Institute of Environmental Medicine
KAROLINSKA INSTITUTET

GLOBAL CLIMATE CHANGE AND HEALTH – A NEW THEME FOR RESEARCH IN ENVIRONMENTAL MEDICINE

(Global klimatförändring och folkhälsa – Nytt tema för miljömedicinsk forskning)

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Förord

Denna rapport är resultatet av ett utredningsuppdrag som Institutet för miljömedicin (IMM) gav professor Tord Kjellström i slutet av 2008. Uppgiften var att sammanställa den kunskap som finns angående hälsoeffekter av den globala klimatförändringen och de forskningsfrågor som är av betydelse för framtida forskning i Sverige inom detta område. Rapporten utgör en del av institutets ansatser för att ta fram en strategi för dess engagemang kring klimat och hälsa.

Enligt uppdraget skulle rapporten utgå från och tydligt hänvisa till pågående svenska aktiviteter, däribland Klimatberedningen och Stockholm Resilience Centre samt relevanta utredningar såsom Klimat och sårbarhetsutredningen (SOU 2007:60) och Svensk klimatpolitik (SOU 2008:24). Även relevanta remissvar skulle beaktas och tonvikt läggas på konkreta förslag på miljömedicinska forskningsteman och - frågeställningar, där bl.a. Formas är en viktig mottagare för rapporten.Texten på engelska har redigerats av Adrienne Taylor.

Författaren ansvarar själv för rapporterns innehåll och framförda åsikter avspeglar inte nödvändigtvis institutets hållning.

Foreword

This report is the result of an assignment that the Swedish Institute of Environmental Medicine (IMM) gave Professor Tord Kjellstrom towards the end of 2008. The task was to assemble in a broad manner the knowledge available concerning health effects of the global climate change and the research questions that are of importance for future research in Sweden concerning these health effects. The report is part of the Institute´s efforts to develop a strategy for its engagement regarding climate and health.

According to the contract the report should be based on and clearly refer to ongoing Swedish activities including the Climate policy development, the Stockholm Resilience Centre and Investigations by the Swedish government. The focus should be on concrete proposals for environmental medicine research themes and questions, considering that the Swedish research funding council is a recipient of the report. The work was carried out in communication with staff at IMM, and advice and comments on the report outline and content was provided by Marika Berglund, Göran Pershagen, Gunnar Johanson and Monica Nordberg. The English text was edited by Adrienne Taylor.

The author is solely responsible for the contents of the report and the views expressed do not necessarility reflect those of the Institute.

Table of contents

Förord 1

Table of contents 2

Abbreviations (Förkortningar) 3

Executive summary 4

Sammanfattning (Executive summary in Swedish) 7

Introduction 10

Global and regional climate change trends 12

Overview of documented and potential health threats of climate change 17

Mechanisms for specific health effects 21

Positive and negative health impacts of mitigation and adaptation 36

Recent Swedish assessments and policy statements on climate change 37

Current research activities in Sweden on climate change and health 44

Knowledge gaps and research needs stated in other reports 45

Conclusions and recommendations for future research in Sweden 50

References 54

Appendix 1. Relevant Swedish reports on the web 62

Appendix 2. Current research in Swedish institutions 63

Abbreviations (Förkortningar)

APELL = Awareness and Preparedness for Emergencies at Local Level

DALY = Disability-Adjusted Life Years

DPSEEA framework = Driving force, Pressure, State, Exposure, Effect, Action

EHEC = Entero-Hemorrahagic *Escherichia Coli*

GBD = Global Burden of Disease

GHG = Green-House Gas

ICD = International Classification of Disease

IMM = Swedish National Institute of Environmental Medicine

IPCC = Intergovernmental Panel on Climate Change

ISO = International Standards Organization

KSU = Klimat- och Sårbarhets-Utredningen

ODA = Official Development Aid

PM = Particulate Matter

Sida = Swedish International Development Agency

TBE = Tick-Borne Encephalitis

WBGT = Wet Bulb Globe Temperature

WHO = World Health Organization

YLL = Years of Life Lost

YLD = Years of Life with Disability

Executive summary

Environmental medicine research is missing in the field of climate change and health

The recently published report from the Intergovernmental Panel on Climate Change (IPCC, 2007) as well as a number of books, films and mass-media programs have put the issue of climate change in the spotlight. Research on the mechanisms of climate change and the contribution made by different sources to harmful greenhouse gas emissions has progressed well while many gaps exist concerning the obvious, likely and possible health effects of climate change. A few research groups in other countries have focussed on this area, while only sporadic activities have taken place in Sweden. Stockholm Resilience Centre at Stockholm University has carried out studies on vector-borne diseases in Sweden and at Lund University some research on climate as a physical environmental health hazard is taking place. One reason for the lack of research is the fact that climate change is still at an early stage and the future exposures to different hazards and their related health effects can only be estimated but not measured. However, the mechanisms behind most of the possible health effects can already be studied and better knowledge about these would increase the possibilities to prevent health impacts.

Global climate change is ongoing and more will come

The IPCC report (2007) showed that a global warming due to greenhouse gas emissions is already happening. In cities of many countries the "heat island effect" contributes to additional warming. Climate change also involves less rain in some parts of the world and more in other parts. The incidence and strength of hurricanes and storms will increase. According to IPCC this trend will continue and strengthen during this century. The impacts in Sweden may be limited because the country has the resources to counteract the effects, including health effects, but the situation in other parts of Europe and in tropical countries is more worrying. Low income countries with large populations of poor people will be particularly affected. Sweden has an important international role to contribute to global scientific studies of health effects and the search for preventive methods.

Documented and expected global health impacts

Several different mechanisms underlie the health effects caused by climate change. Direct effects of heat (high temperature and humidity) on morbidity and mortality occur to an increasing degree. Heat also affects people's ability to work and may also increase exposure to certain chemicals both in the general and the working environment. Extreme weather injures many people (e.g. the floods in New Orleans), and increases the risk of epidemics in infectious diseases. Increases in air pollution, particularly in ozone, and exposures to particles in the air, cause an increased health risk when combined with heat. Infectious diseases that spread via water or food may increase due to damaged water sources and lack of secure storage of foodstuffs. In areas with drought and agricultural crop failure, or with floods, malnutrition and famines may occur. In addition, vector-borne diseases are spread to new places because of the ability of the vectors (e.g. mosquitoes and ticks) to live and grow in new places and new seasons. An assessment by WHO in 2004 concluded that approximately 166,000 deaths had occurred in the year 2000 due to the climate change that had occurred between 1990 and 2000. Most of these calculated deaths were expected to have occurred in low income countries. Swedish research in environmental medicine in collaboration with

researchers in these countries can contribute to limitation of these future effects among the world's most vulnerable populations.

Emerging effects in Sweden and Europe

In Sweden studies have shown increased distribution of tick-borne diseases due to ecological changes linked to slow climate change. In addition, a recent study in Stockholm has shown increased mortality during periods with high summer temperatures. An increased concentration of air pollution in Sweden may be related to climate change not only in Sweden, but also in parts of Europe south of Sweden. Social changes caused by global climate change can also influence public health in Sweden, for instance through an increased number of refugees from tropical countries that have been affected by climate related catastrophes. In the warmer parts of Europe other effects may occur, for example the extreme heat wave in 2003 caused 35,000 additional deaths. Swedish environmental medicine research can contribute to identification of the health risks and create effective preventive approaches as a part of European collaboration.

Important to get a better understanding of the causal relationships

Several of the potential cause-effect relationships described in this report are poorly documented, making risk assessment and preventive activities more difficult. High quality research by Swedish environmental medicine professionals could make important international contributions in this area. The effects of combined exposure to heat and other environmental hazards, e.g. heat and air pollution or other chemical exposures, are also important topics for further studies. Some of this research could be experimental and be carried out in climate exposure chambers.

Quantification of effects and environmental medicine monitoring

Epidemiological studies and analyses that complement experimental research can be used to quantify the effects and provide an improved basis for health impact assessments. The lack of epidemiological measurements concerning, for instance, direct effects of heat on people's ability to carry out work, makes it difficult to estimate the economic impact of climate change. An important role for epidemiology is also to develop and evaluate methods for monitoring the emerging health effects of climate change.

Development of preventive actions

The development of approaches to prevent health effects in Sweden as well as in Europe and low income countries in tropical areas is directly linked to the increased understanding of mechanisms and the epidemiological analysis. Such approaches include different methods to reduce the levels of greenhouse gases in the planetary atmosphere (mitigation), and a combination of different programs to reduce the burden of the specific health problems caused by climate change (adaptation). Research and development work in the area of adaptation will require an active contribution from environmental medicine science. This report includes a list of suggested research topics concerning preventive actions, as well as quantifications of effects and understanding of causal relationships.

Links to the work of IMM

According to the implementation plan for the National Institute of Environmental Medicine, IMM, 2006-2008 the organisation should take on a greater national responsibility within the physical and

chemical environmental medicine area, including working environment issues. Climate is one of the physical environmental hazards and research about its effects was an important part of the work of the predecessor of IMM over several decades. Climate change also has potential links to the occurrence of allergens in the environment and exposures to certain chemical substances. Health impact assessment is an important part of international environmental medicine science concerning future climate change. IMM has long experience of international collaboration in other areas, and can contribute to studies and assessments of the health impacts of global climate change.

Sammanfattning (Summary in Swedish)

Miljömedicinsk forskning saknas inom området klimatförändring och hälsa

Den nyligen publicerade rapporten från IPCC (Intergovernmental Panel on Climate Change, 2007) och olika böcker, filmer och mass-media program har satt klimatfrågan i rampljuset. Forskningen angående klimatförändringens mekanismer och bidrag från olika källor till de skadliga växthusgasutsläppen är väl framskriden, medan många gap finns i vetenskapen angående klimatförändringens uppenbara, troliga och möjliga hälsoeffekter. Några få forskningsgrupper utomlands har specialiserat sig på detta område, medan i Sverige enbart sporadiska aktiviteter förekommer. Stockholm Resilience Centre vid Stockholms Universitet har gjort studier av vektor-burna sjukdomar i Sverige och vid Lunds Universitet pågår viss forskning om klimat som fysikalisk miljöfaktor för hälsan. En anledning till bristen på forskning är naturligtvis att klimatförändringen fortfarande är i sin linda och de framtida exponeringarna för olika hälsorisker och relaterade hälsoeffekter kan enbart uppskattas och ej mätas. Emellertid kan mekanismerna bakom de flesta av de möjliga hälsoeffekterna redan nu studeras, och en bättre kunskap om dessa ökar möjligheterna att förebygga hälsoeffekter.

Globala klimatförändringen pågår och mer kommer

IPCC-rapporten (2007) visade att en global uppvärming på grund av västhusgasutsläpp redan pågår. Inom städer i många länder bidrar den s.k. "heat island" effekten till ytterligare uppvärmning. Klimatförändringen innebär också att vissa delar av världen får mindre regn och andra får mer. Frekvensen och styrkan av orkaner och stormar kommer också att öka. Enligt IPCC kommer denna trend att fortsätta och förstärkas under detta sekel. Effekterna i Sverige kan möjligen bli begränsade eftersom landet har resurser att motverka en stor del av dessa effekter, inklusive hälsoeffekter, men sitationen i andra delar av Europa och länder i tropiska områden är mer bekymmersam. Speciellt drabbade kommer låginkomstländer med stora fattiga befolkningar att bli. Sverige har en viktig internationell roll att bidra till det globala vetenskapliga arbetet att studera hälsoeffekter och finna förebyggande metoder.

Beskrivna och förväntade hälsoeffekter globalt

Flera olika mekanismer kan påverka hälsan på grund av en underliggande klimatförändring. Direkta effekter av hetta (hög temperatur och luftfuktighet) på sjuklighet och dödlighet förekommer i ökande utsträckning. Hetta påverkar också förmågan att utföra arbete, och kan också tänkas öka exponeringen för vissa kemikalier både i allmänmiljön och på arbetsplatser. Extrema oväder skadar många människor (t.ex. översvämingen i New Orleans) och ökar risken för epidemier av infektionssjukdomar. Luftföroreningar ökar, f.a. ozon, och partikelföroreningar ger ökad hälsorisk i kombination med hetta. Infektionssjukdomar spridda via vatten och föda kan öka på grund av skadade vattentäkter och brist på säker förvaring av livsmedel. I områden med torka och missväxt, eller med översvämningar, kan svält förekomma. Dessutom sprids vektor-burna sjukdomar till nya områden p.g.a. vektorernas (t. ex. myggor eller fästingar) möjligheter att frodas på nya platser och nya årstider. En utvärdering för WHO år 2004 drog slutsatsen att cirka 166000 dödsfall hade inträffat år2000, p.g.a. global klimatförändring mellan 1990 och 2000. Huvuddelen av dessa beräknade dödsfall uppskattades inträffa i låginkomstländer. Svensk miljömedicinsk forskning i

samarbete med forskare i dessa länder kan bidra till att begränsa framtida effekter bland de mest utsatta befolkningarna i världen.

Gryende effekter i Sverige och Europa

I Sverige har studier visat ökad spridning av fästingburna sjukdomar p.g.a. ekologiska förändringar kopplade till långsam klimatförändring. Dessutom har nyligen en studie i Stockholm visat ökad dödlighet under perioder med hög sommartemperatur. En ökad halt luftföroreningar i Sverige kan orsakas av klimatförändring inte bara här utan också söder om Sverige i Europa. Sociala förändringar orsakade av global klimatförändring kan också påverka folkhälsan i Sverige, t.ex. en ökning av antalet flyktingar från tropiska länder som drabbats av klimatrelaterade katastrofer. I Europas varmare delar kan andra effekter komma att inträffa, som t.ex. den extrema värmeböljan år 2003 vilken orsakade 35000 extra dödsfall. Svensk miljömedicinsk forskning kan bidra till att bättre identifera hälsoriskerna och skapa effektiva förebyggande åtgärder som en del av det Europeiska samarbetet.

En bättre förståelse av orsakssamband viktig

Flera av de möjliga orsakssamband som beskrivs i denna rapport är dåligt dokumenterade vilket försvårar riskbedömningar och förebyggande arbete. Svensk miljömedicinsk forskning av hög kvalitet skulle på detta område kunna göra en viktig internationell insats. Kombinationseffekter av olika miljöexponeringar är i detta sammanhang också ett viktigt studieområde. Det gäller till exempel kombination av exponering för hetta och luftföroreningar eller andra kemiska miljöfaktorer. En del av denna forskning kan vara experimentell och bedrivas t.ex. i klimatexponeringskammare.

Kvantifiering av effekter och miljömedicinsk bevakning

Epidemiologiska studier och analyser som komplementerar experimentell forskning kan användas för att kvantifiera effekter och ge bättre underlag för riskbedömningar. Bristen på epidemiologiska mätningar när det gäller t.ex. direkta effekter av hetta på personers arbetsförmåga gör det svårt att uppskatta den ekonomiska effekten av klimatförändringen. En viktig roll för epidemiologin är också att utveckla och implementera metoder för epidemiologisk bevakning av begynnande effekter av klimatförändringen.

Utveckling av förebyggande åtgärder

Direkt kopplat till ökad förståelse av mekanismer och de epidemiologiska analyserna är också utvecklandet av åtgärder för att förebygga hälsoeffekter, både för Sveriges och Europas del och för de tropiska låginkomstländerna. Sådana åtgärder inkluderar olika sätt att minska växthusgashalterna i jordens atmosfär (mitigation) och en kombination av olika program för att minska sjukdomsbördan av de specifika hälsoriskerna (adaptation). Forskning och utvecklingsarbete inom området "adaptation" kräver en aktiv insats från miljömedicinsk vetenskap. Denna rapport innehåller en lista över rekommenderade forskningsfrågor inom förebyggande av hälsoeffekter, kvantifiering och orsaksamband.

Koppling till IMMs verksamhet

Enligt IMMs verksamhetsplan 2006-2008 skall IMM (Institutet för Miljömedicin) ta ett större nationellt ansvar inom den fysikaliska och kemiska miljömedicinen, inklusive arbetsmiljö. Klimat är en av de viktiga fysikaliska miljöfaktorerna och forskning om dess effekter var för flera decennier sedan en viktig del av IMMs föregångares verksamhet. Klimatförändringen har också potentiella samband med allergeners förekomst och exponeringar för kemikalier. Hälsoriskbedömning är en viktig del av den internationella miljömedicinens vetenskapen kring framtida klimatförändring. IMM är väl förtroget med annat internationellt arbete, och skulle kunna bidraga till studier och riskbedömningar av globala klimatförändringens hälsoeffekter.

Introduction

Climate change presents a threat to the ecological systems that support life and health of humans on this planet as well as all other species (IPCC, 2007). We have evolved within a temperature, humidity and solar radiation environment that has not varied much during thousands of years. The human core body temperature needs to be kept close to 37 ^{o}C. This requires intricate methods of adaptation to the different climate zones on Earth, but there is a limit to our ability to adapt, and the ongoing global climate change may well eventually bring certain areas on the planet beyond those limits. We depend on food and water systems and other natural ecological services that are not easily able to adapt to a changing climate. The greatest health challenges may come from lack of food and water, in addition to direct effects of extreme weather, heat exposure and wider spread of certain infectious and vector-borne diseases.

WHO (World Health Organization) published its first brief assessment of climate change health impacts in 1989 (WHO, 1989) followed by a substantial review in 1996 (McMichael et al., 1996), a more recent update (McMichael et al., 2003) and a number of other reports in recent years. For instance, an attempt to estimate the global burden of disease and injury due to the climate change that had occurred between 1990 and 2000 was supported by WHO (McMichael et al., 2004). The WHO Kobe Centre coordinated a Knowledge Network on Social Determinants of Health in Urban Settings that discussed climate change effects on health equity in their report (WHO, 2008a). In WHO Regional Offices a variety of activities have taken place and eventually, in 2008, the theme of the World Health Day was "Protecting Health from Climate Change" (WHO, 2008b).

For the first time a WHO resolution on Climate Change and Health was adopted at the 2008 World Health Assembly (WHA61.19). It requests the Director-General to draw the attention of the public and policy-makers to the likely serious impacts of climate change on global health security and on the efforts to achieve the health-related Millennium Development Goals. The aim of the resolution was to ensure that the health security impacts and their resource implications are understood and will be taken into account in the development of national and international responses to climate change. Work in both the health sector and WHO should be carried out in close collaboration with other organizations of the United Nations and national and international agencies representing several societal sectors (Housing, Education, Energy, Transport, etc.).

The WHO resolution also requested the Director-General "to consult with Member States on the preparation of a work-plan for scaling up WHO's technical support to Member States for assessing and addressing the implications of climate change for health and health systems ….". A draft work-plan has now been drawn up and adopted by a meeting in Madrid in October 2008 (WHO, 2008c). The work-plan is organized around four objectives:

1. Advocacy and awareness-raising
2. Partnership with other UN agencies and other sectors at national, regional and international levels to ensure that health protection and health promotion are central to climate change adaptation and mitigation policies.
3. Promotion of and support for the generation of scientific evidence.

4. Strengthening health systems to cope with the health threats posed by climate change, including emergencies related to extreme weather events and sea level rise.

The generation of scientific evidence through the WHO work-plan involves research and pilot projects that analyze health vulnerability to climate change; effectiveness of health protection strategies; health benefits of adaptation or mitigation measures in non-health sectors; decision-support and monitoring tools for assessing vulnerability; and likely financial costs for health protection from climate change.

