11. Human Health

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Executive Summary

[to be developed]

11.1. Introduction

This chapter examines what is known about the effects of climate change on human health, including estimates of the present-day burden of disease and projections of what impacts may occur in the future. We include a wide-ranging review of health outcomes that are sensitive to climate. The chapter then reviews the factors that cause populations and individuals to be particularly susceptible to ill-health caused by variations in climate, and describes interventions that may reduce the impacts of climate change on human health. The chapter includes also a section on co-benefits – significant effects on health, positive and negative, of human responses to climate change.

In the introduction we summarise the major findings on climate change from the 4th Assessment Report (AR4), and indicate, in broad terms, the most important developments in the field since AR4 was published in 2007. We begin with an outline of measures of human health, the major driving forces that act on health world-wide, recent trends in health status, and projections for the remainder of this century.

11.1.1. Background – Present State of Global Health

Definitions

There are many definitions of health, but all are concerned in one way or another with the physical, social and psychological well-being of individuals and groups. Health is both a condition for, and a consequence of, development, and there is a similar inter-dependence between a country's social and economic progress and its ability to protect its population against adverse effects of stressors such as climate change.

Which aspects of well-being are emphasized and valued most highly depends on social norms and values. However there is less diversity in the measures of deviations from (good) health. Mortality is the most commonly reported health statistic, generally in the form of a rate (the frequency of death in a given time period in a defined age group) or average life expectancy. Commonly mortality rates are adjusted or standardized to a given age-sex population structure. Life expectancy is calculated from the age-specific death rates for a population, to provide the average years lived from a given age (e.g. from birth). Measures of non-fatal health outcomes include the occurrence of disease and the quality of life. The former is commonly expressed as incidence i.e. by the number of new cases occurring in a given population per year or by prevalence, the number of cases of a given disease in a population prevailing at a specific point in time (eg breast cancer incidence or blindness prevalence).

Quality of life survey instruments often focus on the level of functional impairment. They may also capture perceptions of the extent to which a disease reduces the full quality of a healthy life. The most commonly cited of these metrics is the Disability Adjusted Life Year (DALY), which combines years in full health lost due to premature death and years lived with less-than-ideal healthiness due to disability. DALYs are widely used in estimates of population health, not only because this measure combines mortality and morbidity, but also because it allows aggregation of impacts that share a common underlying cause. Hence the concept of the "burden of disease" attributable to tobacco use, air pollution and other environmental exposures (including climate change). (World Health Organization, 2008)

Trends in Health

The 4th Assessment Report pointed to dramatic improvement in life expectancy in most parts of the world in the 20th century, and this trend has continued through the first decade of the 21st century. (Christensen *et al.*, 2009) It is important to bear in mind that rapid progress in a few countries (especially China) has swayed global averages, nevertheless most countries have experienced substantial reductions in mortality. There have been exceptions, and there remain sizable and avoidable inequalities within- and between-nations according to education, income and ethnicity. (Beaglehole and Bonita, 2008) In some countries, official statistics are so patchy in quality and coverage that it is difficult to draw firm conclusions about health trends. (Byass, 2010) Life expectancy fell in many countries in Eastern Europe in the 1980s and 1990s, and has been slow to recover. In eastern and southern Africa, HIV/AIDS contributed to a substantial rise in mortality in the 1990s with more than 20% of the adult population infected in some countries. (UNDP, 2005) In some countries this trend has reversed recently (eg Malawi, Zambia); elsewhere (eg Zimbabwe) mortality remains at very high levels. (Reniers *et al.*, 2011) At a regional level, inequalities in mortality have diminished, and convergence has been particularly marked amongst adults. (Clark, 2011) Amongst children, mortality rates continue to fall, but the greatest decreases have occurred in urban areas and in wealthy parts of the world. More than 20 countries, mostly in sub-Saharan Africa, showed no improvement in child mortality between 1990 and 2006. (United Nations, 2010)

Less is known about trends in other aspects of health than mortality. In high income countries, there are signs that the reduction in mortality has been accompanied by decline in disability and improvement in physical function. (Manton, 2008) There are improvements evident also in some of the biggest causes of ill-health in low income countries. The incidence of tuberculosis world-wide appears to be falling, albeit unevenly. It is difficult to interpret malaria statistics – reported declines in total number of cases world-wide must be treated with caution, and progress appears to be most erratic in countries with highest incidence, but the fall in deaths from malaria is encouraging. (World Health Organization, 2009b; World Health Organization, 2011) WHO estimates that the number of new cases of infection with HIV fell by about 16% between 2000 and 2008. (World Health Organization, 2011) However, not all indicators are positive. For instance, child under-nutrition, implicated in about a third of all deaths under 5 years, has become more common in a number of countries since 2005, and world-wide the number of people who are hungry appears to be increasing. (World Health Organization, 2011)

For specific causes of death, the patterns differ widely by region. The dramatic decline in cardiovascular disease in high-income countries is not seen in parts of the world that are developing rapidly, such as India and China. In those countries, the numbers of deaths from heart disease and stroke are increasing for two reasons; ageing populations and prevalent risk factors such as high blood pressure and cigarette smoking. (Samb *et al.*, 2010) Cancer and mental disorders such as depression are also reported more commonly than previously in low and middle income countries, and infectious diseases remain the cause of a substantial amount of early death and morbidity. Maternal mortality (deaths in pregnancy and childbirth) shows the greatest variation between wealthy and disadvantaged regions globally, no region is tracking sufficiently strongly to reach the Millennium Development Goal for this indicator, and progress appears to have stalled altogether in some countries. (Hogan *et al.*, 2010; World Health Organization, 2011)

Projections for Global Health in the 21st Century

Most commentators anticipate mortality rates will continue to fall world-wide, and WHO estimates the total burden of disease (measured in DALYs per capita) will be cut by as much as 30% in 2030, compared with 2004. (World

Health Organization, 2008) These projections assume that economic and social development continue without interruption, particularly among poor populations, and as already noted, the global figures are driven by trends in a few large countries (China and India in particular). Less optimistic development scenarios would undo some of the improvements that have occurred, leading for example to a steep rise in numbers of people affected by HIV/AIDS, a slow down in improvements in child health indicators, and acceleration in the number of deaths caused by tobacco and road traffic crashes. (Mathers and Loncar, 2006) In any event, the underlying causes of poor health are expected to change substantially, with much greater prominence of chronic diseases and injury. On its "baseline development" scenario, WHO projects the top three causes of burden of disease in 2030, world-wide, to be depression, ischemic heart disease and road traffic crashes. (World Health Organization, 2008)

11.1.2. Major Findings of AR4

AR4 found that climate change is already adding to the global burden of disease and premature deaths. Examples cited included changes in disease carrying vectors, new patterns of allergic conditions resulting from changed climate and an increase in deaths caused by heat waves. Looking ahead, the AR4 listed threats to health that may be aggravated by climate change, ranging from malnutrition to ground-level atmospheric pollution, altered patterns of mosquito-borne diseases, and casualties due to storms, floods and other extreme climate events. AR4 anticipated some positive effects on health (such as reduced deaths and injuries caused by extreme cold) but concluded that they would be outweighed by the negative consequences of climate change. Disease and injury due to climate change would not, according to AR4, be evenly spread, but would be concentrated in groups such as the urban poor, coastal communities, the elderly and children, and subsistence farmers.

In terms of DALYs, nearly 90% of the burden of disease due to the climate change that had occurred at the start of this century was estimated to fall on young children in developing countries, mainly because of their vulnerability to malaria, malnutrition, and diarrheal diseases. The report underlined the point that climate change does not create new diseases or other health risks, but exacerbates existing ones, particularly in populations already highly vulnerable.

While poverty is likely to be a pervasive cause of vulnerability to poor health due to climate change, AR4 concluded that economic development, on its own, would not be sufficient adaptation. The manner of development, the social distribution of the fruits of economic growth, and investments in critical institutions and services such as education and health care would be important as well as focused efforts in particular regions, for example where sea-level rise will affect populations.

11.1.3. Developments since AR4

The numbers of papers and reports on climate change and health have grown considerably since the publication of the AR4. In April 2011, there were approximately 11,000 publications on climate change cited in PubMed, the US National Library of Medicine database. Almost 7,000 of these were created after 2006. However, only a small proportion of these papers are directly relevant to this chapter. By one estimate, in the period 2006-2011 there were approximately 1,000 articles in the peer-reviewed literature that bear directly on climate change and health. (Rainer Sauerborn, personal communication, citation to be added) In addition to research papers and commentaries, there have been many reviews and international assessments that are relevant to this chapter. They include the World Development Report 2010 (The World Bank, 2009), series of papers in The Lancet (Costello *et al.*, 2009; Haines, 2009), the Climate Vulnerability 2010 report (DARA, 2010), and the 2011 UN Habitat report on cities and climate change (United Nations Human Settlements Programme, 2011).

More countries have carried out national assessments of impacts, vulnerability and adaptations to climate change, and these analyses have been included in the communications required under the UN Framework Convention on Climate Change. A summary of these assessments, as they relate to health, will be reported later in this chapter.

Since the AR4, there have been developments in the methods applied to investigate climate change and health. They include more sophisticated modeling of possible future impacts (an example being work on climate change, food security, and health outcomes) (Nelson *et al.*, 2010a) and improved measures of personal exposures to heat (Maloney and Forbes, 2010). Other developments include coupling of high quality, longitudinal mortality data sets with down-scaled meteorological data, in low income settings.

New and emerging topics – It is difficult to identify work that is absolutely novel, but there are a number of areas that have grown considerably in the last 5 years. Studies of the ways in which responses to climate change may affect health, so-called "co-benefits", have multiplied. (Haines *et al., 2009*) Another important, emerging topic is effects of greenhouse emissions other than those resulting from warming. A prime example is ocean acidification (Doney *et al.*, 2008) – the effects on calcifying marine species is well documented and the risks for coral reefs are now more closely defined than they were at the time of the AR4, but the implications for human health specifically have not been explored. The effects of heat on occupational health have been researched for decades, but renewed attention is now being paid to the links between climate change, employment, health and economic productivity. (Kjellstrom *et al.*, 2009c) There is also growing appreciation of the social upheaval and damage to population health that may arise from the interaction of large-scale food insecurity, population dislocation, and conflict. (US EPA, 2007)

11.2. Major Climate-Sensitive Health Outcomes

11.2.1. Introduction

In this section we review work done since the last Assessment on the links between climate and significant health outcomes. We concentrate on research that enlarges our understanding of the ways in which human health can be affected by variability in the climate, as shown in Figure 11-1. Discussion of the effects of climate change, up until the present and in the future, is placed later in the chapter (see Sections 11.4 and 11.5).

[INSERT FIGURE 11-1 HERE
Figure 11-1: Ways in which climate, climate variability, and climate change may influence human health.]

11.2.2. Disease and Injury due to Heat and Cold Extremes

It is obvious that heat strokes occur due to heat extremes. However, it may be difficult to determine whether other conditions are weather-related. For example, some studies indicate the association of ambient temperature with suicide (Kim *et al.*, 2011; Likhvar *et al.*, 2011; Page *et al.*, 2007) and accidents (Honda *et al.*, 1995; Ishigami *et al.*, 2008). Although the relation can be spurious in these instances, it is physiologically understandable that mortality and morbidity of circulatory diseases increase along with increase of ambient temperature; displacement of blood to skin surface may lead to cardiac pump failure. In addition, heat stroke explains only a very small fraction of deaths in very hot days. (Honda *et al.*, 1995) In this regard, all-cause mortality may be a good index for outcome. The temperature at which mortality is lowest (the so-called optimum temperature) is area dependent; warmer areas have higher optimum temperature and colder areas have lower optimum temperature. (Curriero *et al.*, 2002) In a Japanese study, the optimum temperature was not related to long term average temperature; instead it was highly correlated with 80 to 85 percentile value of daily maximum temperature. (Honda *et al.*, 2007)

Recent studies have shown mortality increases more during heat waves than would be anticipated on the basis of the temperature level alone. (Anderson and Bell, 2011; Rocklov *et al,* 2011) Also, excess deaths have been noted in younger age groups than are normally affected by heat. (Rocklov *et al,* 2011) One explanation may be that duration of extreme heat exposures compounds the cumulative stress and health risks. Some studies have shown larger effects of heat and heat waves earlier in the hot season (Anderson and Bell, 2011; D'Ippoliti *et al,* 2010). This may be testament to the importance of acclimatisation and adaptive measures, or may result from a large group in the population that is genuinely susceptible to heat early in the season (Rocklov *et al,* 2011; Rocklov *et al,* 2009). During and after the European heat wave of 2003 questions were raised as to why this event had such a devastating effect (Kosatsky, 2005). It is still not clear, but one contributing factor may have been the relatively mild influenza season the year before. Recent studies have found that when the previous year's winter mortality is low, the effect of summer heat is increased (Stafoggia *et al,* 2009). This intrinsic relationship between risk factors in winter and summer time may complicate the attribution of heat and cold effects (e.g. with climate change), given their inter-dependence.

Most analyses have focused on mortality and morbidity in relation to heat waves in high income countries, but recent studies have investigated the relation in low- and middle-income countries. (McMichael *et al*., 2008) The extreme heat wave in Europe in 2003 led to numerous epidemiological studies. The initial reports from France included age-specific rates, and concluded that a very large proportion of the extra deaths occurred in elderly people (80% above age 75). However, little mention was made of the fact that the extra heat wave-related mortality in the age range 25-64 years was substantial (approximately 1000 deaths), and only in this age range did more men than women die. The explanation may be that men were more likely to be working in very hot circumstances.

Morbidity studies based on hospital admission or emergency presentations (Hansen *et al*., 2008; Knowlton *et al*., 2009) have shown that cardio-vascular and respiratory diseases dominate, but an interesting finding has been that the greatest relative increase of morbidity occurred in kidney diseases. It should be pointed out that health risks due to heat extremes are very much greater in people carrying out physical activity, whether through active transport, voluntary exercise, or laboring work. The intra-body surplus heat created by physical activity (only 20% ends up as external “work”; (Parsons, 2003)) causes particular vulnerability to heat effects in these population groups. This has importance for public health promotion of outdoor physical activity and it is of special relevance to analysis of the impacts of climate change on occupational health (see separate section below).

Cold weather is related to hypothermia, accidents due to slippery lands, and carbon monoxide poisoning. (Parsons, 2003) Carbon monoxide poisonings may be considered as indirect effect of cold, due to improper use of heating devices that involve indoor burning. In case of ice storms, power lines can be interrupted and people may use kerosene heaters or other devices not requiring power, which would cause carbon monoxide poisoning. Another example of the indirect effect of cold would be snow-shovelers' myocardial infarction in heavy snow areas. (Janardhanan *et al*., 2010)

11.2.3. Injury and Disease Resulting from Storms and Floods

In the IPCC Fourth Assessment Report, floods were reported to be the most frequent natural weather disaster. This is still true; in 2010, among the ten most important disasters by number of victims, floods occupied six of them and accounted for more than 90 percent of the number of victims, i.e., 175 million people. The worst flood occurred in China, and other important floods occurred in mid- to low-income countries such as Pakistan, Thailand, Cambodia, India, and Colombia. However, as exemplified by flood in Eastern Australia in 2010, developed countries are not immune.

The direct impacts of storms and floods include drowning, injuries, hypothermia, whereas indirect impacts include complication of injuries, poisoning due to hazardous materials in the debris, poor mental health, infectious diseases and starvation. (Du *et al*., 2010) Although the total numbers of deaths and injuries are likely to be underestimated, acute effects are possibly reported more fully. It is the mid- to long-term effects that are most difficult to evaluate. One of the reasons is population displacement; it is common for substantial numbers of people move to other places after severe floods. (Milojevic *et al*., 2011)

11.2.4. Vector-Borne and Other Infectious Diseases

11.2.4.1. Vector-Borne Diseases

Vector-borne diseases (VBDs) are infections transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, triatomine bugs, sandflies and blackflies. VBDs are among the most well-studied of the diseases associated with climate change, due to their widespread occurrence and sensitivity to climatic factors. Since the Fourth Assessment Report, new findings of the relationship between climate and vector-borne diseases have been published.

