What is dangerous climate change?

Initial Results of a Symposium on Key Vulnerable Regions Climate Change and Article 2 of the UNFCCC

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Organizing Committee
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INTRODUCTION

This report outlines initial results from an international Symposium on “Key vulnerable regions and climate change: Identifying thresholds for impacts and adaptation in relation to Article 2 of the UNFCCC[1]”, which was held, 27-30 October 2004 in Beijing, China (see: www.european-climate-forum.net/events).

The aims of the Beijing Symposium were to take a risk assessment approach to:

- Identify the projected effects of climate change in a selected set of regions with respect to the question of tolerable limits to climate change within the framework of a consideration of Article 2 of the UNFCCC.

- Stimulate scientific and political discussion and a dialogue in relation to tolerable levels of climate change and in particular as to what might constitute dangerous levels of climate change, or more technically dangerous anthropogenic interference with the climate system, within the framework of Article 2 of the UNFCCC.

The question of what may be dangerous levels of climate change is a critical issue which cannot be addressed without an in depth debate and dialogue between scientists, policy makers and society. Indeed, it was repeatedly noted at the Symposium that policy makers urgently need the support of the research community in structuring the debate and interpreting dangerous levels of climate change. The findings of the Symposium will hopefully contribute to this debate.

The regions selected for the Symposium were weighted towards developing countries and highly vulnerable regions, including China, Sahelian Africa, the Maghreb and North Africa, Southern Africa, South Asia (Indian subcontinent), North-West and Central Europe, the USA, Amazon, Andean Region, Russia, High Arctic Region, and Small Island States of the Pacific and Caribbean. Although it was not possible to include all such regions or all issues relevant to each region considered due to time and resource constrains, we believe that the selected regions cover many of the key vulnerable regions, according to the present knowledge about climate change.

At the beginning of the Symposium a number of cross-cutting issues were outlined at the global level and included health, global agricultural and ecosystem impacts, implications of increases in magnitude and frequency of extreme for sustainable development, legal aspects and interpretations of Article 2, as well as the risk of rapid or abrupt changes in the climate system, the risk of ice sheet decay and consequent sea level rise. For each region presentations and papers were given on ecosystems, food production and sustainable development by scientists and were commented on by stakeholders.

In this report we present a summary of some key overall conclusions, regional vulnerabilities and climate system risks discussed and identified during the Symposium. The summaries are located at the beginning of report and more detailed background information on the regions considered and climate system risks associated later in the document. Further publications based on the papers at the Symposium and the discussion there are planned and will elaborate on these areas and on the cross cutting issues mentioned above.

The report has been written based on the work of the Rapporteurs and Participants in Beijing and has been through several rounds of review amongst the participants, many of whom provided detailed comments and suggestions that we hope have been fully incorporated. The detailed contributions in the regional summaries and background material were contributed largely by the participants in each region as listed in the participants list. As a consequence we hope that the report reflects the views of the Symposium participants – remaining errors and inaccuracies are the responsibility of the small team assembling the report between Beijing and UNFCCC COP10, in Buenos Aires. An electronic version can be downloaded from the European Climate Forum Web site and translations into several languages of the summaries will also be available from the same location.

[1] Article 2 states that “The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.”

KEY MESSAGES

Concepts of danger

Many of discussions at the Symposium were focused on the question of what impacts identified might be dangerous, to what and to whom and over what timeframe. There was no attempt made to draw final conclusions on the subject but several ideas, concepts and potential limits emerged in the discussions at the Symposium. This section attempts to describe these in the spirit of putting these forward for further debate by the scientific and policy community.

From the discussion at the Symposium at least three distinct, but not necessarily mutually exclusive, concepts of danger emerged:

(1) **Determinative** dangers that may be sufficient on their own to define dangerous levels of climate change with respect to Article 2. The table below lists in its left hand column a list of indicators of dangers that could be determinative. These include dangers from catastrophic events whose effects may be felt in the distant future that will become inevitable without early action, e.g. sea level rise of several metres over the next for 300-500 years. The Symposium did not attempt to agree on dangers that are strictly determinative and the ideas put forward below are a reflection of different viewpoints.

For example a 3°C global warming above pre-industrial levels appears likely to cause a 3-5 meter sea level rise increase by 2300. Such a sea level increase would cause the widespread loss of coastal and deltaic areas such as Bangladesh, the Nile, Yangtze and Mekong Delta regions.

Collapse of the North Atlantic thermohaline circulation would have substantial adverse consequences in Europe for fisheries, ecosystems and agriculture and also generate adverse effects according to recent studies in India, Africa and Latin America. A new, systematic expert elicitation (analysis of scientific opinion) indicates that a complete collapse cannot be ruled out and the probability for this is seen in the range of a few percent for low warming projections (1-3°C), but may increase to above 50% for 4-5°C warming above pre-industrial.

Other indicators in this table such as the loss of cultures or unique ecosystems do not have the broad global risk element of the catastrophic changes but appear to be potentially determinative. For example, does one say that the loss of ten unique ecosystems matters more than the loss of one for the purposes of defining dangerous under Article 2? Other indicators in this table such as food security may depend for their determinative significance on the scale of the risk. In the right-hand column are listed examples of impacts or risks that are associated with each of the potential determinative indicators.

(2) **Early warning dangers**. These are often already clear and present in limited places, and are likely to spread and increase in severity with increased warming. On their own these may not be sufficient to be defined as dangerous with respect to Article 2 but when taken together with other dangers could do so. In some cases if the severity were to increase beyond some point these could also become determinative. Examples include arctic sea ice retreat and boreal forest fires, or increasing losses from extreme events and recent increases in drought frequency.

Climate changes are already experienced and are already causing disruption to ecosystems and human societies. There is increasing evidence that present extreme climate events can be attributed to human-induced climate change to a large degree rather than mere climate variability. For many affected by such changes these effects may already be dangerous.

(3) **Regional dangers.** These are often large risks at a regional level in relation to food security, water resources, infrastructure or ecosystems and species. These may be dangerous for individual regions but may not be determinative in relation to Article 2 from the point of view of other regions.

The Symposium could not cover all issues relevant to a discussion of what might be dangerous climate change and this paper could not cover, in the time available between the Symposium and COP-10, all of the issues raised in the Symposium (health issues in particular have not been included). Nevertheless very many key issues were covered and, it seems clear conceptually that if there are issues identified here which are viewed as determinative on their own (or when taken together with other issues) in relation to defining dangerous climate change the absence of other key issues from the analysis means only that the findings here may establish an upper bound on dangerous levels of climate change. Determinative indicators of danger would be sufficient on their own to define dangerous. Some examples of indicators or risks that could be defined as determinative include:

- A 3-5 metre sea level rise over several centuries. It was estimated that a sustained global mean 3°C warming above preindustrial over the period to 2300 could produce a sea level rise in this range. From the point of view of Article 2 of the UNFCCC, which is about prevention of dangerous levels of climate change, this would imply that global mean temperatures would need to be limited well below 3°C in order that such a sea level rise would be prevented from occurring.

- Significant risks to food production regionally, with varying degrees of severity, are indicated for South Asia, southern Africa and parts of Russia by the time global mean warming reaches the range 2-2.5°C above pre-industrial. For higher temperatures the risks appear to grow in China, Africa and Russia, although it is very hard to ascribe a probability to the risks. Risks in China for example appear to be severe if CO_2 fertilization of crop production is low but small to modest if CO_2 fertilization is high. Avoidance of the risks to food production identified for the 2-2.5°C warming range, if defined as dangerous in relation to Article 2 of the UNFCCC, implies that global mean temperatures would need to be limited below this level of warming.

- A number of ecosystems and endemic species have been identified as subject to the risk of substantial damage or extinction for warming levels in the range of 1.5-2.0°C in Australia. These include parts of the Great Barrier Reef, the Alpine region of south eastern Australia and endemic fauna and flora in the wet tropics of North East Queensland. If these risks to ecosystems, which appear to be beyond their capacity to adapt naturally as defined in Article 2, are defined as dangerous, global mean temperatures would need to be limited in the long run to below 1.5-2.0°C range.

The examples above, if defined as determinative and hence sufficient to define levels of climate change that would constitute dangerous anthropogenic interference with the climate system under Article 2 of the UNFCCC, imply the need to limit global mean warming to levels that would prevent the projected impacts or avoid (or reduce to 'acceptable levels') the indicated risks.

Key characteristics of climate impacts

In addition to the specific climate impacts that were discussed by the Symposium's participants under the above three impact categories, the Symposium covered some general characteristics of climate impacts and key vulnerabilities in relation to Article 2 of the UNFCCC, including the following:

- Climate change can act synergistically with other changes and processes caused by human activity that can bring systems to critical, irreversible thresholds well below levels of warming at which impacts of climate change alone might be destructive. Examples include the Inuit in the Arctic region, the pressure on pastoralists in the Sahel, and the interaction between population pressures, flooding, sea level rise climate change in Bangladesh, and the potential interaction between deforestation and climate change in the Amazon region.

- Increases in extreme events (tropical storms, flooding rain, increase drought frequency, increased variability of the Monsoon, more extreme heat waves) appears to be one of the major threats to sustainable development arising from climate change in some regions. Whereas the private sector can often insure against losses (as long as re-insurers stay in the market), governments must pay for emergency services and lost tax revenue after natural catastrophes; and, individuals bear the brunt of unanticipated impacts on their livelihoods.

- The economic costs of climate change often fall disproportionately on the poor. It was argued that to be poor in a world experiencing rapid climate change could be a dangerous position to be in. Significant changes are to be expected, increasing the North-South gap, because developed countries are largely projected to experience positive agricultural effects for warming up to 2-3ºC, whilst developing countries are confronted with damages in an earlier stage.

- Changes in the climate system that could lead to positive feedbacks such as the release of soil carbon from warming soils and that threaten the ability to limit warming to some level could be dangerous. In other words, impacts that lead to a loss of ability to "control" the warming could be dangerous.

Indicators	Examples of impacts or risks
Circumstances that could lead to global and unprecedented consequences.	Shutdown of the North Atlantic ocean thermohaline – scientific opinion indicates a probability a few percent for 1-3°C global mean warming above preindustrial, which may increase to above 50% for a global mean 4-5°C warming above pre-industrial. Collapse of the West Antarctic Ice Sheet raising sea levels some 5-6 metres. This could be triggered if ice shelves fringing the ice sheet collapse which could be occur with a global mean warming of around 2.5-3°C above preindustrial Projected climate change could trigger a collapse of the Amazon with Savannah replacing the forests with a global mean warming in the range of 2-3°C above preindustrial as predicted by one climate model. However, the probability of this dangerous event is not clear. Synergistic interactions with the effects of forest clearing and fragmentation could flip the ecosystems of this region from forest to savannah and to desert in parts of North-eastern Brazil. Some indications that these interactions are already being detected. Biodiversity, human livelihoods, and economic development consequence would be enormous.
Extinction of “iconic” species or loss of entire ecosystems.	Australia a 1.5-2°C increase in global mean temperature above preindustrial threatens species and ecosystems in the Alpine region, coral reefs on the Great Barrier Reef and World Heritage Rainforests and tropical wetlands. Europe – For a global mean warming beyond 1-2°C above preindustrial species composition will change drastically and, especially in the northern areas, entire ecosystems will be modified, with a substantial risk of species extinctions. Russia - Polar bears at the northern edge of Russia, Snow leopards in the high mountain areas of the Altai-Sayan region are endangered and adverse effects on migratory bird populations on the Eurasian continent are expected. Arctic - The projected loss of summer sea ice projected for a global mean warming of roughly 2.5°C above pre-industrial levels will push Polar bears, walruses, some marine birds and certain types of seals to extinction, and species on land currently adapted to the Arctic environment, like lemmings, arctic foxes and snowy owls, are at risk. USA - Cold temperate forests at risk for a global mean 2-2.5°C warming above preindustrial, coastal wetlands and tundra for slightly higher levels of warming Southern Africa – a global mean warming roughly 2.4°C above pre-industrial levels results in a projected ~25% loss of endemic plant species in the southern-most regions by the 2050s.
Loss of human cultures.	Inuit, Arctic – destruction of the traditional Inuit hunting culture is endangered is very likely if warming continues with substantial difficulties already being reported.
Water resource threats	Western China – Water security in the dry season would be jeopardised as a consequence of glacial retreat and well before complete loss of glaciers which is anticipated by 2100 for a global mean warming of around 2.5-3°C. California - a 30-70% loss in snow pack for a 2.3°C increase in global mean temperature suggesting a loss of 13-30% of California’s water supply in the absence of massive increases in water capture and storage capabilities. Peru – loss of glacial fed water supply affects food security and power generation (in Peru almost 70% of power generation is hydro-electric). El Nino linked decline in rainfall and increase in the frequency of drier years is already leading to water shortages in Lima and further rainfall declines are projected. Major problems are foreseen related to drinking water, energy generation and agriculture and it is not clear that economically feasible adaptation options exist. Africa Maghreb - All climate change projections indicate a decrease of precipitation, in some cases up to -40%, by the 2050s compared to 1961-1990 levels for a global mean warming of 1.8-2.6°C above pre industrial. Australia – south west has experienced an abrupt decline in rainfall that appears to have an anthropogenic component although the size of this is not certain compared to natural variability.

