Summary

This guide sets out the main facts and uncertainties regarding climate change, and helps provide Australians with policy-relevant, but not policy-prescriptive, advice and source material. It is largely based on, and consistent with, the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC TAR) published in 2001. However, this guide has been substantially updated with relevant summaries of the latest international and Australian observations, scientific developments, and studies regarding the impacts of, and adaptation to climate change in Australia.

While much progress in understanding the climate change issue has been made, uncertainties continue to exist about aspects of the climate change science, and regarding societal developments that will affect the extent of future climate change and societal vulnerability. Some impacts of climate change are now inevitable. However, more certainty and understanding is needed to guide decision-makers towards the most effective and cost-efficient means to adapt to climate changes in the near-term (next decade), and to avoid unacceptably large climate changes in the longer term (multi-decades to centuries) through emissions reductions measures.

The high probability of at least some global warming, given the inertia in the climate and socioeconomic systems, means that some adaptation will be necessary. This will be most efficient if the location- and activity-specific nature of the likely impacts is taken into account. Considerable uncertainties about location-specific impacts can be further reduced by targeted research, while case-by-case assessments of adaptation strategies will be needed for many particular sectors and locations.

Any emission reductions will progressively reduce the likelihood of impacts at the high end of the existing large range of emissions scenarios, and thus help to avoid the potentially most damaging climate change possibilities. Thus, in order to establish minimum objectives for emissions reductions, attention needs to be given to the more extreme possibilities to which adaptation may not be possible. These will determine critical greenhouse gas concentration thresholds that must be avoided if the objective of the United Nations Framework Convention on Climate Change is to be achieved. Increased research is needed to quantify the probability and global and local consequences of these high impact scenarios.

Climate Change Science: The Global Perspective

The TAR concluded that global warming has taken place over the last century, and there is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities. It is likely that the 1990s was the warmest decade in the last 1000 years, at least in the Northern Hemisphere. Other observations are consistent with this observed warming, including a rise in global average sea level and ocean heat content, and decreases in snow cover and ice extent both in mountain glaciers and Arctic sea ice. Recent evidence suggests that a predicted slow-down in the deep ocean circulation driven by variations in temperature and salinity may also be occurring.

The TAR reported that statistically significant associations between increases in regional temperatures and observed changes in physical and biological systems have been documented in freshwater, terrestrial, and marine environments on most continents. While overall levels of confidence in this conclusion are still debated, surface and satellite-based observations since the TAR support this conclusion.

Projected warmings in the 21st century are dependent on scenarios of future emissions of greenhouse gases and aerosols. Using the *Special Report on Emissions Scenarios* (SRES), global average warming projections range from 1.4 to 5.8 ºC by 2100 relative to 1990. These scenarios were regarded as 'plausible' by the IPCC, but not assigned any probabilities. While recent criticism of the technical basis of these scenarios is being considered by the IPCC, it is likely that future projections will lie in roughly the same range, with values near the middle of the range being more probable.

TAR projections of global average sea level rise by 2100 range from 9 to 88 cm, made up about half by thermal expansion of sea water, about one quarter from melting of glaciers, and a small positive contribution from Greenland ice melt and possibly a negative contribution from snow accumulation over Antarctica. However, the contribution from Antarctica is especially uncertain, with recent events on the Antarctic Peninsula raising the possibility of an earlier positive contribution from the West Antarctic Ice Sheet (WAIS).

The TAR stated that it is likely there will be higher maximum temperatures and heat indices over many land areas, and reduced frequency of low temperatures, including frosts. More intense precipitation events are likely over many mid- to high-latitude land areas. Increased summer continental drying and associated risk of drought are likely in mid-latitudes. Tropical cyclones are projected to become more intense with higher peak winds and rainfall intensities. Other patterns of climate variability, including the El Niño-Southern Oscillation (ENSO), may vary in intensity and frequency, with some climate models suggesting more El Niño-like average conditions, and others no change.

The TAR chapter on radiative forcing (Houghton *et al.*, 2001, Chapter 6) notes several possibly interacting anthropogenic causes for climate change, including increasing greenhouse gas concentrations, the direct and indirect effects of anthropogenic particulates, and stratospheric ozone depletion. Subsequent papers consider the effects on the atmospheric circulation of these various forcings, noting particularly that while aerosol radiative effects are largely confined to the Northern Hemisphere, effects may propagate into the Southern Hemisphere via atmospheric dynamics. They also find that increasing greenhouse gas concentrations and stratospheric ozone depletion may both be contributing to a strengthening of the polar vortex in both hemispheres, with a polewards movement of the mid-latitude westerly winds, and associated effects on regional climates.