Range shifts of a variety of VBDs and their hosts and vectors in response to rising temperatures have been observed. These range shifts have generally been poleward and upward (toward higher elevations). (Hickling *et al.*, 2006) Altitudinal and latitudinal range shifts have occurred for *Ixodes ricinus*, the vector of the agents of Lyme disease and tick-borne encephalitis (TBE) in Europe (Gage *et al.*, 2008), while shifts, contractions and expansions have been reported in sub-Sahara Africa for East Coast fever (Olwoch JM, Reyers B, Engelbrecht FA, Erasmus BFN, 2008; Olwoch JM, Reyers B,Jaarsveld ASV, 2009). Northerly range shifts also have been observed for *Ixodes scapularis*, a vector of Lyme disease, human granulocytic anaplasmosis, and babesiosis in North America. In Canada endemic areas for Borrelia burgdorferi, the etiological agent of Lyme borreliosis (LB) in North America, are increasing. (Ogden *et al.*, 2008)

Changes in the geographical distribution of the rodent vector, mainly including the white-footed mouse (*Peromyscus leucopus*), rock vole (*Microtus chrotorrhinus*), Franklin's ground squirrel (*Spermophilus franklinii*) and eastern gray squirrel (*Sciurus carolinensis*), have been reported in Minnesota (USA). Changes have been reported also in the distribution of badger (*Taxidea taxus*) and raccoon (*Procyon lotor*) in the same state.

However, increasing temperatures may have the opposite effect on some vector and vector-borne diseases. For example, *S. mansoni*, a parasite leading to sparganosis mansoni, is not responsive to increased temperatures according to one report. (Mangal *et al.*, 2008)

Malaria

Malaria is caused by four distinct species of plasmodium parasite, transmitted between individuals by Anopheline mosquitoes. There were an estimated 247 million malaria cases among 3.3 billion people at risk in 2006, causing nearly a million deaths, mostly of children under 5 years. 109 countries were endemic for malaria in 2008, 45 within the WHO African region. (World Health Organization, 2009b) Several highland regions in East Africa have already experienced a significant exacerbation in the size of malaria outbreaks over the last three decades but the role of temperature remains controversial. (Chaves and Koenraadt, 2010b) Climate should not be dismissed as a potential driver of observed increase in malaria seen in East African highland during recent decades: however, its relative importance compared to other factors needs further elaboration. (Omumbo *et al.*, 2011) A recent study in this region showed malaria cases exhibit a highly nonlinear response to warming, with a significant increase from the 1970s to the 1990s. (Alonso *et al.*, 2011) Studies of influence of climate on malaria transmission in Africa found that, compared with rates at equivalent constant mean temperatures, daily temperature fluctuation around low mean temperatures acts to speed up rate processes of parasite development of malaria, whereas daily fluctuation around high mean temperatures acts to slow processes down. Analysis of environmental factors associated with the malaria vectors *Anopheles gambiae* and *Anopheles funestus* in Kenya found that the abundance, distribution and malaria transmission of different malaria vectors are driven by different environmental factors. (Kelly-Hope *et al.*, 2009)

Dengue

Dengue is currently a major epidemiological threat for over 100 countries with about 70% of the 2.5 billion populations at risk living in Asia Pacific region. Several studies have reported associations between spatial (Beebe *et al.*, 2009; Russell *et al.*, 2009) temporal (Herrera-Martinez and Rodriguez-Morales, 2010; Hii *et al.*, 2009; Hsieh and Chen, 2009) or spatiotemporal (Chowell *et al.*, 2008) patterns of dengue and climate. However, these associations are not entirely consistent, possibly reflecting the complexity of climatic effects on transmission. While high rainfall can lead to an increase in transmission (Su, 2008), others have found that dengue incidence was only weakly associated with local rainfall (Jury, 2008). Studies have shown that drought can also be a cause if household water storage increases the number of suitable mosquito breeding sites. (Beebe *et al.*, 2009; Padmanabha *et al.*, 2010)

Other Vector-Borne Diseases

Hemorrhagic fever with renal syndrome (HFRS), which was initially described clinically at the turn of the 20th century, is a zoonosis caused by different species of hantavirus (HV). HFRS is primarily distributed in the Asian and European continents. Approximately 150,000 to 200,000 hospitalized HFRS cases are reported each year, with the majority occurring in developing countries. In China, recent studies have indicated that HFRS incidence is associated with climatic factors including local temperature, precipitation, and relative humidity. (Cao *et al*., 2007; Fang *et al*., 2010)

Plague, one of the oldest identifiable diseases known to man, remains endemic in many natural foci around the world. The risk of plague has been reported to be associated with seasonal changes in climate, climatic shift and the prevalence of fleas. (Holt *et al*., 2009; Nakazawa *et al*., 2007b; Stenseth *et al*., 2006) Nevertheless, the conclusions of these studies are not completely consistent. Recently, the effects of time-lagged climatic variables including temperature, precipitation and humidity on the occurrence of Japanese encephalitis (JE) have been quantified in China and India, respectively. (Hsu *et al*., 2008; Murty *et al*., 2010)

A study based on potential impact of climate change on schistosomiasis transmission in China forecast an expansion of schistosomiasis transmission into currently non-endemic areas in the north, with an additional risk area of 783.883 km^2 by 2050, translating to 8.1% of the surface area of China. (Zhou *et al*., 2008) Non-significant impacts of climatic variable on schistosomiasis transmission have been detected in the other studies. (Mangal *et al*., 2008; Zhou *et al*., 2008)

11.2.4.2. Other Infectious Diseases

Hot summers and poor quality of water can exacerbate a range of infectious diseases in both tropical and temperate regions and in developed and underdeveloped countries of the world (IPCC 2007). Locations particularly vulnerable to outbreaks of infectious diseases are closed environments like hospitals, nursing homes and hospices, which are designed to prevent loss of heat, entrance of wind, rain and particulate matter. (Tamerius *et al*., 2011) Perencevich et al. (2008) reported significantly higher rates of gram-negative infections among hospitalized patients during the summer months, compared with other seasons. (Perencevich *et al*., 2008) In enclosed hospital environments with inadequate ventilation, hot and humid conditions can enhance transmission of aerosol droplets from other ill patients or even lead to food spoilage. Added to this, existing conditions in hospitals, hot summers and heat waves can further exacerbate problems (Barriopedro *et al*., 2011) of dehydration of patients and poor hygiene within hospitals. It is well known that the growth of bacterial, viral and fungal pathogens varies depending on the temperature gradient/profile (Burge, 2006; Danaher *et al*., 1999; Nelson, 1943), but the role these factors may play in the proliferation and spread of resistant strains such as methicillin-resistant *Staphylococcus aureus* (MRSA) is uncertain.

Influenza virus outbreaks follow a seasonal pattern (Dushoff *et al*., 2006; Maloney and Forbes, 2010) but the underlying mechanism determining the periodicity is still unknown (Tamerius *et al*., 2011). The modes of transmission are from person to person contact (including contact with contaminated hosts and surfaces) and through large respiratory droplets. (Tellier, 2009; Weber and Stilianakis, 2008) To survive, the virus must cope with a wide variety of environmental conditions including extremes of humidity (Hemmes *et al*., 1962; McDevitt *et al*., 2010; Shaman and Kohn, 2009), solar radiation (Jensen, 1964) and high and low temperatures (Dushoff *et al*., 2006; Eccles, 2002; Lowen *et al*., 2007; Palese *et al*., 2008). Tamerius *et al.,* (2011) reviewed the evidence for seasonal outbreaks of influenza and reported distinct winter epidemics in temperate populations (Tamerius *et al*., 2011) In contrast, Chew *et al*., (1998), Chumkiew *et al*., (2007) and de Mello *et al.,* (2009) reported epidemic outbreaks during the rainy season in several tropical populations when humidity was greatest compared with low indoor humidity during temperate epidemics (Rao and Banerjee 1993, Moura *et al*., 2009, Tamerius *et al*., 2011)

Overcrowding at indoor sites during the winter (Lofgren *et al*., 2007) and during heavy rains in tropical regions (Graham and McCurdy, 2004) provide suitable conditions for airborne spread when susceptible populations are exposed to these pathogens. In addition, temperature and humidity effects on host immunity (Tamerius *et al*., 2011) and antigenic drift and waning immunity (Dushoff *et al*., 2004) have been observed to contribute to seasonal outbreaks. Extreme temperatures may encourage more indoor activities. Temperature and humidity, the El Niño Southern Oscillation (ENSO) (Viboud *et al*., 2004) and solar radiation (Sagripanti and Lytle, 2007) have all been implicated in influenza transmission in temperate climes but the role of climate on influenza in the tropics is not well studied (Soebiyanto *et al*., 2010). There is some evidence in the tropics of a high incidence of influenza during the rainy season especially in India, Vietnam and Brazil (Soebiyanto *et al*., 2010) but this pattern does not occur in other tropical locations like Singapore, Thailand and Philippines (Hampson, 1999; Soebiyanto *et al*., 2010).

Infection with rotavirus caused an estimated 0.5m deaths in children in 2004, 85% of these in South Asia and sub-Saharan Africa (CDC 2011). There is strong seasonality in rotavirus outbreaks particularly in temperate (Fischer *et al*., 2011; Lee *et al*., 2009a; Sagalova, O.I., Pishchulova, O.A., Necht, V.A., Podkolzin, A.T., Maleew, V.V., Abramycheva, E.,Fenske,E.B., 2007) and sub-tropical regions (Carneiro *et al*., 2005; Moe *et al*., 2005; Patel *et al*., 2010; Schael *et al*., 2009). A global meta- analysis using data from 34 studies on 6 continents showed that rotavirus seasonality is less distinct within 10^{o} of latitude from the equator. (Cook *et al*., 1990) Recent studies have attempted to distinguish between the effects of weather and other factors which may affect rotavirus outbreak seasonality such as changes in host behaviour or susceptibility. One such study in Dhaka, Bangladesh found a 40.2% increase in rotavirus cases for every 1^{o}C above a threshold of 29^{o}C contrary to laboratory study findings. This study also found a positive association with river level above a threshold level and a negative association with relative humidity. (Hashizume *et al*., 2008) A 10-year study of rotavirus diarrhoea hospital admissions in 3 Australian cities found higher temperature and humidity in the previous week were associated with a decrease in admissions in the three cities. In Brisbane (the most northerly city, 27^{o}S) the effects of temperature and humidity on admissions differed across seasons (Levy *et al*., 2009)in a meta-analysis of 26 studies from 15 countries found that though there was heterogeneity in the effects of temperature, humidity and rainfall on rotavirus incidence in the individual studies the combined analysis revealed that for every 1^{o}C increase in mean temperature, 1cm increase in mean monthly rainfall and 1%increase in relative humidity the analysis showed reductions in rotavirus incidence of 10%, 1% and 3% respectively. The purpose of these attempts to separate weather effects from other seasonal effects is to better predict outbreaks in order to more effectively deploy health service resources including the recently approved vaccines. It appears that deployment of vaccines may change the seasonality of rotavirus activity. A study in the USA (Tate *et al*., 2009b)found that within 2 years of implementing a rotavirus vaccination program the onset and peak of rotavirus activity were delayed , the season was shortened and the peak number of rotavirus cases was 61% reduced nationally.

Over one-third of the world population is infected with the *Mycobacterium tuberculosis* (TB) bacillus, and 5-10% of those infected may become sick or infectious at some time during their lifetime. It is estimated that 1.7 million people died from TB in 2009 with a high number of deaths recorded in the African region. Seasonal variations in TB notifications have been reported in different geographical regions of the world. (Douglas *et al*., 1996; Nagayama and Ohmori, 2006; Sanchez-Padilla *et al*., 2008) In the temperate region TB incidence increased during winter months when people were confined indoors in China, Mongolia, and South Africa (Douglas *et al*., 1996; Rieder *et al*., 2009), in contrast in the UK and Hong Kong outbreaks peaked during the summer months (Chan, 1999; Douglas *et al*., 1996). In the tropics, seasonal variations were also observed with higher prevalence rates reported during the wet season compared with the dry season in Cameroon and Thailan. (Ane-Anyangwe *et al*., 2006; Kongchouy *et al*., 2010)These results suggest that during heavy rains in tropical regions people congregate indoors and may provide suitable conditions for airborne spread of TB. There is also an indirect link between climate and TB, via nutritional status. (Cegielski and McMurray, 2004)Temperature and humidity, the El Niño Southern Oscillation (ENSO) (Kovats *et al*., 2003; Viboud *et al*., 2004), solar radiation (Sagripanti and Lytle, 2007) and rainfall patterns (Luber and Hess, 2007b; Luber and Prudent, 2009)can impact agriculture and food production.

11.2.5. Food and Water-Borne Infections

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11.2.6. Nutrition

Many studies have analysed the relationship between crop production, climate variability and extreme weather events. Results vary by time, region and crop. (Lobell and Asner, 2003; Lobell *et al*., 2011; Lobell *et al*., 2005; Lobell *et al*., 2011; Lobell and Field, 2007; Nicholls, 1998). There is evidence that the effects on land-based agriculture are increasingly adverse, especially for wheat and corn, but not (yet) for rice and soy (Lobell *et al*., 2011; Lobell and Field, 2007).

The magnitude of detected decline in land-based agricultural production due to increasing temperatures and changes in rainfall is small compared to increased harvests due to improved farming knowledge and technology (Lobell *et al*., 2011) It is also trivial in comparison to the amount of food fed to livestock, used for biofuels, consumed beyond baseline needs by the overnourished and wasted in other ways. However, these background factors are largely constant or only slowly increasing. Against this background, the global food price fluctuates, though with a recently elevating trend. While the main driver of this trend is rising energy costs, amplified by speculation, (Piesse and Thirtle, 2009) there are probably periods when crop loss due to droughts, heatwaves and other weather extremes has contributed significantly to rising food prices, thus increasing the number of undernourished people.

However, the modelling of past and future agro-climatic effects, even without considering their health impact, is a formidable challenge. There is increasing recognition that existing agro-climate models are excessively simple and biased toward the optimistic (Butler, 2010; Gornall *et al*., 2010). Thus the decline detected in food production attributed to climate change is likely to be understated, and that of future climate change even more so.

Concern over future climate change and crops is amplified by increasing doubt over the benefits and strength of the carbon fertilization effect (CFE), especially for C4 plants (Leakey *et al*., 2008; Long *et al*., 2006). In response, agro-climatic models increasingly incorporate positive and more neutral CFE effects (Nelson *et al*., 2010b; Nelson *et al*., 2009). However, the CFE may also enhance the growth of pests (Nelson *et al*., 2010b; Nelson *et al*., 2009) and damage some crops, including cassava, a staple for about 750 million mostly poor people (Gleadow *et al*., 2009). These effects to date are not incorporated into models.

Current agro-climatic models also poorly incorporate increased extremes, including rainfall intensity, (Allan, 2011) sea level rise, saline intrusion, glacial melting, and the possibilities of monsoon weakening and intensification of the El Niño Southern Oscillation and other ocean currents and atmospheric oscillations. They also omit the effect of climate change on mycotoxins, (Wu *et al*., 2011) and crop and animal diseases (Diffenbaugh *et al*., 2008; Purse *et al*., 2005).

Climate change is also predicted to have complex effects on fisheries, by changing the pattern of ocean currents and redistributing marine productivity to higher latitudes (Cheung *et al*., 2010). Warming sea surface temperatures have been linked with a declining trend in the global phytoplankton concentration since 1899, in eight out of ten ocean regions (Boyce *et al*., 2010). Increasing ocean acidity and climate change associated deoxygenated zones will also harm future marine productivity (Keeling *et al*., 2010).

11.2.7. Occupational Health

The health section of AR4 mentions "occupational health" effects of climate variables only briefly or in passing. Since then substantial new evidence has accumulated and the importance of the substantial literature on direct heat impacts on working people has been emphasized in published papers. Heat exhaustion and reduced work capacity due to increasing workplace heat exposures is a significant problem in already hot tropical countries (Kjellstrom *et al*., 2009a). In addition, there are other health risks for occupational groups, which have until now attracted less attention (Bennett and McMichael, 2010b). The recent major reviews of climate change impacts on human health, well-being and community economy (Costello *et al*., 2009; DARA, 2010; World Bank., 2010) have all overlooked the emerging climate change related problems for working people.