Indicators	Examples of impacts or risks
Loss of sovereignty as a consequence of sea level rise.	Small island states and countries with large low lying deltaic regions (Bangladesh) could be at risk of large loss of area
Substantial increases in mortality levels.	Many regions - Increased intensity and duration of heat waves.
Loss of food security.	Indian subcontinent - A significant risk was identified associated with a global mean warming of about 2.6°C (above preindustrial) and a –20% precipitation change. A 2°C increase in surface air temperature would decrease wheat yields in most of South Asian countries. At a global mean increase of 3 to 4°C above pre industrial there is a projected loss in farm level income of between 9% and 25%. China - a 2.5–3°C increase of global mean temperatures over pre industrial levels, rice yield could be reduced by 10-20% under worst case assumptions on CO2 fertilisation and in the best case ranges from a 10% loss to a 20% increase. Sahelian Africa - Dry conditions are projected to strongly increase under global warming in the current century with a likely breakdown of coping strategies leading a ‘dangerous’ situation with reduced food security, increased poverty and vulnerability. Southern Africa – a global mean 2-2.5°C warming over pre industrial levels could be associated with a significant increase in the risk of commercial crop failure. In some regions fish provides a major source of protein and a similar increase in temperature sharply increases the probability of exceeding the critical temperature at which fish populations decline. In the case of Malawi, this could virtually eliminate the primary source of protein for almost 50% of the population. Russia –doubling of the frequency of bad years after the 2020s and even a tripling after the 2070s is projected for warming above 2°C indicating higher probability that several parts of the main crop export regions could experience poor harvests in the same year. This could lead to significant inter-regional political tensions. By the 2070s, an increase in annual average temperature by 3.3–6.3°C above 1961-1990 (around 3.5°C above pre-industrial) is projected to bring a 5-12% countrywide drop in production and a 14-41% reduction in the main agricultural regions.
Large scale displacement of people (climate refugees).	Mediterranean Maghreb and Sahel region - if climate conditions continue to deteriorate impacts might not stop at the regions’ boundaries, with potential for more pronounced water conflicts and risk of climate change induced refugee flows to Europe from the region.
Exacerbation of regional disputes and conflicts, for example over water rights	A number of different regions have the potential for more pronounced water conflicts with neighbouring regions (i.e. transboundary issues in the Nile and in many shared aquifers) however it is not clear as to the relative role of climate change in relation to other main factors.
Large scale damage to infrastructure and threat to human lives	Caribbean region from increased intensity of tropical storms and extreme precipitation events Himalayan region - Further warming will considerably increase the risk of glacier lake outburst floods (GLOF) in the Himalayas Andes - Massive loss of glacial area and volume below 5,000 metres with negative consequences for hydropower, increased seasonality of river flows with adverse consequences for human activities projected if warming continues with glacial outburst floods threatening existing infrastructure. Small Island States - Recent analyses suggest extreme events have increased both in frequency and severity in tropical SIDS regions in the last few decades.

SUMMARY OF KEY REGIONAL VULNERABILITIES

China

The dominant climate impacts on Chinese society include the risk of droughts and flooding. Climate model projections show drought to increase in the northwest, while rainfall might increase in the southeast, both in accordance with the observational records. As 60% of streams and rivers in western China depend on glacial melting for water supply, water security in the dry season will be jeopardised some decades before these glaciers disappear. These glaciers are expected to have largely disappeared by the year 2100.

For a 2.5-3°C increase of global mean temperatures above pre industrial, rice yield could be reduced by 10-20% by the 2080s under worst-case assumptions on CO_2 fertilisation. However, for an optimistic projection of CO_2 fertilisation, yields could change by -10 to + 20%. A general increase in agricultural water demand and in soil drying is projected to lead to reduced yields in the north and northeast, with opposite patterns in the south. In the north substantial adaptation measures will be needed to maintain sustainable development in the region.

Sub-regional scale studies show that all forests tend to shift northwards. Coniferous forests will disappear, while in other parts of the country tropical forest and woodlands are introduced. Sea level rise might pose a problem for low-lying cities such as Shanghai.

Sahelian Africa

The past three decades of drought in the Sahel region have stretched the coping capacity of society and nature. Dry years lead to strongly reduced food security, increased poverty and vulnerability. Dry conditions are projected to strongly increase under global warming in the current century, which would exacerbate the existing problems. A breakdown of coping strategies when overstretched by increased drought leads to what can be classified as a ‘dangerous’ situation. Environmental pressures can boost the drive for regional and intercontinental migration.

The main effects of the observed and projected rainfall deficit on west Sahelian African eco-systems include the disappearance of grass cover on the majority of the area, disappearance of trees including acacia, decrease of underground (phreatic) nape, decrease of biodiversity with disappearance of many flora and fauna species, reinforcement of the sandy movement (shifting sands), and reactivation of some immobilized dunes.

Australia

Many Australian species and ecosystems are threatened by increases in temperature of 1-2.5°C global mean temperature above pre industrial due to narrow geographic ranges, low relief, and ongoing environmental stresses from other sources such as habitat clearing. Several ecosystems identified as being under more immediate threat at the lower end of this temperature range including the parts of the Great Barrier Reef, alpine regions, coastal wetlands and the fauna and flora in the wet tropics of North East Queensland.

Australian water resources are already stressed and vulnerable to regional reductions in rainfall combined with warming, some of which may be related to anthropogenic warming.

The projected increase in the intensity and frequency of extreme events such as fire and drought will have substantial biological and economic impacts.

Southern Africa

The number of people in the region that is affected by climate-change impacts is large. Climate change is an important additional stress on the agricultural and fishery sectors, in particular at the community level. The key drivers of food security in the region are water availability and agricultural practices, and increases in drought frequency or intensity would adversely affect food security. The numbers of drought-affected people in the region has grown from close to zero in the 1970s to around 35 million in 2000, and periods of drought are projected to become more frequent in the future.

By the 2030s much of the continent is projected to suffer from severe water shortages, with estimated water availability declining to under 2,000 m3/capita from about 7,000 m3/capita in 1950. During the reduction in water resources over the last 40 years, the commercial agricultural systems have proven to be more resilient than communal systems. However, the temperature and precipitation changes as projected for the 21st century will especially affect newly introduced commercial crops like Maize, while traditional crops like Millet and Sorghum are more resilient. Crop failure probability could be as high as 80% under around 2.5°C global-mean temperature increase above pre-industrial. There appears to be a twin risk that increased drought and warming could cause significant problems for both commercial Maize and Fruit agriculture and subsistence farmers.

Inland fisheries in natural lakes and large reservoirs contribute significant amounts of protein intake, particularly in the Zambesi basin states and the East African Great Lakes states. Recent data indicates that global warming leads to a reduction in the productivity of pelagic fisheries, as indicate in Lake Tanganyika and Lake Kariba. The mean temperature change of a few degrees sharply increases the probability of exceeding the critical temperature at which fish populations decline, due to blooming of blue-green algae. In the example of Malawi, this virtually eliminates the primary source of protein for almost 50% of the population.

Regarding ecosystems, the expected rate of climate change will be too fast for the adaptive capacity of the semi-arid ecosystems especially in topographically flat landscapes in the biodiversity hotspots, leading to a projected ~25% loss of endemic plant species in the southern-most regions by the 2050s for a global mean warming of roughly 2.4°C above pre-industrial levels. Rangeland production may be reduced, but projections due to the fertilizing effect of rising atmospheric CO_2 are uncertain.

South Asia (Indian subcontinent)

The ecological and socio-economic damage of climate change in the region will have disastrous consequences, cause social unrest and environmental refuges. Economic development in the region, which is currently growing rather rapidly, appears unlikely to benefit over 60% of the population in this region due to poor adaptive capacity.

For each 1°C increase in night time temperature, the decline in rice yield would be about 6 to 10% on an average in the South Asian countries. The CO_2 fertilization effects would not be able to offset these negative impacts. The average change in wheat yields in South Asia would range between +4 to -34% for the mid-21st century under projected increases in global mean temperatures of 3 to 4°C above pre industrial. Under these scenarios, the yields in non-irrigated wheat and rice will significantly decline in South Asia incurring a loss in farm level net revenue of between 9% and 25%. A significant risk was identified on the time scale of 2030-2050 for a warming of about 2.6°C with –20% precipitation change.

The risks of flooding will considerably increase in the main river basins of India, Bangladesh and Nepal. In Bangladesh, a rapid shift in extent and depth of flooding will occur in case of a rise in global mean temperatures of 2.6°C above pre industrial. Sea level rise will cause severe damages to ecosystems, agriculture and water resources especially in the coastal regions of Bangladesh and India. Widespread deglaciation in the Himalayas is likely to adversely impact the hydrological regime of the region.

North-west and Central Europe

An increase in temperature will have negative impacts on biodiversity due to massive shifts of species and the risk that species will not be able to migrate fast enough. An abrupt shutdown of the thermohaline circulation systems would have significant effects.

Substantial loss of wild species and ecosystems could occur locally, especially in Southern parts of Europe reaching a level of up to 60% in 2100 at a warming of 3°C above pre industrial. Species compositions will change drastically and especially in the northern areas entire ecosystems will be modified in terms of their species composition for warming beyond 1-2°C above pre industrial. The EU target of protection and preservation of ecosystems and species may be impossible to achieve if mean temperature continues to rise as predicted.

A decrease of the strength of the Atlantic thermohaline circulation is considered likely. According to a systematic expert elicitation a complete collapse cannot be ruled out; the probability for this is seen in the range of a few percent for low warming projections (1-3°C), but according to some experts the probability may increase to above 50% for 4-5°C warming above pre industrial.

Maghreb and North Africa

In the Maghreb and North Africa climate is an essential component of the natural capital. Climate in the region is among the most variable of the world and recurrent drought problems often affect entire countries over multi-year periods and often result in serious social problems. Many areas face recurrent severe drought problems that result in water scarcity and stress and low quality. Over the last three decades spring rainfall has decreased in many areas of the region exacerbating the severe problems associated with drought. This rainfall decrease is consistent with projections of future climate. The intensive demand of water for agriculture contributes to the conflicts among water users and transboundary water disputes. On top of this, projected climatic change, especially precipitation decreases, further increases in variability and the increase in drought episodes, would hit the region severely. All climate change projections indicate a decrease of precipitation, in some cases up to -40%, by the 2050s compared to 1961-1990 levels for a global mean warming of 1.8-2.6°C above pre industrial

Water conflicts in the region are receiving increasing attention as the concerns of climate experts begin to encompass the realities of current and future water availability. Effective land use and water management policies are often in conflict with policies that aim to stabilize the rural population to avoid migration to cities and contribute to unemployment.

USA – Ecosystems and California

Ecosystem risks were reviewed for the USA as a whole and a case study of impacts on water, agriculture, health and ecosystems for California was presented.

Some impacts are closely linked to temperature, such as loss of snow pack and subsequent water resource risks, heat stress, and some agricultural impacts, for example on the wine industry, but with significant regional differences. Others are linked to changes in ENSO, projections of which are uncertain, although it seems clear that an increase in ENSO events combined with sea level rise would exacerbate coastal storm surge risks. Wildfire risks are very likely to increase and interact with development patterns.

For some ecosystems, which are already close to critical climate related thresholds such as permafrost landscapes in Alaska or High Mountain areas and coastal areas, climate change in the next few decades may provide early warning of “dangerous” levels and rates of change. Small warming levels will be very damaging or even catastrophic to these sentinel ecosystems. Cold temperate forests such as maple are at risk for a 2.3°C global mean temperature increase above pre industrial, coastal wetlands and tundra for slightly higher levels of warming,

For California, a 30-70% loss in snow pack is projected by 2100 for a 2.3^{o}C increase in global mean temperature relative to pre industrial. Snow pack supplies 40-45% of California’s agricultural and urban users, suggesting a loss of 13-30% of California’s water supply in the absence of massive increases in water capture and storage capabilities.

Amazon

The Amazon region can be categorized as a region at great risk from climate change. The risk is not only due to projected climate change but also through synergistic interactions with existing threats not related to climate change, such as land clearance, forest fragmentation and fire. Over the next several decades there is a risk of an abrupt and irreversible replacement of forests by savannah with large-scale loss of biodiversity and loss of livelihoods for people in the region.

Changes in El Nino as a consequence of climate change is a concern for the Amazon region. There are huge impacts on the economic side related to strong El Nino events and an increase in these events would have adverse consequences. There is significant uncertainty in projections of the El Nino response to climate change; nevertheless, more frequent or intense El Nino events will have tremendous deleterious effects on natural sites and bring large economic losses.

Andean Region

High mountain ecosystems and economic activities at high altitude, or (those depending on) high altitude systems, are very vulnerable to climatic warming. Higher sea surface temperatures in the tropical Pacific are expected to lead to rainfall declines on the western slopes of the Peruvian Andes. With human population pressures and increasing demands in the region substantial dangers to water resources are predicted. At present it is not clear that economically feasible adaptation options exist, with the transport of water from the eastern slopes of the Andes being prohibitively expensive and likely to create problems in that region as well.

In the next 20-30 years there is expected to be a massive loss of glacial area and volume below 5,000 metres with negative consequences for hydropower, increased seasonality of river flows with adverse consequences for human activities. Glaciers below 5,500 metres are projected to disappear within 10-20 year timeframe if recent climate trends continue.