Most coupled ocean-atmosphere models suggest a weakening of the convective overturning of the ocean in the North Atlantic and around Antarctica, which would affect ocean circulation and could have significant regional impacts on climate. Conditions setting up such changes may be initiated in the 21st century, but the effects may not become evident until centuries later. The same may be true for melting of the Greenland ice cap and disintegration of the WAIS, both of which could contribute several metres to mean sea level rise over coming centuries. Conditions may also be set for an eventual acceleration of the increase of greenhouse gases in the atmosphere due to the terrestrial biomass changing from a sink to a source of carbon dioxide, a slowing down of absorption of carbon dioxide into the oceans, and possible release of large quantities of methane from crystalline structures (hydrates) on the sea floor.

Some studies suggest that uncertainties about future discount rates mean that the cost of delayed but severe impacts merit greater consideration. Moreover, recent studies by several groups of economists suggest the possibility that such 'catastrophic' impacts, even if their occurrence is uncertain and some time into the future, may dominate any risk analysis of the impacts of climate change.

Time lags in the ocean-atmosphere system mean that climate change, and especially sea level rise, will continue long after stabilisation of greenhouse gas concentrations in the atmosphere. Time lags in socioeconomic systems, while they can be influenced by human decisions, will in general mean that adaptation to the impacts of climate change, and emissions mitigation strategies will take time to implement and would be more costly if they need to be taken rapidly. The longer adaptation and mitigation measures are delayed, the more rapidly they may have to be undertaken later.

Observed Changes in Australian Climate and Ecosystems

Australian average temperatures have risen by 0.7 ºC over the last century, and the warming trend appears to have emerged from the background of natural climate variability in the second half of the 20th century. Rainfall has increased over the last 50 years over north-western Australia, but decreased in the south-west of Western Australia, and in much of south-eastern Australia, especially in winter. The changes are consistent with an observed increase in mean sea level pressure over much of southern Australia in winter. Effects on runoff are potentially serious as evidenced by a 50% drop in water supply to the reservoirs supplying Perth since the 1970s and near-record low water levels in storages in much of south-eastern Australia in 2002–03 due to low rainfall and high temperatures in the south-east since 1996.

Attribution of the rainfall changes is under lively discussion within the scientific community. In the case of the south-west of Western Australia, a combination of natural variability and a trend due to the enhanced greenhouse effect is considered to be the likely cause, although recent papers suggest that stratospheric ozone depletion may also be causing a southward shift of the westerlies and associated rainfall systems. Northern Hemisphere aerosol effects may also have played a part via changes to atmospheric dynamics, but as aerosol lifetimes in the atmosphere are short and precursor sulfur emissions are being curtailed, this effect is probably of diminishing importance. If rainfall decreases are due to anthropogenic effects they may well continue, necessitating "informed adaptation" to a reduced water supply.

It is at least as difficult, with the current state of knowledge, to attribute changes in Australian ecosystems to climate change, as other local causes are possible in many cases. However, a number of observed changes in vegetation, wetlands, terrestrial vertebrates, marine birds and coral reefs are consistent with regional warming trends.

Scenarios for the Australian Region

The Australian region spans the tropics to mid-latitudes and has varied climates and ecosystems, including deserts, rangelands, rainforests, coral reefs and alpine areas. The climate is strongly influenced by the surrounding oceans. The ENSO phenomenon leads to alternations between floods and prolonged droughts, especially in eastern Australia. The region is therefore sensitive to the uncertain but possible change toward a more El Niño-like mean state suggested by the TAR.

Extreme events are a major source of current climate impacts, and changes in extreme events are expected to dominate impacts of climate change. Return periods for heavy rains, floods and storm surges of a given magnitude at particular locations would be reduced by possible increases in intensity of tropical cyclones, mid-latitude storms and heavy rain events. Changes in the location-specific frequency of tropical cyclones could cause either increases or decreases in return periods locally.

