eventual timber production (-) Oversupply of timber?
(f) Increase agroforestry	Yes	Low	Yes	1 to 12	(+) Sustainability benefits of trees in landscapes
(g) Reduce land clearing	Yes	Low	Yes	1 to 4	(+) Preservation of native vegetation
(h) Woody thickening in rangelands	Yes	Low	Uncertain	Potentially large sink (up to 120)	(-) Possible failure to activate Article 3.7 trigger (-) consistency issues

Table 1. Assessment of possible strategies for greenhouse gas abatement by changes to land use and land management, against five of the six criteria.

In summary:

- Land-use and land-management strategies together offer significant greenhouse abatement potential, of up to 30% of Australian 1997 net annual emissions excluding land clearing.
- The outcome within this range depends on the (uncertain) extent of adoption of the various strategies by land managers.
- Most strategies would also increase rural production or have other sustainability benefits besides greenhouse abatement.
- Particularly effective strategies are reductions in methane emissions from livestock; increases in commercial forestry; increases in agroforestry (especially if trees are used to generate biofuels and thereby substitute for fossil fuels); and soil carbon sequestration in agricultural and rangeland soils.
- The extent of adoption of all these strategies, which largely determines the magnitude of the abatement achieved, is contingent upon policy and the regulatory environment.
- There is no single panacea for greenhouse gas increases, but there are significant abatement possibilities in the terrestrial biosphere, through a range of land use and land management strategies.

Geological Sequestration

In contrast to biological sequestration, storage of carbon dioxide within geological structures would be relatively easy to measure and verify. In the context of a long term (multi-decadal, Figure 15) strategy to develop *decarbonised* energy sources through fuel switching, or closed systems that do not release to the atmosphere, geological sequestration could be implemented relatively quickly and store large volumes of carbon dioxide.

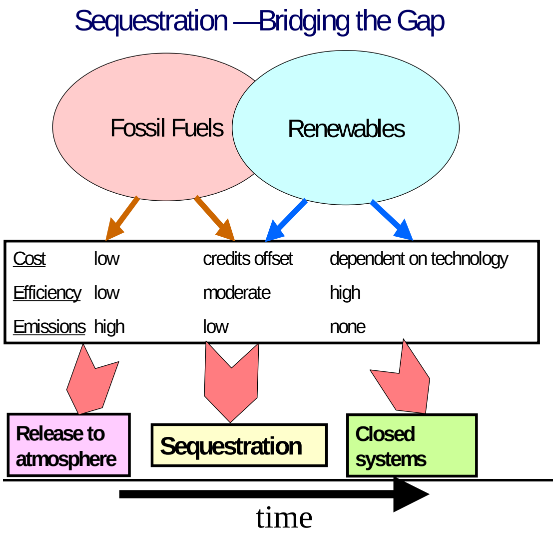

Figure 15. Geological sequestration may provide a transitional approach to sustainable energy generation systems.

Several types of geological structures could be considered for carbon dioxide sequestration:

1. Depleted oil and gas reservoirs
2. Coal seams (carbon dioxide is known to be sorbed onto coal)
3. Large voids and cavities in salt beds and domes or bedded carbonates
4. Deep unusable brackish or saline water-filled reservoir rocks with little or no hydrocarbon potential.

The capacity of Australian basins to sequester carbon dioxide has not been measured. However, due to the extensive nature of these basins, potentially tens of gigatonnes of carbon dioxide could be sequestered. Based on similarities with American basins where recent estimates have been made, a crude approximation indicates that the eastern sedimentary basins of Australia have the potential to sequester up to 60 Gt of carbon dioxide. This equates to a sequestering capacity of 10 times the emissions from the eastern states' power generating sources for the next 50 years.

The techniques that could be applied to geological sequestration of carbon dioxide have been used extensively in enhanced oil recovery in producing fields around the world. Presently over 70 fields use carbon dioxide, mainly derived from natural gas, in enhanced oil recovery floods. In the USA, 100,000 tonnes per year of carbon dioxide are used.