The five Andean countries of South America are especially vulnerable to El Niño events. Increases in extreme events such as flooding, cold surges, droughts, and extreme El Niño related phenomena have been observed and are consistent with projected changes and are expected to increase in the future, with significant risks of economic losses.

Russia

Russia is likely to face temperature increases significantly above the global average, especially in the high latitude arctic regions. While some regions, especially the arctic regions, are likely to face increased precipitation, drought frequency is likely to increase in regions with current agricultural production, including West Siberia and North Caucasus. Under climate change some regions may experience a doubling of the frequency of bad years after the 2020s and even a tripling after the 2070s. Because much of Russia is dependent on the crops produced in these few regions, the effects of drought will be felt throughout the country. Total agricultural production in Russia will peak at a level of 1°C-3°C local temperature increase**.** By the 2070s, an increase in annual average temperature by 3–6°C relative to 1961-1990 will bring a countrywide drop in production, ranging from 5 to 12 percent. and about 14 to 41 percent in the main agricultural regions. Given the likely diverse patterns of potential benefits and adverse impacts on crop production, inter-regional political tensions are likely (i.e. some regions may restrict exports, on which other regions vitally depend).

Some changes in ecosystems can already be observed as a consequence of stress which is attributable to current climate changes, e.g. in the Altai-Sayan Region. With potentially high temperature increases, especially in the high latitude northern regions and in mountainous regions (+4°C and more by 2100 in the north), ecosystem resilience is likely to be challenged beyond its adaptive capacity. Forest fires are projected to increase in frequency and intensity. Polar bears at the northern edge of Russia are among the key endangered species along with snow leopards in the high mountain areas of the Altai-Sayan region. Beyond its geographical boundaries, ecosystem changes in the Siberian tundra will affect migratory bird populations on the Eurasian continent.

Already observed extreme events, such as heat waves in Moscow, are likely to be further enhanced in the future. In conjunction, the accompanying serious impacts on human health will rise. Furthermore, vector-borne diseases are likely to spread northwards.

Arctic

The Arctic Region is experiencing profound environmental, social and cultural impacts of human-induced climate change now. Future impacts will be particularly intensive and will endanger not only animal species but also aboriginal cultures (See recently released key findings of the Arctic Climate Impact Assessment: http://www.amap.no/acia/index.html). A global mean warming of 2.5°C will correspond to much higher Arctic temperatures (roughly between 3.5 and 5.5°C). For a 2.5°C global mean temperature rise above pre-industrial levels summer arctic sea ice is projected by some models to be lost by the end of this century. With the reduction and loss of sea ice, polar bears, ice-dependent seals, walruses and certain sea-birds are facing extinction. For Inuit, warming will mean the destruction of their hunting and food sharing culture.

Increased melt water inflow from the adjacent Siberian, Canadian and Alaskan rivers and a potentially decreasing Greenland Ice Sheet could adversely affect the stability of the thermohaline circulation. Increased freshwater fluxes seem to be already about 20% of what might be needed to shutdown the thermohaline circulation according to some models. Conservative projections suggest that the contribution of Arctic glaciers, including the Greenland Ice Sheet, to global sea-level rise will amount to four to six centimetres over the next century. Over the long term, models predict that if warming is sustained over the Greenland Ice Sheet it will eventually melt completely, contributing about seven meters of global sea-level rise over many centuries to a few thousand years depending in the magnitude of the warming. Methane releases from the Arctic tundra as it melts pose a risk of positive feedback accelerating climate change. The stability of methane clathrates in the relatively shallow Arctic sea bed is difficult to assess but remains a risk.

Small Island Developing States: Pacific and the Caribbean

The Small Island Developing States (SIDS) of the Caribbean, Indian Ocean, Mediterranean and Pacific regions inherently have many common and unique characteristics (e.g., small physical size, geographically located at weather and climate sensitive regions, limited natural and human resources, sensitivity to external shocks, etc.) that serve to increase their sensitivity and vulnerability to the impacts of climate variability, anthropogenic climate change and sea level rise, in particular extreme events such as tropical cyclones (hurricanes) and droughts. Recent analyses suggest extreme events appear to have increased both in frequency and severity in tropical SIDS regions in the last few decades. The cost of extreme weather events in the Pacific in the 1990s alone exceeded US$1 billion. In the Caribbean region the period between 1960 and 2000 witnessed an exponential increase in the occurrence, severity and intensity of disasters, especially during the last decade. Hurricane Ivan in 2004, for example, that struck Grenada, Cayman Islands, Cuba and Jamaica caused billions of dollars in economic losses. Damage in some cases has exceeded the national GDP of some countries such as Samoa in 1990/91 and Niue in 2004. The recent estimate of damage inflicted on Grenada by hurricane Ivan is in the vicinity of close to 0.90 billion US dollars (2.4 billion EC dollars) amounting to 201% of the island's current GDP, according to government officials. Whilst an anthropogenic signal is not yet scientifically determined at this stage, it is clear that anthropogenic climate change and sea level rise are highly likely to substantially exacerbate these present risks and damages.

Many coral reefs currently operate at or above the tolerable level. As climate change progresses, it is expected that the frequency of sea surface temperatures (SST) could exceed local bleaching thresholds which could lead to permanent coral bleaching and other impacts on marine ecology, in some locations for a global warming as low as 1-1.5°C above pre-industrial levels. Apart from being crucial for tourism, coral reefs protect the shoreline. Reefs decay by coral bleaching would further increases vulnerability to storm surges on all time scales (seasonal, interannual and decadal). Within 50 years coral degradation and death could lead to losses annually of 140-420 million $US in the Caribbean alone.

SIDS are key and vulnerable regions in the elaboration of the meaning of the ultimate objective of the UNFCCC. The huge social, human and economic losses associated with present-day extreme events, together with potentially even more losses due to projected climate change impacts, are major threats to SIDS immediate future economic viability. In the longer term, future existence of some SIDS could be fundamentally challenged, particularly low-lying states and those situated in zones often affected by extreme events.

Ultimately, adaptation cannot alone sufficiently address the challenge. It must be accompanied by immediate and significant mitigation measures implemented first and foremost by Annex I parties to the UNFCCC as a first step towards reducing the causes of climate change. Complementary adaptation and mitigation activities will therefore serve to minimise the human and economic costs of present damages from extreme events and prevent a large part of the projected damages from anthropogenic climate change.

SUMMARY OF KEY CLIMATE SYSTEM RISKS

Dangerous climate thresholds can be identified by analyzing changes to the geophysical climate system, its key subsystems and extreme events. The potential physical impacts are of a magnitude which would be widely agreed to be dangerous, highlighted in the following by a couple of examples.

Firstly, several meters sea level rise over a few centuries would result in widespread loss of coastal and deltaic areas (such as Bangladesh, the Nile, Yangtse and Mekong Delta regions), including their ecosystems and human settlements, including many of the world’s largest cities. A 3°C global warming above pre-industrial levels is likely to cause such a 3-5 meter sea level rise increase by 2300. Given that the climate sensitivity might well be 3°C for a doubling of CO_2 concentrations, a stabilization at 560ppm CO_2 would not be sufficient to prevent this dangerous interference.

Secondly, a significant slow-down of the thermohaline circulation would have large impacts on both the North Atlantic region (cooling, additional sea level rise, impacts on marine ecosystems and fisheries) and tropical regions (shift in precipitation belts associated with the intertropical convergence zone).

Thirdly, global warming is expected to lead to changes in large scale oceanic and atmospheric variability patterns. Specifically, a more intense El Niño Southern Oscillations (ENSO) is projected in a number of models or a higher variability in Indian Monsoons with potentially devastating consequences for food security.

Furthermore, extreme events like hurricanes, typhoons, cyclones, storm surges, floods, dust storms, heat waves & droughts may well increase due to human-induced climate change. As well, the nearly complete loss of Arctic summer sea ice is possible for a global mean warming of approximately 2.5°C above pre-industrial levels. With the summer sea ice, the ice-dependent seals, polar bears and walruses would be lost.

In addition to the above cited examples for dangerous interferences, a significant acceleration of climate change due to biogeophysical (carbon cycle or methane hydrate) feedback mechanisms might be considered as dangerous in itself. If large scale positive feedbacks occur then these could make a stabilization of greenhouse gas concentrations impossible with known technologies and policies. Some studies suggest significant releases of soil carbon if global mean temperature increases to 2°C or 3°C above pre-industrial. As well, one climate model suggests that the Amazon forest ecosystem might be replaced by savanna for a global mean warming of approximately 2°C to 3°C, causing not only a precious ecosystem to vanish but as well large releases of carbon.

In summary, the climate system is likely to face several critical limits in its key subsystems if global mean temperature increases to 2°C to 3°C above pre-industrial levels; However, even global temperatures rises below 2°C can not be considered as ‘safe’, given the large uncertainty in some of the thresholds. Long-term sea level rise, and increases in frequency and strength of extreme events are likely to adversely affect particular regions and ecosystems already for moderate warming levels below 2°C.

KEY REGIONAL FINDINGS – BACKGROUND

I. China

The dominant climate impacts on Chinese society include the risk of droughts and flooding. Climate model projections show drought to increase in the northwest, while rainfall might increase in the southeast, both in accordance with the observational records. As 60% of streams and rivers in western China depend on glacial melting for water supply, water security in the dry season will be jeopardised some decades before these glaciers largely disappear, which is expected by the year 2100.

For a 2.5-3°C global mean temperature (GMT) increase above pre industrial[2], rice yield could be reduced by 10-20% by the 2080s under worst-case assumptions on CO_2 fertilisation. However, for an optimistic projection of CO_2 fertilisation, yields could change by -10 to + 20%. A general increase in agricultural water demand and in soil drying is projected to lead to reduced yields in the north and northeast, with opposite patterns in the south. In the north substantial adaptation measures will be needed to maintain sustainable development in the region.

Sub-regional scale studies show that all forests tend to shift northwards. Coniferous forests will disappear, while in other parts of the country tropical forest and woodlands are introduced. Sea level rise might pose a problem for low-lying cities such as Shanghai.

Agricultural and water resources

Observational records over the last decades, or century, show that climate variability and extreme climatic events are crucial to both the water and the agricultural sectors in China. Extreme events, like droughts, floods, pests and diseases, currently destroy much of the harvest specific regions and years decreasing the potential of higher crop yields.

In many regions current climate variability influences the risk of soil degradation by wind and water erosion. The influence of soil degradation is in itself a function of management and grazing practices, and is potentially as important as the direct effect of climate change in some regions. However, policies in this area are expected to be effective in reducing soil degradation and suggest the potential for an increase in mean crop productivity.

The recent UK-China study (Erd 2004) on climate change and Chinese agriculture indicates that in a worst-case scenario rice yield could be reduced by 20% by the 2080s. In terms of the future risks there is a need to look more comprehensively at the coupled effect of, for example, water resource changes and agricultural production.

A general increase in agricultural water demand and in soil drying is projected to lead to reduced yields in the north and northeast, with opposite patterns in the south. In the north substantial adaptation measures will be needed to maintain sustainable development in the region.

Whether there is a risk from increased climate variability seems to be an open question, e.g. the potential for a shift in Monsoon patterns. A part of the variability in agricultural production observed in the last century might be due to the low input of labours chemical fertilizers and limited pest control. Simultaneous oscillations in rainfall regimes on different timescales lead to the extreme swings in water resources and agricultural production. In addition, simultaneous droughts in the northern and southern regions lead to a decrease in national food security. However, it is unknown if the amplitude or frequency of such oscillations might change.

Ecosystems

Identification of vulnerable regions has been based on national scale vegetation models. Ecosystems in the northeast, north, northwest and east regions, and the Tibetan plateau are seen as vulnerable. Forests in eastern China would shift to north under the conditions of future climate change and CO_2 enrichment. An eastward shift of grasslands might occur, while desert areas might shrink. These studies do not include the potential limits to migration rates that might be posed by human activities and soil degradation. Biodiversity was not studied here.

Health

One of the implications of climate change for health appears to be a likely increase in the incidence of dengue fever in southeast China (e.g. Guangdong province).

II. Sahelian Africa

The downward trend in rainfall along with large variability is already threatening society and nature in the Sahelian region. Although both traditional and new strategies are in use and under development to cope with this, the current dangerous situation will remain when the rate of climate change continues to outpace this development.

Ecosystems and livelihoods

The past three decades of drought in the Sahel region have stretched the coping capacity of society and nature. Climate variability of rainfall in the region is the dominant climatic influence. In the Sahel, dry years lead to strongly reduced food security, increased poverty and vulnerability. People respond to this with a number of

[2] All temperatures are global mean and with respect to the pre-industrial period defined as the 1861-1890 climatology.

strategies, some of which increase environmental pressure, like overgrazing and wood over-exploitation. Some of these strategies depend on normal and wet (good) years being able to facilitate re-supplying capital and food stocks, as well as livestock. Dry conditions are projected to strongly increase under global warming in the current century. This would exacerbate existing problems. Although many activities in the region have been developed to enhance resilience, the question is to what extent the current coping strategies will keep pace with the rate of climate change. A breakdown of coping strategies when overstretched by increased drought, or a lagging behind of the strengthening of these, then leads to what can be classified as a 'dangerous' situation. Environmental pressures can boost the drive for regional and intercontinental migration. All of this implies that strengthening of adaptation capacities is required on farm level, as well as national and regional policy levels. This might include the introduction of genetically modified crops. Extreme droughts in the past decade are important to be analysed in order to learn lessons for the future.