This report focuses on the potential role of Swedish scientists and research institutions in the global effort to protect human health from the effects of climate change. Swedish government policies emphasize the importance of this issue and the need for Swedish support of international efforts. International and interdisciplinary scientific collaboration and research initiatives are essential parts of this effort.

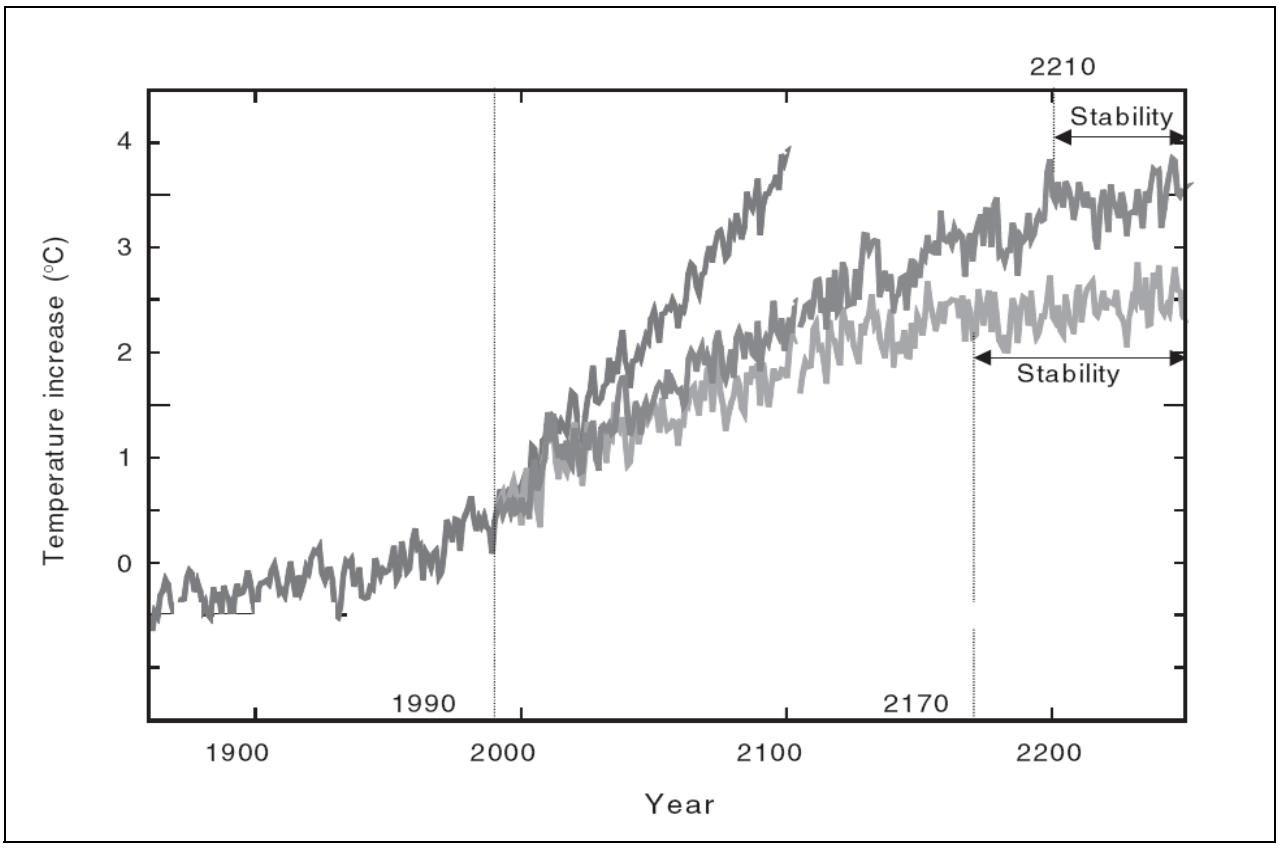
Global and regional climate change trends

The latest international evaluation of climate change, and its causes and effects (IPCC, 2007), has concluded that the generation of greenhouse gases (GHGs) from human activities is a major cause of ongoing climate change. In most countries a significant part of greenhouse gas emissions originate from electricity production from fossil fuels, major industry and transport. These emissions are dominated by carbon dioxide (CO2) from the burning of coal, oil or gas. In some countries methane (CH_4) emissions from cows and sheep are also major contributors. Methane is a powerful GHG and has more short-term impacts on the planetary atmosphere temperature (Smith et al., 2008). A third source of atmospheric warming that has been identified more recently is "black carbon" dust in the air that directly absorbs heat from sun rays and heats the air (Ramanathan and Carmichael, 2008).

In order to prevent further change of the global climate the emissions of greenhouse gases must be significantly reduced (= mitigation). At the same time policies and programs to reduce the impacts of unavoidable climate change (= adaptation), are needed to protect the human population from the inevitable exposures to ongoing climate change. Numerous reports have highlighted that many features of the modern consumer society contribute to climate change and that substantial changes in the societal habits of high income countries are needed to avoid the worst impacts (e.g. Stern, 2007, 2008; Rajan, 2006). One recent report (Edwards and Roberts, 2009) also pointed out that there is a link between obesity in a population and its GHG emissions. For example: if people eat more food than their body needs, GHGs are associated with the extra food intake; if people are heavier it takes more energy input to transport them by motor vehicles, which creates additional GHG emissions. Thus, the ongoing obesity epidemic can be seen as a contributor to climate change, while it is also linked to aspects of the causation of climate change, as will be discussed later in this report.

Global climate change primarily means that the average global temperature increases and the rainfall patterns change. In addition, the climate is expected to become increasingly variable with more and longer periods of extreme weather, (mainly extremely hot or violent weather, but also extremely cold weather in some places). The temperature increase may be between 1.8 and 4.0 ^{o}C (the average estimated increase is 3.0 ^{o}C) until the year 2100 (IPCC, 2007), depending on what actions are taken during future years to limit greenhouse gas emissions (Figure 1). The temperature time trends until 2000 have become progressively steeper (IPCC, 2007). Based on fitting a linear regression between 1850 and 2000 (150 years) the temperature increase was 0.45 ^{o}C per century. The equivalent trend coefficients for 100 years, 50 years and 25 years until 2000 were 0.74, 1.28 and 1.77 ^{o}C/century respectively (IPCC, 2007). The projected trends to 2100 are almost linear (Figure 1) with 2-3 ^{o}C increase at the end of the century.

Figure 1. Time trends and projections of global average temperature depending on three scenarios for GHG reduction to limit global climate change (IPCC, 2007, with permission). (the steepest curve indicates the likely trend if GHG emissions are only slightly controlled; the middle curve requires the more vigorous control actions proposed by EU; the lowest curve requires even stricter controls)

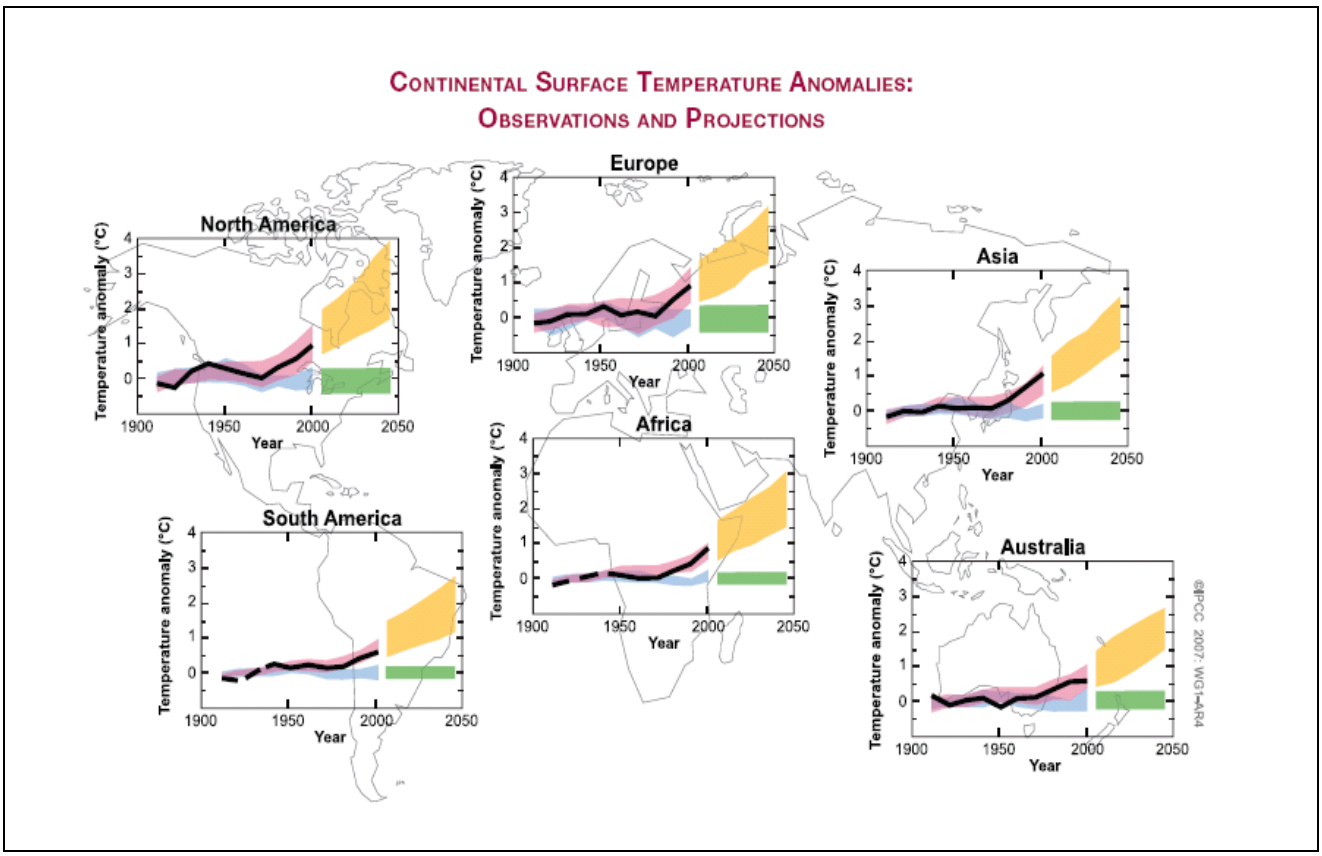


The temperature increase will not be the same at all places on Earth, but all populated areas, including the tropical countries that already suffer from extreme heat exposure during parts of the year, will experience substantial climate change and temperature increase (Figure 2). The Arctic and Antarctica regions may get the largest increases of temperature, leading to the melting of landlocked ice and global sea level rise that will continue for centuries. The sea level rise will lead to intermittent flooding of low-lying populated areas close to coasts, eventually making these areas uninhabitable unless great investments in seawalls are made. This may be realistic for countries like the Netherlands, where sea walls already protect against flooding and can be made higher because the country is relatively wealthy.

However, in low- and middle-income countries with long coasts (e.g. Bangla Desh, India and China) it will not be possible to protect large parts of the currently inhabited areas so millions of people will be affected by flooding and the associated health risks. Eventually the population will have to move to higher ground creating many "environmental refugees", most likely causing increased poverty due to the dislocation and associated socio-economic and public health risks. The melting of inland ice shelves and glaciers (e.g. in Himalaya and the Andes) will cause another health challenge. When the ice has fully melted the water flow in certain rivers will totally cease

during parts of the year (Bradley et al., 2006). Populations downstream will lose their main source of drinking water source, creating new public health risks.

Figur 2. Ongoing and expected temperature changes in different regions of the world (IPCC, 2007, with permission)



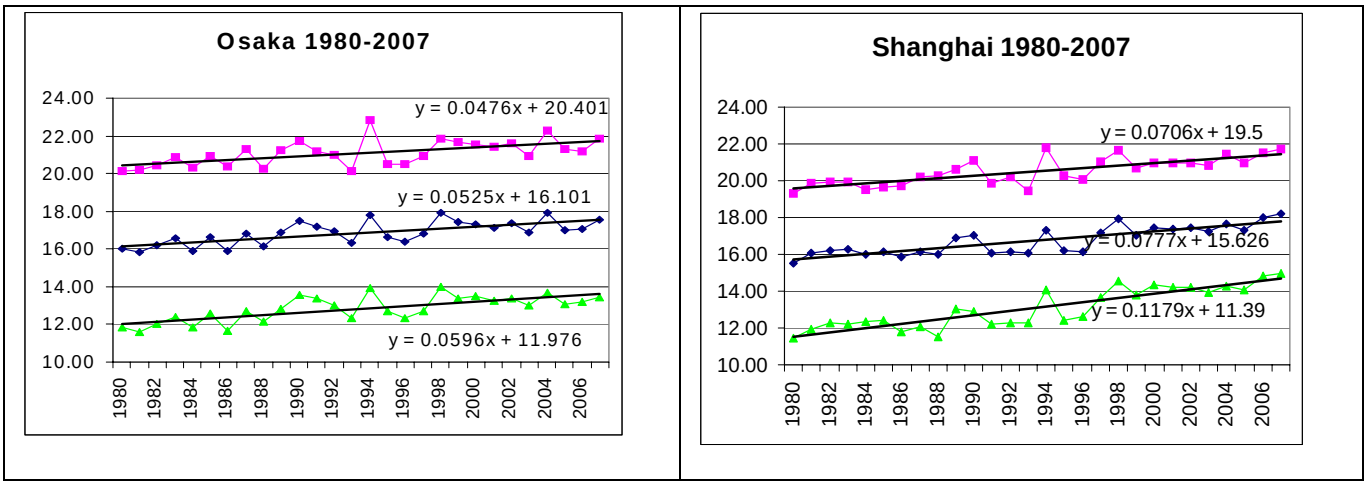
In densely populated tropical and sub-tropical areas the highest projected temperature increases are mainly in inland areas within the large continents with an increase of 1-3 ^{o}C until 2020 and 3-5 ^{o}C until 2080 (IPCC, 2007). Maps in the IPCC (2007) report show that densely populated tropical areas within Latin America, Africa, India, China and Southeast Asia are expected to get substantial temperature increases. In these areas the maximum temperatures during the hottest part of the year already exceed 40 ^{o}C. An additional 3-5 ^{o}C will make daily life activities and work (e.g. outdoors in agriculture and construction work) very difficult to carry out during the hottest periods. Outdoor workers in India and Central America already take long breaks during the afternoons in the hot season due to excessive heat exposure (authors own observation). In addition, vulnerable people with pre-existing diseases (communicable, chronic or mental) will be affected clinically during hot periods, and hospital admissions and mortality will increase due to heat exposure (ref - **saknas??**).

It should be emphasized that the changes in climate variables as expressed by global or regional atmospheric models will not necessarily be equal to the changes in human exposures to climate variables. The difference is related to local variations in the expression of climate change and behavioural patterns of the local population. A common concern in urban areas is the "heat island effect" (Oke, 1973), which creates higher heat exposure in densely populated modern urban areas

with large areas covered in concrete buildings or tar sealed roads that absorb solar heat radiation during the day.

The *local climate change* is the key exposure variable for public health research and impact analysis concerning climate change. In order to quantify local climate change trends a "Population Heat Exposure Profile" tool has been developed (Kjellstrom and Lemke, to be published). It uses data from any weather station around the world that is included in a data base held by the US NOAA (National Oceanographic and Atmospheric Agency, Global Historical Climate Network). (The daily data from approximately 13,000 weather stations [usually at airports], starting in 1960 in some cases, is available for free on the Internet, and hourly data can be purchased on CDs). Kjellstrom and Lemke (unpublished data) analyzed the time trends for selected cities between 1980 and 2007 and found that the daily average, maximum and minimum temperatures were increasing with time for almost all of them. As an example, the time trends for Osaka and Shanghai are shown in Figure 3. The slopes of the trends for 11 cities are presented in Table 1.

Figure 3. Temperature time trends (^{o}C during 29 years) in Asian cities: Osaka and Shanghai (Kjellstrom, 2008)
(top curve is maximum temperature, middle curve is average and lowest curve is minimum; line trend equations are based on time in years).



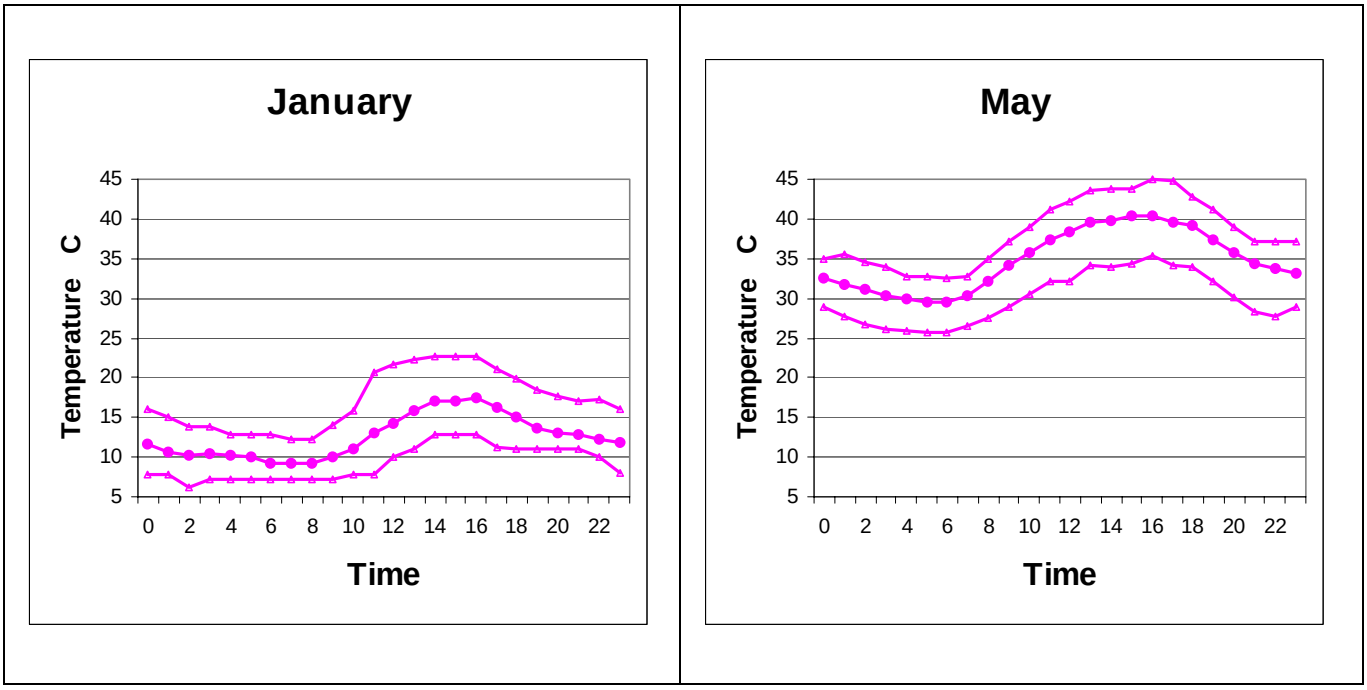
The ongoing climate change in Osaka, Shanghai and other cities (Table 1) is much faster than the global average trends, possibly due to the urban heat island effect. Several billion people will be affected and air conditioning is not an option for outdoor activities or for low income groups. While air conditioning reduces heat exposure indoors, the running costs can be high and are too expensive for large parts of the population in their homes or workplaces. In addition, the energy consumption of air conditioning contributes to the greenhouse gases that cause global warming. Alternative methods to create an acceptable indoor climate are therefore of great importance, including building design that creates natural ventilation, building materials that isolate against heating of the indoor air, and urban design that reduces direct heat exposure and the "heat island effect" (Oke, 1973).

