CLIMATE CHANGE HEALTH IMPACTS IN AUSTRALIA

EFFECTS OF DRAMATIC CO_2 EMISSION REDUCTIONS

Report for the Australian Conservation Foundation and the Australian Medical Association

Prepared by:

Dr Rosalie Woodruff [1], Dr Simon Hales [2], Dr Colin Butler [1], Prof Anthony McMichael [1]

1. National Centre for Epidemiology and Population Health, The Australian National University

2. Department of Public Health, Wellington School of Medicine, University of Otago, New Zealand

Acknowledgements

This paper was prepared for the Australian Conservation Foundation and the Australian Medical Association by the National Centre for Epidemiology and Population Health (NCEPH) at The Australian National University. The authors of the paper were Drs Rosalie Woodruff and Colin Butler, and Prof Tony McMichael from NCEPH, and Dr Simon Hales from the University of Otago (Wellington, NZ). Contributions to the research of the paper were made by Solen Kerneis, Monika Swasti Winarnita Doxey, and Folkert Boersma.

Thank you to Heather McIntyre for her administrative support. Thanks are also due to Ivan Hanigan (NCEPH) for GIS advice, to Roger Jones (CSIRO Atmospheric Research) for the supply of updated climate data and advice. Gavin Fisher, Tord Kjellstrom, and Jon Barnett gave helpful review comments.

This report has been completed with generous funding support from Perpetual Trustees.

The Australian Conservation Foundation (ACF) is committed to inspiring people to achieve a healthy environment for all Australians. For 40 years it has been a strong voice for the environment, promoting solutions through research, consultation, education and partnerships. ACF works with the community, business and government to protect, restore and sustain our environment.

The Australian Medical Association (AMA) is the peak health advocacy organisation in Australia and exists to advance the professional interests of doctors and the health of the community. The views expressed in this document are those of the authors and do not necessarily represent the views or policies of the AMA.

Executive Summary

Human-induced climate change is a reality. It is clear that human-induced climate change is now occurring, and is largely due to the burning of fossil fuels and consequent greenhouse gas accumulation. By 2100, annual average temperatures are predicted to increase by 1 to 6°C over most of Australia (with significantly larger changes in some regions). This report uses climate scenarios prepared by CSIRO (presented in detail elsewhere), and draws on the international scientific literature.

There is some evidence that climate change is already impacting on human health. These include changes in the occurrence of infectious diseases in some locations (tickborne encephalitis in Sweden and the Czech Republic, cholera outbreaks in Bangladesh, malaria in the east African highlands), and increased mortality during heatwaves (such as the 2003 European summer heatwave).

Future projections of global greenhouse gas emissions and climate change present a grave threat to both natural and human systems. Substantial impacts on plants and animals, and on physical systems, are expected. The projected land degradation, freshwater shortages, biodiversity losses, and extreme weather will impact on human societies and on human health. On balance, these impacts will mostly be negative. It is possible that some thresholds for dangerous levels of climate change have already been exceeded. Several critical thresholds are projected to be reached if global temperature rises 2°C above pre-industrial levels. Potentially dangerous consequences may result from this – such as sudden increases in sea level; or the weakening, even collapse, of the Gulf Stream.

Increasing evidence identifies the crucial importance of substantially and speedily controlling greenhouse emission to diminish the impact that uncontrolled greenhouse gas emission could bring. The carbon dioxide emitted into the atmosphere today will influence climate for a long time into the future (hundreds of years). The speed and severity of climate change can still be reduced by the prompt reduction of greenhouse gas emissions. Such action is likely to reduce the harmful impact on ecosystems and humans. This report examines the effects that dramatic and rapid reductions in greenhouse gas emissions could have on health impacts from climate change in Australia. The future health impacts are estimated under different climate change policy conditions:

- Strong policy action - substantial efforts are made now to reduce greenhouse gas emissions.
- No policy action - two plausible uncontrolled emission scenarios.

The analyses in this report indicate that policy action to control greenhouse gas emissions, if it is taken decisively and soon, will reduce the extent and severity of the climate change impacts on the health of Australians.

1. A policy of rapid and dramatic reductions in greenhouse gas emissions would provide immediate additional health benefits from a reduction in annual deaths due to vehicle-related air pollution. Air pollution from motor vehicles caused an estimated 900-2,000 early deaths in Australia in the year 2000, entailing direct costs of between $1.1 and 2.6 billion (Bureau of Transport and Regional Economics). Policies seeking to reduce greenhouse gas emissions from vehicles (principally carbon dioxide) could plausibly also reduce the pollutants nitrogen dioxide and fine particles – which have an established negative effect on health. We estimated the potential health benefits of a proportionate reduction in air pollution following a 50% reduction in greenhouse gas emissions from road transport:

- This could potentially reduce the number of premature deaths each year from transport-related air pollution by 150-250 per year in each of the Sydney and Melbourne airsheds.
- A 50% reduction in greenhouse gas emissions from road transport is also likely to substantially improve local air quality. Further health benefits would be expected if the reduction in vehicle emissions was achieved, in part, by less reliance on personal cars and greater use of public transport and bicycles (via fewer road accidents, increased fitness levels, and less population overweight and obesity).

2. Heatwaves are expected to increase in frequency and become more intense. At present, around 1,100 people aged over 65 years are estimated to die each year due to high temperatures. We estimated the effect of very hot temperatures and climate change on mortality in this age group living in Australian capital cities.

By 2100:

- If a *strong policy action* approach is adopted, the heat-related mortality could be between 1,700 and 1,900 deaths each year.
- With *no climate change policy* action in the near future, and under a path of high emissions, heat–related deaths could be between 2,600 and 3,200 per year.
- Based on these estimates, strong action to control emissions could reduce the number of heat-related deaths by 135-190%.

The above estimates assume the size of the total population in future remains the same as at present. By 2100 the number of people in the 65+ age group is expected to increase two to five times above current numbers. Taking this into account:

- With no *climate change policy* action the number of heat-related deaths may be 8,000-15,000 each year.

- If a *strong policy action* approach is adopted, the increase in heat-related mortality could be between 4,200 and 8,000 deaths each year.
- *Strong action* to control greenhouse gas emissions could halve the number of heat-related deaths.

Most deaths from thermal stress occur at home or in nursing homes before people can seek medical attention. The extent of population acclimatisation and adaptation (such as passive solar building design, heat-reducing urban planning, use of air-conditioners for high risk groups, intake of fluids, changed work hours, etc) will affect the number of people who die from heat.

3. By constraining greenhouse gases significantly now, the southward spread of Australia's dengue transmission zone could be limited and significantly reduce the population at risk from the disease. The climate of north of Queensland is currently suitable for the establishment of the mosquito-borne viral disease dengue, but the virus is not yet endemic in Australia. Local transmission of dengue, passed by infected travellers, has recently been observed in most years in north-eastern Queensland (Cairns, Townsville, Charters Towers).

By 2100:

- The climate of Australia may support dengue transmission as far south as Sydney, including the population-dense coastal and hinterland strip to the north of Sydney (under the high emissions no policy action scenario).
- With strong climate change policy action the zone of potential dengue transmission is limited to Brisbane.

There are many influences on the distribution and occurrence of dengue, apart from climate. The projected increases in risk described here need not necessarily translate into a higher number of dengue cases. The extent to which the public health burden of dengue remains relatively low in future will depend on continuing the adequate financing of public health infrastructure. If future increases in the dengue transmission zone occur (south down to Brisbane or possibly to Sydney by the end of this century), local governments and public health authorities in newly affected areas would need to divert resources from elsewhere towards prevention and control activities.

4. Climate change is likely to exacerbate poverty, increase migration and may lead to large scale population displacement through the Asia/Pacific region. Many neighbouring nations – not only in the Pacific but in many parts of Asia – are more susceptible than Australia to the adverse impacts of climate change. Projected climate change, combined with population growth and other environmental change, is expected to place serious stresses on many countries, and in some cases may reverse the economic growth that is often forecast.

Even in the best case, the number of displaced people within the Asia-Pacific region is likely to greatly increase this century – perhaps well before 2050. This will have ramifications both for regional population health and also for regional foreign policy, even if most displaced people are internally confined within slums and camps.

The timing and geographic pattern of displaced populations depends critically on the quality of governance and other social and cultural factors which contribute to social and ecological resilience. While substantial uncertainty exists in relation to this prediction, the geographical scale, large population size and complex variety among the peoples of the Asia-Pacific region are so vast that it is implausible that all socio-ecological units will cope well with these forecast stresses. Some countries, such as Cambodia, Papua New Guinea, and small island states appear particularly vulnerable.

As stresses increase there is likely to be a shift towards authoritarian governments. At the worst case, large scale state failure and major conflict may generate hundreds of millions of displaced people in the Asia-Pacific region, a widespread collapse of law, and numerous abuses of human rights.

5. To reduce the future health risks Australia must take adaptive measures at the personal and community level. So far, little research has been conducted in Australia or elsewhere that estimates the cost of the current climate sensitive disease burden, or of health-specific adaptation strategies and costs for climate change. The health costs of a particular disease will be direct (personal and public expenditure on treatment, prevention, and control) and indirect (productive income foregone, losses to tourism, etc). Together these represent the costs the health system incurs in responding to outbreaks or disasters, as well as of avoiding them. In a system with finite resources (such as the health system) additional expenses in these areas would be at the expense of other health issues.

CONTENTS

Introduction

Human-induced climate change is a reality. The stream of evidence published in the scientific literature gives an overall picture of a warming world, and documents the influences of this warming on plant and animal phenology and on physical systems. We understand that climate change is largely attributable to the burning of fossil fuels and consequent greenhouse gas emissions. Land-use change and deforestation also contribute substantially to a net increase in emissions. Natural factors (solar variation, volcanic activity) have contributed only a small component to observed warming (IPCC 2001).

This presents an evolving hazard to human societies, and to human health. The projected amount and rate of warming - and consequent changes in temperature, precipitation, extreme events, snow cover, and sea level - is expected to have impacts on human and natural systems, ranging from beneficial to extremely negative. On balance, impacts are mostly expected to be negative, and include widespread land degradation, local depletion of fisheries, freshwater shortages, and biodiversity losses (Thomas *et al*. 2004). There is now some evidence that climate change is impacting on human health. These include changes in the occurrence of infectious diseases in some locations (tickborne encephalitis in Sweden and the Czech Republic, cholera outbreaks in Bangladesh, malaria in the east African highlands), and increased mortality from heatwaves such as the 2003 European summer heatwave (McMichael, In Press). Humans, by virtue of our ability to buffer ourselves from climatic influences, are likely to be less vulnerable than plants and animals. However, some populations are already at the limits of their resources, and will have extremely limited capacity to adapt to climate change.

Emissions of *greenhouse gases* have a lasting effect on atmospheric composition, and there is a substantial time lag between greenhouse gases emitted today and concentrations of greenhouse gases in the atmosphere that influence global warming (of some 50 to 200 years). Global temperatures and sea levels will continue to rise for hundreds of years, even after greenhouse gas concentrations have stabilised (IPCC 2001; Caldeira *et al*. 2003). Health impacts in the future will be partly determined by the level of greenhouse gases emitted in the present and near-term.

Large and dramatic shifts in Earth's climate from one state to another (abrupt climate change) is now a prospect that is being treated seriously within the scientific and policy communities (IPCC 2001). Crossing thresholds in a non-linear system (such as the climate system) can lead to abrupt, often unexpected, changes (IPCC 2001; Hoerling and Kumar 2003). Although there is not yet international agreement about the level of greenhouse gas stabilisation that is both economically and environmentally prudent to aim for, much scientific literature (Azar and Rodhe 1997; Rial *et al*. 2004) and high-level international symposia have indicated that a 2°C rise above pre-industrial levels should be the upper limit of global warming. It is possible that some thresholds for dangerous anthropogenic interference with the climate system are already exceeded (Mastrandrea and Schneider 2004). Above 2°C several critical thresholds are projected to be reached, with potentially dangerous consequences (such as the subsidence of the Greenland and Antarctic ice shelves, resulting in sudden massive increases in sea level rise; or the weakening, even collapse, of the Gulf Stream).

The speed and amount of warming can still be reduced if the level of global emissions is limited promptly. Future carbon dioxide concentrations would then 'stabilise' at a lower level. If this were to happen, the impact on ecosystems, and human and non-human species, could be lessened. One estimate is that a rapid shift to technologies that do not produce greenhouse gases, combined with carbon sequestration, could save 15-20% of species from extinction (Pounds and

Puschendorf 2004). Another study has found that strong climate policy controls (such as carbon tax) could reduce the probability of dangerous global climate change from around 45% under minimal controls to near zero (Mastrandrea and Schneider 2004). For achieving the 2°C target with a probability of more than 60%, CO_2-equivalent concentrations would need to stabilise below 450 parts per million (ppm) by the end of the century (Hare and Meinshausen 2004). This would require global emissions to peak around 2015. A further delay in the peak of global emissions by 10 years doubles maximum reduction rates to about 5% per year, and very likely leads to high costs (Elzen and Meinshausen 2005).

PROJECT SCOPE

Decisions on greenhouse gas emissions influence global climate over many decades, and impacts on human societies are likely to be increasingly evident over similar time periods. In this case, unlike other risk factors for health, the full implications of policy changes are made clear when the exposure (climate change), and associated effects, are considered over the medium to long-term. This research examines the question:

What projected health impacts from climate change in Australia could be averted if there were dramatic and rapid reductions in global greenhouse gas emissions?

To answer this question, we estimate future health impacts that might result from several different future climate change worlds. The first "future world" is one in which substantial efforts are made in the near-term to reduce greenhouse gas emissions, such that stabilisation of greenhouse gas concentrations at approximately 450 ppm would occur by the year 2100. The second and third "future worlds" represent two plausible "business as usual" scenarios, developed by the Intergovernmental Panel on Climate Change. In these possible futures no specific policy actions to mitigate climate change are taken. For these three emission scenarios we estimate the following health impacts:

1. **Short-term gains:** Potential health benefits of a proportionate reduction in local air pollution following reductions in greenhouse gas emissions from road transport.
2. **Health impacts around 2100:**
   * Annual heat-related mortality in Australian capital cities.
   * Population living in regions with climate suitable for the transmission of dengue.
3. **Impacts on the region around Australia:** Many of Australia's neighbouring nations - not only in the Pacific, but in many parts of Asia - are more vulnerable, environmentally, socially and economically. We consider the consequences of projected climate change on food security and settlements, and on geopolitical stability in the Asia-Pacific region.

Climate change: science and methods

OBSERVED CLIMATE CHANGE

Extensive climatological research over the past two decades has brought strong consensus that there has been unusually rapid climate change (an average 0.6°C rise globally) in recent decades (IPCC 2001). This represents the average, and warming in some regions has been even more profound. Siberia and Alaska have already become 2-3°C warmer since the 1950s (ACIA 2004). Detailed spatial-temporal analysis indicates that most of the warming of the last 50 years is attributable to the rise in atmospheric greenhouse-gas concentration (IPCC 2001). Australia's average temperature rose 0.8°C from 1910-2002, mostly since 1950 (Della-Marta *et al*. 2004). Global sea level is rising due to melting land ice and thermal expansion of oceans (White *et al*. 2005); ice caps are disappearing from many mountain peaks (Thompson *et al*. 2002); and summer-autumn Arctic sea-ice has thinned by up to 40% in recent decades (Rignot *et al*. 2003). There has been a marked, step-like, decline in rainfall in south-west Western Australia since the 1970s, due in part to a latitudinal shift in climatic `cells' that has been attributed to a combination of climate change and natural variability (IOCI 2002).

FUTURE CLIMATE CHANGE

Methods for estimating future climate change

EMISSION SCENARIOS

As greenhouse gas emissions are distributed throughout the atmosphere, future emission scenarios are usually first defined at the global level and then estimated at the country-level at a finer spatial resolution. Future estimates of climate change are made in comparison to a baseline period. A logical baseline would be a climate that has not been affected by any human activities. This is commonly approximated by using the previous World Meteorological Office approved standard period from 1961 to 1990 as the baseline (although the IPCC has recently concluded that climate changes since around 1975 are in part attributable to human actions: (IPCC 2001)). Therefore, this baseline tends to produce conservative estimates of attributable future risk.

For the analyses in this report we use three different scenarios of future plausible climate change: one in which *significant policy action* is taken to mitigate emissions, and two others of a world in which *no policy action* is taken.

