&beyond
4degrees

Implications of a global climate change
of 4+ degrees for people, ecosystems
and the earth-system

Abstract Book

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&beyond
4degrees

Opening session

Terra quasi-incognita: beyond the 2°C line

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The G8 countries as well as the most important developing countries have formally acknowledged the emerging scientific consensus that global warming should be confined to maximally 2°C. My presentation will first summarize salient general arguments why that "guardrail" should be observed and then sketch the scope of the challenges involved in holding the line. The latter analysis will be based upon recent insights on the relationship between planetary mean temperature and cumulative CO_2 emissions. According to the new report of the German Advisory Council on Global Change (WBGU), a full, fair and feasible solution of the climate problem can be derived from that "budget approach", yet its adoption by the multilateral political system is rather unlikely. Therefore, a world warming up by 3, 4 or even more degrees needs to be faced or, at least, imagined. The lecture will proceed by reviewing the state of the art concerning the highly nonlinear impacts on the Earth System that can be expected as a consequence of unlimited climate change or cannot be safely excluded to arise beyond the 2°C line. The focus will be on "tipping elements" in the planetary machinery and their possible interactions. The talk will conclude by touching upon the tantalizing question whether there is such a thing on Earth as a "run-away greenhouse effect".

4 degrees of global warming: regional patterns and timing

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If global mean temperatures reach 4°C above pre-industrial, which seems likely if greenhouse gas emissions continue at current rates for much of the coming century, we can expect a very wide variation in regional climate responses across the globe. This presentation examines a large number of climate simulations to assess such potential changes and the ranges of uncertainty in these. While most of the ocean surface is expected to warm at less than the global mean rate, the Arctic ocean surface is projected to warm faster than the global mean due to positive feedbacks from melting sea ice (Figure 1). At 4°C global warming, regional warming of 10°C or more is plausible in the Arctic. High levels of warming such as 7°C are also projected for many land regions. Precipitation patterns are also projected to change, but models disagree strongly on the regional details. On average across model ensembles, precipitation decreases of approximately 20% are projected in some regions, such as the Mediterranean, central America and southern Africa, although some individual models give much larger decreases in some regions (Figure 2).

Of key interest is the timing of when 4°C could occur. This depends on both the emissions scenario and on the strength of feedbacks between climate change and the carbon cycle. There is an emerging consensus that the airborne fraction of CO_2 emissions is expected to increase in response to climate change, accelerating the CO_2 rise and hence accelerating global warming. Clearly this would bring forward the time at which global warming would surpass 4°C for a given emissions scenario. However, uncertainties in the strength of carbon cycle feedbacks are large. This presentation assesses the current range of model projections for this timing, and identifies key uncertainties to be addressed.

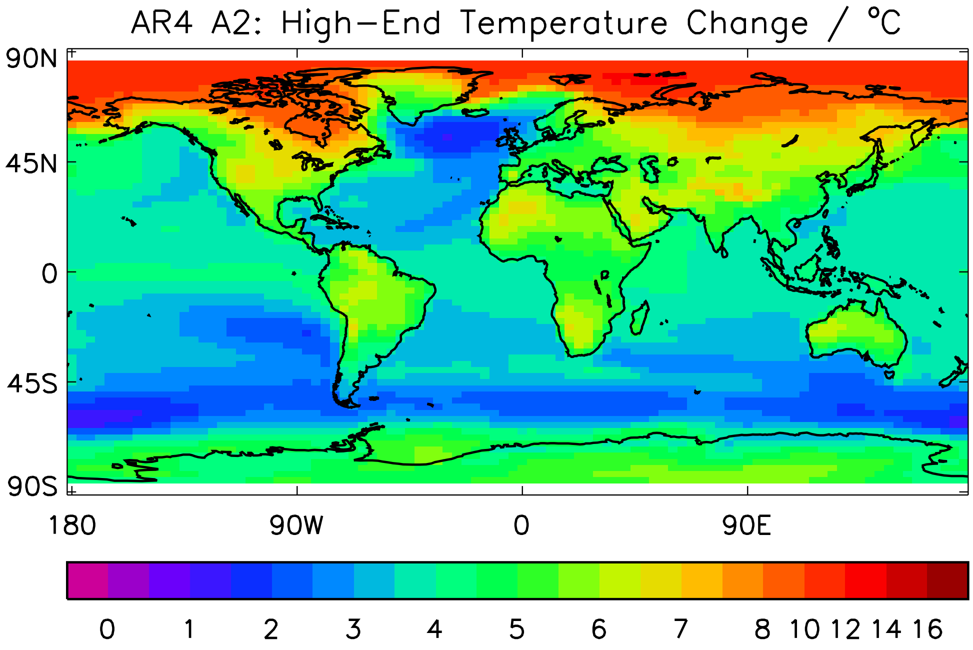

Figure 1. Ensemble mean patterns of temperature change (°C relative to 1961-1990 average) for "high-end" climate change projected by the subset of the IPCC AR4 climate models that exceed 4°C by 2100 relative to pre-industrial when driven by the A2 emissions scenario neglecting the effect of climate-carbon cycle feedbacks. "High-end" climate change is defined as exceeding 4°C relative to pre-industrial.

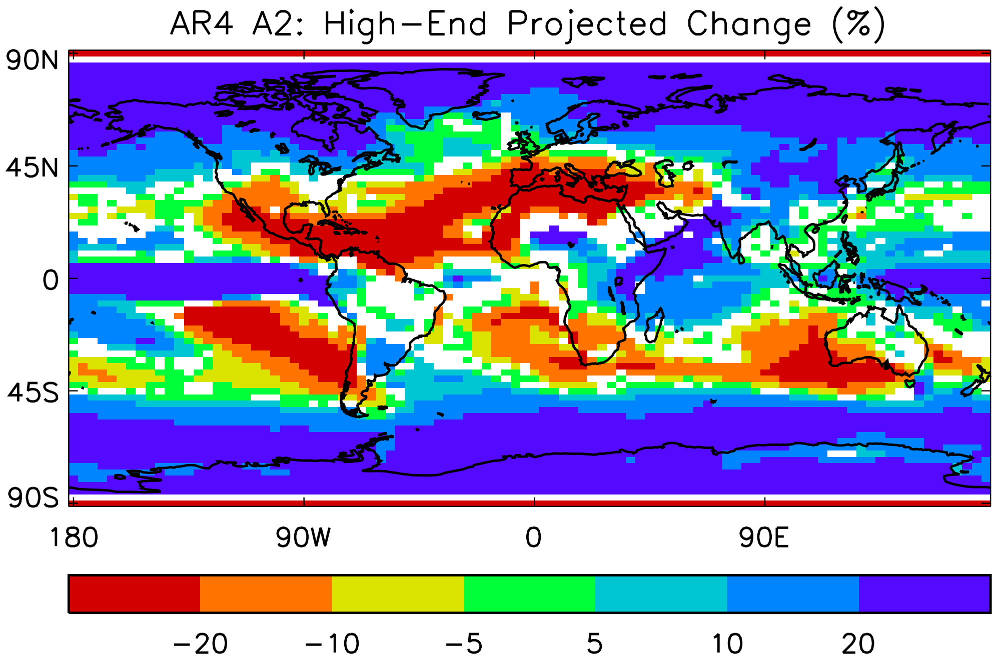

Figure 2. Ensemble mean patterns of precipitation change (% of 1961-1990 average) for "high-end" climate change projected by the subset of the IPCC AR4 climate models that exceed 4°C by 2100 when driven by the A2 emissions scenario neglecting the effect of climate-carbon cycle feedbacks. "High-end" climate change is defined as exceeding 4°C relative to pre-industrial.

Beyond 4°C: impacts across the global scale

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Most studies of the potential impact of climate change focus on impacts at the local and regional scales; there are few consistent projections of impacts across the global domain. The QUEST-GSI project takes a global perspective, using a suite of linked spatially-explicit impacts models with a range of socio-economic and climate scenarios. This presentation focuses on initial assessments of impacts, by the end of the 21st century, under large increases in global mean temperature (more than 4°C higher than pre-industrial), and compares these impacts with those under lower rates of change.

The QUEST-GSI project includes impact indicators representing water resources, flooding, food (crops, fisheries and food security), health, and the environment (terrestrial ecosystem productivity, biome types and soil carbon). The models mostly operate at the fine resolution gridded scale (or by coastal unit), with results aggregated to country and regional levels. Climate scenarios are derived from the climate model simulations presented in the IPCC's Fourth Assessment Report (the CMIP3 data set), and are scaled to represent the regional and seasonal changes in temperature, rainfall and other climate variables corresponding to a set of defined changes in global mean temperature ranging from 0.5°C to 6°C above the 1961-1990 mean. For most of the climate models, estimates of climate change for increases in global mean temperature above 4°C are an extrapolation beyond the climate model results, and at such high increases in temperature the assumption that regional and seasonal climate changes scale linearly with global mean temperature becomes increasingly unrealistic; estimated impacts at such high global temperature changes are therefore more uncertain than estimates at lower temperature changes.

The modelled biophysical impacts of these climate scenarios are then combined with socio-economic scenarios to express impacts in a range of socio-economic indicators.

A number of preliminary conclusions can be drawn from the analyses. A given change in global mean temperature corresponds to different changes in temperature in different places and at different times of the year, with different climate models producing quantitively different patterns of change. Regional temperature changes tend to be above the global mean in high latitudes, and close to or below the global mean in low latitudes (and below the global mean across most of the oceans; overall the increase in temperature across land is greater than the global mean). Temperature changes vary through the year. For example, a 4°C change in global mean temperature change corresponds to an increase in December-February temperature in southern Asia under one model of 6°C, but an incease in June-August of "only" 3°C. Whilst there is a broad degree of consistency in the qualitative patterns of change in climate between models – with notable exceptions in south Asia and parts of Africa – different climate models produce quantitatively different estimates of the regional consequences associated with a given change in global mean temperature. The estimated impacts associated with that change in global mean temperature are therefore quantitatively uncertain, particularly at the local and regional scale, and depend on which climate models are considered.

In many impact sectors, the response between rate of climate forcing and impact is non-linear, so that, for example, impacts under a 4°C global change are not necessarily twice the impacts under a 2°C change. In biophysical systems this can occur because of phase-state changes (e.g. the switch from snowfall to rain produces a "regime shift" in hydrological regimes) or because the relative effects of different drivers of change – such as temperature and precipitation – vary as these drivers change. For example, in some locations wheat yields increase for relatively low temperature and rainfall changes, but decrease for larger changes as the damaging effect of high temperatures begin to dominate. It is not therefore possible to infer directly impacts at one global temperature change from impacts estimated at another.

The shape of the relationship between magnitude of climate change and impact, and hence on the relative impacts with "low" and "high" climate change, varies between regions. Figure 1 shows the proportion of regional population exposed to an increase in water resources stress, under one climate model (different models produce different shape relationships). In some regions a relatively low climate change (<1°C) is sufficient to trigger large adverse impacts, whilst in others major step changes in impact occur only at higher temperatures.

The actual impact in socio-economic terms of a given biophysical change depends on the socio-economic conditions pertaining at the time. For example, a 4°C increase in global mean temperature in 2080 would, under one climate model, mean that approximately 1 billion people would be exposed to increased water resources stress under one population scenario, but under another, more populous scenario, the figure would be closer to 2 billion people (a slightly larger proportion of a much larger population).

The estimated impacts of high rates of climate change are, therefore, dependent on the climate models used to project the regional and seasonal changes in climate associated with a given global temperature change, and assumed future socio-economic conditions (including adaptive capacity); impacts at one temperature change also cannot be inferred directly from impacts at another. Nevertheless, the presentation concludes with a initial qualitative multi-sectoral assessment of impacts across the global domain at 4°C change above 1961-1990, based on multiple climate model runs and a range of socio-economic futures.

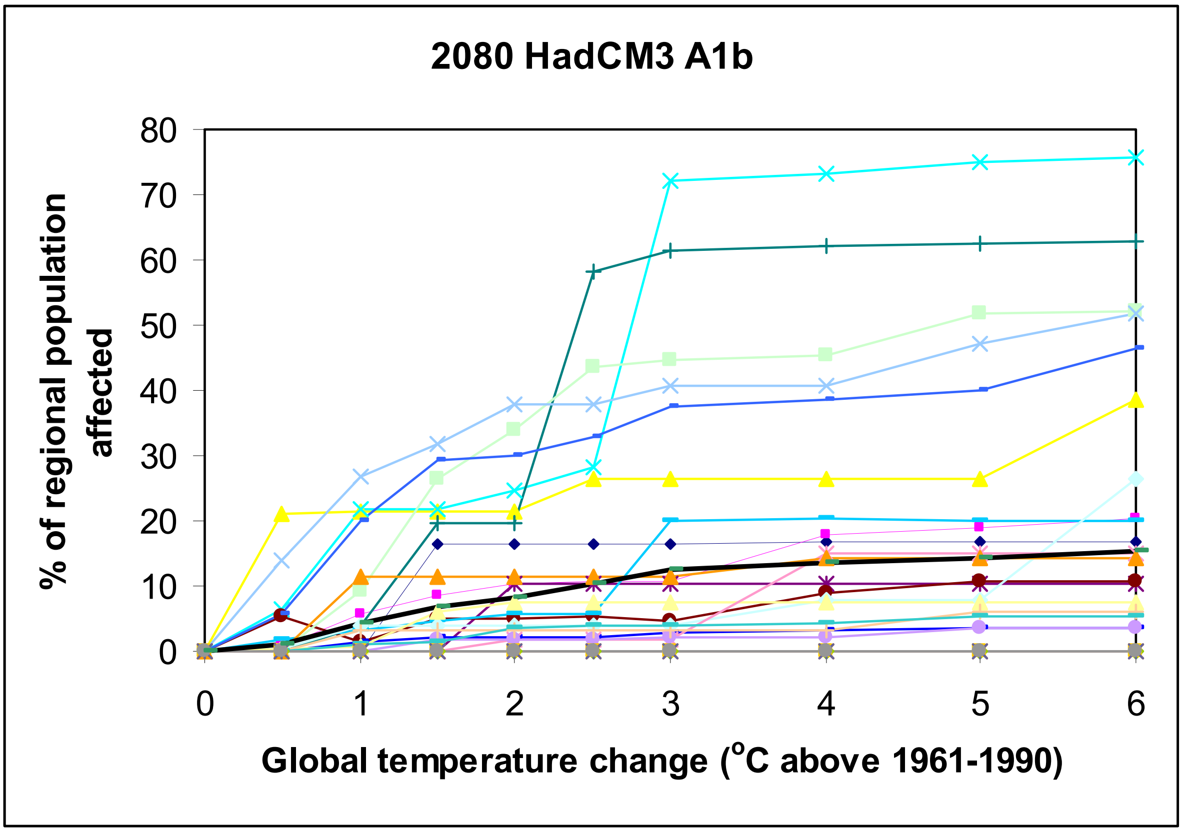

Figure 1: Regional impact of rising global temperature on the proportion of regional

Agriculture, Food and Water Security

Four degrees plus: What might this mean for agriculture in sub-Saharan Africa?

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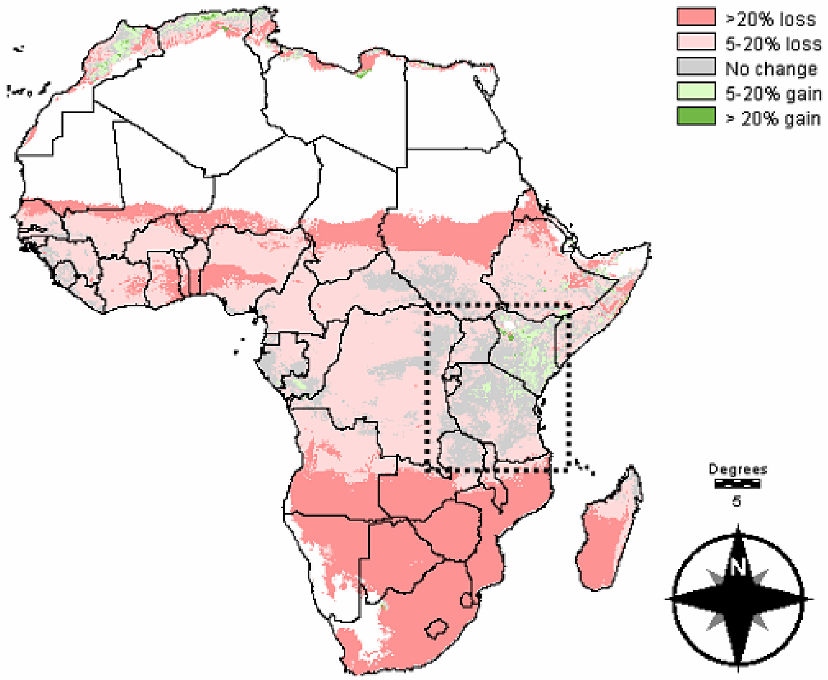
Potential impacts of climate change on agricultural production in sub-Saharan Africa (SSA) have been assessed in numerous studies recently. Ranges for major crops depend on the methods and models used, and the emission scenarios simulated, but for maize there is some consensus that yields may be reduced overall by 10-30% to the middle of the century (Challinor et al., 2007; Lobell et al., 2008). Despite the uncertainty, African agricultural productivity will be severely affected in the coming decades by climate change. The losses estimated in the literature are generally incomplete, however. First, they are often aggregated, hiding great heterogeneity. For example, there will be areas in East Africa, particularly in the lowlands, where crop yield reductions of 40% or more may occur for the staples maize and beans, largely as a result of increasing temperatures (Thornton et al., 2009). Second, it is not clear how the impacts of carbon fertilisation on crop yields in an African context might best be addressed. There is ongoing debate about the size of the effects on the physiology of crops (Ainsworth et al., 2008); there are also knowledge gaps concerning the impacts of changing ozone concentrations on crop growth and how these may interact with CO_2 effects and with other biotic and abiotic stresses (Challinor et al., 2009); and the carbon fertilisation impacts on the low-input subsistence production systems that prevail in SSA will generally be smaller than those seen in controlled, high-input environments. Third, agricultural production will be affected by climate change not only over the long term but also over the short; the impacts of changing extremes and increasing weather variability on agricultural production are largely unknown, pending the generation of robust estimates of future variability associated with specific greenhouse-gas emission scenarios.

The multi-model means of surface warming (relative to 1980–1999) for SRES scenarios A2, A1B and B1 from the IPCC's Fourth Assessment show increases of about 1-2°C to the 2050s and about 1.5-3°C for the 2080s (Meehl et al., 2007), and many of the impact studies carried out to date have used these scenarios. What would be the likely effects on agricultural production in SSA of warming of 4°C or more? To throw some light on this question, we carried out some downscaling and simulation runs using climate projections from AR4 climate model runs assembled by New and colleagues, available at http://www.geog.ox.ac.uk/ ~clivar/ClimateAtlas/ 4deg.html. We used an ensemble mean of the three AR4 emissions scenarios and the 14 GCMs for which data were provided, and anomalies were scaled to a global temperature increase of 5°C. The climate differences were downloaded at a resolution of 1° latitude-longitude. As in previous work, we used WorldClim climate data aggregated to 10 arc-minutes (to speed the analysis) (Hijmans et al., 2005), which we took to be representative of current climatic conditions. We produced a grid file for Africa of climate normals for future conditions at 10 minutes by interpolation using inverse square distance weighting. We then generated the daily data needed (maximum and minimum temperature, rainfall, and solar radiation) for each grid cell using MarkSim, a third-order Markov rainfall generator (Jones et al., 2002) that we use as a GCM downscaler, as it uses elements of both stochastic downscaling and weather typing on top of basic difference interpolation.

We carried out two sets of analyses. First, we estimated the average length of growing period (LGP) for each pixel in SSA. LGP was calculated on a daily basis using methods outlined in Jones (1987), ignoring intervening drought periods, and is thus a proxy for the number of grazing days, but not necessarily of cropping success. Percentage changes in LGP between now and the 2090s are shown in Figure 1, for areas with at least 40 days LGP under current conditions. Much of the cropping and rangeland area of SSA is projected to undergo some loss in growing season length, and most of Africa in southern latitudes may see losses of at least 20%. Parts of East Africa may see moderate increases in growing period. We also calculated the primary season failure rate and reliable crop growing days per year (for methods see Jones and Thornton, 2009). Season failure rates increase for all of SSA except for central Africa; in southern Africa they increase to the point where nearly all rain-fed agriculture below latitude 15°S is likely to fail one year in two. These trends are much in accord with previous analyses (Thornton et al., 2006), only here the effects are considerably greater.

In the second analysis, we ran crop simulations for conditions in this 5-degree warmer world, for maize, *Phaseolus* bean, and an "indicator" pasture species, *Brachiaria decumbens*, a cultivated forage grass widely used for feeding to cattle in the tropics and subtropics. Runs were done using the models in the Decision Support System for Agrotechnology Transfer (DSSAT; ICASA, 2007) for the area in the dotted box in Figure 1, using similar methods as those described in Thornton et al. (2009). We ran 30-year replicated simulations for all pixels classified as cropland and pastureland in the dataset of Ramankutty et al. (2006). Average yields for the three crops are shown in Table 1 for current conditions and for the

Figure 1. Percentage change in length of growing period, 2090s compared with present, for the average of the three AR4 SRES scenarios scaled to a global temperature increase of 5°C, means of 14 GCMs.



2090s with a 5°C temperature increase. The increases in LGP projected for parts of E Africa will not translate into increased agricultural productivity; maize production is projected to decline by 26% and bean production by 54%, all other things (such as area sown) being equal, with little or no change for the pasture grass. These simulated changes take only limited account of shifts in weather variability; a substantial portion of this region that is currently cropped already experiences season failure rates of 25% or more, and these areas will increase in size substantially in the future.

The agriculture in a five-degree warmer Africa will look very different to that of today. Potentially there may be more feed for livestock, but without widespread adaptation there will be much less food for people. More intensive cropping will have to be carried out in the highlands, where temperature stress is less likely to occur. Livestock will play a critical role in the livelihoods of the millions of people living in the rapidly expanding marginal areas. A much warmer SSA will have other repercussions too: greater weather variability, more frequent extreme events, changes in the prevalence pests, weeds and diseases, severe impacts on water availability, and profound impacts on human health -- all this occurring while an extra billion people are being added to the population. The prognosis for agriculture in SSA in a five-degree world is truly appalling. Already today, the number of people at risk from hunger has never been higher: it increased from 300 million in 1990 to 700 million in 2007, and it is estimated that it may exceed 1 billion in 2010 (FAO, 2009). The cost of achieving the food security Millennium Development Goal is around \$40–60 billion per year, and without this investment, serious damage from climate change will not be avoided (Parry et al., 2009) -- and this is for a two-degree world. Currently, the prospects for such levels of sustained investment are not all that bright. Croppers and livestock keepers in SSA have in the past shown themselves to be highly adaptable to short- and long-term variations in climate (Challinor et al., 2007), but the kind of changes that would occur in a five-degree world would be way beyond anything experienced in recent times. There are many options that could be effective in helping farmers adapt even to medium levels of warming -- substantial investments in technological R&D, institution building, and infrastructural development, for example -- but it does not take much imagination to envisage a situation where the adaptive capacity and resilience of most people in SSA would simply be overwhelmed by events. Such a world had better be avoided, quite literally at all costs.

Table 1. Simulated yields (the pixel-weighted averages of 30 independent replications) for the area from latitudes 12°S - 6°N and longitudes 28°E - 42°E, shown by the dotted box in Figure 1, for three crops grown on cropland and pastureland as defined by Ramankutty et al. (2006).

Crop	Yield (kg per ha)		% Yield Change
	2000s	**2090s +5°C**	
Maize	954	706	-26
Beans	656	305	-54
B. decumbens	1386	1368	-1

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Adapting African food systems to a four degree world

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Recent crop modelling results (Jones and Thornton, 2009) (Lobell et al., 2008) suggest that even a 2 degree warming will shift the traditional cropping and livestock patterns throughout Africa. Ongoing research at CIAT (A. Jarvis, personal communication) points to likely shifts in the biogeography of staple food crops like maize, cassava and beans as a result of changes in mean temperature and precipitation patterns. These shifts in what can be cultivated in will require both rural and urban dwellers to make radical changes in diets, food security, and livelihood strategies.

Many of these changes will happen to people who already struggle to make ends meet and face regular periods of food insecurity, and for whom agriculture is a difficult task even in good years (Devereux and Edwards, 2004, Ziervogel et al., 2008). At the national and regional levels, agricultural growth for development is still a critical target for most sub-Saharan African countries (WDR, 2008). The adaptation challenges that climate change poses for both food security and economic development must be addressed if sub-Saharan Africa is to meet its poverty reduction goals.

Several decades of research within the food security and agricultural development community have highlighted key lessons about responding to food insecurity and managing transitions or innovations in cropping systems. These lessons include:

- Chronic poverty and lack of government funds undermines coping and adaptive capacity for the poor and food insecure (Barrett, 2007); one or two good years are often not enough for farming households to recover from repeated crop losses or other shocks to their income and assets. Social protection programmes hold considerable promise but require national and international policy support (Devereux, 2001, Cromwell and Slater, 2004).
- Functioning markets are critical for food security and agricultural growth; often poverty and food insecurity arise because prices for inputs or food are too high, whilst prices for local production are too low. However, it is extremely difficult to get domestic market interventions “right”(Jayne et al., 2002), and sometimes such interventions can exacerbate food insecurity.
- Farmer attitudes towards managing risks are varied and context specific (Eriksen et al., 2005); however they need support (e.g. from extension and credit services) if risks are too big or unknown (Ruben and Pender, 2004).
- Reforming or improving the institutions responsible for managing food and agricultural systems is both critical and extremely challenging. In addition to the market, extension, credit and social policy issues, basic food security planning and relief mechanisms are also important.
- Food security and vulnerability assessments rely upon adequate and proactive frameworks and reliable, up to date monitoring information (Maxwell and Watkins, 2003).
- International donors wield considerable influence over food relief operations; however in recent years they have faced difficulty meeting annual appeals for food aid to “chronically” food insecure countries and regions.