Table 1. Summary of temperature change rate (°C per century) in selected cities according to regression lines in the figures (Kjellstrom, 2008).

City	Maximum (°C)	Average (°C)	Minimum (°C)
Johannesburg	+ 2.97	- 1.27	- 3.86
Atlanta	- 0.89	+ 1.85	+ 3.77
Managua	+ 0.27	+ 1.29	+ 3.51
Cairo	+ 2.62	+ 4.84	+ 6.58
Athens	+ 4.09	+ 5.30	+ 5.14
Delhi	+ 2.08	+ 0.53	+ 0.18
Chennai	+ 2.87	+ 0.41	- 0.43
Bangkok	+ 4.52	+ 5.19	+ 5.37
Chiang Mai	- 1.13	+ 0.22	+ 0.77
Osaka	+ 4.76	+ 5.25	+ 5.96
Shanghai	+ 7.06	+ 7.77	+ 11.79

The hourly variation of temperature, humidity and other climate variables shows the conditions in a city like Delhi in the afternoons of the coldest and hottest months (Figure 4). In January the climate is rather temperate, but in May the average afternoon temperature is 40 °C ! Climate change will make the May temperatures even more extreme.

Figure 4. Hourly air temperatures, Delhi, for the coldest and hottest month, 1999. (Kjellstrom, 2008) (also includes the "tolerance interval" for 95% of observations)



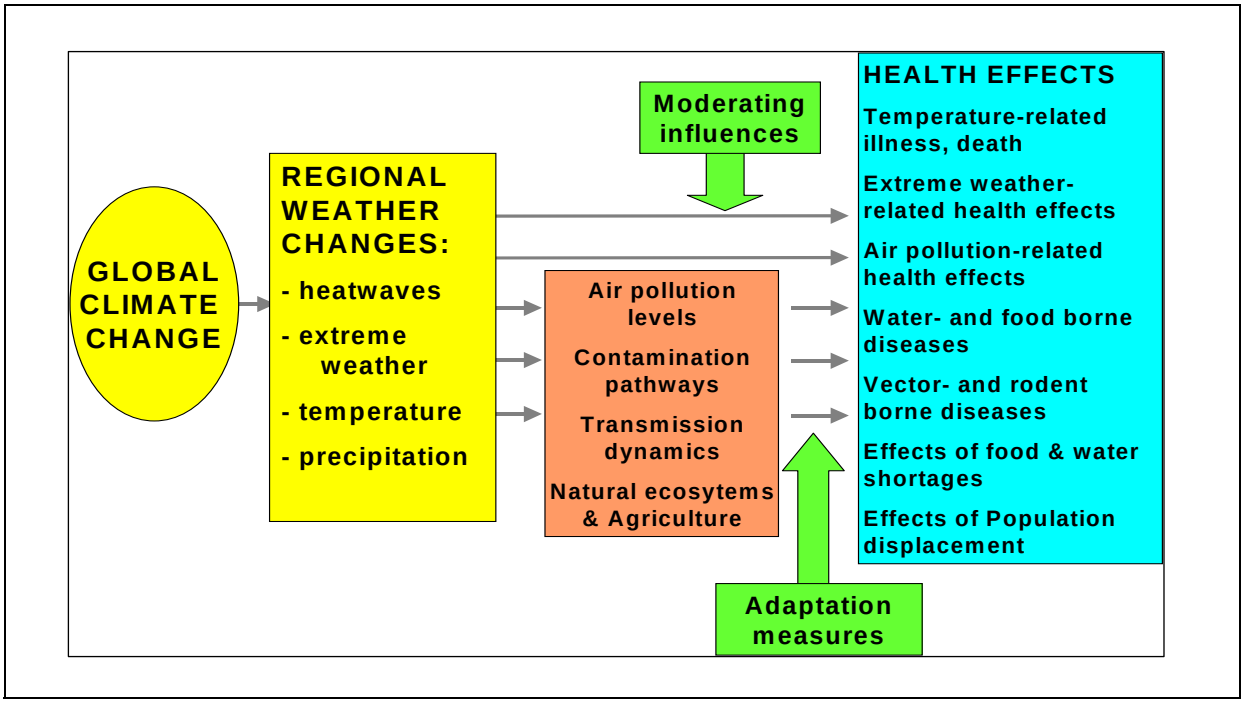
The increasing temperature at the Earth's surface is also expected to lead to an increasing amount of water vapour in the air (increased absolute humidity), and increasing rain in some areas, while in other areas it will be drier (IPCC, 2007). An increase of average humidity might contribute significantly to heat stress exposure during hot months.

Overview of documented and potential health threats of climate change

A variety of health threats

The changes in the climate described above may lead to major health impacts during extreme weather situations, heat waves, floods and droughts and there may also be increased cases of infectious and vector-borne diseases., Weather calamities may cause malnutrition due to lack of food and disruptions to agricultural production. Increasing temperatures combined with high air humidity will also lead to illnesses and deaths due to heat waves, especially among the elderly and young children. These types of effects are already occurring in hot parts of the world as effects of the current climate rather than climate change. Direct heat exposure will also create difficulties in carrying out physical and mental work tasks (Parsons, 2003; IPCC, 2007). Figure 5 summarizes the different health effects and highlights the environmental exposure pathways.

Figure 5. Health relevant exposures and effects of global climate change (source: Patz et al., 2000; McMichael et al, 2003, with permission)



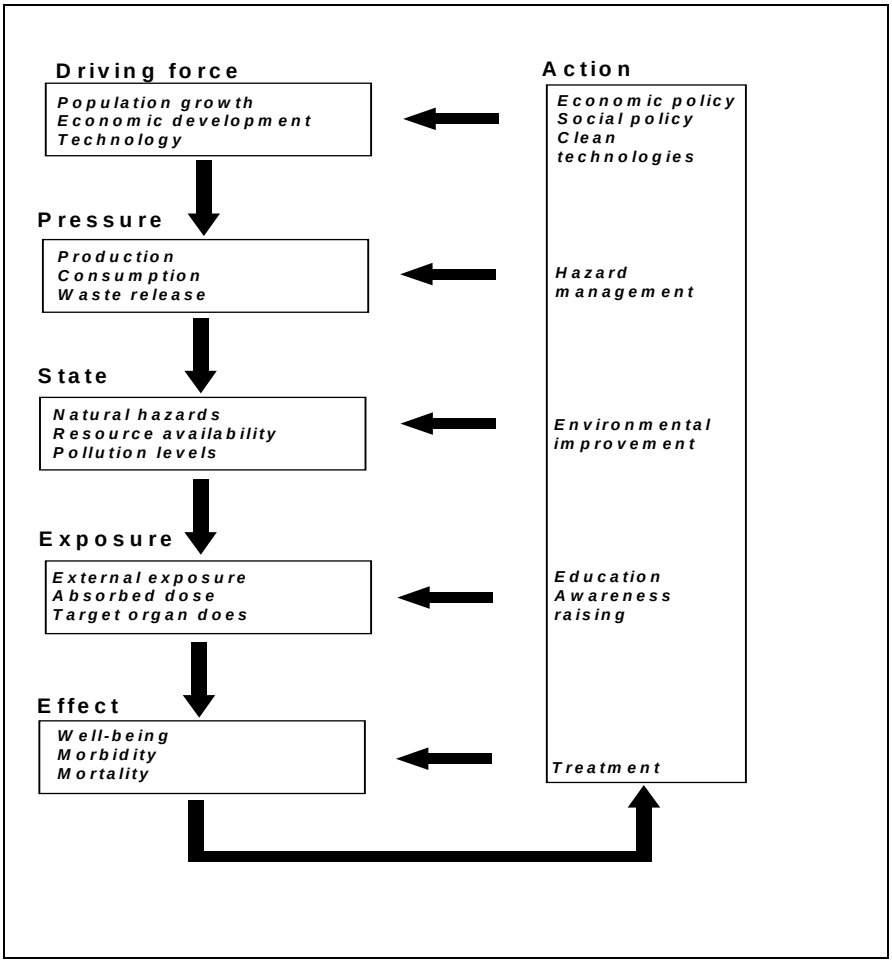
It is possible to conceive both acute and chronic ill health associated with each of the health effects listed at the right side of the figure. (This is only a summary as these effects will be discussed in detail later in the report). Temperature-related illnesses and deaths are largely induced via effects on the cardio-vascular system. Recurrent, chronic, exposures can lead to dehydration and chronic kidney disease. Heat exhaustion can also have mental health consequences as can extreme weather-related effects in the form of post-traumatic stress syndrome. Air pollution (e.g. ozone) affects the respiratory and cardio-vascular systems and can cause chronic conditions. Water- and food-borne diseases are essentially communicable disease issues, but there may also be psychological stress due to lack of water access for drinking or farm use. Diminishing water quality and quantity can also cause additional heat stress for people (mainly women) who have to carry water longer distances to

their household. Vector-borne diseases are essentially acute and communicable. Food shortages and malnutrition will affect the mental state of victims; malnutrition during childhood is a risk factor for certain chronic diseases. Population displacement creates major mental and societal stress.

Pathways for ill health causation

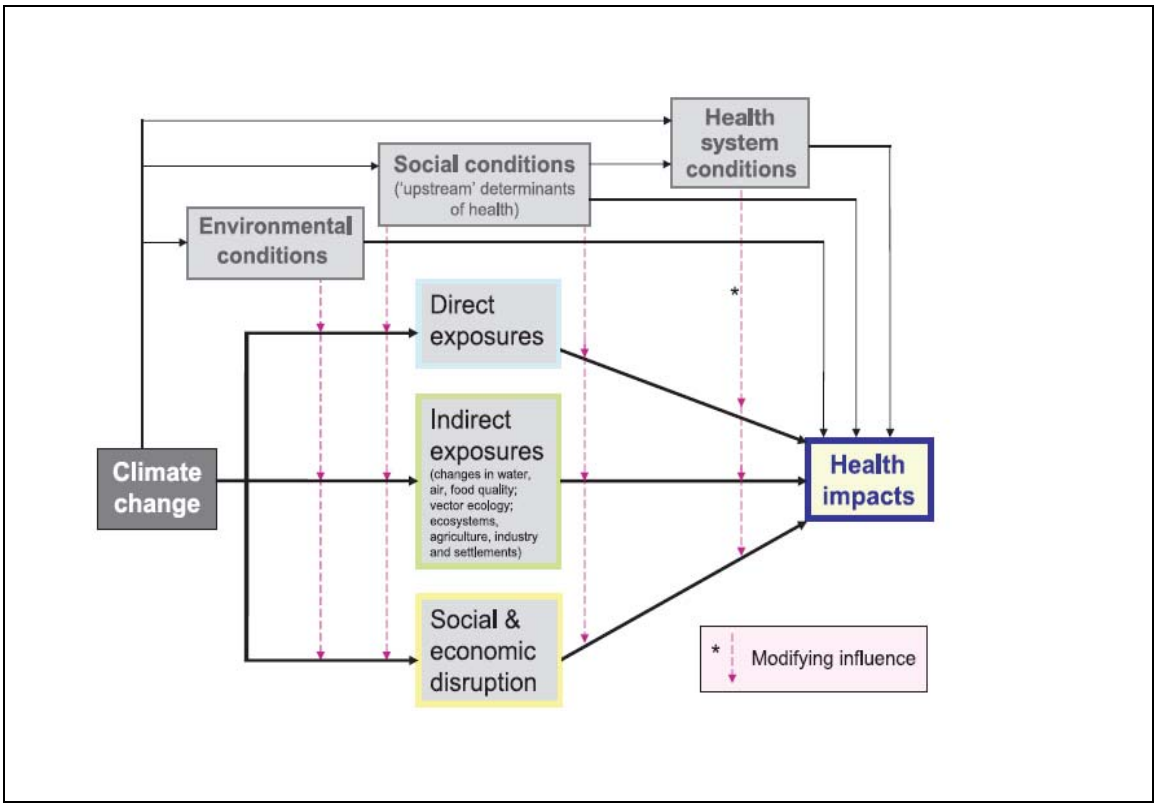
Climate change involves changes in human exposure variables, such as air temperature and humidity, which are very proximate to the human body. The linkages and pathways to health effects can then be described and analyzed in relatively simple terms. However, much of the impact of climate change on health is likely to occur via more indirect routes with the changing climate variables, i.e. "pressures on the environment", causing a variety of actual exposure changes. Thus, the pathway for ill health causation may involve at least the following linkages: Climate exposure, pressures on the environment → Changes in other exposures → Influence of vulnerability, socio-economic status, etc. → Health impacts (incidence, severity, duration, prevalence) → Treatment, health service interventions. This stepwise pathway has been described via the so-called DPSEEA framework (Driving force, Pressure, State, Exposure, Effect, Action) (Figure 6) devised by the WHO in the 1990s (Kjellstrom and Corvalan, 1995; Corvalan and Kjellstrom, 1995).

Figure 6. The DPSEEA framework displaying pathways between health determinants at different proximity to the exposed person. (Corvalan and Kjellstrom, 1995, with permission)



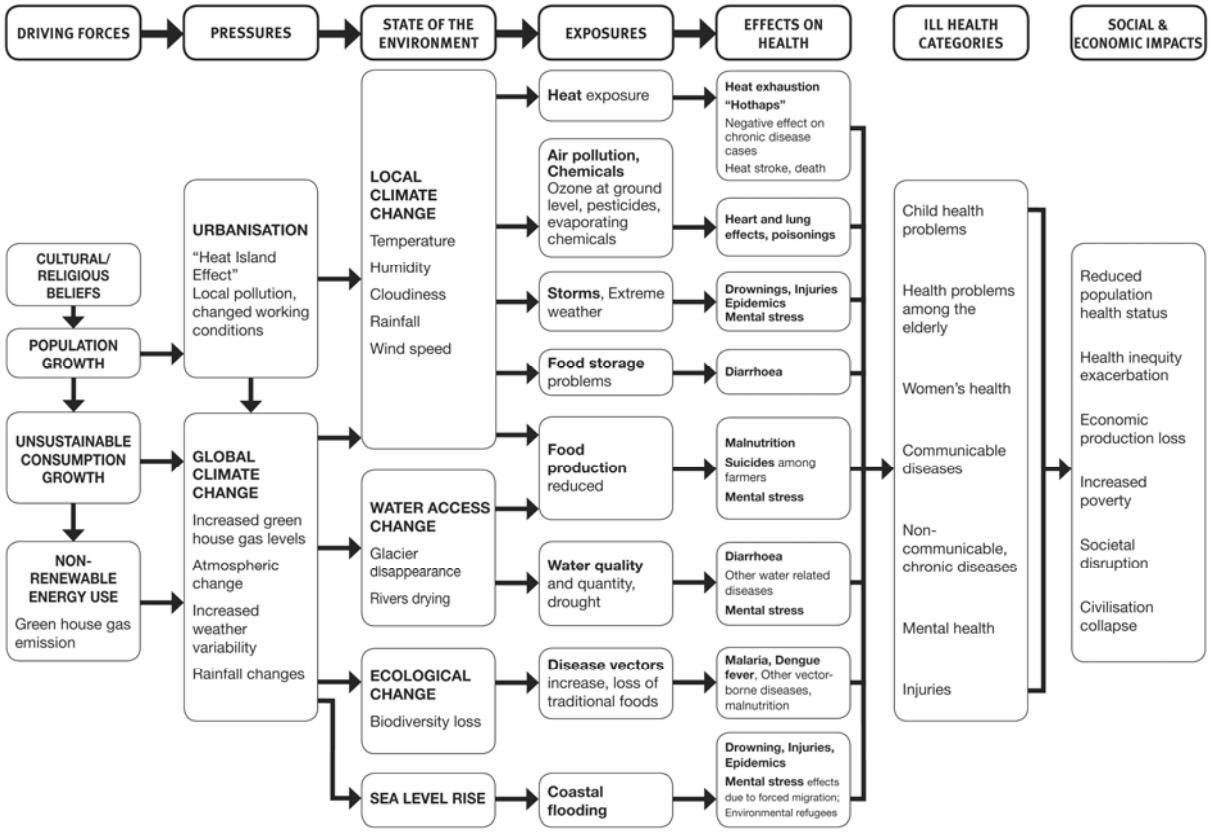
Another way of displaying the pathways is shown in Figure 7. IPCC emphasizes the three major causal patterns for climate change and health relationships: direct exposures, indirect exposures, and social and economic disruption. As will be seen below, some major climate change impacts, chronic diseases, other chronic conditions and mental health can all be affected by the indirect pathways.

Figure 7. Conceptual pathways from climate change to health impacts (IPCC, 2007, with permission)



Using DPSEEA one can better visualize the underlying *driving forces* behind climate change (population growth, energy consumption, meat production and consumption, etc.), the *pressures* on the environment (greenhouse gas levels, global atmospheric change), the *state of the environment* (changes in local climate variables, extreme weather situations, water access change, increased air pollution, etc.), the actual *exposures*, the variety of *effects* (direct and indirect) and the *actions* taken to limit or manage the effects. At each linked stage there are modifying factors that influence the resulting health impacts (Kjellstrom and Shahi, 2004). For instance, geographic conditions influence the impact of pressures on the state of the environment. The daily activities and behaviours of people in the population of concern influence the impact of the state of the environment on actual human exposures. Individual vulnerability (including gender, age, socio-economic status, pre-existing disease) influences the impact of exposure on effects. In addition, all of these linkages are influenced by the type of preventive *actions* already in place in a community (Figure 6). Applying the DPSEEA framework to climate change related health hazard exposures creates a rather complex web of relationships between the different steps in the framework. Figure 8 shows how the DPSEEA framework can be summarized in a series of pathways.

Figure 8. DPSEEA framework for climate change and health (Kjellstrom, to be published)



Mechanisms for specific health effects

Impacts via direct heat exposure

Heat wave mortality increase has been reported in a number of studies from different parts of the world: USA (Luber and McGeehin, 2008), Europe (most extreme in France in August 2003; Poumadere et al., 2005) and cities in developing countries (Hajat et al., 2005). In addition, studies have shown a relationship between increasing daily maximum temperature and daily mortality (McMichael et al, 2004; IPCC, 2007). An increased mortality in relation to heat waves and a potential impact of climate change has even been reported from a relatively cool city like Stockholm, Sweden (Rocklöv and Forsberg, 2007). The direct heat mortality effect is primarily an effect on the cardio-vascular system as it becomes "over-loaded". These demands are associated with the increase of core body temperature and the physiological reactions to heat exposure including peripheral vasodilatation and need for additional cardiac output (Parsons, 2003). Studies have also shown increasing acute hospital admissions due to heart disease symptoms and asthma in relation to increasing daily temperatures (Kjellstrom and Weaver, 2008). The most vulnerable people are the very elderly. It should be pointed out that daily mortality also increases during cold days in the winter (e.g. Rocklöv and Forsberg, 2007), creating a U-shaped exposure-response relationship. The mortality increase per degree of temperature change is, however, lower at the cold end than at the hot end (Rocklöv and Forsberg, 2007).

Figure 9. Map of mortality excess in different parts of France during the two week heat wave of August 2003. Time trend of mean daily temperature and mean daily mortality in Paris during July-August 2003 and the three preceding years (Vandentorren and Empereur-Bissonnet, 2005, with permission).

