



Climate Change and Human Health – Risks and Responses
REVISED SUMMARY 2008



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Preface

Over the ages, human societies have altered local ecosystems and modified regional climates. Today, the human influence has attained a global scale. This reflects the recent rapid increase in population size, energy consumption, intensity of land use, international trade and travel, and other human activities. These global changes have heightened awareness that the long-term good health of populations depends on the continued stability and functioning of the biosphere's ecological, physical, and socioeconomic systems.

The world's climate system is an integral part of the complex of life-supporting processes. Climate and weather have always had a powerful impact on human health and well-being. But like other large natural systems, the global climate system is coming under pressure from human activities. Global climate change is, therefore, a newer challenge to ongoing efforts to protect human health.

This booklet is a revised summary of the book *Climate Change and Human Health – Risks and Responses*, published by WHO in collaboration with UNEP and WMO. The complete volume seeks to describe the context and process of global climate change, its actual or likely impacts on health, and how human societies and their governments should respond, with particular focus on the health sector.

This updated report was prepared by the Pan American Health Organization, and launched on World Health Day, 7 April 2008, with the theme of "Protecting Health from Climate Change."

Global climate change and health: an old story writ large

Climate change poses a major, and largely unfamiliar, challenge. This publication describes the process of global climate change, its current and future impacts on human health, and how our societies can lessen those adverse impacts, via adaptation strategies and by reducing greenhouse gas emissions.

In 1969, the Apollo moon shot provided extraordinary photographs of this planet, suspended in space. This transformed how we thought about the biosphere and its limits. Our increasing understanding of climate change is transforming how we view the boundaries and determinants of human health. While our personal health may seem to relate mostly to prudent behaviour, heredity, occupation, local environmental exposures, and health-care access, sustained population health requires the life-supporting "services" of the biosphere. Populations of all animal species depend on supplies of food and water, freedom from excess infectious disease, and the physical safety and comfort conferred by climatic stability. The world's climate system is fundamental to this life-support.

Today, humankind's activities are altering the world's climate. We are increasing the atmospheric concentration of energy-trapping gases, thereby amplifying the natural "greenhouse effect" that makes the Earth habitable. These greenhouse gases (GHGs) comprise, principally, carbon dioxide (mostly from fossil fuel combustion and forest burning), plus other heat-trapping gases such as methane (from irrigated agriculture, animal husbandry and oil extraction), nitrous oxide and various human-made halocarbons. In its Fourth Assessment Report (2007), the UN's Intergovernmental Panel on Climate Change (IPCC)

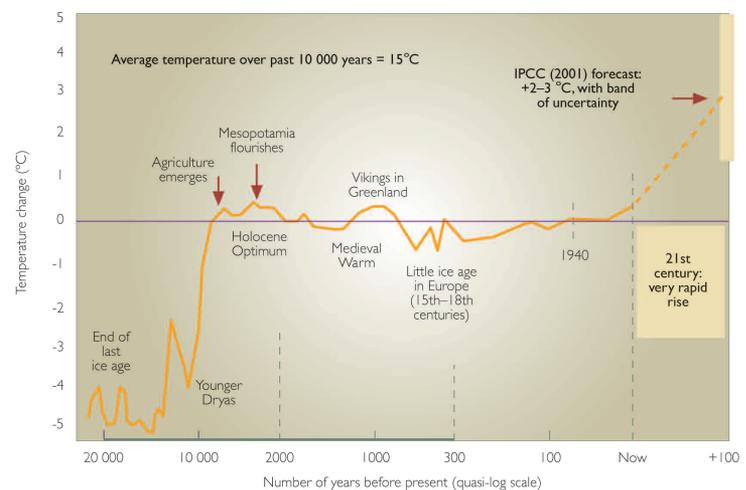
stated: "The understanding of anthropogenic warming and cooling influences on climate has improved since the TAR [Third Assessment Report], leading to very high confidence that the global average net effect of human activities since 1750 has been one of warming." And "the warming of the climate system is unequivocal."^{1,2}

During the twentieth century, world average surface temperature increased by approximately 0.74°C. The linear warming trend over the past 50 years (0.13°C per decade) was nearly twice that for the past 100 years. Climatologists project further warming, along with changes in precipitation and climatic variability, during the coming century and beyond. Their projections are based on

increasingly sophisticated global climate models, applied to plausible future scenarios of global greenhouse gas emissions that take into account alternative trajectories for demographic, economic and technological changes and evolving patterns of governance.

The global scale of climate change differs fundamentally from the many other familiar environmental concerns that refer to localised toxicological or microbiological hazards. Indeed, climate change signifies that, today, we are altering Earth's biophysical and ecological systems at the planetary scale – as is also evidenced by stratospheric ozone depletion, accelerating biodiversity losses, stresses on terrestrial and marine food-producing systems, depletion

Figure 1.1. Variations in Earth's average surface temperature, over the past 20,000 years



of freshwater supplies, and the global dissemination of persistent organic pollutants.

Human societies have had long experience of naturally-occurring climatic vicissitudes (Figure 1.1). The ancient Egyptians, Mesopotamians, Mayans, and European populations (during the four centuries of the Little Ice Age) were all affected by nature's great climatic cycles. More acutely, disasters and disease outbreaks have occurred often in response to the extremes of regional climatic cycles such as the El Niño Southern Oscillation (ENSO) cycle.³

The IPCC (2007) projected that the global average temperature will rise by a best estimate of 1.8–4.0°C

during this century, relative to 1980–1999. For the next two decades, a warming of about 0.2°C per decade is projected. Even if the concentrations of all greenhouse gases and aerosols were kept constant at year 2000 concentrations, a further warming of about 0.1°C per decade would be expected. As is shown in Figure 1.2, there is unavoidable uncertainty in this estimate, because the intricacies of the climate system are not fully understood, and humankind's developmental future cannot be foretold with certainty.

Potential health impacts of climate change

Change in world climate would influence the functioning of many ecosystems and their member

species. Likewise, there would be impacts on human health. Some of these health impacts would be beneficial. For example, milder winters would reduce the seasonal winter-time peak in deaths that occurs in temperate countries, while in currently hot regions a further increase in temperatures might reduce the viability of disease-transmitting mosquito populations. Overall, however, scientists consider that most of the health impacts of climate change would be adverse.

Climatic changes over recent decades have probably already affected some health outcomes. Indeed, the World Health Organization estimated, in its "World Health Report 2002", that climate change was estimated to be responsible in 2000 for approximately 2.4% of worldwide diarrhoea, and 6% of malaria in some middle-income countries.⁴ However, small changes, against a noisy background of ongoing changes in other causal factors, are hard to identify. Once spotted, causal attribution is strengthened if there are similar observations in different population settings.

The first detectable changes in human health may well be alterations in the geographic range (latitude and altitude) and seasonality of certain infectious diseases – including vector-borne infections such as malaria and dengue fever, and food-borne infections (e.g. salmonellosis)

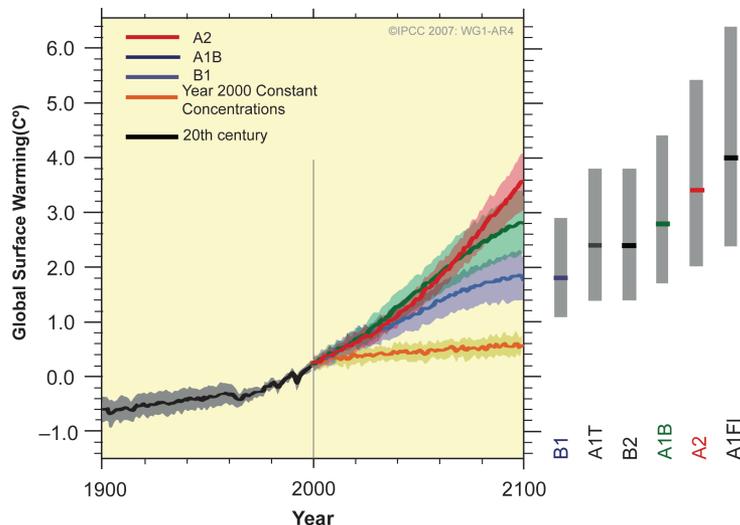
which peak in the warmer months. Warmer average temperatures combined with increased climatic variability would alter the pattern of exposure to thermal extremes and resultant health impacts, in both summer and winter. By contrast, the public health consequences of the disturbance of natural and managed food-producing ecosystems, rising sea-levels and population displacement for reasons of physical hazard, land loss, economic disruption and civil strife, may not become evident for up to several decades.

Conclusion

Unprecedentedly, today, the world population is encountering unfamiliar human-induced changes in the lower and middle atmospheres and world-wide depletion of various other natural systems (e.g. soil fertility, aquifers, ocean fisheries, and biodiversity in general). Beyond the early recognition that such changes would affect economic activities, infrastructure and managed ecosystems, there is now recognition that global climate change poses risks to human population health.

This topic is emerging as a major theme in population health research, social policy development, and advocacy. Indeed, consideration of global climatic-environmental hazards to human health will become a central role in the sustainability transition debate.

Figure 1.2 Global temperature record, since instrumental recording began in 1860, and projection to 2100, according to the IPCC



Source: reference 1

2

Weather and climate: changing human exposures

In discussing "climate change and health" we must distinguish between the health impacts of several meteorological exposures: weather, climate variability and climate change

Weather is the continuously changing condition of the atmosphere, usually considered on a time scale that extends from minutes to weeks. Climate is the average state of the lower atmosphere, and the associated characteristics of the underlying land or water, in a particular region, usually spanning at least several years. Climate variability is the variation around the average climate, including seasonal variations and large-scale regional cycles in atmospheric and ocean circulations such as the El Niño/Southern Oscillation (ENSO) or the North Atlantic Oscillation (NAO).

Climate change occurs over decades or longer time-scales. Until now, changes in the global climate have occurred naturally, across centuries or millennia, because of continental drift, various astronomical cycles, variations in solar energy output and volcanic activity. Over the past few decades it has become increasingly apparent that human actions are changing atmospheric composition, thereby making a significant contribution to global climate change.¹

The Climate System

Earth's climate is determined by complex interactions between the Sun, oceans, atmosphere, cryosphere, land surface and biosphere. The Sun is the principal driving force for weather and climate. The uneven heating of Earth's surface (being greater

nearer the equator) causes great convection flows in both the atmosphere and oceans, and is thus a major cause of winds and ocean currents.

Five concentric layers of atmosphere surround this planet. The lowest layer (troposphere) extends from ground level to around 10–12 km altitude on average. The weather that affects Earth's surface develops within the troposphere. The next major layer (stratosphere) extends to about 50 km above the surface. The ozone within the stratosphere absorbs most of the sun's higher-energy ultraviolet rays. Above the stratosphere are three more layers: mesosphere, thermosphere and exosphere.

Overall, these five layers of the atmosphere approximately halve

the amount of incoming solar radiation that reaches Earth's surface. In particular, certain "greenhouse" gases, present at trace concentrations in the troposphere (and including water vapour, carbon dioxide, nitrous oxide, methane, halocarbons, and ozone), absorb about 17% of the solar energy passing through it. Of the solar energy that reaches Earth's surface, much is absorbed and reradiated as long-wave (infrared) radiation. Some of this outgoing infrared radiation is absorbed by greenhouse gases in the lower atmosphere, which causes further warming of Earth's surface. This raises Earth's temperature by 33°C to its present surface average of 15°C. This supplementary warming process is called "the greenhouse effect" (Figure 2.1).²

Figure 2.1. The greenhouse effect

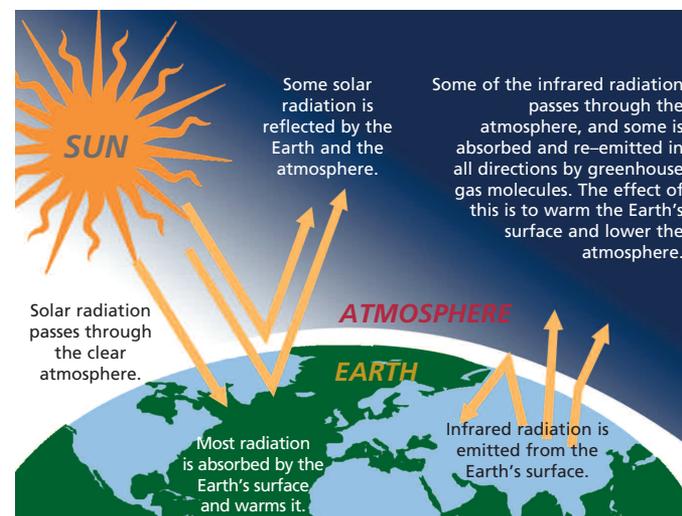
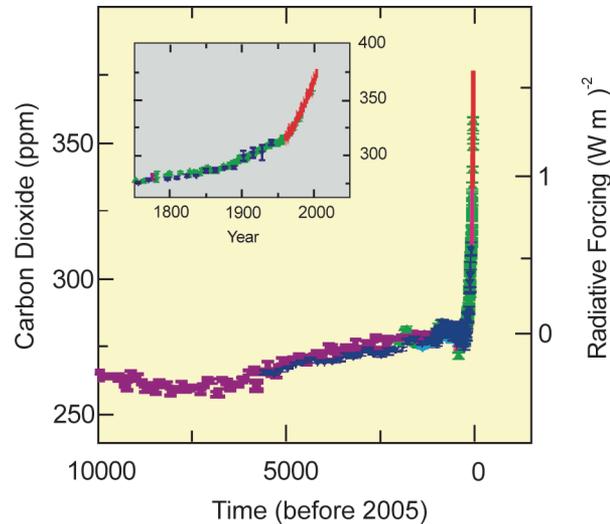


Figure 2.2. Atmospheric concentration of CO₂ from year 1000 to year 2000



Source: Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: Fourth Assessment Report (Volume I). Cambridge: Cambridge University Press, 2007.