These general issues apply to multiple countries. A comparison of Kenya and Zambia is interesting, owing to their differing experiences with food security and agricultural growth in the past decade (Jayne et al., 2008), as well as the potential differences in the impacts of future climate change for each. The arid and semi-arid zones of Kenya have faced repeated droughts in the 1990s and 2000s, which have eroded the coping capacities of many pastoralists and agro-pastoralists, and brought about changes in livelihood strategies (Little et al., 2001, Eriksen and Lind, 2009). Kenya is noted for some of the innovations that a coalition of donors, NGOs and government ministries have made in advancing a cooperative and cross-institutional framework for managing food insecurity, known as the Kenyan Food Security Meeting (KFSM), as well as for integrating climate information into its early warning systems (http://www.kenyafoodsecurity.org/index.php). However the country is (once again) facing widespread crop /and livestock failure this year, and concerns about its ability to meet food needs are serious (FewsNet, 2009). Thus the sustained ability of Kenya to handle repeated climate shocks is open to debate (Speranza et al., 2008, Omiti and Nyanamba, 2007, Orindi et al., 2007). Zambia has less national experience in "responding" to food insecurity situations. It most recently faced food shortages in 2002 and 2006; during both episodes, the country's experiences with food aid, market reform and social protection were mixed (del Ninno et al., 2007, Tembo, 2006). Although flooding of the Zambezi affected some areas in 2008, crop yields for 2009 are projected to be excellent (FewsNet, 2009). Furthermore, Zambia has actually seen improvements in food prices, agricultural yields, and poverty rates since the mid 1990s (Jayne et al., 2007). However the Southern African region as whole is not food secure, and efforts to date to bring about better integration and coordination have been inadequate (Mano et al., 2006).

The implications of these experiences with food insecurity in each country to date suggest that adaptation to a significantly different agricultural "landscape" will require concerted efforts in multiple sectors and policy realms. The debates and proposals around agri-food system adaptation have remained largely about technology and climate information. However, decades of food security and agricultural development interventions have shown us that a much broader, integrated institutional and policy response is needed to prevent a future of increased food insecurity and rural poverty.

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What would happen to barley production in Finland if global temperature increases above 4^{o}C ? - a model-based assessment.

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Background.

So far, climate change has been considered to be beneficial for agriculture in Nordic conditions, since crop production is mainly limited by low temperatures resulting in short growing seasons. If the global temperature will increase beyond 4^{o}C, and the changes in Northern latitudes are even stronger, conditions for crop production would, however, change so dramatically, that it may result in negative impacts for most crops, also when taking the positive CO_2 fertilization effects into account.

The aim of this study is to examine changes in crop yield response to a set of variants of anticipated changes in climatic conditions for Finland using the WOFOST crop growth simulation model. Scenarios include systematic increases in temperatures, changes in precipitation amounts and distribution and changed climatic variability. We also study the effects of enhanced CO_2 concentration and different adaptation options. For comparison, the simulations are also done for selected SRES climate change scenarios. We use spring barley (Hordeum vulgare L.) as an indicator crop, since spring barley covers the largest part of the crop production in Finland.

Methods.

The dynamic crop growth simulation model WOFOST (Boogaard et al., 1998) was applied for two locations, Jokioinen (60^{o}42'N, 23^{o}30'E) and Jyväskylä (62^{o}34'N, 25^{o}40'E) representing the southwestern and central Finnish barley growing environments, respectively. The model runs were made for the heavy clay soil and the sandy soil representing two ends of the wide range of agricultural soils found in Finland. WOFOST was calibrated with the multi-locational field trial data from Southern Finland using data for a modern cultivar (Scarlet) (Peltonen-Sainio et al., 2008). Simulations were done for water-limited (rainfed) production situation. The assumption of autonomous adaptation by farmers of sowing to changed weather conditions was included in all scenario runs. Sowing dates were estimated annually based on well-established criteria (temperature threshold and soil moisture ranges).

The set-up of model (scenario) runs performed is presented in Table 1. We analysed the crop response of the modern cultivar Scarlet for reference period then performed systematic variations in average daily air temperature (T in ^{o}C) and daily precipitation (P in mm) in the summer (May to September) period. We modified various crop model parameters for enhanced CO_2 concentration of 560 ppmv as proposed by Rötter & van Diepen (1994) to study the combined effect of enhanced CO_2 concentration and increased temperature from +4 to +7 degrees (i.e. T4CO2, T5CO2, T6CO2 and T7CO2). Variations in summer precipitation and soil moisture conditions included prolonging the runs of dry and wet spells in the year, and in summer, and changing summer rainfall amounts from -40% to +40% (Table 1). For analysing crop responses to changing variability of temperature and summer precipitation we used the stochastic M&Rfi weather generator developed by Dubrovsky et al. (2000, 2004) to produce synthetic weather series of 200 years. Statistical characteristics of observed weather of the reference period (REF, n=30) and synthetic weather created based on this data (V0, n=200) matched very well. The various runs for changes in variability (V1 to V10), partly combined with +4 ^{o}C warming, are further described in Table 1. For comparison, we also performed runs for SRES scenarios A1F1 and B1 for time slice 2071-2100. Adaptation options included change in time of sowing and in crop cultivar. We tested effects of using different sowing criteria and we designed a new crop cultivar by combining late maturing characteristics with other adapted characteristics to better exploit the extended growing window under +4 degrees (Scenario T4NEW).

Results.

Results for the reference period indicate that growth durations and yields varied considerably among years (Figure 1, top left and right), matching well with observations at experimental stations nearby the two sites. Scenario simulations (T2 to T7) show that increasing temperatures will reduce total growth duration and average yields considerably, but hardly affect yield variability. We also applied one cooling scenario (TM2), which shows that although such temperature decline leads to slightly higher average yields, it increases yield variability; this further indicates that crop cultivar Scarlet is well adapted to current agro-ecological conditions in southwestern Finland. For the clay soil, at Jokioinen grain yield at scenario T4 is on average reduced by 22%, and at scenario T7 even by 45% compared to the reference period (REF), but less (by 10% and 33%, respectively) at Jyväskylä.

Changes in precipitation had negligible effects on the clay soils but led to marked yield reductions on sandy soils. Most striking negative effects were found for increased temperatures (T5, T6 and T7), for distinctly increased variability in temperature conditions (V2), for the combinations of increased temperature (T4), prolonged dry spells and reduced rainfall amounts (V5 to V8), and the high emission SRES scenario (A1FI). Soil type had a huge influence on results (Figure 2), whereby sandy soil led to considerably higher risk of very low yields. Enhanced CO_2 concentration had hardly any effect on the sandy soil. Neither the CO_2 fertilization effect, nor adjusted planting dates could compensate the high yield losses expected from temperatures beyond +4^{o}C, or from more variable temperature and rainfall conditions. On the clay soils, introduction of a new cultivar, better adjusted to warmer conditions (T4NEW), led to average yields comparable to current yields for cultivar Scarlet - though at slightly higher yield variability (Figure 2). On sandy soils the new cultivar could not reach reference average yield levels.

Discussion and conclusions.

Currently, national barley yields in Finland are about 3.3 t ha^{-1} (Öfvertsen et al., 2004), while researcher-managed experimental yields (during period 1991-2005) range between 5.2 and 7.2 t ha^{-1} at Jokioinen, and between 5.0 and 6.5 t ha^{-1} at Jyväskylä depending on the cultivar and year (MTT's official variety trial database, 2008). This mainly shows that there is a considerable yield gap under current management practices. Our results contradict, at least partially, with several other (Easterling et al.,2007) claiming that Northern crop production will clearly benefit from climate change. Our simulation with a newly designed spring barley cultivar having temperature requirements similar to Central European cultivars showed that average yields under a +4 temperature scenario might be maintained on favourable soils. As our results show, adjustment of sowing dates of spring barley will not help, but the most promising adaptation is through improved management (water and nutrient management) on suitable land, and through breeding and selecting new cultivars better suited to the changing environmental conditions. Such breeding success seems feasible given the genetic diversity of barley (e.g. in Europe) and at fairly moderate additional investments. Shifting to other cropping systems (including winter cereals – as, for example, in Denmark) might be an option that we've not yet examined. Increased variability, especially in temperature conditions, however, might make that option questionable. Analyses pertaining to shifts in cropping system should best be carried out at farm household level. The adaptation option 'winter crop' for large areas of Finland calls for further research at high latitudes into the conditions favouring such switch, both in terms of yield and yield stability, and environmental aspects.

Summarizing, it can be concluded that if the climate changes beyond 4^{o}C, effects on cereal production will not be positive anymore, but in many parts of Finland, such changes will lead to high risks for marked yield losses.

Table 1. Set-up of model runs.

Scenario acronym	**Scenario description**	**Simulation period**
REF	Model runs based on observed weather	30 years, 1971-2000
TM2	Daily temperatures decreased by 2 degrees	30 years created based on 1971-2000
T2	Daily temperatures increased by 2 degrees	- " -
T4	Daily temperatures increased by 4 degrees	- " -
T5	Daily temperatures increased by 5 degrees	- " -
T6	Daily temperatures increased by 6 degrees	- " -
T7	Daily temperatures increased by 7 degrees	- " -
T4CO2	Daily temperatures increased by 4 degrees and increased CO_2 level (560 ppmv) implemented by changing the crop parameters	- " -
T5CO2	Daily temperatures increased by 5 degrees and increased CO_2 level (560 ppmv)	- " -
T6CO2	Daily temperatures increased by 6 degrees and increased CO_2 level (560 ppmv)	- " -
T7CO2	Daily temperatures increased by 7 degrees and increased CO_2 level (560 ppmv)	- " -
V0	Weather generated based on the statistical characteristics of observed weather from the reference period	200 years
V1	Changes in variation of temperature 1.5 times standard deviation	- " -
V2	Changes in variation of temperature 2.5 times standard deviation	- " -
V3	Changes in variation of summer rainfall: prolonging periods without rain and longer periods of rainy days without modifying number of rainy days;	- " -

	(Pdw:=0.50*Pdw whole year) whereby Pdw is "Probability of wet day occurrence if the previous day was dry"- with no change of precipitation amount	
V4	(Pdw:=0.25*Pdw whole year) as in V3 but the probability of wet day occurrence after previous dry day is only 25% compared to present	- “ -
V5	Daily temperatures increased by 4 degrees combined with V3, i.e. decreased probability of wet days (Pdw:=0.50*Pdw whole year)	- “ -
V6	Daily temperatures increased by 4 degrees combined with V4, i.e. (Pdw:=0.25*Pdw whole year)	- “ -
V7	Daily temperatures increased by 4 degrees combined with decreased probability of wet days by 50% in summer (Pdw:=0.50*Pdw summer) AND -20% of summer precipitation	- “ -
V8	Daily temperatures increased by 4 degrees combined with decreased probability of wet days in summer (Pdw:=0.25*Pdw summer) AND (-20% summer PREC)	- “ -
V9	Daily temperatures increased by 4 degrees combined with decreased probability of wet days in summer (Pdw:=0.50*Pdw summer) AND (+20% summer PREC)	- “ -
V10	Daily temperatures increased by 4 degrees combined with decreased probability of wet days in summer (Pdw:=0.25*Pdw summer) AND (+20% summer PREC)	- “ -
A1F1*	High emission variant of SRES (A1) scenario using HadCM3 model	2071-2100 time slice
B1*	Low emission SRES (B1) scenario using HadCM3 model	- “ -
T4NEW	Daily temperatures increased by 4 degrees and use of another, “future” cultivar with adjusted crop properties	30 years created based on 1971-2000
PM4	Daily precipitation values decreased by 40% in summer (from May to September)	- “ -
PM2	Daily precipitation values decreased by 20% in summer	- “ -
PP2	Daily precipitation values increased by 20% in summer	- “ -
PP4	Daily precipitation values increased by 40% in summer	- “ -

** A1FI from IPCC Third Assessment Report; B1 from IPCC Fourth Assessment report;*

Figure 1. Simulated grain yield for the reference period 1971-2000 (top) and for 200 years synthetic weather for current climate (bottom) at Jokioinen (left) and Jyväskylä (right) and two soil types.

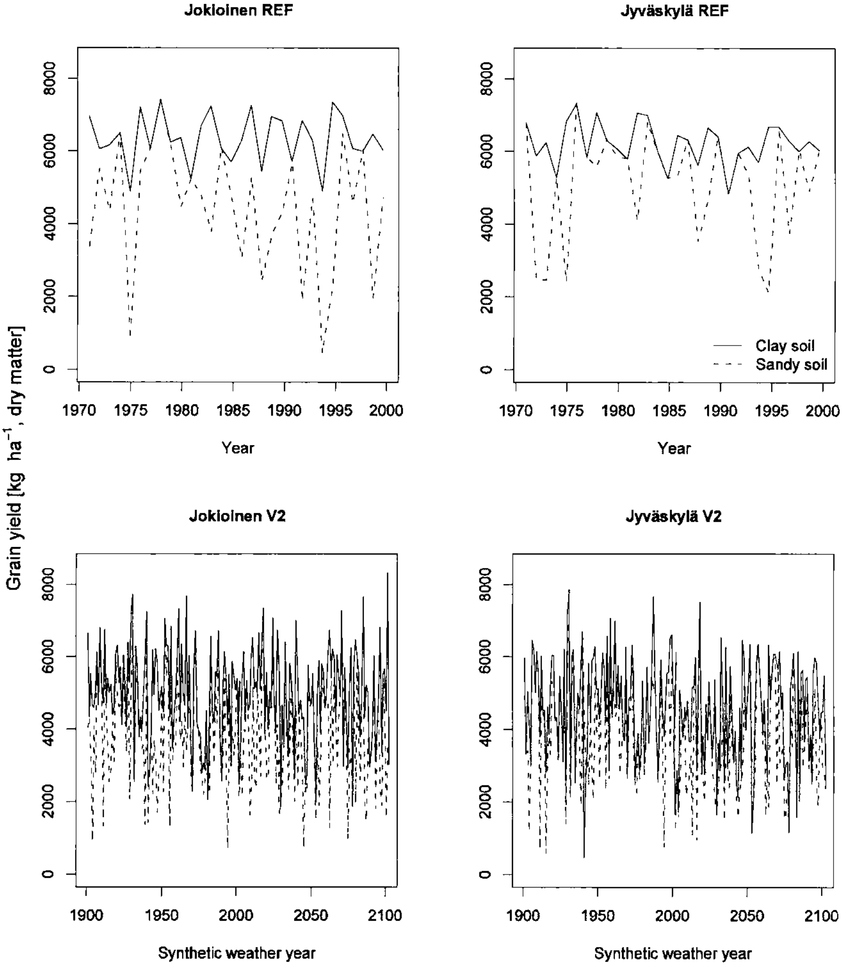
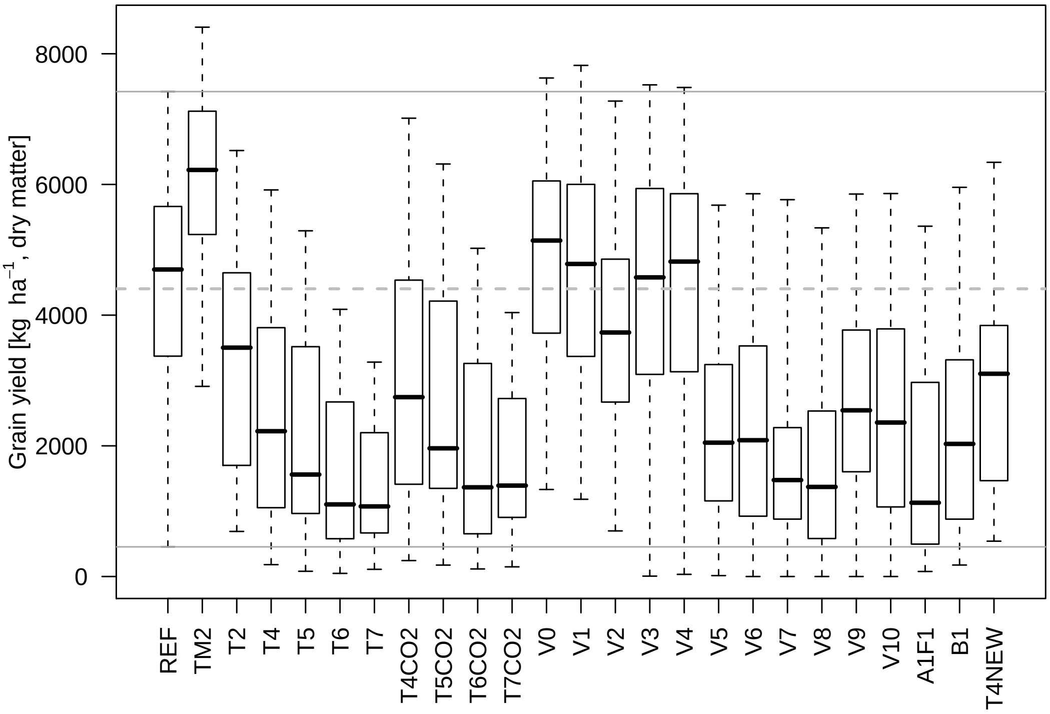
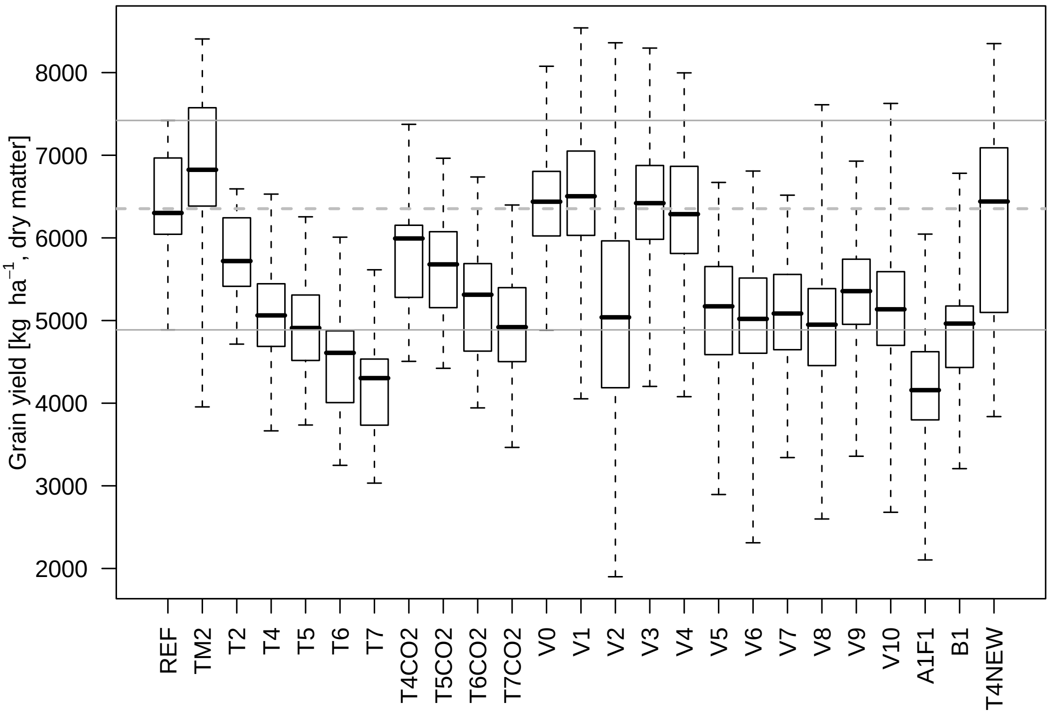


Figure 2. Box-and whisker plots of simulated grain yields for current and possible climate change variants (as explained in Table 1) at Jokioinen for clay soil (top) and sandy soil (bottom) (three additional horizontal lines indicate maximum, mean, and minimum yield for reference period).





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4°C+: A DRASTIC REDUCTION IN THE RENEWABLE ENERGY POTENTIAL OF THE SUGARCANE

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Background

The Republic of Mauritius, a Small Island Developing State, is highly vulnerable to climate change. Its economy, being mainly manufacturing and service-based, presently relies on an intensive use of electricity. This situation will continue with a possible higher dependency on energy as the economy base strengthens in the food processing, tourism and service sectors. With no known reserve of fossil fuel, Mauritius has been heavily dependent on imported heavy oil and coal to meet its energy demand at a reasonable cost. Bagasse, a co-product of the sugar industry has been exploited commercially since the 1950's and all excesses produced and not consumed for sugar processing, have been exported to the national grid. Adoption of more performing technologies over time, coupled with energy savings in sugar processing allowed for sugarcane biomass to contribute nearly 16% of the national energy requirement in 2007 (Figure 1). The National policy is to continue diversifying the energy mix by tapping more renewable sources such as wind and solar while keeping the least-cost solution in order not to jeopardize the socio-economic development of the country.

Figure 1. Electricity generation mix - 2007

Despite the vagaries of the weather, about 1.5 million tonnes of bagasse are burnt annually and in 2007 about 478 GWh of electricity was produced. Of this, some 28% was used in the sugar processing and the remainder exported to the national grid. This exported electricity displaced the utilization of some 79 767 tonnes of heavy oil or 228 895 tonnes of coal, avoiding emissions equivalent to 254 271 tonnes or 632 799 tonnes of CO_2-eq respectively (Table 1). Increasing biomass conversion efficiency through the adoption of more performing technologies is already under way and two power plants are now operating boilers at 82 bars and 525 °C. The older existing plants operate at 20 or 31 bars to produce steam at 420 °C (Nayamuth and Cheeroo-Nayamuth, 2005). Remaining plants will be modernized in a similar manner to raise the efficiency from 78 and 113 kWh t^{-1} cane to 160 kWh t^{-1} cane. This measure will further mitigate the emissions of greenhouse gases in the future, and contribute towards controlling global warming.

Table 1 - Share of bagasse in electricity generated and GHG emissions avoided

Given that the electricity produced from bagasse constitutes part of the base load, either coal or heavy oil can be used as alternative to supplement any shortfall in bagasse to keep the minimal cost option and affordability to users. Unless plant capacity is available for burning extra heavy oil, coal is the replacement fuel since the installed capacity plants as well as those to be improved are bagasse-cum coal units. This is mandatory to enable the continued and more efficient use of bagasse for electricity production. Moreover, this fits quite well within the outline energy policy of Government.

Vulnerability and Adaptation

An assessment of the vulnerability of the sugarcane crop and its adaptation to climate change (V&A) was conducted by Cheeroo-Nayamuth and Nayamuth (1999) using the calibrated and validated simulation model APSIM-Sugarcane Model. (McCown *et al*, 1996; Keating *et al.*, 1997). The baseline for cane productivity was developed on the basis of recorded island yields with regards to the climatic records of three sites for the period 1951 to 1995. Cane productivity was then simulated for four sets of climate change scenarios generated from General Circulation Models (GCMs) and also using incremental scenarios of +/- 10 and 20 % rainfall coupled with +2 °C and 4 °C. Results from the Goddard Institute for Space Sciences GCM (GISS) that predicted a 3.59 °C rise and the incremental scenarios of +/– 10 and 20 % rainfall with +4 °C only will be presented. In fact, the latest projections generated using the MAGICC-SCENGEN (Wigley, 2008) model indicated a reduction of the order of 26 % in rainfall coupled with a temperature increase of 3.28 °C by the year 2100 under the A1F1 scenario, a fossil fuel intensive economy with the world population peaking at mid century (Cheeroo-Nayamuth *et al*, *under preparation*). The observed changes for Mauritius is an increase in temperature of the order of 1.3 °C and a reduction of 15 % (about 300 mm) rainfall during the last 58 years.

In the V&A study, the increase of 4 °C resulted in a reduction in cane productivity ranging from 24% in the best case scenario, that is +4°C accompanied by 20% increase in precipitation to 62% in the extreme case of +4 °C coupled with 20% reduction in rainfall (Table 1). The GISS GCM predicted a 22% reduction under a climate change scenario of +3.59 °C and 19% increase in rainfall. Vulnerability resulted from lower water use efficiencies stemming from higher transpiration rates, result of higher temperatures. Adaptation measures assessed included irrigation, alternate variety types and alternative harvest dates. Only irrigation to fully satisfy the crop demands could negate the impacts of an increase of 4 °C. Implementation of this adaptation measure will require the mobilization of an additional 450 million m^3 of water annually. Presently fresh and groundwater abstraction averages nearly 700 million m^3 (CSO, 2008) with about two thirds of this devoted to agriculture. Already, groundwater reserves are exploited to the maximum and water supply is reduced during the dry season. Thus, harnessing the additional 450 million m^3 needed to maintain this level of sugar and bagasse production appear impossible. Moreover additional surface storage and extension of the existing irrigation networks would demand very heavy investments that may not be accessible to the small economy of the country. It may also be impossible hydrologically as rainfall is seasonal and concentrated over the period January to March.

Table 2 – Reduction (%) in cane productivity under selected climate change scenarios

Impact on GHG emissions

With no adaptation measure implemented, cane production will fall and result in 270 655 t less bagasse for electricity generation under the best-case scenario of +4°C and +20% rainfall. Under the worst-case scenario (+4 °C and -20% rainfall), bagasse production will drop by 813 813 t. To meet that shortfall from renewable sources, the only low cost tangible alternative for the country will be to use coal to meet this base load generated electricity within the same plants. This will result in an additional emission of 129 599 tonnes CO_2-eq in the best-case scenario and 388 797 tonnes CO_2-eq in the worst case one.

Moreover, possibilities exist for further tapping the renewable energy potential of the sugarcane crop through the conversion of unrecovered sugar found in the by-product molasses into ethanol that can be used to partly replace gasoline in cars. If all molasses are presently converted to ethanol, about 25-30 million litres can be produced. If all cars shift to

E10, the amount needed will be about 14 million litres and there will still be an excess for export to mitigate GHG emissions in other countries. Another possibility still under study is the recovery of trash and tops that are left-overs in the fields after harvest for burning in the same power plants. This measure can add up to the equivalent of 20% of the bagasse production to be converted to electricity at the same efficiency (Nayamuth and Cheeroo-Nayamuth, 2005). Reduction in emissions will be the net amount after offsetting fossil fuel used for baling and transporting this trash to the power plants.

Conclusions

Sugarcane is the most efficient converter of solar energy to biomass that can be converted to electricity or biofuels to displace fossil fuel. It is a source of renewable energy with an enormous potential to contribute to reducing GHG emissions and thus restraining global warming. It is however highly vulnerable to climate change, notably because of its high water demands that increases under higher temperatures. For Mauritius, a 4 ^{o}C increase will be beyond the adaptation limit, thus reducing the mitigation potential of the sugarcane industry. The net outcome will be an increase in GHG emissions that will further exacerbate the global warming situation when more fossil fuel will be used to produce electricity for the continued socio-economic development of the country.