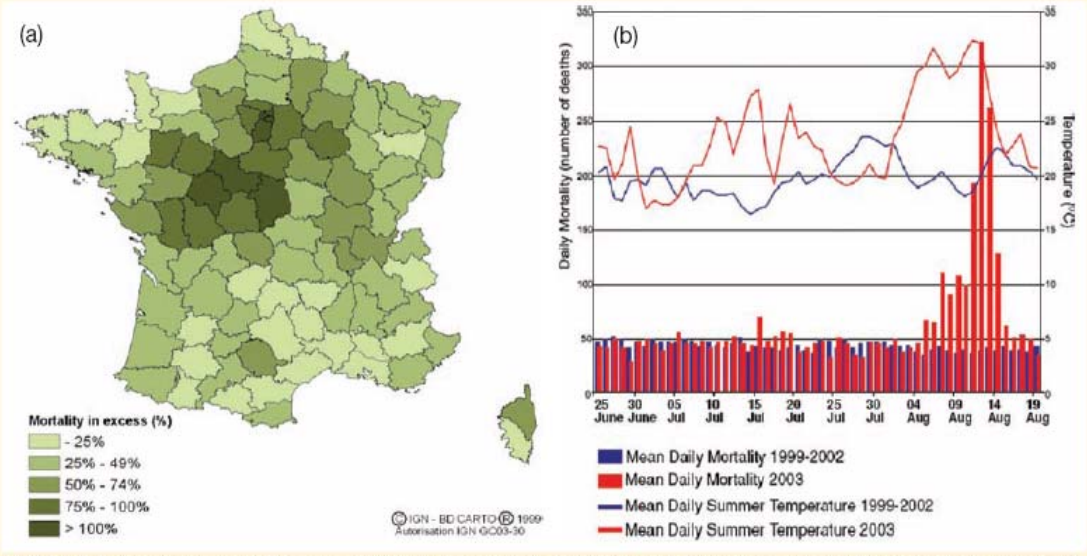


Figure 8.2. *(a) The distribution of excess mortality in France from 1 to 15 August 2003, by region, compared with the previous three years (INVS, 2003); (b) the increase in daily mortality in Paris during the heatwave in early August (Vandentorren and Empereur-Bissonnet, 2005).*

An extreme event of direct heat exposure and resulting effects occurred in Europe in 2003, with particularly serious effects in France (Poumadere et al., 2005). A map of the excess mortality

during the two-week heat wave and the time trend of heat and mortality (Figure 9) shows the extensive health impact. In parts of France close to Paris, mortality more than doubled during the two-week heat wave, which is similar to the excess mortality during the infamous one-week extreme air pollution event in London in 1952 (UKMOH, 1954). During the worst day, mortality was 6 times higher than normal (Figure 9).

Clearly, mortality was the most extreme effect, but emergency admissions to hospitals and attendance at health services also increased (Vandentorren and Empereur-Bissonnet, 2005). These acute effects primarily affect elderly people, while infants, children and people with certain pre-existing diseases are also vulnerable. If high heat exposure occurs every day, the impacts of such repeated exposures need to be considered as a longer term health problem that cannot be dismissed as "acute and preventable".

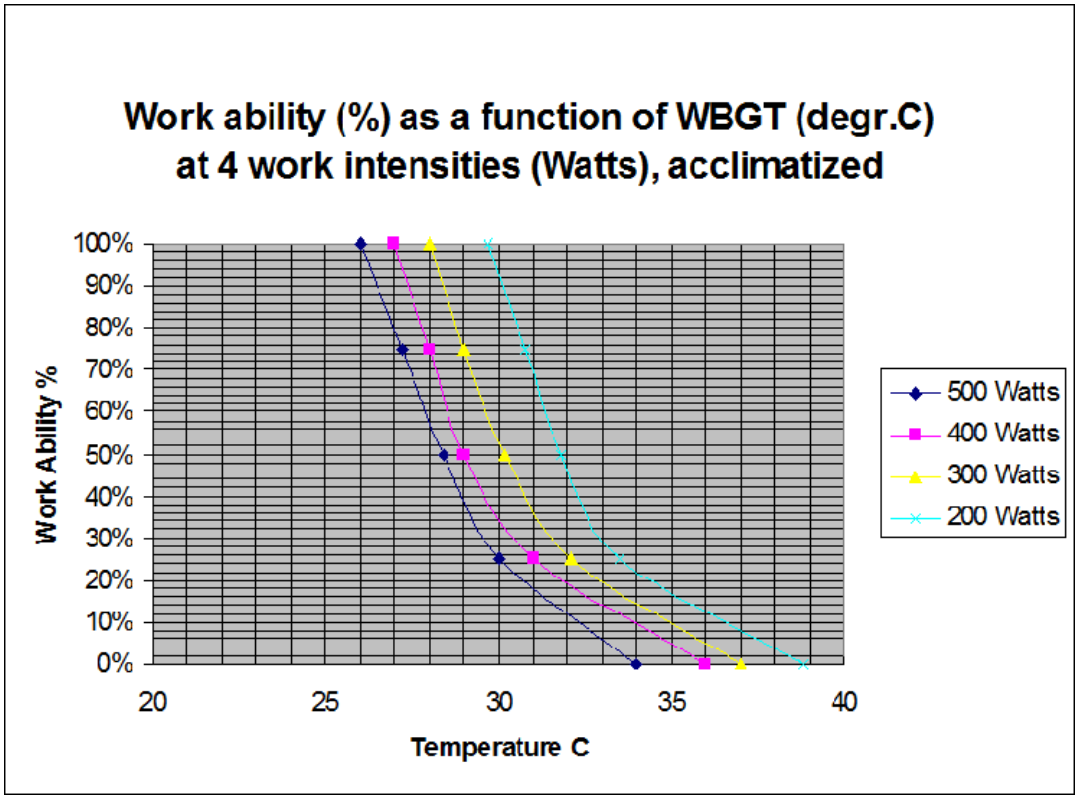
Ergonomists define "heat stress" as the exposure to high heat, while "heat strain" is the physiological impact of heat stress and "heat stroke" is a combination of serious symptoms possibly leading to unconsciousness and death (Ramsey and Bernard, 2000; Parsons, 2003). There is an ICD code, X30, for “exposure to excessive natural heat”, which includes “excessive heat as a cause of sunstroke” and “exposure to heat NOS”, but excludes “excessive heat of man-made origin (W92)”. A recent study in California (Knowlton et al., 2008) showed how important it is to analyse emergency department and hospital admission data together and to include all the assigned ICD codes for each patient when counting the number of patients affected by heat exposure. The study reported dramatic increases (more than a six-fold increase) of acute treatment in hospitals for diagnostic categories that were likely to be heat related (e.g. cardiovascular and kidney diseases). The greatest increases of heat related treatments occurred in the Central Coast region, where the usual climate is rather temperate and the use of cooling devices, such as air conditioning, is less prevalent. The highest relative increase of morbidity during the heat waves was for electrolytic imbalance, nephritis and nephritic syndrome.

Heat exposure and heat stress has a major effect on a persons’ ability to carry out physical activity (Parsons, 2003), whether it is a part of the general daily activities (such as carrying things to and from the household or working in the family garden) or part of daily work. Heavy labour is most affected as it generates heat in the body. If the body cannot be cooled down sufficiently by sweating or other cooling mechanisms, the only way to avoid heat stroke is to work more slowly and reduce the work output (Pilcher et al., 2002). This has been pointed out in relation to workers in Sweden by Axelson (1974) and more recently by Staal Westerlund (1998). This heat stress effect will have an impact on worker productivity or "work ability" (or "work capacity"; different authors use different terms): the "Hothaps" effect (High Occupational Temperature Health and Productivity Suppression) (Kjellstrom, 2000, 2009). Using the common heat stress index WBGT (Wet Bulb Globe Temperature), the reduction of physical "work ability" due to increasing heat exposure based on international guidelines (ISO, 1989) can be seen in Figure 10. The physiological effects also reduce psychological performance with a risk of increased mistakes in daily activities and increased accidental injuries (Ramsey et al., 1983; Ramsey, 1995), and it affects sports performance (Corris et al., 2004).

These relationships are based on the general physiological need to reduce core body heat in situations where internal heat production from work or other physical activity and external exposure to heat create a risk of increased core body temperature. The ISO (1989) standard aims to limit the core body temperature to 38 ^{o}C for a typical person and states that the "reference values are those at which almost all individuals can be ordinarily exposed without any harmful effect".

Using the hourly data from weather stations and the "Population Heat Exposure Profile" (Kjellstrom and Lemke, to be published) it was shown that in places like Delhi during the hottest month (May), the WBGT is extremely high and the resulting work ability for heavy labour outdoors is very low (Figure 11). The WBGT calculation is based on hourly temperature, humidity, solar radiation and wind speed (assumed below 2 m/s). The formula for this calculation of WBGT from climate data is based on the physical principles for the relationships between three different climate measurements (natural wet bulb temperature Tnwb, globe temperature Tg, and air temperature Ta), which are the basis for WBGT (= 0.7 x Tnwb + 0.2 x Tg + 0.1 x Ta) (ISO, 1989).

Figure 10. The reducing work ability with increasing heat exposure at four different work intensities (200 W = office work, to 500W = very heavy labouring) (Kjellstrom, 2000, with permission)

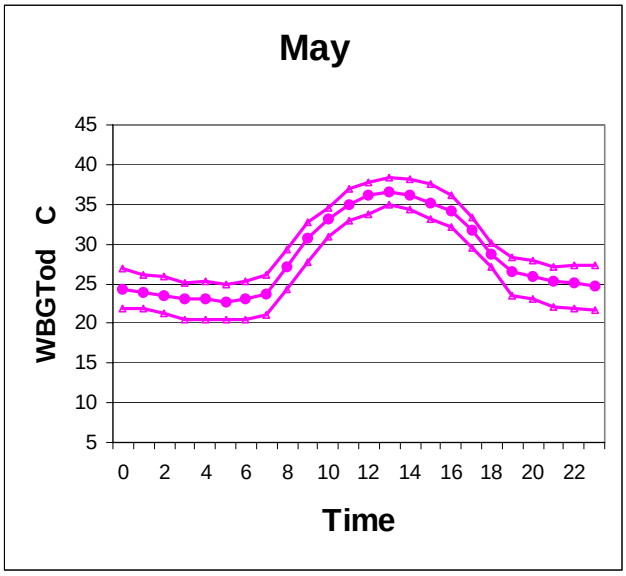


Using calculated WBGT values for each hour (Figure 11) and the corresponding "work ability" values in Figure 10, one can calculate the resulting work ability for each hour. As figure 11 shows, there is not much work ability left between the hours of 10.00 and 17.00 during typical May days. This fits with the work practices observed by the author in India, where, for instance, outdoor

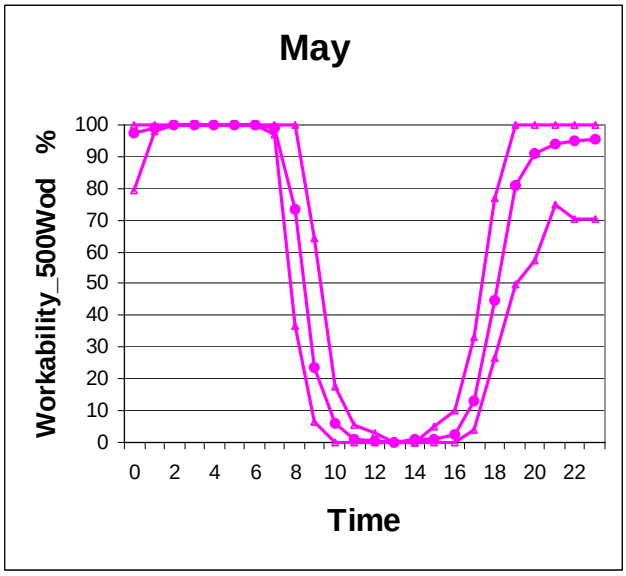
construction workers take a five-hour "lunch-break" each day in order to cope during the hottest season. These extreme heat exposures are primarily a problem in tropical countries and are not likely to occur in Sweden, but in southern Europe some days may reach similar conditions as Delhi. Climate change will, of course, make the situation worse. A detailed description of the thermal work environment issues in Sweden has been published by Gavhed and Holmer (2006).

Figure 11. Calculated hourly WBGT outdoors, in the sun and resulting hourly "work ability" for workers in heavy labour jobs (500W), Delhi, 1999 (Kjellstrom, 2008)

WBGT outdoors



Work ability (%) when working at 500W intensity



One feature of high direct heat exposure that has not been analyzed in relation to climate change is the impact of reducing daily or weekly physical activity for exercise purposes (and the potential increase in obesity). A recent review (Brotherhood, 2008) highlights that for sports people the thermal environment guidelines used for workplace exposures (WBGT) may not be the most appropriate. Another impact of heat exposure that is not well quantified is the more severe clinical status that many people with pre-existing diseases, chronic or acute, are likely to experience.
In order to consider the health impacts in a comprehensive manner, it is important to include these physiological and clinical effects, particularly because they will be repeated every day during the hot season when the threshold for these effects has been reached (Hales and Richards, 1987).

Heat exposure creates a need for additional liquid intake, as body water is lost through sweating (up to 10 litres or more during a day of heavy physical activity and heat exposure; Parsons, 2003). If sufficient drinking water or other liquid is not taken, the body will dehydrate with potential damage to the kidneys. Dehydration is likely to be a particular issue for the elderly and infants, but may also occur among workers doing hard physical work in hot environments without sufficient water access (Schrier et al., 1967). Studies of military troops deployed in hot, arid climates have demonstrated an increase in the occurrence of kidney stones in relation to exposure to higher mean

temperatures (Cramer and Forrest, 2006). A recent report on the incidence of kidney stones in hot parts of the USA (Brikowski et al., 2008) indicates what might be the ultimate effect on public health from heat exposure and associated dehydration. Differences in mean annual temperatures are estimated to account for 70% of the geographical variation in the distribution of kidney stone diseases in the USA. Dehydration increases the concentration of calcium and other compounds in the urine, which facilitates the formation of kidney stones. A hotter climate across the USA is predicted to contribute to an additional 1.6-2.3 million new cases by 2050 (Brikowski et al., 2008).

During the severe heat wave in Chicago in 1995, there was a significant increase of hospital admissions for acute renal failure and co-morbidity of renal disease (Semenza et al., 1997). Another study of hospital admissions during heat waves in Adelaide, Australia, showed an incidence rate ratio of 1.10 for renal diseases and 1.26 for acute renal failure compared with non-heat wave days (Hansen et al., 2008). Interestingly, the highest incidence ratios occurred among men in the age group 15-64 years, raising the question about the role of physical activity during work as a cause of dehydration and renal problems. The heat wave health effect study in California (Knowlton et al., 2008) reported significant increases of emergency visits for diabetes (3% increase), cardiovascular diseases (2% increase), acute renal failure (15% increase), electrolyte imbalance (16% increase), and nephritis and nephrotic syndrome (6% increase).

Another group with renal disease problems potentially influenced by heat exposure is coastland male farmers in hot Central American countries. Chronic renal failure in El Salvador (Gracia-Trabanino et al., 2005) is surprisingly common (prevalence = 12.7% among adult farmers). The usual risk factors (e.g. diabetes and hypertension) were only present among a third of the patients and exposures to pesticides and alcohol did not appear to be important risk factors. One could hypothesize that repeated daily dehydration caused by heavy labouring work undertaken in very hot temperatures could be an important risk factor for renal disease in this population, as workers do not always have sufficient water to drink during work.

The clinical impacts of heat exposure on cardio-vascular diseases during heat waves generally occur among people with pre-existing disease (Poumadere et al., 2005).Clinical practice patients with acute heart symptoms should be protected from heat exposure, as such exposure causes skin blood vessels to expand and blood pressure to drop creating lower blood flow to the heart muscle. Another disease that strongly interacts with heat exposure is multiple sclerosis (MS), a common disabling neurological disorder of young adulthood. In 1890 Wilhelm Uhthoff described a worsening of visual symptoms with exercise in MS cases with optic neuritis (Selhorst and Saul, 1995) that result from delayed nerve conduction when core body temperature increases (Smith and McDonald, 1999).

Obesity has also been shown as a risk factor for heat disorders, even among young, relatively fit, military personnel (Chung and Pin, 1996). It can be expected that disease conditions associated with obesity, such as diabetes, can be negatively affected by increased heat exposure due to climate change. It is also well known that certain common prescription medicines (e.g. beta-blockers and diuretics) reduce the body's ability to manage heat exposure physiologically (Parsons, 2003) so the clinical status of people with certain chronic diseases is likely to be worse with high heat exposure.

This may increase the incidence of acute presentations to emergency departments and demands for other health services.

A final example of the occurrence of heat related disease is meningococcal meningitis (Greenwood, 1999). In Africa a number of epidemiological studies have shown that epidemics of this very serious disease appear to be related to very hot and dry conditions. The exact mechanism for how the bacteria increase their pathogenicity and/or epidemic potential during these periods of local climate variation is not known. However, in areas where climate change increases the occurrence of these conditions, one can imagine a potential increase of meningitis epidemics.

Impacts via increased air pollution

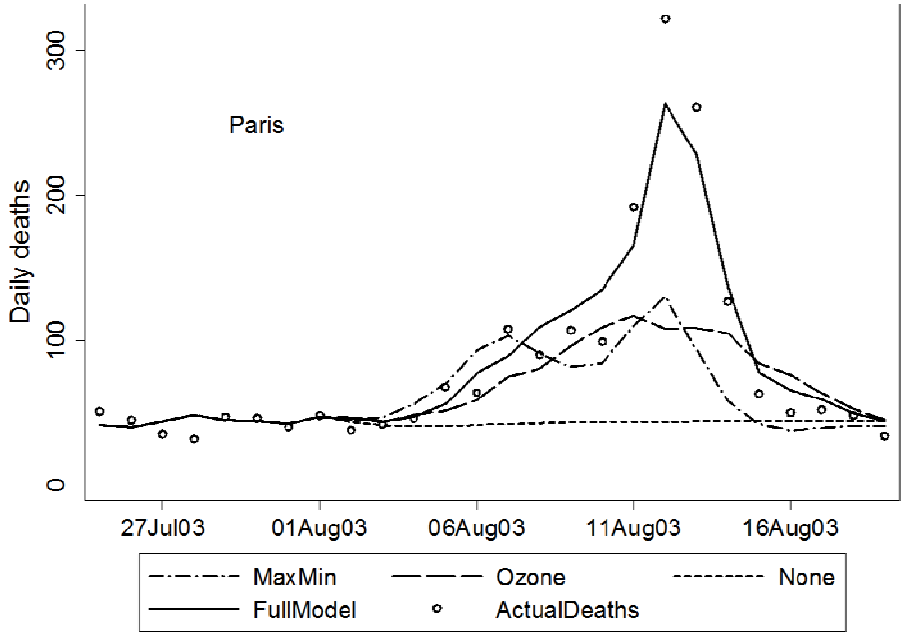
One of the effects of an increasing temperature trend in cities is the increasing level of ozone in the air, assuming that motor vehicle emissions remain at current levels. Ozone is a major pollutant formed when emissions from motor vehicles and UV-radiation from sunshine react in air (WHO, 2005c). Ozone formation is faster and greater when the air temperature increases, as happens with climate change. Ozone is one of the major air pollutants that increase the incidence and mortality of heart and lung diseases as well as causing respiratory irritation symptoms (WHO, 2006).

Efforts to reduce emissions of health damaging air pollutants as well as greenhouse gases from motor vehicles will most likely reduce emissions from new vehicles, but in many cities, older vehicles will remain on the roads for a long time. In addition, increasing numbers of motor vehicles in many cities, particularly in developing countries, will counteract the improvements in engine technology and total pollution emissions in cities may still increase. Thus, it is prudent to assume that vehicle emissions in major cities will not decrease and climate change will lead to increasing ozone exposures to residents.