Greenhouse Gases

Human-induced increases in the atmospheric concentration of GHGs are amplifying the greenhouse effect. In recent times, the great increase in fossil fuel burning, agricultural activity and several other economic activities has greatly augmented greenhouse gas emissions. The atmosphere concentration of carbon dioxide has increased by more than 35% since the inception of the industrial revolution (Figure 2.2).

Table 2.1 provides examples of several greenhouse gases and summarizes their 1790 and 1998

concentrations, their rate of change over the period 1990 to 1999 and their atmospheric lifetime. The atmospheric lifetime is highly relevant to policy makers because the emission of gases with long lifetimes entails a quasi-irreversible commitment to sustained climate change over decades or centuries.^{4,5}

Studying the Health Impacts of Climate

Studying the impact of weather events and climate variability on human health requires appropriate specification of the meteorological "exposure".

Table 2.1: Examples of greenhouse gases that are affected by human activities

	CO ₂ (Carbon Dioxide)	CH ₄ (Methane)	N ₂ O (Nitrous Oxide)	CFC-11 (chloroflu- oro-carbon-11)	HFC-23 Hydrofluoro- carbon-23)	CF ₄ (Perfluoro- ethane)
Pre-industrial concentration	~280 ppm	~700 ppb	~270 ppb	Zero	Zero	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of Concentration change ^b	1.5 ppm/yr ^a	7.0 ppb/yr ^a	0.8 ppb/yr	-1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5-200 yr ^c	12 yr ^d	114 yr ^d	45 yr	260 yr	>50,000 yr

Source: reference 1

- a Rate has fluctuated between 0.9 ppm/yr and 2.8 ppm/yr for CO₂ and between 0 and 13 ppb/yr for CH₄ over the period 1990 to 1999.
- b Rate is calculated over the period 1990 to 1999.
- c No single lifetime can be defined for CO₂ because of the different rates of uptake by different removal processes.
- d This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.
ppm: parts per million. ppb: parts per billion. ppt: parts per trillion.

Weather and climate can each be summarized over various spatial and temporal scales. The appropriate scale of analysis, and the choice of any lag period between exposure and effect, will depend on the anticipated nature of the relationship. Much of the research requires long-term data sets with information about weather/climate and health outcome on the same spatial and temporal scales. For example, it has proven difficult to assess how climate variability and change has influenced the recent spread of malaria in African highlands because the appropriate health,

weather and other relevant data (e.g. land use change) have not been collected in the same locations and on the same scales.

In all such research, there is a need to accommodate the several types of uncertainty that are inherent in these studies. Projections about how complex systems such as regional climate systems and climate-dependent ecosystems will respond when pushed beyond critical limits are necessarily uncertain. Likewise, there are uncertainties about the future characteristics, behaviours and coping capacity of human populations.

3

International consensus on the science of climate and health: the IPCC Fourth Assessment Report

Through recent research, our understanding of climate–health relationships has increased rapidly, largely due to the stimulus of the IPCC and other policy–related reviews at regional and national levels.

In the early 1990s there was little awareness of the health risks posed by global climate change. This reflected a general lack of understanding of how the disruption of biophysical and ecological systems might affect the longer–term wellbeing and health of populations. There was little awareness among natural scientists that changes in their particular objects of study – climatic conditions, biodiversity stocks, ecosystem productivity, and so on – were of potential importance to human health. Indeed, this was well reflected in the meagre reference to health risks in the first major report of the UN’s Intergovernmental Panel on Climate Change (IPCC), published in 1991.

Subsequently, the situation has changed. The IPCC Second Assessment Report (1996) devoted a full chapter to the potential risks to health. The Third and Fourth Assessment Reports (2001 and 2007) did likewise, including discussions of early evidence of actual health impacts, along with assessing potential future health effects. The assessments also highlighted anticipated health impacts by major geographic region and for particularly vulnerable populations.

The IPCC was established by WMO and UNEP in 1988. The IPCC’s role is to assess the world’s published scientific literature on: (i) how human–induced changes to the lower atmosphere, via the

emission of greenhouse gases, have influenced and are likely to influence world climatic patterns; (ii) how this does, and in future would, affect various systems and processes important to human societies; and (iii) the range of economic and social response options available to policy–makers to avert climate change and to lessen its impacts.

The IPCC’s work has been done by many hundreds of scientists, worldwide. On a five–yearly basis, national governments propose scientists with expertise in the many topic areas included within this comprehensive review task. Topic review teams are then chosen to ensure proper geographic and disciplinary representation. Excluding the small number of scientists working at IPCC secretariat level, all this work of reviewing, discussing and writing is contributed voluntarily.

The IPCC’s draft assessments are subject to a series of internal and external peer–review processes. The final wording of IPCC report summaries are subject, via formal international conferences, to detailed and systematic scrutiny by governments.

The IPCC’s assessment of health impacts

In its Fourth Assessment Report the IPCC concluded that: “Climate change currently contributes to the global burden of disease and premature deaths....At this early

stage the effects are small, but are projected to progressively increase in all countries and regions.” And, “Projected climate change related exposures are likely to affect the health status of millions of people, particularly those with low adaptive capacity, through: increases in malnutrition and consequent disorders, with implications for child growth and development; increased deaths, disease and injury due to heatwaves, floods, storms, fires and droughts; the increased burden of diarrheal disease; mixed effects on the range (increases and decreases) and transmission potential of malaria in Africa; the increased frequency of cardio–respiratory diseases due to higher concentrations of ground–level ozone related to climate change; and the altered spatial distribution of some infectious disease vectors.”¹ Figure 3.1 [TS.9] summarizes the direction and magnitude of change of selected health impacts of climate change.²

Broadly, a change in climatic conditions can have three kinds of health impacts:

- Those that are relatively direct, usually caused by weather extremes.
- The health consequences of various processes of environmental change and ecological disruption that occur in response to climate change.
- The diverse health consequences – traumatic, infectious,

nutritional, psychological and other – that occur in demoralized and displaced populations in the wake of climate-induced economic dislocation, environmental decline, and conflict situations.

These several pathways are illustrated in Figure 3.2.³

Our understanding of the impacts of climate change and variability on human health has increased considerably in recent years.

However, several basic issues complicate this task:

- Climatic influences on health are often modulated by interactions with other ecological processes, social conditions, and adaptive policies. In seeking explanations,

a balance must be sought between complexity and simplicity.

- There are many sources of scientific and contextual uncertainty. The IPCC has therefore sought to formalize the assessment of level of confidence attaching to each health impact statement.
- Climate change is one of several concurrent global environmental changes that simultaneously affect human health – often interactively.⁴

A good example is the transmission of vector-borne infectious diseases, which is jointly affected by climatic conditions, population movement, forest clearance and land-use patterns, biodiversity losses (e.g., natural predators of mosquitoes),

reshwater surface configurations, and human population density.⁵

For each potential impact of climate change, certain groups will be particularly vulnerable to disease and injury. The vulnerability of a population depends on factors such as population density, level of economic development, food and safe drinking water availability, income level and distribution, local environmental conditions, pre-existing health status, and the quality and availability of public health care.⁶ For instance, those most at risk of being harmed by thermal extremes include socially isolated city dwellers, the elderly and the poor. Populations living at the present margins of malaria

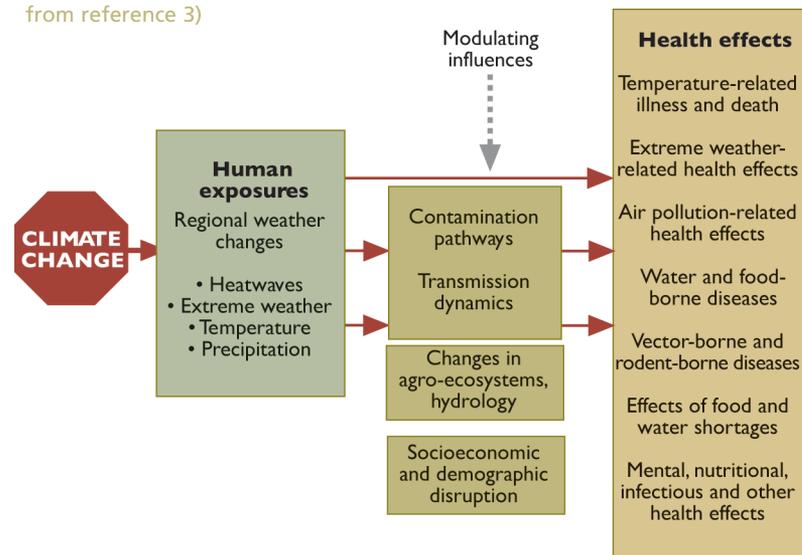
and dengue, without effective primary health care, will be the most susceptible if these diseases expand their geographic range in a warmer world.

The IPCC report also underscores that our understanding of the links between climate, climate change and human health has increased considerably. However, there are still many gaps in knowledge about likely future patterns of exposure to climatic-environmental changes, and about the vulnerability and adaptability of physical, ecological and social systems to such climate change.

Figure 3.1. Direction and magnitude of change of selected health impacts of climate change

	Negative impact	Positive impact
Very high confidence Malaria: contraction and expansion, change in transmission season	←	→
High confidence Increase in malnutrition	←	
Increase in the number of people suffering from deaths, disease and injuries from extreme weather events	←	
Increase in the frequency of cardio-respiratory diseases from changes in air quality	←	
Change in the range of infectious disease vectors	←	→
Reduction of cold-related deaths		→
Medium confidence Increase in the burden of diarrhoeal diseases	←	

Figure 3.2. Pathways by which climate change affects human health (modified from reference 3)

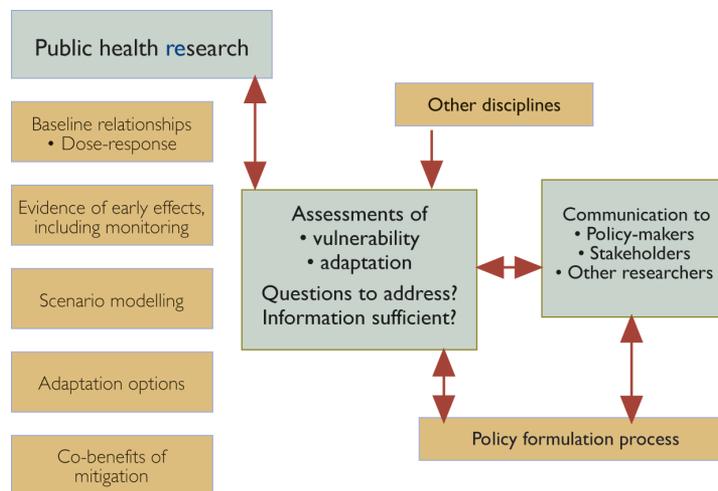


4

Looking to the future: challenges for scientists studying climate change and health

Research on climate change and health spans basic studies of causal relationships, risk assessment, evaluation of population vulnerability and adaptive capacity, and the evaluation of intervention policies (Figure 4.1).

Figure 4.1 Tasks for public health science



The challenges in identifying, quantifying and projecting the health impacts of climate change entail issues of scale, “exposure” specification, and the elaboration of often complex and indirect causal pathways.¹ First, the geographic scale of climate-related health impacts and the typically wide timespans are unfamiliar to most researchers. Epidemiologists usually study problems that are geographically localised, have relatively rapid onset, and directly affect health. The individual is usually the natural unit of observation.

Second, the “exposure” variable – comprising weather, climate variability and climate trends – poses difficulties. There is no obvious “unexposed” group to act as baseline for comparison. Indeed, because there is little difference in

weather/climate exposures between individuals in the same geographic locale, comparing sets of persons with different “exposures” is usually precluded. Rather, whole communities or populations must be compared – and, in so doing, attention must be paid to intercommunity differences in vulnerability. For example, the excess death rate during the severe 1995 Chicago and 2003 Western Europe heatwave varied greatly between neighbourhoods because of differences in factors such as housing quality and community cohesion.