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Crop yield and adaptation under climate change: implications of warming

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Introduction

Understanding the response of agricultural systems to global climate change requires analyses at a range of spatial scales. Different spatial patterns of change can occur for the same increase in global mean temperature and different magnitudes of impacts can occur for different increases in local mean temperature. The use of mean temperature as a metric for climate change impacts, and the use of impact models to develop regional adaptation strategies, therefore require that adequate account is taken of uncertainty. Current efforts to do this often focus on sampling a range of literature and seeking consensus. IPCC AR4 (Easterling et al., 2007) assessed the response of crop yield to mean local temperature in this way. Inverse parabolic curves were fitted to the data, and the authors suggested that tropical agriculture tends to lie near the maximum of the curve and is thus particularly threatened by warming. Other methods for impacts assessment include the use of climate model ensembles (e.g. Collins and Knight, 2007) and/or impacts model ensembles (e.g. Challinor et al., 2009a,b).

This study draws on sets of climate-crop ensemble simulations in order to assess the:

i. The degree of confidence that can be placed in statements regarding the impact of climate on mean yields versus that on crop failures.
ii. Impacts of climate change on crop yields in India, China and the USA for a range of temperature increases.
iii. Efficacy of specific adaptation options as a function of temperature increase.

Methods

A number of ensemble simulation studies (table 1) were used together with the GLAM crop model to produce crop yield ensembles that vary the response of crop and/or climate to increases in CO2. The sensitivity of other crop models to climate change was also tested, and compared to that of GLAM. Results are presented and analysed in terms of local and global mean temperature increase. Results above and below four degrees are contrasted, including comparison with the two degree target. The response of mean yield to temperature is assessed and compared to that of the IPCC AR4 assessment.

Using a combination of field data and simulations, potential adaptation measures were also assessed, for a range of global warming targets. The adaptation measures examined were: i. switching to another existing cultivar, ii. irrigation, and iii. crop varieties developed to tolerate the impact of heat stress during anthesis. The first measure was assessed using the crop variety trial analysis method of Challinor et al. (2009c) and the second and third using the simulations of Challinor et al. (2009d).

Results

Impacts. The analysis shows that the relationship between future mean crop yields and global warming can be weak. Figure 1 illustrates this: no systematic relationship between global mean temperature increase and mean yield was found. Use of local mean temperature for the same analysis results in a more robust relationship, although the form of this relationship varies across crop models and differs to that of the IPCC AR4 (see Challinor et al., 2009c). Statements regarding the impact of extremes are more robust and show some relationship with both local and global mean temperature change. Across all the simulations, incidences of crop failure tend to increase monotonically with global mean temperature (figure 2). However, individual climate realisations show (different) threshold responses (not shown).

Adaptation. In the simulations of Challinor et al. (2009d), adaptation significantly reduces negative impacts for all magnitudes of climate change; although it tends to become less effective at higher temperatures (not shown). Irrigation and heat tolerance, applied individually, both reduce crop failure down to near the baseline value, whilst irrigation and heat tolerance together reduce crop failure to well below the baseline value.
Analysis of adaptation to mean temperature in the USA showed that at +2°C of local warming, 87% of the 2711 varieties examined, and all of the top five most common varieties, could be used to result in a crop duration similar to that of the current climate (i.e. successful adaptation to mean warming). At +4°C this fell to 54% of all varieties, and two of the top five.

Conclusions

The study demonstrates how a full analysis of uncertainty can be used to make statements regarding impacts and adaptation for crop production systems. The analysis suggests that statements regarding mean crop yield as a function of global warming may be difficult to make. Statements regarding the impact of extremes may be more robust, with incidences of crop failure tend to increase monotonically with global mean temperature.

The study also demonstrates that in spite of the inherent uncertainties, adaptation strategies, such as irrigation and the development of heat-tolerant crop varieties, can be identified and prioritised based on model simulations. Such studies can interlink probabilistic projections of regional climate with crop modelling and analyses of existing crop germplasm, in order to increase understanding of biophysical climate change processes and use this understanding to inform adaptation needs (see Challinor, 2009; and the forthcoming NERC consortium project End-to-end Quantification of Uncertainty for Impacts Prediction - EQUIP). Since they are more geographically specific than global-scale assessments, such studies can include assessments of mean yield as well as crop failures.

Overall, the analysis suggests that adaptation to the means and extremes associated with four degrees of global warming is possible for the crops and regions studied. However, adaptation becomes decreasingly effective as global mean temperature rises.

Description	**Climates**	**Crop responses**	**Mean temperature**
All-India A2 groundnut scenario with regional climate model (RCM; Challinor and Wheeler 2008a,b)	1	18	Both > and < Topt
Study of climate and crop modelling uncertainty at one location in India for groundnut under doubled CO2 (QUMP53; Challinor et al., 2009c)	53	36	<Topt [97%]
A1B scenario in north-east China for spring wheat (QUMP17; Challinor et al., 2009d)	17	8	>Topt
Analysis of adaptation to mean temperature in the USA, using a database of 16,000 wheat trials	-	-	<Topt

Table 1. Simulations and analyses used in the study. Topt refers to the optimum temperature for crop development (i.e. at which the crop matures quickest, thus tending to reduce yield). The synthesis study of Challinor (2009) also contributed to the analysis.

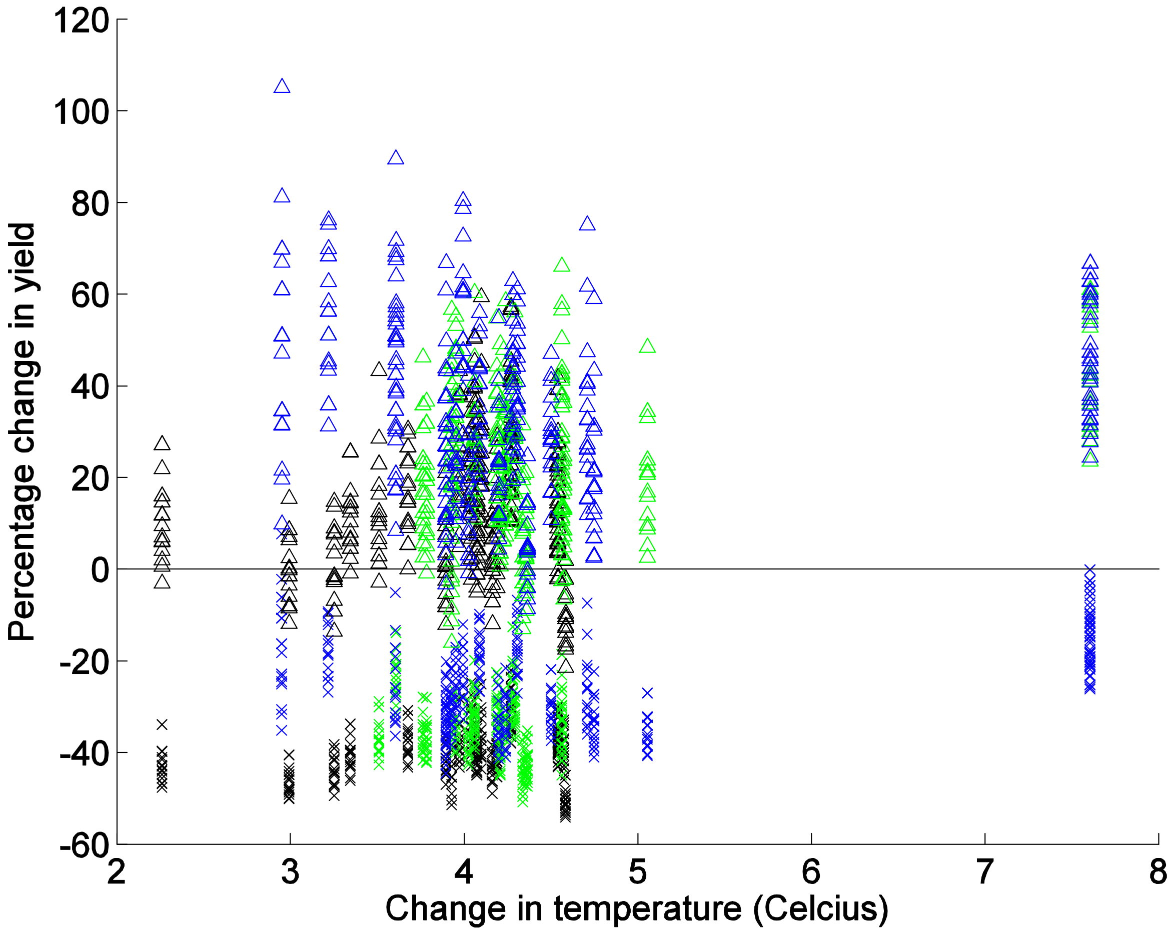

Figure 1. Change in mean simulated groundnut yield from baseline to doubled-CO2 climate at a location in India, taken from the ensemble simulations of Challinor et al. (2009c). Both a 20% (triangles) and 0% (crosses) increase in crop thermal time requirement, representing adaptation and no-adaptation respectively, are shown. The *x*-axis is the increase from the baseline simulations in May-November global mean temperature. Data are split into terciles of absolute change in season-total net solar radiation from simulated planting to maturity. In all cases this change is negative. Black symbols show the largest decrease in radiation, dark grey / green show the central tercile and light grey / blue show the smallest decrease. The terciles are bounded at 376 and 419 MJ for the simulations with no change in thermal time requirement, and 69 and 115 MJ for the simulations with a 20% increase in thermal time requirement.

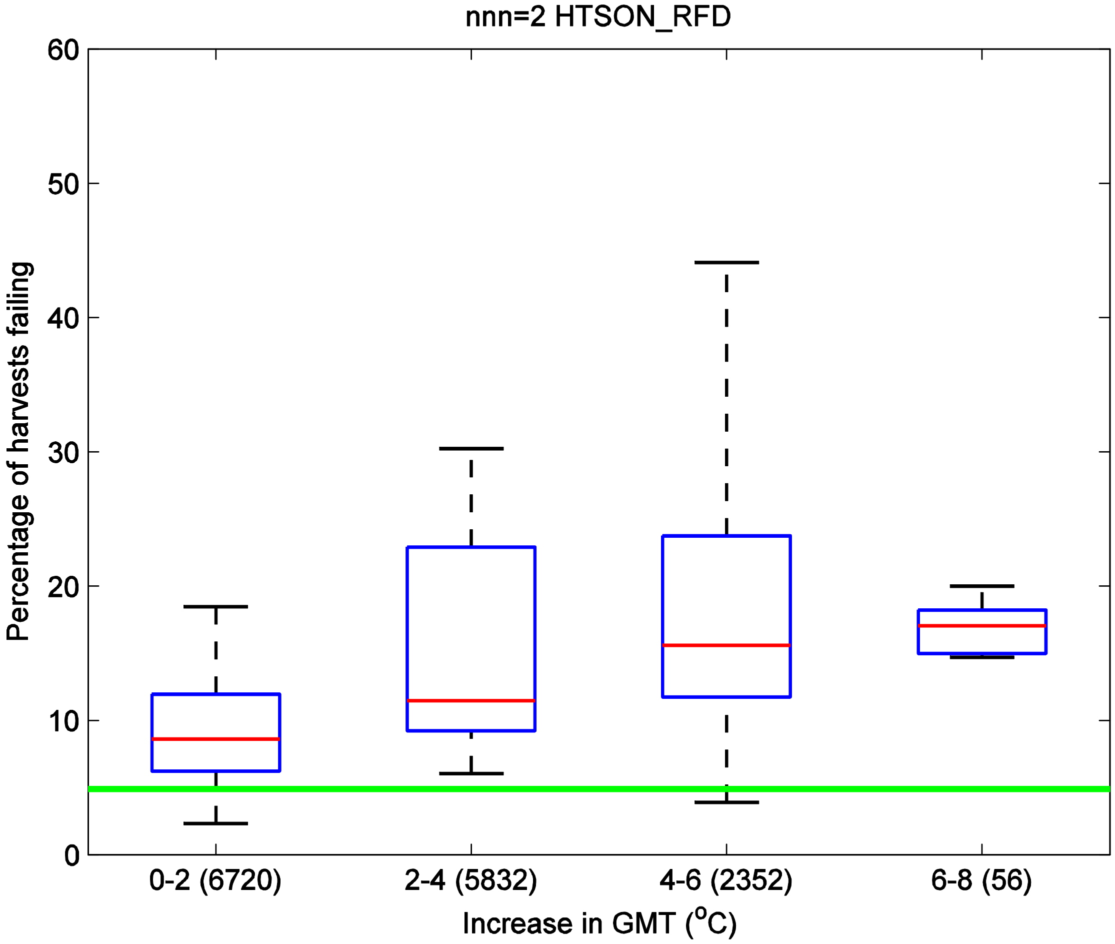

Figure 2. Analysis of the impact of extremes of heat and water stress on spring wheat in north east China, using the simulations of Challinor et al. (2009d). Boxes indicate the inter-quartile range (blue) and median (red) values, with whiskers indicating the full extent of the data. The solid (green) line extending across the figure indicates the percentage of harvests that fail in the baseline simulations. A failed harvest is here defined as being more than two standard deviations (using the baseline simulation period) away from the mean. Numbers in brackets on the *x*-axis indicate the number of simulations falling within that data bin. Bin edges were defined using the last consecutive year in which global mean temperature increase (from the 1960-1989 mean) remained below the top of the temeprature range.

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Risked Posed to Global Water Availability by a 4+ Degrees Climate Change

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Introduction

The global temperature rise presented in the Fourth Assessment Report (AR4) by the intergovernmental panel on climate change shows that out of 23 Global Climate Model (GCM) projections for three emissions scenarios, only two GCMs show a global 4 degree temperature rise by the end of the 21st Century for the A2 scenario. Therefore attempting to determine the impacts of a 4+ degree warming using the IPCC ensemble of climate models will therefore present some difficulty. Moreover, the spread of results by using different GCMs only explores the uncertainty associated with the structure of the different climate models. Alternatively, the dataset generated by the Climateprediction.net (CPDN) experiment allows us to explore the climate model physics uncertainty through a Perturbed Physics Ensemble generated by perturbing the HADCM3L GCM parameterizations within their physically plausible ranges.

In this paper, we present results using the large climate model ensemble from CPDN to explore the risk of a global warming of 4+ degrees and the possible timing of this event. By focussing on climate model runs that show a 4+ degree warming, the associated climate variables are used to drive a global distributed hydrological model. An assessment of the changing risk of drought and water scarcity as we proceed through the 21st Century is presented at the global and continental scale.

The Climate Model Ensembles

Perturbed physics ensembles (PPEs) provide a new approach for exploring a wide range of future climates and the potential impacts of climate change. The climate data used in our analysis has been generated by the CPDN Experiment 3 (forecast ensemble). The GCM used is the HADCM3L, a version of the U.K. Met Office Unified Model. The CPDN experiment explores the effects of perturbing 26 parameters that are relevant to the way radiation, large scale clouds formation, ocean circulation, sulphate cycle, sea ice formation, the land surface and convection are simulated by the GCM.

A subset of the Experiment 3 CPDN ensemble with 1520 members were used in this study and represents a partial sampling of the climate model parameter space. All climate model runs cover the period 1920 to 2079 and were subjected to the A1B SRES forcing scenario. The HADCM3L spatial scale is 3.75 by 2.5 degrees, and time series of decadal seasonal means are stored for each model run. For this study, precipitation and temperature were used and interpolated to a one degree resolution as required by the global hydrological model.

For comparison purposes, the results of the Climate Modelling Intercomparison Project (CMIP) which comprises climate model results for 23 GCMs and three SRES scenarios will also be incorporated in the analysis.

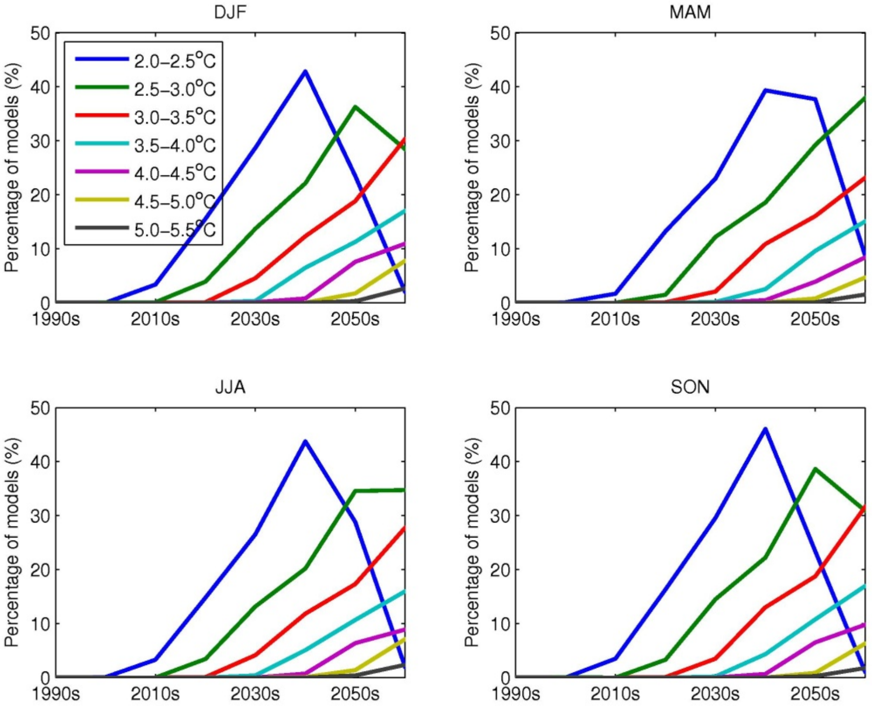
What is the risk of a 4 Degree Warming?

The ensemble of temperature from the climate models were analysed with respect to a baseline of 1961 to 1990 for each of the decades from 2000 to 2079. An analysis of the climate model data shows about 20% of climate models with an annual global warming of more than 4 degrees by the 2060s for the SRESA1B scenario. This value provides some indication as to the risk of a 4 degree world by the 2060s as calculated using the CPDN ensemble with the spread of results representing the uncertainty that can be attributed to the parameterisations of the HADCM3L model. The CMIP climate model results can also be used to explore another source of uncertainty: climate model formulation or structure. In comparison to the CPDN climate model runs the percentage of models is much smaller in the CMIP database which contains only two (≈12%) GCMs with an annual global warming of more than 4 degrees by 2100 and only for the SRESA2 emissions scenario.

The time series of percentage of models that warm within different temperature ranges through the 21st century is plotted in Figure 1 for each of the seasons (December-January-February, DJF; March-April-May, MAM; June-July-August, JJA; September-October-November, SON). There is clearly a warming trend in all climate models for all seasons, demonstrated by the ever-increasing proportion of climate models warming by larger amounts as the 21st Century proceeds. The plots also show only small differences in the percentage of models across the seasons.

In this paper, we concentrate on the differences in temperature, precipitation and runoff for a 4-5°C warming through the 21st century, which represents about 10-20% of the CPDN ensemble in the 2050s and 2060s: these results will also be compared to a 2-3°C warming, a temperature range which has long been considered a suitable target for mitigation purposes.

Figure 1.



The Global Hydrological Model

The CPDN climate model data have been used to drive a global hydrological model (GHM) at one degree resolution as described in Arnell (1990). This is a simple conceptual model that performs a water balance at each grid cell and also contains various parameterisations to represent parts of the hydrological system. Given that it has been shown in many studies (e.g. New et al (2007)) that the largest source of uncertainty is the climate model data driving the hydrological models, we have concentrated only on the response of the GHM due to the perturbed physics of the climate models ignoring hydrological model uncertainty in this work. The GHM is purely a hydrological model and does not include water demands calculations or structural components of a water resources system. Any interpretation with respect to stress on water resources can only be inferred by the change in surface runoff.

The GHM has been run using the CRU observed climate dataset for 1961-1990 to represent runoff during the baseline period. Future climate has then been generated by using change factors that perturb the observed climate dataset. These change factors were calculated from the decadal seasonal means of precipitation and temperature from the CPDN data which were then interpolated to a one degree resolution. Climate model runs that showed a global warming of 4-5 ºC were selected and used to drive the GHM runs.

What does 4 degrees warming mean for global runoff?
The CPDN model data allow us to explore the changing nature of the precipitation and hydrological regime as the 21st century proceeds. Out of the CPDN ensemble, about 10-20% of the models show a 4-5ºC global warming in the 2050s and 2060s: the changing spatial pattern of the direction of change in temperature, rainfall and runoff for the 2050s and 2060s for DJF are presented in Figure 2. The top two rows of plots show the percentage of models that agree with a certain direction of change with the darker the colour (blue for positive and red for negative changes), the stronger the consensus in the climate model ensemble. To demonstrate the difference between the two top plots, the bottom row is the difference between the consensus of 2050s and 2060s. Note that we have only plotted the data for members of the ensemble that show a global warming of 4-5 ºC and where changes are greater than natural variability (assumed here to be two times the standard deviations of the observed time series).

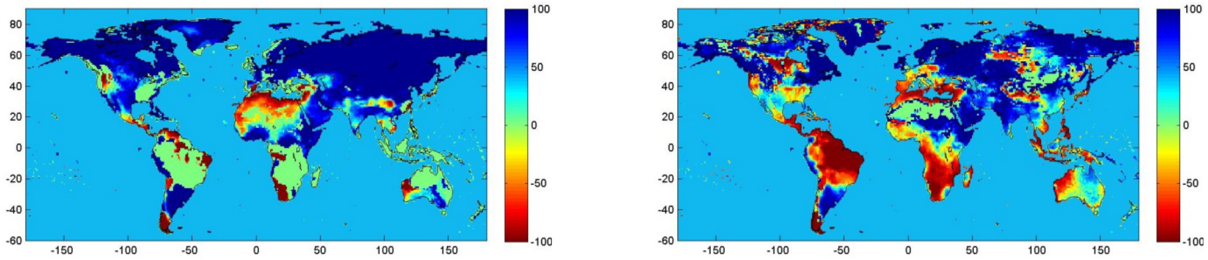
For both rainfall and runoff there are areas in the world where there is high consensus for the direction of change, for example, Northern Europe, Russia, Canada, North Africa, Southern Australia and Argentina. As the 21st Century proceeds, the areas where there are high consensus remain so, which can be observed in the deepening of the blues and reds in the top two rows plots and the green colour in the bottom row of plots in Figure 2. Some of the areas with small consensus tend towards the direction of change of neighbouring high consensus areas. This appears to show that the climate models increasingly agree with each other as time proceeds, tending towards a strong consensus for a spatial pattern of change.

It appears that there are large swathes of South America, Southern Africa and Northern Australia where there may be little consensus in the direction of change in rainfall or the signal may be weak compared to our definition of natural variability. Interestingly, these areas do not necessarily coincide with that for runoff; there are also areas where there is a difference between the direction of change in runoff and rainfall, e.g. Europe, some areas in the high Northern latitudes and Eastern Russia. Although there is strong consensus for the directions of change in the opposite direction, the actual values of change in rainfall and runoff in these areas for the 2050s and 2060s tend to be small, although above natural variability.

The differences between the spatial distribution of consensus for the 2050s and 2060s shows that for the CPDN ensemble, the time at which a 4 degree world occurs is also important to understand the risks posed to water availability. In the paper we will also be exploring the differences in runoff for large river basins and how these compare to world with 2 degrees warming.

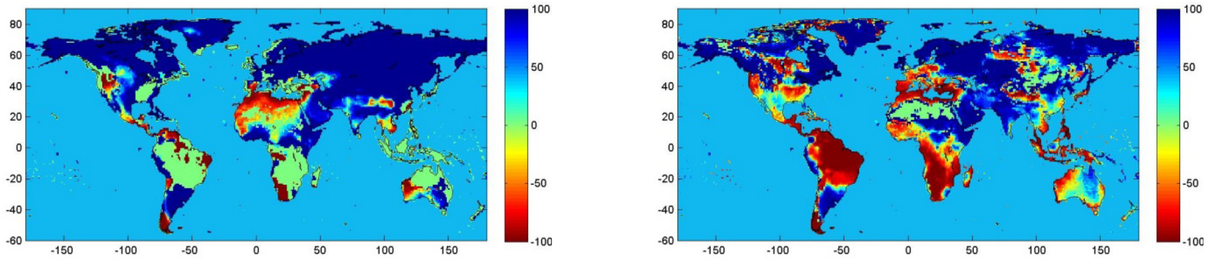
Model Consensus in 2050s, DJF

Rainfall | Runoff



Model Consensus in 2060s, DJF

Rainfall | Runoff



Difference in Model Consensus for 2050s and 2060s, DJF

Rainfall | Runoff

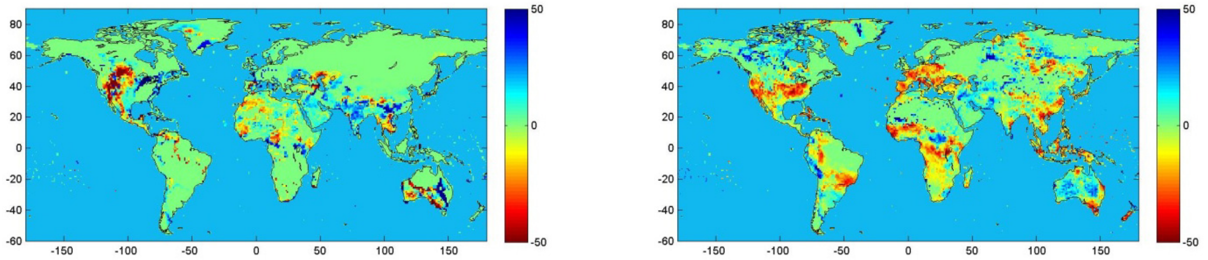


Figure 1 Comparison of patterns of direction of change for rainfall and runoff for a 4-4.5ºC warming in the 2050s and 2060s, where dark blue represents a high percentage of models with a positive change and dark red a high percentage of models with a negative change. Green areas represent lack of consensus between models for direction of change.