One of the first major projects utilising carbon dioxide derived from a coal gasification plant is underway in Canada. The gasification plant is situated in North Dakota, USA and the carbon dioxide will be piped 300 km to a heavy oil field in Saskatchewan. The economic justification for this $1billion project is an expected 60% increase in production and an extension of the field's life for a further 25 years.

Since 1996, separation and injection of carbon dioxide from natural gas is an integral part of gas production on Statoil's Sleipner field in the North Sea. The raw gas contains 9.5% carbon dioxide that has to be removed to convert it into sales gas. The carbon dioxide is separated from the gas stream by the amine process and injected into an aquifer, 800 m below the sea bed.

Apart from these examples in the oil and gas industries, a major technical barrier to geological sequestration of carbon dioxide is capture and separation of carbon dioxide from the flue gases of industrial plants, including power stations.

An analysis by CSIRO based on the cost of currently available technology showed that, if a 500 MW coal fired power station located in the eastern states of Australia incorporated full capture and sequestration, it would result in a cost of $55/tonne of carbon dioxide disposed. This would also result in an overall reduction in thermal efficiency from around 37% to as low as 23%. However, if 30% carbon dioxide in the flue gases were to be recovered, the overall thermal efficiency would drop to around 30% and costs could be reduced to $25/tonne of carbon dioxide. The latter scenario still adds an extra 3-4 cents/kWh to the cost of electricity supply.

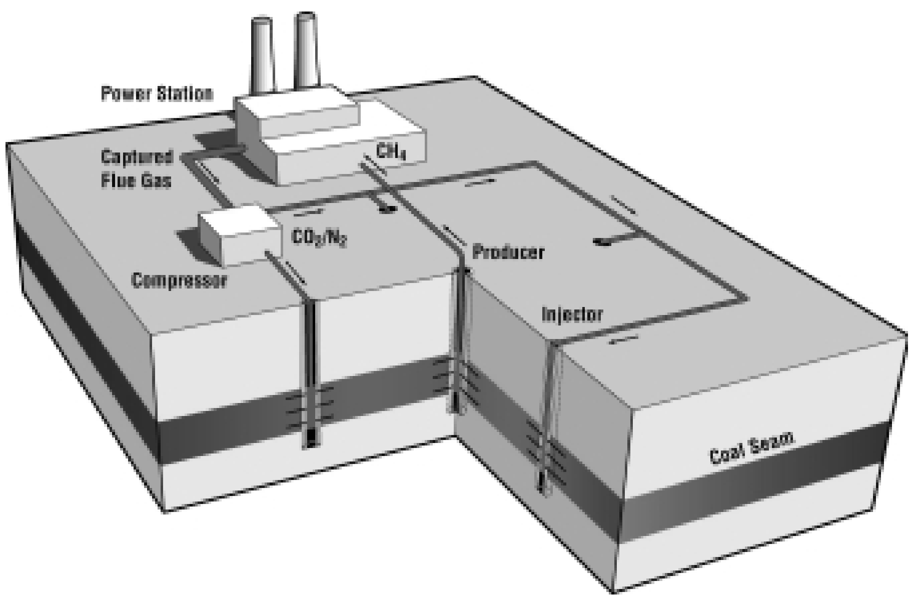

Figure 16. A conceptual diagram of carbon dioxide capture, separation and geological sequestration.

A challenge that is being taken up around the world is to develop technologies and further streamline the process to halve this cost. Other options might include incorporating geological sequestration as part of novel energy generation technologies. Alternatively the cost of geological sequestration might be off-set through using carbon dioxide to enhance the recovery of methane gas from which power can be generated.

In summary:

- geological sequestration holds potential to remove significant quantities of carbon dioxide from the atmosphere, but this potential has not been assessed for Australia
- at present costs of capture of carbon dioxide and its separation from other waste gases are high; reducing the cost of capture and sequestration is a major research task
- geological sequestration may be needed as a transitional strategy to an ecologically sustainable energy system
- geological sequestration is the focus of considerable activity internationally.