The main effects of the observed and projected rainfall deficit on west Sahelian African eco-systems include the disappearance of grass cover on the majority of the area, disappearance of trees including acacia, decrease of underground (phreatic) nape, decrease of biodiversity with disappearance of many flora and fauna species, reinforcement of the sandy movement (shifting sands), and reactivation of some immobilized dunes.

III. Australia[3]

Many Australian species and ecosystems threatened by increases in temperature of 1-2.5°C global mean temperature increase above pre industrial due to narrow geographic ranges, low relief, and ongoing environmental stresses from other sources such as habitat clearing. Several ecosystems have been identified as being under more immediate threat at the lower end of this temperature range, including parts of the Great Barrier Reef, alpine regions, coastal wetlands and the wet tropics of North East Queensland.

Australian water resources are already stressed and vulnerable to regional reductions in rainfall and streamflow, combined with warming. In south western Australia there has been an abrupt reduction in rainfall in recent decades (and a much larger consequential reduction in streamflow). It is not yet known to what extent this change is natural or a response to greenhouse climate changes, though the latter poses the unwelcome prospect of similar changes across the southern reaches of the continent.

Projected increases in the intensity and frequency of extreme events such as fire and drought will have substantial biological and economic impacts.

[3] Background literature (Karoly 2003; Pittock 2003)

Ecosystems

Much of Australia's biodiversity (ecosystems and species) will be very sensitive to climatic warming. The most sensitive species are those with narrow geographical and climatic ranges with limited potential for adaptation. There is a limited opportunity for altitudinal migration, since Australia has low topographic relief. With even small climate changes (1- 2.5°C increase in global mean temperature above pre-industrial) many endemic species may be lost and there are likely to be substantial changes in the structure and function of communities and ecosystems. Australia's infertile soils, extensive habitat fragmentation and ongoing environmental problems such as salinity will also reduce the capacity for species and communities to adapt. Of most immediate concern are species in the alpine region, coral reef communities in the Great Barrier Reef, coastal wetlands, and the endemic vertebrates of upland areas in the Wet Tropics of Queensland. Bioclimatic models project that many species in these areas will lose most or all of their climatic range with as little as a 1.5-2°C°C increase in global mean temperature above pre-industrial.

Water resources

Water resources, or the lack thereof, is both an acute and chronic issue for Australia. Australia's water resources are already stressed, because of low average rainfall over much of the continent and naturally high variability, declining rainfall in some regions such as southwest Western Australia (possibly related to climatic change), combined with inefficient use of water resources.

Water resources are threatened by declining rainfall and stream flow, projected increases in droughts, increasing temperatures and higher evaporation. Increases in ENSO intensity and the potential southward contraction of storm tracks in the southern half of Australia would intensify these threats. Sectoral impacts from declining water supply include loss of environmental flows in stressed river systems, reductions of water quality, degradation of floodplain ecosystems, shortfalls for agricultural use and cities, and the normalization of severe water restrictions. If water resources are not managed more appropriately in the future the impacts of climate change may be even more severe. In particular, if unsustainable agricultural uses of water are allowed to continue then both unsustainable and sustainable users of the resource will suffer.

Responses to water supply deficits, that may be linked with greenhouse warming, in south-western Australia, such as increased groundwater mining could exacerbate stresses on dependent ecosystems.

Extreme events

Australia also has to cope with extreme weather events, such as cyclones, hailstorms, and bush fires all of which are predicted to increase in frequency and/or intensity, at least regionally. Changing rainfall patterns are expected to result in increased drought and floods, affecting agriculture significantly. State Emergency Services and the Rural Bushfire Service will face more severe conditions for longer periods. Small changes in temperature, resulting in increased extreme weather events, will cause large increases in damages to buildings and infrastructure as their designs are often based on historical weather patterns. For example, a 25% increase in peak gust (e.g 40-50 to 50-60 knots) can cause 650% increase in building damages. These extreme weather events result in substantial economic losses, e.g.1.6% decrease in GDP and 30% reduced agricultural output from 2002 droughts, and $1.8bn Aus of insured property losses from the April 1999 Sydney hailstorm.

IV. Southern Africa

The number of people in the region that is affected by climate-change impacts is large. Climate change is an important additional stress on the agricultural and fishery sectors, in particular at the community level. The key drivers of food security in the region are water availability and agricultural practices, and increases in drought frequency or intensity would adversely affect food security. The numbers of drought-affected people in the region has grown from close to zero in the 1970s to around 35 million in 2000, and periods of drought are even projected to become more frequent in the future.

Climate change impacts are likely to most severely be felt on already poorly performing farm systems in the subsistence farming sector where producers normally earn sufficient (or less) to cover themselves until the next harvest. Whilst commercial farm systems have shown some measure of resilience to drought, subsistence agriculture has become increasingly vulnerable to droughts which, often linked with El-Niño, have increased in frequency since 1990..

By the 2030s much of the continent is projected to suffer from severe water shortages, with estimated water availability declining to under 2,000 m^3/capita from about 7,000 m^3/capita in 1950. Water resources reduced dramatically in the region over the last 40 years, during which the commercial agricultural systems have proven to be more resilient than communal systems. However, the temperature and precipitation changes as projected for the 21st century will especially affect newly introduced commercial crops like Maize, while traditional crops like Millet and Sorghum are more resilient. Precipitation has been projected to decrease by 5-20% in the region's river basins. This will affect crop yields in rain fed maize crops, where crop failure probability could be as high as 70% by 2050.

Observational data in the arid south-western regions and winter rainfall region of southern Africa indicate significant monthly temperature increases of up to 2°C since the 1970's, and reductions in chilling units required for fruit crop production. Projections indicate fruit production may be severely curtailed by 2050.

There appears to be a twin risk that increased drought and warming could cause significant problems for both commercial Maize and Fruit agriculture and subsistence farmers.

Inland fisheries in natural lakes and large reservoirs contribute significant amounts of protein intake, particularly in the Zambesi basin states and the East African Great Lakes states. Recent data indicates that global warming could alter both the thermal stratification patterns in these water bodies and their algal species composition. This would lead to a reduction in the productivity of pelagic fisheries, as indicate in Lake Tanganyika and Lake Kariba. Droughts have also affected fish catches in inland draining water bodies as well as flood plain fisheries, for example in Zambia. The mean temperature change of a few degrees sharply increases the probability of exceeding the critical temperature at which fish populations decline, due to blooming of blue-green algae. In the example of Malawi, this virtually eliminates the primary source of protein for almost 50% of the population.

Ecosystems and biodiversity

By the 2050s biome shifts are projected to affect up to 50% of the regional systems, while in the southern-most biome, the Cape Floristic Region, ~25% of representative modelled species are projected to be lost for a global mean warming of 2.4°C above pre-industrial levels. The most vulnerable ecosystems in Southern Africa are the western semi-arid regions. Reduced winter rainfall and warming is expected, and incipient warming has been recorded in these regions (under high uncertainty), with a distinct impact in the Cape floristic region and the succulent Karoo. Impacts on indigenous plant species may already be detectible. Species migration rates depend on the underlying mechanisms, but based on regional vegetation modelling, species will have to migrate 50 to several 100s of kilometres by the 2050s, in order to keep up with a moving habitat under global warming of ~2□C. This migration rate corresponds to over 2 km/yr, which is clearly too fast for most sessile species. In addition, habitats disappear for species at the Southern coast and in higher elevation mountain regions. In the summer rainfall regions, changing CO_2 in combination with fire regimes results in shifts of ecosystem structure, thus transforming grasslands and savannas into woodlands. There was little data available at the Symposium on fauna, however it is expected that Antelopes might be adversely affected, as well as migratory birds, the former due to the aforementioned changes in ecosystem structure while the latter because of decreased access to fresh water pockets. Limited modelling on southern African bird species suggests species range reductions by the 2050's that parallel findings for plant species modelled.

Particularly worrying are the unknown potential interactions between climate change, human land use change and invasive alien species success – a deadly combination punch for biodiversity in this region.

Agricultural and water resources

Exponential growth of stresses has to be expected because of the exponential growth of extremes with a linear increase in mean temperature, combined with population growth. Per capita water availability in Africa has gone down by 75% over the past 50 years due to population growth.

Ninety per cent of farming in the region is considered subsistence agriculture. Large differences exist between commercial and communal land agrarian systems regarding resilience to droughts. In ‘bad’ years commercial farming still reaches a production level equal to the level in communal ‘good’ years.

Capital inputs in the commercial sector are the largest factor, facilitating the construction of dams for water storage, of irrigation technology and systems, and access to modern cropping technology. Regarding the key traditional crops, Millet is expected to remain viable in the region, whereas the probability of crop failure will gradually increase for Sorghum. Currently, the farming of traditional crops has a probability of 20% to fail under current conditions, related to droughts, which might rise to 30% for Sorghum by the 2080s. The strongest impact of further global warming is expected for non-traditional crops like Maize and other cash crops. For rain-fed Maize, the probability of crop failure is projected to rise from the current 60% to 80% under a 2-2.5°C global-mean temperature increase above pre-industrial. Water stress can lead to interruptions in energy production, thus also affecting irrigated agriculture.

Climate change problems are likely to interact with persistent social problems which already lead to substantially increased risks. For example, the Zimbabwean Institute of Security Studies Food reported “Cereal harvest in 2001/02 was ... down by over 60% from the previous year, when production was also significantly down. Emergency food assistance ... is needed for over 50% of the population” and “supply and food access conditions in 2002/03 are substantially worse compared to the 1992/3 drought, primarily due to the lack of maize stocks, the very weak import capacity of the country and a sluggish response from donors.”

Fisheries

In the inland-fisheries sector, catch has gone down in the past decade due to increasing surface temperatures and rising thermocline, the latter decreasing the depth of the productive upper layer. Since these systems are quite effectively managed, overfishing is not the determining factor. The cause is the strongly non-linear response of blue-green algae growth to warming at the expense of green algae, the latter being the food source for the concerned fish species.

V. South Asia (Indian subcontinent)

The ecological and socio-economic damage of climate change in the region will have disastrous consequences, cause social unrest and environmental refuges. Economic development in the region, which is currently growing rather rapidly, appears unlikely to benefit over 60% of the population in this region due to poor adaptive capacity.

Agriculture

The green revolution has contributed self-sufficiency in food productivity in the region during the past three decades. However, limited arable land and poor irrigation infrastructure have led to yield stagnation and even decline in most of the region.

For each 1°C increase in night time temperature, the decline in rice yield would be about 6 to 10% on an average in the South Asian countries. The CO_2 fertilization effects would not be able to offset the negative impacts of high temperature on rice yields in South Asia. An increase of 2°C in mean daily temperature could decrease the rice yield by about 0.75 ton/ha in the high yield areas; and a 0.5°C increase in winter temperature would reduce wheat yield by 0.45 ton/ha. A 2°C increase in surface air temperature would decrease wheat yields in most of South Asian countries. The average change in wheat yields in South Asia would range between +4 to -34% for the mid-21st century under projected climate scenarios by which global mean temperatures are projected to increase by 2.5 to 3.5°C above 1990 . Under these scenarios, the yields in non-irrigated wheat and rice will significantly decline in South Asia incurring a loss in farm level net revenue of between 9% and 25%.

New research and technologies will be needed to achieve additional yield. The scarcity of arable land and water stress will lead to food shortages and insecurity.

Extreme events

In South Asia, climatic variability and the frequency of occurrence of extremes of weather events such as heat waves, droughts, floods and cyclones have increased in recent years. These extreme events are likely to become more frequent and/or intense with climate change and it is expected that large numbers of people, especially among the poorest, will be adversely affected more often and more intensely.

The risks of flooding will considerably increase in the main river basins of India, Bangladesh and Nepal. In Bangladesh, a rapid shift in extent and depth of flooding will occur in case of a rise in global mean temperature of 2.5°C above pre-industrial. Sea level rise will cause severe damages to ecosystems, agriculture and water resources especially in the coastal regions of Bangladesh and India.

Himalayan deglaciation

Widespread deglaciation in the Himalayas is likely to adversely impact the hydrological regime of the region.

Numerous glacier lakes in the Himalayas are close to break out as a consequence of increased melt water from retreating glaciers. Further warming will considerably increase the risk of glacier lake outburst floods (GLOF), creating hazards to life and economic activities, destroying infrastructure such as bridges and roads, and damaging hydroelectric facilities.

Deglaciation will initially lead to an increase in run off in the Himalayan catchments, which could exacerbate downstream flood risks for Bangladesh and India. As the glaciers loose mass with time, the rate of discharge would reduce and hence river run off would most likely decline as well, and combined with higher temperatures lead to increased water supply stress.

VI. North-West Europe and Central Europe[4]

An increase in temperature will have negative impacts on biodiversity due to massive shifts of species and the risk that species will not be able to migrate fast enough if warming is not limited. An abrupt shutdown of the thermohaline circulation systems would have significant effects.