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Limits to adaptation: implications of global temperature changes beyond 4°C for water supply in southern England

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Climate change is expected to produce reductions in water availability in southern England, necessitating adaptive action by the water industry to maintain supplies, as outlined in water company Water Resources Management Plans. These plans could be undermined by further reductions in water availability that may occur if temperature changes to 2080 are far greater than currently considered. According to the Environment Agency Water Resources Planning Guidelines (Environment Agency, 2007a) and the supplementary guidance (Environment Agency, 2007b), companies should incorporate climate change in the calculation of deployable output using estimates of climate change impact derived using the UKCIP02 Medium High (MH) scenario for the 2020s. Under this scenario, global average temperature is expected to rise to 0.88°C higher than the 1961-1990 average in the 2020s, continuing to 3.29°C in the 2080s (see Hulme et al., 2002). The Committee on Climate Change (2008) concludes that the world needs to plan strategies for adaptation to temperature increases of at least 2°C (above pre-industrial levels) but it should also aim to reduce to very low levels the dangers of exceeding 4°C. It is therefore important to understand the potential consequences of temperature increases beyond 4°C, which are expected in the absence of an immediate reversal of existing emission trends. For four resource zones approximating the Medway catchment in South East England, impacts on the supply-demand balance are estimated by rescaling existing water company estimates with climate change ultimately (by 2080) hitting different temperature changes. The implications for adaptation over the current planning horizon (to 2035) and beyond are investigated to see what would happen at higher rates of change.

For each resource zone, supply-demand balance data were extracted from the draft Water Resource Management Plan tables and the estimates of climate change impact (CCI) determined. The impact in 2025 was rescaled using a forcings-based approach for the single UKCIP02 MH scenario, assuming that CCI is a linear function of the temperature change in 2025; itself rescaled from the global average temperature in the 2080s. A total of 13 temperature changes above the 1961-1990 average were used, representing 0.5°C increments to 6°C and including the MH value. The 2025 impact was used to recreate a CCI profile for each planning year using the methods outlined by the Environment Agency (2007b) and the supply-demand balance (SDB) was recalculated and extended beyond the end of the planning period (2034/35) to 2050/51.

CCI increases with each temperature increase and final impact values diverge as time progresses. Table 1 summarizes these impacts for 2025/26, 2034/35, and 2050/51 for the MH scenario, the maximum (6°C) and minimum (0.5°C) temperature changes by the 2080s, and for two critical thresholds of 2°C and 4°C. Also indicated are the summed catchment values. The results show that most (78%) of the climate change impact occurs in one resource zone. Depending on the year, resource zone and ultimate temperature change, up to an additional ~8 Ml/d (~10 Ml/d if the whole catchment is considered) of water will need to be found (relative to the MH scenario) to replace that lost to climate change, although under lower final temperatures more water would be available.

Resource Zone	2080s Temperature change (°C)	Climate change impact (Ml/d) in Year		
		2025/26	2034/35	2050/51
1	0.5	0.08	0.09	0.11
	2	0.31	0.37	0.47
	3.29	0.51	0.60	0.77
	4	0.62	0.73	0.93
	6	0.93	1.10	1.40
2	0.5	0.92	1.09	1.38
	2	3.83	4.52	5.74
	3.29	6.24	7.36	9.36
	4	7.59	8.95	11.38
	6	11.42	13.47	17.12
3	0.5	0.06	0.07	0.09
	2	0.25	0.29	0.37
	3.29	0.40	0.47	0.60
	4	0.49	0.57	0.73
	6	0.73	0.86	1.10
4	0.5	0.13	0.15	0.19
	2	0.53	0.62	0.79
	3.29	0.86	1.02	1.29
	4	1.05	1.23	1.57
	6	1.57	1.86	2.36
Summed	0.5	1.19	1.4	1.77
	2	4.92	5.8	1.77
	3.29	8.01	9.45	12.02
	4	9.75	11.48	14.61
	6	14.65	17.29	21.98

Table 1: Climate change impacts (for each resource zone and summed across the catchment) for 2025/26, 2034/35 (end of the current planning period), and 2050/51 for the MH scenario (3.29°C), the maximum (6°C) and minimum (0.5°C) temperature changes by the 2080s, and for the two critical thresholds of 2°C and 4°C.

Applying the revised climate change impact profiles to recalculate the final planning SDB for each temperature change above the 1961-1990 average means that for all zones the SDB decreases with each increase in global temperature. With each temperature increase the impact of climate change is brought forward. Despite this, all resource zones except one remain in surplus under almost all temperature changes indicating plans that are robust to CCI, at least until the end of the current planning period. Only if temperature changes are >4°C by 2080 will there be catchment-wide problems before 2050. Deficits are likely to increase beyond 2050, potentially requiring additional action before then to maintain supplies.

For one resource zone the current water resources management plan is not robust to more extreme changes in global average temperature; failing at 3°C (which is below the MH temperature value) in 2044. The plan fails in 2038 under the current planning scenario (MH), which strongly indicates the need for further intervention as a consequence of climate change alone before the end of the planning period to ensure future supplies. The current plan fails in

2032 if temperature change reaches 3.5°C in the 2080s indicating that the final plan is not very resilient to potentially higher temperature changes than accounted for. With each further 0.5°C increase in global average temperature by the 2080s, the failure of the final plan occurs 1-2 years earlier, placing increased pressure on the resource zone. Under a 2°C temperature change there is no failure of the plan but at 4°C failure occurs in 2031. Figure 1 shows the minimum new resource requirement in 2025/26, 2034/35 and 2050/51 that is necessary to produce a SDB of 0 Ml/d for each temperature change for this resource zone. By the end of the planning period an additional 1.2 Ml/d is required at 4°C. Under the MH scenario 1.6 Ml/d is needed by 2050 and under the most extreme case 9.4 Ml/d must be found; equivalent to ~10% of deployable output or ~12% of demand. Thus, under more extreme temperatures there is considerable additional supply pressure for one resource zone in the catchment, with potential supply failures occurring if no further steps are taken to increase supply or reduce demand.

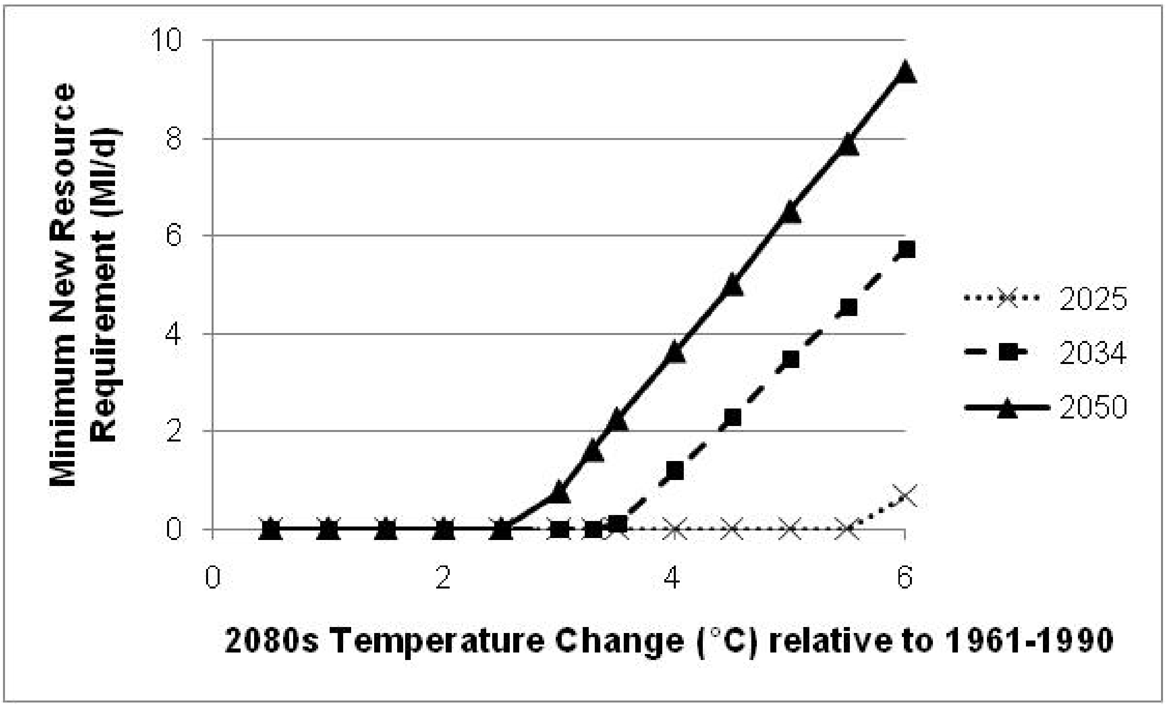

Figure 1. Minimum new resource requirement (Ml/d) for 2025, 2034 and 2050 for each 2080s temperature change for one resource zone.

For the most vulnerable resource zone identified in the catchment the preferred management plan (until 2034/35) relies heavily on new resource management options (increasing reservoir output and a transfer from another resource zone), which provide 79% of the water necessary to maintain the SDB. A major implication of more extreme temperature changes is that options previously rejected from the company's feasible list will need to be re-examined in order to provide a reliable water supply under such conditions. Comparing the feasible list in the draft plan for this zone, it becomes apparent that demand side savings will become increasingly less effective as the CCI increases (there is only an additional 2 Ml/d available in the feasible list) as such schemes appear to reach their water-savings limit. The list of feasible options is also dominated by reservoirs and transfers. However, in addition to numerous potential objections to such schemes from a range of stakeholders (see Arnell and Charlton, 2009), the impacts of climate change may potentially result in reservoirs and transfers becoming less reliable, either exaggerating deficits in the recipient resource zone or increasing pressure on the SDB of other zones. Discussions with stakeholders are in progress to assess how it may be possible to move from the rejected to accepted list should more extreme temperature change impacts occur.

In summary, the developed method for rescaling water company resource zone climate change impacts indicates that current estimates could underestimate impacts if more extreme temperature rises occur than are currently accounted for. The implication of these more extreme temperature changes is that less water will become available causing existing plans to fail increasingly nearer in the future. Additional and earlier intervention will become necessary, potentially drawing on water management options that have been rejected previously (in particular, resource management options). Plans should be reviewed frequently to prevent future supply failures as the trajectory of temperature change becomes clearer. The results reported here are preliminary and conservative estimates, based on a single climate model scenario and assuming that current uncertainty estimates incorporated in the draft plans remain constant. In addition, beyond 2034/35 it is only the climate change impact that is reducing the SDB because all other components remain constant. Thus, the impact on the SDB can be expected earlier and of greater magnitude than the current analysis indicates.

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Basic mechanism for abrupt monsoon transitions

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Monsoon systems influence the livelihood of hundreds of millions of people. During Holocene and last glacial period rainfall in India and China has undergone strong and abrupt changes. An important question is whether monsoon circulations are stable under rapid future warming of four degrees and beyond.

Though details of monsoon circulations are complicated, observations reveal a defining moisture-advection feedback which dominates the seasonal heat balance, acts as an internal amplifier and thereby sustains the circulation: Monsoon winds are driven by land-sea temperature differences in the tropics. Initially these develop in spring, when increasing solar insolation warms the land surface more rapidly than the ocean due to differences in heat capacity. Moist air that is transported landward by these winds rises and yields precipitation. Following this onset of monsoon rainfall, ground temperature on land drops and the entire circulation is sustained by the release of latent heat that is provided by the circulation itself (moisture-advection feedback, figure 1). Such self-amplification is potentially vulnerable to small external perturbations and may lead to abrupt changes in response to relatively weak disturbances.

We present a conceptual model that captures this self-amplification feedback. The basic equations, motivated by observational data, yield threshold behaviour (figure 2). Above a critical value in net radiative influx, R_c, two stable solutions exist – one with and one without monsoon circulation. Below R_c no conventional monsoon can develop. This solution structure allows for two qualitatively different way of abrupt transition. First, climatic shifts can push the system across the critical threshold. The corresponding transition would occur from one season to the other and may last as long as the climatic shift prevails. The second possibility is abrupt transitions within one rainy season, when the system is, as current monsoon circulations are, in the bi-stable regime.

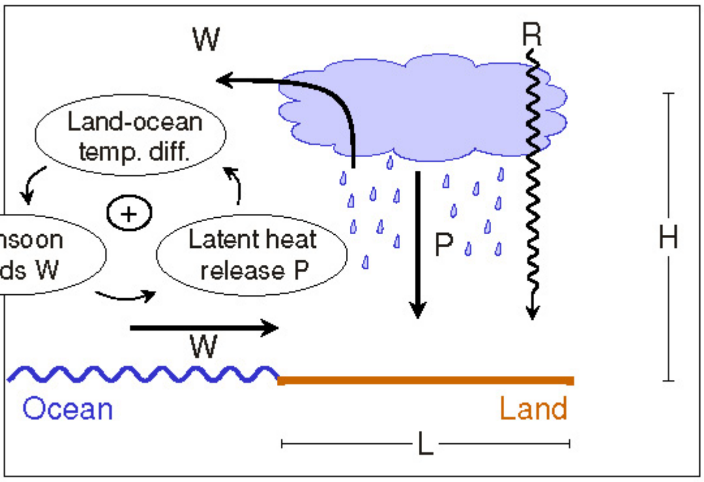

Figure. 1. Geometry of conceptual model and fundamental moisture-advection feedback. Notation as in text: wind, W, precipitation P, net radiative influx R, vertical scale H and horizontal scale L. Arrows in the feedback loop indicate the amplification of one physical processes by another.

The physical mechanism for the threshold behaviour originates from the regional heat budget (figure 3). In the tropics net radiative influx is negative, i.e. radiation cools the atmospheric column. During monsoon season the same is true for the advection of heat by the winds because winds blow predominantly from the colder oceanic surrounding. The release of latent heat compensates for both of these heat loss processes. If monsoon winds get weaker, condensation and therefore latent heat release through precipitation are reduced (moisture-advection feedback, figure 1). The abruptness of the transition emerges through an additional stabilizing effect of the direct heat advection which is cooling the atmospheric column and is also reduced for reduced monsoon winds. Thus both advection-related processes, precipitative warming and thermal cooling, are simultaneously reduced and partly compensate until a threshold is reached at which condensation/precipitation cannot provide the necessary latent heat to sustain a circulation. As a consequence, land-ocean temperature difference ΔT and therewith monsoon winds break down.

We identify a non-dimensional parameter ℓ which defines the threshold and makes monsoon systems comparable with respect to the character of their abrupt transition. This dynamic similitude is helpful in understanding past and future variations in monsoon circulation. Within the restrictions of the model we compute R_c for current monsoon systems in India, China, the Bay of Bengal, West Africa, North America and Australia.

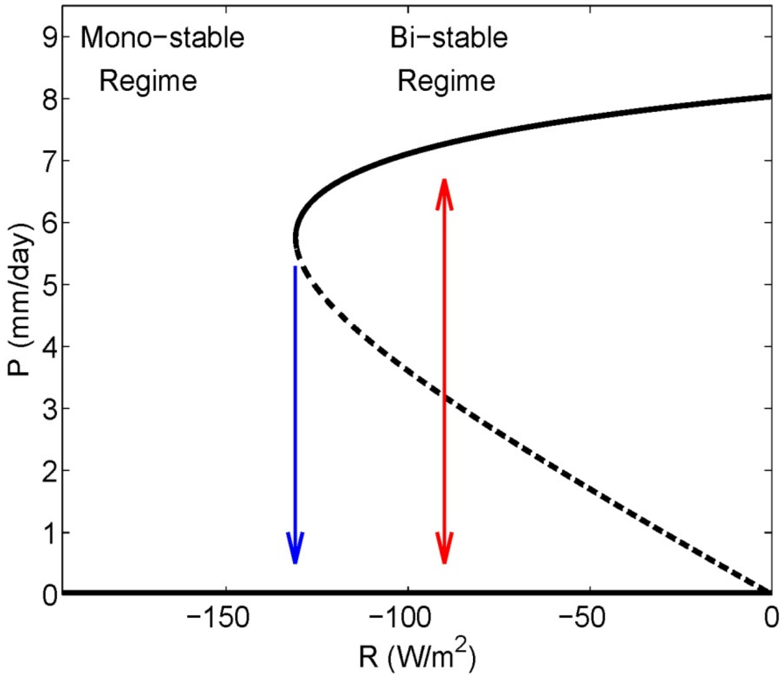

Figure 2 Solutions structure of conceptual model. Below a critical threshold in net radiative influx, R, no conventional monsoon can develop (mono-stable regime). Current monsoon systems are in the bi-stable regime in which rapid transitions in precipitation, P, within one rainy season are possible (red arrow). Abrupt transitions are also possible through a shift across the threshold value, either by changes in R or by alteration of the critical threshold through climate changes.

For monsoon systems which are strongly dominated by the moisture-advection feedback, the critical threshold can be approximated through

$$\boxed{R_C \approx -L \cdot \beta \cdot q_O},$$

where L is a natural constant (latent heat of condensation) but q_O and β have clear-cut dynamical meaning.

q_O is the specific humidity of the air that is blows from ocean towards land. In our model q_O can be interpreted in a rather broad sense as a specific humidity of the vicinity influencing a monsoon region. As an example, the years with anomalously high snow cover over the Tibetan Plateau in spring-early summer could be characterized by a decrease in q_O during mid-summer, which would shift the threshold value R_C for the Indian summer monsoon closer to observed precipitation over the region, thus increasing the possibility of monsoon breakdown in those years. Similarly, colder climate with generally decreased humidity q_O could be closer to the critical threshold which might be the reason for less stable monsoon circulations during glacial periods. Since a warmer atmosphere can hold more moisture and higher sea surface temperatures enhance evaporation, q_O is likely to increase under global warming.

β is the proportionality constant between precipitation and specific humidity. It is governed by the characteristic turnover (recycling) time of liquid water in the atmosphere and thereby determined by atmospheric static stability and vertical velocity in the planetary boundary layer. β is strongly influence by atmospheric aerosol loading. More pollution will generally lead to lower β.

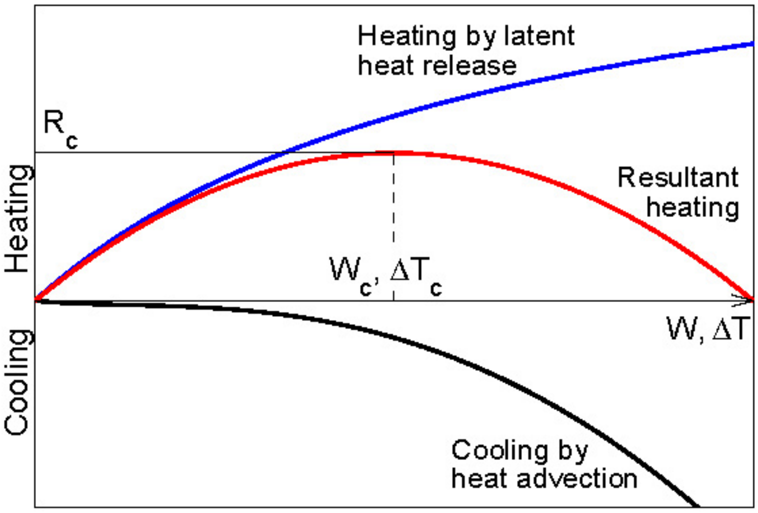

Figure 3 Physical mechanism for threshold behaviour. Heating by latent heat release and cooling through heat advection compensate each other and both decrease with decreasing winds (or equivalently, land-ocean temperature difference ΔT). The resultant heating balances the negative net radiative flux as long as it is above a threshold R_C below which no conventional monsoon exists.

With respect to abrupt monsoon transitions the following possible future risks are evident.

(1) Overall warming and increased moisture transport increases monsoon rainfall. A generally enhanced monsoon circulation may require some adaptive capacity by regional populations for example in India and China, but might be manageable if changes are gradual. However, as physically reasonable and captured by our model, an intensified monsoon will also mean a wider gap between stable monsoon branches (‘on’- and ‘off’-state, figure 2) and thereby enhances abrupt changes in rainfall *within* monsoon seasons. Oscillations between months with strong and months with extremely weak rainfall have already been observed. This effect may enhance in the future.

(2) A future scenario with strong emissions of greenhouse gases and associated warming of 4 degrees and beyond will most likely be associated with strong aerosol emissions, especially in countries like India and China. Aerosols have two major effects with respect to abrupt monsoon transitions. First they reduce net radiative influx and thereby push the system closer towards the critical threshold. Second, aerosols serve

as condensation nuclei and thereby reduce the moisture recycling time. This increases the critical threshold and thereby fosters a breakdown.

The basic mechanism presented here is fundamental to any monsoon circulation and inherently comprises the risk of abrupt circulation break-down. Estimates of the critical threshold for current monsoon systems require a thorough analysis including regional details of the circulation. The non-dimensional parameter ℓ may serve as a guide line for characterizing the tipping potential of individual monsoon systems and thereby make them comparable.

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A model-based approach to predicting the effects of global warming four degrees and beyond on ecosystem primary productivity, land degradatoin and food security at national scale: Case Study Ethiopia

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Introduction

Anthropogenic warming of the global climate system is unequivocal (IPCC, 2007). The effects of climate change are already being felt with various degrees of intensity in different parts of the planet including widespread changes in precipitation amounts, wind patterns and extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (IPCC, 2007). Best estimate and likely range for global average surface air warming for the high emissions scenario (i.e. probably the more realistic) is 4.0°C and the likely range is 2.4°C to 6.4°C (IPCC, 2007). The likely impact of this warming on people's livelihoods is of great interest to policy makers and will dominate policy formulation, particularly concerning mitigation and adaptation measures. A warming of over 4 degrees related to current temperature levels could be of catastrophic consequences in some parts of the planet. The effects of this kind of warming on land productivity, the productivity of agricultural systems and on food security and resource degradation, needs to be assessed carefully. This paper introduces a model-based approach for predicting these effects on the primary productivity of ecosystems, their biomass production, crop yields and ultimately food security at national scale, illustrating the approach with a case study in Ethiopia.

The Approach

The two main modular components to the model-based approach are: (1) Predicting future climate scenarios, as they relate to climate parameters involved in determining soil moisture, plant water supply, growth and productivity (i.e. temperature, radiation, precipitation and evapo-transpiration). Future moisture balances and the Length of Growing Period concept (FAO, 2008) are used and calculated for each scenario (Figure 1). The General Circulation Model (GCM) GLDF_CM21 (NOAA, 2005) is used for these predictions for it represents the "dry" condition or worse case in relation to crop water supply. Two scenarios are predicted: conditions to the year 2050, and conditions assuming + 4 degrees above baseline average values from period ranging from1950 to 2000 (BL+4).