Marine sequestration

Two types of marine sequestration have been proposed.

The first is direct injection of the carbon dioxide into the ocean, where it would then be mixed down into the ocean depths where it would either form a clathrate (many carbon dioxide molecules lined together) on the floor of the ocean or would circulate slowly with a residence time of hundreds to a thousand years.

The second form of sequestration requires the stimulation of phytoplankton growth in the ocean surface layers through the addition of nutrients (nitrogen and iron are the two nutrients proposed). It is suggested that the increased phytoplankton growth would lead to faster uptake of carbon by a mechanism known as the biological pump. There are considerable doubts about whether this approach is capable of genuinely sequestering significant amounts of carbon.

Apart from significant technical difficulties, the ecological implications of ocean sequestration are largely unknown and may therefore receive significant public opposition. Nonetheless other nations are investing in research into examine the potential for ocean sequestration; particularly direct injection methods. CSIRO believes it is necessary to monitor the development of such approaches.

Adapting to climate change

The previous Sections of this submission indicate that continued climate change is likely. Therefore some adaptation to these changes will be required. The previous discussion also points to significant uncertainty in projections of regional climate change; especially in relation to those features of climate that are likely to require the most significant response.

Between 1990 and 1995, CSIRO scenarios were used in 36 impact studies through collaboration involving nine CSIRO divisions, ten Australian universities, five overseas universities, ten Commonwealth and State government departments, three non-government organisations and 13 overseas government organisations. Since then, CSIRO has been involved in a further 39 impact studies, of which 21 are in progress.

Results of these studies have been published in scientific journals, in consultancy reports, in the Australasian chapter of the 1998 IPCC Special Report on Regional Impacts of Climate Change, and on the world wide web.

A summary of the results from this work has indicated:

- A potential increase in bushfire danger throughout Australia.
- 9 to 27% less irrigation water in the Macquarie Valley by 2030, 11 to 32% less water for the Macquarie marsh ecosystem, and 6 to 22% ($38-152 million) less agricultural revenue.
- 18-66% less snow cover by the year 2030, and 39-96% less cover by 2070, leading to insufficient natural snow for viable ski operations by 2030 at low resorts (eg. Mt Baw Baw) and by 2070 at most Australian resorts (see Figure 17).

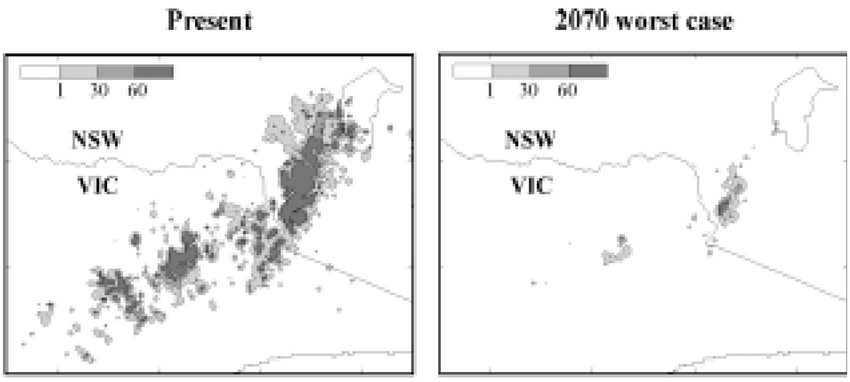

Figure 17. Days of snow cover per year in south-east Australia.