The first scenario of future climate change is one where dramatic and rapid policies to reduce emissions are enforced, such that global concentrations stabilise at approximately 450 ppm around 2100. For this to occur, global CO_2 *emissions* would need to peak at 20% above present levels by the year 2010, and then reduce to 38% below present levels by 2050 and to 70% below present levels by 2100. This action would limit global warming to between 1.2 and 2.3°C by 2100 (CSIRO 2004). The emissions scenario used was **"WRE450"**.

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) has also approved four different storylines that describe plausible relationships between the driving forces for greenhouse gas emissions (demographic, social, economic, technological, and environmental developments etc) and the future concentration of gases in atmosphere. The main scenarios are: **A1, A2, B1** and **B2.** In these scenarios, no specific climate initiatives to reduce emissions (such as the Kyoto Protocol) are assumed. This report uses two of these `no policy action' scenarios to represent the plausible higher and lower range of future emissions in a business as usual world. The two scenarios are: **B2** (a low emissions trajectory) and **A2** (a high level of emissions).

AUSTRALIAN CLIMATE PROJECTIONS

General Circulation Models (GCMs) are used to simulate changes in temperature, precipitation and other climate variables at the global scale, using inputs from the SRES or other scenarios about projected greenhouse gas concentrations and other drivers. These models are too coarse to capture factors that influence climate at the Australian scale. We used the OzClim software (jointly developed by International Global Change Institute, University of Waikato and CSIRO Atmospheric Research) to generate climate change scenarios for 2100. OzClim is grid-based, with an array of about 400 points across Australia, producing a grid spacing of about 25 km.

All climate models show an Australia-wide trend towards warming, with some areas warming less quickly than others (particularly Tasmania). There is wide variation, however, among the models regarding the amount of future warming. To represent the variation in available model projections, the analyses used two climate models - the CSIRO Mk2 (developed by CSIRO Atmospheric Research), and ECHAM4 (from the Max Planck Institute for Meteorology, Hamburg). In addition, the dengue modelling also used the GDFL model to provide another estimate of future climate.
As the GFDL temperature projections have not yet passed regional verification tests, the HADCM2 model (from The UK Hadley Centre) was used to provide a third climate projection for the heat-attributable mortality analyses.

Table 2.1 – Projected greenhouse gas (GHG) concentrations and average global temperature increases around 2100 for each of the three scenarios used in Section 4 of this report.

Policy action to limit emissions	Scenario	GHG concentrations	Ave. global temperature increase
Significant	WRE 450	450 ppm (435-480)	1.8°C (1.15-2.7)
None	SRES B2	680 ppm (645-735)	2.7°C (1.75-3.9)
None	SRES A2	875 ppm (825-940)	2.8°C (1.85-3.9)

UNCERTAINTY IN CLIMATE CHANGE ESTIMATES

There are several levels of uncertainty inherent in the process of estimating climate change health risks. Regarding the estimation of the exposure, we still have incomplete knowledge about how the climate system will respond to continuing change in the composition of gases in the atmosphere. Different climate models assume different amounts of sensitivity in the climate sytem to increases in greenhouse gases. In addition, we cannot know, in advance, what social, technological, demographic and behavioural changes will occur in human societies over coming decades. Obviously these will influence the level of greenhouse gases emitted into the atmosphere and the speed of mitigation activities, both of which will determine the concentrations of CO_2 by 2100. For these reasons, there is no greater probability that the central estimate of a series of scenarios will occur. The results should be interpreted as a range of plausible outcomes.

Australian Climate at 2100

By 2030, annual average temperatures are predicted to be 0.4 to 2.0°C higher over most of Australia, with slightly less warming in some coastal areas and Tasmania, and the potential for greater warming in the north-west. By 2100, annual average temperatures are predicted to increase by 1.0 to 6.0°C over most of Australia (Figure 2.1 - central estimates shown only), depending on emission scenario and climate model. Spatial variation is projected to be similar to that for 2030. The range of warming is greatest in spring and least in winter. In the north-west, the greatest potential warming occurs in summer. Rainfall is projected to remain at similar levels in the tropical north, with some increases in the northwest and centre, and continuing decreases in the southwest and east (CSIRO 2001). Where average rainfall increases there would be more extremely wet years, and where average rainfall decreases there would be more droughts. Rainfall extremes may also be amplified by increased short-term variability (IPCC 2001; Milly *et al*. 2002).

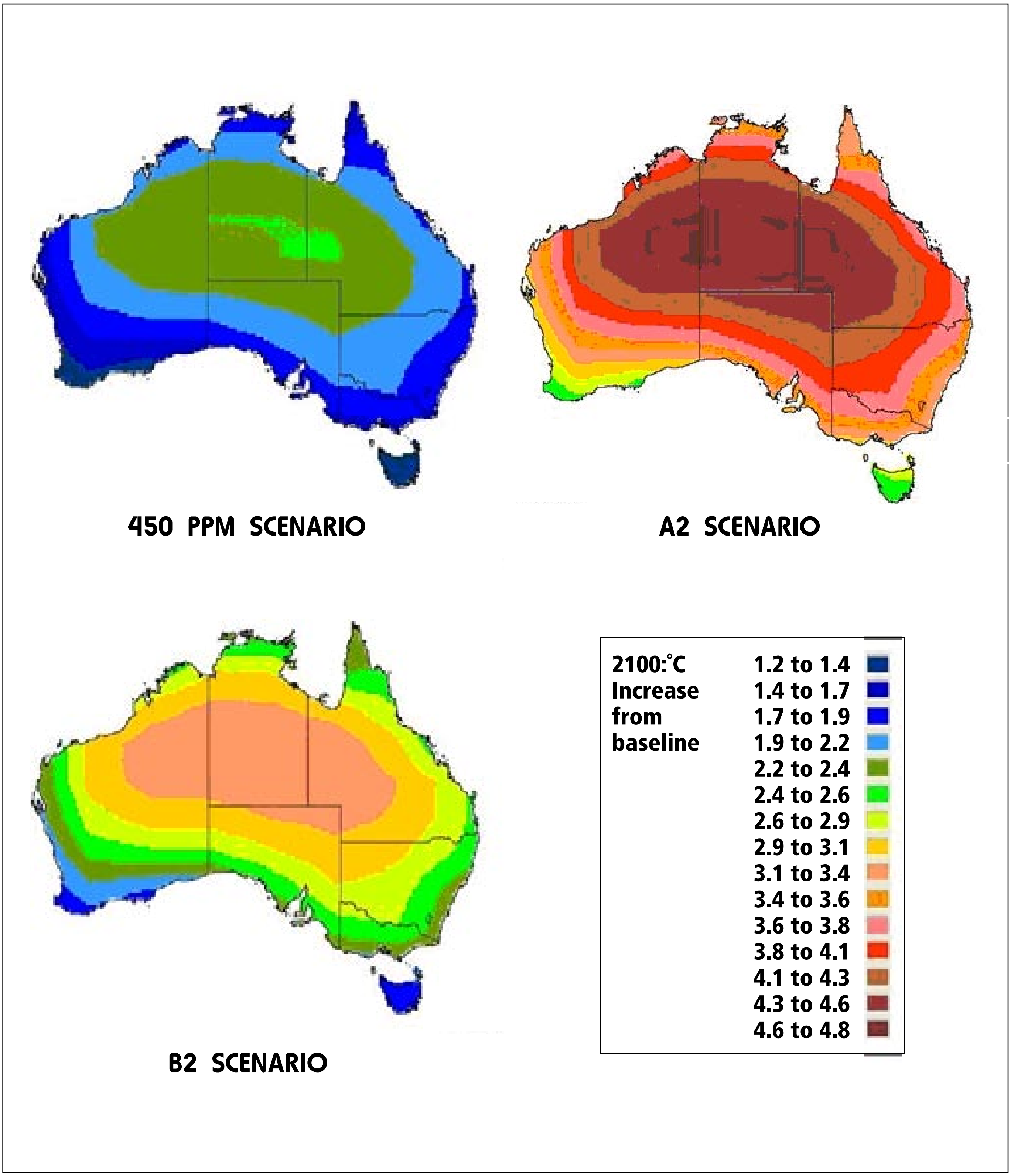


Figure 2.1 Comparison of projected Australian warming around 2100 (CSIROMk2 model), for alternative greenhouse gas emission scenarios: WRE450 (CO_2 stabilised at 450 ppm = strong policy action); and SRES A2 and B2 = no policy action

Short-term health gains

Averted mortality from reductions in vehicle-related nitrogen oxide emissions

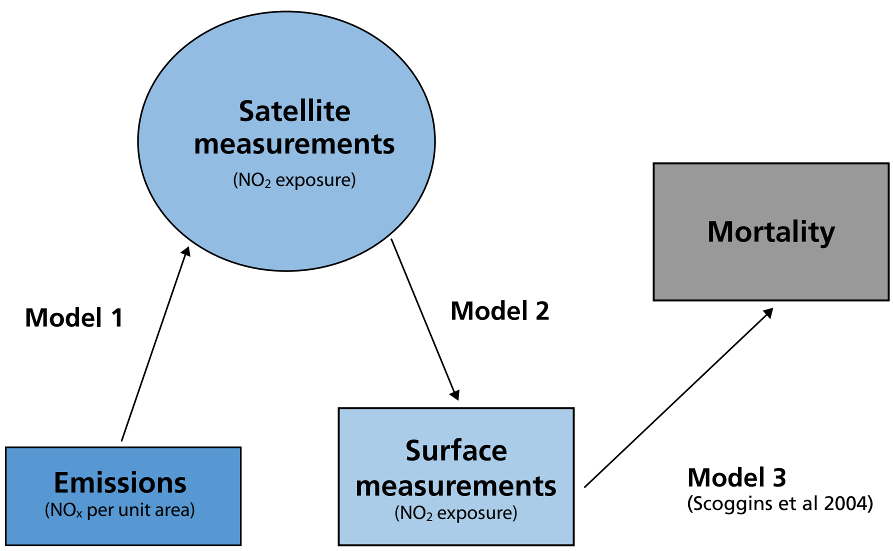
INTRODUCTION

We are interested in the potential health benefit of reducing greenhouse gas emissions from road transport via proportionate reductions in ambient air pollution. Previous analyses have been based on estimates of particulate matter (PM) effects, but models used to estimate changes in PM exposure in response to changes in fossil fuel combustion are complex and not easy to validate. Here we compare measurements from ground-based monitoring stations in Sydney and Melbourne airsheds with remotely-sensed estimates of tropospheric nitrogen dioxide (NO_2). We model the relationship between satellite-derived tropospheric NO_2 and local emissions for the year 2003 from the National Pollutant Inventory.

The Bureau of Transport and Regional Economics estimated that in Australia in the year 2000, ambient air pollution generated by motor vehicles was responsible for between 900 and 2000 early deaths, at an estimated cost of between $1.1 - 2.6 billion (BTRE, 2005). Policies seeking to reduce greenhouse gas emissions from vehicles (principally CO_2) could plausibly also lead to reductions in co-pollutants such as NO_2 and fine particles (Australian Greenhouse Office 2005). However, we do not attempt to quantify the relationship between emissions of CO_2 and co-pollutants here. The results are intended to illustrate the potential scale of mortality reduction attributable to improved air quality, as a co-benefit of greenhouse gas emissions policy. We use the model to forecast the potential reduction in mortality associated with a 50% reduction in vehicle-related emissions.

METHOD

The analysis consisted of several steps, illustrated schematically below.



Emissions of NO_x for Statistical Local Areas

Emissions of NO_x from vehicles (aggregated to airshed level) and from point sources were obtained from the national pollutant inventory (2003-4 data). We estimated vehicle-related emissions by statistical local areas (SLA) as (total vehicle emissions per airshed)*(proportion of airshed population within SLA), and total emissions by SLA as vehicle emissions plus point source emissions, located within SLA boundary. Total emissions per unit area were derived using the geographic area of each SLA.

Satellite measurements of tropospheric NO_2

SCIAMACHY was launched in a Sun-synchronous orbit in March 2002. The instrument alternates between limb and nadir viewing modes and generates global coverage every 6 days. The spatial resolution of nadir viewing scenes (pixels) is generally 30x60 km2. For each pixel, the ratio of Earth radiance and solar irradiance measurements may be used for spectral decomposition in the 426-451 nm band where NO_2 is a moderately optically thin absorber. The tropospheric NO_2 data were available from the website of European Space Agency Tropospheric Emission Monitoring Internet Service (www.temis.nl). Monthly mean values are calculated on a 0.25˚ by 0.25˚ grid by averaging all individual measurements with a cloud radiance fraction <50% (i.e. less than 50% of the light scattered back to the satellite instrument has been reflected from a cloud). Gridding involves weighting individual measurements by their area fraction that falls within a grid cell (Boersma *et al*, 2004). Where more than one retrieval was available for a given grid point, we used the average value at that location. Three surfaces were produced, for January-June, July-December and January-December 2003 (Figure 3.1).

Relationship between observed emissions and satellite-derived NO_2

We regressed satellite-derived tropospheric NO_2 (molecules/cm^2) against the natural log of emissions (kg/km^2) separately for each airshed (Model 1; Table 3.1). Model predictions of tropospheric NO_2 were calculated for a baseline scenario (2003 emissions from the national pollutant inventory) and policy scenario (50% reduction in vehicle emissions). The model producing the lowest estimates of satellite-derived NO_2 (for the Melbourne airshed) was used in subsequent analyses.

Relationship between surface NO_2 measurements and satellite-derived tropospheric NO_2

Annual average NO_2 data for monitoring stations in Sydney and Melbourne airsheds for the year 2003 were used. The locations of the stations were imported into a Geographic Information System (GIS) using latitude and longitude coordinates for each monitoring site. Values of the SCIAMACHY average tropospheric NO_2 for 2003 were extracted for the geographic location of each surface monitoring station. The relationship between surface NO_2 measurements and satellite-derived NO_2 was investigated using linear regression models, run separately for each airshed (Table 3.2; Figure 3.2). The model producing the lowest estimates of surface NO_2 (for the Sydney airshed) was used in subsequent analyses.

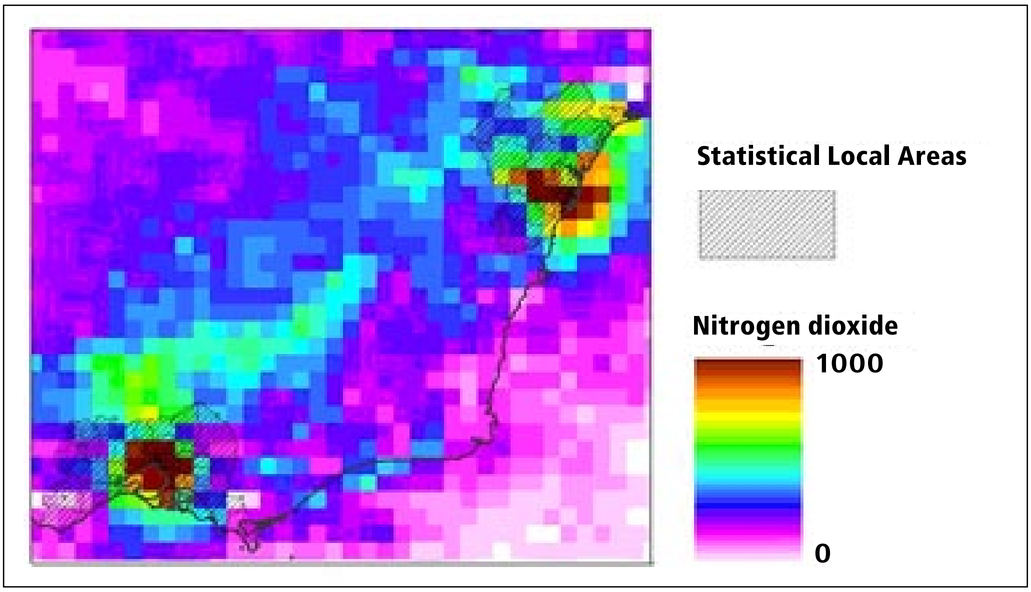


Figure 3.1 Satellite derived tropospheric column NO_2 and statistical local area boundaries for Sydney airshed (upper right) and Melbourne airshed (lower left).

Table 3.1 Model 1: linear regression of SCIAMACHY satellite observations of tropospheric NO_2 with natural log of NO_2 emissions per unit area for the Melbourne airshed Statistical Local Areas (model $R^2 = 0.93$).

Variable	Coefficient	SE	P> |t|	95% CI
ln(emissions)	53	1.41	0.000	50.0 - 56.0

Table 3.2 Model 2: linear regression of surface measurements of NO_2 with the SCIAMACHY satellite observations of tropospheric NO_2 (Melbourne airshed: model $R^2 = 0.97$).