Third, some health impacts occur via indirect and complex pathways. For example, the effects of temperature extremes on health are direct. In contrast, complex changes in ecosystem composition and functioning help mediate the

impact of climatic change on transmission of vector-borne infectious diseases and on agricultural productivity.

A final challenge is the need to estimate health risks in relation to future climatic–environmental scenarios. Unlike most recognized environmental health hazards, much of the anticipated risk from global climate change lies years to decades into the future.

Research strategies and tasks

While much health–impacts research focuses on future risk, empirical studies referring to the recent past and present are important. Standard observational epidemiological methods can illuminate the health consequences of local climatic trends in past decades – if the relevant data-sets exist. Such information enhances our capacity subsequently to estimate future impacts. Meanwhile, we should also seek evidence of the early health effects of climate change, since change has been underway for several decades.

The health impacts of future climate change, including changes in climatic variability, can be estimated in two main ways. First, we can extrapolate from analogue studies that treat recent climatic variability as a foretaste of climate change. Second, we can use computer models based on existing knowledge about relationships between climatic conditions and health outcomes.

Such models cannot project exactly what will happen, but they indicate what could occur if certain future climatic (and other specified) conditions were fulfilled.

The five main tasks for researchers are:

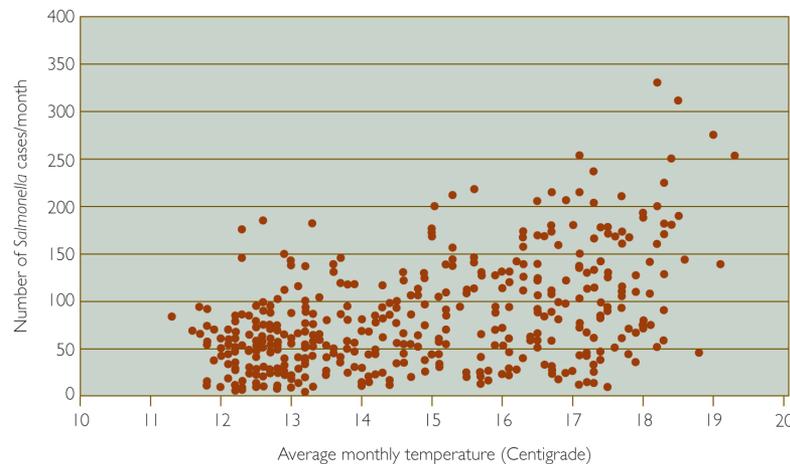
1. Establishing baseline relationships between weather and health

There are many unresolved questions about the sensitivity of particular health outcomes to weather, climate variability, and climate-induced environmental changes. For example, the major pathogens that cause acute gastroenteritis multiply faster in warmer conditions. Do higher ambient temperatures cause more illness? Apparently so – as is evident from the monthly salmonella infection count in New Zealand in relation to average monthly temperature (Figure 4.2).

2. Seeking evidence of effects of climate change

There have been many, coherent, observations on physical and ecological changes attributable to recent global warming – but limited indications of human health effects. Amongst these are changing patterns of infectious disease (such as tick-borne encephalitis² and cholera³). Health researchers must allow for the fact that humans have many coping strategies, ranging from planting shade trees, to changing work-hours, to installing air-conditioning.

Figure 4.2 Relationship between mean temperature and monthly reports of Salmonella cases in New Zealand 1965 – 2000



The challenge is to pick the settings, populations and health outcomes with the best chance of: (i) detecting changes, and (ii) attributing some portion of these to climate change. Impacts are likely to be clearest where the exposure–outcome gradient is steepest, the local population’s adaptive capacity is weakest, and when there are few competing explanations for observed relationships.

3. Scenario-based models to project likely impacts

Unlike most other environmental exposures, we know that the world’s climate will continue to change for at least several decades. Climatologists now can satisfactorily model the climatic consequences of future scenarios of greenhouse gas emissions. By linking these climate scenarios with health impact models, we can estimate the likely impacts on health.

Some health impacts are readily quantified (deaths due to storms and floods for instance); others are more difficult to quantify (e.g., the health consequences of food insecurity). We need models with sufficient representation of the multi-faceted future world to provide useful, or credible, estimates of future health risks. Where possible, we should use a high level of “integration” to achieve realistic modelled forecasts of impact in a world that will have undergone various other demographic, economic, technological and social changes.

4. Evaluating adaptation options

Adaptation means taking steps to reduce the potential adverse impact of environmental change (see chapter 11).

5. Estimating the co-incident benefits and costs of mitigation and adaptation

Steps to reduce GHG emissions (mitigation) or to lessen health impacts (adaptation) may have other coincidental health effects. For example, promotion of public transport relative to private vehicles may not only reduce CO₂ emissions, but also improve public health in the near-term by reducing air pollution and road traffic injuries and increasing physical activity. Information about these “ancillary” costs and benefits is important for policy-makers. Note, however, for impacts that are either deferred in time or that extend into the distant future, the costing is not straightforward.

General issues concerning uncertainty

Researchers should describe, communicate and explain all relevant uncertainties. This gives the decision-maker important insight into the conditions needed for a particular outcome to occur. Because environmental risk perception varies with culture, values and social status, “stakeholders” should assist both in shaping the assessment questions and in interpreting the risk.

5

Health impacts of climate variability

Climatic factors are an important determinant of various vector-borne diseases, many enteric illnesses and certain water-related diseases. Relationships between year-to-year variations in climate and infectious diseases are most evident where climate variations are marked, and in vulnerable populations. The El Niño phenomenon provides an analogue for understanding the future impacts of global climate change on infectious diseases.

Extreme climate events are expected to become more frequent and intense with climate change. These disruptive events have their greatest impact in poor countries. The two categories of climatic extremes are:

- Simple extremes of climatic statistical ranges, such as very low or very high temperatures
- Complex events such as droughts, floods, or hurricanes

The Pacific-based El Niño–Southern Oscillation (ENSO), which occurs about every 2–7 years, influences much of the world’s regional weather patterns, thus illustrating how climatic variability can affect human health.

Climate, weather, El Niño and infectious diseases

Both temperature and surface water have important influences on the insect vectors of vector-borne infectious disease. Of particular importance are mosquito species that spread malaria and viral diseases such as dengue, Chikungunya and yellow fever. Mosquitoes need access to stagnant water to breed and the adults need humid conditions for viability. Warmer temperatures enhance vector breeding and reduce the pathogen’s maturation period within the vector organism. However, very hot and dry conditions can reduce mosquito survival.

Malaria is mostly confined to tropical and subtropical regions. The disease’s sensitivity to climate is illustrated by desert and highland fringe areas where higher temperatures and/or rainfall associated with El Niño may increase transmission.² In areas of unstable malaria in developing countries, populations lack protective immunity and are prone to epidemics when weather conditions facilitate transmission.

Dengue is the most important arboviral disease of humans, occurring in tropical and subtropical regions, particularly in urban settings. ENSO affects dengue occurrence partially through changes in household water storage practices and in surface water pooling. Between 1970 and 1995, the annual number of dengue epidemics in the South Pacific was positively correlated with La Niña conditions (i.e., warmer and wetter).³

Rodents, which proliferate in temperate regions following mild wet winters, act as reservoirs for various diseases. Certain rodent-borne diseases are associated with flooding, including leptospirosis, tularaemia and viral haemorrhagic diseases. Other diseases associated with rodents and ticks, and that show associations with climatic variability, include Lyme disease, tick borne

encephalitis, and hantavirus pulmonary syndrome.

Many diarrhoeal diseases vary seasonally, suggesting sensitivity to climate. In the tropics, diarrhoeal diseases typically peak during the rainy season. Both floods and droughts increase the risk of diarrhoeal diseases. Major causes of diarrhoea linked to heavy rainfall and contaminated water supplies are cholera, cryptosporidium, E.coli infection, giardia, shigella, typhoid, and viruses such as hepatitis A.

Temperature extremes: heatwaves and cold spells

Extremes of temperature can kill. In many temperate countries, death rates during the winter season are 10–25% higher than those in the summer. In August 2003, a heatwave in France caused 14,802 deaths in a 20-day period.⁴

Most of the excess deaths during times of thermal extreme are in persons with preexisting disease, especially cardiovascular and respiratory disease. The very old, the very young and the frail are most susceptible. The number of excess deaths during a heatwave is difficult to estimate because some deaths occur in susceptible persons who would have died in the very near future.

Global climate change will be accompanied by an increased frequency, intensity and duration of heatwaves, as well as warmer summers and milder winters. Modelling studies, using climate scenarios, have projected future temperature-related mortality. For example, the annual excess summer-time mortality attributable to climate change, by 2050, is estimated to increase several-fold, to between 500–1000 for New York and 100–250 for Detroit, assuming population acclimatisation (physiological, infrastructural and behavioural)⁵. Without acclimatisation the impacts would be higher.

The impact of stressful weather on excess winter-associated mortality is difficult to determine. In temperate countries, a reduction in winter deaths may outnumber the increase in summer deaths. However, without better data, the net impact on annual mortality is difficult to estimate. Further, it will vary between populations.

Natural disasters

The total impact of weather disasters (droughts, floods, storms and bushfires) on health are difficult to quantify, because secondary and delayed consequences are poorly reported. El Niño events influence the annual toll of

persons affected by natural disasters.⁶ Globally, disasters triggered by droughts occur especially during the year after the onset of El Niño.

Globally, natural disaster impacts have been increasing. An analysis by the reinsurance company Munich Re found a tripling in the number of natural catastrophes in recent years, compared to the 1960s. This reflects global trends in population vulnerability more than an increased frequency of extreme climatic events. Developing countries are poorly equipped to deal with weather extremes, even as the population concentration increases in high-risk areas like coastal zones and cities. Hence, the number of people killed, injured or made homeless by natural disasters has been increasing rapidly.

Table 5.1. shows the numbers of events, deaths and people affected by extreme climatic and weather events in the past two decades, by geographic region.

Conclusion

The increasing trend in natural disasters is partly due to better reporting, partly due to increasing population vulnerability, and may include a contribution from ongoing global climate change. Especially in poor countries, the impacts of major vector-borne diseases and disasters can limit or even reverse improvements in social development. Even under favourable conditions, recovery from major disasters can take decades.

Short-range climatic forecasts may help reduce health impacts. But early warning systems must

also incorporate monitoring and surveillance, linked to adequate response capacities. Focusing attention on current extreme events may help countries to develop better means of dealing with the longer-term impacts of global climate change, although this capacity may itself decline because of cumulative climate change. For example, increased food imports might prevent hunger and disease during occasional droughts, but poor, food-insecure countries may be unable to afford such measures indefinitely in response to gradual year-by-year drying.

Table 5.1. Numbers of extreme climatic/weather events, people killed and affected, by region of the world, in the 1980s and 1990s

	1980s			1990s		
	Events	Killed (thousands)	Affected (millions)	Events	Killed (thousands)	Affected (millions)
Africa	243	417	137.8	247	10	104.3
Eastern Europe	66	2	0.1	150	5	12.4
Eastern Mediterranean	94	162	17.8	139	14	36.1
Latin America and Caribbean	265	12	54.1	298	59	30.7
South East Asia	242	54	850.5	286	458	427.4
Western Pacific	375	36	273.1	381	48	1,199.8
Developed	563	10	2.8	577	6	40.8
Total	1,848	692	1,336	2,078	601	1,851

6 Climate change and infectious diseases

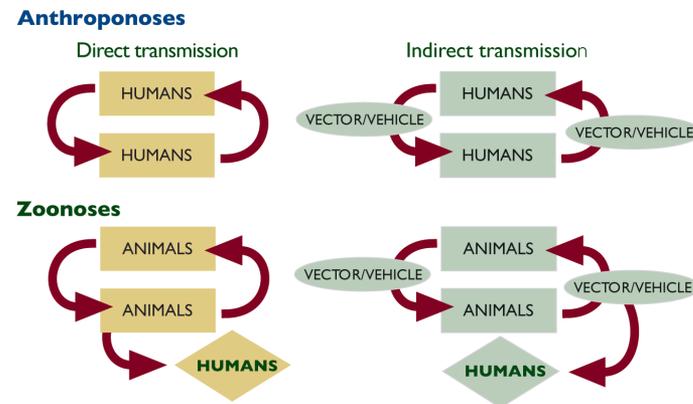
Today, worldwide, there is an apparent increase in many infectious diseases, including some newly-circulating ones (HIV/AIDS, hantavirus, hepatitis C, SARS, etc.). This reflects the combined impacts of rapid demographic, environmental, social, technological and other changes in our ways-of-living. Climate change will also affect infectious disease occurrence.¹

Humans have known that climatic conditions affect epidemic diseases from long before the role of infectious agents was discovered, late in the nineteenth century. Roman aristocrats retreated to hill resorts each summer to avoid malaria. South Asians learnt early that, in high summer, strongly curried foods were less likely to cause diarrhoea.