Ecosystems and species

An increase in temperature will have negative impacts on biodiversity due to massive shifts of species and the risk that species will not be able to migrate fast enough to keep up with the movement of their bioclimatic zones, eventually leading to the possible loss of endemic species. According to (ecological) models natural habitats will become climatically unsuitable for the survival of many species and migration towards northern latitudes will be required for their survival. Some will be able to migrate and others may not be able to. Substantial loss of wild species and ecosystems could occur locally especially in Southern parts of Europe reaching a level of up to 60% in 2100 at a warming of 3°C above pre-industrial. Species compositions will change drastically and especially in the northern areas entire ecosystems will be modified in terms of their species composition for warming beyond 1-2°C above pre-industrial. Up to now observed data are in line with model predictions. The EU target of protection and preservation of ecosystems and species may be impossible to achieve if mean temperature continues to rise as predicted.

Thermohaline circulation effects

A decrease of the strength of the Atlantic thermohaline circulation (THC) is considered likely. According to a systematic expert elicitation a complete collapse cannot be ruled out; the probability for this is seen in the range of a few percent for low warming projections (1-3°C), but according to some experts the probability may increase to above 50% for 4-5°C warming above pre-industrial.

A decrease of the thermohaline circulation will impact marine ecosystems and fish stocks, especially cod. In case of a complete shut-down of the THC large parts of the Northern Hemisphere surrounding the North Atlantic will experience an abrupt relative cooling, as compared to the warming experienced prior to the shutdown. Impacts on agriculture and forestry are difficult to determine as they depend on the timing and intensity of cooling. Scandinavia will probably be the most vulnerable to impacts. Regional sea level rise around the northern Atlantic in the range of one meter (in addition to any global sea level changes) should also be expected as a consequence of dynamic adjustment of sea level to a change in circulation. A shut-down of the THC will further have far-field effects in the tropics (causing a shift in rainfall belts) and in the Southern Hemisphere (making it warmer), with adverse effects projected for example in India and north-eastern Brazil.

VII. Mediterranean – Maghreb and North Africa

In the Maghreb and North Africa climate is an essential component of the natural capital. Climate in the region is among the most variable of the world and recurrent drought problems often affect entire countries over multi-year periods and often result in serious social problems. Many areas face recurrent severe drought problems that result in water scarcity and stress and low quality. Over the last three decades spring rainfall has decreased in many areas of the region exacerbating the severe problems associated with drought. This rainfall decrease is consistent with projections of future climate. The intensive demand of water for agriculture contributes to the conflicts among water users and transboundary water disputes. On top of this, projected climatic change, especially precipitation decreases, further increases in variability and the increase in drought episodes, would hit the region severely. All climate change projections indicate a decrease of precipitation, in some cases up to -40%, by the 2050s compared to 1961-1990 levels (global mean warming across the range of scenarios of 1.8-2.6°C global mean temperature increase above pre-industrial (Arnell *et al.* 2004)), substantial temperature increases, and thereby increased evaporation, resulting in more adverse regional climate conditions than presently experienced. In the case of Egypt climate change will increase water demand for crops to the extent that there is a need to find new ways to increase its water resources.

[4] Background literature (Jalas and Suominen 1972-94; Leemans and Cramer 1991; Parmesan *et al.* 1999; IMAGE-team 2001; Tamis *et al.* 2001; Warren *et al.* 2001; Bakkenes *et al.* 2002; VanHerk *et al.* 2002; Walther *et al.* 2002; Hill and Fox 2003; EEA 2004; Thomas *et al.* 2004)

Water conflicts in the region are receiving increasing attention as the concerns of climate experts begin to encompass the realities of current and future water availability. Effective land use and water management policies are often in conflict with policies that aim to stabilize the rural population to avoid migration to cities and contribute to unemployment.

Vulnerability

Agriculture is both the main use of the land in terms of area and the principal water-consuming sector (over 70% of total water consumption). Therefore the adverse effects of climate change are perceived to be associated with agricultural activities, leading to conflicts over the use of resources with other sectors. Under current conditions North African countries import significant amount of grain and it seems likely that climate change will lead to an expansion of this import requirement. The effects of sea level rise in North Africa, especially on the coast of the Delta region of Egypt, would reduce the area under cultivation and likely reduce agricultural production. Under climate change scenarios irrigation demand increases in all regions of Mediterranean and Maghreb countries, especially where current water scarcity is a major problem (Iglesias *et al.* 2000; Iglesias *et al.* 2002). Improvement of water delivery systems compensates for increases in irrigation demand and projected irrigation area increases in the limited areas of northern Mediterranean countries, but do not achieve the same results in North Africa (Abou Hadid et al., 2004).

In addition to the problem of the scarcity of water, Tunisia is confronted with a problem of quality since the most of water resources have medium to mediocre quality and salinity is often high. Indeed, more than 30% of available water contain more than 3g/l salt (Mougou 2003). To avoid some of the negative impacts of climate stress in the current situation and under climate change conditions, it is necessary to undertake new adaptation methods such as: selecting new cultivars, changing of planting dates, increasing the agricultural area, using new agronomic practices, and enhancing the capacity building for mainly the small farmers that represents about 80 % of the total Tunisian farmers. In Tunisia as in the totality of the Maghreb region, adaptation to predicted climate change needs to be integrated with the program for sustainable development.

Additional deleterious effects of climate change would be felt on tourism, fisheries, and industry and on coastal communities.

In the case of Egypt, studies (Eid *et al.* 1996; Eid *et al.* 1997) indicate that climate change will increase water demand for crops, this means that Egypt with its limited water resources (Egypt’s per Capita share is less than 800 m3/year or less than the poverty level of 1000m3/year) is in need to find new ways to increase its water resources.

Adaptation

Northern Africa’s adaptation capacity is challenged in particular, as climate change comes in conjunction with high development pressure, increasing populations, water management that is already regulating most of available water resources, and agricultural systems that are often not adapted (any more) to local conditions. Evidence for limits to adaptation of socio-economic and agricultural systems in the Mediterranean and North African region can be documented in recent history. For example, water reserves were not able to cope with sustained droughts in the late 1990’s in Morocco and Tunisia, causing many irrigation dependent agricultural systems to cease production. In addition, effective measures to cope with long-term drought and water scarcity are limited and difficult to implement due to the variety of the stakeholders involved and the lack of adequate means to negotiate new policies.

Combined stresses

The human dimension of climate change impacts in the Mediterranean Maghreb might not stop at the regions’ boundaries. There is the potential for more pronounced water conflicts with neighbouring regions (i.e. transboundary issues in the Nile and in many shared aquifers). There is the risk of climate change induced refugee flows to Europe from the region.

The effects of sea level rise on the coast of the Delta region of Egypt would reduce the area under cultivation and likely reduce agricultural production. Deleterious effects would be felt on tourism, fisheries, and industry and on coastal communities. The climate change impact on Egyptian crop productivity will be severe (Eid *et al.* 1996; Eid *et al.* 1997; El-Shaer *et al.* 1997). Under current conditions Egypt imports significant amount of grain, oil and sugar and it seems likely that climate change will lead to an expansion of this import requirement.

VIII. USA - Ecosystems and California

Ecosystem risks were reviewed for the USA as a whole and a case study of regional impacts on water, agriculture, health and ecosystems for California was presented.

Many projected climate-related impacts in California are driven by temperature and ENSO events. As greenhouse gas concentrations rise, increases in temperature are relatively certain. In contrast, changes in the frequency and magnitude of ENSO events are highly uncertain.

Certain impacts are closely linked to temperature. These include loss of snow pack and subsequent water resource risks, heat stress, and agricultural impacts on heat-sensitive crops and products such as wine grapes and dairy, although with significant regional differences. Others that depend more strongly on winter storms and precipitation are linked to El Niño frequencies, future changes in which are uncertain, although it seems clear that more frequent and/or severe El Niño events combined with sea level rise would exacerbate coastal storm surge risks. Wildfire risks are very likely to increase and interact with development patterns as temperature rises, fire suppression management practices continue, and the population continues to expand into previously wild areas. Other impacts are too tightly coupled with many socio-economic factors (GDP, infrastructure) and management decisions (water distribution) for there to be a clear relationship to increases in global mean temperature. In these cases projected climate change plays an exacerbating rather than driving role.

For some ecosystems which are already close to critical climate-related thresholds such as permafrost landscapes in Alaska or High Mountain areas and coastal areas, climate change in the next few decades may provide early warning of “dangerous” levels and rates of change. Small warming levels will be very damaging or even catastrophic to these sentinel ecosystems.

Ecosystems

Ecosystems perched near critical climate thresholds, such as permafrost landscapes and coastal wetlands, provide early warning of dangerous levels and rates of change. Even minor increases in mean annual temperature or sea level rise will be devastating to them. For these landscapes, there is little difference between the impacts of climate change across the whole range of IPCC scenarios as there is little difference between these for the first few decades of this century. Systems and entities that are already at risk include glacial and alpine systems, freshwater fish, and migratory birds. Cold temperate forests such as maple are at risk for a 2.3°C warming above the pre-industrial, coastal wetlands and tundra for slightly higher levels of warming, Some ecosystems, such as permafrost landscapes in Alaska or High Mountain areas and coastal areas, are already close to critical climate-related thresholds. For these climate change in the next few decades may provide early warning of “dangerous” levels and rates of change. Small warming levels will be very damaging or even catastrophic to these sentinel ecosystems[5].

Water Resources - California

The projected loss of snow pack is critical for the timing and overall supply6 of water resources, and increases with increasing temperature. Over the next few decades a moderate snow pack loss is projected to occur as temperatures rise. This rises to a 30-70% loss in snow pack for a 2.3°C increase in global mean temperature above pre-industrial by 2100. Snow pack supplies 40-45% of California’s agricultural and urban users, suggesting a loss of 13-30% of California’s water supply in the absence of massive increases in water capture and storage capabilities. A high risk to water resources is identified over the next few decades due to a combination of existing drought conditions, unsustainable withdrawal of ground water, rising temperatures, and shifts in the timing of runoff from snow melt to earlier in the year. Already, Sierra Nevada snowmelt has shifted to earlier in the year by more than two weeks relative to the early 1900s (Dettinger and Cayan 1995; Stewart *et al.* 2004), a likely indicator of climate change. In the longer term there is a risk that the pressure of climate change coupled with increased demand will lead to major problems that cannot be solved within current planning or adaptation frameworks. With a 5-6°C warming by end-of-century, the snow pack almost entirely disappears.

Agriculture - California

Moderate risks are foreseen for agriculture for California over the next few decades but these appear to be well within the coping and adaptation capacity of the industry. Some will benefit and others will lose on this timescale. Agriculture in California is mainly highly managed specialty crops with high but costly adaptation potential. In the longer term a higher risk is seen for perennial crops (citrus, grapes, other fruits, nuts and vegetables) requiring substantial changes in crop varieties. Such changes may be expensive and change the character of unique wine-growing regions such as Napa and Sonoma.

Extreme events - California

Changes in the risk of extreme weather-related economic losses are very uncertain, although increased human settlement in high-risk areas (low-lying coastal areas, fire-prone regions) is likely to increase the losses experienced in the future.

In the longer term, climate-driven risk from winter storms would likely rise if El Niño-related storms increase in frequency and/or magnitude and are exacerbated by sea level rise. Sea level rise is expected to contribute to increase storm surge risk and in the longer term the scale of the risk is linked to the enhancement of El Niño-driven storm surges. Uncertainties in predicted changes in ENSO make estimates of climate-driven increases in risk highly uncertain.

Similarly, increased wildfire risk caused by climate change may interact with development patterns to increase risk on all timescales, depending on vegetation type, location, and fire suppression strategies. Wild fire frequency and/or intensity may be linked to El Niño events as well, with wet El Niño winters producing higher amounts of vegetation to fuel summer/autumn fires (Westerling and Swetnam 2003).

5 Ecosystems that demonstrate catastrophic responses to incremental change serve as sentinels, providing early evidence of what may be expected from other ecosystems whose vulnerability is not known.

6 Timing may be as important as the net supply of water. Shifts in peak snow melt to earlier in the year have the potential to disrupt California’s carefully-balanced water rights system to a degree comparable to the problem of projected decreases in overall supply from snowpack.

Health - California

Heat stress is projected to increase substantially, with the risk of heat-related mortality rising significantly on decadal timescales and by 100-1,000% by 2070-2100. Adaptation measures such as early warning systems and public infrastructure are key to reducing the impacts in this area, with impacts being strongly differentiated by location, race and income.

Complex vulnerability thresholds for California

The concept of vulnerability thresholds is most relevant to impacts that primarily scale with temperature. For many regions of the world including California, precipitation projections are still inconsistent and do not display a trend that is monotonic with respect to increasing greenhouse gas concentrations. In addition, many impacts are moderated or even controlled by human development and decisions, with climate change acting as an exacerbating factor rather than the primary driver. Hence, it is difficult if not impossible to determine vulnerability thresholds with respect to temperature for impacts driven mainly by factors other than temperature. For California, temperature changes resulting from one of the lower SRES scenarios (B1) which has a global mean change of about 2.3°C relative to pre-industrial (and a region-specific change of 2-3.5°C relative to the climatological 1961-1990 baseline), already produces unacceptable stress on water supply (through reduction of Sierra snow pack and shifts in peak streamflow to earlier in the year) and human health (in terms of heat-related mortality), as well as on some perennial cash crops in certain regions currently at their upper temperature limits. These impacts intensify for larger increases in temperature, with near-complete loss of Sierra Nevada snow pack (70-97%) and severely impaired grape growing conditions for all by the cool coastal regions with a global mean warming of 5-6°C.