Variable	Coefficient	SE	P> |t|	95% CI
Satellite NO_2	0.0016	0.0001	0.000	0.0014 - 0.0019

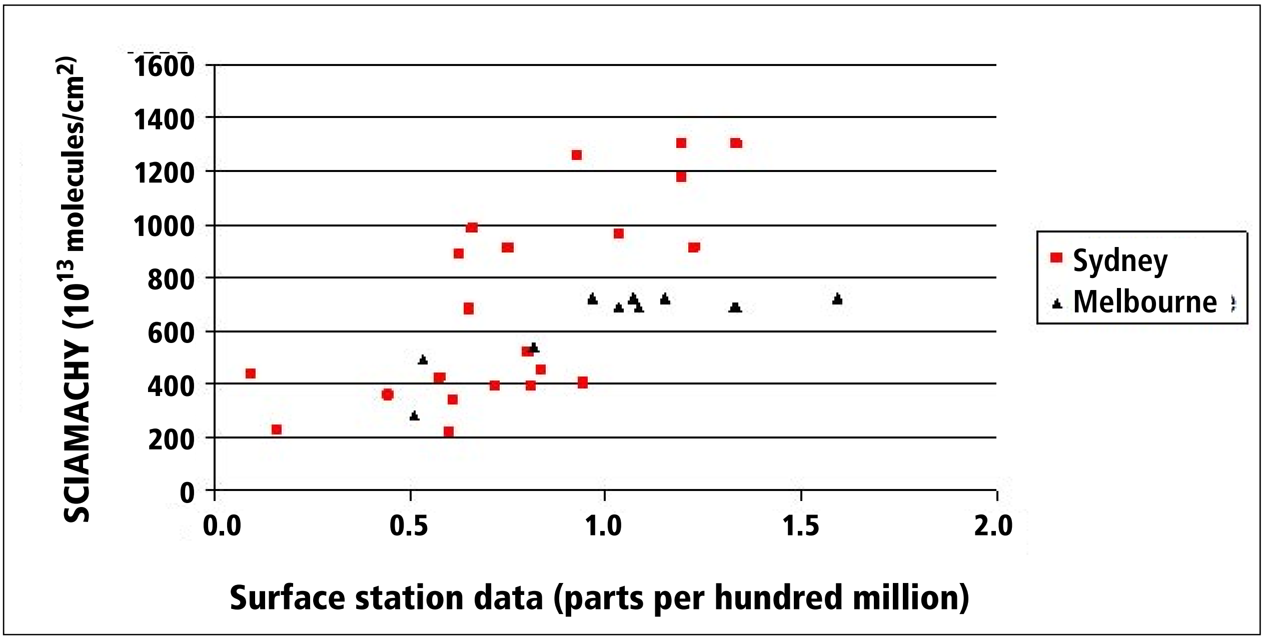


Figure 3.2 Satellite (SCIAMACHY) tropospheric column NO_2 versus surface NO_2 measurements for Sydney and Melbourne airsheds. Annual average values for 2003.

Mortality estimates

We estimated attributable mortality using estimated change in exposure at SLA level, observed mortality from non-external causes and an epidemiologically-derived dose-response relationship for long term NO_2 exposure (Model 3; (Scoggins *et al*. 2004)). In Auckland, there was a 1% - 1.5% change in mortality from non external causes for a 1 $\mu g/m^3$ change in annual average NO_2 exposure (Scoggins *et al*. 2004). Upper and lower estimates of attributable mortality were derived from the upper and lower confidence intervals for the dose-response relationship. Observed mortality was based on 2002 data (the most recent data available).

RESULTS

The spatial pattern of annual average tropospheric NO_2 from the satellite is shown in Figure 3.2. Similar spatial patterns of tropospheric NO_2 concentration were observed in data for January - June and for July - December 2003, suggesting that spatial patterns are reasonably stable (data not shown).

Emission of NO_x per unit area was a good predictor of tropospheric NO_2 within small areas (Model 1; Table 3.1). The remote-sensed data were found to be good predictors of surface NO_2 as measured by monitoring stations (Model 2; Table 3.2). Similar results were obtained using data for each airshed (data not shown).

For each small area, the change in column NO_2 resulting from a 50% reduction in vehicle emissions (estimated from Model 1) was converted to an equivalent change in surface NO_2 (using Model 2). The change in surface NO_2 was converted from parts per million to $\mu g/m^3$ using a standard conversion factor of 0.0005. The change in mortality attributable to the change in surface NO_2 was calculated using the dose-response coefficient for Auckland (Model 3) combined with the observed mortality within each SLA. Within individual SLAs, the attributable mortality reduction ranged from zero to 15 and averaged 2.5 deaths per year per SLA. The attributable mortality reduction at SLA level was aggregated by airshed. There was a 0.5-1% average decrease in mortality, equivalent to approximately 150-250 deaths per year for each of the Sydney and Melbourne airsheds per annum.

CONCLUSIONS

A 50% reduction in vehicle emissions in Sydney and Melbourne airsheds would be expected to lead to substantial improvements in local air quality and corresponding reductions in adverse human health impacts. If the reduction in vehicle emissions were achieved, in part, through a reduction in personal car use, and an increase in public transport and bicycle use, further substantial health benefits would be expected.

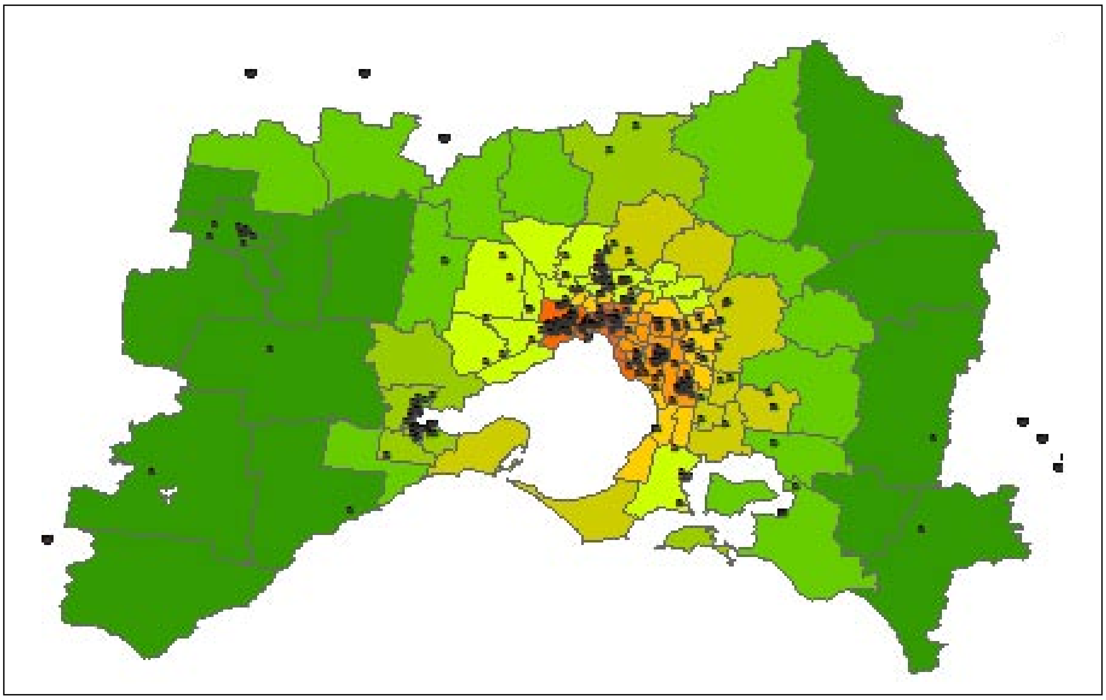


Figure 3.3 Point-sources of NO_2 (triangles) and satellite-derived estimates of ambient NO_2 (colours) for Melbourne area (all SLAs within Melbourne airshed shown).

Health impacts around 2100

HEAT-RELATED MORTALITY

The aim of this analysis is to estimate the effect of climate change on deaths due to thermal extremes. Unlike countries in the northern hemisphere, where much of the temperature-mortality research has been conducted, we have previously estimated that there are very few temperature-related deaths in winter in Australia compared to summer (McMichael *et al*. 2003). Overall, the beneficial effects of climate change in terms of a reduction in annual deaths in Australian capital cities is expected to be very small, although it is likely that there will be benefits in terms of reduced winter morbidity. For this assessment, we estimate the impact of projected temperature increases at the hot end of the spectrum on mortality.

Evidence for a climate relationship

Climate change will bring an increase in the frequency and, probably, the intensity of heatwaves (Meehl and Tebaldi 2004; Schar *et al*. 2004), along with warmer summers and milder winters (IPCC 2001). The record-breaking heatwave of August 2003 in Europe illustrated the vulnerability of people to summer temperatures at the upper end of the average range. Between 22,000 and 35,000 excess deaths occurred in a two-week period (International Federation of Red Cross and Red Crescent Societies 2004).

The relationship between mortality and temperature typically has a reverse "J-shaped" pattern, where the trough represents the comfort zone, the short arm represents the relatively steep mortality increase at hot temperatures, and the long arm shows the increase in mortality with colder temperatures (McMichael *et al*. In Press). The excess deaths that occur during heatwaves are not just deaths of those who would have died anyway in the next few weeks or months due to illness or old age. There is strong evidence that these summer deaths are indeed 'extra' and the result of heat-related conditions alone (UK NHS 2005).

In cool temperate countries, cardiovascular disease shows the strongest temperature mortality relationship, followed by respiratory disease and then "all-cause" mortality. These relationships are supported by physiological evidence for direct links between high and low temperatures and increased blood pressure, viscosity and heart rate for cardiovascular disease (Keatinge *et al* 1984, Pan *et al* 1995) and broncho-constriction for pulmonary disease (Schanning *et al* 1986). This strong epidemiological and physiological evidence linking temperature variations and mortality suggests that the projected increase in global average temperature, accompanied by an expected increase in variability, will increase the number of deaths due to temperature extremes.

In Christchurch, for example, mortality rates have been shown to be lowest on days when the temperature is 12-20°C. Above this range, deaths from all causes increase approximately 1% per degree Celsius (Hales *et al*. 2000). Older people are most at risk of death from both hotter and colder temperatues (McGeehin and Mirabelli 2001; Basu and Samet 2002), and people living in cities are at greater risk than people in non-urban regions (Smoyer *et al*. 2000). This is mainly due to the "urban heat island" phenomenon, where city environments with a lot of concrete and asphalt, and fewer trees, trap and retain heat. This results in higher temperatures (particularly overnight) relative to the surrounding rural areas (McGeehin and Mirabelli 2001).

Methods

We estimated the fraction of annual deaths that could be attributed to hot temperatures in Australian capital cities (at the baseline period, and at 2100 under alternative emission scenarios). We focused on people over the age of 65, as they are at highest risk of dying during hot weather. The physiological functioning of elderly people is less able to compensate for exposures to cold and heat, and consequently they are vulnerable to cardiovascular strain and death (WHO 2004). Older people are also more likely to have a chronic medical condition that upsets the body's normal thermoregulatory mechanism.

ESTIMATING THE BASELINE TEMPERATURE-RELATED MORTALITY

The equation we used for calculating the number of deaths attributable to temperature at the baseline in each city was:

$$A = \{TM_{HOT} * Thresh_{HOT}\} * M$$

where,

A — **Average number of deaths attributable to temperature each year.**

TM_{HOT} — **The percentage increase in deaths for each degree Celsius temperature increase above the hot threshold (the "temperature-mortality relationship").**

$Thresh_{HOT}$ — **The frequency of days in the period where the daily maximum temperature exceeds the hot threshold.**

M — **Mean annual all-cause mortality in the 65+ age group.**

The steps to solving this equation were:

1. Identify the temperature threshold at which mortality from hot temperature commences, and the dose-response relationship for the amount that mortality increases above this threshold.

We used the same temperature-mortality relationship used in a previous Australian assessment (McMichael *et al*. 2003). The method consists of time-series correlations of variations in mortality rates (daily all-cause deaths in people aged over 65 years) and variations in daily maximum temperature, with controlling for confounding factors (such as PM10, a measure of particulate air pollution, seasonal patterns of mortality, and population size). The analyses were conducted in Auckland and Christchurch (both temperate cities). The model showed that temperature-attributable mortality started at 28°C and increased by 3% per degree above that threshold. Our previous research demonstrated that this threshold could be reasonably applied to all Australian capital cities except Darwin (McMichael *et al*. 2003). For that city, we used the temperature-mortality relationship prepared by Rupendra Shrestha. Using the same method, he calculated that attributable daily mortality in people over 65 in Darwin increased by 10% per degree increase in maximum temperature above 34°C.

None of the available models yet account for the plausible contribution of humidity to heat-related deaths, particularly in the northern cities, but possibly in some temperate cities as well. This may mean that deaths in Brisbane in particular are underestimated.

2. Identify the daily maximum temperature distribution for each city, and measure the frequency with which daily temperatures exceed the threshold value.

We used Bureau of Meteorology observations of daily maximum temperature for each city for the years 1990 to 1999 inclusive. The Sydney, Melbourne, Adelaide and Hobart data came from central city weather stations, and data for the other cities came from observations taken at airport stations. In these latter cities, the temperature records are likely to under-estimate the actual temperature due to the "heat-island" effect. Cities – with thermal mass (from buildings and roads) and energy production (from transport and industry) – usually record higher daytime and night-time temperatures relative to outlying suburbs. However, in general a hot day in the outer suburbs will also be a hot day in the city centre, and the variations from day to day recorded at the airport can be assumed to represent the day to day variations in the urban centre (even though these latter will be several degrees higher). For high density city populations, temperature records from the airport can be assumed to give a lower estimate of the true effect of heat on mortality levels.

3. Identify mean annual all-cause mortality figures for each city (for the 65+ age group).

The true number of annual deaths will be more accurately reflected if a time period immediately prior to the assessment is used for the estimate. In this case, we used death records for each city for the period 1997-1999.

ESTIMATING FUTURE TEMPERATURE-RELATED MORTALITY

The equation for calculating the number of deaths attributable to temperature around 2100 in each city is:

$$A = \{TM_{HOT} * Thresh_{HOT}\} * M * P$$

where,

A	**Average number of deaths attributable to temperature each year.**
TM_{HOT}	**The percentage increase in deaths for each degree Celsius temperature increase above the hot threshold (the exposure-mortality relationship).**
$Thresh_{HOT}$	**Frequency of days in future (2100) when the daily maximum temperature is projected to exceed the hot threshold.**
M	**Mean annual all-cause mortality in the 65+ age group during baseline period.**
P	**Estimated proportional change in population size, relative to the baseline.**

The steps to solving this equation were:

1. Identify the temperature threshold at which mortality from hot temperature commences, and the dose-response relationship for the amount that mortality increases above this threshold.

We assumed that the background relationship between mortality and temperature would remain the same in 2100 as in the baseline year.

2. Estimate the distribution of daily maximum temperature values for each city at 2100, and measure the frequency with which daily temperatures exceed the threshold value.

We took the future projected maximum temperature increases for each capital city from the global climate models to estimate distributions of daily temperature values in the future. Table 4.1 shows the projected increase in maximum temperatures by 2100 above the baseline, for alternative scenarios and for each of the capital cities.

3. Identify mean annual all-cause mortality figures for each city (for the 65+ age group).

We assumed that mortality rates due to temperature extremes in future would be the same as at present. That is, we did not account for any adaptive behaviours at the individual or population level that would result in lower levels of mortality for a given temperature. We also did not assume acclimatisation, although this is likely to occur to some extent.

4. Change in population size and structure in the 65+ age group.

The Australian population is expected to increase in size moderately and to age substantially by 2100 (Trewin 2003). This will increase the number of people at risk of death from hot weather. By 2051, there will be a greater proportion of people aged 65 years and over, and a lower proportion of people aged under 15 years than in 2002. The proportion of the population aged 65 years and over will increase from 13% in 2002 to between 29-32% by 2100 (Trewin 2003). Those aged 85 years and over made up 1.4% of the total population at June 2002. The ageing of the population affects the entire age structure of the population. As well as having more people aged over 65 years in 2100 (Trewin 2003), there will also be a greater proportion of people occupying the oldest category (over 85 years) than is currently the case. Those aged 85 years and over made up 1.4% of the total population at June 2002.

Table 4.1 Projected increase (ºCelsius) in annual maximum temperatures around 2100 from the baseline period (1961-1990), by capital city. Alternative greenhouse gas scenarios (stabilisation at 450ppm; SRES A2; SRES B2) and models (CSIROMK2, ECHAM4, HADCM2).