Heat Strain and Heat Stroke

One important feature of human biology is the maintenance of core body temperature (Tc) close to 37 ºC, the temperature at which different biochemical and physiological systems function at their optimum. Basic metabolism, digestion of food, and muscle work all create "surplus heat", which needs to be emitted from the body to avoid the Tc rising in hot environments (Parsons, 2003). The intra-body surplus heat created during physical activity causes a risk for "over-heating" of working people, and they become vulnerable to health effects of heat when working in hot environments. The four environmental climate factors that influence heat stress risk can be measured or estimated: air temperature, humidity, wind speed and heat radiation (outdoors usually from the sun). The interaction between the environmental heat and human physiology also involves the metabolic rate at which a person is working and the clothing he/she wears (Parsons, 2003).

A working person creates internal body heat that needs to be emitted via the skin. In a hot and humid tropical environment there is a risk that the cooling mechanism of sweating is insufficient so the body temperature of the worker increases. If the body temperature goes beyond 38 ºC, the risk of heat strain increases producing symptoms of sluggishness and lack of concentration. If the temperature goes beyond 39 ºC, more serious symptoms of organ damage, eventual unconsciousness (heat stroke), and even death can occur. The clinical manifestations of this over-heating can involve several organs (Ramsey, J.D., Bernard,T.E., 2000), and pre-existing disease or malnutrition makes the clinical status worse. Thus, poor people in low-income countries are at particular risk.

A hard working person may sweat more than 5 litres per work shift, and this water loss has to be replaced in order to avoid dehydration, another serious hazard in hot working environments. If there is a net water loss of more than 2-3 litres during a day there is a risk of damage to the kidneys and other organs (Ramsey, J.D., Bernard,T.E., 2000). The protection of workers from excessive heat exposure and the provision of sufficient clean water for rehydration during the working day, are essential elements of occupational health and efficient management in tropical countries. A dehydrated worker looses performance ability before the clinical effects develop.

Thus, there are two mechanisms for *performance loss* and serious *clinical disease* due to heat exposure during work: 1. the increase of core body temperature, and 2. the loss of body water through sweating: dehydration. Numerous experimental studies and field studies have documented the risks of heat strain and heat stroke (Parsons, 2003; Ramsey, J.D., Bernard,T.E., 2000)and detailed exposure response relationships were described a long time ago (Wyndham, 1969). Heat stroke among working people may lead to heat exposure related fatality risk (Wyndham, 1969)and this is still an ongoing occupational health issue even in a high income country like the USA (Luginbuhl *et al.*, 2008).

Over a period of 100 years a number of heat stress indexes combining the physiological impact of temperature, humidity, air movement and heat radiation have been developed. The most widely used in occupational health is the Wet Bulb Globe Temperature (WBGT) (Parsons, 2003)and the most recently developed is the Universal Thermal Climate Index (UTCI) (see web-site utci.org), which is recommended by the World Meteorological Organization. An international standard for WBGT gives guidance on maximum acceptable heat exposure levels at different work intensity levels (ISO 1989). In hot working conditions the work pace has to be reduced, and this leads to an important conflict between health protection actions and economic productivity (Kjellstrom, T., Lemke, B., Hyatt,O., 2011): as the worker takes longer hourly rest periods to prevent heat stroke, the hourly productivity goes down.

Heat Exhaustion and Work Capacity Loss

The impact of high occupational heat exposure on work capacity loss has recently been analysed in different settings of Asia, Africa and Latin America. The individual variation in sensitivity to heat varies considerably (Parsons, 2003), and acclimatization, which takes approximately 1-2 weeks, reduces the sensitivity, but there is still a limit and international standards of maximum recommended workplace heat exposure exist for either acclimatized or non-acclimatized people.

Thus, in hot countries during the hot season, large proportions of the workforce are affected by the heat exposures, and the increasing exposures that climate change brings, causes new heat exhaustion and heat strain problems (Kjellstrom, T., Lemke, B., Hyatt,O., 2011; Kjellstrom *et al.*, 2009b). The economic impacts of reduced work capacity can be serious, as exemplified in the reports on work capacity loss from different low and middle income countries referred to above.

A recent World Bank Policy Research Working Paper (Lecocq and Shalizi, 2007), discusses the impact of climate change on economic growth including labour stock and productivity. When heat exposure is high enough to reduce the effective daily working hours, it has the same impact as a permanent, disabling, non-fatal disease: the availability of labour is lowered, while the number of mouths to feed is the same. Any worker who is paid on the basis of production output, (e.g. a rickshaw driver, a self-employed house builder or a worker in a factory paid by the piece), will experience reduced income per hour (and possibly the whole day) during days with debilitating heat exposure (Kjellstrom, T., Lemke, B., Hyatt,O., 2011). Impacts of heat exposure on sports performance are well described (e.g. Corris et al. 2004) (Coris *et al.*, 2004).

Other Occupational Health Concerns

The physiological effects reduce psychological performance with a risk of increased mistakes in daily activities and increased accidental injuries in workplaces (Ramsey, J. D., Burford, C.L., Beshir, M.Y., Jensen,R.C., 1983; Ramsey, 1995). It has also been proposed (Bennett and McMichael, 2010b) that a number of ill health categories can be of particular importance for working people. In areas where vector-borne diseases, such as malaria and dengue fever, are common, people working in farm fields without effective protection may experience higher incidence of these diseases. A factor of potential importance is the fact that increasing heat exposure in farm fields during the middle of the day in many places during the planting and harvesting seasons will lead to more work during dawn and dusk when some of the vectors are biting humans more actively.

Another risk factor is increased chemical poisoning where solvents are used, both indoors and outdoors, because higher temperatures make the solvents evaporate faster and creating higher occupational exposures (Bennett and McMichael, 2010b). An epidemic of chronic kidney disease in Central America has been considered as at least partly linked to daily dehydration among sugar cane harvesting workers, due to the insufficient drinking water supplied to replace liquid lost due to sweating (Garcia-Trabanino, 2005).

The Arctic areas of the world already experience the fastest increase of temperatures both in the summer and winter creating new occupational hazards as the traditional hunting and fishing activities may lead to increased incidence of drowning.

11.2.8. Air Quality

Chronic Air Pollution

Tropospheric ozone is formed through photochemical reactions that involve nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) in the presence of sunlight and elevated temperatures (US EPA, 2007). Thus, many air pollution models (Chang *et al.*, 2010; Ebi and McGregor, 2008b; Polvani *et al.*, 2011; Tsai *et al.*, 2008) predict that increasing temperatures, due to anthropogenic climate change, will result in increased ozone production on the local and regional level, especially within and surrounding urban areas where the anthropogenic production of NO_x through the combustion of fossil fuel in the stationary and mobile source sectors (heating, power generation, motor vehicles, etc.) is most elevated (Hesterberg *et al.*, 2009).

While NO_x, CO, and VOCs contribute to local and regional production of tropospheric ozone, methane (CH_4), since it is longer-lived and globally-mixed, contributes to the production of tropospheric ozone on the global scale (West *et al.*, 2006). Although uncertainties of time scale and magnitude are significant {Stotler, #1}, climate change could continue to increase atmospheric concentrations of CH_4 by thawing permafrost in the arctic and marine methane hydrates on the ocean floor, releasing CH_4 sequestered in its soil (Laurion *et al.*). These increases in CH_4 concentrations could lead to notable increases in ozone production (West *et al.*, 2006) as well as more warming, which further contributes to the methane emission feedback loop (IPCC, 2007).

Growing scientific consensus links even small increases in atmospheric concentrations of ground-level ozone to ill-health. Tropospheric ozone has been linked to respiratory-associated morbidity and mortality due to both long (Jerrett *et al.*, 2009)and short-term (Bell *et al.*, 2006; Ebi and McGregor, 2008b)exposures. For instance, Bell et al. (2006) found that even levels that meet the US EPA 8-hour regulation (0.08 ppm over 8 hours) were associated with increased risk of premature mortality; There is a lack of association between ozone and premature mortality only at very low concentrations (from 0 to ~10 ppb) but the association becomes positive and approximately linear at higher concentrations (Bell *et al.*, 2006; Ebi and McGregor, 2008b; Jerrett *et al.*, 2009).

Beyond the effect of temperature on pollution concentration and distribution, research suggests that atmospheric co-pollutant concentrations are increased on local and regional scales by the presence of elevated ambient CO_2 concentrations (Jacobson, 2008). Jacobson (2008) evaluated the interaction between CO_2, ozone, and PM and compared the preindustrial levels of ozone and PM to those of the present day. The results indicate that increasing concentrations of CO_2 also increase the atmospheric concentrations of ozone and PM on the local level, leading to an estimated 1.1% increase in mortality per degree temperature increase over the baseline rate (Jacobson, 2008). Approximately 40% of the increase in mortality was attributable to ozone and 60% to PM, with the majority of the impacts most apparent in locations with poorer air quality and higher population densities (Jacobson, 2008). Thus, reductions of local and global CO_2 emissions may reduce exposure of local and regional populations to elevated levels of PM, ozone, and other health-damaging co-pollutants.

Acute Air Pollution Episodes

Among all air pollutants, literature sources provided most detailed accounts on the relationship between forest fires and PM_{10} levels. For example, during a fire near Denver (USA) in June of 2009, 1-hour concentrations of PM_{10} and $PM_{2.5}$ reached 373μg/m3 and 200 μg/m3. Peak 1-hour concentrations were recorded usually between 4 and 5 pm during fires, and 24-hour average concentrations reached 91 μg/m3 and 44 μg/m3, while the recommended 24-hour NAAQS for these pollutants are 50 μg/m3 and 35 μg/m3, respectively (Vedal and Dutton, 2006). Similar levels of PM_{10} were observed during forest fires in California in June of 2008: peak 1-hour PM_{10} concentrations varied between 200 and 380 μg/m3 (Wegesser *et al.*, 2009), while 24-hour concentrations of PM_{10} near forest fires in 1998-1999 reached 620 μg/m3 (Lee *et al.*, 2009b). During the fires in Quebec (Canada) in July of 2002, $PM_{2.5}$ levels reached 86 μg/m3 (Sapkota *et al.*, 2005). During the fire in Singapore in 1997, PM_{10} levels varied between 50 and 150 μg/m3 (Emmanuel, 2000). Concentrations of ozone increased simultaneously with PM_{10} during forest fires in Georgia in 2002 (Tian *et al.*, 2008).

Even greater levels of PM_{10} were observed in Moscow during the period of fires caused by a heat wave in the summer of 2010. During this heat wave, daily mean temperatures in Moscow exceed the respective long-term averages by 5^0C or more for 45 days in July and August of 2010. The summer of 2010 brought 10 temperature records in July and 9 temperature records in August, for the whole history of temperature measurements since 1885. The anti-cyclone in Moscow region prevented dispersion of air pollutants, while the fires emitted additional quantities of pollutants. The highest levels of air pollution were recorded in Moscow between July 14 and August 19, in the conditions of high atmospheric pressure and temperature inversion. In August, intense fires were responsible for peak concentrations of several air pollutants. For example, PM_{10} levels varied between 431 and 906 μg/m3 and even reached 1500 μg/m3 on particular days. The highest CO concentration was 30 μg/m3, and the levels of formaldehyde, ethyl benzene, benzene, toluene and styrene were also quite high (WHO, 2010a).

11.2.9. Mental Health

Mental health is sensitive to climate through a variety of mechanisms. For example, disruptions in the physical environments may bring financial costs and hardship that is translated in some, susceptible individuals, into

disabling mental disorder. Storms, floods, fires and other weather-related impose immediate financial, infrastructure and health costs and, longer-term, progressively degrade natural resources, the businesses directly based on them (such as mining, forestry, agriculture and fishing) and local 'downstream' services and businesses. In Australia, drying and bushfires are altering landscapes, and causing psychological distress in people who feel intimately connected to their home environment (Albrecht *et al*., 2007). Previous studies have found higher suicide rates in rural areas of Australia (14.6-17.1 per 100,000 persons) compared to capital cities (12.8-12.9 per 100,000 people). Notably, the most significant increases were in communities with populations less than 4000. This rise was attributed to increased economic stress on farming and rural populations {Hoogland, 2000 #1315}.
With livelihoods and local economic productivity under threat, financial and other resources can dissipate and community functioning can weaken, undermining social capital[*34*] (participation, networks and the cohesion that results from them). Paucity of social capital is linked to less social support, fewer work and educational opportunities, poorer communication of and compliance with health messages and, especially, with adverse mental health outcomes[*13*]. This tangled complex of relationships produces multiple, compounding risks to mental health. These pressures will exacerbate disadvantages in the *social environment* (e.g., impoverished services and social contact in remote communities, urban overcrowding), increasing existing *psychosocial stress* and reducing protective social capital[*3*]{Almedom, 2005 #1082}. People living with 'place, space' deficits manifest *poorer health behaviours* than do others, including poorer diet (and less food security) and less physical activity. Each is related to worse mental health{Penedo, 2005 #6103;Bodnarac, 2005 #6104;Melchior, 2009 #6105}. By further degrading, for example, natural resources or food security, climate extremes compound the sources of disadvantage that provoke deleterious health behaviours.

11.2.10. Violence

The current thinking that climate change may cause an increase in violence has its roots in the old concerns over the security implications of population growth and resource scarcity that goes that back to the late 1960s. With an increasing knowledge of environmental consequences of climate change there is an increase in the speculations about how global warming may eventually influence patterns of war and peace (Schwartz, P., Randall,D., 2003). The assumption in the existing literature (Gleditsch *et al*., 2006; Theisen, 2006; Urdal, 2005) is based on the scenarios that if soil degradation, freshwater scarcity and population pressure have influenced the risk of conflict in the past, we assume that this may also inform us about likely security implications of climate change.

Whereas it is known that political, social and economic factors also play a major role in war and conflict, (Collier and Hoeffler, 2004)have shown that poverty, low economic growth and high dependence on primary commodity exports were important predictors of civil war, while ethnic and religious diversity as well as democracy did not. On the other hand (Hegre *et al*., 2001), found that regime type and ethnic heterogeneity matter even after controlling for level of development. (Hauge and Ellingsen, 1998) found that economic and political factors were the strongest predictors of conflict, but that environmental and demographic factors did have some impact. The resultant ambiguity has recently led to much more specified models of the causal patterns between demography, environment and conflict (e.g. (Kahl, 2001)).

The earlier scientists that were concerned with resource scarcity and conflict, focused on cropland and freshwater (Homer-Dixon, 1999) as the renewable resources that can regenerate under conditions of sustainable, studies on climate change and security use increase in temperature and precipitation anomalies and extreme weathers as the main factors that are expected to aggravate processes of resource degradation that is already underway (Klare, 2001; Pervis, N., Busby,J., 2004). Similary, (Hendrix and Glaser, 2007) found that climates that are more suitable for agriculture are associated with a lower risk of conflict in Sub-Saharan Africa, and it appears plausible that the reverse could be true. (Reuveny, 2007) argues that environmentally induced migration can increase the risk of conflict, particularly in less developed countries . The risk is compounded by rapid population growth and limited migration opportunities. In Africa changing rainfall patterns have been included among the factors that may lie behind current conflicts in Darfur (Byers, M., Dragojlovic,N., 2004).

Although caution is attached to over-simplifying the relationship between climate and armed conflict in view of other social, cultural, political and economic factors, most authors (Barnett, 2003; Pervis, N., Busby,J., 2004) agree that the depletion and altered distribution of natural resources could increase the risk of some forms of violent conflict (Brauch, 2002; Tanzler, D., Carius,A., 2002).

