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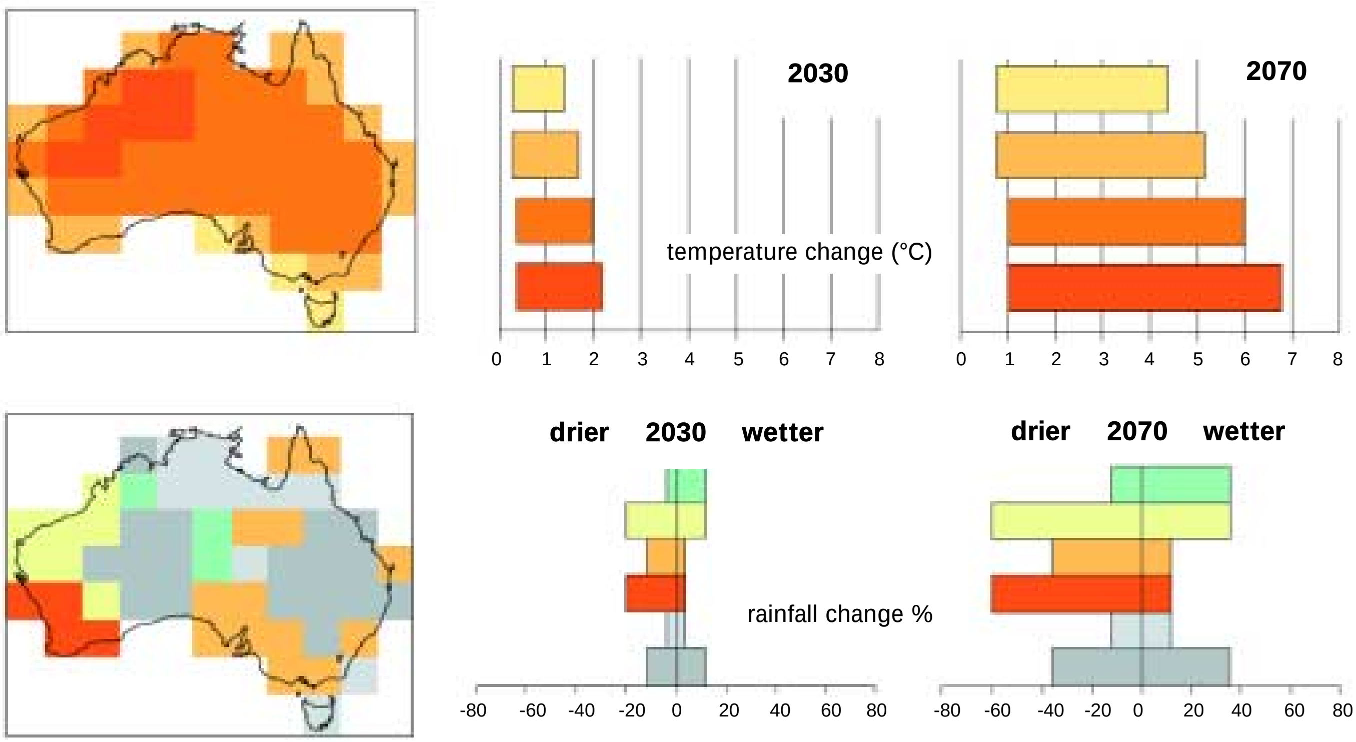
Change in the wind

Using a range of climate models, the Climate Impact Group from CSIRO Atmospheric Research has predicted significant changes in temperature, rainfall and evaporation in the next 100 years.

Wendy Pyper looks at what's in store for Australia this century and at national and international efforts to curb climate change.



Ranges of average annual warming (top) and average annual rainfall change (above) for around 2030 and 2070 relative to 1990. The coloured bars show changes for areas with corresponding colours in the map.

The Earth's energy balance is finely tuned. Sunlight passes through the atmosphere, warming the Earth's surface, while the land and oceans release energy to the atmosphere as infrared radiation. Water vapour, carbon dioxide and other gases absorb some of this radiation, warming the lower atmosphere, while the rest is released into space. Without the heat-trapping ability or 'natural greenhouse effect' of these gases, the Earth's surface would be a chilly –18°C, rather than the comparatively tropical 15°C average we now enjoy.