Infectious agents vary greatly in size, type and mode of transmission. There are viruses, bacteria, protozoa and multicellular parasites. Those microbes that cause “anthroponoses” have adapted, via evolution, to the human species as their primary, usually exclusive, host. In contrast, non-human species are the natural reservoir for those infectious agents that cause “zoonoses” (Fig 6.1). There are directly transmitted anthroponoses (such as TB, HIV/AIDS, and measles) and zoonoses (e.g., rabies). There are also indirectly-transmitted, vector-borne, anthroponoses (e.g., malaria, dengue fever, yellow fever) and zoonoses (e.g. bubonic plague and Lyme disease).

Vector-borne and water-borne diseases
Important determinants of vectorborne disease transmission include: (i) vector survival and reproduction, (ii) the vector’s biting rate, and (iii) the pathogen’s incubation rate within the vector organism. Vectors, pathogens and hosts each survive and reproduce within a range of optimal climatic conditions: temperature and

Figure 6.1: Four main types of transmission cycle for infectious diseases (reference 5)



precipitation are the most important, while humidity, sea level elevation, wind, and daylight duration are also important.

Human exposure to waterborne infections occurs by contact with contaminated drinking water, recreational water, or food. This may result from human actions, such as improper disposal of sewage wastes, or be due to weather events. Rainfall can influence the transport and dissemination of infectious agents, while temperature affects their growth and survival.

Observed and projected climate/infectious disease links

There are three categories of research into the linkages between climatic conditions and infectious disease transmission. The first examines evidence from the recent past of associations between climate variability and infectious disease occurrence. The second looks at early indicators of

already-emerging infectious disease impacts of long-term climate change. The third uses the above evidence to create models to estimate the future burden of infectious disease under projected climate change scenarios.

Historical Evidence

There is much evidence of associations between climatic conditions and infectious diseases. Malaria is of great public health concern, and may be the vector-borne disease most sensitive to long-term climate change. Malaria varies seasonally in highly endemic areas. The link between malaria and extreme climatic events has long been studied in India, for example. Early last century, the river-irrigated Punjab region experienced periodic malaria epidemics. Excessive monsoon rainfall and high humidity were identified early on as major influences, enhancing mosquito breeding and survival. Recent

analyses have shown that the malaria epidemic risk increases around five-fold in the year after an El Niño event.²

Early impacts of climate change

These include evidence that several vectors are changing their geographic range in response to climate change, as well as health impacts of temperature extremes and impacts of extreme climatic and weather events (described in chapter 5).

Modeling

The main types of models used to project future climatic influences on infectious diseases include statistical, process-based, and

landscape-based models.³ These three types of model address somewhat different questions. Statistical models require, first, the derivation of a statistical (empirical) relationship between the current geographic distribution of the disease and the current location-specific climatic conditions. This describes the climatic influence on the actual distribution of the disease, given prevailing levels of human intervention (disease control, environmental management, etc.). By then applying this statistical equation to future climate scenarios, the actual distribution of the disease in future is projected, assuming

unchanged levels of human intervention within any particular climatic zone. These models have been applied to climate change impacts from several vectorborne diseases, including malaria and dengue fever. Some models projected increases in the geographic range of malaria, particularly along the edge of the current distribution; other models suggest the geographic range could be reduced in some areas because temperatures will be too high or precipitation too low.

Process-based (mathematical) models use equations that express the scientifically documented relationship between climatic variables and biological parameters – e.g., vector breeding, survival, and biting rates, and parasite incubation rates. In their simplest form, such models express, via a set of equations, how a given configuration of climate variables would affect vector and parasite biology and, therefore, disease transmission. Such models address the question: “If climatic conditions alone change, how would this change the potential transmission of the disease?” Using more complex “horizontal integration”, the conditioning effects of human interventions and social contexts can also be incorporated.

This modelling method has been used particularly for malaria and dengue fever.⁴ The malaria modelling shows that small temperature increases could greatly

affect transmission potential. Globally, temperature increases of 2–3°C could increase the number of people who, in climatic terms, are at risk of malaria by around 3–5%, i.e. several hundred million. Further, the seasonal duration of malaria could increase in many currently endemic areas. Because climate also acts by influencing habitats, landscape-based modeling is useful. This entails combining the climate-based models described above with the rapidly-developing use of spatial analytical methods, to study the effects of both climatic and other environmental factors (e.g. different vegetation types – often measured, in the model development stage, by ground-based or remote sensors). This type of modelling has been applied to estimate how future climate-induced changes in land cover and surface water in Africa could affect certain mosquitoes and tsetse flies and, hence, malaria and African sleeping sickness.

Conclusion

Changes in infectious disease transmission patterns may be a major consequence of climate change. We need to learn more about the underlying complex causal relationships, and apply this information to the projection of future impacts, using more complete, better validated, and integrated models.

Table 6.1:⁵ Examples of how diverse environmental changes affect the occurrence of various infectious diseases in humans

Environmental changes	Example diseases	Pathway of effect
Dams, canals, irrigation	Schistosomiasis	▲ Snail host habitat, human contact
	Malaria	▲ Breeding sites for mosquitoes
	Helminthiasis	▲ Larval contact due to moist soil
River blindness	River blindness	▼ Blackfly breeding, ▼ disease
	Agricultural intensification	Malaria
Urbanization, urban crowding	Venezuelan haemorrhagic fever	▲ rodent abundance, contact
	Cholera	▼ sanitation, hygiene; ▲ water contamination
Deforestation and new habitation	Dengue	Water-collecting trash, ▲ <i>Aedes aegypti</i> mosquito breeding sites
	Cutaneous leishmaniasis	▲ proximity, sandfly vectors
	Malaria	▲ Breeding sites and vectors, immigration of susceptible people
Reforestation	Oropouche	▲ contact, breeding of vectors
	Visceral leishmaniasis	▲ contact with sandfly vectors
	Lyme disease	▲ tick hosts, outdoor exposure
Ocean warming	Red tide	▲ Toxic algal blooms
Elevated precipitation	Rift valley fever	▲ Pools for mosquito breeding
	Hantavirus pulmonary syndrome	▲ Rodent food, habitat, abundance

▲ increase ▼ reduction

7 How much disease would climate change cause?

To inform policies, an estimation of the approximate magnitude of the health impacts of climate change is needed. This will indicate which particular impacts are likely to be greatest and in which regions, and how much of the climate-attributable disease burden could be avoided by emissions reduction. It will also guide health-protective strategies.

The global burden of disease attributable to climate change has been estimated as part of a comprehensive World Health Organization project.¹ This project sought to quantify disease burdens attributable to 26 environmental, occupational, behavioural and life-style risk factors in 2000, and at selected future times up to 2030.

Disease burdens and summary measures of population health

The disease burden comprises the total amount of disease or premature death within the population. To compare burden-fractions attributable to several different risk factors requires, first, knowledge of the severity/disability and duration of the health deficit, and, second, the use of standard units of health deficit. The widely-used Disability-Adjusted Life Year (DALY)² is the sum of:

- years of life lost due to premature death (YLL)
- years of life lived with disability (YLD).

YLL takes into account the age at death. YLD takes into account disease duration, age at onset, and a disability weight reflecting the severity of disease.

To compare the attributable burdens for disparate risk factors we need to know: (i) the baseline burden of disease, absent the particular risk factor, (ii) the estimated increase in risk of

disease/death per unit increase in risk factor exposure (the “relative risk”), and (iii) the current or estimated future population distribution of exposure. The avoidable burden is estimated by comparing projected burdens under alternative exposure scenarios.

Disease burdens were estimated for five geographical regions (Figure 7.1). The attributable disease burden was estimated for the year 2000. For the years 2010, 2020 and 2030, the climate-related relative risks of each health outcome under each climate change scenario, relative to the situation if climate change did not occur, were

estimated.³ The baseline scenario is 1990 (the last year of the period 1961 to 1990 – the reference period used by the World Meteorological Organization and IPCC).

The future exposure scenarios assume the following projected GHG emission levels

1. Unmitigated emission trends (approximating the IPCC "IS92a" scenario)
2. Emissions reduction, achieving stabilization at 750 ppm CO₂-equivalent by 2210 (s750)
3. More rapid emissions reduction, stabilizing at 550 ppm CO₂-equivalent by 2170 (s550).

Figure 7.1 Estimated impacts of climate change in 2000 by region

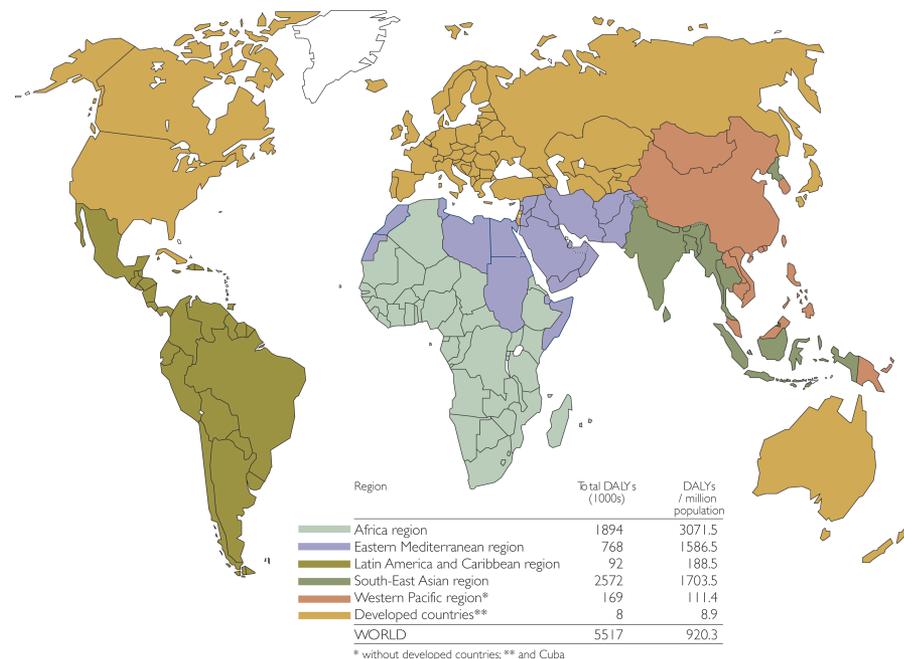


Table 7.1. Health outcomes considered in this analysis

Type of outcome	Outcome	Incidence/Prevalence
Food and water-borne disease	Diarrhoea episodes	Incidence
Vector-borne disease	Malaria cases	Incidence
Natural disasters*	Fatal unintentional injuries	Incidence
Risk of malnutrition	Non-availability of recommended daily calorie intake	Prevalence

*All natural disaster impacts are separately attributed to coastal floods and to inland floods/landslides

Health outcomes assessed

Only some of the health outcomes associated with climate change are addressed here (Table 7.1). These were selected on the basis of: (a) sensitivity to climate variation, (b) projected future importance, and (c) availability/feasibility of quantitative global models.

Additional likely health impacts that are currently not quantifiable include those due to:

- changes in air pollution and aeroallergen levels
- altered transmission of other infectious diseases
- effects on food production via climatic influences on plant pests and diseases
- drought and famine
- population displacement due to natural disasters, crop failure, water shortages
- destruction of health infrastructure in natural disasters
- conflict over natural resources
- direct impacts of heat and cold (morbidity).

All independently-published models linking climate change to quantitative, global, estimates of health impacts (or health-affecting impacts – e.g. food yields) were reviewed. Where global models do not exist, local or regional projections were extrapolated. Models were selected according to their assessed validity. Linear interpolation was used to estimate relative risks for inter-scenario years.

Summary of results

Climate change will affect the pattern of deaths from exposure to high or low temperatures. However, the effect on actual disease burden cannot be quantified, as we do not know to what extent deaths during thermal extremes are in sick/frail persons who would have died soon anyway.

In 2030 the estimated risk of diarrhoea will be up to 10% higher in some regions than if no climate change occurred. Because

few studies have characterized this particular exposure-response relationship, these estimates are uncertain.

Estimated effects on malnutrition vary markedly among regions. By 2030, the relative risks for unmitigated emissions, relative to no climate change, vary from a significant increase in the South-East Asia region to a small decrease in the Western Pacific. Overall, although the estimates of changes in risk are somewhat unstable because of regional variation in rainfall, they refer to a major existing disease burden entailing large numbers of people.

The estimated proportional changes in the numbers of people killed or injured in coastal floods are large, although they refer to low absolute burdens. Impacts of inland floods are projected to increase by a similar proportion, and would generally cause a greater acute rise in disease burden. While these proportional increases are similar in developed and developing regions, the baseline rates are much higher in developing countries.