Fig 1. Methodology for National Level Assessment of the impacts of Climate Change on Land Degradation and Productivity: FUTURE CLIMATE SCENARIOS

Future Climate Scenarios

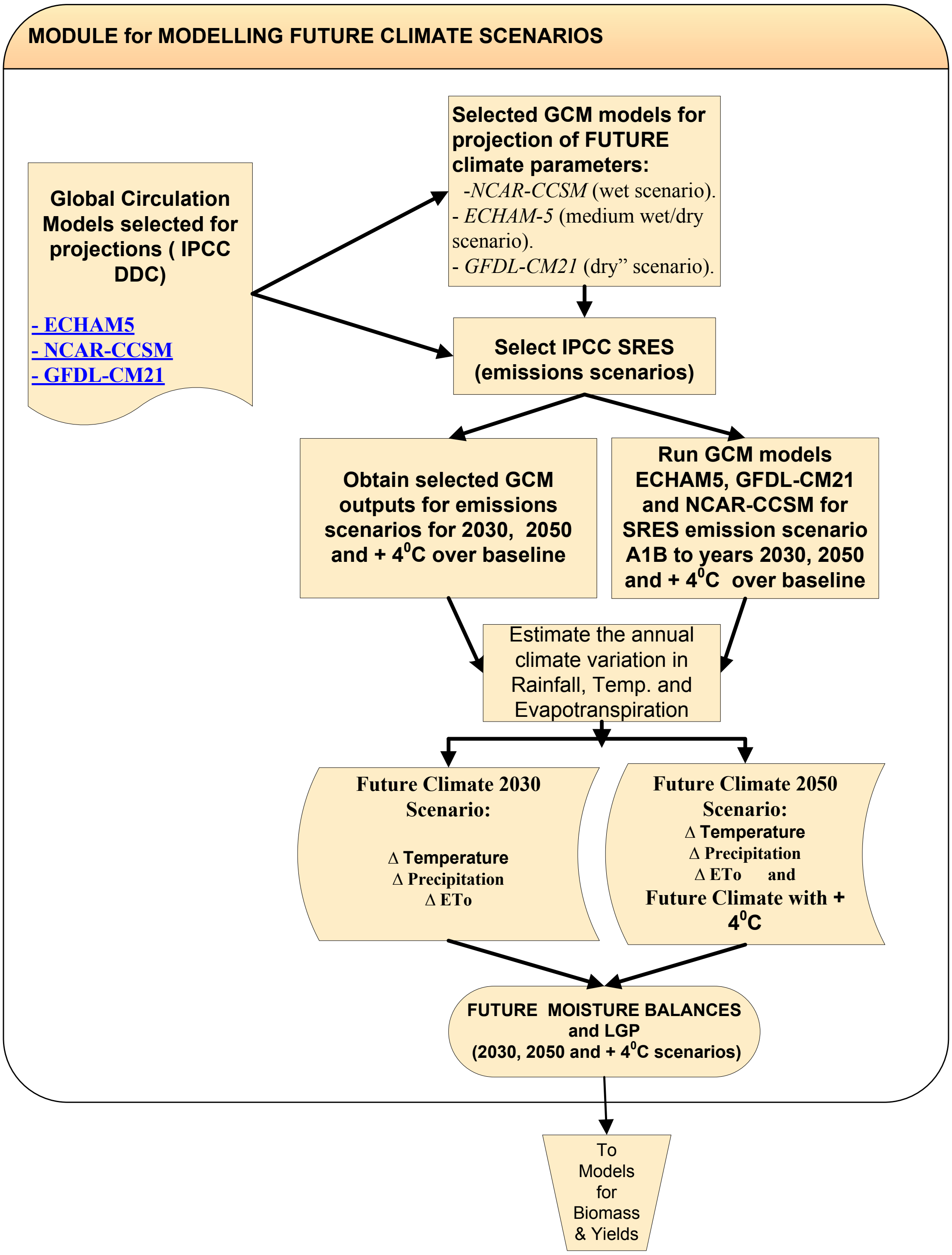

Fig 2. Methodology for National Level Assessment of the impacts of Climate Change on Land Degradation and Productivity: FUTURE PRODUCTIVITY

NPP, Biomass & Yields under Future Climate

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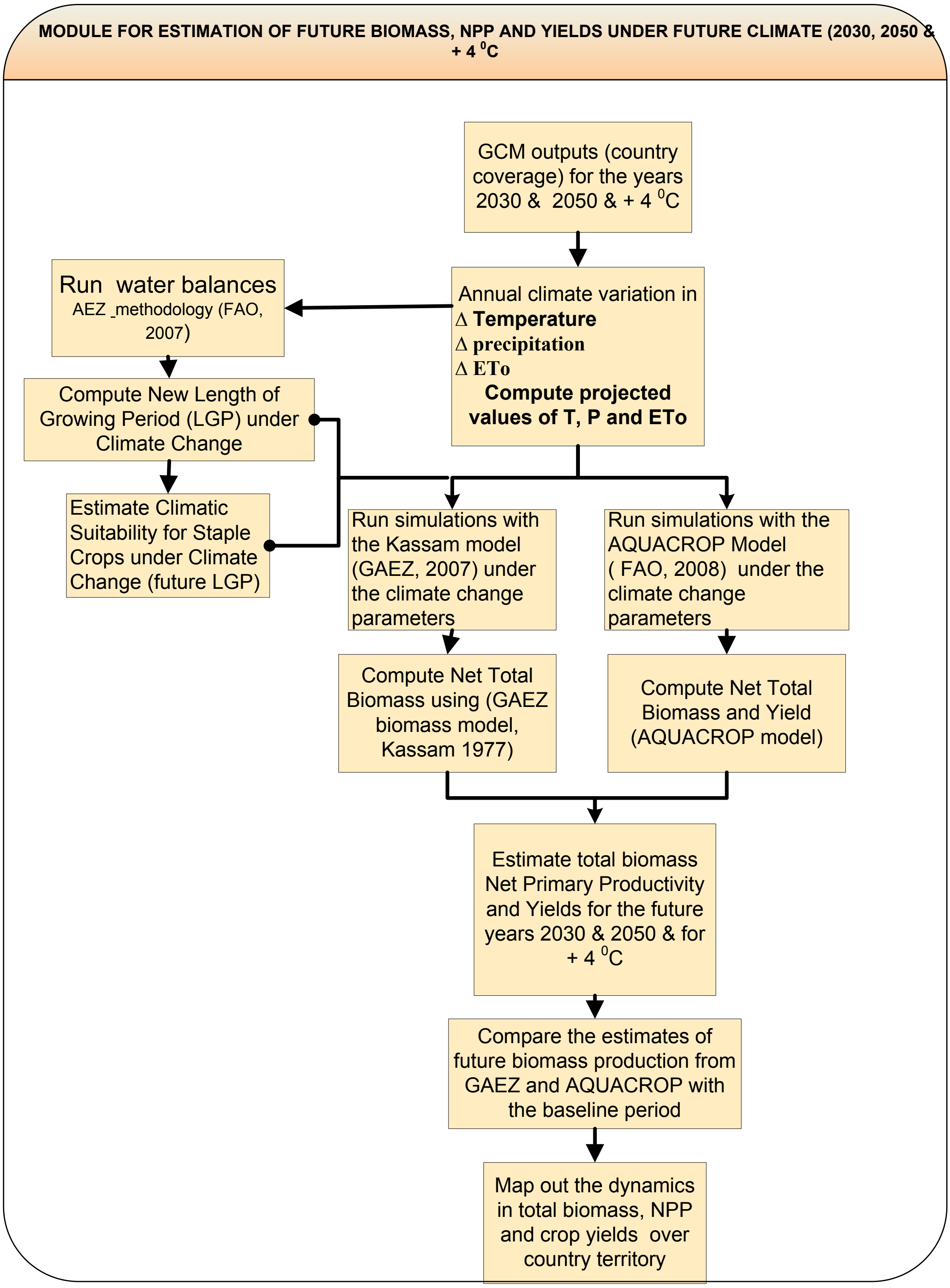


(2) The second module (Figure 2) consists of the set of procedures for the estimation of future productivity under climate change conditions. The AQUACROP simulation model (FAO, 2007) is used for input future climatic parameters and for estimating future biomass and crop yields. Yields for two staple crops in Ethiopia are predicted: corn and wheat, under

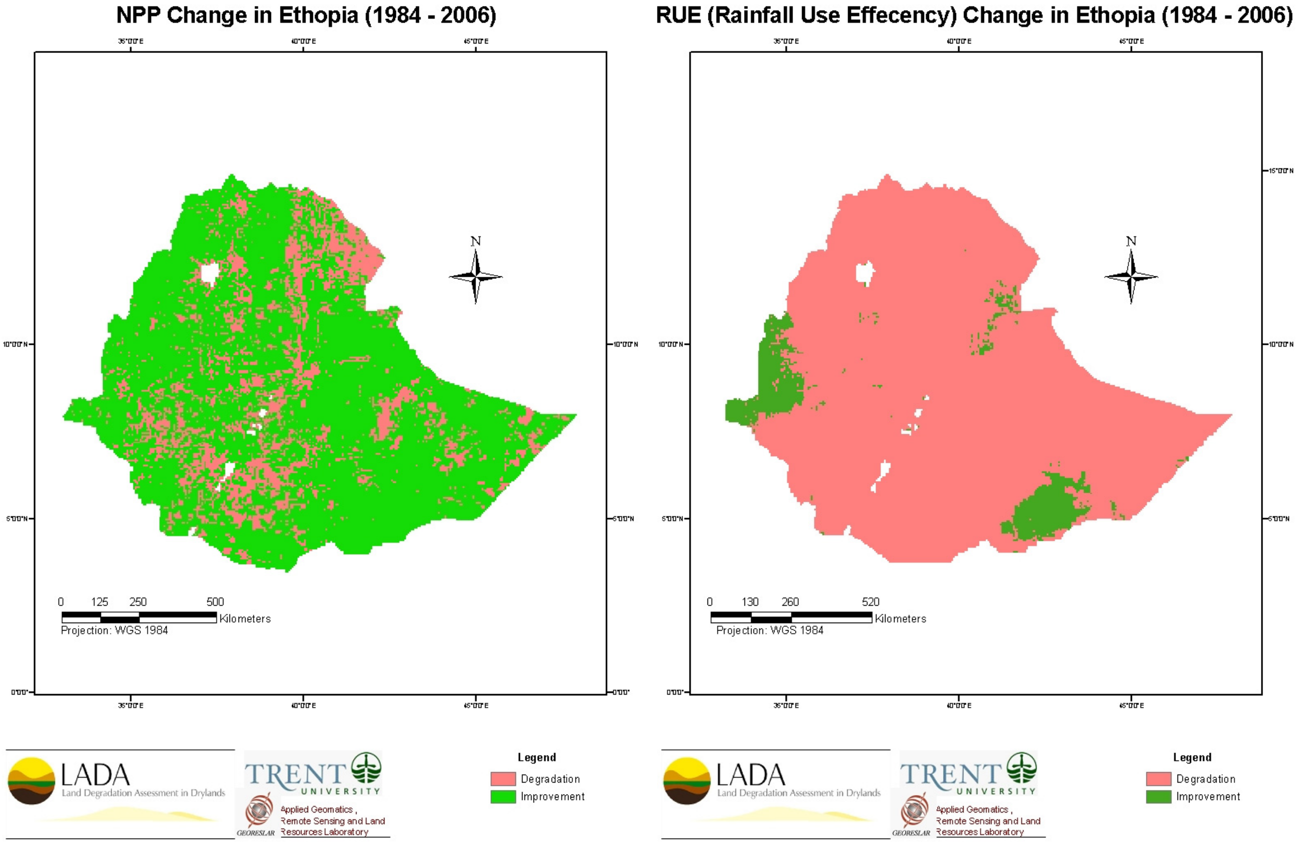
conditions in 2050 and BL+4. The spatial distribution of future biomass and crop yields are mapped out across the country under the two scenarios, 2050 and BL+4.

In order to establish the productivity baseline and detect ongoing trends in productivity changes, Net Primary Productivity (NPP) and Rain Use Efficiency (RUE) are used as indicators of productivity and land degradation.

Results

National maps of historic NPP and RUE were computed from a 22-year time series of Normalized Difference Vegetation Index (NDVI) images computed from NOAA-AVHRR satellite images spanning form 1984 to 2006 (Figures 3a-b). Negative changes in NPP over time were tagged as "degradation" and positive changes as "improvement". A patchy mosaic of NPP in figure 3a showed that productivity decline and degradation are already widespread in Ethiopia, particularly in the south-central and north-western regions, whereas the decline in rain use efficiency (RUE) is generalized over the entire country except for pockets in the north and south-eastern regions (Figure 3b).

Figures 3a & 3b. Spatial distribution of background historic Net Primary Productivity (NPP) and Rain Use Efficiency (RUE) for 22 years (1984 to 2006) in Ethiopia



The GLDF-CM21 model predicts that by 2050 the average increase in temperature could reach 4 ^{0}C in the dry, hot season in April and May, and at least increments of no less than 2

^{0}C in other months, with the warmest regions in the north-central and north-eastern portions of the country (Figure 4). Precipitation deficits (in percent) related to baseline are anticipated to be as large as 90% between February and March in central areas near the capital and span from January to July, with increases in rainfall between August and November, particularly in the central portions of the country and within the Rift Valley and the south-western portions (Figure 5).

Figure 4. Average increase in temperature (°C) in the year 2050 in Ethiopia (Model GLDF_CM21)

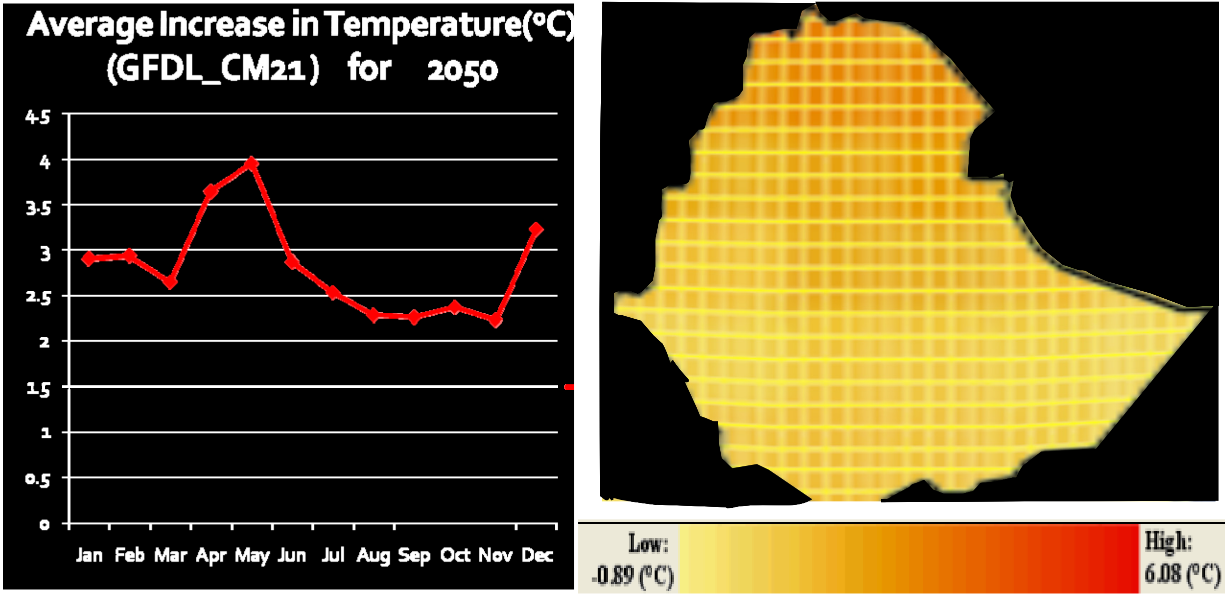
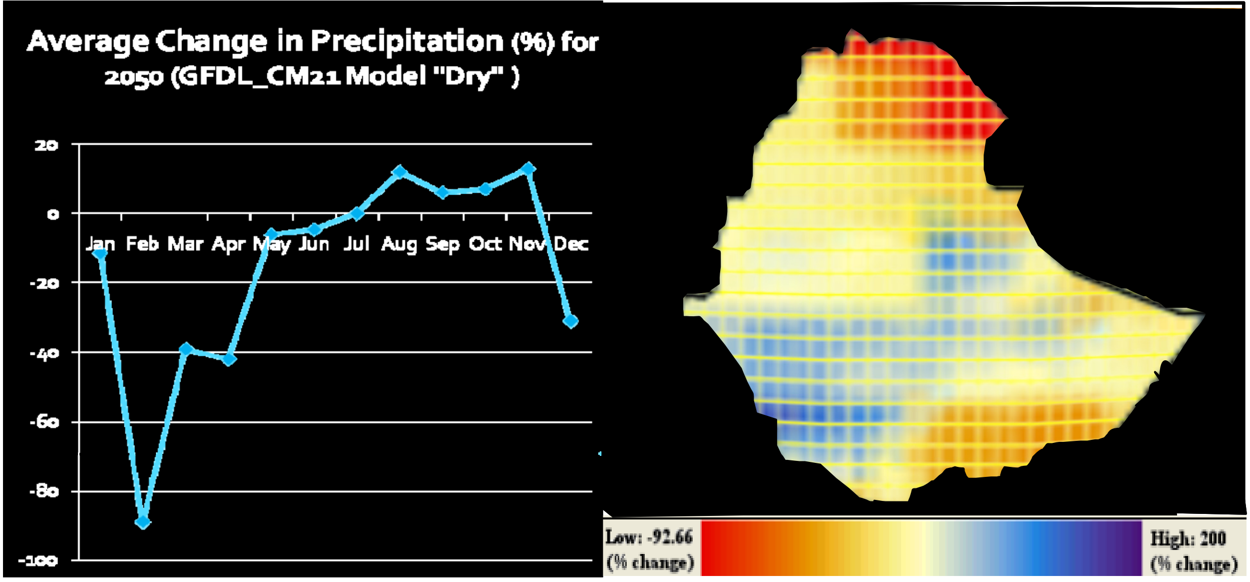


Figure 5. Average change in Precipitation (%) in the year 2050 in Ethiopia (Model GLDF_CM21)



With climate change increased water stress will diminish crop yields making crop failure a realistic possibility. Mapping out the spatial distribution of where the moisture balance (precipitation minus half the potential evapo-transpiration) will not suffice for meeting total yearly crop water requirements is essential for designing adaptation measures. Insufficient moisture availability causing moisture stress will lead to declines in crop yields and even total crop failure. Crop moisture stress areas were mapped for the main grain crops (teff, wheat and corn) in Ethiopia (Figures 6a, 6b and 6c respectively) for the year 2030. The areas of water stress are dominant across the entire territory and the situation is expected to worsen in 2050, and with temperatures reaching increases of 4 degrees and above. It must be mentioned that in these calculations the variability of soil water storage capacity, given soil type and landscape position, was not factored in, since these data were not available for this study. Nevertheless, results show that substantial yield shortfalls and food insecurity may be expected by 2050 and with the BL+4 scenarios raising the spectre of famine in that country again.

Figures 6a & 5b. Scenarios of crop water supply under in 2050 under climate change in Ethiopia for Teff crop (6a, left) and for Wheat (6b, right). Red areas represent water stress and possible reduced yields or crop failure

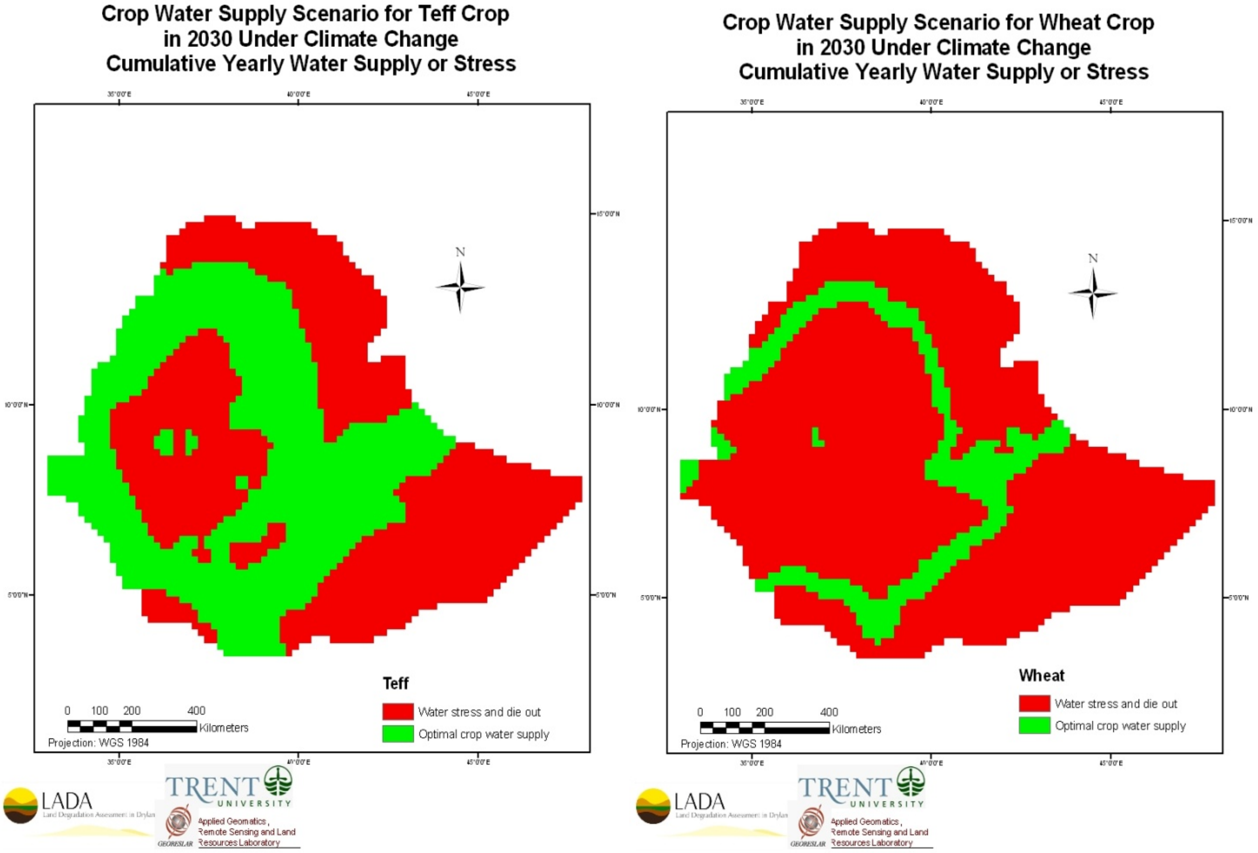
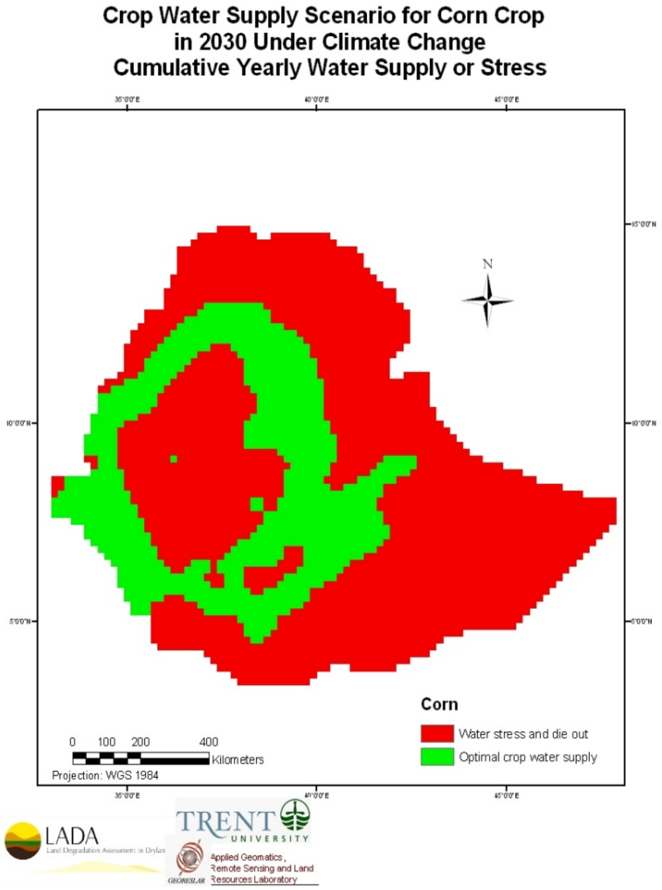


Figure 6c. Scenario of crop water supply in 2050 under climate change in Ethiopia for Corn crop. Red areas represent water stress and possible reduced yields or crop failure



The biomass and yield modelled predictions with AQUACROP allowed for mapping the distribution of crop yields in 2050 and the BL+4 scenarios. Figures 7 and 8 show the expected spatial distributions of crop yields for the year 2050 for wheat and corn crops respectively, under climate change. The changes with respect to the current pattern are quite evident. This may be explained as shifts in precipitation volumes and moisture regimes are also expected in a changed climate.

Figure 7. Spatial Distribution of expected wheat yields in Ethiopia for 2050 under climate change.

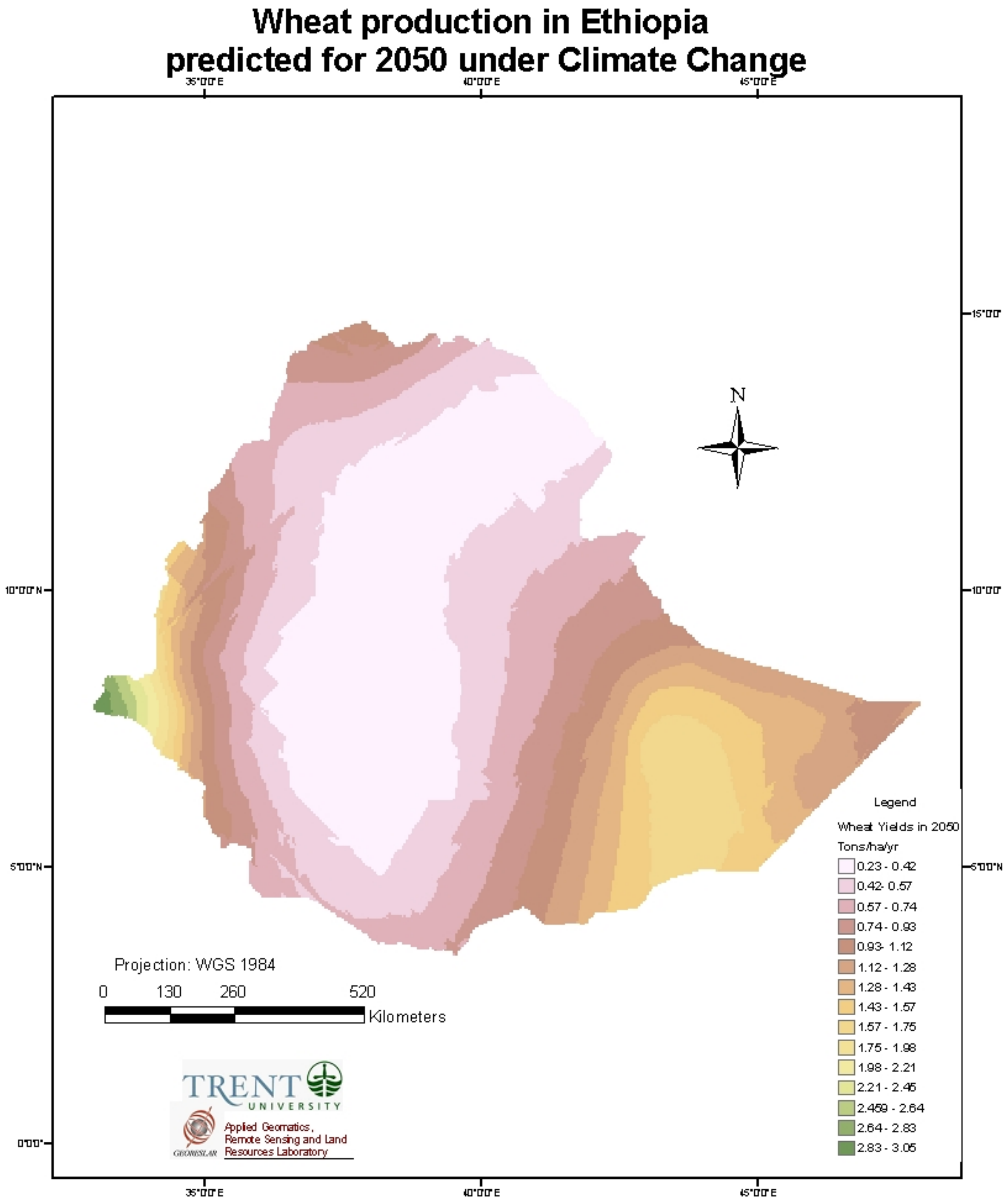
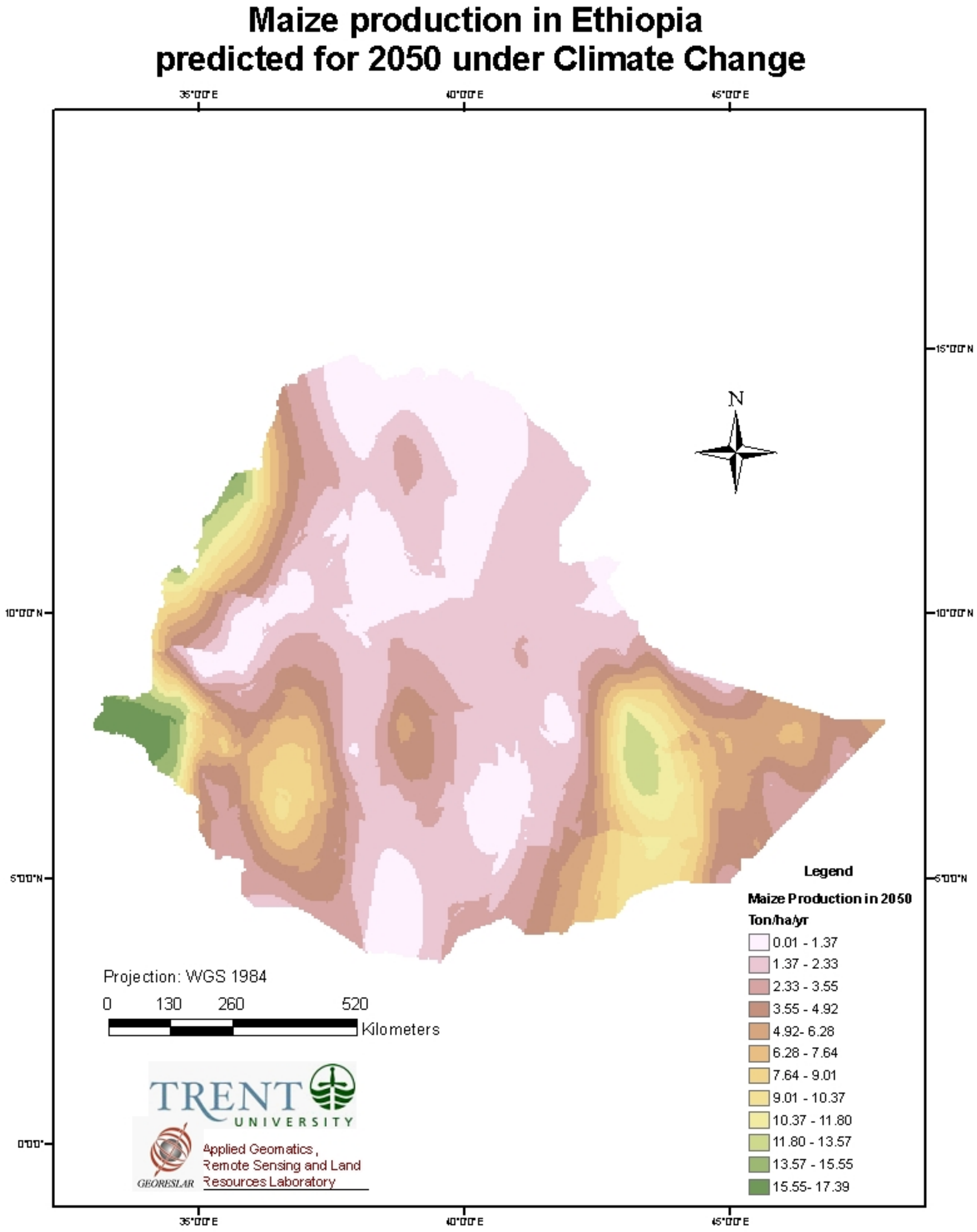


Figure 8. Spatial Distribution of expected corn yields in Ethiopia for 2050 under climate change.