Since the industrial revolution and the expansion of agriculture, however, copious quantities of carbon dioxide and other greenhouse gases – methane, nitrous oxide, ozone, halocarbons and sulfur hexafluoride – have been pumped into the atmosphere. This has led to increased trapping of infrared radiation and greater warming in the lower atmosphere.

During the 20th century, this warming contributed to a 0.6°C temperature increase and a 15cm rise in sea levels (due to the expansion of water when heated). This 'enhanced' greenhouse effect is often referred to as climate change or global warming. Scientists expect that continued increases in greenhouse gas levels will lead to further global warming and regional climate change.

Global concern

In 1997, industrialised nations made an historic, collective agreement to reduce greenhouse gas emissions to 5.2% below 1990 levels by between 2008 and 2012. This agreement, the Kyoto Protocol, placed issues of climate change mitigation firmly on the international political agenda. But the agreement began to unravel earlier this year when the United States announced its withdrawal from the initiative.

International climate change negotiators resuscitated the agreement at a meeting in July, when they agreed on most of the key political issues stalling its implementation. But according to the executive director of the Australia Institute, Dr Clive Hamilton, much of the original Kyoto Protocol has been re-interpreted, such that the emission reduction targets enshrined in the protocol will be less effective in reducing greenhouse gas emissions.

'Under a "business-as-usual" scenario, emissions in industrialised countries are expected to be 25–30% higher in 2012 compared with 1990 levels. While the protocol was expected to restrict emissions to about 5% below 1990 levels, the deal done in Bonn will mean they are stabilised at 1990 levels,' Hamilton says.

'The re-interpreted Protocol also allows countries to meet these targets largely through carbon sinks – reforestation, new plantations and changes in agricultural and forestry practices – as an alternative to reducing fossil fuel emissions.'

Stabilising carbon dioxide

Despite the 'watering down' of the Kyoto Protocol, Kevin Hennessy from CSIRO's Climate Impact Group, says it is an important first step in reducing the greenhouse gases that are contributing to global warming. It also sends a signal to industry that fossil fuels are not the only way to make the world go round. In its current form, however, the protocol will have little impact on moderating future climate change.

Hennessy says many gases have long atmospheric life times, so concentrations of gases continue to rise, even when emissions decrease.

'Imagine you're filling a bucket with water from a hose, and that the bottom of the bucket has two pin holes that allow some of the water out,' he says.

'The two pin holes represent carbon dioxide sinks, which are our oceans and plants. They're able to absorb a lot of carbon dioxide, but not enough to compensate for the amount we're pumping in. So even if we stabilise or reduce emissions – or the amount of water coming out of the hose – the concentration of gases is not going to go down very quickly.'

The Intergovernmental Panel on Climate Change (IPCC) – which assesses scientific, technical and socio-economic information relating to climate change – has shown that it will be impossible to stabilise greenhouse gas concentrations at today's levels (370 parts per million of CO_2). Instead, the IPCC has considered targets of 450 ppm to 950 ppm.

'To stabilise at 550 ppm by the year 2250 requires a prompt reduction in emissions, continuing to 50% below 1990 levels by the year 2125,' Hennessy says.

'The original Kyoto Protocol was trying to reduce emissions by 5% by 2012, so we've got a long way to go before we even stabilise concentrations at a much higher level than present. In the meantime, some amount of climate change is inevitable and we should start planning our adaptation strategies.'

What are the projections?

Climate modelling shows that increasing levels of greenhouse gases will warm the Earth's surface and that the enhanced greenhouse effect is likely to lead to worldwide changes in weather and climate.

The IPCC projects an average increase in global temperature of 1.4–5.8°C by 2100, relative to 1990 (0.1–0.5°C per decade). Associated with this warming, sea levels are projected to rise by 9–88 cm by 2100 (0.8–8 cm per decade).

Many coastal regions will become wetter, while continental interiors will become drier, causing some deserts to expand. Warming will probably be greatest in polar regions, mirroring climate changes already seen last century in both the Arctic and Antarctic.