11.2.11. Skin Cancers, Ozone, and Allergens

The relationship between skin cancer and air temperature is poorly understood at present. Experiments on mice have demonstrated that an increase in room temperature resulted in an increase of the UV effective dose by 3 to 7 % for each 1^0C (van der Leun *et al.*, 2008b). Epidemiological studies conducted in the USA have revealed the relationship between the UV level, maximum summertime day temperatures and the number of non-melanoma skin cancer cases. The number of registered cases of "squamous cell carcinoma" was 5.5% higher (SE 1.6%) for every 1^0C increase in maximum summer time temperature and "basal cell carcinoma" rose by 2.9% for every 1^0C (SE 1.4%). These values correspond to an increase in the effective UV dose by 2% for each 1^0C. Higher temperatures in the northern countries and countries with temperate climates may result in an increase in the time which people spend outdoors and, thus in additional UV-induced-adverse effects. In many countries skin cancer rates are rising, for reasons unrelated to variations in climate. In Great Britain alone, by the middle of this century, 5,000 additional cases of skin cancer are expected annually. (Diffey, 2004)

11.3. Vulnerability to Disease and Injury due to Climate Variability and Climate Change

In the IPCC assessments, vulnerability is said to be "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" (WG2, chapter 19, AR4). This means vulnerability encompasses both the exposure to a hazard, and the response to this exposure.

11.3.1. Current Sources of Vulnerability

Geographic Causes of Vulnerability

Location does not determine susceptibility to loss, but it plays a powerful hand in shaping the potential for loss. (Samson *et al.*, 2011) The inhabitants of low-lying coral atolls are exquisitely sensitive to flooding, contamination of fresh water reservoirs due to sea level rise, and salination of soil, all of which may have significant effects on health. (Nunn, 2009)Those living in inland cities at mid- and low latitudes are more likely to be affected by heat waves than people living in rural and coastal settlements. Rural populations that rely on subsistence farming in low rainfall areas are at high risk of under-nutrition and water-related diseases in future drought. (Although this vulnerability may be modified strongly by local factors, such as access to markets and irrigation facilities. (Acosta-Michlik *et al.*, 2008) In high-income countries, location remains an important measure of susceptibility to the adverse effects of climate change. For example, living within 100 and 500 year flood zones, or within 5 km of coasts subject to sea level rise have been proposed, in the United States, as indicators of vulnerability to climate change. (Acosta-Michlik *et al.*, 2008; English *et al.*, 2009) Regional factors also modulate risk. In the tropics, human populations are often living with temperatures that are close to tolerable thresholds. In the Arctic, there is concern that rising temperatures and associated changes in northern ecosystems may increase the exposure of humans to persistent and widely distributed organic pollutants.

Age

Children and older people are both at increased risk, though for different reasons. (Perera, 2008) It is expected that children will be more vulnerable to heat-related illnesses, due to their small body mass to surface area ratio. Evidence of excess heat-related mortality in this age group is mixed however. In California, a study of summer mortality records for 1999-2003 reported a stronger association of heat and mortality among infants (aged less than 1 year) and those aged 65 years and over than other age groups. (Basu and Ostro, 2008)Other studies have sought, but not detected, such an association. {Kovats, 2008 #221} In some circumstances, children may be relatively protected from climate-related diseases. For instance, maternal antibodies lower the risk of dengue fever in children in the first year of life. However, this effect is relatively short-lived, and older children are more severely affected by many infectious diseases that may be encouraged under climate change. Malaria is one of the most important – parasite loads are greater and mortality rates higher in childhood (from about 6 months to 3 years) due to less well-developed immune responses to infection with the plasmodium. (Michon *et al.*, 2007; Reyburn *et al.*, 2005; Rowe *et al.*, 2006) Children also dehydrate more rapidly than adults when affected by diarrhoeal diseases, and case-fatality rates are correspondingly higher. Studies of populations affected by storms, floods and other climate extremes indicate that children may be affected with psychological problems, such as anxiety and behavioural disturbances, although it is not clear whether these effects are more severe than in other age groups. (Ahern *et al.*, 2005; Durkin *et al.*, 1993; Price, 1978)Children are more likely to be affected by food insecurity than other age groups, partly because families with children tend to have lower incomes than the social average, and partly because childhood is a particularly sensitive period for health and development. (Cook and Frank, 2008)

Older people are at greater risk from storms, floods and other extreme events, in part because they tend to be less mobile than younger adults and so find it more difficult to avoid hazardous situations. Older people are also more likely to suffer from health conditions that limit the body's ability to respond to stressful events. Chronic diseases such as diabetes and ischemic heart disease, for example, magnify the risk of death or severe illness associated with high ambient temperatures. (Basu and Ostro, 2008; Sokolnicki *et al.*, 2009) People over 65 years are also more strongly affected by air pollution due to ozone and other photochemical oxidants. (Medina-Ramon and Schwartz, 2008)

Gender

Vulnerability is associated with gender but the relationship is complex. In the United States, it is reported that men are at greater risk of death following flooding, perhaps because in this setting men are more commonly exposed to risk (e.g. many of the flood drownings in the US are motor-vehicle related). (Jonkman and Kelman, 2005) A study of the health effects of flooding in Hunan province, China, also found an excess of flood deaths among men, often related to rural farming. (Abuaku *et al.*, 2009) In the Paris 2003 heatwave, women were more affected than men in every age group except those aged 25-64. In this instance, the male dominance in the working age group may be related to differential exposures to heat in occupational settings. In Bangladesh, women are more affected than men by a range of climate hazards, at least in part because they are more likely to be suffering from poverty and poor nutrition, and are more frequently exposed to water-logged environments. (Cannon, 2002; Neelormi *et al.*, 2009) There may also be physiological differences in reserve and resilience. After controlling for differences in age and co-morbidities, it appears that women are more strongly affected than men by high temperatures (Yu *et al.*, 2010) and ozone air pollution (Medina-Ramon and Schwartz, 2008). There are signs also that the effect of food insecurity on growth and development in childhood may be more damaging for girls than boys. (Cook and Frank, 2008)

Pregnancy is a period of increased vulnerability to a wide range of environmental hazards, including infectious diseases (such as malaria and foodborne infections) (Jamieson *et al.*, 2006) and illness and injury resulting from climate disasters. For example, an increase in spontaneous abortions was recorded in counties in New York State that had been affected the year before by severe flooding caused by Hurricane Agnes. (Janerich *et al.*, 1981)

Race and Ethnicity

In many countries, race and ethnicity are powerful markers of health status and social disadvantage. Black Americans have been reported to be more vulnerable to heat-related deaths than other racial groups in the United States. (Basu and Ostro, 2008) This may be due to the prevalence of chronic conditions such as over-weight and diabetes, financial circumstances (lower incomes may restrict access to air conditioning), or to community-level characteristics (such as local crime rates or disrupted social networks). Indigenous peoples who depend heavily on local resources, and live in parts of the world where climates are changing quickly, are at greater risk of economic losses and poor health. Studies of the Inuit people, for example, show that rapid warming of the Canadian Arctic is jeopardizing hunting activities which many in these communities rely on for food. (Ford, 2009) In Australia, indigenous peoples experience higher rates of diarrheal diseases and other climate-sensitive conditions than the remainder of the national population and their general health status is poorer and puts them at additional risk of climate stressors such as heat-waves. These factors, and their close attachment to the well-being of the land on which they live, mean indigenous Australians may be affected particularly strongly by climate change. (Green *et al.*, 2009)

Socioeconomic Status

Socioeconomic status typically reflects, and may be measured by, educational attainment, occupational prestige and personal income. In general, individuals and households most vulnerable to climate hazards are those with relatively low socioeconomic status. For instance, a study of the impacts of flooding in Bangladesh found that household risk reduced with increases in both average income and number of income sources. Poorer households were not only more severely affected by flooding, but were less likely to take preventive action, and less likely to receive assistance after flooding. This was explained partly by financial obstacles to relocation and other coping strategies, but there were differences reported also in knowledge of hazards and in beliefs about the preventability of flooding. (Brouwer *et al.*, 2007) Occupation is also directly related to vulnerability to climate variability and extremes. For instance, outdoor occupations have been linked with disease and injury caused by flooding in China (Abuaku *et al.*, 2009) and heat-waves in the United States (Centers for Disease Control and Prevention, 2008). (The effects of heat on working lives are described in detail elsewhere in this chapter.) But a link with socioeconomic status is not always present. In Brisbane, Australia, heat-wave mortality was related to age and gender, but not to small area measures of social disadvantage. (Yu *et al.*, 2010) This null finding, contrary to what has been observed elsewhere with individual-level measures of SES, (Medina-Ramon *et al.*, 2006) may be due to the much greater variability in housing quality within neighbourhoods or the relatively flat social gradient in access to protective factors such as air conditioning and private transport in Australia.

Neighborhoods

The physical environments around where people live and work can influence the health risks due to climate variability and climate change. In Cuba, a country with a well-developed public health system, dengue fever has been a persistent problem in the larger cities, due in part to the lack of a constant supply of drinking water in many neighbourhoods (leading to people storing water in containers that are suitable breeding sites for the disease vector, *A. aegypti*). (Bulto *et al.*, 2006)

Climate extremes may promote the transmission of certain infectious diseases and the vulnerability of populations to these diseases will depend on the baseline levels of pathogen and vector. In the United States, as one example, arboviral diseases such as dengue and the encephalitides are rarely seen after flooding, compared with the experience in other parts of the Americas. The explanation lies in the scarcity of dengue and other viruses circulating in the population, pre-flooding. (Keim, 2008) Schistosomiasis was present in parts of Portugal in the 1950s. However, disease control efforts have eliminated the microbe from local snail populations so that although there is a competent vector and climate projections indicate that both parasite survival and vector survival will be favoured by rising temperatures, the risk of schistosomiasis returning to Portugal is low. (Casimiro *et al.*, 2006) On the other hand, the high prevalence of HIV infection in many populations in Sub-Saharan Africa multiplies the health risks of prolonged drought, which may lead to migration, family disruption, deepening poverty, and increased exposure to unsafe sex.

Summary

We have divided the causes of vulnerability into sections for convenience. In practice, these factors combine, often in complex and place-specific manner. For example, a study of heat mortality in the United States found that combinations of social and environmental factors explained more than 75% of the observed variance. They included neighbourhood green space, personal education and income, the prevalence of diabetes, social isolation and access to air conditioning. (Reid *et al.*, 2009) However there was substantial spatial variation within the US, with greatest vulnerability to heat in the northeast and Pacific coast, and least in the southeast of the country.

There are some factors (such as education, income, health status and responsiveness of government) that might be described as generic causes of vulnerability. Low levels of parental education, for example, are consistently associated with higher child mortality in times of stress, whether it is military conflict, famine, or other natural disasters. (Kiros and Hogan, 2001) But the precise causes of vulnerability, and therefore the most relevant coping capacities, vary greatly from one setting to another. Vulnerability to heat, for example, varies spatially: the factors that are important in rural areas differ from those that put people at risk in cities. (Reid *et al.*, 2009) The lag between high ambient temperatures and increased incidence of salmonella food poisoning varies from one country to another, suggesting that the mechanisms differ (deficiencies in food storage may be the critical link in some places, food handling problems elsewhere). (Kovats *et al.*, 2004)

The 2010 World Development Report concluded that all developing regions are vulnerable to economic and social damage resulting from climate change – but for different reasons. (The World Bank, 2009) The critical factors for Sub-Saharan Africa, for example, are the current climate stresses (in particular, droughts and floods) that are projected to worsen with climate change, sparse infrastructure and high dependence on natural resources. East Asia and the Pacific, on the other hand, are distinguished by the very large number of people living in low-lying areas prone to flooding (this includes roughly half the population of Vietnam).

11.3.2. Projections

Population growth is likely to be one of the strongest influences on vulnerability to the health effects of climate change. Increasing numbers of people, particularly in environments that are already resource-stretched, will magnify harmful impacts. For instance, it is estimated that about 150 million people currently live in cities affected by chronic water shortages (< 100 L per person per day of sustainable freshwater flows). In 50 years, demographic growth will push that number to around a billion (and climate change may add another 100 million). (McDonald *et al.*, 2011) The age structure of the population also has implications for vulnerability. The proportion aged over 60 is projected to increase everywhere (rising from about 10% presently to 32% by the end of the century). (Lutz *et al.*, 2008) In some regions, this change will occur much faster (going from 10% to over 40% in China, for example). However it is by no means certain that age-related vulnerability to climate will remain as it is at present. Alongside the ageing of the population, there is expected to occur a continuing reduction in mortality, and an improvement in average health status at any given age. The implications of mortality decline, if present trends continue, are profound. For instance, it has been estimated that the average years of life remaining globally (a product of average age in the population and prevailing mortality rates) will fall only slightly (43.8 years at present, 41.2 years in 2100). (Lutz *et al.*, 2008)

Future trends in social and economic development are relevant to vulnerability, long-term. For instance, it has been observed that the countries with higher Human Development Indices (a composite of life expectancy, education and literacy and GDP per capita) are less affected by floods, droughts and cyclones. (Patt *et al.*, 2010) Therefore policies that improve such measures are likely to reduce future vulnerability. But these relationships are not linear (in the early stages of economic development, historically, health statistics tend to deteriorate (Szreter and Woolcock, 2004)), and it is not clear that current patterns of consumption (on which GDP per capita is based) are sustainable to the end of the century.

Other global trends that may impact on future vulnerability include the distribution of wealth and resources (inequalities within and between countries), urbanization and changes in the nature and location of work. The flow of people and goods internationally is an important influence on the risk of some climate-sensitive infections, such as those caused by the dengue and chikungunya viruses. (Randolph and Rogers, 2010) For this reason, future trends in trade and migration will affect the susceptibility of many populations to diseases associated with climate change.

11.4. Current Impacts of Climate Change on Health

AR4 (Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats,B.Revich and A.Woodward, 2007) concluded that there was weak to moderate evidence (low to medium confidence) of climate change effects on three main categories of health exposures: vectors of human infectious diseases, allergenic pollen, and extreme heat exposures (heat waves). There was a lack of evidence for observed effects in human health outcomes, and this remains the case. The complexity of human disease systems, and the importance of social and non-climate environmental factors means that robust studies would require long time series of data on disease rates as well as other potential or actual causative factors. Such datasets are extremely rare.

Climate change effects will be experienced in the context of rapid changes in disease incidence, distribution, and the emergence of new diseases (Jones *et al*., 2008). [A disease is classified as emerging if it appears in a new area where it was not previously detected]. The number of disease systems (which are very location specific) that have been investigated intensively to elucidate the role (if any) of decadal temperature changes are few. In fact, only two disease systems have been well studied where health data are high quality (to minimize reporting biases), and changes in incidence occurred after observed warming periods (i.e. malaria cases in Kericho, Kenya, and tick-borne encephalitis cases in central and eastern Europe). The contemporaneous increase in temperature (or other climate factor) during a change in incidence or distribution is a necessary but not sufficient criterion for attribution to observed climate change (Omumbo *et al*., 2011; Pascual *et al*., 2009; Randolph, 2010).

Socio-economic factors rather than temperature were the main cause of the upsurge in TBE in the 1980-90s in central and eastern Europe (Sumilo *et al*., 2008; Sumilo *et al*., 2009). Specifically, increases in human-tick contact were caused by changes in human behaviour (increased foraging), changes in agricultural practices, and increased unemployment. Changes in the observed incidence of TBE in central Sweden remain unexplained (Randolph, 2010). Several studies have reported changes in the latitudinal and altitudinal distribution of ticks in Europe consistent with observed warming trends (see AR4 and also Gray et al. 2009), however, there is no evidence so far of any associated changes in the *distribution* of human cases of tick-borne diseases. In North America, there is good evidence of northward expansion of the distribution of the tick vector (*Ixodes scapularis*) in the period 1996 to 2004 based on an analysis of active and passive surveillance data (Ogden *et al*., 2010).

Further studies have tried to elucidate the role of local warming on malaria transmission in Kericho region of Kenya but these are limited by lack of time series data on non-temperature causes (e.g. drug resistance, vector control measures). A study using a mosquito-human model showed that predicted malaria cases exhibited a strongly non-linear response to observed warming (Alonso et al. 2011). Data from local weather stations showed a warming trend (Omumbo *et al*., 2011). A detailed review by Chaves and Koenraadt (Chaves and Koenraadt, 2010a) concluded that there is robust evidence that decadal temperature changes have played a role in changing malaria incidence but temperature trends should not be considered the main or sole cause of such changes in the east African highland region.