The combination of heat and ozone exposures was studied in conjunction with the extreme heat wave in Europe in 2003. With the use of a multiple regression models Dear et al., (2005) and Filleul et al. (2006) showed that ozone and heat both impacted on the daily mortality in French cities. The extent of the effect varied between the cities, but according to Dear et al., (2005) the ozone contribution was approximately half of the total additional mortality in Paris (Figure 12). This finding could be of particular importance for the type of preventive public health actions that are triggered by a heat wave. In places with a lot of car traffic, mortality may be significantly reduced by reductions of the traffic.

Air pollution in the form of particulate matter (PM) and nitrogen dioxide (NO_2) are well-known and wide-spread health hazards (e.g. Brunekreef and Holgate, 2002; Brunekreef and Forsberg, 2005; WHO, 2006) with significant exposure levels in Sweden (e.g. Bellander et al., 2001). A significant proportion of the finest particles are secondary organic particles, condensed from gaseous SO_2 and NO_2 pollution, which is expected to increase over coming decades (WHO, 2006; SOU, 2007). It has been shown to increase asthma, lung cancer and daily mortality in Sweden (e.g. Pershagen et al., 1995; Nyberg et al., 2000; Forsberg and Sjöberg, 2005).

Figure 12. Daily reported and modelled mortality in Paris, 2003, in relation to heat and ozone exposure. (Dear et al., 2005)
(MaxMin curve = mortality effect of temperature; Ozone = mortality effect of ozone; FullModel = combined effect; none = background mortality without heat wave)



Substantial research on air pollution health effects has been carried out in Sweden and at the Swedish Institute of Environmental Medicine (IMM) in Stockholm, and it is not possible to refer to all the studies of this health threat in Sweden in this report. Among the most recent IMM studies one has given support for an association between long-term air pollution exposure (NO2, CO and PM) and fatal cardiovascular disease (Rosenlund et al., 2006). Another study (Nordling et al., 2008) indicated that air pollution exposure early in life can increase airways disease and allergic sensitization in preschool children.

Studies where both heat and particulate air pollution were included in time series daily mortality analysis have shown a significant combined effect (e.g. Hales et al., 2000). Annual mortality is also affected by annual average air pollution (e.g. Scoggins et al, 2004), but such studies have yet to include an analysis of the impact of heat exposure. The air pollution mortality and morbidity is very much due to impacts on cardio-vascular diseases, effects that are also affected by cold air (Brunekreef and Holgate, 2002). In the past the mechanisms behind these effects were unknown, but recent research is finding several plausible mechanisms (Simkhovich et al., 2008). A recent study that included IMM participation (Schneider et al., 2008) showed that a decrease of temperature caused an increase of C-reactive protein and Interleukin-6 in blood a few days later. This may partly explain the seasonal variation in cardiovascular disease mortality with higher risks during the really cold season. However, total air pollution exposure levels in many places are higher during the cold season, which may add to the seasonal population risk for this type of disease.

A particular type of air pollution associated with climate is pollen from selected plants that cause allergies. Approximately 15-20% of young adults in Sweden are allergic to pollen (SOU, 2007)

representing 40% of all allergies in Sweden. Reports from Europe and North America indicate that the pollen season starts earlier and earlier, most likely due to climate change (IPCC, 2007). The length of the high pollen season for the common allergenic trees (e,g, birch) may, however, stay the same and the total allergy risk may be unchanged. Another factor of importance is the introduction of foreign plant species into Sweden and other European countries due to contaminated imported seeds e.g. ragweed among grain seeds from North America. Ragweed is very strongly allergenic and the amount of pollen it produces increases as the carbon dioxide levels in air go up (SOU, 2007). It has spread throughout Europe and into Sweden. Every place where it gets established experiences an increase of pollen allergies (SOU, 2007). Allergies related to mould indoors may also be affected by climate change via changes in humidity and temperature indoors (Beggs, 2004).

Impacts via increased chemical exposures

When the climate gets warmer certain toxic environmental chemicals will evaporate more easily and cause higher exposure via air in workplaces and in the general environment. Absorption through skin may also increase (Johanson and Boman, 1991) creating higher exposures. This aspect of potential climate change health risks has not been investigated sufficiently.

There will also be changes in the long distance transport of environmental chemicals, such as the one that creates a global distribution of the so-called "persistent organic pollutants" or POPs. PCBs are part of this group of chemicals and environmental exposures in Sweden have been shown to influence, for instance, bone mineral density (Hodgson et al., 2008).

Another toxic chemical with the potential to contaminate the environment and increase human exposures is mercury, which in Canada has created an important public health concern in remote areas (Lucotte et al., 2005). Environmental changes due to floods may transfer toxic chemicals to food stuffs (e.g. fish).This has already happened in Canada due to new dams, but climate change flooding could possibly create similar exposure conditions.

In areas where surface water supplies become insufficient, for instance due to the reduced water flow from glaciers melting due to climate change or from reduced rainfall, a local population may become more dependent on ground water. In some geographic areas this may create higher intakes of arsenic in drinking water. The author has heard anecdotal stories about this happening in the Andes mountain area, but this issue merits further studies and risk analysis.

Extreme weather and floods can also cause chemical contamination from industries, damaged sewage systems or hazardous waste dumps. In this way climate change may increase the need for "disaster toxicology" research and preventive actions. Many industries that use and process toxic chemicals are located close to rivers, lakes, coasts and ports, and storms or floods can cause serious chemical emergencies in such places as pointed out in an APELL document (APELL = Awareness and Preparedness for Emergencies at Local Level) (IMO/UNEP, 1996). Extreme weather can also damage road access or electricity supply to industrial establishments with potential consequences for chemical emergencies and associated health impacts.

Impacts via reduced food access

Malnutrition due to climate change is expected to have the largest impact on climate change related mortality 1990-2000 (McMichael et al., 2004). This impact is primarily based on estimations of the impact of droughts and other climate calamities on food production among subsistence farmers in rural areas of low income countries. However, as recently shown, an imbalance between global food production and consumption, as well as shortages partly due to climate change (e.g. lower production in Australia), has created rapidly increasing food prices around the world. The push for production of bio-fuels as a climate change mitigation method has also contributed to increasing food prices during 2008.

One result of increased food prices is that poor urban populations with limited or no ability to produce food themselves get less access to food. This is likely to increase malnutrition among pregnant women, their foetuses and children of poor urban families. In addition, these families may get less access to fruit and vegetables resulting in increased risk of cancer and cardio-vascular diseases. A possible consequence of foetal, antenatal and childhood under-nutrition and malnutrition is the impact it can have development and health status in later life (Gluckman and Hanson, 2006). These 'programming' changes in early life can impact the susceptibility to the development of a number of conditions such as cardiovascular disease, obesity, diabetes and other metabolic disorders in later life (Barker, 1997).

Malnutrition in early life also stunts physical growth, and in extreme cases causes marasmus (severe wasting) or kwashiorkor (malnutrition with oedema), as well as increasing susceptibility to diarrhoea and infections (Muller and Krawinkel, 2005). These and other consequences of malnutrition come from deficiencies in micro- and macro-nutrients as well as in gross caloric intake; both the quality and quantity of food is important.

Impacts via extreme weather

As mentioned earlier, climate change is likely to create more extreme weather variability as well as a slowly increasing global temperature (IPCC, 2007). Such extreme weather situations will cause emergencies through floods, landslides that block roads and damage houses, high winds, typhoons or hurricanes that damage electricity and water supply, buildings, etc. Another type of emergency is forest fires caused by extremely dry conditions. Fires have been linked to climate change in Australia and other places. Injuries caused by extreme weather conditions may lead to long-term disabilities, particularly in people with pre-existing diseases. Lack of access to pharmaceuticals for people with diabetes, high blood pressure, and other diseases requiring continuous medication, would make their condition worse. People relying on equipment powered by electricity for their survival (e.g. dialysis machines, ventilators) are at extreme risk if there are power cuts.

The most vulnerable will be poor people and those with pre-existing chronic diseases or disabilities. A striking example of this occurred during the flooding of New Orleans where the effects were greatest on elderly rest home patients and poor people who could not evacuate because of lack of transport (Sharkey, 2007).

Other groups that are particularly affected by extreme weather events are emergency workers, fire fighters and police involved in efforts to reduce the health impacts on a local population. The health risks related to burns, injuries, and heat stress in, e.g. fire fighting, are reasonably obvious. In addition, these groups are affected mentally and the reports about the aftermath of Hurricane Katrina in New Orleans present various mental stress symptoms, depression and posttraumatic stress disorder (Tak et al., 2007; West et al., 2008; NIOSH, 2007).

Extreme weather events in Sweden during recent years have caused flooding, landslides, forestry damage, blocked roads and major cuts in electricity and telecommunications supply. The latter impacts may have important health consequences in societies where the population is ageing. More and more people have ongoing chronic diseases but can manage well with medication and are able to live alone as they get older. Climate change in Sweden may create special health risks for these people.

It is noteworthy that on Red Cross/Red Crescent Day, 8 May, 2009, this global humanitarian movement launched a new campaign "Our world. Your move", a campaign that aims at developing better preparedness for emergencies caused by extreme weather and other aspects of climate change. The Official statement on their web-site says: "*All can, in one way or another, each in his own sphere and within his own limitations, do something to help the good work forward. --- These words, written by Henry Dunant following the Battle of Solferino, embody the spirit of our International Red Cross and Red Crescent Movement. This year, we mark the 150th anniversary of Solferino and the origins of our Movement by celebrating his belief that individuals have the power to make a difference.*

Today, we launch the 'Our World. Your Move' campaign – an ambitious undertaking aimed at raising awareness of today's Solferinos and the unprecedented challenges we all face, ranging from armed conflict and mass displacement to climate change and the global economic crisis. We have a collective responsibility to make our world a better place. It's up to each of us, as individuals, to make a move and do something to help others. Young or old, we can all make a difference."

Impacts via infectious and vector-borne disease agents

While the broader health issues related to climate change are currently emphasized (Frumkin and McMichael, 2008; Shahab, 2008), assessments of specific medical conditions have focussed on infectious and vector-borne diseases in developing countries (McMichael et al., 2003). Much of the climate change and health research has also studied these diseases as their causal pathways clearly involve climate factors (Gage et al., 2008). Infectious diseases caused by contamination and too high storage temperatures are other exposure risks of climate change (Hall et al., 2002). Pathogens of particular concern are Staphylococcus aureus, Clostridium perfringens and Salmonella. Changes in the seasonal patterns of infectious diseases may occur, influenced not only by climate but by seasonal food consumption patterns.

Several vector-borne diseases have been reviewed in some detail by Gage et al., (2008) and their categorization by vector type and pathogen are summarized in Table 2. Particular concern has been raised in Sweden about Lyme borreliosis and TBE carried by ticks that are spreading northwards in

Sweden due to climate change (Lindgren, 1998). Another disease risk discussed by Lindgren et al., (2008) is visceral leishmaniasis spread by "sand mosquitoes" (or sand flies). These types of insect-borne diseases are not a new phenomenon in Sweden. Espmark and Niklasson (1984) reported on the mosquito-borne "Ockelbo disease" caused by the "Edsbyn 5/82 virus". This disease is a syndrome causing rash, arthralgia and moderate fever that occasionally causes epidemics in middle Sweden. The mosquito competence to transmit the virus is closely related to temperature (Lundstrom et al., 1990) and one can expect increasing disease risk with the warming caused by climate change. A review of mosquito-borne viruses in Western Europe (Lundstrom, 1999) has identified several diseases that could cause increased risks with climate change.

Those with communicable diseases will suffer from excessive heat exposure and extreme weather conditions in a similar manner to the way in which pre-existing chronic diseases makes people more vulnerable. Another problem that may cause concern in Sweden is the outbreaks of mosquito growth during certain climate conditions in the summer in central Sweden (myggplågan vid Dalälven). The impact on the mental state of affected people may merit special studies if it is expected that climate change will make the situation worse.

Table 2. Climate related vector-borne diseases by vector and pathogen types (Gage et al., 2008) (the two diseases marked in bold are of particular importance in Sweden)

Vectors / Pathogens	**Parasites**	**Arbo-viruses**	**Bacteria and Rickettsia**
Mosquitoes	Malaria	Dengue fever Yellow fever Chikungunya fever West Nile virus Rift Valley fever Ross River virus	
Ticks		**Tickborne encephalitis (TBE)**	**Lyme borreliosis** Tularemia Human granulocytic anaplasmosis Human monocytic ehrlichiosis
Other **- sand flies** **- Triatomine bugs** **- Black flies** **- Fleas**	 - Leishamniasis - Chagas disease - Onchocerciasis		 - Plague

Impacts on chronic diseases and mental health

The impact of climate change on chronic diseases and mental health has not been given much attention until addressed by a recent WHO report (Kjellstrom, 2008) and two papers that will be

published soon (Kjellstrom et al., 2009a; Berry et al., 2009). "Chronic diseases" is not a totally unequivocal term. Generally it might be assumed to include all non-communicable diseases, but some of these are actually acute conditions. There is also a distinction between chronic diseases and chronic conditions, the latter being defined as "health problems that require ongoing management over a period of years or decades" (WHO, 2005a). This definition would of course incorporate chronic communicable diseases, such as HIV/AIDS, and long-term disabilities from injuries. In addition, it is important to include acute effects that will occur repeatedly due to "chronic" exposure to climate factors.

For a long time the global health discourse considered chronic diseases to be a problem for high-income countries, while lower income countries focused on the major problems of communicable diseases and malnutrition (as highlighted in WHO policies and technical reports until the latest decade). Injuries were always a major public health problem in both low-income and high-income countries, particularly among young people, but received less international attention, probably because many health professionals considered them "accidents caused by unpredictable chance events", difficult or impossible to prevent. An analysis of the priority health issues for adults in the middle age range (15 to 60 years) (Feachem, et al., 1992) highlighted the importance of both chronic diseases and injuries in this "productive" age range and the role of population age distributions in the disease panorama of a country.

The steady improvement of child health in many low- and middle-income countries has shifted the burden of disease and injuries to older age groups, and recent analysis and policy development at WHO has emphasized the importance of chronic diseases in all countries (WHO, 2005b). The first global burden of disease calculation (Murray and Lopez, 1996) put the traditional child disease problems of malnutrition, diarrhoeal diseases and acute respiratory diseases at the top rankings for 1990, but chronic diseases and mental health problems were expected to rank at the top levels in 2020. WHA resolutions on different aspects of these diseases have been passed during recent years in order to strengthen international and national efforts to control and manage the chronic disease "epidemic" (e.g. WHA53.17 in 2000). Thus, any impacts of climate change that increase chronic disease occurrence are of concern in this context.

Mental health is also a major growing global concern. Depression, particularly among older people, is expected to be one of the greatest components of the global burden of disease in 2020 (Murray and Lopez, 1996; WHO, 2002). A major WHA resolution on mental health (WHA28.84 in 1998) has raised the visibility of the issue and a number of papers in the Lancet in 2007 (e.g. Prince et al., 2007) has highlighted the importance of this health problem. There are several ways by which local climate change can influence the mental health status of the local population (Berry et al., 2007, 2008), and adaptation to climate change may in itself cause mental stress. Extreme weather and drought may seriously damage local agricultural production leading to increased suicides among farmers (Berry et al, 2008) and suicides rates are associated with temperature (Page et al., 2007). Dislocation due to flooding leads to mental stress and depression among these "environmental refugees". People with mental health problems may be affected by extreme heat because they don't perceive that there may be adverse effects from or risks associated with it. As mentioned earlier,

emergency workers dealing with extreme weather events are also at risk of mental health sequelae (West et al., 2008).

Gender differences in impacts

The extent to which men and women are affected differently by climate change health hazards has been reviewed by Jämting (2008). A United Nations program GENCC has produced a series of web-based materials with useful information, both on mitigation and adaptation issues of climate change in relation to gender differences.

For a number of the health problems mentioned above, women are more vulnerable and could therefore be more affected, but detailed research is missing in the cultural and social settings where the health impacts will become the greatest problems. An important variable for the degree of direct heat stress that women can be exposed to is the time-use variable (Kes and Swaminathan, 2006). If heat exposure is high enough to force a person to slow down daily physical activities, the time women in poor communities of tropical countries spend on collecting water, food or fire wood will get longer shortening the time available for other important household activities potentially creating health risks for the whole family. Therefore, research on and implementation of preventive approaches is therefore of importance. Women who are the main care-givers in families will also be affected by the health effects on their children.

Variability of impacts in different population groups: health equity and vulnerability aspects.

As mentioned earlier, the greatest changes in climate change related health hazards are likely to take place in tropical low- and middle-income countries. Poor people are most vulnerable as they live in areas that are already hot and are vulnerable to extreme weather or sea level rise (Patz et al., 2007). In addition, poor people do not have access to the resources required for preventive measures, such as air conditioning, safe housing design, or efficient escape mechanisms during floods. Poor people are vulnerable because of the social determinants that create health inequities, and it has become clear that climate change mitigation and adaptation policies need to go hand-in-hand with the global efforts to achieve health equity (Friel et al., 2008).

One way of assessing the overall health impact of climate change globally and in different countries or population groups, is to use the Global Burden of Disease (GBD) methodology, developed for WHO and the World Bank by Murray and Lopez (1996). The GBD method estimates the number of deaths in a population that are preventable, based on the mortality rate in the country with the lowest rates in the world, and assigns the risk attributable to different risk factors (e.g. climate change) for the relevant disease types in order to calculate the number of preventable deaths that are due to climate change. This calculation produces a YLL (Years of Life Lost) due to the risk factor. For each of the relevant diseases there is also a calculated YLD (Years of Life with Disability) equivalent to the preventable non-fatal ill health in this population. If the attributable risk is applied to the YLDs, the morbidity part of the preventable ill health can be calculated. The sum of YLL and YLD is the burden of disease and injury expressed in DALYs (Disability-Adjusted Life Years lost).

During recent years WHO has been developing estimates of the Environmental Burden of Disease (Pruss-Ustun and Corvalan, 2006), and a series of documents have presented results for different environmental health hazard types, for instance: Outdoor air pollution (Ostro, 2004) and Water, sanitation and hygiene (Fewtrell et al., 2007). It is very difficult to produce valid attributable risks for climate change exposures, and so far no detailed estimation using DALYs has been produced. An attempt was made (McMichael et al., 2004), but it was concluded that estimates of number of deaths would be less uncertain. Table 3 shows the estimated number of deaths due to different ill health categories caused by the limited climate change that has occurred between 1990 and 2000.

Table 3. Estimated number of deaths (thousands) in different WHO regions likely to be caused by global climate change between 1990 and 2000. (source: McMichael et al, 2004). (The six WHO regions and division by population health status level. D and E countries have the worst health status and are the poorest. AFR = Africa, AMR = Americas, EMR = Eastern Mediterranean, EUR = Europe, SEAR = South-East Asia, WPR = Western Pacific).