- Increased forest productivity although some declines may occur in northern Australia. However, there may be significant increases in risks of damage from fires, pests and diseases, and significant potential impacts on biodiversity conservation.
- A 20% increase in national wheat yield is possible for a doubling of carbon dioxide and mid-range climate change scenarios by the year 2100. This incorporates varietal changes made by farmers to optimise yield. If planting schedules are also optimised to suit a reduced frost period, the yield could increase by 26%. Yield enhancement will decline rapidly if the warming exceeds 2^{o}C or rainfall decreases (Figure 18). Reduced wheat quality will need to be managed by improved fertility management, and/or increased fertiliser application rates, and development of heat-tolerant varieties.
- Integrated climate impact assessments for Queensland fruit fly, light brown apple moth and insect-related dieback of rural woodlands have been undertaken. These assessments offer the opportunity, of aiding control by showing the likely zones of activity of these pests.
- The frequency of heat stress in Australian beef cattle increased by 40% from 1957-1996, and is estimated to increase by a further 138% by about the year 2050 due to a doubling of carbon dioxide and a warming of 2.8^{o}C.
- Increased pasture growth, live-weight gains and improved financial outcomes on the rangelands. Increases in heat stress, water consumption, possible changes in

grass distributions, and increased soil waterlogging and salinity in susceptible areas may offset some of the above advantages.

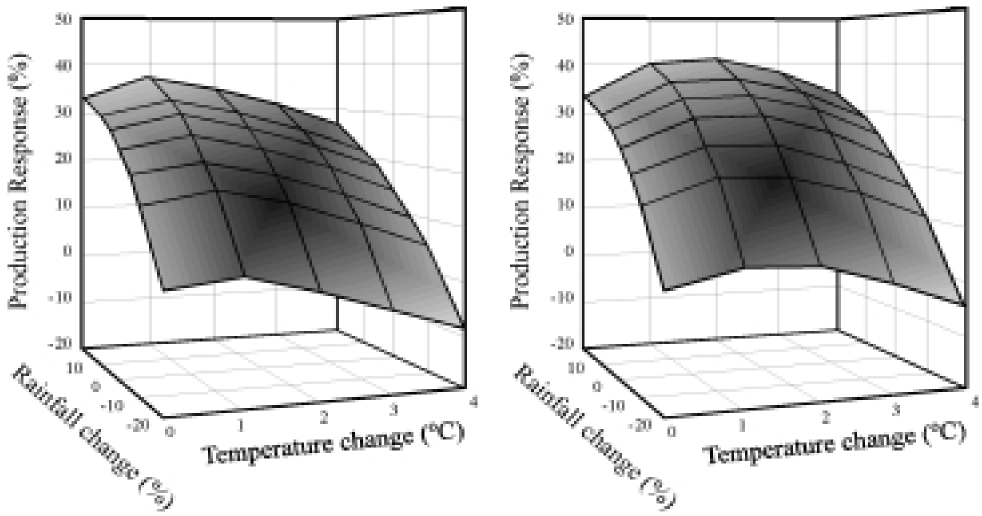

Figure 18. National wheat production response to a doubling of carbon dioxide and climate change for present (left) and optimised (right) planting schedules.

- More overlap between extreme rainfall events and oceanic storm surges in coastal regions of NSW, leading to more coastal flooding.
- The possibility of accelerated coral bleaching, with destruction of much of the Great Barrier Reef by the year 2040. CSIRO involvement in this study was limited to supplying climate model results to the biologist who undertook the investigation. We understand that the Great Barrier Reef Marine Park Authority and others have provided submissions to the Inquiry.
- Little effect on human death rates due to increased heat stress in Australia's five largest cities by 2030.

Partly in response to these studies CSIRO has established an *Impacts and Adaptation Working Group.* A major effort is required to conduct integrated assessments of climate change involving closer partnerships with communities. Further more, we are developing risk management approaches to the problem of climate change as a strategy to assist the development of adaptive responses in the absence of unambiguous and well-defined descriptions of potential impacts.

In summary:

- Our ability to plan for, and adapt to, climate change is still limited by inadequate insights into regional climate change, particularly changes to extreme climatic events.
- Paradoxically the need to consider adaptation to climate change has become more important over the past five years as evidence for climate change has become stronger and the practical difficulties and costs associated with mitigation have become more apparent.

- The magnitude and rate of climate changes anticipated through the course of this century (provided substantial mitigation is not achieved) will produce discernible impacts in Australia.
- Some of these impacts are potentially positive, while other impacts are potentially negative
- Development of risk-management approaches is promising to be useful in developing strategies for adapting to climate change.