There is limited evidence of a change in distribution of rodent-borne infections in the US (plague and tularaemia) consistent with observed warming (Nakazawa *et al*., 2007a). Specifically, a northward shift of the southern edge of the distributions of the disease (based on human case data for period 1965-2003) was observed. No change in the northern edge of the distribution was found. Studies have also report temperature and rainfall effects on the incidence of rodent-borne hantavirus infections in Europe. The report increase in NE (nephropathia epidemica) in Belgium since 1993 is associated with temperature in the previous year causing an increase in rodents food sources (mast) (Clement *et al*., 2009). However, there is insufficient evidence to attribute the trend in cases per se to the observed warming trend.

Consistent with observed climate change affects on tree and plant species, further studies have confirmed observed changes to seasonality in pollen production in mid to high latitudes. Studies have shown an earlier onset but not an extension of the *Betula* pollen season in Finland (e.g. (Yli-Panula *et al*., 2009) and earlier onset of grass pollen season in Spain (García-Mozo *et al*., 2010) A study of several data series in North America, indicated an extension of the ragweed (*Ambrosia* spp.) pollen season at high latitudes (Ziska *et al*., 2011). An increase in the length of the season by 13-27 days since 1995 was observed at latitudes above 44N. One published study reported changes in allergic sensitization in humans (Ariano *et al*., 2010). An increase in the percentages of patients sensitized to five specific pollens over 25 year period in Italy was observed, but the attribution to observed warming remains unclear.

The previous assessment concluded that an increase in heatwave-related deaths could be attributed to climate change. However, this assessment does rely on the attribution of single weather events (or a short term trend in weather events) to anthropogenic forcing (see chapter x WGI for further discussion on this point). The association between very hot days and increases in mortality in temperate populations is very robust (see studies reviewed in section 11.2.2 above). It is therefore very likely that the observed increase in very hot days will have been associated with an increase in number of heat-related deaths in mid-latitude populations, and similarly a decline in cold-related deaths.

As reported in AR4, in 2004 the World Health Organization published the first Comparative Risk Assessment (CRA), which used common methods, rule of evidence, and databases for estimating aggregate disease burdens attributable to different risk factors (McMichael, 2004). In addition to other environmental, nutritional, infectious, and behavioral risk factors, these were applied to published and newly developed models for a range of climate-sensitive diseases in order to estimate the effect of global climate change on current disease burdens and likely proportional changes in the future (McMichael, 2004). The approach places climate change within the same criteria for epidemiologic assessment as other health risks and accounts for the size of the burden of climate-sensitive diseases rather than just proportional change, which highlights the importance of small proportional changes in diseases such as diarrhea and malnutrition that cause a large burden (Campbell-Lendrum and Woodruff, 2006).

In 2009, an updated burden of disease assessment of climate change was published by the Global Humanitarian Forum, which estimated that the global premature mortality attributable to climate change at the end of the decade was about 300,000 or roughly twice that estimated in the WHO CRA for 2000 (GHF, 2009).

In late 2011, a consortium including the WHO will publish the second CRA with a larger set of risk factors than those included in the first round, and more resolution by age and region. The results of the assessment will be added here and discussed. [At least one summary figure or table to be used]

These exercises help clarify important knowledge gaps such as a relatively poor understanding of the role of non-climatic factors (socioeconomic and other) that may modify future climatic influences and a lack of empiric evidence and methods for quantifying more complex climate–health relationships, which consequently are often excluded from consideration. These exercises highlight the need for risk assessment frameworks that make the best use of traditional epidemiologic methods and that also fully consider the specific characteristics of climate change. These include the long-term and uncertain nature of the exposure and the effects on multiple physical and biotic systems that have the potential for diverse and widespread effects, including high-impact events. [to be revised when new CRA is finished]

11.5. Future Risks

With the expectation that the world's population will reach nine billion by 2050 (*World population ageing* 2007), the future direct and indirect impacts of climate change on health are a growing concern. Although by no means certain (McMichael *et al*., 2006), effects stemming from air pollution, extreme events, heat and cold, food and waterborne infections, vector-borne and other diseases and violence are anticipated (Haines *et al*., 2006; Patz *et al*., 2005). Also expected are increased occupational health risks as well as stresses on mental health and nutrition.

The majority of research concerning the future health effects of climate change is based on health risk assessments and models of climate and health. Most studies have been conducted in high-income countries, where climate change is expected to have less of an impact due to wealth and well-developed public health infrastructure (Patz *et al*., 2005). In developing countries, the impact is likely to be much higher and compounded by the shortage of research and resources in these areas. Discussions of future health effects from climate change regarding indirect effects are also lacking (Reiter, 2008). Indirect associations like regional food yield fluctuations, loss of livelihoods and population displacement are typically more difficult to identify and their processes and effects more complex to

determine (McMichael *et al.*, 2006). More research has been on direct health effects resulting from heat waves, physical hazards such as floods, storms and fires and vector-borne infectious diseases and are easier to define (McMichael *et al.*, 2006). However, those effects that are the most easily predictable may not be the most important. Effects could also be non-linear (Wilkinson *et al.*, 2007b).
Overall, the predicted health consequences for climate change are expected to be adverse, with a few benefits. These include fewer cold-related deaths in temperate developed countries as well as reduced mosquito viability in hot regions from further warming or drying (McMichael *et al.*, 2006). Climate change effects are largely not expected to result in new diseases or health conditions but rather change or expand into new populations and increase the frequency and intensity of exposures (Hanna *et al.*). Rare events may also become more common (Luber and Hess, 2007a; Patz, J.A., Gibbs, H.K., Foley, J.A., Rogers, J.V., Smith,K.R., 2007).

The burden of these health effects are expected be borne more heavily by the elderly and people with infirmities or preexisting medical conditions. In addition, children and the poor are also expected to suffer disproportionately from climate change-induced health effects. Climate sensitive diseases such as diarrhea, malaria and undernutrition-related infections are also childhood diseases of poverty (Neira *et al.*, 2008).

Estimates of the future health effects of climate change are not without controversy and uncertainty. Some papers have questioned the attribution of recent health changes to changes in climate (McMichael *et al.*, 2006; Wilkinson *et al.*, 2007b). It is important to note that predicted climate-related health effects are based on scenarios that include a number of assumptions.

Air Quality

As urbanization and industrial development are expected to increase, especially in developing countries, fossil fuel use and air pollution are also expected to concurrently rise. However, the technological efficiency of fuel consumption is also expected to improve so greenhouse gas emissions may be relatively lower. Despite this, the dependence of developing countries on solid biomass fuels that are burned inefficiently in poorly ventilated homes is predicted to continue in the short-to-medium term and increase morbidity and mortality in these countries (Wilkinson *et al.*, 2007b).

Meteorological conditions may also influence the concentration, formation and dispersion of air pollutants. Air pollution is also expected to have synergistic effects with temperature in urban areas, contributing to heat-related morbidity and mortality (Bernard *et al.*, 2001; Samoli *et al.*, 2005). Physical exertion outdoors on hot, sunny, high-ozone days is thought to exacerbate health risks by placing increased demand on cardiorespiratory systems, although further study is still needed. (Hanna *et al.*)

Other health outcomes of concern regarding future climate changes and air pollution include asthma and chronic obstructive pulmonary disease (Luber and Hess, 2007a) . Increased hospital admissions for respiratory diseases and premature deaths stemming from exposure to ozone and fine particulate matter ($PM_{2.5}$) are predicted for 2050 in parts of the US (Tagaris *et al.*, 2009). Unfortunately, predictions are usually lacking for developing countries (Wilkinson *et al.*, 2007b).

Climate change is also predicted to have effects on aeroallergens (Wilkinson *et al.*, 2007b). Species of plants that are sources of aeroallergens are known to be sensitive to changes in temperature, rainfall, CO_2 concentrations and other climate variables (Beggs, 2010). Future climate-induced impacts on aeroallergens could affect production levels, atmospheric concentrations, seasonal duration, plant, pollen or mould spatial distribution and allergenicity (Beggs, 2010).

Extreme Events

Climate change is expected to have an effect on the future frequency, intensity, timing and duration of extreme events, which will have ramifications for population health including increased mortality and morbidity (Greenough *et al.*, 2001). Indirect effects including population displacement from the inundation of low-lying areas resulting from a rise in sea level are also expected (Wilkinson *et al.*, 2007b). Other indirect health effects may also result from changes in ecological systems and public health infrastructure (Greenough *et al.*, 2001). However, the accurate estimation of future morbidity, in some cases such as from floods and storms, is hindered by the absence of empirically documented exposure-response evidence (McMichael *et al.*, 2006).

Food and Water-Borne Infections

An increase in the occurrence of food and water-borne diseases is likewise expected (Wilkinson *et al.*, 2007b). Rises in sea surface temperatures and levels from climate change could lead to a higher incidence of waterborne diseases like cholera (Bezirtzoglou *et al.*, 2011; Luber and Hess, 2007a). Recent cases of cholera imported to Europe from Kenya have already been linked to the El Niño phenomenon (Bezirtzoglou *et al.*, 2011). Higher temperatures could also lead to higher bacterial food and animal gut proliferation rates for *Salmonella spp*. (McMichael *et al.*, 2006).

Heavy rainfall may trigger outbreaks of diarrhea from the contamination of water sources (McMichael *et al.*, 2006). Flooding has been related to excess cases of leptospirosis and campylobacter enteritis in the Czech Republic. Flooding has also been associated with increases in cryptosporidiosis in the United Kingdom (Bezirtzoglou *et al.*, 2011). The effects of harmful algal blooms are also a concern for seafood intoxication (Bezirtzoglou *et al.*, 2011; Luber and Hess, 2007a). Model projections in the US estimate that extreme precipitation events will become 10% to 40% stronger in southern Wisconsin, increasing the risk of flooding and the occurrence of waterborne diseases (Patz *et al.*, 2008).

Vector-Borne and Other Infectious Diseases

The key climate variables affecting the distribution and impact of vectors and vector-borne diseases are temperature, rainfall and humidity, which can interact to produce synergistic or antagonistic effects (Reiter, 2008). Vector development and disease transmission are also dependent on ecological settings (Aron, 2006). Currently, highly specific spatio-temporal predictions may not be technically feasible (Aron, 2006). The role of climate and seasonality in disease transmission is complicated by drivers operating at different spatial scales, which may be affected by biological and social changes (Pascual and Dobson, 2005). Biological and social factors that could have an effect on future vector-borne disease incidence include vector adaptivity; higher birth rates, which may promote larger communities with a higher density of people and subsequently higher attack rates; forest clearance and agricultural activities that can create new habitats; the movement of people, which can introduce vectors and diseases to new areas; urbanization that may lead to increased water storage and/or inadequate water disposal, creating habitats for vectors; insecticide and/or drug resistance; the degradation of health infrastructure as well as water and civil strife (Reiter, 2008). Transmission is also influenced by intrinsic human immunity (McMichael *et al.*, 2006). Furthermore, all models are associated assumptions and uncertainties, which can pose serious impediments to longer-term heath predictions related to climate change (Aron, 2006).

Nonetheless, the distribution and transmission of vectors and vector-borne diseases will likely be altered with changes in climate (Wilkinson *et al.*, 2007b). Regions that currently experience low temperatures, low rainfall or the absence of vector habitats, all of which restrict the transmission of vector-borne diseases, may be at risk of epidemics should these parameters change (Luber and Hess, 2007a). Changing vector distributions have already occurred with respect to tickborne encephalitis in parts of Europe although it appears the contribution of rising temperatures has been minor (Bezirtzoglou *et al.*, 2011). Lyme disease is predicted to expand its range in North America (Bernstein and Myers, 2011). Changes in temperature can also affect vector and pathogen development and transmission in regions already at risk. Higher temperatures could shorten pathogen developmental periods (McMichael *et al.*, 2006)or conversely decrease vector viability if temperature increases are beyond vector limits (Kirby and Lindsay, 2009). Increases in rainfall can also flush out larvae from their habitats and reduce mosquito populations (McMichael *et al.*, 2006) or create new breeding sites. Outbreaks of vector-borne diseases may also become longer in duration, more frequent and more widespread (Gubler *et al.*, 2001).

To date, modeling the effects of future climate change on vector-borne diseases has typically focused on malaria and dengue fever, although little has been done regarding the social, economic and topographical aspects of transmission (McMichael *et al*., 2006). It is expected that the number of cases of malaria will rise in the coming decades in regions where the disease is already present. For 2050, the projected population at risk is estimated to be 5.2 billion with only climate effects and 1.95 billion with the combined effects of GDP growth and climate (Béguin, A., Hales, S., Rocklöv, J., Åström, C., Louis, V.R., Sauerborn,R., 2011). Malaria vectors may also move to higher latitudes and altitudes (Reiter, 2008). Increased rainfall or temperatures may lead to an increase in dengue transmission, depending on local conditions such as housing standards and vector control activities. Drought may also increase the number of suitable breeding sites for dengue vectors should household water storage also concurrently increase (Barclay, 2008).

Ecosystem changes resulting from warming and shifts in rainfall may have effects, both direct and indirect on avian influenza. The rapid temperature increases near the poles, increased rainfall in some areas (e.g. eastern parts of north and South America, northern Europe, and north and central Asia) and drought in other areas like the Sahel, South Africa, the Mediterranean and parts of Asia) (Soebiyanto *et al*., 2010) can influence the quality of the wetlands and its ecosystem services. These changes in rainfall patterns alter the distribution, abundance, and quality of wetlands and can impact migratory bird or waterfowl populations. Therefore, climate change may affect migration patterns of many species of birds with some long distance migrant birds travelling earlier in the season while others remain unaffected (Moller *et al.,* 2008). It is plausible that climate related changes in the distribution, composition, and migratory behaviour of wild birds may affect the epidemiology of avian influenza but there is no direct evidence of such effects, nor is it clear what difference there would be on the burden of disease among humans.

Health of Workers

Climate change is also predicted to increase the occupational health risks and strain for those working in hot environments (Hanna *et al*.). People at risk include those working outdoors or engaged in maintenance work, mining (Donoghue *et al*., 2000), shearing (Gun and Budd, 1995), farm work (Taylor *et al*., 2008), firefighting (Budd, 2001)and other emergency and essential services. (Hanna *et al*.) Work indoors close to heat-generating equipment like ovens with poor ventilation also pose heat risks. (Hanna *et al*.) Compounding the problem is that many workers in these environments are required to wear protective clothing, which can hamper evaporative heat loss and reduce sweating efficacy (Hanna *et al*.). Miners and other manual workers may also work long shifts in these hot environments, further exposing them to heat-related risks. (Hanna *et al*.) Humid conditions and air pollution may also worsen heat exposure effects in workers. (Dear *et al*., 2005)

The health effects of exposure to extreme heat, especially with insufficient fluid replacement, include cognitive and physical impairment as well as psychological and behavioral effects (Hanna *et al*.; Zivin, J.G., Neidell,M.J., 2010). Longer-term effects from chronic dehydration include renal disease and premature death (Brake and Bates, 2002). Work and other physical exertion activities during extreme heat events also increases the burden on cardiorespiratory systems. (Hanna *et al*.)