Changes in various vector-borne infectious diseases are projected. This is particularly so for malaria in regions bordering current endemic zones. Smaller changes would occur in currently endemic areas. Most temperate regions would remain unsuitable for transmission, because either they

remain climatically unsuitable (e.g., most of Europe) or socioeconomic conditions are likely to remain unsuitable for reinvasion (e.g., southern United States). Uncertainties relate to how reliable is extrapolation between regions, and to whether potential transmission would become actual transmission.

Application of these models to current disease burdens suggests that, if our understanding of broad relationships between climate and disease is realistic, then climate change may already be affecting human health, and that health burdens will increase with increasing climate change.

The total current estimated burden is small relative to other major risk factors measured under the same framework. However, in contrast to many other risk factors, climate change and its associated risks are increasing rather than decreasing over time.

8 Stratospheric ozone depletion, ultraviolet radiation and health

Strictly, stratospheric ozone depletion is not part of “global climate change”, which occurs in the troposphere. There are, however, several recently described interactions between ozone depletion and greenhouse gas-induced warming.

Scientists 100 years ago would have been incredulous at the idea that, by the late twentieth century, humankind would be affecting the stratosphere. Yet, remarkably, human-induced depletion of stratospheric ozone has recently begun – after 8,000 generations of *Homo sapiens*.

Stratospheric ozone absorbs much of the incoming solar ultraviolet radiation (UVR), especially the biologically more damaging, shorter-wavelength, UVR. We now know that various industrial halogenated chemicals such as the chlorofluorocarbons (CFCs – used in refrigeration, insulation and spray-can propellants) and methyl bromide, while inert at ambient Earth-surface temperatures, react with ozone in the extremely cold polar stratosphere. This destruction of ozone occurs especially in late winter and early spring.

During the 1980s and 1990s at northern mid-latitudes (such as Europe), the average year-round ozone concentration declined by around 4% per decade: over the southern regions of Australia, New Zealand, Argentina and South Africa, the figure approximated 6–7%. Estimating the resultant changes in actual ground-level ultraviolet radiation remains technically complex. However, exposures at northern mid-latitudes, for example, are likely to peak around 2020, with an estimated 10% increase in

effective ultraviolet radiation relative to 1980s levels.¹

In the mid-1980s, governments recognized the emerging hazard from ozone depletion. The Montreal Protocol of 1987 was adopted, widely ratified, and the phasing out of major ozone-destroying gases began. The protocol was tightened in the 1990s. Scientists anticipate a slow but near-complete recovery of stratospheric ozone by the middle of the twenty-first century.

Main types of health impacts

The range of certain or possible health impacts of stratospheric ozone depletion are listed in Table 8.1, with a summary evaluation of the evidence implicating UVR in their causation.

Many epidemiological studies have implicated solar radiation as a cause of skin cancer (melanoma and other types) in fair-skinned humans.² Recent assessments by the United Nations Environment Program project increases in skin cancer incidence and sunburn severity due to stratospheric ozone depletion³ for at least the first half of the twenty-first century (and subject to changes in individual behaviours).

The groups most vulnerable to skin cancer are white Caucasians, especially those of Celtic descent living in areas of high ambient UVR. Further, culturally-based

Table 8.1 Summary of possible effects of solar ultraviolet radiation on human health

Effects on skin

- Malignant melanoma
- Non-melanocytic skin cancer – basal cell carcinoma, squamous cell carcinoma
- Sunburn
- Chronic sun damage
- Photodermatoses

Effects on the eye

- Acute photokeratitis and photoconjunctivitis
- Climatic droplet keratopathy
- Pterygium
- Cancer of the cornea and conjunctiva
- Lens opacity (cataract) – cortical, posterior subcapsular
- Uveal melanoma
- Acute solar retinopathy
- Macular degeneration

Effect on immunity and infection

- Suppression of cell mediated immunity
- Increased susceptibility to infection
- Impairment of prophylactic immunization
- Activation of latent virus infection

Other effects

- Cutaneous vitamin D production – prevention of rickets, osteomalacia and osteoporosis
 - possible benefit for hypertension, ischaemic heart disease and tuberculosis
 - possible decreased risk for schizophrenia, breast cancer, prostate cancer
 - possible prevention of Type 1 diabetes
- Altered general well-being
 - sleep/wake cycles
 - seasonal affective disorder
 - mood

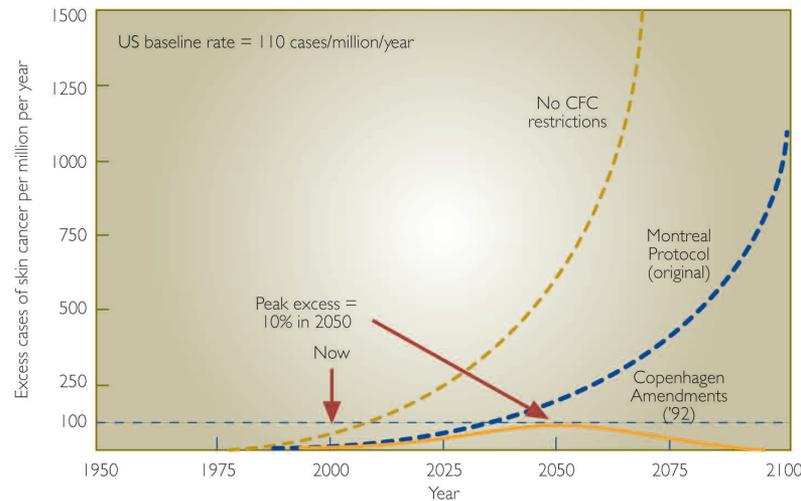
Indirect effects

- Effects on climate, food supply, infectious disease vectors, air pollution, etc

behavioural changes have led to much higher UV exposure, through sun-bathing and skin-tanning. The marked increase in skin cancers in western populations over recent decades reflects, predominantly, the combination of background, post-migration, geographical vulnerability and modern behaviours.

Scientists expect the combined effect of recent stratospheric ozone depletion and its continuation over the next 1–2 decades to be (via the cumulation of additional

Figure 8.1. Estimates of ozone depletion and skin cancer incidence to examine the Montreal Protocol achievements. (Source: Adapted from reference 6)



UVB exposure), an increase in skin cancer incidence in fair-skinned populations living at mid to high latitudes.³ The modelling of future ozone levels and UVR exposures study has estimated that, in consequence, a ‘European’ population living at around 45 degrees North will experience, by 2050, an approximate 5% excess of total skin cancer incidence (assuming, conservatively, no change in age distribution). The equivalent estimation for the US population is for a 10% increase in skin cancer incidence by around 2050.

Laboratory studies demonstrate that exposure to UVR, in particular to UVB, in various mammalian species induces lens opacification. The epidemiological

evidence for a role of UVR in human lens opacities is mixed. Cataracts are more common in some (but not all) countries with high UVR levels.

In humans and experimental animals, UVR exposure, including within the ambient environmental range, causes both localised and whole-body immunosuppression.⁴ UVR-induced immunosuppression could influence patterns of infectious disease. It may also influence the occurrence and progression of various autoimmune diseases and less certainly, vaccine efficacy.⁵

Finally, there is a wider, ecological, dimension to consider. Ultraviolet radiation impairs the molecular

chemistry of photosynthesis both on land (terrestrial plants) and at sea (phytoplankton). This could affect world food production, at least marginally, and thus contribute to nutritional and health problems in food-insecure populations. However, as yet there is little information about this less direct impact pathway.

Conclusion

Encouraging total sun avoidance (with the related notion of solar radiation as a “toxic” exposure) is a simplistic response to the hazards of increased ground-level UVR exposure due to stratospheric ozone depletion, and should be avoided. Any public health messages concerned with personal UVR exposure should consider the benefits as well as the adverse effects. Nevertheless, we must be alert to the potential increase in some particular risks to health posed by stratospheric ozone depletion.

9

National assessments of health impacts of climate change

Estimates, even if approximate, of the potential health impacts of climate change are an essential input to policy discussion on reducing greenhouse gas emissions and on social adaptation to climate change. Societies must respond despite the unavoidable uncertainties. Indeed, national governments have a responsibility, under the UN's Framework Convention on Climate Change (1992), to carry out formal assessments of the risk to their population's health posed by global climate change.

Health impact assessment (HIA) has been defined as “a combination of procedures, methods and tools by which a policy, project or hazard may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population”.¹ Despite recent advances in health impact assessment methods, its integration into mainstream policy-making has yet to be satisfactorily achieved. Besides, impact assessments typically refer to health impacts over the next 10 to 20 years (e.g. due to current smoking rates, obesity levels, or population ageing), rather than the 50 to 100 year time-scale appropriate to climate change projections. So there is need for scenario-based impact assessments that incorporate, and communicate, a higher level of uncertainty. The steps in climate change impact and adaptation assessment are shown in figure 9.1.²

Several types of national health impact assessments have been undertaken. A basic assessment identifies the types, but not much about the magnitudes, of potential impacts. In contrast, comprehensive well-funded and well-supported assessments are undertaken. For example, in the United States assessment, published in 2000, population health was one of the five target sectors included in the 16 detailed regional assessments and in the overall assessment. The US assessment involved stakeholder participation and extensive consultation and peer review.³ Further comparative details of two national assessments are shown in the box.

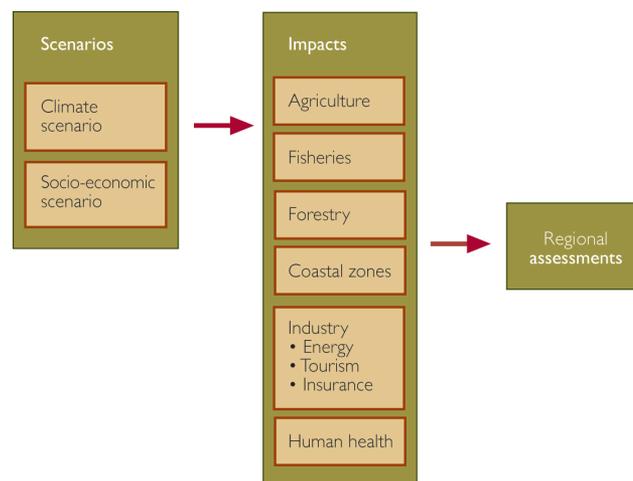
Several countries, including the USA, Canada, the UK and Portugal, have conducted comprehensive multi-sectoral assessments. Assessments in

developing countries have been undertaken only under the auspices of donor-funded capacity-building initiatives. (Other sub-national or local assessments of potential health impacts may have been undertaken for climate change, but, if so, such studies are in the “grey” literature, not widely available.) The outcomes listed refer to the likely health impacts reported for that particular country. The level of uncertainty accompanying these estimates is usually not described. Vector-borne diseases, particularly malaria, have been widely addressed. Other impacts, such as from weather disasters, have been less well addressed.

Out of these experiences, several conclusions can be drawn:

- Assessments should be driven by region and country priorities in order to determine which health impacts are considered. No single set of guidelines covers all health and institutional situations.
- HIA is a policy tool, therefore the actual process of conducting assessments, particularly the involvement of stakeholders, is very important.
- Assessments should set an agenda for future research. Nearly all the assessments done to date have identified research gaps, and they often specify detailed research questions.
- Assessment should be linked to follow-up activities such

Figure 9.1. Steps in climate change impact and adaptation assessment



Box: Comparing Assessments: UK and Fiji

The UK assessment concentrated on producing quantitative results for the following health outcomes⁴, for three time periods and for four climate scenarios:

- Heat-related and cold-related deaths and hospital admissions
- Cases of food poisoning
- Changes in distribution of *Plasmodium falciparum* malaria (global) and tick-borne encephalitis (Europe), and in seasonal transmission of *P. vivax* malaria (UK)
- Cases of skin cancer due to stratospheric ozone depletion.

The large uncertainty surrounding these estimates was acknowledged. The main conclusions of the report were the health impacts of increases in river and coastal flooding, and severe winter gales. This report also clearly addressed the balance between the potential benefits and adverse impacts of climate change: the potential decline in winter deaths due to milder winters is much larger than the potential increase in heat-related deaths. Climate change is also anticipated to lessen air pollution-related illnesses and deaths, except for those associated with tropospheric ozone, which will form more readily at higher temperatures.

The Fijian assessment addresses health impacts in the context of current health services. Fiji's

main concerns were dengue fever (recent epidemic in 1998), diarrhoeal disease and nutrition-related illness. The islands are malaria free and an anopheline mosquito vector population has not been established despite a suitable climate. Hence, the risk of introduction and establishment of malaria and other mosquito-borne diseases due to climate change was considered to be very low. Filariasis, an important vector-borne disease on the islands, is likely to be increased by warmer temperatures. The distribution of the vector (*Aedes polynesiensis*) may also be affected by sea level rise, because it breeds in brackish water. A dengue fever transmission model was incorporated into a climate impacts model developed for the Pacific Islands (PACCLIM). The modelling indicates that climate change may extend the transmission season and geographic distribution in Fiji.