Scenario	Model	Adelaide	Brisbane	Canberra	Darwin	Hobart	Melbourne	Perth	Sydney
450ppm	CSIROMK2	2	2	1.9	1.8	1.4	1.8	1.5	1.7
	ECHAM4	1.4	2	2.1	2.3	1.4	2	1.4	2.1
	HADCM2	1.9	2.2	2.8	2.2	0.8	1.7	2.4	2.6
A2	CSIROMK2	3.9	4.1	3.8	3.6	2.7	3.6	3.1	3.3
	ECHAM4	2.8	3.8	4.2	4.5	2.8	3.8	2.8	4.1
	HADCM2	3.7	4.4	5.4	4.4	1.6	3.3	4.7	5.1
B2	CSIROMK2	2.7	2.8	2.7	2.6	1.9	2.5	2.1	2.3
	ECHAM4	2	2.7	3	3	2	2.7	2	3
	HADCM2	2.6	3.1	3.8	3.1	1.2	2.4	3.4	3.6

This group is projected to represent between 6%–11% of the total population by 2100 (Trewin 2003).

It is likely that the 'heat effect' on the population will be amplified by this change in age structure. However, temperature-mortality relationships are not yet available for sub-populations in the "above 65" age group. Hence it is not possible to accurately estimate the potential interactive effect of increasing temperature and an increasing ageing population. We made some simplifying assumptions about how proportional increases in the older age groups could increase the proportion at risk of heat-related mortality, to indicate the importance that temperature increases due to climate change will have for an ageing population.

Results

BASELINE TEMPERATURE - ATTRIBUTABLE DEATHS

Around 1100 people are estimated to die each year due to temperature in Australian capital cities (Table 4.3). Capital cities in Australia cover a broad range of latitude (from 12ºS to 41ºS) and have much variation in annual climate patterns (Table 4.2). A much higher death rate is modelled in Adelaide and Perth (both in the hot/dry zone) than in other cities, due to the higher frequency with which maximum temperatures above 35 and 40 degrees are recorded. Although these cities have low annual average temperatures, daily maximum temperatures in a typical summer month can fluctuate widely. Hobart and Sydney recorded the lowest rates (20 and 40 per 100,000 respectively).

Table 4.2 Classification of Australian capital city climates into broad zones.

Zone	Climate definition	Study cities in zone	Mean annual temperature (°C) (10^{th}–90th percentile)*
Hot/dry	Average maximum temperature of warmest month above 30°C.	Adelaide	19.5 (15–18)
		Perth	20.5 (15–21)
Warm/humid	Average maximum temperature of warmest month below 30°C, and of coldest month above 18°C.	Brisbane	19.5 (18–21)
		Darwin	28.5 (27–30)
Temperate	Average temperature of warmest month above 10°C, and of coldest month between -3°C and 18°C.	Sydney	19 (15–18)
		Melbourne	13.5 (12–18)
		Canberra	12 (9–15)
		Hobart	10.5 (9–15)

* Source: Bureau of Meteorology (based on climate data 1961-1990).

Table 4.3 Annual temperature-attributable deaths and death rates (from all-causes) in people aged 65 and older in Australian capital cities during the baseline period (1997-1999), and in the year 2100.

	BASELINE		2100	
	Temperature-attributable deaths	Rate/100 000	Rate/100 000 (lower range)	Rate/100 000 (upper range)
Adelaide	200	135	179	281
Brisbane	89	56	130	267
Canberra	14	64	106	234
Darwin	2	69	446	1407
Hobart	5	20	24	41
Melbourne	289	77	112	169
Perth	294	220	287	495
Sydney	176	40	79	239
All Cities	**1069**	**82**	**131**	**246**

TEMPERATURE - ATTRIBUTABLE DEATHS AT 2100

By 2100, the number of deaths due to high temperature for all cities combined is expected to increase by a half to three times the baseline number – depending on which greenhouse gas emissions trajectory is followed (Table 4.4). From the baseline of around 1100, annual deaths could increase to between 1700 and 1900 if the 450ppm scenario was adopted. Under the higher emission scenario of A2, deaths could increase to between 2600 and 3200.

Temperatures will not increase evenly across the country. Depending on the emissions scenario and model, temperatures will increase more substantially in some cities than in others. In general, projections agree that Hobart, followed by Perth, will have the smallest increases in temperatures. Even so, the annual temperature-attributable mortality rate in Perth is estimated to be 495/100 000 by 2100 (more than double present values).

IMPLICATIONS FOR AN AGEING POPULATION

By 2100 the population is predicted to change in total size by -4% (to 18.8 million), +34% (26.4 million), or +92% (37.7 million), depending on Australian Bureau of Statistics population scenarios (Trewin 2003). Regardless of the total size of the population, the proportion of people aged over 65 years is expected to be very similar under the three projection scenarios – increasing from 13% in 2002 to 29-32% around 2100. The proportion of people in this age group, relative to 2002, will therefore increase 2.5 to 4.7 times. It is reasonable to assume that capital cities populations will, in aggregate,

Table 4.4 Australian capital cities: estimated annual number of deaths due to high temperatures in people aged 65 and older at the baseline period (1997-1999), and around 2100 (with different climate scenarios and models).

		All Cities	Adelaide	Brisbane	Canberra	Darwin	Hobart	Melbourne	Perth	Sydney
Baseline deaths		1069	200	89	14	2	5	289	294	176
At 2100										
Scenario	**Model**									
450ppm	CSIROMK2	1711	296	206	23	13	7	428	392	344
	ECHAM4	1748	265	206	25	18	7	445	385	397
	HADCM2	1922	291	222	29	17	6	419	459	478
	RANGE	*1711-1922*	*265-296*	*206-222*	*23-29*	*13-18*	*6-7*	*419-445*	*385-459*	*344-478*
A2	CSIROMK2	2618	417	390	36	32	10	613	515	606
	ECHAM4	2701	344	360	40	43	10	636	491	778
	HADCM2	3207	403	422	51	41	7	578	663	1042
	RANGE	*2618-3207*	*344-417*	*360-422*	*36-51*	*32-41*	*7-10*	*578-636*	*491-663*	*606-1042*
B2	CSIROMK2	2024	338	270	28	21	8	494	436	430
	ECHAM4	2107	296	262	30	25	8	514	428	544
	HADCM2	2390	332	295	36	26	7	484	541	669
	RANGE	*2024-2390*	*296-338*	*262-270*	*28-36*	*21-26*	*7-8*	*484-514*	*428-541*	*430-669*
Policy action		**1700-1900**	265-296	206-222	23-29	13-18	6-7	419-445	385-459	344-478
No action		**2000-3200**	296-417	262-422	28-51	21-41	7-10	484-636	428-663	430-1042

increase by the same proportion as the population of the country as a whole, as these cities comprise the greatest proportion of the population. On this basis, the number of heat-related deaths in people aged 65 years and older is more likely to be in the order of 4 000 to 15 000 each year (see Table 4.5).

Discussion

MAIN SOURCES OF UNCERTAINTY RELATED TO THE MORTALITY ESTIMATES

Temperatures associated with the lowest mortality vary between locations (Keatinge *et al*. 2000; Curriero *et al*. 2002), which suggests that people are able to adapt to climatic conditions. The limits to this adaptative capacity have not been quantified, nor have a wide range of populations been studied. It is likely that the process of population acclimatisation and adaptation (increased use of air conditioners, additional intake of fluids, changed work hours, better insulation and building design etc) will affect the estimate of future deaths due to both heat and cold. The changing pattern of predisposing conditions, such as hypertension, will also affect an individual's vulnerability to heat stress. However, even if people are able to acclimatise to the mean rise in temperature, the expected increase in variability is likely to cause more extreme heatwaves (Stott *et al*. 2004), in which people do not have time to adapt to high temperatures.

ADAPTATION POSSIBILITIES

Some evidence indicates that affluent populations can be partially protected from extremely hot temperatures by the use of air-conditioners (e.g. studies in Chicago (Semenza *et al*. 1996)). Increasing the proportion of the population who have domestic air-conditioning (or other mechanical ventilation units) appears an intuitively simple adaptive strategy for reducing the risk of exposure to heatwaves. Most deaths from thermal stress occur at home or in nursing homes before people can seek medical attention (O'Neill *et al*. 2003; Dhainaut *et al*. 2004). Older people, the sick, and in some situations people with disabilities, are also less able to travel to cooler environments for relief from the heat (such as public spaces). Air-conditioning ownership (at least at the population level) has been identified as protecting people from dying during some heatwaves. But ownership is not always enough to protect people in some situations. High mortality rates have occurred in heatwave-accustomed cities with high levels of both prevention awareness and air-conditioning (Smoyer 1998). Reliance on air-conditioning may have several undesirable consequences. First, such systems can increase exposure to water-breeding bacteria (such as legionella) or aeroallergens if regular maintenance is not undertaken. Second, there are environmental (and by extension of the casual chain, human health) costs incurred in this adaptive strategy, in the form of an increase in energy consumption and the production of greenhouse gases, if the strategy is not selectively used for those at highest risk. Passive cooling techniques for houses should be investigated as a companion strategy for groups at lower risk. As yet the study has not been undertaken that compares the mortality risk during a heatwave of living in a well-designed and constructed naturally ventilated house with an air-conditioned house. Future building design and construction (which will be based on current and near-term building code standards) will occupy a critical niche for adaptation possibilities.

Table 4.5 Projected change in Australian population size and structure around 2100, and effect on the annual number of temperature-related deaths in people over 65 years in capital cities (Australian Bureau of Statistics).

Year	Total Aust. Pop^{n} (million)	People 65+ (million)	Increase 65+ relative to 2002	2100 heat deaths in 65+* 450ppm (low)	A2 (high)
2002	19.7	2.5	–	–	–
2100 (1)	37.7	11.7	4.7	*8 000*	*15 100*
2100 (2)	26.3	7.6	3.1	*5 200*	*9 800*
2100 (3)	18.9	6.1	2.5	*4 200*	*7 800*

* To represent the range of results from the different scenarios and models used, we have taken the lowest number of annual deaths estimated (450ppm scenario, CSIROMK2 climate model) and the highest (A2 scenario, HADCM2 climate model). Future population projections are captured by the Australian Bureau of Statistics scenarios 2100(1), 2100(2), 2100(3). The last two columns are an estimate of future heat-related deaths heat deaths in 2100 (over 65 age group), adjusted for population age and structure at that point.

DENGUE

Introduction

Dengue is the most common arbovirus infection in humans. Humans are the main host of the virus, and dengue viruses are transmitted to humans through the bite of *Aedes* mosquitoes, the most important of which is the predominantly urban species *Ae. aegypti* (WHO 1993). There are four serotypes of the dengue virus. Dengue haemorrhagic fever and dengue shock syndrome are life-threatening complications that are thought to result from a second dengue infection, with a virus different in serotype to that which caused the primary infection (Halstead *et al*. 1970).

Dengue fever is transmitted in Australia by the freshwater breeding mosquito *Ae. aegypti* (Sutherst 1994). The north and central areas of Queensland are considered potentially receptive to the establishment of dengue, but the evidence suggests that the virus is not yet endemic in Australia (Mackenzie *et al*. 1996a). Imported cases are regularly diagnosed in all capital cities. About 4,000 cases of dengue were recorded in the period 1991-2005, approximately 270 cases per year (Communicable Diseases Network Australia 2002). Local transmission following the importation of virus occurs occasionally, and since the 1940s such cases have been confined principally to the northern and eastern parts of Queensland, specifically Cairns, Townsville and Charters Towers (Mackenzie *et al*. 1996). In these cases, infection typically spreads from a traveller via mosquitoes to local residents.

Malaria is another mosquito-borne disease of concern to Australia. However, although both diseases have a human host and a mosquito vector, dengue is more likely to present a greater public health threat to Australia than malaria for several reasons. First, local transmission of dengue now occurs in most years in northern Australia. With the exception of a very few cases (including 10 in Cape Tribulation in 2002, resulting from one parasitaemic individual), locally acquired malaria has not occurred since 1962. Second, there is more potential for dengue outbreaks to spread rapidly within the population. Effective, fast-acting treatments are available for malaria that kill the parasite, and malarious people remain infectious for a much shorter period (no treatments are available that reduce the period of viraemia with dengue). Third, the dengue mosquito *(Ae. aegypti)* prefers to breed in the urban environment and to feed on humans. Prevention of infection requires attention to clearing or treating domestic containers that hold water and to applying mosquito repellents during outbreaks. In contrast, bed nets provide a simple and effective form of protection (the *Anopheles* mosquito does not have the same breeding and biting habits). For these several reasons, the risk of infection and the complexity of prevention and control is higher for dengue than for malaria in Australia.

A complex interplay of social, economic, political, and biophysical factors shape the patterns of mosquito-borne diseases (Daily and Ehrlich 1996). Population and individual-level ability to protect against dengue can be challenged by changes in public health infrastructure and a shift in emphasis from prevention to emergency response (Gubler 1998; Githeko *et al*. 2000). Close geographic regions that share the same climate and weather, but have widely different economic resources, can exhibit significantly different rates of dengue infection (Reiter *et al*. 2003).

Notwithstanding these influences, climate zones broadly determine the distribution of mosquito-borne diseases (Bergquist 2001), and weather is a major determinant of incidence of disease. Rainfall and temperature are crucial for breeding and replication of the virus. Humidity strongly affects mosquito survival, and hence the probability of transmission (Sellers 1980; Reiter 1988; Leake 1998).

Methods

The assessment used an empirical model (Hales *et al*. 2002) to estimate the population living in a region climatically suitable for dengue transmission. This model was developed from a regression of climate parameters with the reported distribution of dengue epidemics around the world (for the period 1975-1996). The climate variable which best predicted dengue epidemics was long-term humidity expressed as average annual vapour pressure (from the baseline climate period of 1961-1990). The output of the model was a number between 0 and 1, representing the estimated probability that one or more epidemics of dengue fever would have occurred in a given location under baseline climate conditions.

Vapour pressure data for Australia (baseline and future) were extracted from the OzClim software at a cell size of 0.25° (approximately 25 km^2). The Hales model was fitted to these data, and resulted in a modelled risk of dengue transmission between zero and one for each grid cell in Australia. These data were imported into a geographic information system. Regions were defined as "at risk" of dengue where the model indicated a greater than 50% probability of transmission. The output – showing regions at risk – was produced in map format.

Results

BASELINE ESTIMATE OF RISK REGION

The model estimates for the current potential dengue risk region include the towns of Broome, Darwin and Katherine in the north (Figure 4.1). On the east coast, the model slightly under-estimates the areas where dengue is reported. A narrow section of the coastline from Townsville to the north of Mackay is highlighted (a large outbreak of dengue occurred in Townsville in 2005). The model estimates for several towns where dengue is known to occur were predicted to be right on the margin of climatic suitability. Cairns had a probability of 0.46, and Townsville of 0.48, where the criterion for suitability was 0.50 (50%).

ESTIMATE OF RISK REGION AROUND 2100

Overall comments

- The **WRE450** scenario shows slightly less southward extension (east and west) and notably less hinterland expansion (particularly on the east coast) of the dengue region than the SRES B2 scenario.
- The **SRES A2** scenario shows substantially greater increases in the southward (east and west) and hinterland expansion of the dengue region than the other two scenarios.
- Under all scenarios there is only a minimal extension of the dengue zone southwards into the Northern Territory from the predicted present day limits.

WRE450 scenario The dengue region moves southeast as far as Rockhampton with the GDFL and CSIRO models, and down to the region of Gympie with the ECHAM model. The possibility of transmission exists as far southwest as Port Hedland under the ECHAM and GDFL models, and down to Carnarvon with the CSIRO model.

SRES B2 scenario The dengue region moves southeast as far as Brisbane with the ECHAM and CSIRO models, and down to the region of Gympie with the GDFL model. The possibility of transmission exists as far southwest as Exmouth under the ECHAM and GDFL models, and down to Denham with the CSIRO model.

SRES A2 scenario The dengue region moves southeast as far as Sydney with the CSIRO model. There are pockets of suitability south to the Lismore region with the GDFL model, and more substantial coastal coverage down to Coffs Harbour with the ECHAM model. The possibility of transmission exists as far southwest as Denham/Carnarvon region under the ECHAM and GDFL models, and down to the Geraldton area with the CSIRO model.