Extreme heat also leads to more work-related accidents (Bates *et al*., 1996) and is associated with reductions in work capacity, output and economic productivity (Bates and Schneider, 2008). A 4% body water loss reduces physical work capacity by approximately 50% (Hanna *et al*.). Additionally, remunerated output may encourage workers to push themselves beyond their safe limits, which can lead to poor decision-making and increased risks for workers and their colleagues (Hanna *et al*.). Other effects include a greater risk of infectious diseases from exposure to vectors, extreme weather morbidity or morality, stress and mental health issues as well as malnutrition. (Bennett and McMichael, 2010a)

Heat and Cold

Health effects related to changes in temperature are expected be both detrimental and beneficial. Under predicted climate change scenarios, heat waves will likely increase in frequency and intensity and worsen heat-related exposures, although acclimatization and improvements in energy efficiency may mitigate some of these effects (Bi *et al*., 2011; Hanna *et al*.; Wilkinson *et al*., 2007a; Wilkinson *et al*., 2007b). In Australia, the number of "dangerously hot" days when core body temperatures may increase by ≥ 2ºC and outdoor activity becomes impossible is forecasted to rise. An increase from the current 4 to 6 days per year to 33-45 days per year by 2070 is expected for unacclimatized people. Among acclimatized people, an increase from 1-5 days per year to 5-14 days per year is expected (Hanna *et al*.). A rise in the proportion of elderly will also increase populations' vulnerability to extreme heat events (Luber and Hess, 2007a) and lead to health system strain. Other heat-related heat effects may also include direct thermal injury or the exacerbation of existing illnesses. (Luber and Hess, 2007a)

Conversely, cold-related mortality is expected to drop in temperate regions but the increase in heat-related mortality is expected to outweigh these gains, especially in developing countries with limited adaptive capacities (Wilkinson *et al*., 2007b). Model predictions in three Quebec cities predict an increase in summer mortality of 2% and an annual overall mortality rise of 0.5% by 2020. By 2080, summer mortality is predicted to rise to 10% and annual mortality to 3% compared to current rates, which will outweigh predicted fall and winter decreases (Table 2) (Doyon *et al*., 2008). The same trend is echoed in a study modeling heat-related premature mortality in the New York City Metropolitan region. By the 2050's, an increase in premature mortality between 47-95% with a mean increase of 70% is expected, compared to the 1990's (Knowlton *et al*., 2007). Acclimatization may reduce the expected number of summer heat-related premature mortality regionally by up to 25%. Urban areas are expected to show greater numbers of deaths due to population density but an overall smaller percentage increase than less-urbanized counties (Knowlton *et al*., 2007). Socioeconomic status may also play a role in the uneven distribution of heat-related deaths as households that live in poverty or in older residential neighborhoods in New York City often do not have air conditioning, which can increase mortality risk. Thus, despite the uncertainty associated with forecasts regarding climate and future health vulnerability, as well as the expected reduction in mortality estimates from acclimatization, research still suggests an overall net increase in heat-related premature mortality (Knowlton *et al*., 2007).

Mental Health

An understudied effect of climate change is mental health (Berry *et al*., 2010). In Australia, drying and bushfires are altering landscapes and livelihoods, which may be producing psychological distress in people who feel directly connected to their home environment (Albrecht *et al*., 2007). Climate change pressures could also exacerbate existing farming stresses {Fraser, 2002 #283;Fragar, 2008 #344}. Previous studies have found higher suicide rates (Berry *et al*., 2010) among those in rural areas of Australia (14.6-17.1 per 100,000 persons) compared to capital cities (12.8-12.9 per 100,000 people). Notably, the most significant increases were in communities with populations less than 4000. This rise was attributed to increased economic stress on farming and rural populations. The increased vulnerability of rural populations to mental health problems is also worsened by lower socioeconomic status, reduced access to health services and the resistance of those in the community in seeking help for mental health issues. (Berry *et al*., 2010)

Climate change-induced mental health stresses may also disproportionately affect younger generations due to out-migration as well as those affected by disasters and economic hardship from ecosystem change (Berry *et al*., 2010). Over the long-term, drought or other weather-related disasters could erode the social and economic bases of farming communities, leaving an aging farm population, fewer health services and low morale (Berry *et al*., 2010; Hossain *et al*., 2008). Other mental health effects may result from population displacement due to climate change. (McMichael *et al*., 2006)

Nutrition

An important consequence of climate change may be a greater prevalence of malnutrition (McMichael *et al*., 2006). This could occur in a number of ways under different climate scenarios: temperature and water induced stress that lowers crop and livestock productivity; socioeconomic and population dislocation of environmental refugees; increasing use of agricultural land to grow biofuels that raises food prices (Wilkinson *et al*., 2007b); increases in the frequency and severity of extreme events such as heat waves, droughts, flooding, cyclones and landslides that affect food availability and accessibility and as well as plant disease and infestation outbreaks (Hanna *et al.*). Ocean-food productivity may also be affected (Slingo J M, Challinor A.J.Hoskins B.J. and Wheeler, 2005). Longer-term climate change events can also affect agriculture through farmland loss, soil erosion, diminishing fertilizer response, emergence of new types and combinations of food and plant parasites and declining genetic crop diversity.

In countries with larger food-insecure populations like parts of Africa and South Asia, climate change will also likely aggravate existing production and consumption constraints (Webb, 2010). Regions such as rural Australia are likely to suffer from diminishing agricultural production as drying trends across Southern Australia are predicted to continue (Hanna *et al.*). Climate change impacts on food supply can also lead to an increase the health equity gap between privileged and underprivileged people. If rising prices lead to the inaccessibility of healthy foods by underprivileged groups, unhealthy foods may be substituted in the diet, which can increase the risk of lifestyles diseases such as diabetes and cardiovascular disease (Sulda *et al.*)

Research suggests that there also may be some benefits associated with climate change with respect to plant growth. The combined effects of increased CO_2, a 3ºC temperature rise and altered rainfall and soil moisture could increase wheat yields by 20% among late-maturing varieties in Australia. However, this same combination could halve the yields of some early-maturing wheat varieties. (Bi and Parton, 2008)

Violence

In addition to mental health stresses, climate extremes have also been linked to increased violence (McMichael *et al.*, 2006). Significant correlations have also been predicted between poor weather, crop yields, the gross domestic product (GDP) of a country and violence (Miguel, E. Satyanath, S., Sergenti,E., 2004). It has been estimated that for every 1% drop in the GDP, the probability of major violence increases by 2%. By 2080, when the average annual temperature is predicted to be 3.5°C warmer and the annual rainfall lowered by 24%, the effects are expected to be lower agricultural yields, lower GDP and a 15% increase in the probability of violence (Miguel, E. Satyanath, S., Sergenti,E., 2004). In Chad, given a probability of major violence in any year of 10%, the probability is predicted increase by as much as 25% by 2080 (Walker, 2009). A significant relationship has also been shown between poor crop yields and the killing of elderly women denounced as witches (Miguel, 2005). In Darfur, northern pastoralist tribes shifted to a reliance on mercenary payments when faced with a collapsing pastoral economy, which may worsen with predicted climate effects (Young, H., Osman, A.M., Abusin, A.M., Asher, M., Egemi,O., 2009). Political instability, regional tension and armed conflict over resource availability could also increase the probability of violence. (Luber and Hess, 2007a)

Other Effects

Other health effects that might be associated with future climate changes are a rise in chronic disease incidence and severity. Sun-induced skin cancers has been predicted to rise from mice experiments when the combined effects of ozone depletion, climate change and a rise in ambient temperature are taken into account (van der Leun *et al.*, 2008a). Injuries stemming from extreme weather events (Luber and Hess, 2007a), water insecurity (Goater *et al.*, 2011) and economic disruption (Patz *et al.*, 2000) may also occur.

11.6. Adaptation to Protect Health

Adaptation is modification of natural or human systems in response to actual or expected climate changes and their effects. It may be deliberate, “planned adaptation”, or result from autonomous feedbacks that involve no explicit, human decision-making.

The importance of adaptation is demonstrated by the recent history of natural disasters, and their impacts on population health. For example, when cyclone Bhola (category 3 in severity) hit East Pakistan (present day Bangladesh) in 1970, more than 500,000 people died. Then in 1991 a cyclone of similar severity caused about

140,000 deaths. In November 2007, cyclone Sidr (category 4) resulted in only 5-10,000 deaths, although the population of the country had grown by more than 30 million in the intervening period. (Mallick *et al.*, 2005) Bangladesh achieved this remarkable reduction in disaster mortality through effective collaborations between government, local communities and non-governmental organizations. (Khan, 2008) Alongside improving the general education of the population (which has been greatly assisted by rising literacy rates, especially among women), the country deployed early warning systems and built a network of cyclone shelters. Early warning systems included both high technology information systems and relatively simple measures such as training volunteers who could distribute warning messages by bicycle.

In this section we will concentrate on planned adaptations, including what might be described as "generic" adaptation, and interventions designed specifically to reduce the adverse impacts of climate change.

11.6.1. General Adaptations

Climate change acts as a multiplier of risk – in most instances, changes in temperature, rainfall and extreme events compound health problems that are already present. Where rates of diarrheal disease among children are already high, for instance, rising temperatures will have much greater effects than in populations where children are seldom affected. One recent review concluded that the baseline health status of a population is probably the single most important predictor of both the future health impacts of climate change, and the costs for that country of adapting. (Pandey, 2010)This means that reducing background rates of disease and injury is an important step to improving population resilience and minimizing poor health outcomes resulting from climate change.

Improvements in basic public health functions such as disease surveillance, monitoring of risky exposures, and coordination between health and other sectors also constitute adaptation. (Woodward *et al.*, 2011) A United States review proposed ten essential public health services, all relevant one way or another to the responses that are likely to be required if present climate trends continue. (Frumkin H., Hess J., Luber G., Malilay J.,McGeehin M., 2008)For example, food safety in a time of rising temperatures and extremes in rainfall depends on well-functioning links between human health and veterinary authorities, integrated monitoring of food-borne and animal diseases and improved detection methods to pick up pathogens and contaminants in food. (Tirado *et al.*, 2010)

Better access to health care is another example of "generic" adaptation. In Benin, one of the measures that is proposed as part of the response to sea level rise and floods is expanded health insurance arrangements, so that diseases that may be aggravated by climate change (malaria, enteric infections) can be treated promptly and effectively. (Dossou and Glehouenou-Dossou, 2007)

Other sectors than health care play an important part in protecting against disease and injury resulting from climate change. EuroHEAT, a European review of public health responses to extreme heat, identified transport policies, building design and urban land use all as important elements of national and municipal heat-health action plans. (World Health Organization, 2009a) In the United States, a study examined well-established interventions to reduce the urban heat island effect (replacing bitumen and concrete with more heat-reflective surfaces, and introducing more green spaces to the city) and found these would reduce heat-related emergency calls for medical assistance by almost 50%.(Silva *et al.*, 2010) Urban green spaces lower the temperature, and also improve air quality, provide shade and may be good for mental health. (van den Berg *et al.*, 2010) A more variable climate is expected to increase the risk of child under-nutrition in some parts of the world, but a review of food aid programmes indicates that a rapid response, targeted to those in greatest need, with flexible financing and the capacity to rapidly scale-up depending on need, may reduce damaging health consequences. (Alderman, 2010)

Migration is a common coping strategy in the face of adverse changes in climate, and may itself have significant effects on health, both positive and negative. For instance, large numbers of Pacific islanders have moved to countries around the Pacific rim, partly as a result of environmental pressures, and comparisons of the health of migrants and peers in the islands show mixed effects (higher levels of risk factors such as raised blood pressure and cigarette smoking among migrants, but also lower mortality rates overall and higher life expectancies). Climate-related migration includes both the movements of population between countries, and within-country shifts, such as flows to cities from drought and heat affected rural areas. (Acosta-Michlik *et al*., 2008) Where people choose to live may reflect a complex balancing of risks and benefits. A study in Indore in India found that low-income households were willing to live in flood-prone areas because of other advantages provided by these sites, including access to health care (and low-cost housing). (United Nations Human Settlements Programme, 2011)

There are many effects of community organization that are pertinent to climate change adaptation. In the Philippines, for example, interventions in low-income urban settings include savings schemes, small-scale loans, hygiene education, local control and maintenance of water supplies, and neighbourhood level solid waste management strategies. (Dodman *et al*., 2010) All these have the potential to reduce harmful effects of climate extremes on health.

11.6.2. Specific Adaptations

Early Warning Systems

Early warning systems have been developed in many areas as a means of alerting public health authorities to climate-related health risks.

Heat-health warning systems (HHWS) are instruments to prevent negative impacts of the thermal environment on health during heat waves. Weather forecasts are used to predict situations that are associated with an increase in mortality or morbidity. The essential and common components of HHWS are identifying weather situations that adversely affect human health, monitoring weather forecasts and activating mechanisms for issuing warnings. Few papers have been published since 2006 on the effectiveness of HHWS on mortality or morbidity – the most informative are listed in Table 11-1.

[INSERT TABLE 11-1 HERE
Table 11-1: Studies of the effectiveness of heat-health warning systems.]

Studies of the effectiveness of heat warning systems may struggle to attribute changes in health outcomes to specific public health interventions rather than subtle differences in weather conditions or differences in the underlying population vulnerability. Also, several public health interventions are often implemented simultaneously. We note also that the existing early warning systems have been calibrated to current variations in temperature and other weather variables. It is difficult to tell how these systems will respond to the conditions that apply in the future under climate change.

Early warning systems have also been developed on the basis of predictive models for vector-borne and food-borne infections. In Botswana, forecasts of malaria incidence up to 4 months ahead have been made on the basis of observed rainfall, on the basis of evidence that inter-annual and seasonal variations in climate are associated with outbreaks of malaria in this part of Africa. The outputs from the model include probability distributions of disease risk and measures of the uncertainty associated with the forecasts. (Thomson *et al*., 2006) The incidence of several bacterial enteric infections is known to vary with ambient temperature, (Fleury *et al*., 2006) and this information has been used to develop health alerts based on projected temperatures. A study of campylobacteriosis in the United States developed models of monthly disease risk that showed a very good fit in validation data sets (R^2 up to 80%). (Weisent *et al*., 2010)

Early warning systems have been effective in preventing deaths and injuries due to floods: one review cited examples of forecasting systems that cut mortality from flash floods by more than 50%. (Keim, 2008)

Vulnerability Mapping

Remote sensing applications are now sufficiently fine-grained to allow mapping of local factors associated with vulnerability to climate, and guide the allocation of interventions to reduce exposures and/or impacts. For instance, these technologies can be used to map surface temperatures and urban heat island effects at the neighbourhood scale, indicating where city greening and other urban cooling measures should be concentrated, and alerting public health authorities to populations that may be at greatest risk of heatwaves. (Luber and McGeehin, 2008) Mapping at a coarser level, for instance regionally, may also be useful to guide adaptation. In Portugal, modelling of Lyme disease, spread by ticks that are sensitive to ambient temperatures and soil moisture, indicates that future conditions will be less favourable for disease transmission in the south, but more favourable in the centre and northern parts of the country. (Casimiro *et al*., 2006)

Public Education

Much of the adaptation to climate change to protect health happens at the neighbourhood and community levels. Information, education and engagement of populations is essential to mobilizing community resources and responding appropriately to natural disasters. For example, the 1997-98 El Nino event resulted in severe drought across much of the Pacific. In some islands, this caused serious health problems (diarrhoeal diseases, malnutrition). However it was noted in Pohnpei in the Federated States of Micronesia that admissions of children to hospital for diarrhoeal disease did not rise. It is thought this may be due in part to an effective public education campaign to alert families to the risks of water-borne diseases. (Ebi *et al*., 2006) In the summer of 2006, France was affected by the most severe high temperatures that had occurred since the serious heat-wave of 2003. About 2000 excess deaths were recorded in the 2006 heat-wave, but this was about 4000 less than was anticipated, on the basis of the experience in 2003. A national assessment concluded that the most likely reasons included greater public awareness of the health risks due to heat, as well improved health care facilities and the introduction, in 2004, of a heat health watch warning system. (Fouillet *et al*., 2008)

Health Care

Health care interventions aimed at primary prevention may reduce harm caused by climate and other environmental stressors. As one example, vaccination programmes have been shown to reduce the incidence and alter the seasonality of illness caused by rotavirus, a common climate-sensitive pathogen. (Tate *et al*., 2009a) Post-disaster initiatives are important also. Studies of the severe European heat-waves of the early 2000s showed that there were serious deficiencies in many countries in care of those affected by extreme temperatures. The EuroHEAT assessment has since recommended a number of practical steps that health services can take to reduce morbidity and deaths caused by heat. Examples include staff planning over the summer period, cooling of health care facilities, training of staff in recognition and treatment of heat strain, and monitoring of those in the highest risk population groups. (World Health Organization, 2009a)In a similar vein, there have been many studies carried out on the effects of Hurricane Katrina in the US, and what improvements need to be made in order to deal more effectively with large-scale floods and storms in the future. Diabetes care, for example, was compromised following Katrina by a lack of blood glucose testing kits, insulin and other diabetes medications, and calls have been made for these, and similar essential medical supplies for care of individuals with chronic conditions, to be better stockpiled and more rapidly and appropriately distributed post-disaster. (Cefalu *et al*., 2006)

11.7. Health Co-Benefits

Essentially every human activity affects (and is affected by) climate and health in some way, but not all are strongly linked to either and even fewer to both. A few measures to mitigate the atmospheric concentration of warming CAPs (climate active pollutants), however, also hold the potential to offer significant co-benefits for human health (Apsimon *et al*., 2009; Haines *et al*., 2007; Smith and Balakrishnan, 2009; UNEP, In Press). The health co-benefits associated with climate change mitigation strategies fall into five categories (Smith *et al*., 2009): (1) Reduction of health-damaging co-pollutants; (2) Increases in active transportation from modifications to the built environment; (3) Increases in urban green-space; (4) Decreases in ruminant meat consumption; (5) Increased access to reproductive services. In addition, there are also *cross-benefits*: measures that are climate cooling but deleterious for human health and vice versa.