For many other serious impacts, including ecosystem and vegetation shifts, coastal impacts from sea level rise and El Niño-driven winter storms, wildfire extent and damages, and the net impact of climate change on the water supply system there is not a straightforward relationship with increasing global mean temperature. Whilst in general there is an increasing risk with increasing global mean temperature, changes in precipitation and in large scale atmospheric circulation patterns, socio-economic change, human choices and behaviour all play roles of equal or greater importance than temperature in determining the final magnitude and timing of adverse impacts in these areas. In other words the risk can be very low or high depending on how the other factors develop as a consequence of both climate change and socio-economic choices. Consequently for these kinds of impacts there may not be a specific temperature threshold for damages that is uncoupled with the other factors and instead there may be a multi-dimensional threshold involving the relative role of several key drivers (e.g., temperature, precipitation, population, settlement patterns, water demand) would be more suitable than temperature as simultaneous changes in multiple factors could push a system over the limits of acceptable change, whereas changes in temperature alone may not. For example a temperature increase, combined with a precipitation drop, and bad management choices and/or more frequent El Niño-driven storms could lead to unacceptable changes for some systems. Different combinations of multiple factors could drive the same amount of impact.

The type of multivariate thresholds proposed above have two main benefits. First, they would capture the combinations of possible changes and triggers that would result in an impact passing a “dangerous” level. Secondly, by incorporating issues of population, health, socio-economic and sustainable development, multivariate thresholds reveal the many different circumstances in which climate change, although perhaps not a primary driver of change, can exacerbate non-climatic stressors and thereby lead to “dangerous” levels of change.

IX. Amazon

The Amazon region can be categorized as a region at great risk from climate change. The risk is not only due to projected climate change but also through synergistic interactions with existing threats not related to climate change, such as land clearance, forest fragmentation and fire. Over the next several decades there is a risk of an abrupt, and irreversible replacement of forests by savannah with large-scale loss of biodiversity and loss of livelihoods for people in the region.

Risk of abrupt change

The Amazon region appears to be very sensitive to projected climate change and synergistic interactions with existing pressures. It is one of the world’s mega biodiversity regions.

Projected climate change could trigger a collapse of the Amazon with Savannah replacing the forests. The probability of this dangerous event occurring is not clear in part because it is the outcome of one model. Nevertheless over the next several decades there is a risk that the synergistic interaction of regional climate changes caused by global warming combined with the effects of forest clearing and fragmentation could flip the ecosystems of this region from forest to savannah in large parts of Amazonia and to desert in parts of North-eastern Brazil.- There are some indications that these interactions are already being detected. The consequences of a collapse of the Amazon forests for biodiversity, human livelihoods, and economic development would be enormous.

El Nino impacts

Changes in El Nino as consequence of climate change is a concern for the Amazon region. There are huge impacts on the economic side related to strong El Nino events and an increase in these events would have adverse consequences. There is significant uncertainty in projections of the El Nino response to climate change; nevertheless, more frequent or intense El Nino events will have tremendous deleterious effects on natural sites and bring large economic losses.

The Amazon and the Carbon cycle

The Amazon plays an important role in the planetary carbon cycle however the current carbon balance is uncertain. Deforestation leads to large releases of carbon whereas elsewhere in the forests there appears to be a large uptake. Recent studies indicate that the rivers and aquatic systems in the region play an important and unexpected role in the regional carbon balance through the out gassing of large amounts of CO_2 (0.5 GtC/yr). It is not yet known what the disruption to this natural process would do to the global carbon cycle and to the global balance of sources and sinks of carbon.

X. Andean Region

High mountain ecosystems and economic activities at high altitude, or (those depending on) high altitude systems, are very vulnerable to climatic warming.

Loss of glaciers

In the next 20-30 years there is expected to be a massive loss of glacial area and volume below 5,000 metres with negative consequences for hydropower, increased seasonality of river flows with adverse consequences for human activities. Glaciers below 5,500 metres are projected to disappear within 10-20 year timeframe if recent climate trends continue.

Water resources

Higher sea surface temperatures in the tropical Pacific are expected to lead to rainfall declines on the western slopes of the Peruvian Andes. With human population pressures and increasing demands in the region substantial dangers to water resources are predicted. Lima with a current population of 8 Million people is experiencing water shortages associated with a recent decline in rainfall and increase in the frequency of dryer years. Further rainfall declines are projected while the population is projected to increase considerably over the next few decades - major problems are foreseen related to drink water, energy generation and agriculture. At present it is not clear that economically feasible adaptation options exist, with the transport of water from the eastern slopes of the Andes being prohibitively expensive and likely to create problems in that region as well.

Glacial retreat is expected to reduce water availability in the region after a period of floods threatening existing infrastructure due to glacier melting. Food security and power generation will be affected as in the case of Peru almost 70% of power generation is hydro-electric.

Economic development

Loss of life and damages to main economic activities such as mining are predicted for high altitude regions as a consequence of warming and related climate changes leading to increased risk of avalanches, land slides, glacial outburst floods etc.

Food production

Risks to food production are already evident due to recent rainfall declines and are expected to grow rapidly with temperature increases that lead to further reductions in rainfall. Rice production may not be possible in the coast in the near future.

Extreme events

The five Andean countries of South America are especially vulnerable to El Niño events . Increases in extreme events such as flooding, cold surges, droughts, and extreme El Niño related phenomena have been observed and are consistent with projected changes and are expected to increase in the future, with significant risks of economic losses.

XI. Russia

Russia is likely to face temperature increases significantly above the global average, especially in the high latitude arctic regions. While some regions, especially the arctic regions, are likely to face increased precipitation, drought frequency is likely to increase in regions with current agricultural production, including West Siberia and North Caucasus.

Food production

Climate change is expected to cause either small losses or even some increase in total agricultural production in Russia, which peaks at a level of 1°C-3°C local temperature increase. Impacts will not be evenly distributed so that some key "productive" regions face declining production while most other ("consumption") regions get significant benefit from wetter and warmer weather. For example, average potential production of grain (wheat and rye) in the highly populated and productive regions (Volga, Central Black Earth, North Caucasus) will drop by 8 to 29% in the 2020s. The decrease is unlikely to affect food situation in these regions and they will still have some crop surplus to export. By the 2070s, increase in annual average temperature by 3–6°C (relative to “climate normal”) will bring a countrywide drop in production, ranging from 5 to 12 percent. and about 14 to 41 percent in the main agricultural regions. These results of recent modeling of impact of climate change on Russian agriculture (Kirilenko 2004) are consistent with earlier findings (Sirotenko and Abashina 1994).

But the preceding small changes averaged over many years may be not be as important from the standpoint of food security as changes in the frequency of poor harvests. Small average losses do not imply a serious food problem since they can be probably be compensated by food imports or by small changes in the types of crops grown. More serious are the occasional but severe droughts that can lead to temporary but serious shortfalls in food production (Golubev 2004). Under current climate conditions, bad harvest typically occur in the main crop export regions during roughly one to three years out of every decade. Under climate change some regions may experience a doubling of the frequency of bad years after the 2020s and even a tripling after the 2070s (Alcamo 2003). This also means that there is a higher chance that several parts of the main crop export regions will experience poor harvests in the same year. Because much of Russia is dependent on the crops produced in these few regions, the effects of drought will be felt throughout the country. Given the likely diverse patterns of potential benefits and adverse impacts on crop production, inter-regional political tensions are likely (i.e. some regions may restrict exports, on which other regions vitally depend).

Potential adaptation strategies for the agricultural sector might include: balanced production of crop and livestock, diversification of crop varieties, expanding of irrigated area, food imports and northward shifting of cultivation areas. Each potential adaptation strategy has its own economic, social, and political costs and limits.

Ecosystems

Based on historic observations, one might expect Russian ecosystem’s resilience to be generally high. Several facts mitigate against this however. Firstly, some changes in ecosystems can already be observed as a consequence of stress which is attributable to current climate changes, e.g. in the Altai-Sayan Region. Secondly, climate is likely to change beyond historically experienced bounds in the future. With potentially high temperature increases, especially in the high latitude northern regions and in mountainous regions (+4°C and more by 2100 in the north), ecosystem resilience is likely to be challenged beyond its adaptive capacity. Forest fires are projected to increase in frequency and intensity. Furthermore, as in many other regions of the world, climatic stresses are often enhanced by other human-induced factors, such as air water and ground pollution.

Polar bears at the northern edge of Russia are among the key endangered species along with snow leopards in the high mountain areas of the Altai-Sayan region. Beyond its geographical boundaries, ecosystem changes in the Siberian tundra will affect migratory bird populations on the Eurasian continent (WWF 2001a, b, 2002, 2003a, b).

Human health

Already observed extreme events, such as heat waves in Moscow, are likely to be further enhanced in the future. In conjunction, the accompanying serious impacts on human health will rise. Furthermore, vector-borne diseases are likely to spread northwards (Adamant 2004).

XII. Arctic Region

The Arctic Region is experiencing profound environmental, social and cultural impacts of human-induced climate change now. Future impacts will be particularly intensive and will endanger not only animal species but also aboriginal cultures (See recently released key findings of the Arctic Climate Impact Assessment: http://www.amap.no/acia/index.html). A global mean warming of 2°C will correspond to much higher arctic temperatures.

Different models predict the nearly complete loss of summer arctic sea ice by the end of this century. With the reduction and loss of sea ice, polar bears, ice-dependent seals, walruses and certain sea-birds are facing extinction. For Inuit, warming will mean the destruction of their hunting and food sharing culture.

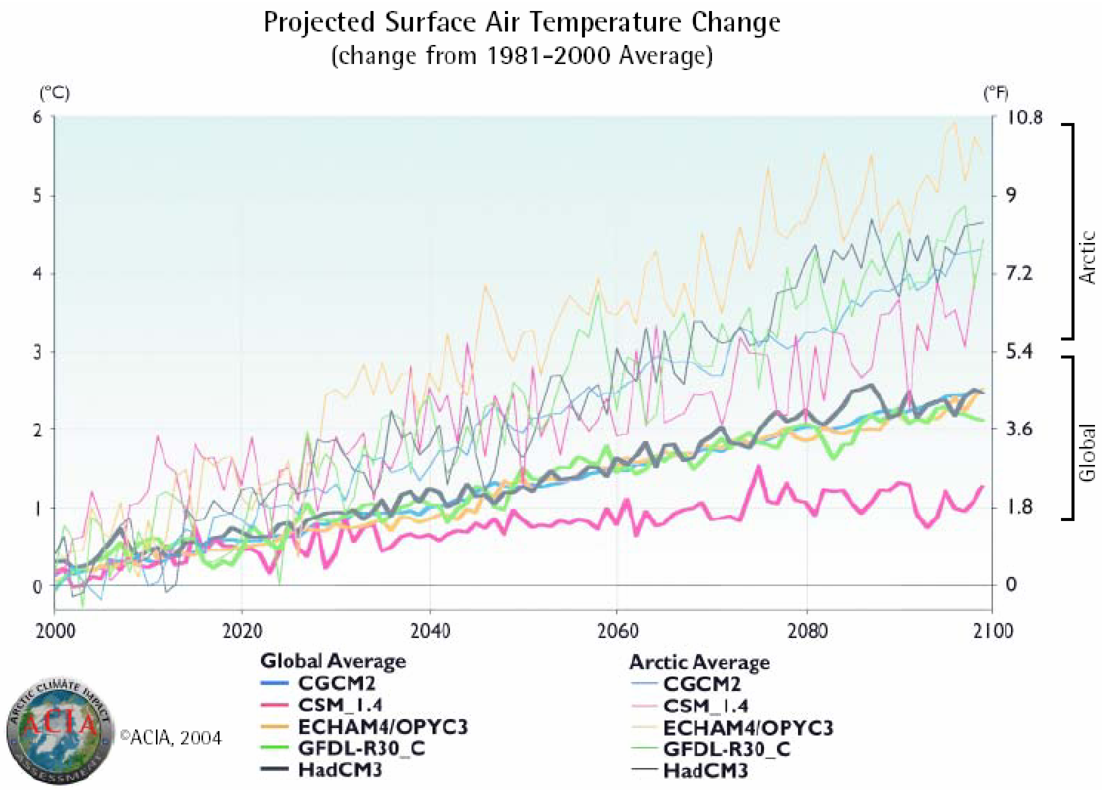

Figure 1 - Projected Surface Air Temperature Change for global average and Artic region (Source: ACIA 2004)

Complete loss of summer sea ice possible

The already experienced warming in the past three decades is about 1.8°C. Winter increases in Alaska and Western Canada have been 3-4 ºC over the last fifty years. Sea ice extent has decreased by 15% to 20%. Sea ice now retreats earlier in the year from the coast causing increased coastal erosion and disrupted access to food sources for indigenous people. The projections for the Arctic region are dire. For a 2°C global mean temperature rise above pre-industrial levels (corresponding to a 4 to 8°C increase in the Arctic) models predict the loss of summer arctic sea ice by the end of this century (Johannessen *et al.* 2004).