The land is expected to warm more than the sea and the daily range in temperature is likely to decrease. Climate modellers predict that global warming will also lead to greater extremes of drying and heavy rainfall, increasing the risk of droughts and floods.

Projections of likely changes to Australia's climate by 2030 and 2070 were released by the CSIRO Climate Impact Group earlier this year.

This average annual warming map (see previous page) shows that by 2030, most of Australia will have warmed by 0.4–2°C and by 1–6°C by 2070, relative to 1990. Temperature modelling for each season has also shown that the range of warming will be greatest in spring and least in

Models of **uncertainty**

THE Climate Impact Group at CSIRO Atmospheric Research has used several computer models to assess the degree of climate change Australia can expect in 30 to 100 years' time.

Group leader, Dr Peter Whetton, says these models include the CSIRO global climate model, the CSIRO regional model and various international models.

'Models do differ from one another in their results, so we believe the best assessment of climate change in Australia will take account of results from all the models,' Whetton says.

'The key point about climate projection is that we don't provide a single answer, but rather a range of uncertainty for temperature, rainfall and evaporation. These ranges reflect the results from different models and uncertainties due to human behaviour: population growth, economic change, the adoption of new technologies and so on.'

Whetton says climate projection models work in a similar way to weather forecasting models. But where weather forecasts are based on simulations over a particular region for a few days into the future, climate projections are based on simulations of the global climate for the next 100 years. Climate models also account for gradual increases in greenhouse gases, which induces a gradual warming in the simulation.

The global warming scenarios used by CSIRO were developed by the IPCC. The scenario that induces the least warming is based on a global population that peaks mid-century and then declines. It also incorporates the introduction of clean and resource-efficient technologies and an emphasis on global solutions to economic, social and environmental sustainability. The scenario that induces the most warming is based on a similar population trend, but assumes an intensive reliance on fossil fuels.

Climate change on the World Wide Web

The Greenhouse Effect
http://www.dar.csiro.au/publications/Holper_2001b.htm
Modelling climate change
www.dar.csiro.au/publications/greenhouse_2000b.htm
CSIRO summary of climate change impacts
www.marine.csiro.au/iawg/impacts2001.pdf
CSIRO climate change projections for Australia
www.dar.csiro.au/publications/projections2001.pdf
Intergovernmental Panel on Climate Change (IPCC)
www.ipcc/ch

winter, while in the north-west, the greatest warming will occur in summer.

These increases in average temperature could lead to large changes in the number of extremely hot or cold days.

Perth, as well as being one of the hottest places in Australia in 2070, will also be one of the driest, receiving up to 60% less rain than in 1990. In contrast, seasonal projections have shown that some inland and eastern coastal areas may become wetter in summer (south-east Queensland for example), while other inland areas could become wetter in autumn. In winter and spring, most locations tend towards decreased rainfall. In the tropical north, however, the climate will change little from present conditions. These projections include the effect of climate change on El Niño and La Niña.

The effect of global warming on tropical cyclones has been considered, but details are sketchy. Scientists say maximum wind speeds may increase by 5–20% in some parts of the world by the end of the century and preferred cyclone paths may alter. As tropical cyclones are associated with oceanic storm surges, gales and flooding rains in northern Australia, the frequency of these events could increase.

Computer modelling has predicted that evaporation will increase in all seasons and, annually averaged, range from 0 to 8% per

degree of global warming over most of Australia (0–10% by 2030 and 0–30% by 2070). In the eastern highlands and Tasmania, evaporation is expected to increase a little faster. When the increases in evaporation are combined with changes in rainfall, there is a net decrease in moisture available from the atmosphere over the whole continent. This means that Australia will be under greater moisture stress.

While these climate projections are based on the most up-to-date computer simulations, scientists point out that uncertainties about future human behaviour and shortcomings in the modelling process, place limitations on the projections.

Scientists expect the future cost of flood damage to the built environment will increase.

Gas gas gas

THE MAIN greenhouse gases that are increasing in concentration due to human activities are carbon dioxide, methane, nitrous oxide and chlorofluorocarbons (CFCs). The long atmospheric lifetimes of these gases mean that any benefits derived from reducing emissions will be delayed.