Diarrhoeal disease may increase in Fiji because of increased temperature and altered patterns of rainfall. No evidence was presented on the association between flooding or heavy rainfall and cases of diarrhoea. The 1997/1998 drought (associated with El Nino) had widespread health impacts, including diarrhoeal disease, as monitoring and updated reports. malnutrition and micronutrient deficiency in children and infants.⁵

The development of formal guidelines for the national assessment of health impacts will improve methods used, will achieve some standardization, and will facilitate the development of relevant indicators. Health Canada has prepared an initial framework⁶, proposing that there are three distinct phases to the assessment task:

1. Scoping: to identify the climate change problem (concerns of vulnerable groups) and its context, describe the current situation (health burdens and risks) and identify key partners and issues for the assessment.
2. Assessment: estimations of future impacts and adaptive capacity, and evaluation of adaptation plans, policies and programmes.
3. Risk management: actions to minimize the impacts on health, including follow-up assessments.

This type of health impact assessment, in relation to large-scale climatic-environmental changes, requires guidelines that accord with the mainstream HIA framework of WHO and other international agencies. Achieving this would help to move the climate change policy discussion beyond the environmental impact domain and into the social and public health impacts arenas. Currently, in most countries, sector differentiation and the associated policy environment neither

facilitates nor fosters intersectoral collaboration. Within the health sector, resources are allocated primarily in relation to dealing with existing problems, taking some account of the relative burden of disease.

A major shortcoming of many climate change health impact assessments has been the superficial treatment of the population's adaptive capacities and policy options. Strategies to enhance population adaptation should promote measures that are not only appropriate for current conditions, but that also build the capacity to identify and respond to unexpected future stresses/hazards. The restoration and improvement of general public health infrastructure will reduce population vulnerability to the health impacts of climate change. In the longer-term, and more fundamentally, improvements in the social and material conditions of life and the reduction of inequalities within and between populations are required for sustained reduction in vulnerability to global environmental change.

Monitoring the health effects of climate change

Both the detection and measurement of health effects of climate change are necessary as evidence to underpin national and international policies to protect public health, including mitigation of greenhouse gas emissions.

Good evidence requires good data. The climate varies naturally as well as in response to human influences, and, in turn, climate is only one of many determinants of population health. Therefore, assessing the health impacts of climate change poses challenges. Further, the process of climate change is detectable only over decades, and the resultant health impacts will be similarly slow to emerge.

Monitoring is “the performance and analysis of routine measurements aimed at detecting changes in the environment or health of populations”.¹ In many public health investigations, it is possible to measure changes in a defined health impact and to attribute this trend to changes in a directly-acting risk factor. However, the monitoring of the impacts of climate change on health is more complex. There are three main issues:

(i) Distinguishing apparent from real “climate change”

Climate is always fluctuating naturally, and many indices of health show seasonal and interannual fluctuation. The demonstration of such a relationship provides no direct evidence that climate change per se has occurred — rather, it merely confirms that these diseases have a seasonal or climatic dependence. An excess of heat-related deaths in a particularly hot summer, or even a succession of hot summers, indicates the potential for climate change to increase mortality, but

it does not prove that mortality has increased as a result of climate change. That would require evidence of a change in the 'baseline' climate conditions – i.e. that the sequence of hot summers was exceptional, and due to climate change rather than random variation.

(ii) Attribution

Because climate is one of many influences on health, the attribution of an observed change in population health to an associated change in climate is not straightforward. The influence of concurrent changes in other environmental, social or behavioural factors must be first allowed for.

(iii) Effect modification

Over time, as the climate changes, other changes may also occur that alter the population’s vulnerability to meteorological influences. For example, vulnerability to extreme weather events, including floods and storms, will depend on where and how residential housing is built, what flood protection measures are introduced, and how land-use is changed. Effective monitoring must include parallel measurements of population and environmental data, to allow study of potential modifying influences.

General Principles

The principal criteria for selecting diseases and settings for monitoring should include the following:

- Evidence of climate sensitivity – to be demonstrated through

either observed health effects of temporal or geographical climate variation, or evidence of climate effects on components of the edisease transmission process in the field or laboratory.

- Significant public health burden – monitoring should be preferentially targeted towards significant threats to public health. These may be disease with a high current prevalence and/or severity, or considered likely to become prevalent under conditions of climate change.
- Practicality – logistical considerations are important given that monitoring requires dependable and consistent longterm recording of health-related indices and other environmental parameters. Monitoring sites should be chosen where change is most likely to occur and where appropriate capacity for reliable measurement exists.

Data Requirements and Sources

The data needed for monitoring climate effects on health comprise: (i) climatic variables; (ii) population health markers; and (iii) other nonclimatic explanatory factors (Table 10.1).

The choice of non-climatic variables will depend on the specific disease, but the principal categories of confounding or modifying factors include:

- age structure of population
- underlying rates of disease, especially cardiovascular and

- respiratory disease and diarrhoeal illness
- level of socio-economic development
 - environmental conditions, e.g. land-use, air quality, housing conditions
 - quality of health-care
 - specific control measures, e.g. vector control programmes.

Specific Categories of Health Impacts: Data Needs, Opportunities

To monitor the health effects of thermal extremes, reliable long time-series of temperature and mortality/morbidity data are available in many countries. An important focus of research data

should be the assessment of how the temperature-mortality/morbidity relationship is modified by individual, social and environmental factors. Existing databases (e.g. EMDAT) for extreme weather events may be a key resource. To maximize their usefulness, complete and consistent reporting of extreme weather events across a wide geographical area, along with standard definitions of events and methods of attribution, is needed.

Current monitoring data can provide only a broad quantification of the relationship between climate and most vector-borne disease. Assessment of the climate contribution to long-term trends

requires linked data on factors such as land-use, host abundance and intervention measures. Clearer understanding of relationships should result from high-quality serial data on vectors at a modest number of sites within or at the margins of endemic areas. Data from sites along specified transects could indicate changing vector distributions (including altitude). Geographical comparisons based on remote sensing data may give additional insights into disease trends.

Conclusion

With all forms of monitoring, interpretation of evidence will be strengthened by procedures for

standardization, training and quality assurance/quality control. Long time-series of health changes in populations in relation to steep (i.e. sensitive) climate-disease relationships will be the most informative. Such monitoring will become more effective through international collaboration and integration with existing surveillance networks.

Table 10.1. Data required to monitor climate impacts on health

	Principal health outcomes	Which populations/ locations to monitor	Sources and methods for acquiring health data	Meteorological data	Other variables
Thermal extremes	Daily mortality; hospital admissions; clinic/emergency room attendance;	Urban populations, especially in developing countries	National and sub-national death registries (e.g. city specific data)	Daily temperatures (min/max or mean) & humidity	Confounders: influenza & other respiratory infections; air pollution Modifiers: housing conditions (e.g. household/workplace air conditioning), availability of water supplies
Extreme weather events (floods, high winds, droughts)	Attributed deaths; hospital admissions; infectious disease surveillance data; (mental health); nutritional status	All regions	Use of sub-national death registries; local public health records	Meteorological event data: extent, timing & severity	Disruption/contamination of food & water supplies; disruption of transportation. Population displacement The above parameters will have an indirect impact on health
Food- & water-borne disease	Relevant infectious disease deaths & morbidity	All regions	Death registries; national & sub-national surveillance notifications	Weekly/daily temperature; rainfall for water-borne disease	Long term trends dominated by host-agent interactions (e.g. S enteritidis in poultry) whose effects are difficult to quantify. Indicators may be based on examination of seasonal patterns.
Vector-borne disease	Vector populations; disease notifications; temporal and geographical distributions	Margins of geographical distribution (e.g. changes with latitude, altitude) and temporality in endemic areas	Local field surveys; routine surveillance data (variable availability)	Weekly/daily temperature, humidity and rainfall	Land use; surface configurations of freshwater

11 Adaptation and adaptive capacity, to lessen health impacts

Even if greenhouse gas emissions are reduced in the near future, Earth's climate will continue to change. Hence, adaptation strategies are needed to reduce disease burdens, injuries, disabilities and deaths.

The IPCC has defined the following two closely-related terms:¹

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with consequences.

The extent to which human health is affected depends on: (i) the exposures of populations to climate

change and its environmental consequences, (ii) the sensitivity of the population to the exposure, and (iii) the ability of affected systems and populations to adapt (Figure 11.1). We therefore need to understand how decisions are made about adaptation, including the roles of individuals, communities, nations, institutions and private sector.

Adaptation and prevention

Many adaptive measures have benefits beyond those associated with climate change. The rebuilding and maintaining of public health infrastructure is often viewed as the “most important, cost-effective and urgently needed” adaptation strategy.¹ This includes public health training, more effective

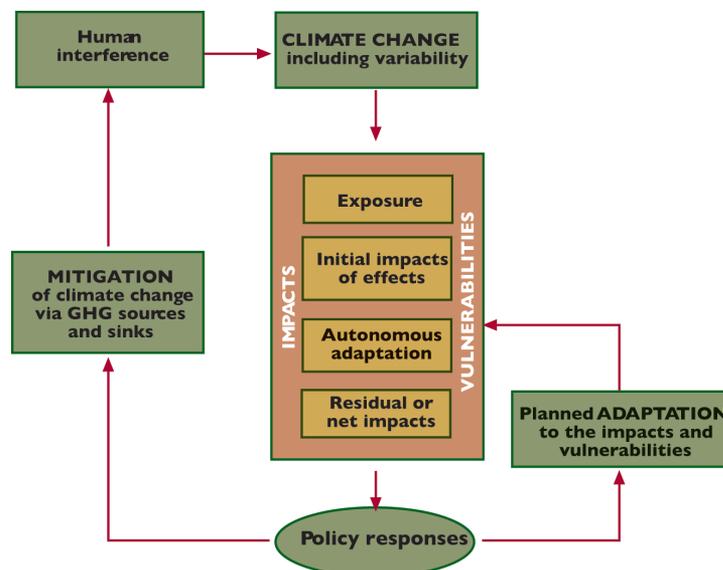
surveillance and emergency response systems, and sustainable prevention and control programs. Extreme weather events can have vastly different impacts because of differences in the target population's coping capacity. For example, cyclones in Bangladesh in 1970 and 1991 were estimated to have caused 300,000 and 139,000 deaths respectively.² In contrast, Hurricane Katrina struck the United States in 2005, causing more than 1,450 deaths in Louisiana.³ Climate-related adaptation strategies must therefore be considered in relation to broader characteristics – such as population growth, poverty, sanitation, health care, nutrition, and environmental degradation – that influence a population's vulnerability and capacity to adapt.

Adaptations that enhance a population's coping ability may protect against current climatic variability as well as against future climatic changes. Such “no-regrets” adaptations may be especially important for less developed countries with little current coping capacity.

Adaptive capacity

Adaptive capacity refers to both actual and potential features. Thus, it encompasses both current coping ability and the strategies that expand future coping ability. For example, access to clean water is part of the current coping

Figure 11.1. Relationships between vulnerability and impacts (including both risks and opportunities) and society's main response options – i.e., mitigation of greenhouse gas emissions and adaptation (Source: reference 1)



capacity for developed countries – but represents potential adaptive capacity in many areas of less developed countries.

Highly-managed systems, such as agriculture and water resources in developed countries, are thought to be more adaptable than less-managed or natural ecosystems. Unfortunately, some components of public health systems are often relaxed when a particular health threat recedes. For example, the threat of infectious diseases appeared to be retreating thirty years ago because of advances in antibiotic drugs, vaccines and pesticides. Today, however, there is a general resurgence of infectious diseases – and relevant public health measures need to be reinvigorated.

The main determinants of a community's adaptive capacity are: economic wealth, technology, information and skills, infrastructure, institutions, and equity. Adaptive capacity is also a function of current population health status and pre-existing disease burdens.

Economic resources

Wealthy nations are better able to adapt because they have the economic resources to invest, and to offset the costs of adaptation. In general, poverty enhances vulnerability – and we live in a world in which approximately one-fifth of the world's population lives on less than US\$1 per day.

Technology

Access to technology in key sectors and settings (e.g., agriculture, water resources, health-care, urban design) is an important determinant of adaptive capacity. Many health-protecting adaptive strategies involve technology – some of which is well established, some new and still being disseminated, and some still being developed to enhance coping with a changing climate.

The health risks from proposed technological adaptations should be assessed in advance. For example, increased air conditioning would protect against heat stress, but could increase emissions of greenhouse gases and other air pollutants. Poorly designed coastal "defences" may increase vulnerability to tidal surges if they engender false security and promote low-lying coastal settlements.