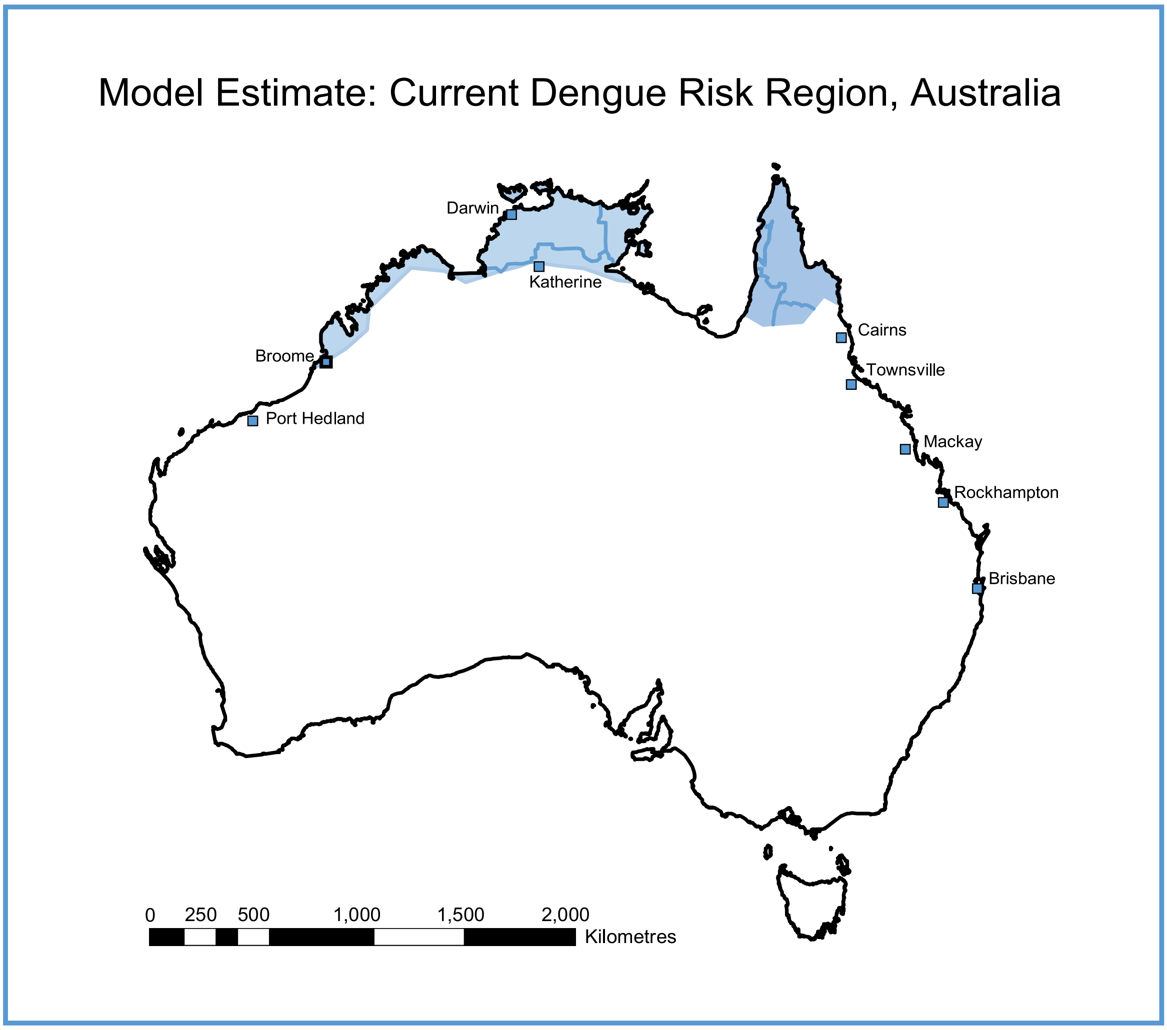


Figure 4.1 Model estimate of the current region suitable for transmission of dengue in Australia, based on the model by Hales (2002).

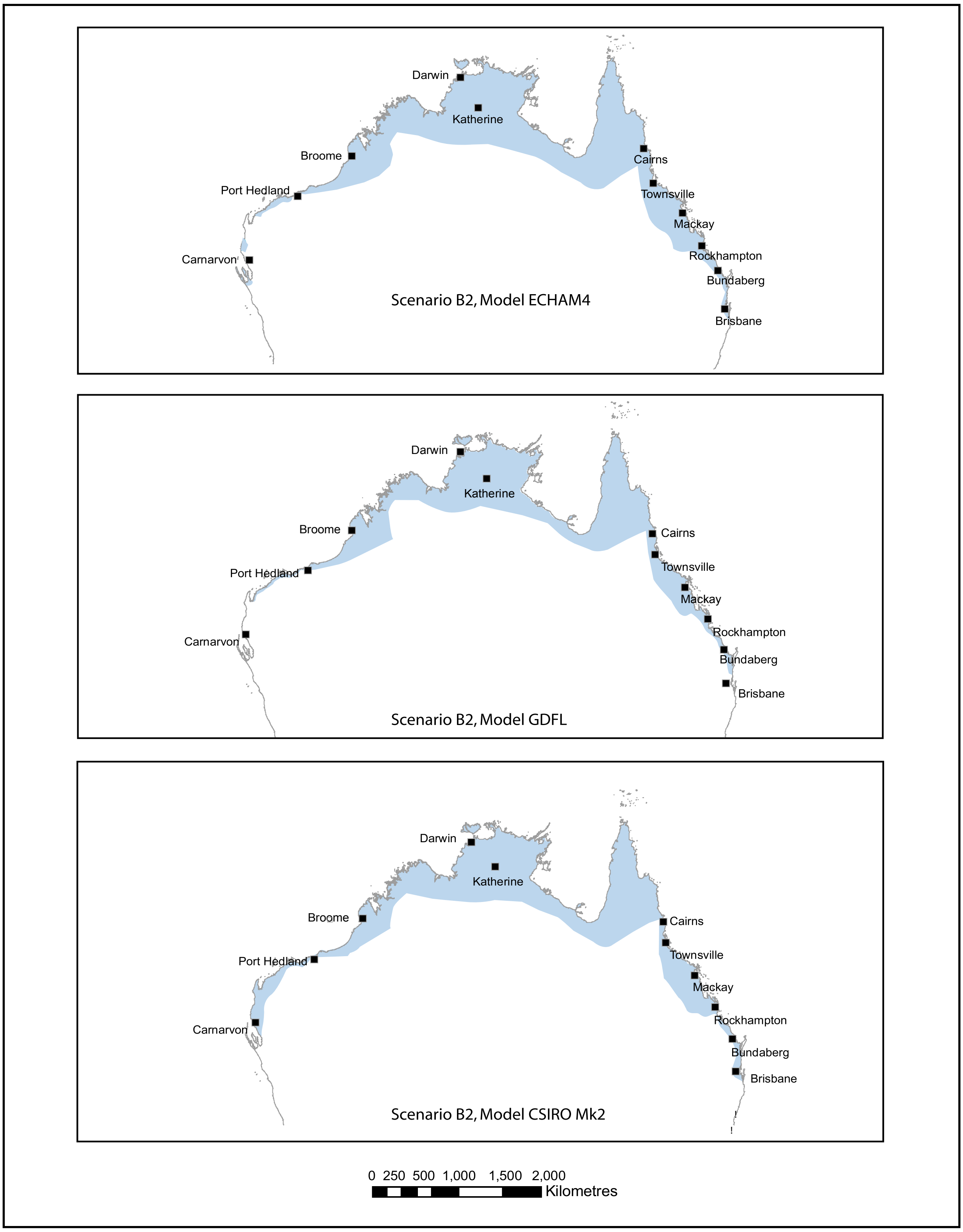


Figure 4.2 Estimated geographic region suitable for the transmission of dengue in 2100: SRES B2 greenhouse gas emission scenario and different climate models.

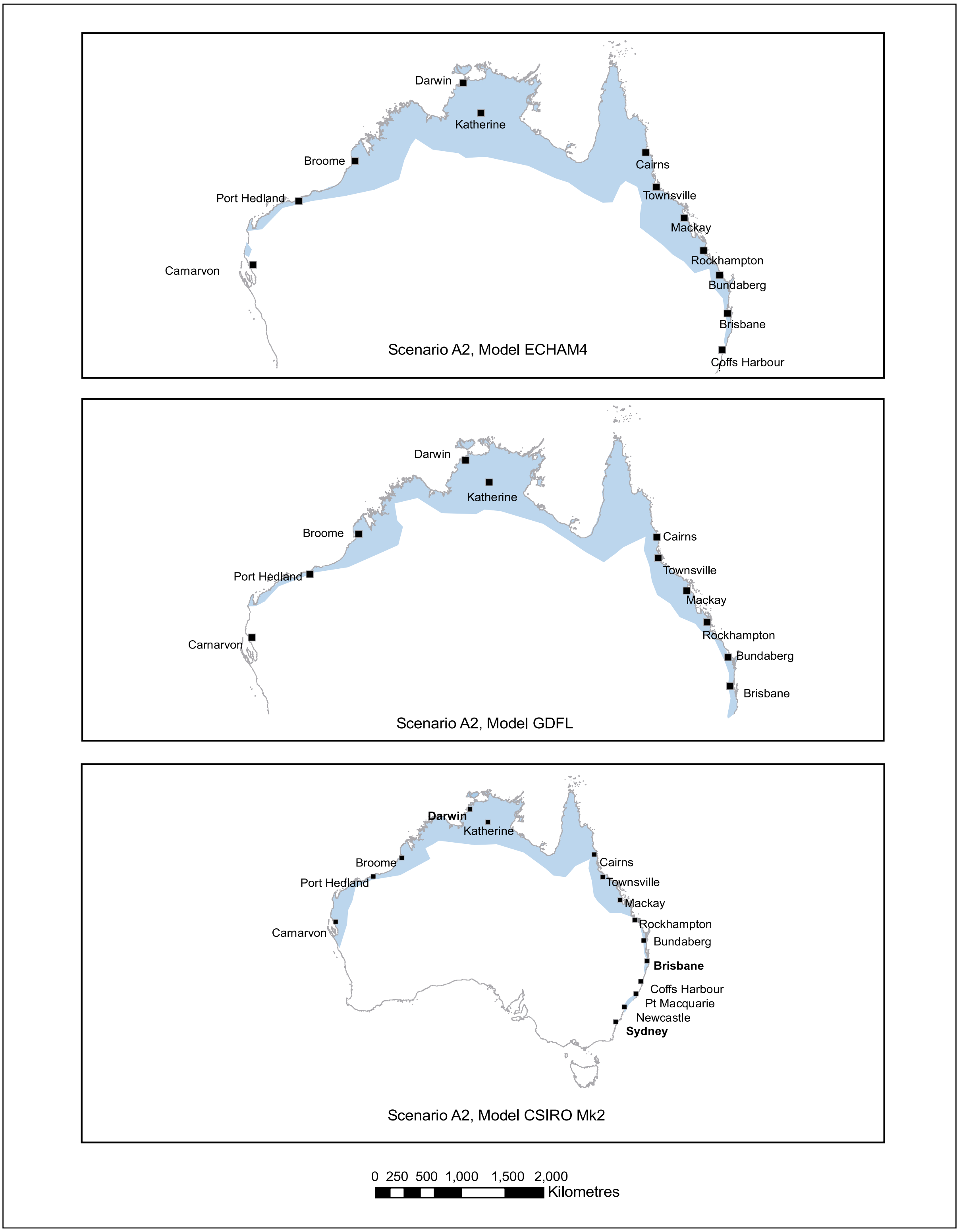


Figure 4.3 Estimated geographic region suitable for the transmission of dengue in 2100: SRES A2 greenhouse gas emission scenario and different climate models.

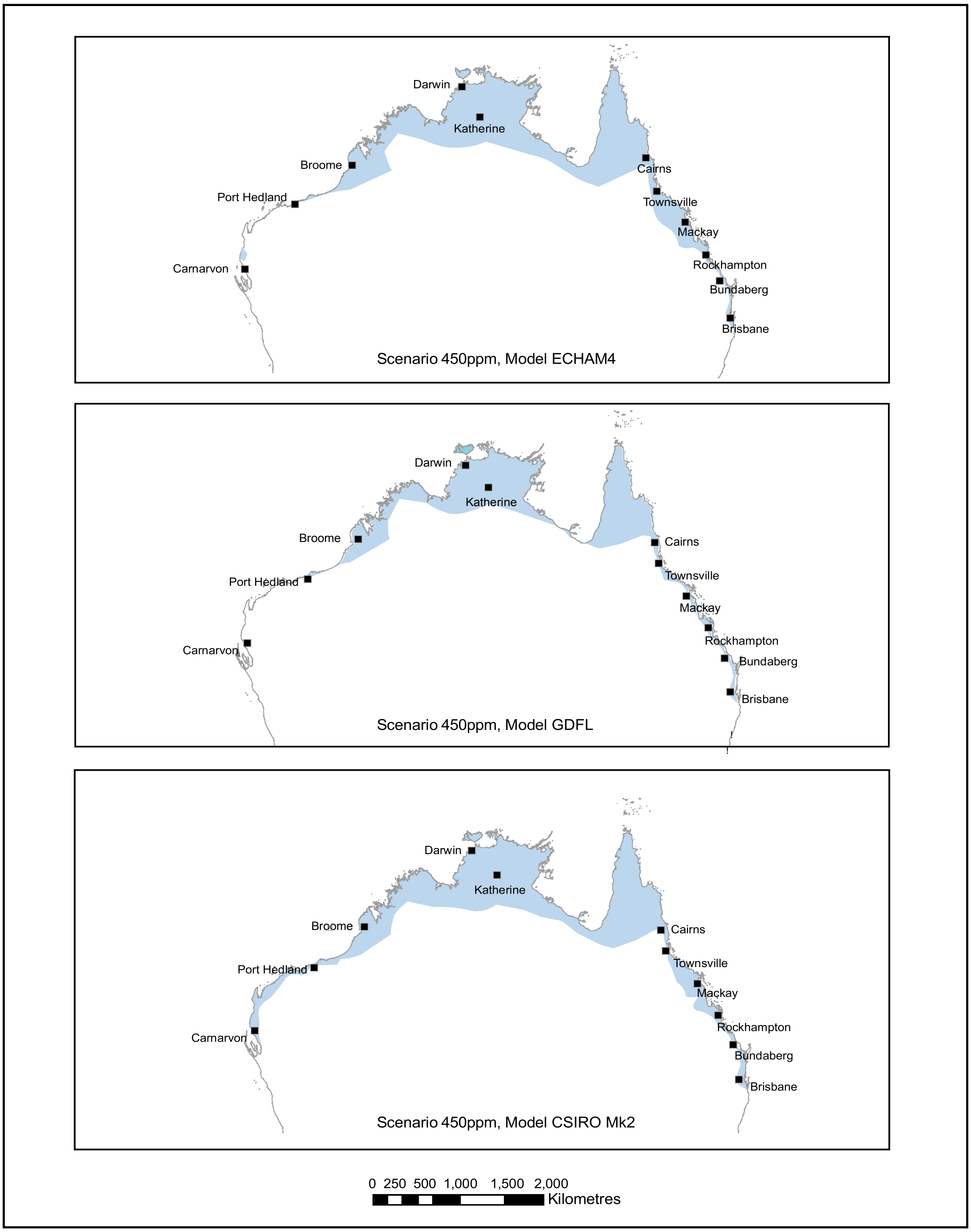


Figure 4.4 Estimated geographic region suitable for the transmission of dengue in 2100: WRE 450 ppm greenhouse gas emission scenario (strong policy action) and different climate models.

Implications

A substantial expansion of the geographic regions suitable for the transmission of dengue is projected to occur by around 2100. The warmer, more humid, world projected to occur under the A2 scenario (high CO_2 emissions), would mean that dengue transmission could be possible as far south as Sydney (including the population dense coastal and hinterland strip up to Brisbane and north of that). Under the lowest strong policy action the likelihood exists that the "dengue risk region" is projected to move far south of its current limits (down to just north of Brisbane).

As noted already, dengue is a disease with many causes – a suitable climate being one necessary factor. The projected increases in risk described here need not necessarily translate into an increase of dengue cases, provided the public health response (i.e. surveillance, prevention and control) continues to expand into new regions, if and when they become suitable for maintenance of the dengue mosquito. This is likely to mean a large extra drain on public health resources. Although outbreaks used to occur infrequently, they are now recorded in most years in Cairns. In 2004, three simultaneous outbreaks occurred in Cairns, and staff and resources were not able to cope as well as they had in previous years (Ritchie, 2004).