***Carbon dioxide (CO_2)*:** Carbon dioxide increases are primarily due to the burning of fossil fuels such as oil, coal and natural gas, and from deforestation. About seven billion tonnes of carbon dioxide are emitted each year during the combustion of fossil fuels and one to two billion tonnes per year from land clearing. In Australia, annual carbon dioxide production per person is about 16 tonnes.

Methane (CH_4): Methane forms when organic material is broken down in the absence of oxygen, such as in the guts of ruminant animals. Other sources of methane are landfills, burning vegetation, coal mines and natural gas fields. Most atmospheric methane is eventually converted into carbon dioxide.

Nitrous oxide (N_2O): Nitrous oxide concentrations are increasing because of land-use changes, biomass burning, fertiliser use and some industrial processes. Oceans and soils are also natural sources of the gas.

Halocarbons and sulfur hexafluoride: Chlorofluorocarbons (CFCs) are the best known of the halocarbon gases. They are industrially produced and were first used in the 1920s as coolants for refrigerators. Later, they were used in air-conditioners, as propellants in aerosol cans, to make the bubbles in plastic foams and as solvents. In the future, emissions of halocarbons and sulfur hexafluoride – a gas used for electrical insulation – will be controlled by the Kyoto Protocol.

Ozone (O_3): Ozone is a component of photochemical smog, which is a problem in many cities. In the lower atmosphere it is a powerful greenhouse gas.

Aerosol: Aerosol are fine particles and droplets suspended in air. Although they are not a 'greenhouse gas', they are a climatically active atmospheric constituent. Burning coal and oil (such as in power stations) produces aerosol such as sulfate particles, which cause acid rain. Other aerosol include dust from soil erosion and desertification. Aerosol have a cooling effect on climate by reflecting some of the incoming sunlight. They also facilitate the process by which water vapour turns into cloud droplets.

Water vapour: Warming caused by increases in other greenhouse gases is likely to increase evaporation from the ocean and therefore the amount of water vapour in the atmosphere, adding to global warming.

Sunburnt **country**

MANY of our natural systems will be adversely affected by climate change, and this will in turn affect our tourism industry. Alpine ecosystems for example, are highly vulnerable to global warming and scientists expect less snow and shorter snow seasons in the future.

A 'low change' scenario for 2030 indicates that a 0.3°C warming and no change in precipitation would reduce the area covered in snow by 18%. Under a 'high change' scenario for 2030 – a warming of 1.3°C and an 8% reduction in precipitation – the snow area declines by 66%. This will not only reduce the area available for skiing, but also the alpine habitats for animals such as the mountain pygmy possum.

Coral reefs will also be affected by warmer oceans, rising sea levels and increased cyclone intensity. Scientists say natural adaptation will probably be too slow to avert a decline in the quality of the world's reefs.

In native forests and woodlands, warming and lower rainfall could threaten many eucalypt species and harm most frogs and mammals. Wetlands, riverine environments and rainforests will all be affected by reduced rainfall, disturbance from more frequent flooding or fires and invasion by pests, weeds and exotic species.

With so much carbon dioxide in the air, could Australia become a lush green paradise? If carbon dioxide increases were accompanied by a warming of 3°C and no rainfall change, scientists say tree growth would increase (25–50%) across much of southern Australia, particularly in the wheatbelt and semi-arid regions. Modest increases (0–25%) in tree growth are also likely to occur in parts of the semi-arid tropics. However, if rainfall decreases in winter and spring in southern Australia (as climate models have projected), tree growth will decrease and the risk of forest fires will increase.

Greenhouse gas emissions depend on population growth, technological change and social and political behaviour. And future climate change could be influenced by relatively unpredictable factors, such as changes in solar radiation, volcanic eruptions and chaotic variations within the climate system itself.

Impacts on Australia

According to research conducted by Dr Andrew Ash from CSIRO Sustainable Ecosystems, Dr Peter Whetton, and many external collaborators, rising temperatures could see reductions in crop yields, forage and animal production, while sensitive natural habitats, many of which are already under stress, could be severely affected.

'Impacts of climate change were assessed by incorporating climate projections into models for a myriad of other processes,' Whetton says.