WHO-region	Mal-nutrition	Diarrhoea	Malaria	Floods, extreme weather	Cardio-vascular disease	Total
AFR-D	8	5	5	0	1	19
AFR-E	9	8	18	0	1	36
AMR-A	0	0	0	0	0	0
AMR-B	0	0	0	1	1	2
AMR-D	0	1	0	0	0	1
EMR-B	0	0	3	0	0	3
EMR-D	9	8	0	1	1	19
EUR-A	0	0	0	0	0	0
EUR-B	0	0	0	0	0	0
EUR-C	0	0	0	0	0	0
SEAR-B	0	1	0	0	1	2
SEAR-D	52	22	0	0	7	81
WPR-A	0	0	0	0	0	0
WPR-B	0	2	1	0	0	3
Total (T)	**78**	**47**	**27**	**2**	**12**	**166**
% of Total=T/166	*47*	*28*	*16*	*1*	*7.2*	*100*
Sub-total, D + E (S)	**78**	**44**	**23**	**1**	**10**	**156**
% , D + E = S/T	*100*	*94*	*85*	*50*	*83*	*94*

Among the estimated 166,000 deaths due to climate change between 1990 and 2000 (Table 3), approximately half are due to malnutrition, one quarter to diarrhea, and most of the rest due to malaria. More health effects are likely to happen in the future, and the report by McMichael et al. (2004) included likely regional increases of climate change related deaths by 2030 due to the different disease categories. For example, depending on the climate change scenario used, the

relative risks for malnutrition deaths could increase from a range of 1.00 – 1.05 in 2000 to a range of 1.00 – 1.17 in 2030. A relative risk of 1.05 implies that 5% of the malnutrition mortality is due to climate change, and if this relative risk increases to 1.17, it will mean more than three times as many deaths in this illness category due to climate change between 1990 and 2030.

The principal health impacts listed in Table 3 are due to diseases of poverty that are amenable to preventive action if sufficient global resources were applied to improving health in all countries. Improved health equity would generally reduce the vulnerability of the poor to climate change health impacts.

Children are a particularly vulnerable group. The deaths in the three first disease categories in Table 3 are primarily among infants and young children, These disease categories represent 152,000 (91%) of the estimated total of 166,000 annual deaths in the year 2000 due to global climate change from 1990 to 2000. However, it is expected that socio-economic development, particularly in India (SEAR-D), will reduce these effects of climate change. Elderly people are another vulnerable group. An ageing population in most parts of the world will increase the number of people vulnerable to cardio-vascular disease deaths during heat waves (Table 3). Thus, with ageing the relative distribution of estimated deaths is likely to shift towards the right side in the table. For cardiovascular disease deaths the relative risks were in the range 1.000 – 1.002 in 2000 changing to 1.000 – 1.007 in 2030, thus it is possible that there is a three times increase of climate change related deaths due to this cause.

The regional distribution of DALYs is likely to be similar to the distribution of deaths. One additional factor of importance when calculating climate change impacts in the form of DALYs is that the YLDs in the DALY calculations are not only a function of the duration of disability for a specific disease or health condition, but also a function of the clinical severity of the disease or condition (Murray and Lopez, 1996). Increasing exposure to heat as an effect of climate change in already hot climates may cause significant deterioration of the clinical status of people with heart or lung disease, diabetes, cancer or mental health conditions. With approximately half of the global burden of disease in the form of YLDs, even a small change in YLDs (say, 4-10%) would create an important impact on the DALYs (2-5%). Few risk factors of the global disease burden account for more than 1% of the burden (WHO, 2002).

An updated version of the climate change related burden of disease up to the year 2005 is currently being developed by WHO and will be part of a recalculation of all aspects of the global burden of disease coordinated by Professor C Murray at the University of Washington, Seattle (funded by the Bill and Melinda Gates Foundation).

Positive and negative health impacts of mitigation and adaptation

It should be pointed out that mitigation and adaptation actions may in themselves affect physical or mental health. These issues will not be discussed in detail here, but they need to be considered in national climate change policies and research programs in order to avoid increasing one type of health risk while preventing health risks of another type. For instance, if mitigation involves a greater use of bicycles for commuting to work or school, the injury risks from bicycling need to be taken into account and prevented by the design and construction of safe bicycle tracks. On the other hand, increased bicycling promotes health through physical activity and reduced motor vehicle transport (Kjellstrom et al., 2009b).

Motor vehicle transport is an area with a number of health hazards: crash injuries, air pollution, traffic noise, lack of physical activity and climate change (Kjellstrom et al., 2009b). When programs for GHG reductions are implemented by reducing such transport, the other health risks related to motor vehicles will also be reduced (a health "co-benefit"). However, the risks of alternative transport modes need to be considered.

Reduced energy use in heating and cooling systems may also lead to positive or negative health impacts via air pollution from home heating (e.g. more use of wood stoves) and power stations. Ruminant meat production (cows and sheep) emits GHGs in the form of methane and there are positive and negative health aspects of changing the patterns of meat production and consumption. These areas merit detailed research analysis in the future.

Recent Swedish assessments and policy statements on climate change

(based on reports listed in Appendix 1)

The Parliamentary Climate Initiative (Klimatberedningen) and Swedish climate policy (Svensk klimatpolitik)

The Swedish cabinet decided on 19 April 2007 to establish a Parliamentary Initiative to carry out a major review of the Swedish climate related policies (Klimatberedningen, 2007). Their aims included the development of specific objectives and activities within these policies. The existing targets for greenhouse gas reductions and storage of carbon in forests should be assessed, as well as the impact of carbon trading schemes and other international measures to mitigate global climate change. The Initiative should also propose new methods to limit climate change and its economic consequences. Such work should be based on assessments from scientific councils and relevant authorities, coordinated with the work of the "Climate and Vulnerability Investigation" (Klimat- och Sårbarhets-utredningen) and the Commission for Sustainable Development (Kommissionen för Hållbar Utveckling). Close collaboration with a number of international initiatives is expected and the important role of a scientific basis for the Initiative's recommendations is highlighted.

In February 2008 the Initiative reported that global climate change was a major hazard for the global community (http://www.regeringen.se/content/1/c6/09/83/86/f865af27.pdf) and that strong actions are needed to mitigate the ongoing climate change by reducing greenhouse gas (GHG) emissions. Sweden and the other high income countries have a special responsibility to take mitigation actions, as these countries emit more GHGs per capita than the low and middle income countries. On the other hand, the latter countries are, and will be more affected by climate change (e.g. see Table 3). The impacts on human health and ability to carry out essential life functions are not specifically mentioned, but the importance of developing full knowledge about the various aspects of climate change is stressed. Research and technological development to identify and deal with climate change problems is a priority. The strength of expertise available in the scientific and technical institutions in Sweden is mentioned as an asset that the country can offer the global community to help solve these problems.

Swedish climate policy follows the same principles and highlights the urgent need for global coordinated action to reduce greenhouse gas (GHG) emissions and to improve the global carbon balance. Sweden needs to take responsibility for its contributions to ongoing global climate change and will work closely with the European Union to reduce GHG emissions and to develop and apply technology that can prevent climate change and its impacts. Sweden should take an active role in international initiatives to deal with this issue, such as IPCC, and will use aid funding to support actions to protect poor people in developing countries, who are under threat from climate change hazards. Scientists and institutions in Sweden should also contribute to global research to deal with the climate change issues.

The Swedish National Institute of Public Health was asked to provide comments on the draft report from IPCC and agreed with the conclusions and summaries drawn in the Health chapter (FHI, 2006). The main point was that the impacts of climate change will vary between different

geographic regions and local adaptation plans need to be developed. In the response to the Climate Policy document (Svensk klimatpolitik) the Swedish National Institute of Public Health provided strong support for actions to limit the Swedish contribution to the global greenhouse gases and to set targets for maximum acceptable temperature change (FHI, 2008a). A specific temperature limit makes it possible to link unavoidable future changes to documented health impacts. The Institute supported greater investments in climate effects research and the use of foreign aid funds to support adaptation planning and implementation in low income countries. As expected, this Institute pointed out the importance of public health impacts of climate change and that research, and stressed that analysis and actions dealing with the health impacts should be included in national climate change plans. It was also emphasized that certain mitigation actions, for instance the reduction of motor vehicle travel, would have public health co-benefits (less accident injuries, less air pollution, less traffic noise). The Institute supported active international involvement of Sweden in developing mitigation and adaptation programs, including carbon taxes, and suggested that Sweden should use its period as chair of the EU in 2009 to promote climate change prevention.

Climate and Vulnerability Investigation (Klimat- och Sårbarhets-Utredningen, KSU)
This Investigation (KSU) was completed in 2007 and contains a detailed analysis of the Swedish vulnerability to climate change and the actions needed to reduce this vulnerability (SOU, 2007). The health aspects were analysed and described in detail in Appendix 34 (Lindgren et al, 2007) to the main report, and these aspects have also been presented briefly in a Swedish journal article (Lindgren et al., 2008). This health analysis focuses only on the population of Sweden, which means that the major health risks in low income tropical countries are missing from the report.

The health risks in Sweden described in KSU include effects from an increased number of days with extremely high temperatures. Extreme heat affects elderly people and people with pre-existing health conditions, e.g. cardio-vascular diseases, respiratory diseases and kidney diseases. In addition, people on prescription drugs, such as beta-blockers or diuretics for blood pressure control, may have increased sensitivity to heat exposure. With an ageing population and the common prevalence of these diseases and conditions, the Swedish population will be at increased risk with climate change. One study of heat related mortality (Rocklöv and Forsberg, 2007) has shown the U-shaped exposure-effect relationship for temperature on mortality in Stockholm. The increase of the mortality rate per degree of increased temperature at the hot end is greater than the increase of mortality per degree of reduced temperature at the cold end. These relationships are of course influenced by the availability of heating and cooling systems in Swedish buildings, however, the net effect of a shift of the temperature distribution towards warmer temperatures will be increased mortality, if all other factors stay the same. Obviously, less dramatic health impacts are also affected by increased heat: hospital admissions, health service attendance, heat strain affecting work and daily household activities, and the clinical condition of people with certain pre-existing disease conditions.

Changed air quality is another factor that may increase health risks. As mentioned above, ground level ozone concentrations will increase with higher air temperatures, but ozone is also influenced by the emissions of selected air pollutants, mainly from motor vehicles. Thus, it is concluded that in Sweden the ozone concentrations may change very little if motor vehicle air pollution emissions

are reduced (SOU, 2007). Of greater importance may be the combined effect of heat and particulate air pollution from vehicles, industry and coal-fired power stations. The latter is a well-known health hazard (already briefly described above) that has been shown to cause health effects in Sweden and many other countries.

A particular type of air pollution associated with climate is pollen from selected plants that cause allergies. Approximately 15-20% of young adults in Sweden are allergic to pollen (SOU, 2007) and pollen allergies represent 40% of all allergies in Sweden. Ragweed is a strongly allergenic plant that has spread throughout Europe and is new in Sweden (SOU, 2007). Every place where it gets established experiences an increase of pollen allergies (SOU, 2007). Another health threat in Sweden from climate change mentioned in KSU could be that increased outdoor temperatures may lead to higher absolute humidity levels indoors and an increase of allergenic mites and/or microbes. This may create a need for new guidelines for ventilation in residential and commercial buildings.

The Investigation (KSU) highlights the problems that extreme weather and floods can cause for the emergency and health services in Sweden (SOU, 2007). Injuries are an obvious risk, and cuts in electricity or water supplies can cause serious health problems. Infectious diseases may increase due to contaminated water or food. Pathogens of particular importance are Cryptosporidium, Giardia, Campylobacter, norovirus and EHEC (SOU, 2007). Other water related diseases, due to lake and river water temperature increase related to climate change, are "swimming itch" and "swimming sore fever" (SOU, 2007). The latter is a serious disease caused by a pathogen that can only grow in fresh and brackish water (as in the Baltic Sea) at a temperature higher than 20 ^{o}C. Toxic algeal growth with cyanobacteria is another emerging health risk (SOU, 2007).

Infectious diseases caused by contamination and too high storage temperatures are other health risks of climate change in Sweden discussed in KSU (SOU, 2007). Pathogens of concern are Staphylococcus aureus, Clostridium perfringens and Salmonella. Changes in the seasonal patterns of infectious diseases may also take place, particularly when the diseases are spread by vectors affected by the seasonal changes. Some examples are given in this report in a previous section (e.g. TBE and Lyme Borreliosis; Table 2). An informative table in SOU (2007) and Lindgren et al., (2007) summarizes the strength of the association with climate change of each infectious disease pathogen relevant in Sweden and the risk of outbreaks and consequences for public health.

The National Institute of Environmental Medicine (IMM) made a submission on the KSU text in January 2008 (IMM, 2008) focussing on health impacts associated with chemical and physical environmental hazards. It was pointed out that the KSU Investigation presented comprehensive and important information on the potential health effects of climate change. The uncertainty of all quantitative estimates in KSU was pointed out. The health risks of extreme temperature exposures, allergenic pollen exposures, indoor air quality, increased mobility of chemical pollutants in the environment, and chemical emergencies were seen as key issues that require further research and analysis. This report has made use of comments in IMM (2008) when relevant.

The Swedish National Institute of Public Health provided comments (FHI, 2008b) on the Investigation, agreeing with the importance of the threats of climate change to public health. The

need for Sweden to work internationally to deal with climate change issues was emphasized, including the necessity to support efforts to assist vulnerable people in low income countries to reduce the health risks of climate change. Systems to map vulnerable areas and to provide early warnings to residents in such areas are suggested. The proposal of a new cross-disciplinary research centre was also supported by the Institute.

Formas

In 2005 the Swedish National Research Council, Formas, developed a national programme for climate research (Formas, 2005). It is pointed out that global climate change will have "far-reaching consequences for many of the vital functions of society", and that "the problem needs to be dealt with on a holistic basis". However, population health is not mentioned anywhere in the document, and none of the seven funding organisations of the coordinating group for climate research represent health. It may be useful to seek expert population health input from e.g. the National Department for Health and Welfare (Socialstyrelsen in Stockholm), the National Institute of Infectious Diseases (Smittskyddsinstitutet in Stockholm), the National Institute of Public Health (Statens Folkhälsoinstitut in Östersund), the National Food Authority (Livsmedelsverket in Uppsala), the National Occupational Health and Safety Authority (Arbetsmiljöverket in Solna), the Emergency Services Agency (Räddningsverket in Karlstad), and/or the National Institute of Environmental Medicine (IMM) at the Karolinska Institute in Stockholm, the latter being the prime health research institution in Sweden.

Among the research needs Formas (2005) mentions are a better understanding of climate systems and processes, development of modelling of effects on ecosystems and infrastructure, as well as development of new technology. It states that the programme aims to achieve "breakthroughs in the national and international climate work", being a "platform for the development of a scientific basis for Swedish participation in the international research cooperation", and acting as "a network for Swedish researchers' participation in the work of IPCC". The very advanced level of health research in Sweden could be an important basis for contributing to these aims.

The Research Proposition 2008 (Forskningspropositionen)

This government proposition (2008/09:50) dated 20 October 2008 raises the funds available for research and innovation in Sweden and highlights the role of universities in research efforts (Utbildningsdepartementet, 2008). The proposition also stresses the importance of making use of research results for practical improvements in society and economic progress. The strategic areas for investments include:

- those where research can contribute to finding solutions to important global problems and questions
- areas where Sweden already carries out world class research
- areas where Swedish corporations carry out their own research and development and government input can strengthen national development and competitiveness

It is also emphasized the importance of encouraging and facilitating international collaboration. University institutes should play a key role in international research initiatives and in the exchange

of students and teachers. Interestingly, Swedish corporations are mentioned as many of them carry out activities in tropical countries where the health impacts of climate change will be greatest. Staff of these corporations, from both Sweden and the country hosting the operation, will be at risk for the occupational health hazards due to heat exposure described in this report.

Three specific strategic research areas are mentioned in the government proposition. These are:

- medicine and biological life science
- technology
- climate

The detailed proposals on these specific issues do not mention the linkages that cut across the three issues, such as climate impacts on health and approaches to prevent health impacts via new or improved technology. The links between the three areas could be explored in new research initiatives by selected key institutions, such as relevant university departments and the National Institute of Environmental Medicine (IMM) at Karolinska Institute in collaboration with the Stockholm Resilience Centre among others.

The specific areas mentioned under Medicine are: Molecular bioscience, Stem cell research, Diabetes, Neuroscience, Epidemiology, Cancer, Psychiatry, and Health care research. Under Technology we find: Nanotechnology, E-science (e.g. climate modeling), Material science, Production technology, IT and mobile communications, Transport research, Air transport and Space research. Under Climate we find: Energy science, Sustainable use of natural resources, Impacts on natural resources, ecological services and biological diversity, Climate modeling, and Marine environment research. The focus appears to be on Mitigation, while scientific collaboration between the three strategic areas will be required to develop new and improved evidence-based Adaptation approaches.

Stockholm Resilience Centre

According to the centre's website, this is “a new international centre that advances trans-disciplinary research for governance of social-ecological systems with a special emphasis on resilience - the ability to deal with change and continue to develop". It is a joint initiative between Stockholm University, the Stockholm Environment Institute and the Beijer International Institute of Ecological Economics at The Royal Swedish Academy of Sciences. The centre is funded by the Foundation for Strategic Environmental Research, Mistra.

The aim is to create a world-leading trans-disciplinary research centre that advances the understanding of complex social-ecological systems and generates new and elaborated insights and means for the development of management and governance practices. The new centre will advise policymakers from all over the world, and develop innovative collaboration with relevant actors on local social-ecological systems to the global policy arena”.

The website emphasizes the words of Johan Rockström, Executive Director of the Stockholm Resilience Centre: “*in order to solve the great environmental problems of the world, we need to*

change course. Our hope is that the Stockholm Resilience Centre will contribute essential knowledge that is needed to steer development onto a sustainable path". The idea is to build a unique trans-disciplinary research environment where innovative ideas can flourish.

Clearly good population health is a key element of sustainability and resilience to global environmental change, in which global climate change is of particular importance. The Centre's research themes do not include specific human health aspects, but much of the research has relevance for how population health is influenced by social and environmental determinants.

The Swedish International Development Agency (Sida)

Sida is the national agency that provides Swedish official development aid (ODA) based on funds from tax collected. The government contribution to ODA as a percentage of the Swedish GDP is one of the highest in the world, close to 1%. Sweden is one of the five countries that have long achieved the 1974 UN recommendation for high income countries to provide at least 0.7% of GDP to ODA.

The fundamental principles of Sida's work are: poverty reduction, achieving the Millennium Development Goals, and a just and sustainable development in low and middle income countries (Utrikesdepartementet, 2008). The focus is on better aid work through multilateral organizations with proactive and strategic thinking in Swedish interaction with the multilateral agencies. The main criteria for implementation of country-based aid projects are relevance and efficiency.

The policies of Sida have included concerns about public health, environment protection and sustainable development for a long time, a fact that is obvious from the content of information documents available on the Sida website. The links between the lack of sustainability and poverty, and the particularly damaging impact on the poor peoples' health from insufficient environmental management is highlighted, for instance, in the document "Consideration of the environment essential for sustainable development" (Sida, 2002). In 2007, Sida published several materials on the impact of climate change on society stating for example, "A changed climate affects the poor the most" and "The aim is a good climate for development". Associated materials are on the website.

Sida has also provided funds for research in selected developing countries and also for research by Swedish institutions in collaboration with those countries, via the research unit Sarec. On 17 December 2008 a new approach to the promotion of Sida funded research was taken through the organization of a "Sida Science Day". The aim is to develop a new Swedish strategy to support international collaboration for research based on Sida plans to strengthen research in specific countries, including Tanzania, Uganda, Mozambique, Ethiopia, Rwanda, Burkina Faso and Bolivia. The research should focus on the fight against poverty and a just and sustainable development. All these countries will be affected by tropical heat exposure and the different health risks associated with climate change.