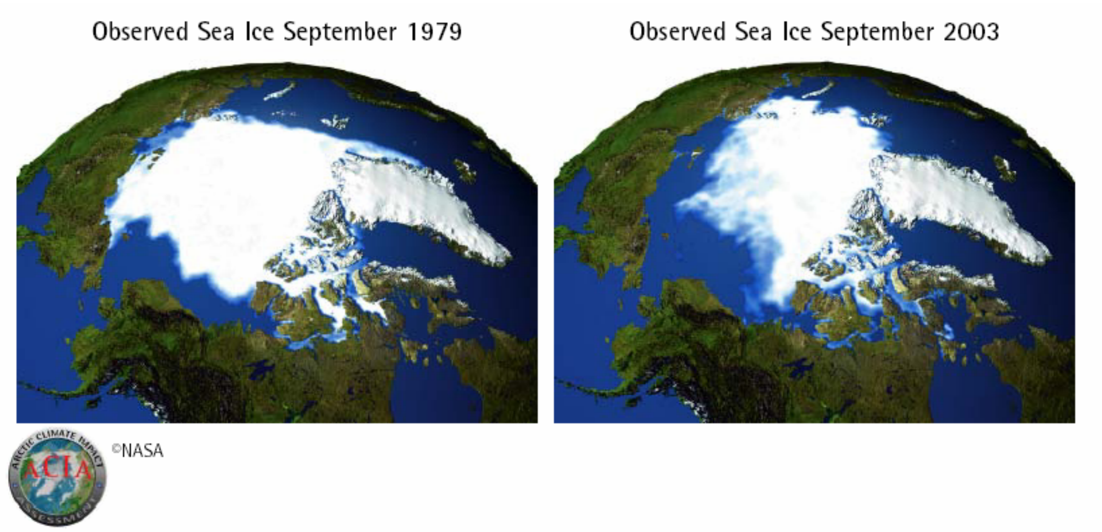

Figure 2 – Observed sea ice extent in September 1979 and September 2003 (Source: ACIA 2004).

Figure 3 – Projected ice extent 2070 to 2090 (5-model average for September) (Source: ACIA 2004).

The human dimension

In the Arctic, the consequences of human-induced global warming pose profound ethical questions as the survival of the traditional Inuit hunting culture is endangered. Currently, the arctic region provides hunting grounds and living space for 155,000 Inuit who have lived sustainably for millenia As the species that Inuit depend on are less accessible and become extinct, the foundation of the Inuit hunting culture will no longer exist. Human-induced climate change will also severely disrupt infrastructure that is dependent on permafrost and will increase the risks to coastal settlements.

Ice-dependent animals facing extinction

Polar bears, walruses, some marine birds and certain types of seals are tightly linked to the Arctic's summer sea ice. The loss of the summer sea ice will push these species to extinction. Furthermore, species on land currently adapted to the Arctic environment, like lemmings, arctic foxes and snowy owls, are at risk. Caribou and reindeer herds will also be stressed. Vegetation shifts in tundra ecosystem including reduction in permafrost create substantial risks. In addition, there is a risk to fisheries, especially northern freshwater fisheries.

Global implications

Increased melt water inflow from the adjacent Siberian, Canadian and Alaskan rivers and a potentially decreasing Greenland Ice Sheet could adversely affect the stability of the thermohaline circulation. Increased freshwater fluxes seem to be already about 20% of what might be needed to shutdown the thermohaline circulation according to some models. Conservative projections suggest that the contribution of Arctic glaciers, including the Greenland Ice Sheet, to global sea-level rise will amount to four to six centimetres over the next century. Over the long term, the contribution will increase greatly. Models predict that if warming is sustained over the Greenland Ice Sheet it will eventually melt completely, contributing about seven meters of global sea-level rise over many centuries to a few thousand years depending in the magnitude of the warming. Methane releases from the Arctic tundra as it melts pose a risk of positive feedback accelerating climate change. The stability of methane clathrates in the relatively shallow Arctic sea bed is difficult to assess but remains a risk.

XIII. Small Island Developing States: Pacific and the Caribbean

The Small Island Developing States (SIDS) of the Caribbean, Indian Ocean, Mediterranean and Pacific regions inherently have many common and unique characteristics (e.g., small physical size, geographically located at weather and climate sensitive regions, limited natural and human resources, sensitivity to external shocks, etc.) that serve to increase their sensitivity and vulnerability to the impacts of climate variability, anthropogenic climate change and sea level rise, in particular extreme events such as tropical cyclones (hurricanes) and droughts (Nurse *et al.* 2001).

Past and present climate trends

Much of the natural variations in the weather and climate of SIDS are determined by the El Niño Southern Oscillation (ENSO) phenomenon at the seasonal to interannual time scales and the Interdecadal Pacific Oscillation (IPO) on decadal time scales. For the South West Pacific, ENSO operates in conjunction with other large scale oceanic and atmospheric circulation modes like the South-Pacific Convergence Zone (SPCZ) and the Intertropical Convergence Zone (ITCZ), increasing the amplitude and spatial extent of the variability in temperature, rainfall and extreme events' patterns (Manton *et al.* 2001; Folland *et al.* 2002; Griffiths *et al.* 2003; Nicholls *et al.* 2004)

Analyses of temperature and precipitation trends in the Southwest Pacific showed temperatures increase between two decades, 1911 to 1920 and 1981 to 1990 amount to 0.9°C, with the first decade being the coolest, and the last the warmest (Salinger 2001). Salinger, (2001) showed the two regions south-west of the SPCZ display steady climate warming from the beginning of instrumental records and two zones north-east cooled until the early 1970s, and subsequently warmed. The period since 1950 showed quite substantial climate warming in both near-surface land and ocean temperatures throughout the region. Trends in SST are less, only amounting to 0.2°C. Sea surface temperatures also have increased by about 0.4°C since 1951. Minimum air temperature increased by 0.8°C, almost twice the magnitude of maximum air temperatures increase of 0.4°C. This relates closely to significant decreases in sunshine (-1.7%/decade) and increases in cloud cover. Since the 1980s rainfall has increased 30% relative to the reference period. A recent analysis of island and marine temperature trends by (Folland *et al.* 2003) showed there are some differences in island and marine temperature trends especially in the two regions southwest of the SPCZ.

Rainfall has been observed to decrease in the Western hemisphere and the Subtropics, and in the Eastern equatorial region, a pattern that is projected to be reinforced in the coming century. This is consistent with the general expectation of more frequent El Niño-like conditions. The consequence of more frequent El Niño-like conditions are generally adverse and include the likelihood of increased convective activity and sea surface temperatures (SST) (IPCC 2001). While increases in SST favour the development of more and stronger (tropical cyclones, increased isolated convection stabilises the tropical troposphere and this in turn could suppresses organised convection making it less favourable for vigorous tropical cyclones to develop (Stocker *et al.* 2001).

Recent analysis suggests projected increased surface air temperature for all regions in which the SIDS are located. The range of projected increases in surface air temperature for the period 2010 to 2099 is 0.49 to 4.19°C for the Northern Pacific, 0.45 to 3.11°C for the Southern Pacific and 0.48 to 4.18°C for the Caribbean (Ruosteenoja *et al.* 2003).

Recent analyses (Krishna *et al.* 2000; Trotz 2002; Hay *et al.* 2003) suggest extreme events appear to have increased both in frequency and severity in tropical SIDS regions in the last few decades. Tropical Cyclone Val in Samoa in the South Pacific in 1991, for example, caused an estimated US$300 million damages. The cost of extreme weather events in the Pacific in the 1990s alone exceeded US$1 billion (World-Bank 2000). Tropical Cyclone Heta caused extensive damage to property and loss of lives in Niue, Tonga and Samoa in 2004. The Caribbean region also experienced major damages from extreme events largely due to hurricanes. The period between 1960 and 2000 witnessed an exponential increase in the occurrence, severity and intensity of disasters, especially during the last decade (Table 1).

Hurricane Ivan in 2004, for example, that struck Grenada, Cayman Islands, Cuba and Jamaica caused billions of dollars in economic losses. The Director-General of the Planning Institute of Jamaica (PIOJ) was quoted in a local newspaper nearly four weeks after that Ivan caused an estimated $36 billion (over US$580 million) damages in Jamaica alone. Local insurance companies in Cayman Islands indicated that six weeks after the passage of Hurricane Ivan, based on claims notified, estimated losses to the insurance industry have surpassed the CI$700million (nearly US$850 million) mark (Cayman Islands Future, 2004).

Damage in some cases has exceeded the national GDP of some countries such as Samoa in 1990/91 and Niue in 2004. The recent estimate of damage inflicted on Grenada by hurricane Ivan is in the vicinity of close to 0.90 billion US dollars (2.4 billion EC dollars) amounting to 201% of the island's current GDP, according to government officials.

Whilst an anthropogenic signal is not yet scientifically determined at this stage, it is clear that anthropogenic climate change and sea level rise are highly likely to substantially exacerbate these present risks and damages.

Table 1: Main Natural Disasters in the Caribbean (1979–2001)

Year	*Country (Hazard Type)*	*Persons Affected*	*US (000´s)**
1979	Dominica (David and Frederick)	72,100	$44,650
1980	St. Lucia (Allen)	80,000	$87,990
1988	Dominican Republic (Flood)	1,191,150	
1988	Haïti (Gilbert)	870,000	$ 91,286
1988	Jamaica (Gilbert)	810,000	$ 1,000,000
1989	Montserrat (Hugo)	12,040	$ 240,000
1989	Antigua, St. Kitts/Nevis, Tortolla, Montserrat (Hugo)	33,790	$ 3,579,000
1991	Jamaica (Flood)	551,340	$ 30,000
1992	Bahamas (Andrew)	1,700	$ 250,000
1993	Cuba (Storm)	149,775	$ 1,000,000
1993	Cuba (Flood)	532,000	$ 140,000
1994	Haiti (Storm)	1,587,000	
1995	St Kitts & Nevis (Luis)	1,800	$ 197,000
1995	US Virgin Islands (Marilyn)	10,000	$ 1,500,000
1998	Dominican Republic (Georges)	975,595	$ 2,193,400
2000	Antigua/Barbuda, Dominica, Grenada, St. Lucia (Lenny)		$ 268,000
2001	Cuba (Michelle)	5,900,012	$ 87,000

** valued at the year of the event.Source: OFDA/CRED International Disaster Database (EM-DAT) 2002. #USAID/Jamaica 2000, Hurricane Lenny Recovery in the Eastern Caribbean.*

Future climate trends

Scenarios developed by the Adapting to Climate Change in the Caribbean (ACCC) project, suggest that the number of severe hurricanes (category 4 and 5 storms) is assumed to be 2 in the low case and to equal the 1999 level of 4 in the high case. The intensity (maximum wind speed) of the strongest hurricanes is projected to rise by 5% in the low scenario and by 15% in the high scenario (IPCC 2001).

A recent study by NOAA (Knutson and Tuleya 2004) on the impact of CO_2-induced warming on simulated hurricane intensity and precipitation and their sensitivity to the choice of climate model and convective parameterization demonstrated nearly all combinations of climate model boundary conditions and hurricane model convection schemes show a CO_2-induced increase in both storm intensity and near-storm precipitation rates. The aggregate results, averaged across all experiments, indicate a 14% increase in central pressure fall, a 6%

increase in maximum surface wind speed, and an 18% increase in average precipitation rate within 100km of the storm centre. One implication of the results is that if the frequency of tropical cyclones remains the same over the coming century, a greenhouse gas induced warming may lead to a gradually increasing risk in the occurrence of highly destructive category 5 storms.

Other analyses to characterise trends in extreme events in the SIDS region (Henderson-Sellers *et al.* 1998; Brazdil *et al.* 2002; Folland *et al.* 2003; Burgess 2004) demonstrated the dominant role of ENSO in modulating the climate of the region leads to significant variability in the frequency of many extreme events, such as tropical cyclones, droughts, SSTs, floods and in some cases, fire weather.

Henderson-Sellers *et al*., (1998) found the North Atlantic and the western Pacific show substantial multidecadal variability, particularly for intensity Atlantic hurricanes but there was no clear evidence of long-term trends. They also demonstrated thermo dynamical estimation of the maximum potential intensities (MPI) of tropical cyclones shows good agreement with observation.

Burgess (Burgess 2004) showed the number of tropical cyclones affecting the tropical South Pacific was slightly below the long term average for the South West Pacific in recent seasons with the 2003- 2004 season recording the lowest ever number of tropical cyclones since records began with only four affecting the region. There is however a possibility that this low occurrence of tropical cyclones in the tropical South Pacific could be attributed to the synchronisation effect between tropical cyclone occurrence in the Atlantic Ocean and the tropical Pacific ocean. During an El Niño, for example, the incidence of tropical cyclones typically decreases in the Atlantic and far western Pacific and the Australian regions, but increases in the central and eastern Pacific (IPCC 2001). Thus decreases in one region may be offset by increases in another region because of the global connectivity of the tropical atmospheric circulation.