'You can simulate expected yields for say wheat, under a given climate. And you can do similar things for natural ecosystems, other forms of agricultural production, water resources and so on. And importantly, we can force some sort of climate change on the models.'

Little is known about the effects of climate change and rising carbon dioxide levels on plants, animals and ecosystems in the rangelands.

Understanding the likely impacts of climate change now will enable suitable adaptation strategies to be implemented in some cases.

A warmer climate could see tropical pests and weeds, like the cattle tick and the Queensland fruit fly, spread southwards. Other temperate pests, such as the light brown apple moth, may actually be displaced by warmer weather. This would benefit crops normally affected, but would transfer the problem to cooler southerly regions.

Water shortages in southern Australia are likely, due to lower rainfall. This could help reduce recharge to groundwater in the Murray-Darling basin, slowing the onset of dryland salinity. But it will also mean greater competition between different water users, especially where large diversions to river systems are made for industry and irrigation.

Although rainfall is expected to decrease, when it does rain, it is likely to be heavier. Torrential rainfall over cities and surrounding catchments can produce severe runoff and flooding, while buildings are damaged by flooding and the force of water flow. As a result, scientists expect the future cost of flood damage to the built environment will increase.

Humans cannot escape the impact of global warming either. Health and lives will be at greater risk from heat waves, tropical cyclones and floods, an increase in mosquito-borne diseases such as dengue fever, water-borne diseases such as giardia, and skin cancer.

Abstract: Increasing emissions of greenhouse gases, such as carbon dioxide, has contributed to the gradual warming of the Earth's atmosphere. Scientists expect that unless these emissions are dramatically reduced this century, temperatures will increase while rainfall and evaporation will change. Some industrialised countries are attempting to address climate change through the Kyoto Protocol. This agreement is an important first step in reducing greenhouse gas emissions, but in its current form it will have little impact on climate change. Using several climate models, CSIRO has predicted changes in Australia's climate in 2030 and 2070 under various global warming scenarios. The impact of these changes on agriculture, natural and built environments considered.

Keywords: climate change, climate modelling, global warming, greenhouse gases, environmental impact, CSIRO Climate Impact Group, Kyoto Protocol.

A **mixed message** for farmers

FOR SOME farmers, increases in carbon dioxide could be a positive thing, as higher concentrations increase plant growth and improve water-use efficiency. This is known as the 'fertiliser' effect of CO_2. However if warmer conditions are accompanied by rainfall decreases, particularly in winter and spring, these benefits will be limited.

Dryland wheat in south-western Australia, for example, is at risk because the projected decreases in winter and spring rainfall are potentially large. If carbon dioxide doubles to 700 ppm and rainfall decreases by 20%, wheat yield will actually increase for a 1°C warming, but decrease thereafter. This is because higher temperatures increase the speed of crop development, reducing grain yields.

Higher average temperatures across the country will also mean a decline in the frequency of frosts, which is good news for frost-sensitive plants. But as temperate fruits such as stone-fruit and apples need winter chilling to ensure normal bud-burst and fruit set, scientists expect there will be lower fruit yields and reduced fruit quality. To counteract this effect, scientists say adaptive strategies could include increased use of chemical treatments or the selection of varieties with lower chilling requirements.

Dairy farmers could also be worse off as rising temperatures cause reduced milk yields from cows. Models project that by 2030, annual milk losses are likely to be 250–350 litres per cow (see *Ecos* 105). However adaptation using shade sheds and sprinklers could limit annual milk losses to between 60 and 90 litres per cow.

In Australia's rangelands, home to an enormous diversity of species, unique ecosystems and the majority of our sheep and cattle, the effect of global warming could be mixed. If rainfall decreases in southern Australia by more than 10% in winter and spring – the main growing seasons for herbage in this area – then forage and animal production will be reduced, despite the benefits of increased carbon dioxide. But in northern Australia, where summer rainfall is predicted to change very little, higher carbon dioxide levels should have a positive impact on plant production.

Little is known about the effects of climate change and rising carbon dioxide levels on other plants, animals and ecosystems in the rangelands. But scientists say interactions between plant species could be significantly altered, particularly where there is a delicate balance between woody and grassy layers.