In the short term, there are of course many areas of research related to climate change in these low income countries that can contribute to a more just and sustainable development. This includes

research in agriculture, nutrition, water supply, energy systems, environmental protection, and public health. As mentioned earlier, these countries will be increasingly affected by the local consequences of global climate change in the longer term. Thus, research undertaken now can set the stage for more effective prevention of later impacts. Swedish scientists can play a very useful role in encouraging, facilitating and collaborating in new research initiatives on climate change and health impacts in these low income countries. Sida should therefore be a logical partner in development of climate change and health research in Swedish institutions.

The Swedish Road Administration (Vägverket)

This agency has coordinated research on the total public health and associated economic impacts of the Swedish road transport sector (research supported by the Environmental Objectives Council, Miljömålsrådet). The report (Kjellstrom et al., 2009b) included a section calculating the likely health impacts of the global climate change due to the Swedish road transport contribution to the global GHG emissions. Swedish road transport emits approximately 0.13% of the global GHGs. This may seem a small amount, but it was assumed that the same proportion of the global health effects would be due to these GHG emissions, and the resulting health impact numbers were significant in comparison with the other health impacts of road transport.

The calculation started out from the estimates of climate change related mortality in Table 3. It used estimates of the future trends of impacts until 2030 (McMichael et al., 2004) to extrapolate until 2080, assuming a linear increase of climate change and its health impacts (probably an underestimate). The population growth until 2080 was assumed to follow United Nations estimates and the resulting number of annual global deaths due to climate change would be approximately one million between 2008 and 2080.

Based on these tentative estimates the likely annual average global number of deaths, 2008-2080, due to climate change from Swedish road transport GHGs, would be approximately 1,200. Most of these deaths will occur in tropical low income countries. This annual number of deaths is much greater than the number of deaths (appr. 500) due to traffic accident injuries in Sweden (Kjellstrom et al., 2009b). The uncertainty of these climate change health impacts is very large, but it is reasonable to consider it as an important aspect of transport system health impacts, and to carry out further research and analysis to develop a less uncertain estimate.

Current research activities in Sweden on climate change and health

Appendix 2 provides copies of web-site information from the six largest universities in Sweden, the Karolinska Institutet, the Swedish Environmental protection Board and CIRCLE (Climate Impact Research Coordination for a Larger Europe). It will not be repeated here, but the general impression is that few institutions carry out specific research on climate change and health.

The few detailed descriptions that are available on the web-sites indicate that Karolinska Institutet (via Dr Elisabeth Lindgren), Lund University (via Professor Ingvar Holmer) and Umea University (via Professors Stig Wall and Dr Rainer Sauerborn) are the main actors in this field at this time.

It is likely that additional active researchers can be identified in a subsequent detailed review of research on climate change and health in Sweden.

The reference list to this report has aimed at including the majority of the published studies carried out at Swedish institutions on this research topic during the last decade. The reader is advised to consult the reference list to find what was available to this author. Please let the author know about any missing published references by sending an email to: kjellstromt@yahoo.com

Knowledge gaps and research needs stated in other reports

Many knowledge gaps have been identified in the IPCC (2007) assessment and in the report on the estimation of the global burden of disease as an effect of climate change (McMichael et al, 2004), as well as in other reviews referred to in this report. Some of the recommendations about required research are rather general and do not deal specifically with the need to address the knowledge gaps for specific hazards or diseases/conditions. However, this research area is rapidly evolving and new studies will undoubtedly point towards major knowledge gaps and research needs. The most recent international attempt to identify gaps and recommend future research was the meeting in October 2008 organized by WHO, the United Nations Foundation, the US National Institute of Environmental Health Sciences and the Ministry of Health of Spain (WHO, 2009) (see below).

Again it should be emphasized that the already occurring public health impacts of climate change are primarily seen in low and middle income countries So, epidemiological research and health impact assessments for the populations of those countries is a priority. This environmental health problem is a truly global one with preventive actions (mitigation) required in Sweden and other high income countries to protect public health in other countries, particularly tropical countries. Thus, it is logical to expect that the research expertise and financial resources of high income countries are used to measure and assess health impacts in low and middle income countries.

Gaps identified by IPCC, 2007, WG 2, Chapter 8, section 8.8 "Key uncertainties and research priorities"

The lack of appropriate longitudinal health data makes attribution of adverse health impacts to observed climate trends difficult. Gaps of information persist on trends in climate, health and environment in low-income countries. Climate change related health impact assessments in low- and middle-income countries will be instrumental in guiding adaptation projects and investments. Considerable uncertainties surround projections of health effects of climate change under a range of scenarios.

A better understanding is needed of the factors that convey vulnerability and the changes that need to be made in health care, emergency services, land use, urban design, and settlement patterns to protect populations against heatwaves, floods and storms.

Key research priorities:

- Development of methods to quantify the current impacts of climate and weather on a range of health outcomes, particularly in low-and middle-income countries.

- Development of health impact models for projecting climate change related impacts under different climate and socio-economic scenarios

- Investigations on the costs of the projected health impacts of climate change; effectiveness of adaptation; and the limiting forces, major drivers and costs of adaptation.

There is also a need to strengthen institutions and mechanisms that can more systematically promote interactions among researchers, policymakers and stakeholders.

Gaps identified by McMichael et al., 2004:" Global Burden of Disease due to Climate Change"
This assessment highlighted the most important gaps in data and understanding that should be addressed for the next global burden of disease assessment. Marked improvements in our assessment of the health impacts of climate change would come from:

- investigations on the costs of the projected health impacts of climate change, costs, and effectiveness of adaptation, as well as identifying the barriers and major drivers of adaptation;

- the use of multiple climate models (for health impact assessments);

- analysis of climate–health relationships derived from a greater range of climatic and socioeconomic environments (more research in low income hot countries needed);

- more explicit and routine validation of the accuracy of disease models in the present or recent past;

- formal analyses to aggregate uncertainty in health impact assessments arising from multiple causes (i.e. GHG emissions scenarios, climate models, climate–health relationships, and effect modifiers);

- efforts to formally model climate change effects through to disease burden, rather than intermediate indicators such as population at risk and exposure-response relationships;

- a greater emphasis on investigating the consequences of increased climate variability, rather than gradual changes in mean conditions; and

- the development of analytical tools to assess outcomes acting through more complex causal mechanisms.

Gaps identified in WHO report by Menne and Ebi (2006)
The knowledge gaps identified in this report are summarized in Table 4. While many are similar to those identified in the other reports referred to earlier, the table is included for the reader's convenience. Even such a long list has omitted to mention some issues, though. For instance, the effects of direct heat exposure are not only occurring during 'heat waves", but are, and will be, health threats also during "normal" hot days during the hot season when WBGT exceeds the safe limits for an exposed individual. The potential effects of additional chemical exposures due to a hotter climate are also not mentioned.

Table 4. Knowledge gaps in understanding health impacts of climate variability and change (adapted from Menne and Ebi, 2006)

Subject	Gaps	Audience
Vulnerability and adaptation assessments	- better understanding of weather/climate - health relationships - indicators of early effects - health scenarios - more accurate climate projections - effectiveness of adaptation options - incorporate health into climate effect models - co-benefits on human health of mitigation and adaptation - effective communication of health risks - more adaptation options to reduce vulnerability	Health sector; climate change community; insurance sector; international law; remote sensing communities
Extreme weather events	- better understanding of effects of extreme events - find thresholds for population vulnerability - costs of health outcomes of extreme events and benefits of adaptation to reduce effects	As above plus: economists; international disaster community; civil protection agencies
Heat-waves (should also include "normal" high heat exposure) **Air pollution** (should include other chemical exposures)	- impacts on morbidity, particularly in children - socio-economic and clinical risk factors for heat-related morbidity and mortality - synergies between heat-waves and air pollution and most vulnerable groups - effectiveness of public health interventions and warning systems - lessons learned from community interventions - more effective risk communication - early detection of health impacts - risks and benefits of air conditioning - better understanding of occupational health impacts	Health sector; weather services; insurance sector; energy sector; economists; international disaster community; civil protection agencies
Floods	- flood related morbidity and mortality - impacts of floods on European health care systems - effectiveness of flood early warning systems - costs and benefits of preventing flood effects	Health sector; river related authorities; insurance sector; international environmental law; international disaster community; civil protection agencies
Water- and food-borne diseases	- climate change impacts on domestic water supplies - how do weather and climate affect transmission of pathogens - associations between weather, water quality and health - incorporate climate factors into food safety regulations	Health sector; regulatory agencies; international law
Vector-borne diseases	- quantitative models of vector-borne disease transmission - factors determining geographic distribution of vectors - role of climate in vector-host relationships - new international surveillance networks for existing and emerging pathogens - standardization of methods for vector control - scenarios that incorporate drivers of vector-borne diseases	Health sector; climate change community; international health regulations
Other infectious diseases	- understanding of risks of introduction of new or re-emerging diseases	Health sector; security; international health regulation

Proposed climate change and health research by a recent WHO meeting (WHO, 2009)

The report from a recent WHO meeting in Madrid (October 2008) concerning "Guiding research to improve health protection from climate change" (WHO, 2009) refers to the WHA resolution 61.19, 2008, which called for further research and pilot projects on:

- health vulnerability to climate change and the scale and nature thereof;
- health protection strategies and measures relating to climate change and their effectiveness, including cost-effectiveness;
- the health impacts of potential adaptation and mitigation measures in other sectors, such as water resources, land use and transport, in particular where these could have positive effects for health protection;
- decision-support and other tools, such as surveillance and monitoring, for assessing vulnerability and health impacts and targeting measures appropriately;
- assessment of the likely financial costs and other resources necessary for health protection from climate change.

The meeting report (WHO, 2009) further elaborates the research gaps and mentions mental health consequences, occupational heat strain, heat stress and physiological function, diseases associated with dehydration, heat-sensitive diseases and allergies due to pollen/spores exposure. Each disease issue is described in a similar way to the text in previous sections, but disease-specific research gaps are addressed rather general terms. Major gaps are identified concerning research and assessment methods and data availability. For instance, there are substantial needs to establish "baseline" climate-health relationships as well as the actual impacts of the *change* in climate. The methods to estimate the burden of disease attributable to climate change need to be improved, as well as methods to estimate future health risks based on climate change scenarios. Much of this research is hampered by the lack of useful population based data on climate exposures and the key health variables (WHO, 2009). The report also makes a strong call for applied research that links the health assessments to analysis of the effectiveness of specific preventive adaptation policies/actions and evaluation of the usefulness of decision-support tools.

The draft WHO work plan for implementation of WHA61.19

This draft work plan lists the following priority actions of direct relevance to chronic disease and mental health protection:

- development of tools, guidance, information and training packages to support countries awareness and advocacy campaigns to protect health from climate change at the national and regional level;
- provide the health sector with information, tolls advice in order to enhance their involvement and active participation in national, regional and international mechanisms;
- assess the burden of disease attributable to climate change and project it to the future years using existing and new approaches;
- review and develop methodologies and guidelines on how to evaluate vulnerability to climate change related health effects at local, national and regional scales;
- support and monitor research to improve public health knowledge on the health risks of climate change and on the most effective interventions to manage those risks;
- assess the health impact of adaptation and mitigation policies taken in other sectors and identify the most effective actions which have the potential to benefit health while reducing greenhouse gas emissions;

- identify and develop indicators to monitor climate change related health outcomes within surveillance systems;
- advocate for strengthening of primary health care services to support capacity of local communities to become resilient to climate related health risks.

Research recommendations in the Swedish "Climate and Vulnerability Investigation" report (Klimat- och Sårbarhets-utredningen)

Each sub-section of the health section of the Investigation report includes a short list of recommendations for research. It is of interest to quote the key recommendations.

Concerning extreme heat exposures the Investigation points out that town planning and building technology approaches can be used to reduce heat exposure for the Swedish population in the future. As city designs and buildings have a very long life time, it would be expensive to adjust to a hotter climate in the future if the current designs are sub-optimal. Research on the best designs and energy efficient cooling systems (based on similar concepts as current "distance heating systems") would be useful and short term health impacts could be investigated in intervention studies. There is also a need for research on the best heat stress indicators for the different types of effects that may occur. Temperature is not likely to be enough. How much does humidity influence the risks? How to take solar radiation and wind movement into account? Can workplace heat indices (such as WBGT) be used for general health risk analysis? How important are the peak heat levels as compared to daily averages, daytime averages, night-time averages? Which population groups are most vulnerable in the cultural and social setting of Sweden?

The Investigation states that more research is needed on the combined effects of air pollution and climate in Sweden. Simulation models based on atmospheric chemistry and global climate projections should improve predictions of different climate variables as well as air pollution levels. The release of pollen and emergence of related allergies also needs further studies.

In relation to infectious diseases the Investigation proposes the new methods for rapid sanitation of contaminated drinking water supplies are needed. Methods to adapt storage methods for food in a warmer climate also need to be developed for Sweden. In addition there is a lack of knowledge about the survival of pathogens in the environment at higher temperatures and different aspects of the spread and risk of vector-borne diseases in Sweden.

Conclusions and recommendations for future research in Sweden

This report makes it clear that climate change will be a major challenge to health in many parts of the world during this century. Public health in Sweden will be at risk unless mitigation efforts limit global climate change and adaptation efforts prevent the health impacts from the change that is unavoidable. However, populations in tropical low and middle income countries and island countries with populated land areas close to sea level are at particular risk.

Climate change is a new and important environmental health hazard. The population groups that are particularly vulnerable include poor people, children, chronic and mental disease cases and the elderly. Each country with a strong science community needs to develop the skills and experience to analyse the changing climate, identify the causes for the change (which include global atmospheric change, ecological and land use changes within the country and local heat island effects) and assess the local effects, including health effects, within the country and beyond.

This report has highlighted the potential health effects of climate change and the mechanisms behind these effects. These are quite varied as effects may occur due to several exposures: direct heat exposure, air pollution, extreme weather, additional chemical exposures, infectious agents and disease vectors, lack of water or food, dislocation from usual living location, increased poverty and community disruption.

The health hazards of climate change are truly global threats and the future health research on these hazards needs to incorporate a global perspective. Research by scientists and institutions in Sweden should therefore include studies of vulnerable people in vulnerable countries, in addition to studies of climate change health impacts in Sweden.

The Institute of Environmental Medicine (IMM) at Karolinska Institutet is a national focus for environmental health and medicine research and expertise. It has world class expertise in epidemiology, toxicology, environmental physical factors research, and other special topics within environmental medicine. It is therefore natural that it would take major new initiatives for research on public health impacts of climate change.

The research gaps and other information provided in this report lead to a great number of potential research ideas. A short list of general recommendations for IMM and examples of specific research ideas will be given here, in order to contribute to the creation of a Swedish scientific framework for studies of the health impacts of climate change in Sweden, Europe, tropical developing countries, and the world as a whole. As an example of research recommendations in other countries, a list of proposed research questions developed in Australia is included.

General recommendations for IMM:

A. Develop an IMM research plan for the next three years based on the information in this report and other sources. Incorporate components focusing on health effects in Sweden and Europe, as well as a major section on effects in tropical developing countries. Include cross-cutting issues, such as gender-related health impacts and impacts of health effects on health equity and economic development for the most vulnerable people.

B. Prepare at regular intervals updated reviews of the full literature on relevant research in Sweden and who the researchers in this field are in Sweden, what they do and what they plan.

C. Establish collaboration agreements with relevant research partners; for instance IHCAR at Karolinska Institutet, Stockholm Resilience Centre, Lund University Climate research group, the Umeå University Global Health research group, and other research groups (listed in Appendix 2).

D. Seek funding from MISTRA, Formas, Sida and other sources to implement the research plans.

Examples of climate change and health research questions proposed in Australia (adapted from several recent reports by the Australian National University and government agencies):

1. Which categories of persons, in city, town and countryside, are at greatest risk of death, serious illness or heat strain event (i.e. most 'vulnerable') from extremes of heat and cold? Do levels of understanding of the nature of these risks, and personal/household-level ways to ameliorate them, vary between these population sub-groups?

2. Do early warning systems for heat-waves alter the population's health outcomes (deaths, hospitalizations, temporary disabling symptoms at work or at home)? If so, which warning systems work best? Is this a function of warning-modality, critical 'trigger' temperature, or something else?

3. Can meteorological forecasts of impending seasonal weather conditions provide useful advance warning of altered risks of vector-borne infectious disease outbreaks? Does this differ between human-only and zoonotic VBDs? Are such forecasts enhanced by inclusion of information about changes in environmental indicators (e.g. surface water, vegetation levels, etc.)?

4. What key characteristics of rural communities determine their level of resilience to the stress of long-term changes in climatic and environmental conditions? Which types of intervention most effectively increase the level of resilience?

5. What role can the primary health-care system play in educating families and communities to the health risks from climate change? Which activities are most effective in reducing adverse health outcomes? What additional training/education does the health-care personnel require in order to fulfil this role?

6. How well-equipped/prepared is the hospital system (and associated facilities: ambulance service, etc.) for the heightened spikes in demand that would arise from an increase in climatic variability and the occurrence of weather disasters? What improvements are needed, feasible and effective?

7. In order to reduce mental stress and anxiety about 'global warming' in school-age children, what types of information, education and discussion are most effective – and, for each, at what age-ranges? Do such interventions also lead to changes in child and family behaviours?

8. For occupational groups exposed to periodic extremes of heat in the work-place, what are the most effective protective strategies? Are current heat strain protection guidelines sufficient, and on what basis and time-scale might they need revision in future?

Research ideas for specific areas of this science:
(brief topic headings only; focus on research in Swedish institutions)

Impacts via direct heat exposure

- better knowledge of the way to express heat exposure of relevance to different effects of heat (finding the best heat stress indicator based on temperature, humidity, wind-speed and heat radiation)
- developing methods to estimate such heat stress indicators based on routinely recorded climate data from weather stations
- quantifying heat impacts on daily activities and worker productivity, in order to assess social and economic impacts of increasing heat exposure with climate change
- better understanding of mechanisms behind effects on the kidneys and the cardiovascular system from direct heat exposure, including dehydration effects from excessive sweating
- quantifying epidemiology of such clinical effects in tropical countries

Impacts via increased air pollution

- quantifying the combined impacts of heat exposure and specific urban air pollutants
- forecasting changes in exposure patterns with climate change taking temperature, humidity, cloudiness and wind speed into account

Impacts via increased chemical exposures

- reviewing the evaporation potential of the major toxic chemicals used in industry and agriculture
- quantifying differences in absorbed exposures in different climate conditions
- identifying problems in using chemicals protective equipment in different climate conditions
- occupational epidemiology studies of exposures and effects of chemicals for which increased exposures are forecasted

Impacts via reduced food access

- combine agricultural science and social sciences to assess what impact climate change may have on food availability in different communities of low and middle income countries
- improve the health risk assessment methodologies to forecast these health challenges
- develop intervention approaches to reduce the related health risks

Impacts via extreme weather

- improve the modeling methods for future extreme weather events in Sweden and any other part of the world
- develop health impact assessment methodology that can be used to forecast and prevent the impacts of extreme weather
- assess vulnerability of the health sector infrastructure and the interventions needed to reduce risks

Impacts via infectious and vector-borne disease agents

- create better knowledge about pathways and mechanisms for pathogen distribution and disease causation for all relevant disease agents
- develop methods to identify vulnerability in different population groups and intervention methods (e.g. immunisations)
- record outbreak data and relate these to climate variables, in order to understand any climate-related epidemiology better

Impacts on chronic diseases and mental health

- epidemiological studies of kidney and heart diseases association with climate exposures

- establish any linked causations paths between climate factors and other exposures (e.g. air pollution, nutrition, smoking habits) and the chronic diseases
- study different aspects of mental stress and more severe mental health impacts of climate exposures

Gender differences in impacts
- study differences between men and women concerning how they are affected by any of the health issues referred to above, and how preventive interventions can best be developed

Variability of impacts in different population groups: health equity and vulnerability aspects.
- study differences in vulnerability to climate exposures and climate change between age groups, socio-economic groups and populations in different countries

Links to the IMM work plan (IMMs verksamhetsplan)

According to the IMM work plan 2006-2008, IMM should take a greater national responsibility within the area of physical and chemical environmental medicine, including occupational health aspects. Climate is an important physical environmental factor and research on its effects was, several decades ago, an important part of the activities of IMMs predecessor. Climate change also has important links to the occurrence of allergens and exposure to chemicals in the environment. Epidemiological analysis and health risk assessments are important parts of environmental medicine science activities concerning future climate change. The research in this area needs international links and IMM is well versed in international work in this field. Thus, a number of the research gaps identified above could be the focus of future research at IMM in collaboration with other research institutions in Sweden, Europe, other high income countries and developing countries.