Conclusions

The model-based approach presented in this paper can be useful as a tool for predicting expected changes in productivity and degradation of land resources under a changed climate. Moisture regimes will be greatly affected by 2050 and under an increase of 4 degrees. This will impact negatively crop yields and the frequency of crop failures are expected to increase. Crop yields for the staple grains are expected to change in their spatial distribution pattern and in their quantities. Measures to mitigate and adapt to these changes, particularly concerning food security should be formulated immediately and implemented according to the country’s response capacity.

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Implications of 4+°C global warming on potential of carbon trading for mitigation and food security - analytical framework and an Ethiopian case

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Introduction

In Africa, warming and drying may reduce crop yields with 10 to 20%. In Ethiopia these losses will be 10 to 30% on an average but in some places much more severe (Jones and Thornton, 2009). Carbon trading offers an opportunity to finance mitigation and adaptation of climate change and to enhance equity between the developed world emitting most and the low-income countries especially in sub-Saharan Africa (SSA) suffering hardest. It offers win-win situations for food and energy security in terms of supply, stability and access, and for sustainable resource use. The mitigation potential through agriculture in Africa has been estimated at 17% and the economic potential at 10% of the global total mitigation potential. Further, avoidance of African deforestation accounts for 29% and forests for 14% of the global total mitigation potential. However, the share of SSA constitutes less than one percent of the carbon market at present. In Ethiopia, agriculture-related emissions represent 67% of the total greenhouse gas emissions, with a high projected growth rate in the near future due to growing population, wealth and rising demand for livestock products. This creates a high potential for mitigation options with benefits for agricultural productivity and adaptive capacity, and a need for access to the global carbon markets.

The aim of this study is to create an analytical framework to examine factors affecting the potential of carbon trading to enhance food and energy security and rural livelihoods of the poor in a changing climate. It focuses on the impact of the land use related mitigation options in SSA on food security, with special attention to scenarios of 4+°C global warming. The analytical framework is applied to a case of the Ethiopian Central Rift Valley (CRV).

Material and methods

Options for mitigation, e.g., carbon sequestration, are quantified through a bottom-up approach based on available literature, on new data provided by on-going collaborative studies and on own baseline data to fill gaps when necessary. Alternative scenarios for the implications of 4+°C global warming on the mitigation options and on their impact on food security are constructed. Special attention is put on the impact on capacity to adapt to climate variability and varied changes, taken the high degree of uncertainty in the climate change especially in the national and regional scale. The opportunities and bottle-necks of the mitigation options and of the carbon and emission trading instruments, and their impact on distribution of benefits, are explored based on interviews of key stakeholders from Ethiopia and representatives from the global carbon trading system and climate policy arena.

Results and discussion

At present, avoidance of deforestation is clearly the option with superior mitigation potential (Table 1). Thus, avoidance of deforestation has the highest technical potential to income acquisition through carbon trading. For food security in terms of availability and stability, mitigation through restoration of degraded land is of utmost importance, improvement of grassland having higher potential than that of cropland.

Table 1. Carbon sequestration potential Tg C ha^{-1} a^{-1} depending on land use type

	Cropland		**Grassland**		**Degraded land**	
	TP		TP		TP	
SSA	100%	16-32	100%	75-226	100%	273-547
	20%	3.2-6.4	10%	7.5-22.6	90%	246-492
Ethiopia	100%	3.7-7.4	100%	2.2-67.5	100%	21-42
	20%	0.7-1.5	10%	0.2-0.6	90%	19-38
CRV	100%	0.12-0.24	100%	0.04-0.12	100%	0.01-0.02
	20%	0.02-0.05	10%	0.04-0.01	90%	0.09-0.02

(Avoided deforestation SSA 21000-384000, Ethiopia 800, CRV 2)
TP = Technical potential

Climate change to 2050 will result in temperature increase of 1-2^{o}C and changes in precipitation patterns. About 5-10% of the currently marginal cropland (with reliable growing days of 90 days and more) will become transition zones from cropping to livestock keeping. For Ethiopia and the CRV the increase of land unsuitable for cropping will be higher (Jones and Thornton, 2009). This change will further emphasise the importance of restoration of degraded lands and grassland management as mitigation options relative to cropland management.

Especially in Ethiopia, the unclear property regimes of land form a major barrier for maintenance and enhancement of land use related carbon stocks and carbon trading, and thus for equity in distribution of benefits and for food security. Besides this key in hands of the national decision-makers, serious international and local barriers in access to carbon markets need to be tackled to fully exploit the great potential of carbon trading to reduce environmental degradation, poverty and hunger. Solutions are proposed based on fresh stakeholder interviews.

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Implications of 4+ºC in Japan. -- Quantitative analysis of sectoral impacts of climate change in Japan using an integrated assessment model, AIM/Impact[Policy] --

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The authors have been developing an integrated assessment model (AIM/Impact[Policy]), the purpose of which is to perform integrated assessments of the greenhouse gas (GHG) emission paths, GHG concentrations, temperature increases, and sectoral impacts at future points in time that are anticipated when setting and attaining climate stabilization targets such as the upper bounds of atmospheric GHG concentrations and the upper bound of global mean temperature increase.

Major outputs are the time-series of (1) global GHG emission (reduction) required for economically achieving the prescribed targets, (2) global mean temperature increase and sea level rise under the GHG stabilization targets, (3) national/prefectural climate change scenarios calculated with the pattern scaling method, and (4) impacts of sensitive sectors in each nation/prefecture.

In the AIM/Impact[Policy], detailed impact assessments which place a large calculation burden on computer are not carried out. Rather, numerous simulations are performed outside this model beforehand with different combinations of prescribed changes in climate/non-climate factors (i.e. intensive sensitivity analysis) and the results of the simulations are averaged for each nation/prefecture and stored as look-up tables to be implemented in this model (we call them "impact response functions"). The developed impact response functions can be also used in a stand-alone mode for example in order to browse implications of 4+ºC in each sector.

In the research project for comprehensive assessment of climate change impacts in Japan, which are funded by Ministry of Environment for the period 2005-2009, impact response functions for hydrology, natural vegetation, agriculture, coastal zones, and human health have been developed by experts of each sector and they have been implemented into AIM/Impact[Policy]. At the conference, implications of 4+ºC in Japan will be discussed with using this model in a stand-alone mode. Our tentative assessment revealed that Japan will be severely impacted even by a comparatively small temperature increase.

Implications of Extreme Global Warming Scenarios for Global Water Availability

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Motivation and outline

The world's freshwater system is among the most vulnerable systems towards climatic changes, and changes therein will have consequences for both ecosystems and human societies. While a number of previous studies have investigated worldwide changes in water resources and stress for different time slices in the future and also for different levels of mean global warming reached by the end of the 21st century (e.g. Arnell 2006), there are to our knowledge no estimates available of changes in water resources for extreme increases in global temperature.

Here we used the LPJmL Dynamic Global Vegetation Model (version 3.3) for the biosphere and agrosphere (Bondeau et al. 2007; Rost et al. 2008) to quantify changes in freshwater availability (per person) under very high increases in global mean temperature (4K to 8K), globally and spatially explicitly. For this, the model was forced for the period up to 2200 by pattern-scaled climate from the ensemble average of 24 General Circulation Models. The trajectories of global mean temperature and CO_2 concentration were taken from the MAGICC6 Model for the Assessment of Greenhouse-Gas Induced Climate Change (Wigley & Raper 2001, Meinshausen et al. 2008). This model captures thermal inertia of the earth system, carbon cycle feedbacks and radiative forcing of a wide range of greenhouse gases and aerosols to emulate the response of global mean temperature to emissions of CO_2 and other greenhouse gases.

Note that all results presented herein are preliminary.

Methodology

Model Setup

In order to assess the impact of extreme global warming on water availability and scarcity, we forced the LPJmL model with scenarios of global mean surface temperature increase reaching 4 to 8 K (in 1 K intervals) above preindustrial level by the end of the 22nd century. These warming levels correspond to trajectories of atmospheric CO_2 concentration reaching, respectively, 793, 1038, 1351, 1761, and 2225 ppm, which were also used as model forcing. The global mean temperature was pattern-scaled to derive monthly regional estimates of temperature, precipitation and cloud cover used to force LPJmL (see below). To bring the LPJmL model into equilibrium it was run over a spinup period of 1000 years by forcing it with the continuously repeated 1901–1930 climatology of a homogenized and extended version of the CRU TS2.1 climate dataset (Österle et al. 2003; Mitchell & Jones 2005) and preindustrial CO_2 concentration (280 ppm). Then, a transient run for the period 1901–2220 was performed for each temperature level using observed climate and CO_2 concentrations until 2000 and the climate and CO_2 data, described in the following section, thereafter.

Generation of Climate Scenarios

Global mean temperature and corresponding CO_2 concentration trajectories were generated using the MAGICC6 model. The model was parameterized to give the average response of all 24 GCM used in the IPCC AR4 (Randall et al. 2007) and forced with an emission mix of

aerosol and greenhouse gases derived by applying the 'Equal Quantile Walk' method (Meinshausen et al. 2006). This assures that the respective proportion of all components is the same quantile as in the existing distribution of SRES and Post-SRES scenarios.
In order to generate spatially explicit climate change scenarios for temperature, precipitation and cloudiness, a pattern scaling approach was applied. Based on the data fields from the 24 different GCMs for the SRES A1B scenario and the period 2000–2099 (available from the WCRP CMIP3 data base), an ensemble median was calculated and linearly interpolated to 0.5 degree spatial resolution. Then, for each month and each grid cell regression functions were fitted, which describe the relationship between global mean temperature change and local climate response (Mitchell et al. 1999). For temperature and increasing precipitation a linear relationship was assumed, whereas for decreasing precipitation and cloud cover an exponential relationship was assumed. The derived patterns of function coefficients were then used to scale the observed baseline climatology (1971–2000) relative to the increase of global mean temperature produced by MAGICC.

Water Availability
We calculated freshwater availability on the basin level by summing up all runoff (the water resource) generated within each river basin around the globe, and by subtracting 30% from this amount to roughly account for environmental flow requirements in rivers (Rockström et al. 2009). The thus determined water resources were related to the population living in the respective basin, using the population distribution from Grübler et al. (2007) for the intermediate B2 scenario in 2100 (global population of 10.4 billion; for the period beyond 2100, no population estimates are available). We then used the Falkenmark water shortage index (Falkenmark 1989) to group rivers basins into water stress categories according to the average annual per capita availability within each basin. Basins with < 500 m^3/cap/yr are classified as having extreme stress, with 500–1000 m^3/cap/yr as having high stress, and with 1000–1700 m^3/cap/yr as having moderate stress (> 1700 m^3/cap/yr, unstressed).

4. Results and preliminary conclusion

Assuming the freshwater resources under the climate of the period 1971–2100, we first calculated future water availability under the assumption that no further climate change will occur, to derive a baseline scenario that demonstrates effects of population change only. We found that under these conditions 3.3 billion (34%) of global B2 population in 2100 will live in basins with extreme water stress, 3.2 billion (33%) in basins with high stress, and 1.2 billion (12%) in basins with moderate stress. The global distribution of water stressed basins in the four stress categories is shown in Figure 1.

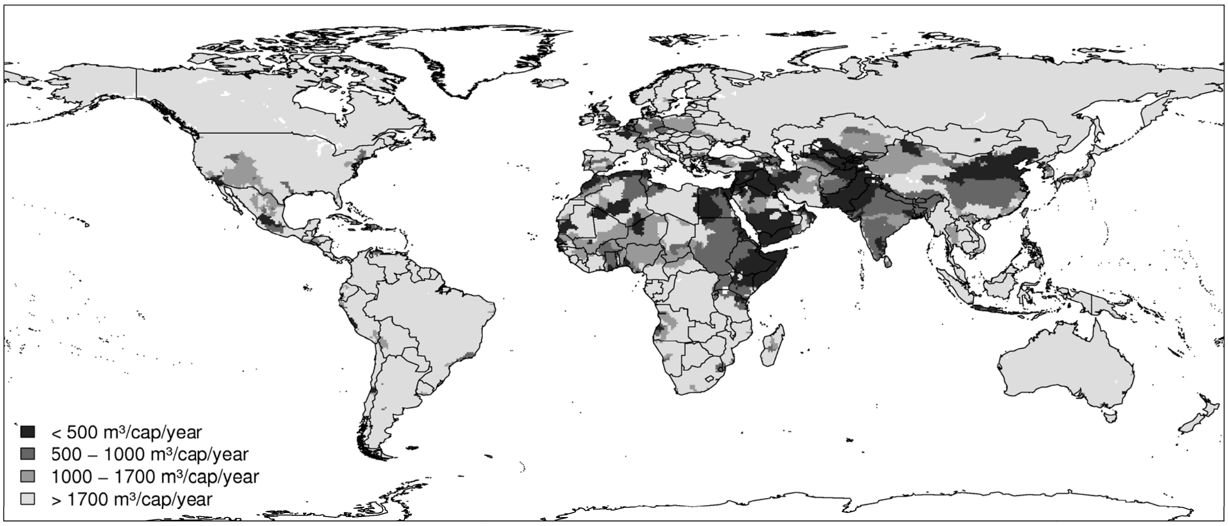

Figure 1. Global map of average annual per capita fresh water availability in river basins. Calculations are based on current water resources (1971–2000 average) and population projections of the B2 scenario for the year 2100.

In a next step, we calculated the changes in freshwater resources and in the number of water stressed people under the different degrees of global warming (4–8 K, ensemble median). As an example, the change in water resources for 6 K global temperature increase is shown in Figure 2. The direction of change at a particular location remains generally the same throughout the different levels of warming (since the pattern-scaling approach relates regional precipitation uniformly to global temperature), while the intensity of change increases. However, a few cases occur where a decreasing trend of runoff at lower levels of warming in one part of a basin is outbalanced by an increasing trend in other parts at higher levels of warming (data not shown).

Figure 3 shows that more people become water stressed with increasing global mean temperature while at the same time the number of non-water stressed people also increases, reflecting different precipitation patterns (increases in high northern and temperate regions, decreases especially in subtropical regions). Yet, the adverse impact of warming on water availability appears to be highest in the extreme stress category.

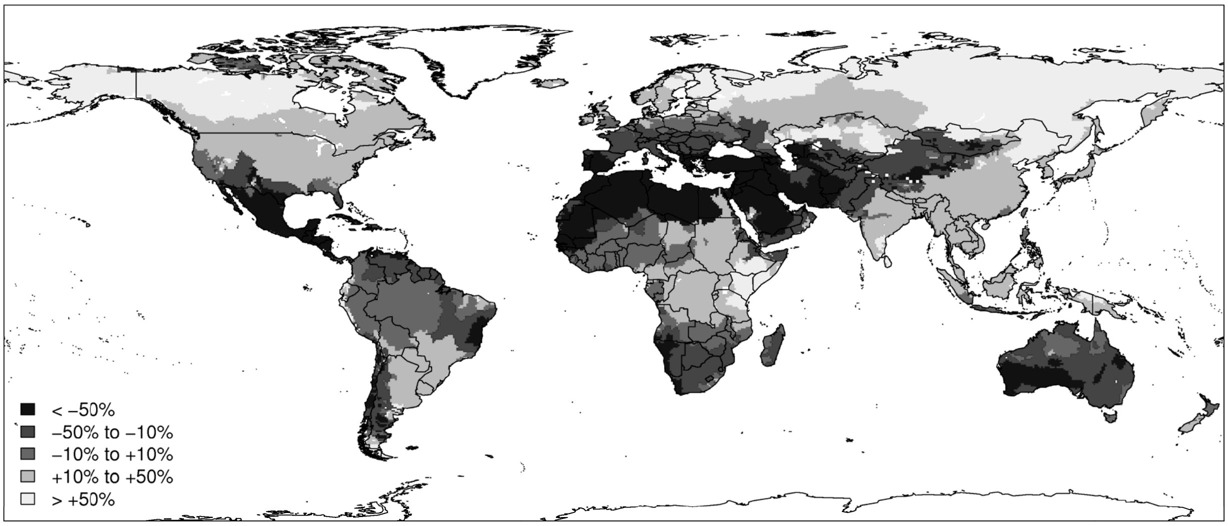

Figure 2. Percentage of change in fresh water resources for the 6K warming scenario.

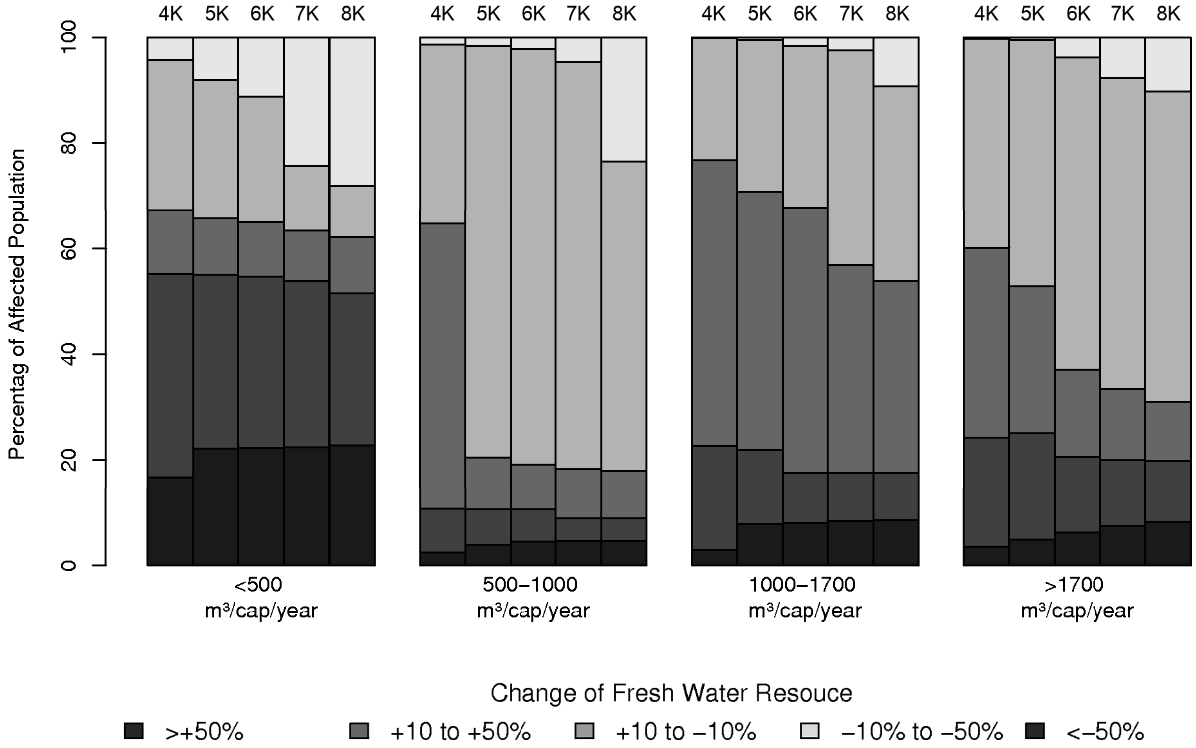

Figure 3. Impact of climate change on freshwater availability for the population of the B2 scenario in 2100 in the different stress categories and for the different levels of global warming.

Thus, more than 50% of a future population of 3.3 billion people (B2 scenario) who are projected to live with less than 500 m³ per year without climate change would see a further loss of water resource at high levels of global warming. The pressure on water resources is already very high in this category making adaption extremely costly if not impossible. Second, further warming beyond 4 degrees appears to not aggravate water scarcity very much. Instead, there seems to be a progressing trend towards higher water availability for large parts of the population throughout all stress categories. However, this does not necessarily mean that this additional water is accessible. The increase may occur during the wet season and/or lost as storm flow, possibly associated with a higher probability of flooding. A decrease in water availability on the other hand is undisputably detrimental. As the strongest decrease occurs at temperature levels *below* 4 degrees, our results emphasize the need of climate mitigation to stabilize global mean temperature way below that level.

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Stochastic and perturbation techniques to assess the influence of climate change-induced multi-seasonal drought on water resource vulnerability at Weir Wood Reservoir, North Sussex, UK

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With climate-change water stress expected to increase in the UK throughout the 21st century (Bates *et al*., 2008), effectively managing water resources on long time scales is one of the major challenges we face. This paper shows that information from weather generators can produce a best estimate of future water resource vulnerabilities to multi-seasonal drought on fine spatial scales that are more severe than using a perturbation approach. In this case study the Environment Agency Rainfall and Weather Impacts Generator (EARWIG) (Kilsby *et al*., 2007) is applied to Weir Wood Reservoir, North Sussex, to signify multi-seasonal drought in a baseline period (1961-1990) and, using change factors from the PRUDENCE project, the 2080s. A range of 4 climate models and 2 SRES scenarios (A1FI and A2) are used. The perturbation approach uses the A1B SRES scenario and change factors from 5 ENSEMBLES models.

Using the weather generator approach, substantial climate change-induced rises in evapotranspiration rate in the 2080s compared to the baseline period (1961-1990) and historical droughts (figure 1) associated with a 4ºc or more annual mean temperature rise are projected to create large increases in hydrological multi-seasonal drought severity at Weir Wood. Worst case 2080s inflows in 13th-ranked multi-seasonal droughts are reduced to a total of 47.33 cumulative cumecs over 30 months (a decrease of 83.88% from their equivalent rank in the baseline period) (figure 2). This is largely due to winter evapotranspiration rates becoming high enough to reduce effective winter rainfall, on which the reservoir relies almost exclusively for recharge. The most extreme future multi-seasonal droughts are from the HIRHAM RCM driven by ECHAM4, which creates very high PET and less of a shift towards wetter winters and drier summers than the other models, leading to warm winters with less rainfall (and therefore less reservoir recharge). However, climate models driven by HADAM3H project 2080s 13th-ranked droughts of a similar hydrological severity as 1919-22.

The simple nature of the reservoir means that with some confidence it can be implied from the inflow data that yields in the 2080s multi-seasonal drought periods will fall below yields observed during notable droughts in the historical record (figure 3); however there is significant disagreement on the scale of this reduction between models. This occurs despite greater winter rainfall totals in most cases. Inflows and yields are substantially reduced from baseline levels in the 2080s at Weir Wood reservoir regardless of whether a meteorological drought is apparent. Even in the best-case scenarios with increased annual rainfall and increased seasonality (HIRHAM_H), the scale of the evapotranspiration increase creates multi-seasonal hydrological droughts more severe than the baseline (figure 1), and yields lower than the droughts of the 1890s (figure 3). The baseline period contains a very extreme 1st-ranked drought event in comparison to the rest of the dataset, whereas the future projections do not, possibly as a result of the weather generator being unable to produce extreme blocking events in future simulations (Jones *et al*., 2009). It should be noted that the 1st-ranked drought would have an extremely high return period given the long dataset and would therefore represent an unlikely event that would not be taken into account when planning water resources.

Conversely, when the perturbation method is used, only small increases in hydrological drought severity at Weir Wood in the 2080s are apparent, and some models project an increase in inflow compared to the historical droughts with which they are associated (figure 1). Rises in evapotranspiration rates are significantly less pronounced in the perturbed drought events than the stochastic drought events, so all winter rainfall remains effective and the reservoir is recharged to some extent even in the most extreme drought (the perturbed 1919-22 drought). It is important to take into account that the stochastic droughts are selected specifically as 3-winter low rainfall events, whereas the historical droughts may not necessarily have 3 consecutive low rainfall winters (e.g. the rainfall associated with the drought may include particularly low summer rainfall events that are not significant to the recharge of the reservoir). Furthermore, there is a large temporal disparity between the datasets, with a 747 year record to represent the 2080s from EARWIG and a 108 year historical record from which the perturbed data is gained. However, the 1919-22 drought is the worst 3-winter meteorological drought in the record and the perturbed 2080s drought from this period does not create a hydrological drought as severe as the 13th-ranked stochastic meteorological drought. This shows that the perturbation technique projects vastly less severe droughts than the weather generator approach, with increases in rainfall and PET effectively cancelling each other out.