Information and skills

In general, countries with more "human capital" or knowledge have greater adaptive capacity.¹ Illiteracy increases a population's vulnerability to many problems.⁴ Health systems are labor-intensive and require qualified and experienced staff, including those trained in the operation, quality control, and maintenance of public health infrastructure.⁵

Infrastructure

Infrastructure specifically designed to reduce vulnerability to climate

variability (e.g., flood control structures, air conditioning, and building insulation) and general public health infrastructure (e.g., sanitation facilities, wastewater treatment systems, laboratory buildings) enhance adaptive capacity. However, infrastructure (especially if immovable) can be adversely affected by climate, especially extreme events such as floods and hurricanes.

Institutions

Countries with weak institutional arrangements have less adaptive capacity than countries with well established institutions.¹ For example, institutional and managerial deficiencies contribute to Bangladesh's vulnerability to climate change.

Collaboration between public and private sectors can enhance adaptive capacity. For example, the Medicines for Malaria Venture – a joint public-private initiative to develop new antimalarial drugs – is developing new products for use in developing countries.

Equity

Adaptive capacity is likely to be greater when access to resources within a community, nation, or the world is equitably distributed⁶. Under-resourced and marginal populations lack adaptive resources. While universal access to quality services is fundamental to public health, many still lack access to health care. Overall, the developing

world, with 10 per cent of the world's health resources, carries 90 per cent of the disease burden.⁵

Health Status and Pre-existing Disease Burdens

Population well-being is an important ingredient and determinant of adaptive capacity. Great progress has been achieved in public health, yet 170 million children in poor countries are underweight, of whom over three million die each year. Many countries face the double burden of increases of non-communicable diseases, but with continued prevailing infectious diseases.

Conclusions

Adaptive strategies intended to protect public health will be needed whether or not actions are taken to mitigate climate change. Building capacity is an essential preparatory step. Adapting to climate change will require more than financial resources, technology, and public health infrastructure. Education, awareness-raising and the creation of legal frameworks, institutions and an environment that enables people to take well-informed, long-term, sustainable decisions are all needed.

12

From science to policy: developing responses to climate change

Change

Policy choices are guided by several principles. These include considerations of equity, efficiency and political feasibility. The usual public health ethics considerations may also apply: respect for autonomy, nonmaleficence (not doing bad), and justice and beneficence (doing good).

To make informed decisions about climate change, policy-makers will need timely and useful information about the possible consequences of climate change, people's perceptions of those consequences, available adaptation options, and the benefits of slowing the rate of climate change.¹ The challenge for researchers is to provide this information.

Once policy-makers have received input from the impact assessment community, they must integrate this information into a broader policy portfolio. Response options include actions to mitigate greenhouse gas emissions to slow the rate of climate change; measures to adapt to a changing climate in order to increase society's resilience to the changes that have occurred and that are coming; activities to increase the public's awareness of the climate change issue; investments in monitoring and surveillance systems; and investments in research to reduce key policy-relevant uncertainties.

Climate change, however, should not be considered in isolation from other global environmental stresses. Further, policy-makers usually deal with multiple social objectives (e.g., poverty elimination, promotion of economic growth, protection of cultural resources), while competing stakeholder desires compound the allocation of scarce resources. Climate change should therefore be viewed as part of the

larger challenge of sustainable development.

Using the information provided by the research community, risk managers must make decisions despite the existence of scientific uncertainties. Policy-focused assessments analyze the best available scientific and socioeconomic information to answer questions being asked by risk managers. They characterize and, if possible, quantify scientific uncertainties to the extent possible, and explain the potential implications of the uncertainties for the outcomes of concern to the decision makers. Ultimately, it is up to society to decide whether a perceived risk warrants action. But the scientific uncertainty, by itself, does not excuse delay or inaction.

Decision-making criteria

Many different criteria exist for making decisions about climate change policy. Two approaches to decision making that are often discussed are the "precautionary principle" and "benefit-cost" analysis.

The precautionary principle is a risk management principle applied when a potentially serious risk exists, but significant scientific uncertainty also exists.² The precautionary principle allows some risks to be deemed unacceptable not because they have a high probability of occurring, but because the consequences if

they occur may be severe or irreversible. This principle was featured in the 1992 Rio Declaration on Environment and Development as Principle 15, stating: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Another widely used approach is the "benefit-cost" criterion, weighting the expected benefits and costs of a proposed action. Questions arise about how benefits and costs should be measured, and how they should be compared among different societies. The benefit-cost criterion emphasizes the efficient use of scarce resources – but does not deal with equity. Nor does it deal well with consequences that are displaced into the future, and therefore, by economic convention, often discounted. Climate change has the potential for catastrophic outcomes in the distant future, the "present value" of which would be small if discounted. Despite these concerns, benefit-cost analysis should not be dismissed. This would only deprive decision makers of one set of insightful information.

Response options

The mitigation of greenhouse gases provides a mechanism for slowing, and perhaps eventually halting, the buildup of greenhouse gases

in the atmosphere. A slowing of the rate of warming could yield important benefits in the form of reduced impacts to human health and other systems; however, the inertia in the climate system means that there will be a significant temporal lag between emission reduction and slowing in the rate of warming.

Adaptation (discussed in chapter 11) is another important response option. Such actions enhance the resilience of vulnerable systems, thereby reducing potential damages from climate change and climate variability.

Communication of information about climate change, its potential health impacts, and response strategies, is itself a public policy response to climate change. So, too, are the development and implementation of monitoring and surveillance systems, and investments in research. Monitoring and surveillance systems are integral and essential to providing the information needed to support decisions by public health officials.

Building the bridge from science to policy: policy-focused assessment

Policy-focused assessment is a process that can help resource managers and other decision makers meet the challenge of assembling an effective policy portfolio. It is a process by which the best-available scientific information can be

translated into terms that are meaningful to policy makers.

A policy-focused assessment is more than just a synthesis of scientific information or an evaluation of the state of science. Rather, it involves the analysis of information from multiple disciplines – including the social and economic sciences – to answer the specific questions being asked by stakeholders. And it includes an analysis of adaptation options to improve society's ability to respond effectively to risks and opportunities as they emerge. Formulating good policy requires understanding the variability in vulnerability across population sub-groups, and the reasons for that variability.

In the assessment of adaptation options, a number of factors related to the design and implementation of strategies need to be considered. These include the fact that (1) the appropriateness and effectiveness of adaptation options will vary by region and across demographic groups; (2) adaptation comes at a cost; (3) some strategies exist that would reduce risks posed by climate change, whether or not the effects of climate change are realized; (4) the systemic nature of climate impacts complicates the development of adaptation policy; and (5) maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided.

Complicating the assessment process is the fact that there are significant scientific and socioeconomic uncertainties related to climate change and its potential consequences for human health. Uncertainties exist about the potential magnitude, timing and effects of climate change; the sensitivity of particular health outcomes to current climatic conditions (i.e., to weather, climate, and climate-induced changes in ecosystems); the future health status of potentially affected populations (in the absence of climate change); the effectiveness of different courses of action to adequately address the potential impacts; and the shape of future society (e.g., changes in socioeconomic and technological factors).

A challenge for assessors is to characterize the uncertainties and explain their implications for the questions of concern to the decision makers and stakeholders. If uncertainty is not directly addressed as part of the analysis, a health impacts assessment can produce misleading results and possibly contribute to ill-informed decisions.

Public awareness: communicating assessment results

Stakeholders should be engaged throughout an assessment process. A communication strategy must ensure access to information, presentation of information in a usable form, and guidance on

how to use the information. Risk communication is a complex, multidisciplinary, and evolving process. Often information has to be tailored to the specific needs of risk managers in specific geographic areas and demographic groups. This requires close interaction between information providers and those who need the information to make decisions.

Conclusion

Some have argued that the existence of scientific uncertainties precludes policy makers from taking action today in anticipation of climate change. This is not true. In fact, policy makers, resource managers, and other stakeholders, despite the existence of uncertainties, make decisions every day. The outcomes of these decisions may be affected by climate change. Or the decisions may foreclose future opportunities to adapt to climate change. Hence, the decision makers would benefit from information about the likely impacts of climate change. An informed decision is always better than an uninformed decision. Care must be taken to respect the boundary between assessment and policy formation. The goal of policy-focused assessment is to inform decision-makers, not to make specific policy recommendations.

Conclusions and recommendations for action

Sustainability is essentially about maintaining Earth's ecological and other biophysical life-support systems. If these systems decline, human population wellbeing and health will be jeopardised. Technology can buy time, but nature's bottom-line accounting cannot be evaded. We must live within Earth's limits. The state of human population health is thus a central consideration in the transition towards sustainability.¹

Climate change, like other human-induced large-scale environmental changes, poses risks to ecosystems, their life-support functions and, therefore, human health (Figure 13.1)^{2,3}. WHO, WMO and UNEP collaborate on issues related to climate change and health, addressing capacity building, information exchange and research promotion.

Recommendations

- *The IPCC's Fourth Assessment Report* projected that, as we continue to change atmospheric composition, global average surface temperature will rise by 1.8 to 4.0°C (best estimate) in this century,

relative to 1980–1999, along with changes in precipitation and other climatic variables. Research needs include developing innovative approaches to analysing weather and climate in relation to human health; setting up long-term data sets to answer key questions; and improving understanding of how to incorporate outputs from general circulation models of climate change into human health studies.

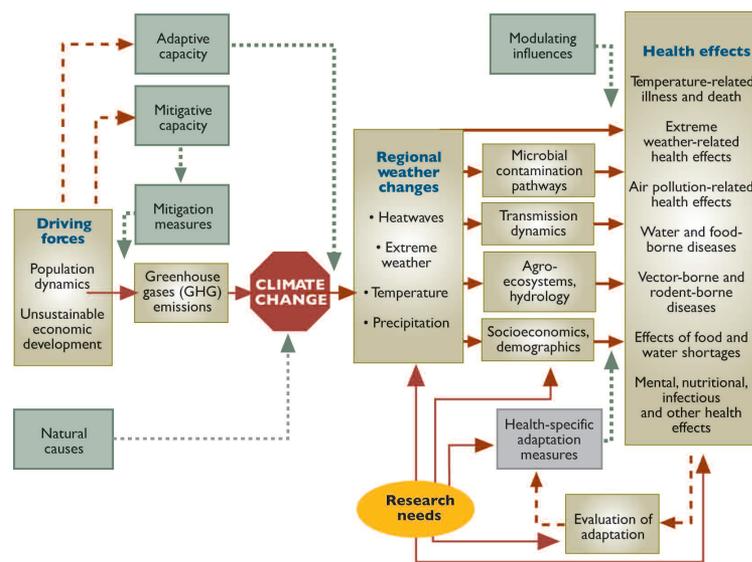
- *Reaching consensus on the science* There is increasing evidence that human health is and will increasingly be affected in many and diverse ways. Knowledge is still limited in many areas, for example on the

contribution of short-term climate variability to disease incidence; on development of early warning systems for predicting disease outbreaks and extreme weather events; and on understanding how recurring extreme events may weaken adaptive capacity.

- *Challenges for scientists* Climate change poses some special challenges, including the complexity of causal process, the unavoidable uncertainties, and temporal displacement of anticipated impacts into the future. Some key research topics to address include identifying current effects of climate change on human health; improving estimates of future impacts; and better expressing the uncertainties associated with studies of climate change and health.

- *Extreme climate events* The IPCC's Fourth Assessment Report projected changes in extreme climate events that include more, and more intense, hot days and heat waves; more intense precipitation events; increased risk of drought; increase in winds and tropical cyclones (over some areas); intensified droughts and floods with El Niño events; and increased variability in the Asian summer monsoon. Research gaps to be addressed include further modelling of relationships between extreme events and health impacts; improved understanding of factors affecting vulnerability to

Figure 13.1. Climate change and health: pathway from driving forces, through exposures to potential health impacts. Arrows under research needs represent input required by the health sector. (Modified from reference 4)



climate extremes; and assessment of the effectiveness of adaptation in different settings.

- *Infectious diseases*

Infectious diseases, especially those transmitted via insect vectors or water, are sensitive to climatic conditions. Disease incidence data is needed to provide a baseline for epidemiological studies. The lack of precise knowledge of current disease incidence rates makes it difficult to comment about whether incidence is changing as a result of climatic conditions. Research teams should be international and interdisciplinary, including epidemiologists, climatologists and ecologists to assimilate the diversity of information from these respective fields.

- *The burden of disease*

The stock of empirical evidence relating climatic trends to altered health outcomes remains sparse. This impedes estimating the range, timing and magnitude of likely future health impacts of global environmental changes. Even so, an initial attempt has been made, within the framework of the WHO Global Burden of Disease 2000 project. Analyzing only the better studied health outcomes, the climate change that occurred since the climate baseline period 1961–1990 was estimated to have caused 150,000 deaths and 5.5 million DALYS in the year 2000.⁵

- *Stratospheric ozone depletion, climate change and health*

Stratospheric ozone depletion is essentially a different process from climate change. However, greenhouse-warming is affected by many of the chemical and physical processes involved in the depletion of stratospheric ozone.⁶ Also, because of changes in climate (in addition to public information and education campaigns), patterns of individual and community sun exposure behaviour will change – duly affecting received doses of ultraviolet radiation.