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Appendix 1: *Reports and policies from Swedish agencies*

Klimatberedningen, 2007
http://www.sweden.gov.se/content/1/c6/08/07/79/22c3a4cf.pdf

Svensk klimatpolitik (SOU 2008:24)
http://www.regeringen.se/content/1/c6/09/96/94/8393cd02.pdf

Klimat och sårbarhetsutredningen (SOU 2007:60)
http://www.regeringen.se/sb/d/8704/a/89334
http://www.regeringen.se/content/1/c6/08/93/34/05245f39.pdf
Remiss-svaren finns i Google under titeln ovan

Formas (see Appendix 2)
http://www.formas.se/default____529.aspx
The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning

Forskningspropositionen
Regeringens proposition 2008/09:50. Ett lyft för forskning och innovation.
http://www.regeringen.se/sb/d/10003/a/113957

Stockholm Resilience Centre
http://www.stockholmresilience.org/

Swedish Road Administration, (Vägverket)
Report on the Public health impacts of the Swedish road transport sector (Appendix 3), which includes the first preliminary analysis of the potential global public health impact of greenhouse gases from Swedish road motor vehicles.

Appendix 2. *Current research in Swedish institutions*

A Google search for websites and reports concerning past, current and planned climate change and health research in Sweden found a few items specifically on human health aspects of climate and climate change. In order to present the context, the list below includes the opening text on "climate research" for each major university. Additional information was sought on the web, and in some cases via email contacts.

A more detailed search may find additional research activities on climate change and health, but this was not possible to carry out for this report. The general impression is that this area of research is not well represented in Sweden and lacks a coordination and leadership.

The government reports referred to in the text above contain references to published research reports from Swedish institutions, but not much about ongoing and future research.

Another source of information about past research is the report "Klimatforskning i Sverige, 1998-2001, Stockholm, Naturvårdsverket, Rapport 6264, 2001.".

1. General information on climate research in Sweden

If one enters "climate health research Sweden" into Google, the only meaningful hit concerning ongoing research and specific research institutions in Sweden is the Umeå Centre for Global Health Research (described below). Background information on activities in Sweden is presented in the website of CIRCLE (Climate Impact Research Coordination for a Larger Europe):
http://www.circle-era.net/recent-country-news/sweden/

CIRCLE (Climate Impact Research Coordination for a Larger Europe) Information on activities in Sweden:

Integrated climate and energy bill

On March 17th the Swedish government released their “Integrated Climate and Energy bill”. It focuses on how to reduce emissions so they will have fossil free transportation in 2030, how to reach 50% renewable energy and on information on energy efficiency to households and industry. It also addresses adaptation on a national level.

CLIMATOOLS report

So far, relatively little research has been performed on goal conflicts and conflict resolution in adaptation to climate change. The aim of this new report, produced as part of Swedish research programme CLIMATOOLS, is to provide basic data on what kind of goal conflicts Swedish decision makers will likely have when making decisions on adaptation in the sectors of the built environment, tourism and outdoor recreation, and human health.

Swedish research program on Climate, Impacts and Adaptation (SWECIA)

SWECIA is a new interdisciplinary Swedish research program that will be launched in January 2008. SWECIA extends and brings together disciplinary research on climate, biology/ecology, economics and social sciences. The participating institutes are the Swedish Meteorological and Hydrological Institute (SMHI), Stockholm University, Lund University and the Stockholm Environmental Institute.

21st Century Challenges in Regional Climate Modelling

In May 2009 an international conference on climate modelling and impact studies will take place in Lund. The meeting will cover a wide range of RCM-related topics from basic research to applications such as impact studies in the context of climate variability and change.

Sweden: Climate-related Challenges and Opportunities

In December 2006 the Swedish Government took three steps to broaden and deepen cooperation between business, scientists and politicians by setting up

A Commission for Sustainable Development
A Scientific Council on Climate Issues
A Parliamentary Drafting Committee

It is the Government's hope that these initiatives will make possible a deeper analysis of climate-related challenges and opportunities on which to base conclusions, goals and concrete action.

One of the outcomes will be the Climate Policy Bill which the Government plans to present in 2008. Another purpose behind the initiatives is to enable Sweden to play a leading part in the international negotiations for a new climatic order, which need to take place during the Swedish EU presidency in 2009.

Commission for Sustainable Development

The Government has set up a Commission for Sustainable Development. Raised ambitions in the field of climatic policy call for deeper, more advanced cooperation between business, politicians and scientists. The work of the Commission will be essential to the transformation of Swedish society.

Taking sustainable development as a starting-point, the Commission will encourage cross-disciplinary research, adopting an international perspective and taking ecological, social and economic considerations into account.

The focus of the Commission's work will be climate change. The Commission will have in view in particular the horizon of 2009, the year of Sweden's EU presidency. It will investigate how progress towards sustainable development and environmentally driven growth can be encouraged by the streamlining and modernisation of organisations, regulations and policy instruments.

The Commission will be chaired by Prime Minister Fredrik Reinfeldt, with Minister for the Environment Andreas Carlgren as vice-chair. It will be a broad-based group, comprising representatives of business and autonomous organisations, scientists, civil servants and politicians.

Scientific Council on Climate Issues

The Government has set up a Scientific Council on Climate Issues. Its principal role will be to provide scientific analysis ahead of the Climate Policy Bill 2008.

An important task of the Council will be producing scientific documentation and recommendations for future commitments by the EU and Sweden. In the first instance the Council will recommend the appropriate goal or goals of Swedish climate policy at both national and international levels.

The Scientific Council on Climate Issues will be chaired by Professor Lisa Sennerby Forsse, vice-chancellor of the Swedish University of Agricultural Sciences. Other members have been appointed having specific expertise on climate issues.

The Council is expected to announce its recommendations on new climate policy goals in summer 2007.

Parliamentary Drafting Committee on Climate

All the parliamentary parties have been invited to participate in a parliamentary drafting committee whose main task will be the drafting of the Climate Policy Bill. The committee's directives and chairperson will be announced early in 2007. The Government will aim to achieve a broad political consensus on Sweden's climate policy efforts.

The Swedish Environmental Protection Agency and the Swedish Energy Agency have been jointly commissioned by the Government to prepare documentation ahead of the evaluation of climate policy. Part of this documentation will be handed over in spring 2007 and will play an important part in the committee's initial deliberations.

The committee will have early access to the latest evaluation report from the UN Intergovernmental Panel on Climate Change and other international reports for its assessment of Sweden's efforts.

Another important input will be the recommendations of the Scientific Council on Climate Issues, which will be delivered to the drafting committee.

Swedish Vulnerability Analysis

The government inquiry on Climate and Vulnerability was appointed in the summer of 2005 to map the vulnerability of the Swedish society to climate change and the potential to adapt to it. The investigators will present their proposals in October 2007.

Most of the focus will be on infrastructure (i.e. roads, railways and telecommunication), buildings, energy- and water supply, forestry, agriculture, human health and biodiversity. A specific objective during 2006 is to solve the urgent need for regulation of the runoff from the big lake Vänern and from lake Mälaren.

The vulnerability analysis will be based on climate scenarios from the IPCC and regionalisations of climate change scenarios produced by the Rossby centre at SMHI. A broad cooperation with central, regional and local authorities, representatives from the trade and industry as well as the research community and other organisations, will enhance the analysis and raise awareness amongst sectors. Experiences from activities in other countries regarding vulnerability and adaptation will also be taken into consideration.

2. Information from the Swedish Environmental Protection Agency (Naturvårdsverket)

Report: Sweden must adapt to a new climate: October 3, 2007

Sweden will be greatly affected by climate change. Adaptation to climate change should start now. This is the conclusion drawn by the Swedish Commission on Climate and Vulnerability in its final report. The Commission makes recommendations including increased responsibility for municipalities and county administrative boards and government support for large-scale high-cost initiatives, the Swedish government reports in a press release.

Over 300,000 buildings are in high-risk areas for landslides and erosion. Buildings to a value of SEK 30–100 billion, depending on how the climate develops, are expected to be affected over the next century if no action is taken. Flooding of the built environment may cost over SEK 100 billion.

"The climate scenarios the Commission has produced contain uncertainties, but are sufficiently robust to be used as a basis for public planning", says the Chair of the Commission, Bengt Holgersson.

Swedish nature will undergo change, and ecosystems in the Baltic Sea may change dramatically. The warmer climate will also bring health risks, such as increased spread of infection to both humans and animals. The report, Sweden and Climate Change – Threats and Opportunities, comprises 721 pages and was presented on a press conference held by the Swedish government on Monday. The report proposes the establishment of a new institute focused on climate research and climate adaptation in order to harness efforts in this area.

(I have not been able to find out if this "new institute" was established and if it has any ongoing or planned human health research.)

3. Website information from Karolinska Institutet

The only specific information that describes climate change and health research is the information about the work of Dr Elisabeth Lindgren at the IHCAR department within Karolinska Institutet.

3. Website information from the six largest universities

This is based on searches for the universities in Göteborg, Linköping, Lund, Stockholm, Umeå and Uppsala.

No overall information on climate research was found for Linköping University. The other information is presented below in alphabetical order.

3.1. Göteborg University

(the main item of information was the following)

Mistra idéstöd gave impetus to the climate research

Aerosol particles in the air affect both our health and environment. One of the most important research projects on the subject is at the Department of Chemistry, with support from Mistra developed new methods for aerosolstudier. Our health is adversely affected by breathing in aerosol. You can even make estimates of how the presence of particles shortens our life, and how many hospitals they cause. But exactly what in the particles that cause damage, and how aerosol particles affect the climate, there is great uncertainty about.

Develops new methods

A research project at the Department of Chemistry has been using a idéstöd from Mistra able to develop new analysis and measurement, which increased understanding of aerosol effects. Together with the Technical Research Institute, researchers in the project developed methods to try and determine the chemical content of the particles. The results have been very useful in aerosolforskningen, and the project has helped to develop

the so-called EMEP-model (European Monitoring and Evaluation Program) which is used in the political negotiations at European level.

- "Our results have contributed to the development EMEP to better and safer tools for different particle calculations, which are of great importance because it is the basis for political decisions to be taken on various measures. It is perhaps one of the project's main contributions to the social benefits, "says Hall Quist, associate professor at the Department of Chemistry.

International cooperation

In total, around 20 researchers from Sweden, Switzerland, United Kingdom, Norway, Japan, India and Egypt have been involved in the project. Today, continuing parts of the work of the EPA's research program Scarpa (Swedish Clean Air Research Project). Mattias Hall Quist think Mistra idéstöd been crucial so as to develop their research ideas on the aerosol particles.
- It has given us the opportunity to work with a number of international researchers, and created unique conditions for linking modeling, laboratory and outdoor measurements, "he says.
Idéstödsprojektet Development of application of analytical methods for characterization of organic aerosol highlighted recently by Mistra as an example of successful research projects.

Facts Mistra idéstöd
During the years 2001-2009 have Mistra funded a total of 30 so-called idéstödsprojekt with around 160 million. The aim has been to contribute to the achievement of innovative research projects with great potential for a better environment. A idéstödsprojekt to have strong elements of boldness, originality and creativity. Research should be detection, innovation and / or reviewed. Research may also explicitly challenge or question the established view.

3.2. Lund University

(for this university there was a specific webpage about climate research)

Eleven research areas

Climate Initiative has identified 11 thematic areas in which important, climate-related research conducted in several disciplines and disciplines:

Klimatets storskaliga mönster och dynamik Large-scale climate patterns and dynamics
Atmosfärens och hydrosfärens processer och dynamik Atmosphere and hydrosphere processes and dynamics
Den globala kolcykeln The global carbon cycle
Ekosystem och biodiversitet Ecosystems and Biodiversity
Kuster, havsmiljö och avrinningsområden Coasts, Marine and river basins
Konflikter, sårbarhet och risker Conflicts, vulnerability and risks
Energieffektivisering och hållbar energiförsörjning Energy efficiency and sustainable energy
Avancerade teknologier Advanced technologies
Transportsystem och logistik Transport and Logistics
Policy och strategier Policies and strategies
Innovation och entrepenörskap Innovation and entrepreneurship

(if we follow the page "Konflikter etc." One gets the following text)

Conflicts, vulnerability and risks

New, effective management tools will be needed to combat but also for the adaptation and management of climate change. Therefore, opportunities and needs for economic and national and international regulatory beforskas, coupled with conflict and risk analysis. Research at Lund University include:

Synergies, trade-offs, conflicts and international security issues in relation to the policy of adaptation, migration and international law

Risks, crises and disasters from the social, cultural and technological perspective

Conflicts in relation to the allocation of ecological resources in relation to climate change

Health and vulnerability in developing countries

Theories concerning the interpretation and practice in relation to risk and rationality

At Lund University there is research on climate exposures and health carried out in the Thermal Environment Laboratory (Professor Ingvar Holmer and colleagues) on different physiological and ergonomic aspects of climate and air pollutant exposures in experimental exposure chambers. This research team is also closely involved in the international development of standards for climate variable exposures. There is also research in the Department of Occupational Medicine on the kidney disease epidemiology among heat-exposed sugar cane cutters in Central America.

3.3. Stockholm University

Climate and environment

Climate research follows two main tracks: commercial researchers analyzing sediments, land ice and other natural climate archives for the understanding of natural climate changes, and students study the climate processes that are now underway and the human impact on climate. Environmental research spans a wide field. From global issues related to sustainable development, water resources and transboundary environmental pollution of the Baltic Sea environmental problems and ecology to environmental toxins in our surroundings and nature.

Stockholm University has the most complete climate research environment in the country. Here are the leading international research on, inter alia, the Arctic climate development, aerosols and CLOUD, and if the last glacial cycle. Leading international environmental research includes in ecosystem dynamics and management, landscape ecology, water resources, impacts of algal blooms and research focused on environmental pollutants in air, water and food.

(at Stockholm University, the Stockholm Resilience Centre is presented as the main focus for climate research)

About Stockholm Resilience Centre

The Stockholm Resilience Centre is a new international centre that advances transdisciplinary research for governance of social-ecological systems with a special emphasis on resilience - the ability to deal with change and continue to develop. The Stockholm Resilience Centre was established on 1 January 2007.

Centre goals

The aim is to create a world-leading transdisciplinary research centre that advances the understanding of complex social-ecological systems and generates new and elaborated insights and means for the development of management and governance practices.

It is a joint initiative between Stockholm University, the Stockholm Environment Institute and the Beijer International Institute of Ecological Economics at The Royal Swedish Academy of Sciences. The centre is funded by the Foundation for Strategic Environmental Research, Mistra.

The Centre for Transdisciplinary Environmental Research (CTM) at Stockholm University and The Baltic Nest Institute (former MARE) are also part of the Stockholm Resilience Centre.

The FORMAS-provided project Resilience and Sustainability: Integrated Research on Social-Ecological Systems, is an acknowledgement of Stockholm Resilience Centre also being a Swedish Centre of Excellence.

Building a unique transdisciplinary research environment
In June 2006 Mistra decided to invest 205 million Swedish crowns (22 million Euros, or close to 30 million USD) in the creation of the Stockholm Resilience Centre.

Mistra´s grant will be distributed over a period of 12 years: 2.7 million Euros during a three year start-up phase (2007-2009), and then 8.7 million Euros during the coming four years (2010-2013). After that, an evaluation will be conducted before the remaining 11 million Euros are handed out. All in all, the Institute´s yearly budget is expected to be 4.8 million Euros once it is up and running.

The aim is to create a world-leading transdisciplinary research centre that advances the understanding of complex social-ecological systems and generates new and elaborated insights and means for the development of management and governance practices. The new centre will advise policymakers from all over the world, and develop innovative collaboration with relevant actors on local social-ecological systems to the global

3.4. Umeå University

Climate Impacts Research Centre (CIRC)

Climate Impact Research Centre (CIRC) undertakes research on how climatic and environmental changes are impacting the environment in the north. CIRC is part of the Department of Ecology and Environmental Science at Umeå University and stationed year-round in Abisko, Kiruna municipality.

The sub-arctic environment is diverse, relatively untouched by man, and sensitive to climatic and environmental changes. Research on the environment in the north can thus provide important answers to the questions of how the environment will react to future climatic changes and environmental impacts.

Umea Centre for Global health research

(this research involves five themes):

Theme I: Epidemiological Transition
Theme II: Life-course Perspective
Theme III: Strengthening Primary Health Care
Theme IV: Gender and Health
Theme V: Climate Change and Health

Theme V: Climate change and health
The increasing global concern around climate change and its possible effects on health has led us to introduce a new research theme in this area. As a springboard for developing this new ‘Climate change and health’ theme, we held a one-day conference in November 2008 to bring together interested researchers from within Umeå University’s Medical Faculty.

Research proposals are currently being developed and we have issued a call for papers for a theme issue of our open access journal, *Global Health Action*. Research conducted within this theme is

intended to fill the knowledge gap with regards to links between climate change and health, focusing particularly on non-communicable diseases and aging populations, and health sector responses in low-income countries.

Recent developments: The links to the centre's collaboration with the INDEPTH network (International Network for the Demographic Evaluations of Populations and Their Health) will provide a basis for field study collaboration with tropical low income countries of different aspects of climate change and health.

A seminar in November 2008, titled "Towards a global health research agenda on Climate Change and Health" highlighted the different elements of the growing research program in this Centre. (copies of the abstracts of papers at the seminar can be requested from Maria.Nilsson@epiph.umu.se).

The elements include:

Infectious diseases, vector-borne diseases (e.g. Puumula virus in North Sweden), Tularemia, Meningococcal disease, Air pollution and heat, High ambient temperatures, Links to INDEPTH network, and general aspects of climate and public health.

3.5. Uppsala University

(the main item of information was about the following new research support initiative)

Skype Founder supports climate

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The man behind Skype, Niklas Zennström, donates 15 million for climate research at Uppsala University.

The money will be used to link the world's leading researchers to the university. It is of course no coincidence that Niklas Zennström chosen to donate money through his family and one and half years old charity Zennströms Philantropies, founded together with his wife Catherine Zennström, to just Uppsala University. Niklas Zennström read himself physics and economics at Uppsala, where he grew up.

- "I have for some time had a view that I want to help universities that have meant a lot to me. We have had a dialogue and come to the conclusion that this is the right thing, "says Niklas Zennström.

Zennström Philantropies donated money to two international environmental organizations, but also supported the project for human rights. It was the former U.S. vice president Al Gore who opened the eyes of Niklas Zennström that something must be done about the global environment and the urgency.