11.7.1. Reduction of Co-Pollutants

Most of the interaction of CAPs and health-damaging pollutants relate to fuel combustion and are in two major categories. 1) Improvement in energy efficiency will reduce emissions of CO_2 and health-damaging pollutants if the energy is derived from combustion of fossil fuels or non-renewable biomass fuels, either directly or through the electric power system. 2) In addition, increases of combustion efficiency (decreasing emission of incomplete combustion products) will have both climate and health benefits, even if there is no change in energy efficiency and/or fuel itself is renewable, i.e. carbon neutral. This is because a number of the products of incomplete combustion are climate active and all are damaging to health (Smith *et al*., 2009).

Studies of the health co-benefits of reduction in air pollutants include sources that produce outdoor air pollution (Bell *et al*., 2008) and household sources (Po *et al*., 2011) where much of the pollution exposure occurs indoors. In recent years, however, it has become clear that in many parts of the world, household fuel (poorly combusted biomass and coal) is responsible for a substantial percent of primary outdoor fine particle pollution as well, perhaps a third to a half in China and India, for example (Chafe et al. submitted) indicating that reductions in emissions from household sources could yield co-benefits through the outdoor pollution pathway as well.

Outdoor Sources

Outdoors, health-damaging pollutants can be separated into two categories -- primary and secondary. Primary co-pollutants, such as particulate matter (PM) and carbon monoxide (CO) are those released at the point of combustion, while secondary co-pollutants, such as tropospheric ozone and sulphate particles, are formed downwind from the combustion source via atmospheric chemical interactions (Jerrett *et al*., 2009). As noted in Section 11.2, outdoors, the production and distribution of some secondary co-pollutants is exacerbated by temperature-associated attributes of climate change itself, thus posing a positive feedback effect.

The burden of disease from outdoor exposures in a country may often be greater in populations with low socioeconomic status, both because of living in areas with higher exposures and because these populations often have greater pre-existing ill-health and are often subjected to multiple additional negative environmental and social exposures (Morello-Frosch *et al*., 2011).

Household Sources

Globally, the largest exposures from the pollutants from poor fuel combustion, however, occur in the poorest populations. This is because household use of biomass for cooking is distributed nearly entirely by income. Essentially, no poor family can afford gas or electricity for cooking and very few families who can afford to do so, do not. Thus, the approximate 41% of all world households using solid fuels for cooking are all among the poor in developing countries (Adair, submitted).

Primary Co-Pollutants

Outdoor exposure to PM, especially to particles with diameters less than 2.5 um ($PM_{2.5}$), contributes significantly to ill-health including cardio- and cerebrovascular disease, chronic and acute respiratory illnesses, lung cancer, and possibly other diseases. The WHO Comparative Risk Assessment for outdoor air pollution found xx [to be updated with new results in late 2011]. Importantly, reductions in ambient PM concentrations have also been shown to decrease morbidity and premature mortality (Boldo *et al*., 2010).

Because of higher exposures, an additional set of diseases has been associated with combustion products in households burning biomass and/or coal for cooking and heating. Thus, in addition to the diseases noted above, cataracts, low birth weight, and stillbirth have been associated strongly with exposures to incomplete combustion products, such as PM and CO. There is also growing evidence of exacerbation of tuberculosis in adults and cognitive effects in children. The WHO Comparative Risk Assessment found xxx [to be updated with new results in late 2011]. Importantly, there are also studies showing health benefits of household interventions, including child pneumonia (Smith et al. forthcoming), blood pressure (McCracken *et al.*, 2007), lung cancer (Lan *et al.*, 2002), and chronic obstructive pulmonary disease (Chapman *et al.*, 2005).

Carbon monoxide (CO), another by-product of fuel combustion, is also associated with a range of health effects including impacts on unborn children in utero through exposures to their pregnant mothers (WHO, 2010b) as well as being a CAP (WG1).

Black carbon (BC), a primary product of incomplete combustion, is both a strong CAP and health-damaging (IPCC, 2007; Ramanathan and Carmichael, 2008). Smith et al. (2009) conducted a systematic review, meta-analysis, and the largest cohort study to date of the health effects of BC. A nationwide United States cohort representing 66 cities and 18 years of data was used to estimate mortality effects of long-term exposure to elemental carbon (EC) – the best available measure of BC. It was found that there were probably stronger effects on mortality from exposure to EC than for undifferentiated fine particles ($PM_{2.5}$). The conclusion is that BC abatement represents an opportunity to achieve both climate mitigation and health benefits, a conclusion of other recent reviews as well (UNEP, in press).

Secondary Co-Pollutants

Tropospheric ozone is formed through photochemical reactions that involve nitrogen oxides and volatile organic compounds in the presence of sunlight and elevated temperatures (US EPA, 2007). Thus, many air pollution models (Chang *et al.*, 2010; Ebi and McGregor, 2008a; Polvani *et al.*, 2011; Tsai *et al.*, 2008) predict that increasing temperatures, due to anthropogenic climate change, will result in increased ozone production, especially within and surrounding urban areas where the anthropogenic production of NO_x through the combustion of fossil fuel in the stationary and mobile source sectors (heating, power generation, motor vehicles, etc.) is concentrated (Hesterberg *et al.*, 2009).

Growing scientific consensus links even small increases in atmospheric concentrations of ground-level ozone to ill-health. Tropospheric ozone has been linked to respiratory-associated morbidity and mortality due to both long (Jerrett *et al.*, 2009) and short-term (Bell *et al.*, 2006; Ebi and McGregor, 2008a) exposures. For instance, Bell et al. (2006) found that even levels that meet the US EPA 8-hour regulation were associated with increased risk of premature mortality(Bell *et al.*, 2006) There is a lack of association between ozone and premature mortality, only at the very low concentrations (from 0 to ~10 ppb) but the association becomes positive and approximately linear at higher concentrations (Bell *et al.*, 2006; Ebi and McGregor, 2008a; Jerrett *et al.*, 2009).

In addition to being a strong CAP, CH_4 is also a significant precursor to anthropogenic tropospheric ozone production. Thus, reductions in CH_4 could lead to reductions in ambient tropospheric ozone concentrations, which in turn could result in reductions in population morbidity and premature mortality (Figure 11-2).

[INSERT FIGURE 11-2 HERE
Figure 11-2: Avoided global premature mortalities from a 65 mt-yr^{-1} CH_4 emission reduction, beginning in 2010 (West et al., 2006).]

In an analysis of ozone trends from 1998-2008 Lefohn et al. (2010) found that 1-hour and 8-hour ambient ozone averages, have either decreased or failed to increase due to successful regulations of ozone precursors, predominantly NO_x and CH4 (Lefohn *et al.*, 2010). This analysis agrees with the US EPA (2009) conclusions that for the period 1980-2008, the downward trending percent change in emissions for nitrogen oxides and volatile organic compounds was 40% and 47%, respectively (Lefohn *et al.*, 2010; US EPA, 2009). These results point to the effectiveness of reducing ambient ozone concentrations through regulatory tools that reduce the emissions of ozone precursors, some of which, like CH4, are GHGs.

Smith *et al.,* (2009) found, in both a meta-analysis and in a cohort analysis of 66 United States cities with 18 years of follow-up that ozone is significantly associated with cardiopulmonary mortality. These results are consistent with most analyses on the mortality burden of tropospheric ozone. For example, West et al. (2006) found that a reduction of global anthropogenic CH4 emissions by 20% beginning in 2010 could decrease the average daily maximum 8-h surface ozone by 1 ppb by volume, globally (West *et al*., 2006). When they applied epidemiologic ozone mortality relationships, a reduction of 1 ppb ozone was estimated to prevent 30,000 premature all-cause mortalities globally in 2030, and 370,000 between 2010 and 2030. When they considered only cardiovascular and respiratory mortalities, 17,000 deaths globally were found to be avoidable in 2030 (West *et al*., 2006). CH_4 emissions are generally accepted as the primary source of tropospheric ozone concentrations above other ozone precursors (West *et al*., 2007) and thus, the indirect health co-benefits of CH_4 reductions are epidemiologically significant.

Case Studies of Co-Benefits of Air Pollution Reductions

A study of the benefits of a 10-year program to introduce advanced combustion cookstoves in India found that in addition to reducing premature mortality by about 2 million and DALYs by 55 million over that period, there would be reduction of 0.5-1.0 billion tons CO2-eq (Wilkinson P, Smith KR, Davies M,et al., 2009).

In their estimation of effects of physical and behavior modifications in UK housing, Wilkinson and colleagues (2009) found that the magnitude and direction of implications for health depended heavily on the details of the intervention. However, the interventions were found to be generally positive for health. In a strategy of housing modification that included combined fabric, ventilation, fuel switching, along with behavioral changes, it was estimated that 850 fewer DALYs, and a savings of 0.6 megatonnes of CO_2 per million population in one year could be achieved. These calculations were made by comparing the health of the 2010 population with and without the specified physical and behavioral modifications (Wilkinson P, Smith KR, Davies M,et al., 2009).

Markandya *et al.,* (2009) assessed the changes in emissions of $PM_{2.5}$ and subsequent effects on population health that would be likely to result from climate change mitigation measures aimed to reduce GHG emissions by 50% by 2050 (compared with 1990 emissions) from the electricity generation sector in the EU, China, and India (Markandya *et al*., 2009). In all three regions, changes in modes of production of electricity to reduce CO_2 emissions were found to reduce $PM_{2.5}$ and associated mortality. The greatest effect was found in India and the smallest in the EU. The analysis also found that health benefits greatly offset the cost of GHG emission reductions, especially in the Indian context where emissions are high but costs of implementing the measures are low (Markandya *et al*., 2009).

11.7.2. Increases in Active Transportation Associated with Modifications to the Built Environment

Transportation accounts for a significant proportion of CO_2 and total CAP emissions from global energy use (Kahn *et al*., 2007). At the same time, the prevalence of obesity is growing throughout the world and is associated in part with chronic diseases such as CVD, diabetes, and cancer [cite new CRA when out]. A complex web of mechanisms that include increasingly caloric diets as well as increasingly sedentary lifestyles drives the interaction between the built environment, obesity, and chronic diseases. Data from cross-sectional studies and recent reviews have demonstrated associations between environmental features, such as the presence of sidewalks, proximity of residents to parks, and the access of certain types of food stores, and certain outcomes such as physical activity and body mass (Babey *et al*., 2007; Babey *et al*., 2008; Casagrande *et al*., 2009; Durand *et al*., 2011; Kaczynski and Henderson, 2008; McCormack *et al*., 2004; Reed and Ainsworth, 2007; Rundle *et al*., 2009).

A number of jurisdictions promote active transportation (walking, bicycling, public transport) over personal vehicle travel (Giles-Corti *et al*., 2010; IPCC, 2007). Scholars note significant correlations between land-use mix (distribution of land between residential, commercial, office, and institutional uses), street connectivity (how effectively streets connect a starting point and destination) and behavioral variables, such as time spent driving, that, simultaneously contribute to inactive lifestyles and obesity burdens in populations (Frank *et al*., 2004).

In recent years, research on the associations between the built environment, energy use, physical activity, body mass, chronic disease and other health-oriented outcomes have increased dramatically (Day and Cardinal, 2007; Durand *et al*., 2011; Sallis *et al*., 2009) and regional CAP reduction policies increasingly include city planning tools as components of their CAP abatement portfolios (Heath *et al*., 2006). One study that evaluated the relationships between built environment, transportation habits and BMI (body mass index) found that one additional hour of automobile travel per day was associated with a 6% increase in the likelihood of obesity (Frank *et al*., 2004). In a systematic review of over 200 articles, it was found that five smart growth factors – diverse housing types, mixed land use, housing density, compact development patterns, and levels of open space – were associated with increased levels of physical activity, and especially walking, but indicators of body mass showed little correlation (Durand *et al*., 2011).

Woodcock et al (2009) conducted a comparative analysis of Delhi, India and London, UK in which three alternative land transport scenarios – lower-carbon-emission motor vehicles, increased active travel, and a combination of the two – were compared with a BAU 2030 projection(Woodcock *et al*., 2009). The researchers developed separate models that linked transport scenarios with physical activity, air pollution, and risk of road traffic injury. It was found that in both cities, reductions in CO2 emissions through an increase in active travel and less use of motor vehicles had larger health benefits per million population than from the increased use of lower-emission motor vehicles, but that a combination of active travel and lower-emission motor vehicles would provide the most extensive health benefits. (Woodcock *et al*., 2009)

11.7.3. Access to Urban Green-Space

Forests and soil tend to sequester carbon that could otherwise be emitted to the atmosphere if the land were converted to urban space (WG1). In addition, green spaces help attenuate the heat-island effect that contributes to localized warming in urban areas. Although the there is a paucity of studies, current data suggests that relationships exist between the presence of green space and a number of physical and mental health indicators. For instance, a number of studies have found that green space is positively correlated with self-perceived health status (Maas *et al*., 2009; Mitchell and Popham, 2007; Takano *et al*., 2003) and risk of psychological morbidity (van den Berg *et al*., 2010).

Van den Berg et al. (2010) found that green space was associated with significantly fewer self-reported health complaints and higher perceived general health than those without these green spaces ($p<0.05$). This study did not find significant effects of green space within a 1 km radius of residences, which supported their hypothesis that the effect of larger green spaces (more prevalent further away from residential areas) are stronger than smaller ones (van den Berg *et al*., 2010).

Maas et al. (2009), in their assessment of physician-classified morbidity in Denmark, found that the prevalence of a variety of diseases was significantly lower in neighborhoods with more green space in a 1 km radius than areas without it. The diseases that were found to be less prevalent in areas with more green-space were coronary heart disease (OR=0.97, CI: 0.95 to 0.99); neck and back complaints, sever back complaints, severe neck and shoulder complaints (0.98, CI: 0.97 to 0.99); severe elbow, wrist and hand complaints (OR=0.97, CI: 0.96 to 0.98); depression (OR=0.96, CI: 0.95 to 0.98); anxiety disorder (OR=0.95, CI: 0.95 to 0.97); Upper respiratory infection, asthma, and COPD (OR=0.97, CI: 0.96 to 0.98); and other disorders. Relationships between access to green space and decreased morbidity were found to be especially significant among children and communities of low socioeconomic status (Maas *et al*., 2009)

Mitchell and Popham (2008) found that communities of low socioeconomic status seemed to benefit most from green space(Mitchell and Popham, 2007). In this study, mortality of the pre-retirement-age population of England was categorized into groups on the basis of income deprivation and access to green space and mortality records of the population were evaluated. The authors assessed whether the association between income deprivation, all-cause mortality, and three cause-specific mortality outcomes (circulatory disease, lung cancer, and intentional self-harm) was modified by access to green space. Health inequalities related to income deprivation in all-cause mortality and from circulatory diseases were found to be significantly lower among populations that live in the areas with the most green space. Further, the incidence rate ratio for all-cause mortality for the most income-deprived quartile compared with the least income-deprived quartile was 1.93 (95% CI: 1.86 to 2.01) in the least green areas, whereas it was 1.43 (95% CI: 1.34 to 1.53) in the most green areas(Mitchell and Popham, 2007).

11.7.4. Ruminant Meat Consumption

Livestock production systems are responsible for approximately one-fifth of all human-caused CAP emissions (Eshel and Martin, 2006; FAO, 2006; McMichael *et al.*, 2007) with four-fifths of those emissions being generated by the agricultural sector (Friel *et al.*, 2009). These CAP emissions are predominantly in the form of CH4 emissions from the animals or indirectly through growing the animal feed and processing/shipping the livestock products. Red meat consumption from ruminants (cows, sheep, goats) in turn is associated with higher rates of bowel cancer and heart disease (Sinha *et al.*, 2009). It is also associated with obesity and other cancers (WHO/FAO, 2003AO 2003). On the other hand, lack of protein and the micronutrients in meat (e.g., iron) are still problems in many poor countries (UN, 2008).