- *National assessments*

Several developed and developing countries have undertaken national assessments of the potential health impacts of climate change, including reference to vulnerable areas and populations. There is a need to standardize the health impact assessment procedures, and tools and methods are being developed. More accurate climate information at the local level, particularly on climate variability and extremes, is needed.

- *Monitoring climate change impacts on human health*

Climate change is likely to affect diseases that are also influenced by other factors. Monitoring to assess climate-change impacts on health therefore requires data-gathering coupled with analytical methods able to quantify the climate-attributable portion

of such diseases. Monitoring and surveillance systems in many countries currently cannot provide useful data on climate-sensitive diseases. Less developed countries should strengthen existing systems in order to meet current needs.

- *Adapting to climate change*

Because climate change is already underway, we need adaptation policies to complement mitigation policies. Efficient implementation of adaptation strategies can significantly reduce adverse health impacts of climate change. Human populations vary in their susceptibility, depending on factors such as population density, economic development, local environmental conditions, pre-existing health status and health-care availability. Adaptation measures usually will have near-term as well as future benefits, by reducing the impacts of current climate variability. Adaptation measures can be integrated with other health strategies.

- *Responses: From science to policy*

The magnitude and character of global climate change necessitates a community-wide understanding and response, guided by policies informed by good scientific advice. A successful policy-focused assessment of the potential health impacts of climate change should include: i) a multidisciplinary assessment team; ii) responses to questions asked by all stakeholders; iii) evaluation of risk management

adaptation options; iv) identification and prioritisation of key research gaps; v) characterization of uncertainties and their implications for decision-making; and vi) tools that support decision-making processes.

Conclusion

International agreements on global environmental issues such as climate change should consider the principles of sustainable development proposed in Agenda 21 and the UNFCCC. These include the “precautionary principle”, the principle of “costs and responsibility” (the cost of pollution or environmental damage should be borne by those responsible), and “equity” – both within and between countries and over time (between generations).

Adherence to these principles would help prevent future global environmental threats and reduce existing ones. With climate change already underway, there is need to assess vulnerabilities and identify intervention/adaptation options.⁷ Early planning for health can reduce future adverse health impacts. The optimal solution, however, lies with governments, society and individuals – and requires changes in behaviour, technologies and practices to enable a transition to sustainability.

Glossary

adaptation: Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, public and private adaptation, and autonomous and planned adaptation.

anthropogenic emissions:

Emissions of greenhouse gases and aerosols associated with human activities. These include fossil fuel burning for energy, deforestation and land use changes that result in net increase in emissions.

atmosphere: The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen and oxygen, together with a number of trace gases such as argon, helium and radiatively active greenhouse gases such as carbon dioxide and ozone. In addition, the atmosphere contains water vapour, clouds, and aerosols.

biosphere: The part of the Earth's system comprising all ecosystems and living organisms in the atmosphere, on land (terrestrial biosphere), or in the oceans (marine biosphere), including derived dead organic matter such as litter, soil organic matter, and oceanic detritus.

carbon dioxide (CO₂): A naturally occurring gas as well as a by-product of burning fossil fuels and land-use changes and other industrial processes. It is the principal greenhouse gas which affects the Earth's radiative balance and the reference gas against which other greenhouse gases are measured.

chlorofluorocarbons (CFCs):

Greenhouse gases which are used for refrigeration, air conditioning, packaging, insulation, solvents, or

aerosol propellants. They are all covered under the 1987 Montreal Protocol. Since they are not destroyed in the lower atmosphere, CFCs drift into the upper atmosphere where, given suitable conditions, they break down ozone. These gases are being replaced by other compounds, including hydrochlorofluorocarbons, covered under the Kyoto Protocol.

Climate: Usually defined as the 'average weather' or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years as defined by the WMO. These relevant quantities are most often surface variables such as temperature, precipitation and wind.

climate change: Refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere. The UNFCCC defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. See also climate variability.

climate variability: Variations in the mean state and other statistics (e.g. standard deviations, the occurrence of extreme events etc) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system or to variations in

natural or anthropogenic external forcing.

Disability Adjusted Life Year

(DALY): An indicator of life expectancy combining mortality and morbidity into one summary measure of population health to account for the number of years lived in less than optimal health. It is a health measure developed for calculating the global burden of disease which is also used by WHO, the World Bank and other organizations to compare the outcomes of different interventions.

El Niño/Southern Oscillation

(ENSO): El Niño, in its original sense, is a warm water current that periodically flows along the coast of Ecuador and Peru. This event is associated with a fluctuation of the intertropical surface pressure patterns and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as the El Niño Southern Oscillation or ENSO. During an El Niño event, the prevailing trade winds weaken and the equatorial counter current strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña.

greenhouse effect: Greenhouse gases absorb infrared radiation, emitted by the Earth's surface, the atmosphere itself due to the same gases and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat

within the surface–troposphere system. This is called the ‘natural greenhouse effect’. Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing, an imbalance that can only be compensated for by an increase of the temperature of the surface–troposphere system. This is the ‘enhanced greenhouse effect’.

greenhouse gases (GHGs): Those gases in the atmosphere which absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere and clouds. Water vapour, carbon dioxide, nitrous oxide, methane and ozone are the primary greenhouse gases in the atmosphere. Moreover, there are a number of entirely human-made gases in the atmosphere, such as the halocarbons and others dealt with under the Montreal and Kyoto Protocols.

impacts: Consequences of climate change on natural systems and human health. Depending on the consideration of adaptation, we can distinguish between potential impacts and residual impacts:

- Potential impacts are all impacts that may occur given a projected change in climate, with no consideration of adaptation.
- Residual impacts are the impacts of climate change that can occur after adaptation.

Intergovernmental Panel on

Climate Change (IPCC): A group of experts established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP).

Its role is to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change, based mainly on peer reviewed and published scientific/technical literature. The IPCC has three Working Groups and a Task Force.

monitoring: Performance and analysis of routine measurements aimed at detecting changes in the environment or health status of populations. Not to be confused with surveillance although surveillance techniques may be used in monitoring.

morbidity: Rate of occurrence of disease or other health disorder within a population, taking account of the age-specific morbidity rates. Health outcomes include: chronic disease incidence/prevalence, hospitalisation rates, primary care consultations and Disability-Adjusted-Life-Years (DALYs).

mortality: Rate of occurrence of death within a population within a specified time period.

ozone: Form of the element oxygen with three atoms instead of the two that characterise normal oxygen molecules. Ozone is an important greenhouse gas. The stratosphere contains 90 % of all the ozone present in the atmosphere which absorbs harmful ultraviolet radiation. In high concentrations, ozone can be harmful to a wide range of living organisms. Depletion of stratospheric ozone, due to chemical reactions that may be enhanced by climate change, results in an increased ground-level flux of ultraviolet-B-radiation.

scenarios: A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving

forces and relationships. Scenarios are neither predictions nor forecasts and may sometimes be based on a narrative storyline.

sensitivity: Degree to which a system is affected by climate-related changes, either adversely or beneficially. The effect may be direct (e.g. a change in crop yield in response to temperature change) or indirect (e.g. damages caused by increases in the frequency of coastal flooding).

stratospheric ozone depletion: The reduction of the quantity of ozone contained in the stratosphere due to the release of greenhouse gases as a result of human activity.

stratospheric ozone layer: The stratosphere contains a layer in which the concentration of ozone is greatest, the so-called ozone layer. The layer extends from about 12 to 40 km. This layer is being depleted by human emissions of chlorine and bromine compounds. Every year, during the Southern Hemisphere spring, a very strong depletion of the ozone layer takes place over the Antarctic region, caused by human-made chlorine and bromine compounds in combination with the meteorological conditions of that region. This phenomenon is called the ozone hole.

surveillance: Continuous analysis, interpretation and feedback of systematically collected data for the detection of trends in the occurrence or spread of a disease, based on practical and standardized methods of notification or registration. Sources of data may be related directly to disease or factors influencing disease.

ultraviolet radiation (UVR): Solar radiation within a certain wavelength, depending on the type of radiation (A, B or C). Ozone absorbs strongly in the UV-C (< 280nm) and solar radiation in

these wavelengths does not reach the earth’s surface. As the wavelength is increased through the UV-B range (280nm to 315nm) and into the UV-A (315nm to 400nm) ozone absorption becomes weaker, until it is undetectable at about 340nm. The fractions of solar energy above the atmosphere in the UV-B and UV-A ranges are approximately 1.5% and 7% respectively.

UN Framework Convention on Climate Change (UNFCCC):

Convention signed at United Nations Conference on Environment and Development in 1992. Governments that become Parties to the Convention agree to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity.

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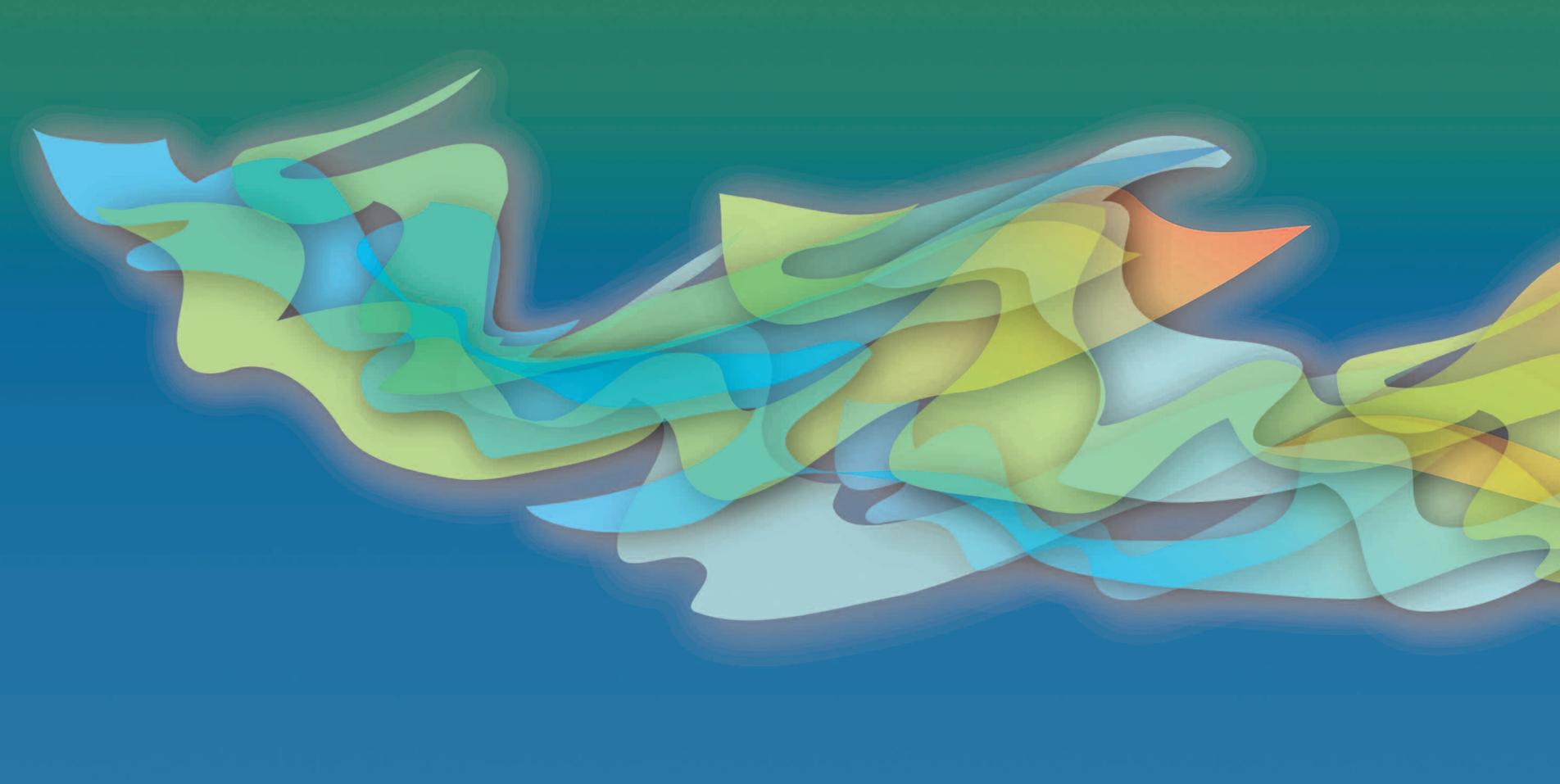
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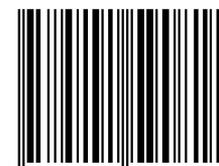
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