Based on the SRES scenarios used by the IPCC, and regional changes in climate simulated by nine climate models, annual average temperatures in Australia are projected to increase by 0.4 to 2.0 °C by 2030, and 1.0 to 6.0 °C by 2070, relative to 1990. There would be associated increases in potential evaporation and heatwaves, and fewer frosts. Warming is expected to be greater inland than near the coast. Projections for changes in annual rainfall suggest changes in the south-west lie in the range of –20% to +5% by 2030, and –60% to +10% by 2070, with changes of –10% to +5% by 2030 and –35% to +10% by 2070 in parts of south-eastern Australia. Projected changes in other parts of northern and eastern Australia show either that there could be an increase or decrease in rainfall at a given locality. When rainfall changes are combined with increases in potential evaporation, a general decrease in available soil moisture is projected across Australia, with droughts likely to become more severe. Most regions would experience an increase in the intensity of heavy rain events.

Before stabilisation of greenhouse gas concentrations at any level greater than the present, the north-south temperature gradient in mid-southern latitudes is expected to increase, strengthening the high-latitude westerlies in the Southern Hemisphere and the associated west-to-east gradient of rainfall across Tasmania in winter. Following stabilisation of greenhouse gas concentrations, these trends would be reversed.

Warming is likely to continue for centuries after stabilisation of greenhouse gas concentrations, but at a slower rate, while sea level would continue to rise almost unabated for many centuries.

The central estimates of the global average warming by 2100 in typical scenarios for the stabilisation of carbon dioxide at concentrations up to 1000 ppm (present concentration is about 370 ppm) lie in the bottom half of the range of warmings for the SRES range of scenarios. Stabilisation at any concentration between 450 and 1000 ppm would thus limit impacts and risks in Australia by 2100, although impacts would still be significant. The higher the stabilised carbon dioxide concentrations, the greater would be the impacts and risks, especially beyond 2100.

Water Supply and Hydrology

Climate variability is a major factor in the Australian economy, principally through the flow-on effects of ENSO-related major droughts on agriculture. Farmers will be increasingly vulnerable if interannual droughts occur more frequently or are more intense in the future. Less secure water supplies would accentuate competition between users and threaten allocations for environmental flows and future economic growth. Adelaide and Perth are the main cities with water supplies that are most vulnerable to climate change. Rising salinity in the Murray River is already of increasing concern for Adelaide. Any increase in flood frequency would adversely affect housing and other aspects of the built environment, such as industry and communication networks in low lying areas.

In some areas, water resources are already stressed and are highly vulnerable, with intense competition for water supply. This is especially so with respect to salinisation and competition for water between agriculture, power generation, urban areas and environmental flows. Increased evaporation and possible decreases of rainfall in many areas would adversely affect water supply, agriculture and the survival and reproduction of key species. Water quality may also be affected due to increased soil erosion following drought, lower flows and higher water temperatures, leading to more eutrophication and algal blooms.

Evidence suggests that the observed warming trend in Australia has already contributed to an increased severity of drought through higher potential evaporation and water demand.

While there are many pressing problems regarding water supply, climate change is likely to add to them, making solutions more difficult. An integrated approach is needed to optimise results.

Ecosystems and Conservation

Australia had been isolated from the rest of the world for millions of years until relatively recent human settlement. Some species are found over quite limited ranges of average climate. These two factors leave many of the region's ecosystems vulnerable to climate change and to invasion by exotic animal and plant species introduced by human activity. This vulnerability has been exacerbated by fragmentation of ecosystems through land-use changes.

Warming of 1 °C would threaten the survival of species currently living near the upper limit of their temperature range, notably in some Australian alpine regions where some species are already near these limits, as well as in the south-west of Western Australia. Other species that have restricted climatic niches and are unable to migrate because of fragmentation of the landscape, soil differences, or topography could become endangered or extinct. Other ecosystems that are particularly threatened by climate change include coral reefs and freshwater wetlands in the coastal zone and inland.

Australia has one of the greatest concentrations of coral reefs in the world. Rising sea level by itself may not be deleterious. However, the combination of sea level rise with other induced stresses—notably, increasing atmospheric carbon dioxide (which leads to a decrease in calcification rates of corals); increasing sea temperatures, leading to coral bleaching; possibly increased riverine outflow events causing low salinity and high pollution; and damage from tropical cyclones—may place much of this resource at risk.

Projections for coral bleaching suggest that serious bleaching events will become more frequent, decreasing the chance of recovery and leading to increasing death of corals. Major bleaching events in 1997–98 and 2002 may be forerunners, with warming trends combining with El Niño events to produce sea surface temperatures above bleaching thresholds.