McMichael et al. (2007) found that policies to reach a per capita convergence on 90 grams of meat with not more than 50 grams of red meat per day from ruminants (i.e., cattle, sheep, goats, and other digastric grazers) could achieve major health benefits globally, in both developed and developing countries, while significantly reducing CAP emissions. As of 2007, the global average for meat consumption was 100 g per person per day, with about a ten-fold variation between developed (200-250 g/day) and developing (25-50 g/day) countries (McMichael *et al.*, 2007). The proposed shift would be approximately halve global red meat consumption and distribute it more evenly. Among more developed countries where red meat consumption is especially high, reductions to 90 g/day would likely reduce the risk of heart disease, stroke, colorectal cancer, breast cancer and overweight/obesity (McMichael *et al.*, 2007). Although meat products from other sources, e.g., chicken and fish, do not have the same set of climate and health implications, they are not without other concerns such as avian flu, over fishing, and water pollution. In addition, in poor populations, an increase in meat protein consumption would have health benefits.

Friel et al. (2009) analyzed the red meat consumption target recommended by the UK Committee on Climate Change to reduce UK GHG emissions by 80% by 2050 compared to 1990, which would require a 50% reduction by 2030. One component of this climate change mitigation portfolio was a 30% reduction in livestock production through a decrease in meat consumption. Assuming these reductions, the UK and in Sao Paulo, Brazil were compared using data to model the potential benefits of reduced consumption of livestock products on the burden of ischaemic heart disease. It was found that, in one year, the burden of IHD would decrease by approximately 15% in the UK (equivalent to 2,850 DALYs per million population) and 16% in Sao Paulo city (equivalent to 2,180 DALYs per million population) (Friel *et al.*, 2009).

11.7.5. Access to Reproductive Services

Population growth is another factor involved in the consumption of resources and emissions of CAPs. Although population growth rates and total population size do not alone determine emissions (WG1), population size is an important factor. Slowing population growth through lowering fertility[1], as might be achieved by increasing access to family planning has been associated with improved maternal and child health in two main ways: increased birth spacing and reducing births by very young and old mothers.

[INSERT FOOTNOTE 1 HERE: Fertility is defined as the number of live births by a woman over her lifetime.]

Birth and Pregnancy Intervals

Current evidence supports, with moderate confidence, that short birth intervals (defined as birth intervals between <19 and <25 months and inter-pregnancy intervals <6 months) are associated with increased risks of uterine rupture in women attempting a vaginal birth after previous cesarean delivery and uteroplacental bleeding disorders (placental abruption and placenta previa (Bujold *et al*., 2002; Conde-Agudelo *et al*., 2007; Huang *et al*., 2002; Shipp *et al*., 2001). Bujold and colleagues (2002) reported, in a high quality observational cohort study, a possible dose-response relationship between increased risks of uterine rupture in women with short intervals between births (4.8% for intervals <13 months; 2.7% for intervals 13-24 months; and 0.9% for intervals >24 months) (Bujold *et al*., 2002).

Several studies indicate correlations between short birth intervals and elevated risk of low-birth-weight (Adams *et al*., 1997; Basso *et al*., 1998; Kallan, 1997; Khoshnood *et al*., 1998; Rawlings *et al*., 1995). One study found that the risk is increased when the firstborn child had died of sudden infant death syndrome (Spiers *et al*., 1996). Zhu et al. (2005) found, in a review of three studies performed in the United States that a J-shaped relationship existed between inter-pregnancy spacing in that the lowest risk of adverse birth outcomes (i.e., low birth weight, existed between 18-23 months and risk increased as it departed, in either direction (Zhu, 2005). This J-shaped relationship is reported in other studies as well (Rousso *et al*., 2002).

Although an ecological analysis, a review across 17 countries shows a strikingly coherent picture of the relationship between birth spacing (as preceding birth intervals), malnutrition, and reductions in child, infant and neonatal mortality (Figure 11-3) with risk of child malnutrition and mortality both increasing with shorter birth intervals (Rutstein, 2005). One study estimated, for example, that shifting birth spacing from current patterns in the world to a minimum of 24 months would reduce by 20% (~2 million) the current excess child mortality in the world (Gribble *et al*., 2009; Rutstein, 2005).

[INSERT FIGURE 11-3 HERE
Figure 11-3: Reduction in child mortality due to increasing spacing of birth based on studies in 17 countries. Cited from (Rutstein, 2005).]

On the other hand, long inter-pregnancy intervals (between 48 and 60+ months) are independently associated with an increased risk of preeclampsia. In the largest systematic review to date on birth spacing and maternal morbidity and mortality (Conde-Agudelo *et al*., 2007), the majority of studies reported a likely dose-response relationship with odds ratios increasing with increasing inter-pregnancy or birth interval (Basso *et al*., 2001; Conde-Agudelo and Belizan, 2000; Mostello *et al*., 2002).

Studies of birth spacing are difficult because of confounding with social risk factors. Risk factors for the mother and child that are associated with short inter-pregnancy intervals include low socioeconomic status, unstable lifestyles, postpartum stress, inadequate use or access to pre- and post-natal health care services. Conversely, risk factors for maternal and child health for long inter-pregnancy intervals are associated with advanced age, infertility, unplanned pregnancy, illness of the mother, and social or family disruptions. All of these social exposures are associated with increased risk of adverse pregnancy outcomes, independent of birth spacing (Conde-Agudelo *et al*., 2007; Rousso *et al*., 2002).

Maternal Age at Birth

Risk of death during delivery is highest in very young and very old mothers, which are also the age groups most wishing to control their fertility (Engelman, 2010). Women who begin child bearing under the age of 20 years are at an increased risk of developing pregnancy complications such as cephalopelvic disproportion, obstructed labor, preterm delivery, toxemia, bleeding, and death (Tsui *et al*., 2007) Additionally, children born to women under the age of 20 are at an increased with of fetal growth retardation and low birth weight, which can both lead to long term physical and mental developmental problems. (Tsui *et al*., 2007) Childbearing at later ages (>35 years) is associated with increased risks for the child of miscarriage, perinatal mortality, preterm birth, low birth weight, congenital and chromosomal abnormalities, and increased risks for the mother of placental previa, gestational diabetes, cesarean delivery and maternal death (Cleary-Goldman *et al*., 2005; Ujah *et al*., 2005)

Thus, providing access to family planning saves women's lives by reducing the total number of births and, in particular, through the reduction of births in high-risk groups (Prata, 2009). Studies have found that when women have access to family planning, it is the highest risk age groups (youngest and oldest women) who reduce their fertility most, in other words, family planning has a differential impact on maternal mortality reduction through reducing births in the highest risk groups (Diamond-Smith and Potts, 2011 (Forthcoming))

11.7.6. Climate Change-Human Health Cross-Benefits

Not all climate change mitigation measures carry co-benefits for health, and in some cases, actions taken to attenuate radiative forcing lead to adverse exposures for human health and conversely, certain measures taken to protect human health are not always sound climate decisions.

Mitigation Strategies that are Positive for Climate but Negative for Human Health

Sulphate particles (SO_4), which are the product of atmospherically transformed SO_2 emissions, are climate cooling and, when derived from combustion, seem to be at least as health damaging as undifferentiated particulate matter (Smith *et al*., 2009). Thus, ongoing measures to reduce sulphur emissions around the world to protect health and ecosystems (from acid precipitation) have the effect of unmasking more warming from anthropogenic CAPs (WG1). It has been suggested that slowing the rate of sulphur emission reductions or even purposely emitting sulphate particles into the atmosphere could be an effective climate change mitigation measure. However, such actions must be considered carefully from health and ecosystem perspectives (see geoengineering section in WGIII).

Promoting diesel in personal vehicles increases fuel efficiency and lowers CO_2 emissions, but, depending on the technology and the associated regulatory context, can emit more health-damaging co-pollutants, such as diesel PM, than gasoline (USNRC, 2010; Walsh, 2008).

Carbon taxes or cap-and-trade schemes that increase the price of carbon-rich fuels can have important benefits for climate by reducing consumption and shifting to cleaner energy sources, but also can increase the rate of “energy poverty”, i.e. the number of poor people unable to afford energy services (Wilkinson P, Smith KR, Davies M,et al., 2009). For example, a study by the United States Congressional Budget Office (2007) shows how a program implemented to cut CO_2 emissions by 15% could cost 3.3% of the average income of households in the lowest income quintile as opposed to only 1.7% of the average income of households in the top income quintile (CBO, 2007). [should be some more refs on energy poverty].

While cap-and-trade, under certain circumstances, is efficient at reducing CAPs and associated co-pollutants on a regional basis, the strategy makes no guarantee about the reduction of these emissions from any one source. Thus, there are also concerns that cap-and-trade schemes may not help to reduce local air pollution emissions where they are highest (Morello-Frosch *et al*., 2009; Shonkoff *et al*., In Press).

Mitigation Strategies that are Positive for Human Health but Negative for Climate

Perhaps the most fundamental trade-off of this kind comes from economic development itself, at least as historically accomplished. For poor populations, more income generally brings more health, but has always been accompanied as well by increased fossil fuel energy use and other climate-negative impacts, such as meat consumption and land-use changes. It would seem that decoupling development from climate-damaging activities is essential for blunting this unfortunate cross-connection between health and climate.

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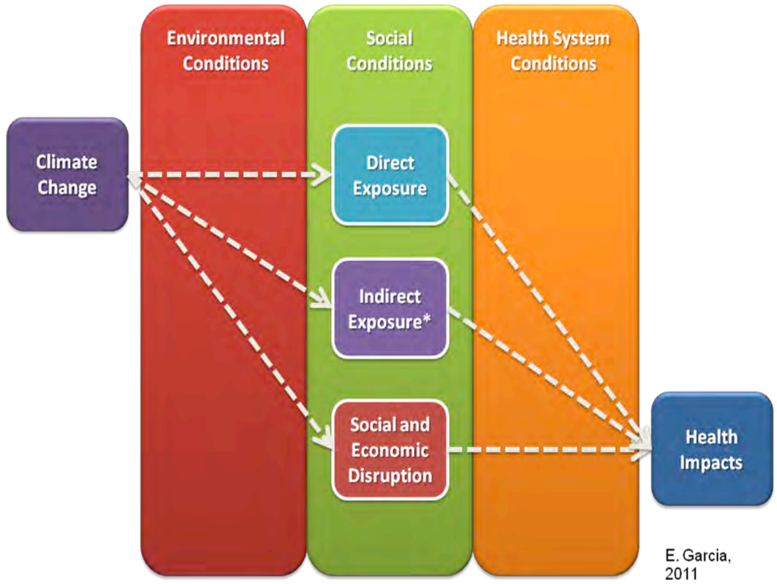
Table 11-1: Studies of the effectiveness of heat-health warning systems.

Measure of effectiveness	**Area**	**Study type**	**Findings**	**Reference**
Public awareness of an extreme heat episode and subsequent changes in practices (e.g. individual practices, use of services)	Phoenix, Arizona, U.S	Survey of general public on risk perception and warning response to heat episodes	Majority of population were aware when a heat advisory warning had been issued. However, only about half the population actually changed behavior in response to a heat event. Variation in awareness across different demographic groups (greater awareness in women and those aged >65 years).	Kalkstein et al., 2008
	France	Survey of general public in 2005-2006 to assess awareness and practices during heat alerts	Recall of media heat alerts was high (74%). High proportion (73%) of respondents reported increased efforts to support vulnerable friends and family. However, only 63% of the elderly reported being helped and only 14% asked for help when they felt discomfort. 63% of respondents took protective measures against the heat in 2006 compared to 48% in 2005.	INPES, 2006 [Cited and discussed in Bassil 2010, original article in French]
	3 US cities and Toronto, Canada	Survey of people aged >65 years to assess knowledge of heat warnings	Knowledge of the heat warning system was high (90%) and likely due to extensive media coverage (particularly television). However, actual details of the mitigation plans were less well understood and few people changed practices in response to the warnings. Many respondents did not believe the messages applied to them or that they were vulnerable. Some confusion around differences between ozone precautions and heat precautions.	Sheridan, 2007
Morbidity and mortality attributed to public health interventions	Czech Republic	Regression analysis	Decrease in mortality in the 2003 European heat waves compared to heat waves in earlier years. Increase in mortality much lower than in western European countries. Part of the decrease in mortality likely to be due to greater public awareness of heat related risk, regular biometeorological forecasts and warnings, and enhanced media coverage. Decrease in mortality also attributed in part	Kysely et al., 2008

Measure of effectiveness	Area	Study type	Findings	Reference
			to an improved response to heat (short-term adaptation to heat, improvements in socioeconomic factors and in general health, medical-technological changes and more widespread use of air conditioning). Other possible factors include that the 2003 heat wave was less severe in central Europe compared to western Europe and night-time temperatures were not particularly elevated. The lower night-time temperatures and stronger family and neighborhood ties in rural areas were also considered as possible protective factors.	
	France	Regression analysis	National Heat Wave Plan in place since 2004 in response to the 2003 heat wave. The Plan includes a heat warning system with alerts; implementation of measures aimed at the public, health and other institutions; and real-time surveillance of health data. Excess mortality during the July 2006 heat wave markedly less than expected (2065 excess deaths compared to 6452 predicted). Reduction in mortality most pronounced in women and the elderly. However, there is some difficulty in attributing reduction in excess mortality to a particular factor and is likely to be due to a combination of greater public awareness of the risk of heat, implementation of the heat health warning system, and setup of preventive measures by health and other authorities.	Fouillet et al., 2008 (Fouillet *et al.*, 2008)



*Changes in water, air, food quality; vector ecology; ecosystems, agriculture, industry, and settlements
†Arrow inside 'condition' box indicates modifying influence

Figure 11-1: Ways in which climate, climate variability, and climate change may influence human health.

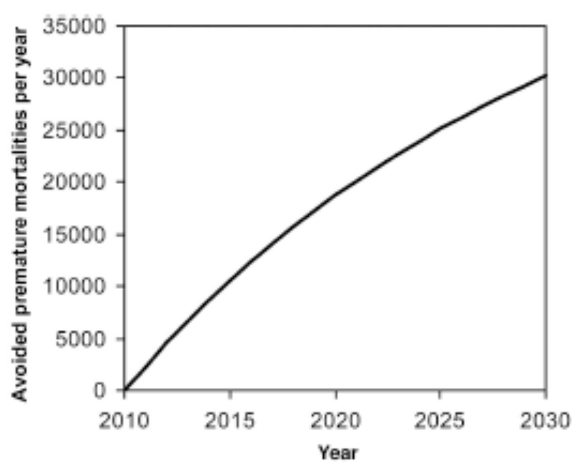


Figure 11-2: Avoided global premature mortalities from a 65 mt-yr^{-1} CH_4 emission reduction, beginning in 2010 (West *et al*., 2006).

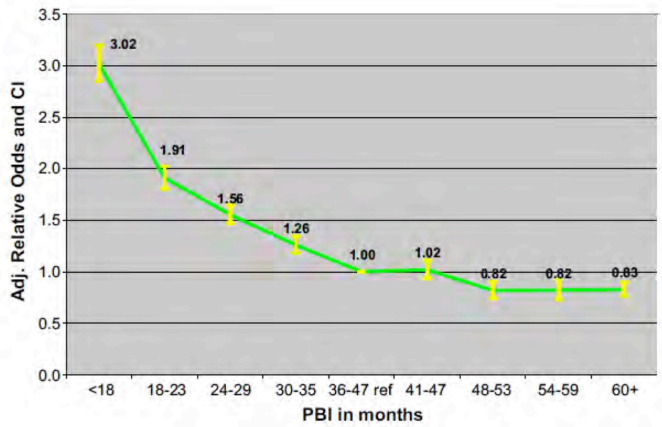


Figure 11-3: Reduction in child mortality due to increasing spacing of birth based on studies in 17 countries (Rutstein, 2005).