The threat of dengue epidemics expanding beyond the current small zone in northern Australia has become more immediately plausible: in June 2005 the "Asian tiger" mosquito *(Aedes albopictus)* was found on at least 10 inhabited islands in the Torres Strait between Australia and Papua New Guinea. This mosquito is more cold tolerant than *Aedes Aegypti*, and represents a significant management issue for Northern Australian ports (given possible entry from overseas in car tyres and freight). In addition, the potential for epidemics of dengue haemorrhagic fever or dengue shock syndrome in North Queensland has increased in recent years, following widespread infection of several populations with dengue type 2. With the increasingly large numbers of tourists that now travel between Australia and countries in Asia and the Pacific (where dengue is endemic) the risk of the introduction of other serotypes also increases (McBride 1999).

Impacts on the region around Australia

INTRODUCTION

Health impacts from climate change in the short-to medium-term in Australia are expected to be less than in surrounding countries (McMichael *et al*. 2003). This relates to Australia's pre-existing higher status of health, economic wealth, and public health infrastructure, and its ability to divert resources from elsewhere in the economy towards climate change adaptation. In contrast, many of Australia's neighbouring nations – not only in the Pacific, but in many parts of Asia – are far more vulnerable, environmentally, socially and economically. Projected climate change, combined with poverty, population growth and other forms of environmental change, is expected to place serious stresses on many populations. Some of these are listed in Table 5.1. An additional, so far under-recognised, possibility is that the cumulative effect of these stresses is a potentially substantial increase in the number of displaced people in the Asia Pacific region. This section discusses some of the health, social and political implications of this situation, both for Australia and for the wider region.

CLIMATE CHANGE AND POPULATION DISPLACEMENT

Human migration can be considered as an interaction of "push" and "pull" factors, which, if high, increase the chance of migration, and "glue" and "fend" factors which have the opposite effect. For most poor people in developing countries, migration (both internal and international) can be the only feasible way to escape poverty, even though migration is never risk free.

Explicit recognition that climate change may substantially increase the size of displaced populations (Myers 1997) and unravel development (Simms *et al*. 2004) is surprisingly recent, given the multitude of plausible pathways which link all but the most benign climate change scenarios to an exacerbation of regional poverty, to possible increased restrictions upon freedom, and to increased migration pressure.

For example, a climate change associated increase in the frequency or severity of extreme weather events (such as droughts, storms, floods and heatwaves) could incrementally and cumulatively harm infrastructure, agriculture and population health, both directly and indirectly. The damage from storms and flooding is likely to be magnified by sea surges in association with the higher sea levels that are inevitable as the oceans warm. Coastal populations, particularly those living on coral atolls (Barnett and Adger 2003) appear particularly vulnerable. This is not only because of rising sea levels and salinated water lenses, but also because of ecological damage to coral (from warmer seas, agricultural runoff, increased dissolved CO_2, and loss of biodiversity). This will harm the regulating ecosystem service which coral currently provides against storm surges, although the vulnerability of coral atolls to increased levels of dissolved CO_2 has recently been questioned (Kench *et al*. 2005).

There is a growing consensus that altered agricultural capacity, increased extreme weather events and a gradual increase in sea level (Meehl *et al*. 2005) will all occur as a result of climate change. It remains possible, though speculative, that an increase in the concentration of CO_2 and other greenhouse gases could precipitate one or more of several major 'tipping points' that would affect the world's geophysical systems, including a truly catastrophic feedback between climatic and ecological change (Cox *et al*. 2000; Gill *et al*. 2002; Stokstad 2004). The occurrence of any of these – such as a collapse of the north Atlantic 'Gulf Stream' circulation, a major weakening in the Asian Monsoon, an expansion of the Sahara Desert or a marked shrinkage of the Greenland or Antarctic ice-sheets (Schellnhuber 2002) – would be devastating, and be likely to greatly magnify the number of people seeking refuge – at least in the absence of extraordinary technological, social and cultural advances. But substantial population displacement does not require "worse case" climate change scenarios.

CLIMATE AND ECOSYSTEM SENSITIVITY

Climate sensitivity is normally defined as the temperature increase that will result from a doubling in the atmospheric concentration of greenhouse gases, compared to their pre-industrial level. For temperature increase this has been estimated to range from 1.5°C to 9°C (Yohe *et al*. 2004). Other forms of climate sensitivity are logical, but poorly characterised in the literature. Many of these sensitivities are relevant to the possibility of population displacement (see Table 5.2). These include the sensitivity of extreme weather events, agricultural capacity, and other ecological and social effects to increasing concentrations of greenhouse gases (O'Brien *et al*. 2004).

Table 5.1 Projected health impacts from climate change in the Asia / Pacific region.

Climate change impact	Vulnerability
Extreme events & pathogen transmission	• Extreme events have increased in temperate and tropical Asia, including floods, droughts, forest fires, and tropical cyclones. • Increased intensity of rainfall would increase flash & riverine flood risks in temperate and tropical Asia. • Increased exposure to heat stress (especially in mega cities). • Vector-borne infectious diseases could expand into northern temperate and arid Asia. Waterborne diseases (e.g. cholera, diarrheal diseases) could become more common in South Asia in a warmer climate – depending on the level of resources.
Food security	• Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise, floods and droughts, and tropical cyclones may diminish food security in many countries of arid, tropical, and temperate Asia. • Crop yields would increase in northern areas, and decrease in lower latitudes. • Some plant diseases would become more widespread. • The gap between grain supply and demand may grow in some regions, increasing reliance on imports.
Human settlements	• Sea-level rise and an increase in the intensity of tropical cyclones could increase flood events for millions of people in low-lying coastal areas of temperate and tropical Asia.
Water availability	• Runoff and water availability may decrease in arid and semi-arid Asia but increase in northern Asia.

[1] This table was compiled from evidence presented in (IPCC 2001)

The socio-ecological response to any degree of climate change can also be conceptualised as exhibiting a range of sensitivity from benign to favourable. For example, both the CO_2 fertilisation effect and reduced frosts could buffer any decreased crop yields due to warmer nocturnal temperatures (Peng *et al*. 2004). The distribution of excessively hot, wet or windy days could promote good harvests, while alternatively, a small change in the total number or the distribution of unfavourable crop-growing days could be disproportionately harmful, for example by leading to soil water-logging (Rosenzweig *et al*. 2002).

The fires that regularly burn across the Indonesian archipelago during the dry season can also be conceptualised as reflecting sensitivity, as can deforestation. Like agriculture, the frequency of fires and the extent of deforestation are a function of interacting human and environmental factors. Climatic and ecological factors (for example more intense droughts, and biodiversity changes) will be either magnified or dampened by human factors, such as the demand for wood products, agricultural land, and roads.

Some sensitivities are likely to be high. It is therefore discomforting that as evidence and scientific understanding accrue, the evidence against comparatively favourable scenarios appears to be strengthening. For example, stronger and more frequent winds and storms have long been predicted by climate modellers to be a part of climate change (Knutson *et al*. 1998), and empirical evidence now supports this (Milly *et al*. 2002; Meusel *et al*. 2004). The projected sea level rises by 2050 remain comparatively low, but concerns of a higher ultimate sea level rise are more credible, as fears increase over the long term stability of the Greenland and Western Antarctic ice shelves (Thomas *et al*. 2004). According to some climate models, extreme warming of up to 11 degrees C is possible this century (Kerr 2005). However, even a warming of 1 to 2 degrees will probably be sufficient to greatly increase the number of displaced people.

CLIMATE CHANGE AND AGRICULTURAL CAPACITY

Among the most obvious climate change related mechanisms that could drive increased poverty, undernutrition, population displacement and conflict (where other co-factors for conflict exist) (Uvin 1996; Barnett 2003; Butler 2005; Butler *et al*. 2005) is a substantial decline in regional agricultural capacity, such as could plausibly occur through an intensification of droughts, or a shift in the range or intensity of the Asian monsoon. While climate change models for regions of the Asia Pacific are limited, there is considerable evidence, from global climate change models which suggests that the distribution of agricultural productivity will be substantially altered by climate change (Parry *et al*. 2004). Such a change could generate strong push and pull factors, stimulating large scale population movement, particularly if, as is plausible from history, human factors such as the redistribution of food stocks or employment (Sen 1981) do not fully compensate for food scarcity in adversely affected areas.

Most climate models forecast comparative or absolute declines in agricultural production in many parts of the Asia-Pacific region, including India, southern China and Indonesia (Fischer *et al*. 2001; Parry *et al*. 2004). These forecasts relate mostly to at least a doubling of pre-industrial CO_2 concentration to 560 ppm. Models account for the carbon dioxide fertilisation effect, but do not adjust for soil quality. It is unlikely that the relationship between greenhouse gas concentrations and agricultural productivity will be linear. However, reduced local agricultural capacity is not necessarily disastrous, because food can still be imported or donated from areas with food surpluses.

It seems unlikely that all socio-ecological units within the vast and varied Asia-Pacific region will cope well with these forecast stresses. Some regions, such as Cambodia, Papua New Guinea and small island states (Simms 2002; Barnett and Adger

Table 5.2 The plausible range (sensitivity) of climatic, ecological and social effects for a doubling of CO_2 concentration.

	SENSITIVITY		
	Least	**Moderate**	**Highest**
CLIMATIC EFFECT			
Temperature	1.5°C	…	9°C
Extreme weather events (droughts, storms, floods)	less than present (background) level	background level (unchanged)	increased
Sea level rise	slight	moderate	substantial
ECOSYSTEM EFFECT			
Agricultural capacity	beneficial	neutral	worse
Fires/deforestation	less	unchanged	more

2003) are particularly vulnerable to all but the most benign climatic and ecological scenarios. The co-existence of high rates of HIV/AIDS in New Guinea, and possibly elsewhere, could also interact with other adverse factors, including climate change, to drive large scale population displacement.

INSTITUTIONS, GOVERNANCE, SOCIAL CAPACITY AND POPULATION DISPLACEMENT

Climatic and other environmental factors are far from being exclusive or even the main drivers of the "push" factors likely to increase population displacement. Many human factors, such as the quality of governance, laws, history, culture, norms and rules which influence human behaviour are also of great importance. These human "institutions" which lubricate and govern social interactions – both influence and are influenced by the underlying geographic, ethnic and distributional landscape of any population (see Figure 5.1) (Adams *et al*. 2003; Butler *et al*. 2005 (in press)).

Poorly characterised feedbacks and interactions complicate these human and environmental factors. A way to conceptualise these complex factors is to consider the "carrying capacity" of societies. (Boserup 1981; Butler 2004). There is no doubt that human carrying capacity has been expanded in most areas by ingenuity and co-operation and, in some cases by a more benign environment. A higher regional carrying capacity is likely to reduce the risk of displacement and out-migration and could, in theory, also be used to accommodate an inflow of people from a population exporting areas. In reality, however, migration (except of people with desired skills) into most such favoured areas is likely to be restricted by strong `fend' factors.

The recent increase in carrying capacity has led some experts to question the reality of environmental limits to human carrying capacity, but there is a growing recognition that ingenuity has expanded, but not abolished these boundaries (Kelley 2001; Butler 2004; Diamond 2005). Any decrease in future human carrying capacity, because of climate change will increase the risk of population displacement.

Magnifying this complexity is that the near term future will be characterised by two modifiers, both of which will increase the stress upon the linked socio-ecological systems in this region. These are an increased human population (multiplied by increased effective demand (Sen 1981) for many kinds of resources) and an environment that will become more stressed due not only to climate change, but to many forms of human-caused ecological and environmental deterioration, such as deforestation, depleted fish stocks, damaged coral reefs, eroded and exhausted soils (Balmford *et al*. 2005). Lower reserves of oil and gas are likely to increase the cost of the myriad goods and services which depend on cheap energy.

SOCIO-ECOLOGICAL RESILIENCE

Another way to conceptualise these issues is to consider the degree of adaptive capacity (O'Brien *et al*. 2004) of various socio-ecological systems. This can be defined as the capacity of a society, linked to its ecological base, to adapt to stresses in ways that enhance or preserve the existing level of human well-being. Populations with higher adaptive capacity are likely to avoid, or at least defer reaching a threshold point beyond which push factors become so great that large scale population displacement is inevitable.

The scientific literature concerning the adaptive capacity of socio-ecological systems is still limited (Gunderson and Holling 2002; Adger *et al*. 2005). However, it is clear that complex, mutually interactive links between the social and environmental elements underpin human well-being (Butler *et al*. 2003). Reduced environmental provision can be partially substituted by social mechanisms, but beyond thresholds (whether of severity, duration or both) a deterioration of environmental amenity will inevitably impair well-being. A particularly harmful manifestation of such a decline in well-being may be the weakening of traditional bonds and tolerance, leading to synergistic declines in the capacity of a given socio-ecological area to supply the components of human well-being (Butler 2004). In such cases poverty, and often inequality, is likely to be worsened. Violent conflict, population displacement, and increased mortality among the most vulnerable groups are commonplace in many developing countries.

Socio-ecological systems with low adaptive capacity risk higher population displacement for any given level of eco-climatic stress. The factors that determine the resilience of any defined socio-ecological system are likely to include many forms of distribution (i.e. not only material, but also the scatter of opportunity, respect, human rights and long-nursed resentment) as well as the composition and strength of ethnic and other forms of group identification. For example, the Balkans, which has a centuries old tradition of conflict between tightly knit groups, appears to have a lower level of socio-ecological resilience than Iceland, where the population is very homogenous. At the same time, social cohesion alone does not guarantee that all environmental challenges can be met. The Nordic population in Greenland, equally homogenous to that of Iceland, collapsed in response to the colder climate during the Little Ice Age (McMichael 2001).

GOVERNANCE, SOCIAL CAPACITY AND POPULATION DISPLACEMENT

Some optimists (few in the scientific literature, but common among mainstream economics) argue that the growth of knowledge, capacity and socio-ecological resilience will outstrip climatic and ecological stresses (Johnson 2001). But it is also possible that social capacity could compensate for a while, as pressures mount, but then decline, after a threshold. Such a scenario might then see an increase in violent conflict, civil war, terrorism, famine or a combination of these. The real question is not whether violence and conflict will continue, but whether they will increase, and the extent to which climate change is a contributory cause.

The quality of present and future governance is a particularly important determinant of future social capacity. Gross corruption is particularly likely to weaken social capacity and resilience, including through its tendency preserve and even enhance inequality, to favour nepotism over merit, and to drive ecological destruction by the conversion of natural capital to more liquid forms (Dauvergne 1997; Jepson *et al*. 2001). Corruption is also likely to divert development resources towards consumption.

However, many indicators of human well-being and human capacity have recently improved in large parts of the Asia Pacific region. Fertility rates have declined, reducing one major source of the projected stress. Finally, the Asia Pacific region is itself part of a global system. Forces outside this region, both beneficial and harmful, will also influence its capability, resilience, and future stress (see Figure 5.1).

ENVIRONMENTAL, ECONOMIC AND POLITICAL REFUGEES

The term "environmental refugee" is credited to El-Hinnawi in 1985 (El-Hinnawi 1985). The concept was further popularized by Norman Myers during the 1990s (Myers 1997). In a paper published in 1997 based on an extensive consultative process, Myers argued that there were at least 25 million environmental refugees worldwide – more than the number of "traditional" refugees. Myers predicted that this number could double by 2010, and that the number of refugees from climate change could eventually exceed 200 million.

A continuum is likely to exist between displaced populations that are of "purely" environmental origin (such as people fleeing the immediate vicinity of the Chernobyl nuclear reactor following its explosion in 1984) and refugees whose causation may appear to have little to do with environmental factors (such as military conscripts seeking to avoid the draft). But the great majority of "traditional" refugees, especially when occurring in large groups, are likely to have a significant ecological element in their causation. As Peter Uvin writes: "Ecological, economic, and political processes do not form separate spheres in reality … Fundamentally, political conflicts rest on an environmental and economic substratum" (Uvin 1996).

In many cases the contributory ecological causal component in the generation of displaced populations is obscured, possibly intentionally. That ecological and environmental factors (such as oil scarcity) are rarely explicitly acknowledged as important factors in either the genesis or fate of displaced populations is unsurprising at a time when a substantial section of the dominant economic, social and political milieu continues to discount and even to occasionally ridicule (Anonymous 1997) the reality and proximity of "Limits to Growth".

GOVERNANCE, ECO-CLIMATIC SENSITIVITY AND POPULATION DISPLACEMENT

The chance of population displacement is likely to vary as a function of eco-climatic sensitivity and governance. Proactive eco-climatic policies (eg vigorous efforts to reduce poverty internationally and the ecological footprint domestically) are likely to create the lowest eco-climatic stress. These policies will also aim to improve institutions, including honouring and reviving many forms of traditional knowledge, and to improve socio-ecological resilience (Folke 2004). These policies, even if successful (for example if facilitated by major technological breakthroughs, and widespread public support and co-operation) do not guarantee a low level of displacement. If eco-climatic sensitivity proves to be high then many critical thresholds are still likely to be reached, leading to high levels of population displacement (cell 3 in Table 5.3). In turn, this is likely to drive more authoritarianism, particularly if substantial inequalities remain.