Coral reefs and beaches in the Caribbean and the Pacific

The economy in many SIDS relies on tourism depending on high biodiversity of marine ecosystems, like coral reefs and mangrove forests. Coral reefs are under pressure from a range of human influences and coral bleaching is becoming more frequent. Many coral reefs currently operate at or above the tolerable level. As climate change progresses, it is expected that the frequency of sea surface temperatures (SST) could exceed local bleaching thresholds which could lead to permanent coral bleaching and other impacts on marine ecology, in some locations for a global warming as low as 1-1.5°C above pre-industrial levels. Apart from being crucial for tourism, coral reefs protect the shoreline. Reefs decay by coral bleaching would further increases vulnerability to storm surges on all time scales (seasonal, interannual and decadal). Within 50 years coral degradation and death could lead to losses annually of 140-420 million $US in the Caribbean alone (Burke and Maidens 2004).

Sea level rise, fisheries

Variability in fishery production, movement and distribution of fishery stocks (e.g. tuna) are highly dependent on the ENSO as well as to harvesting by local and commercial fisheries industries.

In the mid term (2050s) sea level rise is a concern for beach erosion and salt-water intrusion into freshwater lenses with adverse effects on water and food production, where it would exacerbate existing problems.

In the longer term sea level rise will be the crucial factor for these issues.

Limits to adaptation and need for mitigation

Given this background, there is an urgent need for SIDS to better adapt to existing climate variability and to projected anthropogenic changes, but this must also be accompanied by equally urgent and significant international efforts to reduce GHG emissions, in particular, by Annex I parties of the UNFCCC. The most immediate need for SIDS is to act now to reduce vulnerability to extreme weather events. This would go a long way towards preparing themselves for the future, and reducing the magnitude of damage from projected anthropogenic climate change.

Conclusions

The Small Island Developing States are key and vulnerable regions in the elaboration of the meaning of the ultimate objective of the UNFCCC. The huge social, human and economic losses associated with present-day extreme events, together with potentially even more losses due to projected climate change impacts, are major threats to SIDS immediate future economic viability. In the longer term, future existence of some SIDS could be fundamentally challenged, particularly low-lying states and those situated in zones often affected by extreme events.

Ultimately, adaptation cannot alone sufficiently address the challenge. It must be accompanied by immediate and significant mitigation measures implemented first and foremost by Annex I parties to the UNFCCC as a first step towards reducing the causes of climate change. Complementary adaptation and mitigation activities will therefore serve to minimise the human and economic costs of present damages from extreme events and prevent a large part of the projected damages from anthropogenic climate change.

CLIMATE SYSTEM RISKS - BACKGROUND

Introduction

Participants felt that the identification of potentially dangerous climate changes can be undertaken on different levels. These levels are hierarchically ordered along the cause-effect chain, albeit often interlinked. One set of dangerous climate thresholds can be identified by analyzing changes to the geophysical climate system, its key subsystems and extreme events. That is because in these cases the potential physical impacts are of a magnitude which would be widely agreed to be dangerous, even without detailed analysis of the ‘downstream’ impacts, e.g., on ecosystems or food production. For example, several meters sea level rise over a few centuries would result in widespread loss of coastal and deltaic areas (such as Bangladesh, the Nile, Yangtse and Mekong Delta regions), including their ecosystems and human settlements, including many of the world’s largest cities.

A significant acceleration of climate change due to biogeophysical (carbon cycle or methane hydrate) feedback mechanisms might be considered as dangerous in at least two ways. Firstly the additional temperature increases could be dangerous as above certain magnitudes and rates of change there is the potential to significantly magnify climate impacts. Secondly there is a danger in feedbacks leading to “loss of control” over the climate system. At present, technologies and polices that are considered feasible could plausibly limit warming and even ultimately reduce it. However, if large scale positive feedbacks occur then these could make a stabilisation of greenhouse gas concentrations impossible with known technologies and policies. Hence, feedback mechanisms are here included in the analysis of changes to key climate subsystems.

Below, a distinction is drawn between potentially dangerous levels of climate change that result from changes to key climate subsystems, like sea level or thermohaline circulation (see Table I), and a potential increase in the frequency, strength and duration of extreme events (Table II). The primary concern of the discussions in the climate system group was climatic changes that result in direct physical damages, rather than the more subtle long-term shifts of regional climates that might cause dangerous impacts to ecosystems, food security or human health (Table III).

Potentially dangerous changes of key climate subsystems

- *Sea level rise:* Given that a major part of human settlements, agricultural zones and unique ecosystems are located in coastal areas, significant sea level rise, say 3 to 5 meters over a few centuries, would clearly constitute a ‘dangerous interference’ of global dimensions. Most beaches, small island states, many heavily populated deltaic regions and many large cities would be lost. A review of the recent scientific advances in our understanding show that a sustained global mean surface temperature increase of about 3°C above pre-industrial levels is likely to cause such a 3-5 meter sea level rise increase by 2300. Hence, a long-term stabilization of greenhouse gas concentrations at twice the pre-industrial CO_2 concentrations (2x280 ppm = 560 ppm CO_2eq) would not be sufficient to prevent this dangerous interference. Our current knowledge of the climate system points towards a climate sensitivity of approximately 3°C for CO_2-doubling and higher warming cannot be excluded, hence stabilizing greenhouse gas levels well below 560 ppm seems warranted as a precautionary measure. Even a 2°C global mean warming may not avoid the risks of disintegrating ice-sheets and significant sea level rise in the long term. Besides the thermal expansion of sea water and the melting of mountain glaciers, the potential decay of the Greenland and the irreversible disintegration of the West Antarctic Ice Sheet may contribute to rising sea levels in excess to what has been estimated in the IPCC TAR, as recent observations show dynamical processes of ice sheet decay at work which have not been included in the ice sheet models used for the TAR projections.
- *Arctic warming:* As warming rates in the Arctic are up to several times larger than the global mean average, the sea ice extent and thickness is projected to decrease significantly, particularly in summer. For a global mean warming of approximately 2.0°C above 1981-2000 or roughly 2.5°C above pre-industrial levels, the near complete loss of arctic summer sea ice and its ice-dependent seals, polar bears and walruses is projected by some models.
- *Thermohaline circulation:* A significant slow-down of the circulation would have large impacts on both the North Atlantic region (cooling, additional sea level rise, impacts on marine ecosystems and fisheries) and tropical regions (shift in precipitation belts associated with the intertropical convergence zone). The sensitivity of the thermohaline circulation to global mean warming is uncertain. A recent expert elicitation showed that several experts estimate that there is an at least 5% chance of a complete shutdown for a global mean warming of 2°C, and even in excess of 50% chance if warming exceeds 4 or 5 ºC. All asked experts expect a weakening of the North Atlantic current by 10%-50% within this century for a CO_2-doubling scenario.
- *Oceanic and atmospheric circulation systems*: Global warming is expected to lead to changes in large scale oceanic and atmospheric variability patterns. For example a shift to more intense El Niño Southern Oscillation (ENSO) event is projected in a number of models and there is emerging observational support for this (Boer *et al.* 2004). Associated impacts could be large as witnessed in the past for extreme El Niño events. Furthermore, it is expected that the Indian Monsoon would exhibit higher interannual variability(Lal *et al.* 1998; Lal *et al.* 2001; Lal

2003) with potentially devastating consequences for food security.

- *Carbon cycle and methane feedbacks*: Increased temperatures might cause terrestrial carbon cycle feedbacks and releases of methane hydrates, which in turn will accelerate global warming. Some studies suggest significant releases of soil carbon if global mean temperature increases to 2°C or 3°C above pre-industrial (see e.g. fig 3 in Jones *et al.* 2003). As well, one climate model suggests that the Amazon forest ecosystem might be replaced by savanna for a global mean warming of approximately 2°C to 3°C, causing not only a precious ecosystem to vanish but as well large releases of carbon (see Cox *et al.* 2004). Recent work by Archer (Archer *et al.* 2004; Buffet and Archer in press) estimates a substantial long term warming feedback from methane hydrate release triggered by warming oceans.

Potentially dangerous change of frequency, and strength of extreme events

Hurricanes, typhoons, cyclones, storm surges, floods, dust storms, heat waves & droughts may well increase due to human-induced climate change. Such a rise in frequency, and strength of extreme events might be defined as dangerous interference with the climate system. However, two issues currently complicate the task to draw clear lines of dangerous thresholds. Firstly, every single extreme event is likely to be a tremendous hazard for the affected regions, with impacts depending strongly on the level of preparedness. Thus, drawing a line where too much damage can be considered intolerable is an intrinsically difficult issue. Secondly, our current knowledge is still patchy when it comes to projecting changes in the timing, location, frequency and strength of extreme events (see Table II).

Summary

The climate system is likely to face several critical limits in its key subsystems if global mean temperature increases to 2°C to 3°C above pre-industrial levels; in some cases these are true thresholds, like the critical density threshold for shutting down important parts of the North Atlantic ocean circulation. Crossing such critical levels or thresholds is likely to result in widespread, often irreversible, damage and could therefore be termed 'dangerous anthropogenic interference with the climate system'. However, even global temperatures rises below 2°C cannot be considered as 'safe', given the large uncertainty in some of the thresholds. Long-term sea level rise, and increases in frequency and strength of extreme events are likely to adversely affect particular regions and ecosystems already for moderate warming levels below 2°C, while some risk of major ocean circulation changes also cannot be ruled out for lower levels.

Table I - Changes to key subsystems

What is dangerous anthropogenic interference with the climate system?	*Dangerous to whom? / Dangerous to what?*	*Dangerous by when?*	*Comments / Reference*
Sea Level Rise	Global coastal zones, especially river deltas, low-lying areas, small islands	2°C already too high for long-term. Assuming 3°C global mean temperature (~560 ppm CO_2eq) would cause 3-5m by 2300.	Large time lag, decisions now affect centuries to come / (Rahmstorf and Jaeger 2004)
> Decay of Greenland ice sheet	Global due to rise in sea level and depends in rate of decay of ice sheet and other sea level rise terms	2.7°C local warming threshold for complete decay. Global threshold: 1.5-2.9°C global mean temperature (GMT) increase over pre-industrial Rate of decay is thought to be linked to magnitude of temperature increase. For global mean warming in the range 2.4-5.2°C above pre-industrial levels the ice sheet is projected to raise sea level by about 3m over 1000 years (30cm/century)	Irreversible once ice sheet has lost sufficient altitude. / (Huybrechts *et al.* 1991; Gregory *et al.* 2004) Range here is due to uncertainty in amplification of warming over Greenland.
> Disintegration WAIS – Antarctica and consequent abrupt rise of sea level over several centuries of order 4-6metres.	Global due to rise in sea level	If ice shelves fringing the WAIS collapse, there would be a major risk of ice sheet disintegration. This could occur for a global mean warming between 2.5°C to 4.5°C above pre-industrial levels.	Irreversible. / (Oppenheimer and Alley 2004)
Sea ice	Polar Regions	Near complete loss of arctic summer sea ice predicted by some models for 2100 for approximately 2.5°C GMT.	(ACIA 2004; Johannessen *et al.* 2004)
Thermohaline circulation	North Atlantic region and tropics	Threshold exists, but unknown. Several experts estimate 5% at 2°C GMT.	Irreversible at least for 50 years, probably longer. / (e.g. (Rahmstorf 2000, see as well expert elicitation by PIK, in prep.))
Frequency & Magnitude of ENSO	Global	Already trend in ENSO index seen	(Timmermann *et al.* 1999)
Changes in other oceanic and atmospheric circulation features (Monsoon, IPO, etc.)	Regional impacts	Threshold unknown but some trends in frequency, duration, and timing of oceanic and atmospheric circulation patterns already seen	very uncertain
Carbon Cycle feedbacks / Destabilization methane hydrates	Global through enhanced greenhouse effect – regional through loss of ecosystems	Possible thresholds at 2°C to 3°C GMT (terrestrial carbon storage, including Amazon rainforest). Uncertainty on methane hydrates	Paleodata shows positive feedback / (Cox *et al.* 2000; Cramer *et al.* 2001; Jones *et al.* 2003; Archer *et al.* 2004; Cox *et al.* 2004)

Table II - Extreme events

What is dangerous anthropogenic interference with the climate system?	*Dangerous to whom? / Dangerous to what?*	*Dangerous by when?*	*Comments / References*
Hurricane frequency & intensity / typhoons / cyclones	Tropical & other coastal regions	No clear threshold. Increase of intensity and associated precipitation expected with warmer SST.	(see e.g. Knutson and Tuleya 2004)
Storm surges	Coastal areas		Linked to hurricanes and increased by sea level rise.
Dust storms	Arid/Semi-arid continental regions	No clear threshold.	
Heavy rainfalls / floods	Global	No threshold. Increase in majority of regions expected.	
Heat waves	Nearly global	Already increased in some regions. Further Increase expected.	(see e.g. Schär *et al.* 2004)
Droughts, including long-term drying	Many regions	Already increased in some regions. Further Increase expected.	
Landslides	Mountains, coastal regions		thawing of ground, heavy rainfall
Tornados			high uncertainty
Thunderstorms / Lightning			high uncertainty

Table III - Long-term shifts

What is dangerous anthropogenic interference with the climate system?	*Dangerous to whom? / Dangerous to what?*	*Dangerous by when?*	*Comments*
• Rain / Snow ratio • Permafrost thawing • Mountain glaciers • Diurnal changes • Humidity changes • Lake level • Surface moisture • Seasonal changes	Impact on identity and character at local and regional level	Some trends already observed at regional level.	

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