As a tool to create entirely synthetic data, the weather generator is able to capture variability and change in droughts in the latter 21st century better than the perturbation technique. Crucially, the periods of high evapotranspiration within the synthetic dataset that are the stimulus for the major droughts of the 2080s are not apparent in the perturbed data. The increases in evapotranspiration need to be further investigated to determine exactly why they are occurring at such a greater rate in the weather generator approach than the perturbation approach. It may be the case that differences in the methods of PET calculation account for some of the disparity.

It is suggested that with the projected global temperature increases over the coming century raising evapotranspiration rates faster than we have observed in the past century, more emphasis needs to be placed on evapotranspiration in water resource studies rather than relying on comparing droughts to previous meteorological droughts and a focus on rainfall alone. Even in the best case scenario given from the stochastic data, evapotranspiration is still having very large effects that are dominating the increases in winter rainfall in the 2080s. It is speculated that PET and AET may be somewhat overlooked in multi-seasonal drought discourses, and relying solely on precipitation totals as indicators of drought events (which may show a gradual decrease in drought severity at Weir Wood over the period covered by this project) will become impractical in the near future. Furthermore, this study shows that in continuing to use perturbation methods to project future drought vulnerabilities we run the risk of underestimating the scale of hydrological droughts in our reservoirs as temperatures increase in the latter half of the 21st century, particularly in south-eastern England. Finally, the study shows that the choice of GCM is the most important factor affecting the projected inflows to the reservoir.

Given the large-scale and high cost decisions that are made within water resource management, longer time horizons must be taken into account in decision making. Inconclusive evidence for increased hydrological drought at Weir Wood in the 2020s is as a result of the full effects of anthropogenically-induced temperature rise on evapotranspiration rates not being felt until the mid-to-late 21st century. There is a risk of maladaptation if decisions were only based on scenarios looking 20-30 years ahead, as in current water resource planning methods.

There is a large amount of work that can follow on from this paper. Using a probabilistic approach would provide more informative results than the scenario-based approach used here (New et al., 2007), and would ideally utilise the UKCP09 scenarios. Weir Wood reservoir was selected due to its simplicity, but the weather generator approach to assessing water resource vulnerability can be extended to any reservoir (or water resource input) in the UK, and it would be interesting to see how those affected by summer rainfall performs (e.g. run-of-river abstractions). It would also be useful to further study the synthetic dataset used here to assess the vulnerability of Weir Wood to shorter droughts (i.e. 6, 12, 18 and 24 month droughts).

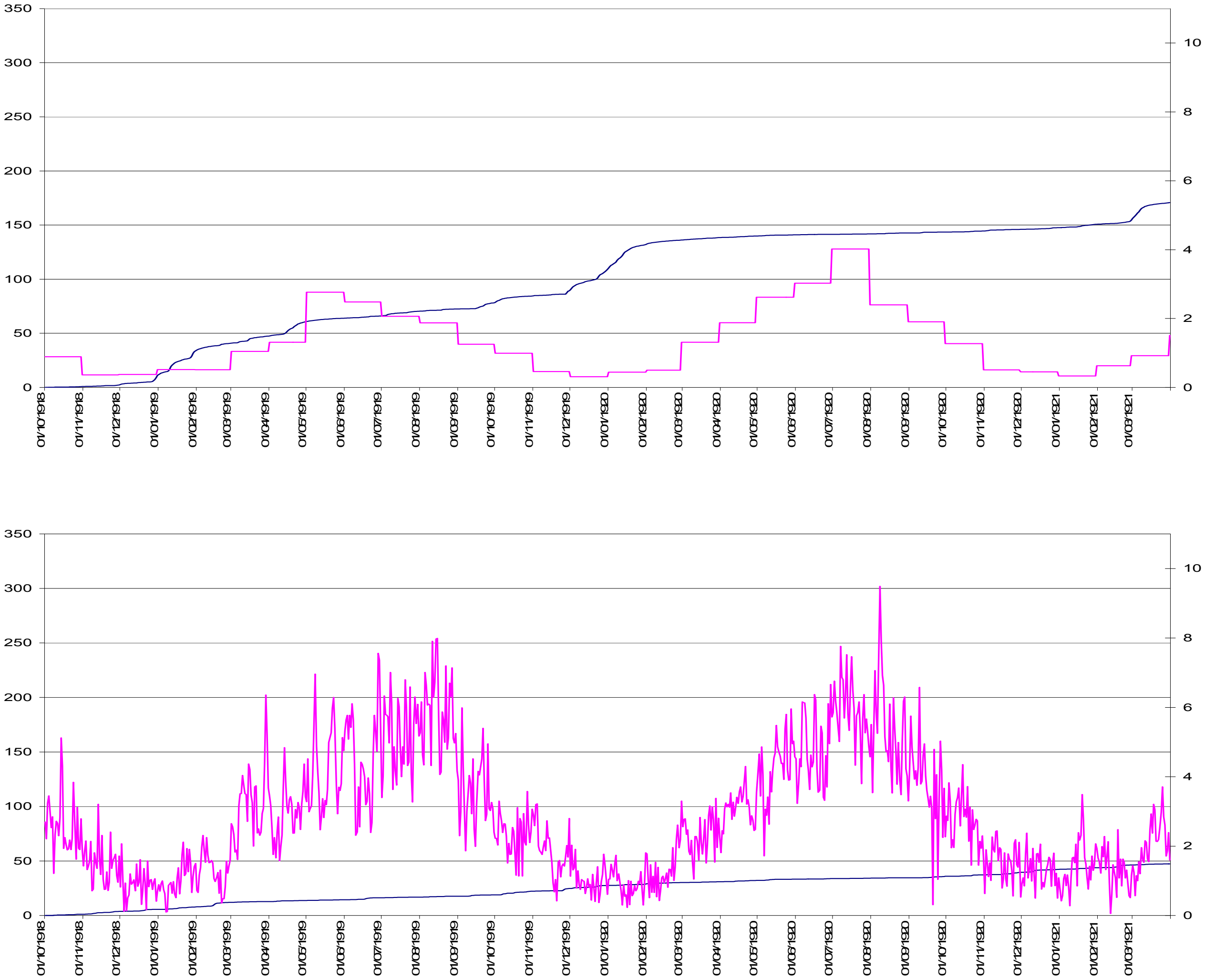

Figure 1. Top: Instrumental cumulative flow (cumulative cumecs)/PET (mm) for the 1919-22 drought. Bottom: Simulated cumulative flow/PET for the 13th-ranked drought event in the HIRHAM_H 2080 with high (A1FI) emissions scenario dataset.

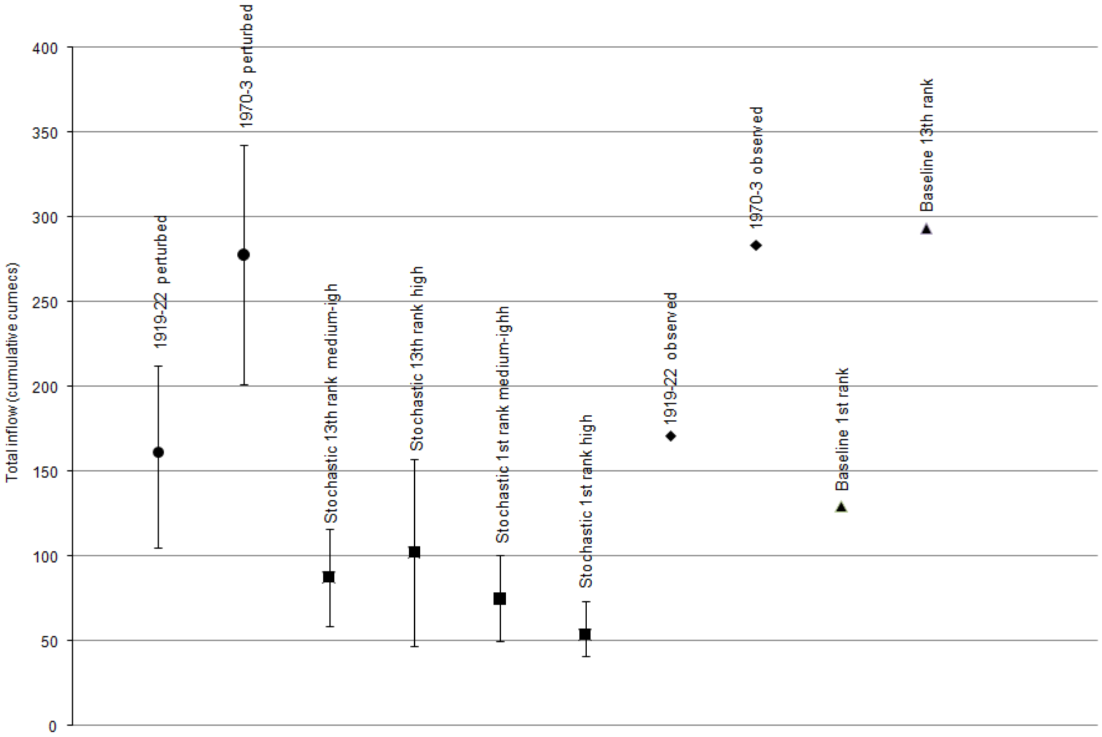

Figure 2. Total inflow at Weir Wood Reservoir in the 2080s, as well as baseline inflows for reference. Uncertainty ranges are the highest and lowest values of the models used, points are the mean.

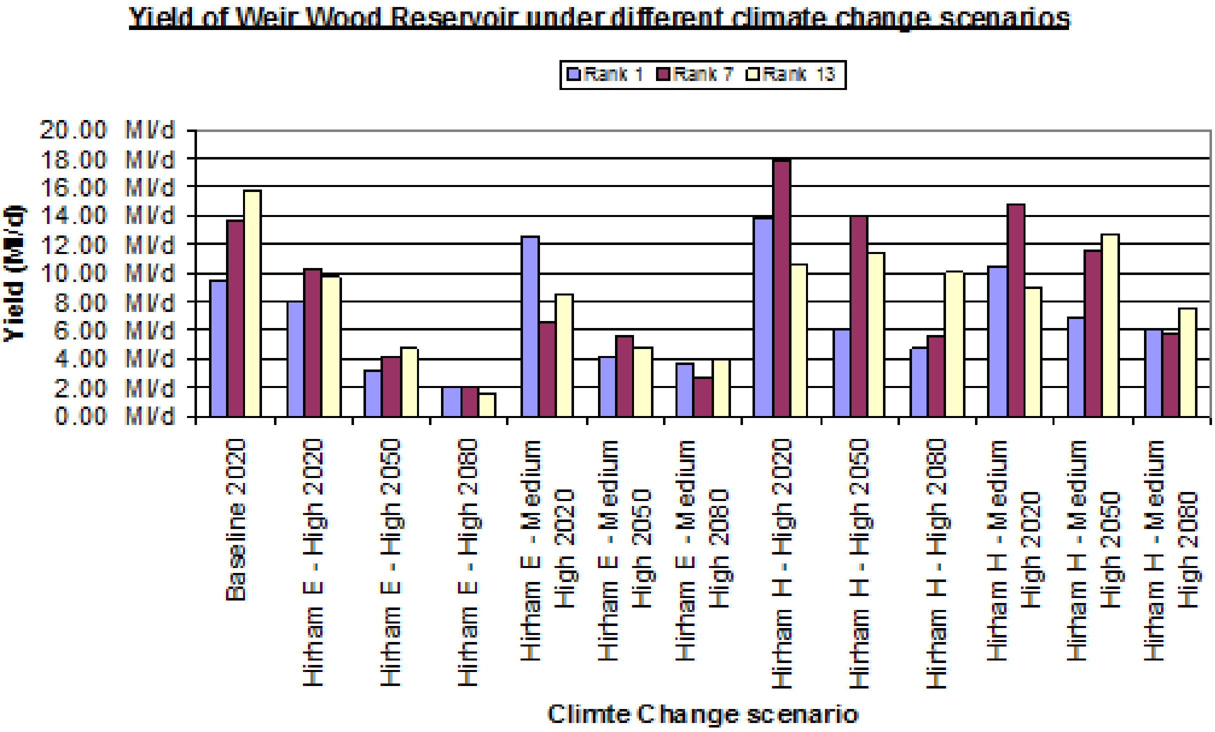

Figure 3. Estimated yields at Weir Wood Reservoir during the 21st century. The 2080s data driven by both ECHAM4 (HIRHAM_E) and HADAM3H (HIRHAM_H) project that yields during major droughts are likely to be lower than the minimum yields in the droughts of the 1890s (8.9 Ml/d).

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Ecosystems and Ecosystem Services

Tropical forests in a 4+°C World

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Tropical forests are biologically the richest biomes on Earth, home to half of global biodiversity, and have harboured this immense biological wealth in a climate that has only shifted slowly throughout paleohistory. In this paper I will examine how tropical forests may respond a global warming of 4° within a timescale of a century. The rate of tropical warming projected this century is perhaps unprecedented for 55 million years, and may present acute problems for tropical organisms, which are not adapted to large temperature fluctuations. The tropics also have very shallow spatial gradients in temperature, and organisms would have to migrate or disperse great distances to remain in equilibrium with climate. There would inevitably be a substantial reorganisation of the ecology and species composition of tropical forests, with increased risk of extinction of those species ill-adapted to such rapid climate change. The warming and high CO2 would affect water use by tropical forests, and may lead to enhanced water stress even in the absence of precipitation change. Tropical forests will experience regional changes in precipitation, and some may face substantial decline in precipitation, with increased likelihood for the spread of fires. Much attention has focussed on the potential for a dieback of the Amazon forest, and we will review the evidence and mechanisms for such a dieback. The interaction between climate change and ongoing tropical deforestation may be crucial in determining the fate of many tropical forests. This will almost certainly be the most challenging century that tropical forests have faced for a long, long time.

Changing climate, land use and fire in Amazonia under high warming scenarios

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Expected losses in Amazonian and other tropical rain forests during the 21st century result from both deforestation and climate change, but changing fire regimes may play an important role. Annually, tropical forests process approx. 18 Pg C through respiration and photosynthesis – more than twice the rate of anthropogenic fossil fuel emissions (Dirzo & Raven, 2003). The Amazon basin has now lost approx. 18% of its original forest cover and continues to loose 0.18% to 0.44% per year by deforestation and fires (INPE, 2008). Current climate change may be transforming this carbon sink into a carbon source by changing forest structure and dynamics (Cramer *et al.*, 2004, Phillips *et al.*, 2009). Increasing temperatures may accelerate heterotrophic respiration and thereby enhance carbon emissions from soils (Malhi & Grace, 2000). Potentially decreasing precipitation and thus prolonged drought stress may lead to increasing physiological stress and reduced productivity for trees (Malhi *et al.*, 2008). Resulting decreases in evapotranspiration and therefore convective precipitation could further accelerate drought conditions and destabilize the tropical ecosystem as a whole and lead to an "Amazon forest dieback" (Cox *et al.*, 2004). Fire frequency, negligible in undisturbed rainforests, is likely to increase with drier climatic conditions and an increasing number of human ignitions. Although negative feedbacks, e.g., due to CO_2 fertilization, are possible, it cannot be rules out that the combination of deforestation, climate change and fire could lead to a tipping of the system (Lenton *et al.*, 2008, Nobre & Borma, in press).

Assessing the sensitivity of tropical forests to the combination of these changes requires a multi-scenario approach (GHG emissions, CO_2 concentration, temperature and rainfall changes incl. variability, and land use change) and it must be acknowledged that not all processes are fully known. Process-based simulation models account for several fundamental physiological impacts of warming on tree growth and mortality, but for some others, such as the direct effect of atmospheric CO_2, several hypotheses need to be tested. Since previous studies mostly consider the range of climate change present in IPCC-AR4 scenarios (Poulter *et al.*, in press), we here present a sensitivity study of the dynamic global vegetation model LPJmL (Bondeau *et al.*, 2007, Sitch *et al.*, 2003) for selected high warming scenarios beyond four degrees global temperature rise. In order to consider fire effects using an appropriate process algorithm, we use a new fire module in LPJmL (SPITFIRE, Thonicke *et al.*, in review) permitting the study of forest composition changes near the edges of deforested areas, which lead to increased post-fire tree mortality. Specifically, this module allows the investigation of "escaping fires" into undisturbed forests (Cochrane et al. 1999).

For our study, we use all available 24 IPCC-AR4 scenarios, weighted according to their capability to recover present-day climatic trends in the Amazon basin using a Bayesian approach. In the present analysis, we analyse those scenarios with more than 4°C global warming. Some selected high warming climate scenarios (e.g., HadCM3) lead to a degradation of Amazonian forests due to strongly reduced rainfall (Figure 1) – while other scenarios do not show this amount of drought. Where increased temperatures coincide with stable or increasing rainfall, biomass may in fact increase, possibly further assisted by CO_2 'fertilization' due to greater photosynthetic capacity as well as enhanced water use efficiency.

Where temperatures increase and rainfall fails, biomass may decrease. Shifts in forest composition from closed rainforest to more open seasonal-dry forest or even woodland or shrubland occur, e.g., in north-eastern Amazonia. CO_2 effects could help trees to survive single drought events, but longer-term drying trends or very heavy droughts, as are projected by the HadCM3-A2 climate model towards the end of the 21st century, still lead to substantial losses of biomass in rainforests (Figure 1, left panels). Overall, our results are strongly dependent on the positive direct impact of enhanced atmospheric CO_2 concentrations which cause relatively high resilience of forests to drier conditions. If this ‘fertilization effect’ should turn out to be over-estimated then considerably higher vulnerability of Amazonian forests to drought would be the consequence (Figure 1, right panels).

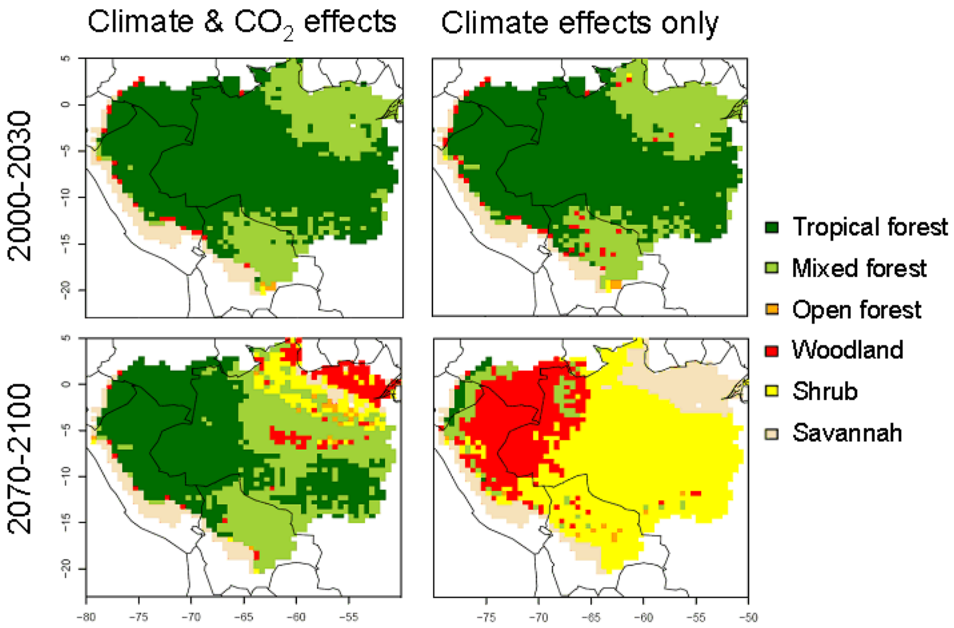

Figure 1: Change in vegetation in the Amazon basin simulated by LPJmL under 4.2°C global temperature increase and reduced precipitation (HadCM3/SRES-A2), with and without physiological effects of CO_2 ‘fertilization’. Vegetation types are determined by a combination of biomass and tree cover. Substantial degradation of rain forests occurs under this particular climate scenario, particularly severe if CO_2 is not assumed to enhance water use efficiency.

Additional degradation of forests in the Amazon basin results from deforestation and increased fire frequency and escaping fires into natural vegetation. Following climatic drought and ongoing deforestation, degradation and the associated fires contribute substantially to further loss of forests, thereby releasing additional 23 Pg C to the atmosphere until 2050. Even at high warming, uncertainty remains concerning the extent of the drought due to the variation between climate scenarios. For several scenarios, however, we find that forest fragments weakened by deforestation and escaped fires become particularly vulnerable to climate change during the second half of the 21st century.

SPITFIRE results indicate that fires escaping from deforested land into undisturbed forest could accelerate the degradation of tropical vegetation substantially. While deforestation alone leads to 42% degraded forests and 23% biomass loss, this is increased by approx. 10% releasing additional 9 Pg C. Under the driest climate scenarios and with escaped fires taken into account such degraded forest covers more than 46% of the basin - possibly a crucial threshold to put the Amazon rainforest at risk to become a tipping element if global warming was to reach four degrees C.

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Living with uncertainty – UK forestry in a 4°C world

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UK forestry policy is based on the principle of Sustainable Forest Management, which emerged through political negotiation after the United Nations Conference on Environment and Development (the Rio Earth Summit) in 1992. This concept recognised the value of woodlands and forests for timber production, but formalised the need to consider them also for their value as wildlife habitat, as landscape features and as places for amenity and recreation. Subsequent evolution of forestry strategies in England, Wales and Scotland during the 1990s focussed especially on the need to embrace biodiversity and public engagement in policy formulation, and consequent management practice. Climate change, also considered at the Earth Summit, did not receive as much attention.

However, climate change has accelerated in importance in UK forestry policy since the turn of the century as a result of the growing appreciation of the likely severity of its effects. There has also been a political realisation that an expanded UK forestry sector could help to mitigate climate change through carbon sequestration and product substitution, supply appropriate goods and services in a world affected by climate change, and demonstrate a national responsibility towards a global problem. Today, climate change is perhaps the most important plank of forestry policy for the future.

Climate change is already affecting a range of forest and wider forest sector attributes, although there is some scientific uncertainty in identifying definitive impacts. The impacts of climate change on forestry can be grouped into:

- primary or direct effects at the stand-scale. For example, on tree growth and timber productivity, woodland soil functioning, fauna and flora community structure and composition, forest hydrology and the incidence of insect pests and diseases.
- secondary indirect effects at the regional scale, caused by wider environmental, economic and social changes likely to occur with a 4^{o}C+ world. Examples may be impacts on the continuity of timber supply, increased risk of tree and forest mortality from new pests and diseases brought in through globalisation, and increased likelihood of forest fires.
- tertiary, global scale effects. Examples are changes in global plant and timber trade driven directly by climate change or indirectly by evolving international climate change agreements, including policies targeted at other regions and countries (e.g. REDD).

Clearly, the types of uncertainties change and multiply as the scale of these different categories of effects increases.

In addition, forests will increasingly be needed to provide ecosystem services such as carbon sinks, wildlife habitat, supply of woodfuel and other forms of renewable energy, flood control, and relief from elevated temperatures, especially close to urban centres. However, we do not yet have a robust framework for balancing the delivery of these ecosystem services whilst ensuring that the sustainability concept is honoured appropriately.

A key area of uncertainty is future government attitudes to supporting a public forest estate, or incentivizing forest enlargement on private land, and investing in public and community involvement to increase the diversity and potential resilience of UK forests. However, the scale of likely climate change and the long timescales of forests means that forest adaptation measures need to be introduced now despite such uncertainty. Current silvicultural practice in the UK is largely drawn from management models based on forestry practiced in Europe during the nineteenth century, and their applicability for the future is increasingly being questioned. Adaptation is vital for the forestry sector whose goods and services at any time are dependent upon management decisions made decades, if not centuries, earlier.

In the face of such varied types of uncertainty, a range of tools and techniques are required in order to avoid, reduce, or manage the risk associated with inevitable change. For example, primary-level uncertainty can be reduced by harnessing the power of ecophysiological, biogeochemical and forest management models which can help predict some of the likely ways that UK trees, woodland and forests can and should change to meet these challenges. The recent UK Climate Projections are an invaluable basis on which to build these models, but further research will be necessary to refine them and make them applicable for national, regional, local and stand management purposes. Furthermore, 4^{o}C+ changes will move many such models well outside their calibrated range, adding to uncertainty. Climate analogue modelling can also provide biophysical insight, but the historical and management differences between countries and regions limits the value of this approach. These approaches can help with vulnerability and risk assessment in order to target particular areas, forest types or activities at risk and on what timescales.

However, methods for planning for the secondary and tertiary impacts exemplified above are not as clear. They may include foresight, market and policy analysis, and use of integrated monitoring and inventory of woodlands and their response to changing climate, pests and diseases. There is a new need for a coherent policy to avoid or reduce and manage the risk of new threats to forest biosecurity, especially exacerbated by climate change and from trade overseas.

Societal and institutional needs for, and constraints to, adaptive forest management will need to be embraced, and appropriate mechanisms (for example fiscal, regulatory, educational and/or inspirational) explored and then put in place. Newly published forestry strategies for England, Wales and Scotland discuss these challenges and provide a range of actions set to ensure the future sustainability of the component parts of the domestic forestry sector. No one doubts that there is much to do.

Although inevitably uncertain, there are already a range of ‘no regrets’ or ‘low regrets’ forestry options regarded as future best practice. One important mechanism to minimise risk is to build up the resistance and resilience of woodland and forests by diversifying tree species and genotypes, and using silvicultural systems such as Continuous Cover Forestry considered more suitable for climatic extremes and possible increasing effect of pests and diseases. Amending rotation lengths and felling coupe size can also help build resilience. The consequences of altering forest management in these ways on biodiversity and amenity provision will need to be deliberated and a new societal consensus agreed. In some cases, significant change in policy will be necessary. For example, steadfast favouring of native over non-native species or seeking the planting of trees of local genotypes make little sense as we move towards a 4^{o}C+ world. Forthcoming Government guidance will focus on these and other options for forest adaptation, based on best available knowledge, even if direct evidence is not available, nor could be gathered in the short time-scale now. It is vital that guidance is published as soon as possible, and changes to (and willingness to change) existing forestry practice accelerated.