A second possibility is that governments could pursue policies aimed at reducing global poverty (particularly through trade liberalisation) but with little attention to eco-climatic issues, except reactively, in response to various crises. This scenario is thus similar to the "Global Orchestration" scenario developed by the Millennium Ecosystem Assessment, which concluded this was the most promising way to improve human well-being (Butler *et al*. 2005 (in press)). Even if eco-climate sensitivity is low, higher levels of population displacement are likely because of the greater eco-climatic stress imposed by the reactive policies in this scenario (cell 4 in Table 5.3). Because of its assumption that environmental amenity will be left to market forces greenhouse gas emissions will peak at a much higher level in this scenario. If sensitivity proves high then much higher levels of population displacement are likely, and the scenario is likely to transform to either collapse or an "authoritarian fortress".

A third possibility is that governments will react to eco-climate stress by trying to impose ever-stricter environmental protection and strict rationing of ecosystem services. This can be characterised as "proactive authoritarian". It is unlikely that this kind of governance will be supported until far higher levels of eco-climatic stress are evident than at present, evolving from cells 3, 6, or 12 in Table 5.3.

The least promising form of governance can be characterised as "reactive authoritarian". This leaves market forces to determine environmental amenity and the level of poverty and governance in developed and developing countries. This scenario – which appears closest to the current state – has the highest level of population displacement for any eco-climatic sensitivity, and is likely to generate the highest levels of eco-climatic stress. In this scenario, most displaced people will initially either struggle for existence in huge slums (Davis 2004) or be confined to camps (Table 5.3). At some stage a transformation to proactive eco-climatic policies is likely (to cell 9), but if the climate sensitivity is sufficiently high then even desperate measures may be unlikely to prevent widespread civilisation failure and collapse (Butler 2000).

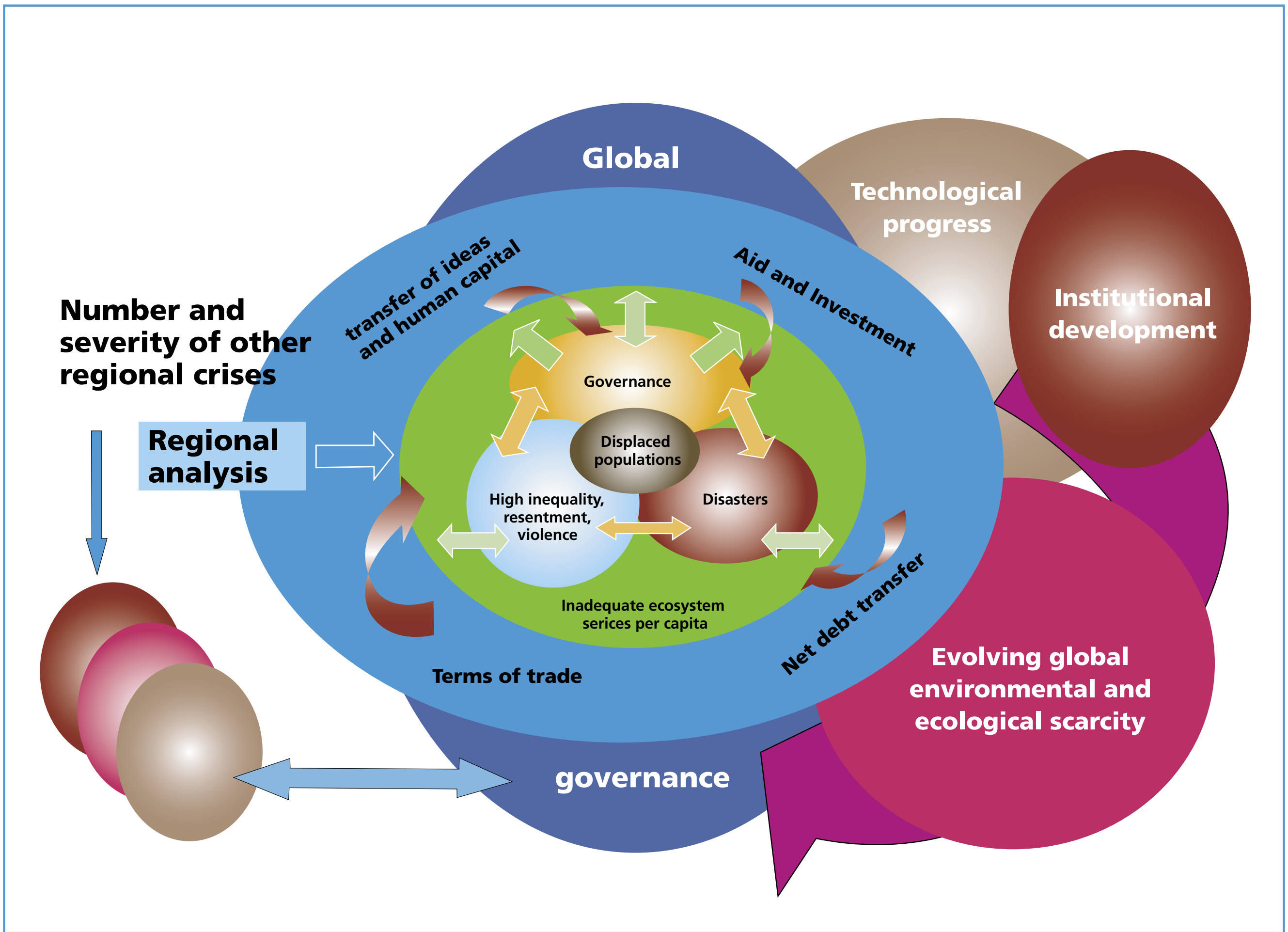


Figure 5.1 Many human factors, including the quality of governance, laws, rules and norms which influence human behaviour modify the likelihood of large populations displacements. These human "institutions" interact with the underlying environmental, cultural, ethnic and distributional landscape. No region is independent of global factors. More than one regional crisis may occur simultaneously.

IMPLICATIONS FOR AUSTRALIA

The degree of apparent indifference to these issues in Australia may seem incomprehensible. Two possible explanations are offered. One is that Australian policy makers sincerely believe that the best way to generate universal prosperity is to continually expand the ecological footprint, and to leave the provision of public goods (including security, peace, health, Third World development and a favourable environment) to market forces. The second explanation is more unsettling. A serious contemplation of the scenarios discussed in this paper opens a Pandora's Box full of risk and uncertainty, including – perhaps – the spectre of millions of boat people assailing an increasingly aged, indebted, and inward looking population. Such a prospect is very difficult, politically, to discuss, in Australia. This is unsettling because it is likely to generate the longest paralysis of policy, with a steady erosion of the resources, and especially the time, needed to act effectively.

Even in the best case, the number of displaced people within the Asia-Pacific region is likely to increase by hundreds of thousands of people, most of whom will be internally confined within slums and camps. Recent Australian history suggests that even this modest level of increased instability implied by this scenario is likely to drive a higher "fend" factor than has so far occurred. Alliances with powerful friends, be they Chinese or American, are likely to be sought and strengthened, as an attempt to buy insurance.

Such a policy may, however, paradoxically increase the risk of adverse scenarios (including those which are truly catastrophic). Security and military strategies may be affordable and successful in the short run. In the long run, strategies which aim to dramatically accelerate the sustainability transition, through a combination of new technology, reduced consumption, and poverty relief which slows population growth, are likely to be much more successful. The Australian government's recent interventions in both the Solomon Islands and Papua New Guinea suggest a dawning comprehension that "prevention is better than cure", but these efforts, in comparison to what is needed, are like splashing a bucket of water on a bushfire. Replacing the war on terror with a rejuvenated war on want still appears a pipedream, as does a rapid energy transition. If a "coalition of the giving" between Australia, China, India, and the G-8 could combine forces in an effort to genuinely reduce greenhouse gas emissions then the future could again be promising.

Table 5.3 The risk of population displacement (PD) is an interaction between social, climatic and ecosystemic scenarios. (Numbers in brackets refer to cell numbers refered to in text; number of + refer to magnitude of population displacement).

	Governance			
	Progressive		**Authoritarian**	
Ecological sensitivity	Ecologically proactive	Ecologically reactive	Ecologically proactive	Ecologically reactive
Low	least PD (1)	++ (4)	Unlikely (7)	+++ (10)
Moderate	++ (2)	+++ (5)	+++ (8)	+++++ (11)
High	+++ (3)	++++++ (6)	++++ (9)	++++++ (12)

CONCLUSION

Most wealthy, urbanised populations are currently protected from ecological scarcity because of the buffer enabled by their greater financial capacity to import ecological resources. In contrast, poor urbanised populations are highly vulnerable to adverse environmental and ecological circumstances, including extreme weather events (if living in flimsy housing, or in flood prone areas), food shortages consequent to drought, flooding and other climate change related mechanisms, and in the future, to sea level rise. Such constraints are likely to exacerbate poverty, increase migration and may lead to large scale population displacement.

A substantial increase in atmospheric greenhouse gas concentrations is likely in the next 50 years. Continued eco-climatic change is also inevitable in coming decades, though its impact will depend on the sensitivity of various natural and human systems.

The temporal and spatial pattern of displaced populations in the Asia Pacific depend critically on the quality of governance and other social and cultural factors which contribute to socio-ecological resilience. The size, population and complex variety of the people of the Asia-Pacific region mean that it is implausible that all socio-ecological units will cope well with these stresses. Some countries, such as Cambodia, Papua New Guinea and small island states are particularly vulnerable to all but the most benign climatic and ecological scenarios, as are many poor sub-populations in larger countries.

As stresses increase there is likely to be a shift towards authoritarian governments. Although this will reduce freedom, it could, at the best case, reduce population displacement, if rationing and other means are used to fairly distribute the more limited pool of resources. At the worst case large scale state failure and major conflict may generate hundreds of millions of displaced people in the Asia Pacific region, a widespread collapse of law, and numerous abuses of human rights. This scenario may seem overly pessimistic, but is more plausible than the optimistic counter view, which is that population displacement, conflict and poverty will steadily diminish in the Asia Pacific throughout this century.

The risk of climate change was described by the UK chief scientist as “worse than terrorism” (May 2005). In fact, climate change, poverty, and ecological damage could combine to exacerbate terrorism, and hasten civilisation failure, or even global collapse.

The costs of avoiding health impacts

Recognition that Australia's climate will continue to change is now focusing attention on the range of adaptive strategies that will be needed in future (Pittock 2003). To reduce the future health risks (such as mortality from heatwaves or dengue fever, described in this report) Australia must take adaptive measures at the personal and community level. Some of these will be planned (by governments, health institutions, etc) and are likely to involve recurrent annual expenditures, such as expanded surveillance and control programs for infectious diseases and their vectors. Others will be spontaneous or deliberate modifications of personal, family and community lifestyles. Recent trends in regional climate have already triggered some adaptive responses. For example, the State Government of Western Australia has recognised that the rainfall decline evident over the past quarter-century will continue, and plans to spend over $300 million on desalination in 2005-06 to secure Perth's future water supplies (Water Corporation 2005).

It is standard to consider the health costs of a particular disease in terms of direct costs (personal and public expenditure on treatment and prevention, or the cost of a life lost) and indirect costs (productive foregone income, longer-term losses to tourism, etc). Together these represent the costs the health system incurs in responding to outbreaks or disasters, as well as of avoiding them. In a system with finite resources (such as the health system) additional expenses in these areas would be at the expense of other health issues. In addition to these health system costs, there are a range of lifestyle changes that will be necessary for protection from the anticipated health risks. These changes (some of which are outlined in Table 6.1) are less easy to value, but nonetheless represent an important component of the broad health costs of climate change.

So far, little research has been conducted in Australia or elsewhere that estimates the cost of the current climate sensitive disease burden, or of health-specific adaptation strategies and costs for climate change. Some approximate estimations have been published of the impacts on national economies of major mosquito-borne disease outbreaks, such as might occur under anticipated climate change conditions (McMichael and Githeko 2001). A dengue fever epidemic in Thailand in 1994 cost in the range of US$19-51 million (Sornmani and Okanurak 1995). In Puerto Rico, mosquito control measures during a large epidemic of dengue comprised about 8-20% of the total cost of the outbreak (Von Allmen *et al*. 1979). In northern Queensland the direct costs of dengue surveillance and control in 2001 were in the order of $300-400,000 for a population of several hundred thousand people (McMichael *et al*. 2003). Other dengue activities that were not estimated include hospital and general practitioner attendance, treatment, pathology, time off work, and quarantine charges. The extent to which the public health burden of dengue remains relatively low in future will depend on continuing the adequate financing of public health infrastructure in currently affected regions. If future increases in the dengue transmission zone occur (south down to Brisbane or possibly to Sydney by the end of this century, Section 4), local governments and public health authorities in newly affected areas would need to divert resources from elsewhere towards prevention and control activities.

The projections of future increases in heatwave mortality were made assuming that health system and social responses would be the same as at present. The severity and frequency of heatwaves is projected to increase in future under all scenarios, although more so under the no policy scenarios. Whether these conditions translate into higher heat-attributable deaths will depend on a range of adaptive factors including the health system response (e.g. the development of heat early warning systems), identifying and supporting high risk groups in the community during events, changes to the built environment (e.g. to the Australian Building Code, housing design and urban planning), and to lifestyle.

Table 6.1 Indicative direct and indirect health cost items and broader social options for adaptation to reduce the impact of heatwaves and dengue transmission.

Health issue	Direct Cost Items	Indirect Cost Items	Social Adaptation Options
Dengue	• Medical care, disease treatment, laboratory costs • Personal prevention and mosquito control; community education; quarantine services to avoid establishment of vector species	• Losses in tourism	• More communities on dengue prevention alert • Changed water storage practices • Change housing design (screening windows)
Heatwaves	• Loss of life (esp. elderly) • Possible increases in workplace accidents and heat stroke	• Productive work time reduced • Development of heat early warning systems	• Changes in building guidelines, housing construction and design (to passive solar) • Urban planning to reduce heat island effect • Altered lifestyle (more time spent indoors in summer) – impacts on exercise? • Changed work times for certain industries over summer months

Conclusions

Future projections of unabated global greenhouse gas emissions for the medium-term, and of the climate change these would cause over the next 100 years and beyond, present a grave threat to both natural and human systems. Increasing evidence identifies the crucial importance of substantially and speedily mitigating greenhouse emissions to diminish the impacts that the present emissions trajectory could bring.

The analyses show that rapid and dramatic reductions in greenhouse gas emissions would provide immediate ancillary health benefits from a reduction in annual deaths due to vehicle-related air pollution, but these benefits cannot be gained unless policies to achieve this are implemented.

In the longer-term (around 2100), increases in health impacts due to climate change above the present levels are estimated under all policy scenarios. Some amount of adaptation will be required to respond to the projected increases in heatwave frequency and intensity, and in the expanded zone of dengue transmission, regardless of the near-term actions taken. However, mitigatory policy actions could reduce the increase in the annual number of heat-attributable deaths – 4,600-7,800 fewer deaths per year (depending on the size of future population increases). Similarly, the region suitable for dengue transmission might expand as far south as Sydney under one scenario of no policy action. By constraining greenhouse gases significantly now, this transmission zone may move just north of Brisbane. The assumption underlying these estimates is that dramatic reductions in greenhouse gas emissions would occur such that GDP remained at equivalent levels to present, and that investment in health system infrastructure was not compromised.

The relationship between climate change and the origin, number and fate of displaced persons over the next century is highly complex and uncertain. Important factors involved in this relationship include the quality of governance and other human services and institutions, and the sensitivity of climatic, ecological and social factors in response to any given concentration of greenhouse gases. In contrast to this complexity, the trajectory and likely concentration of major greenhouse gases in the near future (especially until 2040) is comparatively predictable and restricted in range. Greenhouse gas emissions uncertainty increases as the century progresses. Despite the manifold uncertainties, many socio-ecological circumstances that are conceivable by 2100 are likely to increase the number of displaced people within the Asia-Pacific region, possibly by orders of magnitude.

In summary, regardless of the emissions policies taken by governments at this point in time, the climate over this century will continue to change as a result of human influence and additional health impacts will accrue as a result. Decisive and immediate action to mitigate greenhouse gas emissions will reduce the extent and severity of the impacts discussed in this report.