Agriculture and Forestry

A significant proportion of exports from Australia are agricultural and forestry products—production of which is sensitive to any changes in climate, water availability, carbon dioxide fertilisation, and pests and diseases. Returns from these commodities could be affected by a projected increase in agricultural production in mid- to high-latitude Northern Hemisphere countries and resulting impacts on commodity prices and world trade. Climate change will be only one factor affecting Australian agriculture, but it may exacerbate an already difficult situation, particularly in regard to the availability of water for irrigation.

Agricultural activities are particularly vulnerable to projected regional reductions in rainfall in the south-west and possibly other parts of southern Australia, and are especially threatened by general warming that will increase potential evaporation and water demand. Drought frequency and severity, and consequent stresses on agriculture, are likely to increase in many agricultural regions of Australia. This would be exacerbated by any tendency toward a more El Niño-like average state. Enhanced plant growth and water-use efficiency resulting from carbon dioxide increases may provide initial benefits that offset any negative impacts from climate change, although the balance is expected to become negative with warmings in excess of 2–4 °C and associated rainfall decreases. Thus by the mid to late 21st century net effects on agriculture are likely to be negative.

Fisheries

Australian fisheries are influenced by the extent and location of nutrient upwellings governed by prevailing winds and boundary currents. In addition, ENSO influences recruitment of some fish species and the incidence of toxic algal blooms. There is as yet insufficient knowledge about impacts of climate changes on regional ocean currents and about physical-biological linkages to enable confident predictions of changes in fisheries productivity. The increasing importance of marine aquaculture makes this industry of particular concern, as warming coastal waters may adversely affect production, especially of Atlantic salmon, which are near their high temperature limit in southern Tasmania.

Settlements, Industry, and Human Health

About 80% of Australia's population live within 50 km of the coast. Marked trends to greater population and investment in exposed coastal regions are increasing vulnerability to tropical cyclones and storm surges. Thus, projected increases in tropical cyclone intensity and possible changes in their location-specific frequency, along with sea level rise, would have major impacts—notably, increased storm-surge heights for a given return period. Increased frequency of high-intensity rainfall and fire would increase damages to settlements and infrastructure. The increased risk of exposure to extreme events has strong implications for the insurance industry, with increased premiums possible for clients, insurers and re-insurers, or reduced coverage. This in turn may adversely affect some property values.

Reduced runoff, higher riverine, estuarine and coastal aquifer salinity, and increased algal blooms would exacerbate water supply and water quality problems in some urban areas (notably Perth and Adelaide) and in a number of smaller inland communities. Some small communities with particular dependence on adversely affected agricultural and tourism industries may be threatened.

A greater frequency of extreme events such as floods, fires and high winds may adversely affect the security and continuity of supply of electricity transmission and other communications systems. Higher temperatures will also increase peak demand for electricity for air conditioning, requiring either adaptation to reduce demand or greater installed peak generating capacity.

Tourism would be adversely affected by the death of coral reefs and loss of some freshwater ecosystems, such as Kakadu. The ski industry and dependent communities will need to adapt to reduced natural snow cover.

There is high confidence that projected climate changes will enhance the spread of some disease vectors, thereby increasing the potential for disease outbreaks (e.g. Dengue fever and Ross River virus), despite existing bio-security and health services. Despite the likely spread of the malaria vector, there is unlikely to be increased malaria infection, provided existing bio-security measures are maintained.

Economically and socially disadvantaged groups of people in Australia, especially Aborigines and Torres Strait Islanders, are particularly vulnerable to additional stresses on health and living conditions induced by climate change.

External Issues

The impacts of climate change overseas may affect Australia through trade and commodity prices. Adverse effects on developing countries may increase the dislocation of populations in those countries due to economic and environmental problems, raising issues for Australia's aid program.

Vulnerability

Climate change will add to existing stresses on achievement of sustainable land use and conservation of terrestrial and aquatic biodiversity. These stresses include invasion by exotic animal and plant species; degradation and fragmentation of natural ecosystems through agricultural and urban development; increased fire frequency and intensity; dryland salinisation; removal of forest cover and competition for scarce water resources. Soil erosion from dust storms and water runoff may increase due to more severe droughts, bushfires and loss of vegetative cover, coupled with higher winds and more intense rainfall events. While climate change is just one of many stresses, it may in some cases cause systems to exceed critical management thresholds.