REFERENCES

ACIA. (2004) *Impacts of a warming Arctic: Arctic climate impact assessment.* Cambridge: Cambridge University Press.

Adams WM, Brockington D, Dyson J, *et al*. (2003) Managing tragedies: understanding conflict over common pool resources. *Science* 302: 1915-1916.

Adger WN, Brown K and Hulme M. (2005) Redefining global environmental change [editorial]. *Global Environmental Change Part A* 15(1): 1-4.

Anonymous. (1997) Plenty of gloom. *The Economist* 345(20 December): 19-21.

Australian Greenhouse Office. (2005) Reducing greenhouse emissions from transport: what local government can do.

Azar C and Rodhe H. (1997) Targets for Stabilization of Atmospheric CO_2. *Science* 276(5320): 1818-1819.

Balmford A, Bennun L, Brink B, *et al*. (2005) The Convention on Biological Diversity's 2010 target. *Science* 307: 212-213.

Barnett J. (2003) Environment, Development and Security in Pacific Island Countries: Challenges for the United States and Australia. Melbourne, School of International Development, University of Melbourne: 13.

Barnett J and Adger WN. (2003) Climate dangers and atoll countries. *Climatic Change* 61: 321–337.

Basu R and Samet JM. (2002) Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiol Rev* 24(2): 190-202.

Bergquist NR. (2001) Vector-borne parasitic diseases: new trends in data collection and risk assessment. *Acta Tropica* 79(1): 13-20.

Boersma HJ, *et al.* (2004) Error Analysis for Tropospheric NO_2 Retrieval. *Geophys.*

Boserup E. (1981) *Population and Technological Change : A Study of Long-term Trends.* Chicago: University of Chicago Press.

Bureau of Transport and Regional economics. (2005) *Working Paper 63: Health Impacts of Transport Emissions in Australia: Economics Costs.* Commonwealth of Australia.

Butler CD. (2000) Inequality, global change and the sustainability of civilisation. *Global Change and Human Health* 1(2): 156-172.

Butler CD. (2004) Human carrying capacity and human health. *Public Library of Science Medicine* 1(3): 192-194.

Butler CD (2005). Inequality and conflict. *In Search of Sustainability*. R M Douglas *et al* (eds). Melbourne: CSIRO: 33-48.

Butler CD, Chambers R, Chopra K, *et al*. (2003). Ecosystems and Human Well-being. *Ecosystems and Human Well-being. A Framework for Assessment.* Washington: Island Press: 71-84.

Butler CD, Corvalan CF and Koren HS. (2005) Human health, well-being and global ecological scenarios. *Ecosystems* 8 (2):153-164.

Butler CD, Oluoch-Kosura W, Corvalan C, *et al*. (2005 (in press)). Human well-being across the scenarios. *Scenarios. Findings of the Scenarios Working*. Millenium Ecosystem Assessment. Washington: Island Press: 389-409.

Caldeira K, Jain AK and Hoffert MI. (2003) Climate sensitivity, uncertainty, and the need for energy without CO_2 emission. *Science* 299(5615): 2052-2054.

Communicable Diseases Network Australia. (2002) National Notifiable Diseases Surveillance System, Communicable Diseases and Health Protection Branch, Australian Commonwealth Department of Health and Ageing. 2002.

Cox PM, Betts R, Jones CD, *et al*. (2000) Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature* 408: 184-187.

CSIRO. (2001) Climate Change Projections for Australia. Melbourne, Climate Impact Group, CSIRO Division of Atmospheric Research: 8.

Curriero FC, Heiner KS, Samet JM, *et al*. (2002) Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology* 155(1): 80-87.

Daily GC and Ehrlich PR. (1996) Global change and human susceptibility to disease. *Annual Review of Energy and the Environment* 21: 125-144.

Dauvergne P. (1997) *Shadows in the Forest: Japan and the Politics of Timber in Southeast Asia.* Cambridge MA: MIT Press.

Davis M. (2004) Planet of Slums. Urban Involution and the Informal Proletariat. *New Left Review* 26: 5-34.

Della-Marta P, Collins D and Braganza K. (2004) Updating Australia's high-quality annual temperature dataset. 53: 75-93.

Dhainaut JF, Claessens YE, Ginsburg C, *et al*. (2004) Unprecedented heat-related deaths during the 2003 heat wave in Paris: consequences on emergency departments. *Crit Care* 8(1): 1-2.

Diamond J. (2005) *Collapse: How Societies Choose to Fail or Succeed.* London: Viking/Allen Lane.

El-Hinnawi E. (1985) *Environmental Refugees.* Nairobi, Kenya: UNEP.

Elzen MGJd and Meinshausen M. (2005) Meeting the EU 2°C climate target: global and regional emission implications. Bilthoven, The Netherlands, Netherlands Environmental Assessment Agency: 44.

Fischer G, Shah M, Velthuizen Hv, *et al*. (2001) Global Agro-ecological Assessment for Agriculture in the 21st Century, International Institute of Applied Systems Analysis: 44.

Folke C. (2004) Traditional knowledge in social-ecological systems [editorial]. *Ecology and Society* 9(3): 7.

Gill RA, Polley HW, Johnson HB, *et al*. (2002) Nonlinear grassland responses to past and future atmospheric CO_2. *Nature* 417: 279-282.

Githeko AK, Lindsay SW, Confalonieri UE, *et al*. (2000) Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization* 78(9): 1136-1147.

Gubler DJ. (1998) Dengue and dengue hemorrhagic fever. *Clinical Microbiology Reviews* July: 480-496.

Gunderson L and Holling C, Eds. (2002) *Panarchy: Understanding Transformations in Human and Natural Systems.* Washington DC: Island Press.

Hales S, de Wet N, Maindonald J, *et al*. (2002) Potential effect of population and climate changes on global distribution of dengue fever: an empirical model. *Lancet* 360(9336): 830-834.

Hales S, Salmond G, Town GI, *et al*. (2000) Daily mortality in relation to weather and air pollution in Christchurch, New Zealand. *Australian and New Zealand Journal of Public Health* 24(1): 89-91.

Halstead SB, Nimmanitya S and Cohen SN. (1970) Observations related to pathogenesis of dengue haemorrhagic fever. I: relation of disease severity to antibody response and virus recovered. *Yale Journal of Biology and Medicine* 42: 311-328.

Hare W and Meinshausen M. (2004) How much warming are we committed to and how much can be avoided? Potsdam, Germany, PIK Report No. 93, Potsdam Institute for Climate Impact Research.

Hoerling M and Kumar A. (2003) The perfect ocean for drought. *Science* 299(5607): 691-694.

International Federation of Red Cross and Red Crescent Societies. (2004) World Disasters Report.

IOCI. (2002) Climate variability and change in south west Western Australia. Perth, Indian Ocean Climate Initiative: 34.

IPCC, Ed. (2001) *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

IPCC, Ed. (2001) *Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Jepson P, Jarvie JK, MacKinnon K, *et al*. (2001) The end for Indonesia's lowland forests? *Science* 292(5518): 859-861.

Johnson DG. (2001) On population and resources: a comment. *Pop Dev Rev* 27(4): 739-47.

Keatinge WR, Donaldson GC, Cordioli E, *et al*. (2000) Heat related mortality in warm and cold regions of Europe: observational study. BMJ 321(7262): 670-673.

Kelley AC (2001). The population debate in historical perspective : revisionism revised. *Population matters: demographic change, economic growth, and poverty in the developing world.* SW Sinding. Oxford ; New York: Oxford University Press: 24-54.

Kench PS, McLean RF and Nichol SL. (2005) New model of reef-island evolution: Maldives, Indian Ocean. *Geology* 33(2): 145-148.

Kerr RA. (2005) Climate modelers see scorching future as a real possibility. *Science* 307: 497.

Knutson TR, Tuleya RE and Kurihara Y. (1998) Simulated increase of hurricane Intensities in a CO_2-warmed climate. *Science* 279: 1018-1020.

Leake CJ. (1998). Mosquito-borne arboviruses. *Zoonoses.* DIH Simpson. Oxford: Oxford University Press. 401-413.

Mackenzie JS, Brooy JTL, Hueston L, *et al*. (1996) Dengue in Australia. *Journal of Medical Microbiology* 45(3): 159-161.

Mastrandrea MD and Schneider SH. (2004) Probabilistic Integrated Assessment of "Dangerous" Climate Change. *Science* 304(5670): 571-575.

May R. (2005) Under-informed, over here. *The Guardian.*

McBride JH. (1999) Dengue fever. An Australian perspective. *Australian Family Physician* 28(4): 319-23.

McGeehin MA and Mirabelli M. (2001) The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. *Environ Health Perspect* 109 Suppl 2: 185-9.

McMichael A and Githeko A (2001). Human health. *Climate change 2001: Impacts, adaptation and vulnerability. Contribution of Working Group II to Third Assessment Report of Intergovernmental Panel on Climate Change.* JJ McCarthy, OF Canziani, NA Leary, DJ Dokken and KS White. Cambridge: Cambridge University Press: 451-485.

McMichael AJ. (2001) *Human frontiers, environments and disease.* Cambridge, UK: Cambridge University Press.

McMichael AJ, Woodruff RE and Hales S. (In Press) Climate change and human health: present and future risks. *Lancet.*

McMichael AJ, Woodruff RE, Whetton P, *et al*. (2003) Human health and climate change in Oceania: a risk assessment. Canberra, Australia, Commonwealth Department of Health and Ageing: 116.

Meehl GA and Tebaldi C. (2004) More intense, more frequent, and longer lasting heat waves in the 21st century. *Science* 13 August(305): 994-997.

Meehl GA, Washington WM, Collins WD, *et al*. (2005) How much more global warming and sea level rise? *Science* 307: 1769-1772.

Meusel D, Menne B, Kirch W, *et al*. (2004) Public health responses to extreme weather and climate events—a brief summary of the WHO meeting on this topic in Bratislava on 9–10 February 2004. *Journal of Public Health* 12(6): 371-381.

Milly PCD, Wetherald RT, Dunne KA, *et al*. (2002) Increasing risk of great floods in a changing climate. *Nature* 415(6871): 514-517.

Myers N. (1997) Environmental Refugees. *Population and Environment* 19(2): 167-182.

O'Brien K, Leichenko R, Kelkar U, *et al*. (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change Part A* 14(4): 303-313.

O'Neill MS, Zanobetti A and Schwartz J. (2003) Modifiers of the temperature and mortality association in seven US cities. *Am J Epidemiol* 157(12): 1074-82.

Parry ML, Rosenzweig C, Iglesias A, *et al*. (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14(1): 53-67.

Peng S, Huange J, Sheehy JE, *et al*. (2004) Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Science* 101(27): 9971-9975.

Pittock B. (2003) Climate change: An Australian guide to the science and potential impacts. Canberra, Australian Greenhouse Office.

Pounds JA and Puschendorf R. (2004) Clouded futures. *Nature* 427: 107-109.

Reiter P (1988). Weather, vector biology, and arboviral recrudescence. *The arboviruses: epidemiology and ecology.* TP Monath. Boca Raton, Florida: CRC Press. 1: 245-255.

Reiter P, Lathrop S, Bunning M, *et al*. (2003) Texas lifestyle limits transmission of dengue virus. *Emerg Infect Dis* 9(1): 86-9.

Rial JA, Sr RAP and Beniston M. (2004) Nonlinearities, Feedbacks and Critical Thresholds within the Earth's Climate System. *Climatic Change* 65(1-2): 11 - 38.

Rignot E, Rivera A and Casassa G. (2003) Contribution of the Patagonia icefields of South America to sea level rise. *Science* 302(5644): 434-437.

Ritchie S (2004). Dengue Control Measures in North Queensland. *Arbovirus Research in Australia*, Queensland. pp. 324-330.

Rosenzweig C, Tubiello FN, Goldberg R, *et al*. (2002) Increased crop damage in the US from excess precipitation under climate change. *Global Environmental Change* 12(3): 197-202.

Schar C, Vidale PL, Luthi D, *et al*. (2004) The role of increasing temperature variability in European summer heatwaves. *Nature* 427: 332-336.

Schellnhuber H. (2002). Coping with Earth System complexity and irregularity. *Challenges of a Changing Earth. Proceedings of the Global Change Open Science Conference, Amsterdam, The Netherlands,* 10-13 July 2001. C Bradshaw. Berlin Heidelberg New York, 2002: Springer-Verlag: 151-156.

Scoggins A, Kjellstrom T, Fisher G, *et al*. (2004) Spatial analysis of annual air pollution exposure and mortality. *Science of the Total Environment* 321(1-3): 71-85.

Sellers RF. (1980) Weather, host and vector - their interplay in the spread of insect-borne animal viral diseases. *Journal of Hygiene* 85: 65-102.

Semenza JC, Rubin CH, Falter KH, *et al*. (1996) Heat-related deaths during the July 1995 heat wave in Chicago. *New England Journal of Medicine* 335(2): 84-90.

Sen AK. (1981) *Poverty and Famines: An Essay on Entitlement and Deprivation.* Oxford, New Delhi: Clarendon Press.

Simms A. (2002). Pacific islands foretell future of climate change. *World Disasters Report 2002*. Red Cross.

Simms A, Magrath J and Reid H. (2004) Up in smoke?, International Institute for Environment and Development

Smoyer KE. (1998) A comparative analysis of heat waves and associated mortality in St. Louis, Missouri--1980 and 1995. *Int J Biometeorol* 42(1): 44-50.

Smoyer KE, Rainham DG and Hewko JN. (2000) Heat-stress-related mortality in five cities in Southern Ontario: 1980-1996. *Int J Biometeorol* 44(4): 190-7.

Sornmani S and Okanurak K. (1995) Social and economic impact of dengue haemorrhagic fever in Thailand. Bangkok, Thailand, Social and Economic Research Unit, Mahidol University.

Stokstad E. (2004) Defrosting the carbon freezer of the North. *Science* 304: 1618-1620.

Stott PA, Stone DA and Allen MR. (2004) Human contribution to the European heatwave of 2003. *Nature* 432(7017): 610-614.

Sutherst RW (1994). Climate change and arbovirus transmission. *Arbovirus Research in Australia.* BH Kay. Brisbane: CSIRO, University of Queensland, and Queensland Institute of Medical Research. 6: 297-299.

Thomas CD, Cameron A, Green RE, *et al*. (2004) Extinction risk from climate change. *Nature* 427(8 January): 145-148.

Thomas R, Rignot E, Casassa G, *et al*. (2004) Accelerated sea-Level rise from West Antarctica. *Science* 306: 255-258.

Thompson LG, Mosley-Thompson E, Davis ME, *et al*. (2002) Kilimanjaro ice core records: Evidence of Holocene climate change in tropical Africa. *Science* 298(5593): 589-593.

Trewin D. (2003) Population projections, Australia, 2003 to 2101. Canberra, Australian Bureau of Statistics.

UK NHS. (2005) Heatwave plan for England: protecting health and reducing harm from extreme heat and heatwaves. UK, National Health Service.

Uvin P. (1996) Tragedy in Rwanda: The political ecology of conflict. *Environment* 38(3): 7-15.

Von Allmen SD, Lopez-Correa RH, Woodall JP, *et al*. (1979) Epidemic dengue fever in Puerto Rico, 1977: a cost analysis. *American Journal of Tropical Medicine and Hygiene* 28(6): 1040-4.

Water Corporation. (2005) Perth water desalination project.

White NJ, Church JA and Gregory JM. (2005) Coastal and global averaged sea level rise for 1950 to 2000. *Geophysical Research Letters* 32(1): L01601.

WHO. (1993) Monograph on Dengue/Dengue Haemorrhagic Fever. Regional publication SEARO, No. 22. Delhi, Regional Office for South-East Asia: 163.

WHO. (2004) WHO technical meeting on “Housing-health indicators”. Results of review and data availability screening in Member States. Copenhagen, World Health Organization, Regional Office for Europe.

Yohe G, Andronova N and Schlesinger M. (2004) To hedge or not against an uncertain climate future? *Science* 306: 416-417.

AUSTRALIAN CONSERVATION FOUNDATION
FLOOR ONE, 60 LEICESTER STREET CARLTON VIC 3053
phone 03/ 9345 1111 // facsimile 03/ 9345 1166
email acf@acfonline.org.au // web acfonline.org.au

AMA
Australian Medical Association
42 Macquarie Street, BARTON ACT 2600
PO Box 6090, KINGSTON ACT 2604
TEL +61 2 6270 5400 · FAX +61 2 6270 5499
Email ama@ama.com.au

Printed on 100% recycled paper