Settlements, industry and infrastructure will be vulnerable to adverse effects of extreme weather events, and particularly to increased heat stress on people and materials.

Major exacerbating problems include rapid population and infrastructure growth in vulnerable coastal areas, inappropriate use of water resources, behavioural barriers, economic disincentives and complex institutional arrangements.

Adaptation

Adaptation to climate change, as a means of maximising gains and minimising losses, is important for Australia, but is relatively little explored at the location-specific level and in a cost-benefit framework. Impacts assessments, to be realistic, must include at least some adaptation. Options include improving water-use efficiency and effective trading mechanisms for water; more appropriate land-use policies; provision of climate information and seasonal forecasts to land users to help them manage for climate variability and change; improved crop cultivars; revised engineering standards and zoning for infrastructure development; and improved bio-security and health services. Such measures often will have other benefits, but they will also have costs and limitations. Systematic exploration of adaptation options, and the need for appropriate foresight where this involves investment, would require more attention to the understanding, interests and motivation of multiple stakeholders.

While Australians are experienced in dealing with climate variability, human-induced climate change is likely to take us outside the range of previous experience, and thus requires new strategies to cope with new situations that cross over previous management thresholds. This will apply especially in relation to the long-term sustainability of industries and resources.

Integrated Assessments

Since climate change is only one of many issues, decision-making needs to consider climate change in conjunction with other issues affecting the same decision strategies. Adaptation to, and mitigation of, climate change are both necessary complementary strategies, so it may be advantageous to consider both in any integrated assessment. Integrated assessments will enable co-benefits and possible clashes of interest to be identified, and the overall least cost and most beneficial strategies to be chosen. This requires wide understanding of natural and human systems, and consultation with stakeholders so that the human element can be included and stakeholders can identify with strategies to be adopted.

Any assessments must take into account uncertainty. This requires that assessments be set in a risk management framework, where risk is seen as the product of the probability of a climatic effect and the consequences of that effect.

Climate change, and our understanding of it, is evolving rapidly in the real world, and on the scientific, technological and policy fronts, so policies and decisions need to be decided on the basis of the best current information, but in the knowledge that they will need to be adjusted with time.

Costing

Comprehensive cross-sectoral estimates of net climate change impact costs for various greenhouse gas emission scenarios, as well as for different societal scenarios, are not yet available. Confidence remains very low in the previously reported estimate in the IPCC TAR for Australia and New Zealand of –1.2 to –3.8% of gross domestic product for an equivalent doubling of carbon dioxide concentrations. This out-of-date estimate did not account for many currently identified effects and adaptations. Costs due to impacts and costs of adaptations will increase with increasing global warming. They will increase even more rapidly as various critical thresholds are reached, such as changes from profit to loss in particular farming enterprises, or riverine and coastal flooding exceeding present planning limits. Potential costs and benefits of climate change need to be balanced against costs and benefits of mitigation in any overall policy response.

A number of overseas studies have emphasised the likely dominance in any realistic global cost-benefit analyses of the impacts of extreme events, the existence of critical thresholds, and the possibility of large-scale changes to the climate system that could have disastrous impacts. The latter high-impact but low-probability and/or long-delayed impacts may dominate cost-benefit analyses due to their magnitude, and uncertainty about appropriate discount rates, which could be low or even negative if there are economic downturns or disasters.

Conclusion

Australia is vulnerable to changes in temperature and precipitation projected for the next 50 to 100 years, because it already has extensive arid and semi-arid areas, relatively high rainfall variability from year to year, and existing pressures on water supply in many areas. In addition, vulnerability arises due to high fire risk, Australian ecosystems sensitive to climate change, and invasion by exotic animal and plant species introduced by human activity. Australia also has a high concentration of population in coastal areas, an economy strongly dependent on world commodity prices, tourism dependent on the health of the Great Barrier Reef and other fragile ecosystems, and economically and socially disadvantaged groups of people. Impacts of climate change will be complex and to some degree uncertain, but increased foresight would enable us to optimise the future through planned adaptation and mitigation. Mitigation can reduce the ultimate extent of climate change and its impacts, but is a global problem requiring cooperative global solutions. Adaptation is essential to cope with unavoidable climate changes, and in this country is essentially a task to be performed by Australians for Australians in each local situation.

Further research is necessary to reduce the uncertainties, better establish probabilities, and identify the most cost-effective adaptation and mitigation options and strategies, which in most cases need to be location- and sector-specific.