A major uncertainty is, of course, whether these actions will work, and whether an approach based on evidence based guidance, standards and limited regulatory control and fiscal stimulation will be sufficient to encourage an adequate change to adaptive management. Uncertainty, and complacency, are probably the largest obstacles to effective forest adaptation. Nevertheless, there has been significant research in recent years to understand how forests and the forestry sector can adapt to climate change. Considerable planning has been undertaken, and although inevitably uncertain, the worst response the sector can make for the future is to delay adaptation further. Certainly, there is a strong commitment in the public forestry sector to explore options ‘on the ground’ and to take risks on behalf of the sector as a whole. Science will be needed to ensure that new knowledge to support this approach is robust. It is essential, too, for foresters to work with others in the land-use sector in order to facilitate adaptation, build resilience and optimise ecosystem services across the wider landscape.

Projections of regional impacts of a 4 °C global warming in the semi arid land of Northeast Brazil

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1. INTRODUCTION

Although climate change is seen as a global issue, its effects are felt at local scale. The changes in the climate of the earth during the past few decades have become the focus of scientific and social attention. As a result climate change has become one of the hot topics and is considered a threat to the entire world, and research undergoing in many parts of the world is directed towards the adverse impacts of the climate change on the ecosystem, forests, water resources, agriculture, livelihood etc. Climate change threat is real and will affect all economic sectors to some degree, and the impact of climate change may be felt more severely in developing countries. Vulnerability and risk of the population and economic sectors to climate variability and extreme events seem to be increasing in South America as population increases and land use patterns change. Poor regions are disproportionately affected by weather related hazards, owing to their intrinsically greater vulnerability to hazards and comparatively low capacity for risk reduction measures. Water deficit in the soil and other components of the water balance may be other indicators that can be used in vulnerability assessments, especially in semiarid regions such as in Northeast Brazil (NE Brazil).

NE Brazil occupies 1.600.000 km^2 of the nation's territory and in 62% of this area is covered by the Drought Polygon, a semiarid region of 940,000 km^2, which extends over nine states of the Northeast and which faces a chronic shortage of water and rainfall levels of less than 800 mm a year. In the semiarid region, which encompasses large part of the territory of the Northeast, there are approximately 30 million inhabitants, or about 15% of the national population. These numbers make this area the most populated dry region in the world. The irregularity of rainfall is a constant obstacle to the development of agricultural activities and the lack of efficient systems to store water - which are almost always controlled by a minority - intensifies the negative social impacts. To make things worse, strong cycles of drought customarily occur in the region in intervals varying from a few years to even decades. The main hazard is drought, and history of drought in the region has been documented as far back as the XVII Century (major droughts in 1710-11, 1723-27, 1736-57, 1744-45, 1777-78, 1808-09, 1824-25, 1835-37, 1844-45, 1877-79, 1982-83, 1997-98, as well as minor droughts in 2003 and 2005) have shown that lack of water heavily contribute to a breakdown of the already fragile life conditions in the region, affecting more the poor and small farmers, and increasing the social problems. The prospects of a future dry and warm climate more prone to drought and the risk of desertification represents a major problem for this region vulnerable to climate extremes. Drought and poverty work together to permanently destroy the already fragile living conditions of small farmers and other poorer groups, and are often the excuse needed to leave the region.

2. PROJECTED CHANGES IN CLIMATE IN NE BRAZIL: A REVIEW

Air temperatures in Brazil have increased by about 0.6 C during the last 40 years in Brazil, and in the Northeast region the observed increase in air temperatures varies between 0.8 and 1.5 °C since 1960. The first studies of vulnerability of this region to climate change, conducted in 2005-2007 yielded the first regional scenarios of climate change in Brazil and South America, which used regional models (Eta CCS, RegCM3 and HadRM3-PRECIS) to make projections for the period 2071-2100. This was done for high and low SRES emissions scenarios (A2 and B2, respectively), with a spatial lat-lon resolution of 50 km, derived from downscaling of the Met Office Hadley Centre's global HadAM3P model. This study, referred to as *"INPE's Climate Report"* (www.cptec.inpe.br/mudancas_climaticas; Marengo et al, 2009), represents a milestone, because it was the first time high spatial resolution future climate scenarios were generated and made available to the broader scientific community. The projected mean warming in the region for the A2 high emissions scenario is about 4.6 °C for 2071-2100, relative to 1961-90 (Fig 1).

Projections of changes in future rainfall suggest reductions of about 40-60% by 2100 relative to the present. Rainfall reductions of the order of 40-60% projected for the future, as well as an increase in the length of dry spells, reaching a mean of up to 30 days/year in 2071-2100 in the A2 scenario compared to 12 days/year in the current climate. This would indicate the high risk of drought may increase in the future.

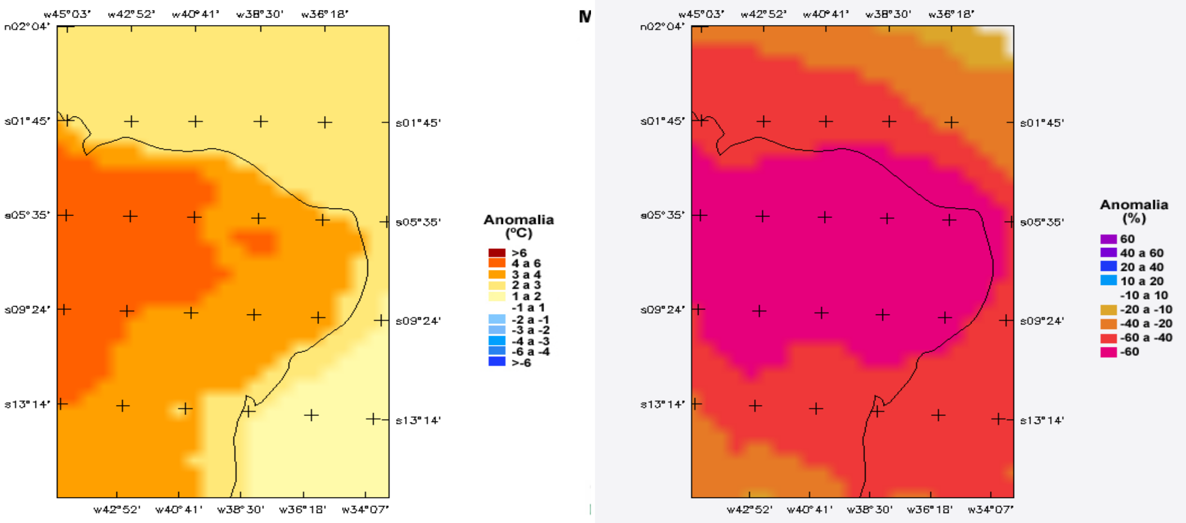


Figure 1. Changes in annual temperature-left (° C) and rainfall-right (%) in Northeast Brazil for the future 2071-2100 relative to the present 1961-90. Changes reflect the mean of three regional models run at a resolution of 50 km lat-lon for the A2 high emissions scenario. (Sources: INPE Climate Report -www.cptec.inpe.br/mudanças_climaticas)

This regional warming of 4.6 °C for the A2 scenario as projected by the ensemble of 3 RCMs is linked to a global warming of about 3.3 °C by 2100 in the HadAM3P global model that provided the driving data to the RCMs. For the NE Brazil region the HadAM3P model shows a mean warming of 3.6 °C. The combined effects of these changes result in an increase in evaporation and a drying of the climate, and together with the projected increases in the duration of dry spells it certainly has the potential to affect activities that depend heavily on water (such as small scale agriculture), and human populations.

3. PROJECTED CLIMATE CHANGE IN NE BRAZIL UNDER A GLOBAL WARMING OF 4 °C AND 5 °C

In the context of the 4 °C and Beyond International Conference, we assess the regional projections of changes of rainfall and temperature derived from multiple GCMs, scaled to a global warming of 4 °C and 5 °C. We have used the web-based interface that provides the IPCC GCM data for plotting model fields scaled by global temperature increases of 4 and 5 °C (http://www.geog.ox.ac.uk/~clivar/ClimateAtlas/4deg.html). Changes in temperature are for 2071-2100 relative to 1971-90, for the ensemble mean (as well as for the maximum and minimum projections) from the IPCC models. Units are in mm/day. Rainfall changes are as ratio between Climate of the XXI century divided by Climate of the XX Century, expressed as a dimensionless index. Index>1 means increased rainfall in the future and index<1 means reduced rainfall in the future. For our analyses we have used changes in mean temperature and rainfall, A2 emissions scenario, and a global warming of 4 and 5 °C (Fig. 2). The idea is to compare those scenarios to those projections derived from the 3 regional models for 2071-2100 relative to 1961-90 shown in Fig. 1.

Fig. 2 shows that for the 4 °C global warming, the scaled projections for NE Brazil give an ensemble mean warming of between 3.5 and 4.5 °C in the semiarid region, although in the ensemble maximum this warming reaches up to 5 °C, and in the minimum it remains below 4 °C. In rainfall changes, rainfall reductions are detected across large areas of Northeast Brazil, especially in the semiarid and coastal regions, for the ensemble mean, maximum and minimum. The changes projected for a 5 ° C global warming show patterns of tendency similar to those under 4 °C, but the regional warming is more intense, reaching up to 6 °C from the coastal region into the interior of NE Brazil where the semiarid region is located. This warming is projected to exceed 5.8 °C in the maximum and close to 5 °C in the minimum. Rainfall changes show perhaps an increase in the rainfall reductions shown on regional scaled projections for 4 °C global warming.

The projected temperature change from the regional models is 4.6 °C for the high emissions scenario, while the global mean temperature from the HadAM3P model run that forced the regional climate models is 3.3 °C. Therefore, we can say that the regional model-generated climate change response is likely to be higher when scaled to a global warming of 4 and 5 degrees. This is confirmed in Fig. 2.

Based on a visual comparison, we can consider that the regional climate change for 2071-2100 scaled for the global warming of 4 °C for the A2 scenario is somewhat similar in the regional distribution and intensity of changes to the scenarios simulated by the mean of the 3 regional models shown in Fig 1. Because the model was run for South America we do not know if this regional warming corresponds to a global warming of 4 °C, or warmer or cooler than that. The intensity of the changes derived from the regional model climate change projections in Fig.1, and the following assessment of impacts, could potentially be applied to the regional scaled projections for a global warming of 4 °C.

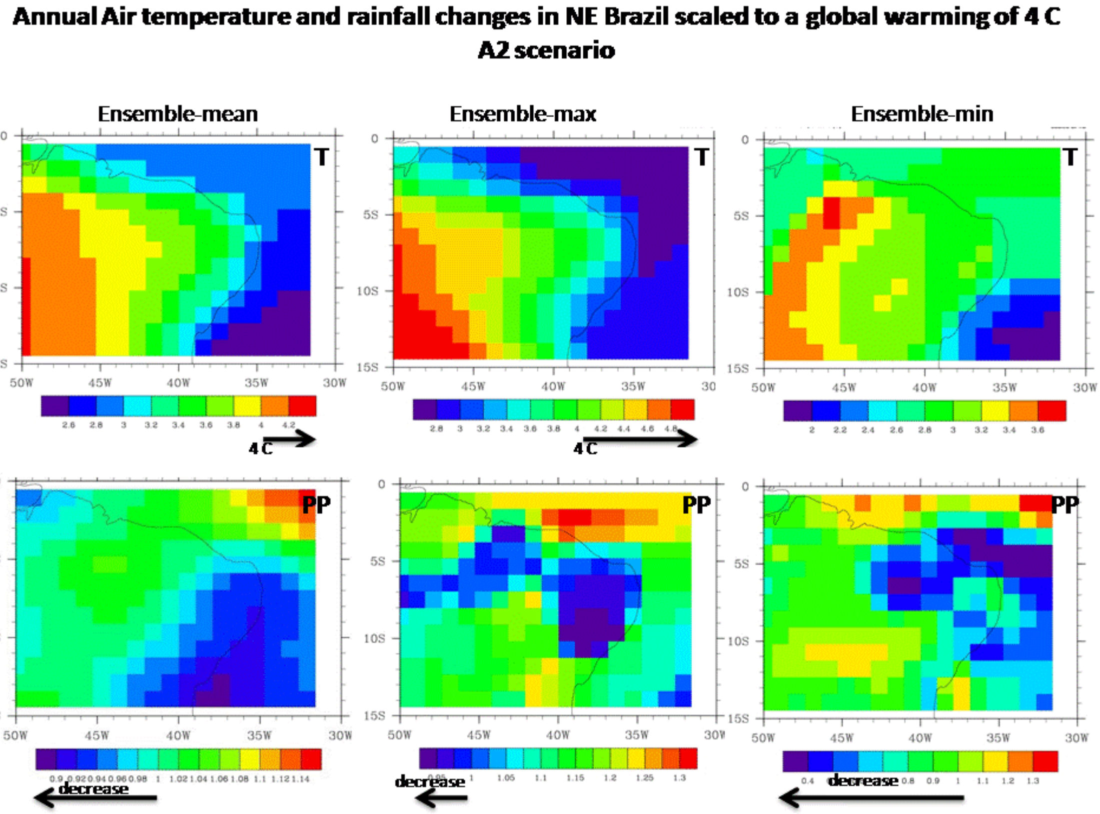
4. PROJECTED IMPACTS IN NE BRAZIL OF A GLOBAL WARMING OF 4 °C AND 5 °C AND OF A REGIONAL WARMING OF ABOVE 4 °C

Various studies on impacts and vulnerability of climate change in Brazil have been produced based on the climate change projections shown in Section 2. Among these impacts studies and vulnerability assessments we can include Brazil's Climate Change and Energy

Security Report (Schaeffer et al. 2008), the Global Warming Report, and the New Geography of Agricultural Production in Brazil (Assad and Pinto 2008). Another large study in process, which also uses these regional climate projections, is entitled the Economics of Climate Change in Brazil (ECCB) and results from the collaboration of Brazilian institutions representing various productive sectors, from government to academia, instructed to evaluate the economic impacts of climate change in Brazil.

Some of the projected impacts in NE Brazil that one might expect at 4.6°C warming, resulting from the 40-60% reduction in rainfall and longer dry spells as projected by the regional models, may be summarized as follows: This region is the most vulnerable region to climate change in Brazil, where small scale agriculture will be affected greatly. Water resources would be scarce in a warmer future, social conflict and migration would be more common, unemployment rate would be high and health problems would increase. On the ecological side, the natural vegetation (caatinga) would be replaced by a more arid-type vegetation, with risk of long term desertification. The risk of migration and environmental refugees from this region to other parts of Brazil may exacerbate existing social problems outside the region.

To put the projected 40-60% rainfall reduction in the semiarid lands of NE Brazil into historical context, it is instructive to consider some drought episodes in the region. One of the worst droughts - which took place during recent times and was well documented - occurred in 1998 (El Niño year), where rainfall in this region was only 40-50% of the normal. However, further studies are needed on the historic droughts listed in Section 1, to assess whether it might be possible to treat future changes in rainfall as comparable to extreme historic droughts, in order to comment on changes in frequency or intensity of drought episodes: could an "extreme" event of the past become normal or more common in the future?



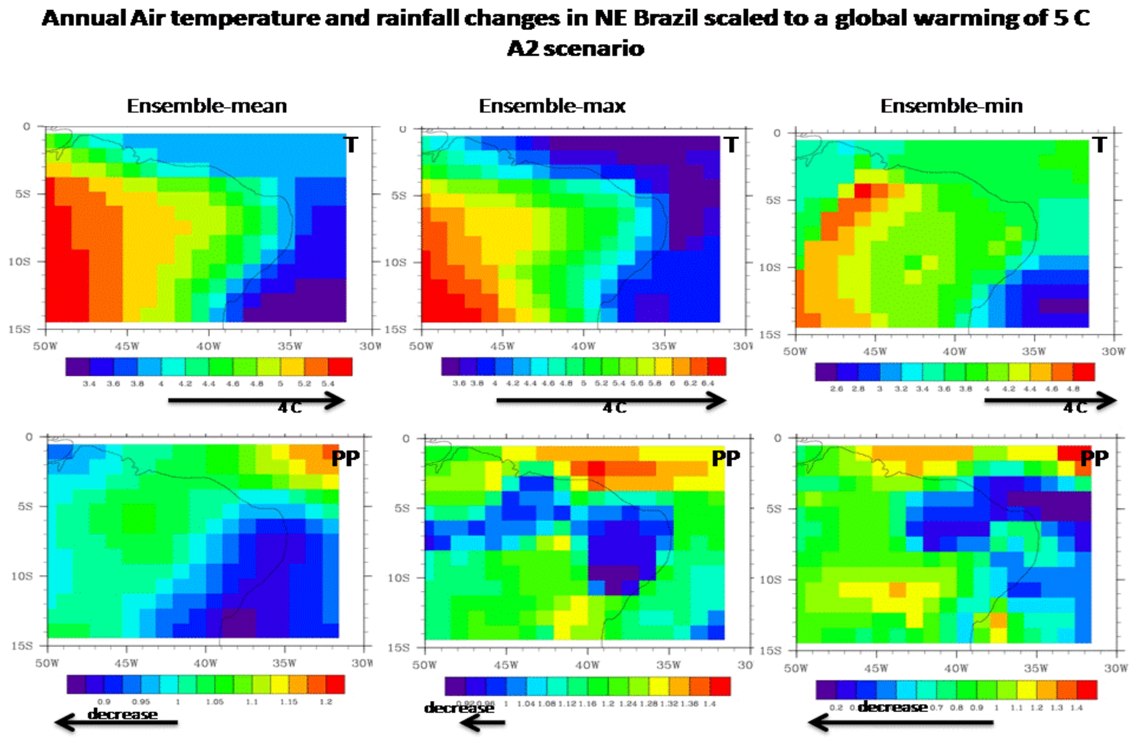


Figure 2 Projected changes in temperature (TT- ^{o}C) and rainfall (PP-mm/day) for the future 2071-2100 relative to the present 1971-90, for the ensemble mea, and the maximum and minimum projections for global warming of 4 ^{o}C (above) and 5 ^{o}C (below). Source: http://www.geog.ox.ac.uk/~clivar/ClimateAtlas/4deg.html. Arrows indicate when the regional warming is higher than 4 ^{o}C and when the rainfall index is below 1, indicating decreases.

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Ecosystem-based conservation in a 4+ degree world

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Abstract

A 4+ degree world is likely to need a radical application of ecosystem-based conservation to cope with the development of non-analogous climates and non-analogous ecological communities (i.e. different to any found currently). Wholesale changes in biodiversity will lead to an emphasis on ecosystem function and structure, in contrast to the current focus on individual species. This might mean accepting quite different species and habitats within areas of conservation interest than originally occurred there. Increased pressure on the countryside may lead to a reduction in its multi-functionality at certain spatial scales, and zoning for specific purposes may require quite different conservation adaptation practices than are currently employed. It is important to start researching and discussing options now.

Introduction

In recent years, a new paradigm has begun to pervade conservation thinking – an ecosystem-based approach. This is additional to existing approaches that began with species protection, progressed into site protection and finally developed into wider-countryside enhancement. Ecosystem-based conservation takes a broader landscape-scale approach and emphasises the services that the natural environment provides to society. The premise is that healthy, fully functioning ecosystems not only provide important benefits to people but also ensure the conservation of all the elements that make up those ecosystems (Sutherland 2004). The concept was very clearly described in the landmark Millennium Ecosystem Assessment (MEA 2005).

With the advent of climate change as a key threat to the continued functioning of ecosystems, a range of principles have been put forward to guide adaptation to climate change for conservation managers and policy-makers(Hopkins *et al.* 2007; Smithers *et al.* 2008). However, there are a number of methods that pervade conservation adaptation planning, that may become increasingly irrelevant or difficult to maintain beyond four degrees of warming. We highlight some of these concepts and how they might be affected by a 4+ degree world.

Protected Sites & Resilience

At the heart of efforts to protect the natural environment in the face of climate change is the current suite of protected areas. They provide high quality habitat and often contain features that are likely to contribute to climate change resilience, such as varied topography and land cover types. Their resilience could also be enhanced by reducing pressures from external factors and by providing buffer areas in which the intensity of landuse is reduced, for example to help maintain water levels inside a protected area.

The issue of resilience is key, but has a range of different meanings (Gunderson 2000). The IPCC (Parry *et al.* 2008) define resilience as "*The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the* *capacity for self-organisation, and the capacity to adapt to stress and change*". Historically, conservation has placed greater emphasis on what may be termed "resistance", in which the habitats within sites are enhanced to resist major shifts in communities and ecosystem structure and function. This conforms to the widespread interpretation of conservation legislation which requires protection of species and habitats *in situ*. Many stable, natural or semi-natural plant communities show this sort of resistance to climatic extremes such as one-off droughts. Reducing other pressures, maintaining stability of management and high population sizes can increase resistance and may reduce the impacts of relatively low rates of climate change. Moving up from communities to the spatial scale of designated sites, habitats may be managed to allow species to move within a site to alternative micro-habitats, as has been demonstrated autonomously by butterflies in Britain (Thomas *et al* 2001; Davies *et al*. 2006). However, as climate change becomes more extreme, these strategies will gradually become untenable, and maintaining functioning ecosystems similar to those that currently exist will require more radical approaches. For example, the introduction of species or varieties of plant with more southerly distributions may be a way of enhancing resilience to increasing summer heat and drought.

Eventually, however, if we move towards a 4+ degree world, ecosystems may be perturbed into a new "ecological space", an alternate stable state. This could occur, for example, where bioclimatic zones shift completely, or an area becomes subject to a "non-analogous climate" - one with characteristics unrepresented within the current biogeographical region (Hossell *et al.* 2005). In addition, different rates of colonisation and dispersal are likely to lead to the formation of novel plant and animal communities that make up these ecosystems (Keith *et al* 2009). In such cases, the transition to a completely new ecosystem will result in a "regime shift" Anderson *et al.* 2009). The Ecosystem Approach to conservation would be able to accommodate such changes, even though they might involve wholesale changes in species and habitats within an area. The key would be to ensure that the new ecosystem was functioning in a "healthy" way so that it was able to provide valuable ecosystem services and continue to deliver high biodiversity value (EASAC 2009).

The need to measure ecosystem health under regime shift will be a new challenge that won't be able to rely upon straightforward species lists and habitat classifications. The concept of functional diversity, which measures the diversity of different functional types (e.g. at its most basic form, by classifying species into different types of consumers (herbivores, carnivores) or producers (grasses, herbs etc)) within a system may be more useful (Tilman *et al.* 1997; Petchey *et al*. 2004). However, the use of functional diversity alone, while providing a potentially useful measure for ecosystem functioning, will not necessarily encompass all the biodiversity interest in a location, because of the functional redundancy that may occur between species (Petchey *et al.* 2007). Thus, additional measures may be required, that won't depend on the presence or absence of particular species, but will measure the overall biodiversity interest. One such is Phylogenetic Diversity, which emphasises the presence of taxonomically unique species (Faith 1992). More research is required to fully understand how these various measures of diversity reflect (a) the underlying biodiversity (Hooper *et al*. 2005) and (b) the associated ecosystem services (EASAC 2009; Eigenbrod *et al*. in press), before they can be used by conservationists facing the challenges of a 4+ degree world..

Connectivity & Permeability

Another key conservation strategy to aid adaptation to climate change is the creation of landscapes in which there are networks of habitat patches of high conservation value, connected by corridors or "stepping stones" of habitat that facilitate movement between patches (Hopkins *et al*. 2007, Vos *et al.* 2008). This is associated with the suggestion that the "permeability" of the "matrix" surrounding these patches should also be improved. Thus, for example, in England, the Environmental Stewardship scheme provides farmers with a range of environmentally friendly options, some of which will have the effect of increasing the permeability of farmland habitats to some species (e.g. provision of hedgerows may facilitate dispersal by adult dormice (Bright 1988)).

However, the wider countryside matrix will be under increasing anthropogenic pressure from a range of factors including the indirect effects of climate change, mediated through social and economic factors. Under a 4+ degree world, in which human population pressure and food shortage are increasing issues, aggravated by climate change (Battisti & Naylor 2009), there may well be pressure to increase the intensity of farming in the UK (and in many other cool temperate countries) rather than decrease it. Green *et al*. (2005) show that "land sparing" may become a way to balance the conflicting interests of maximising food production while maintaining ecosystem services and biodiversity interests. Land sparing involves the zoning of land – some will be subject to intense agricultural pressure and be generally inhospitable to wildlife, other areas will be zoned for biodiversity and ecosystem service provision. If this strategy was to be considered, then there would be potential ecological consequences: connectivity across, and permeability within, the land zoned for agriculture may be reduced. Such deterioration in environmental quality of the wider countryside would suggest that protected areas will need to support large enough source populations, with sufficient propagule pressure, to overcome the barriers to dispersal. Conservation in a 4+ degree world may need to concentrate on providing large, buffered, areas of high ecosystem quality that, for some species, will provide sufficient opportunities for longer distance dispersal between these core ecosystem areas. For species unable to disperse over such long distances, then assisted dispersal may become an increasingly important conservation tool. There is an urgent need for research to understand these issues in order to make informed decisions and for discussion with the wider public.

Conclusion

A 4+ degree world is likely to be a hard one for conservationists (and, indeed for biodiversity). However, the general public and decision makers should increasingly value, and value highly, the ecosystem services provided by healthy natural environments as they will form a vital component of our efforts to both mitigate and adapt to climate change (World Bank 2009; TEEB 2008). A paradigm shift is taking place in conservation policy towards an ecosystem-based approach, partly in response to the needs of adapting to climate change. A 4+ degree world is likely to make this paradigm shift even more necessary, and conservationists will have to develop new and more flexible approaches to conservation through their adaptation strategies.

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Conifer trees of the south Siberia mountains in a changing climate of XXI Century

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Regional studies in the Altai-Sayan mountains of southern Siberia registered climate warming of 1-2^{o}C over the two decades of 1981-2000 of the 20th century (Tchebakova *et al.* 2009). Strong evidence for the current vegetation change associated with the temperature increase was derived from literature: treeline shifts varied between 50 to 120 m during a 50-year span in the mid-20th century; moraines are now being colonized by larch and Siberian cedar following the retreat of the glaciers since the 1950s; intensive fir dieback in the mid- and highlands was found locally possibly because of the meiosis disorder; and on the lower treeline, the poor seed production in the *Pinus sibirica* forest during the warmest decade of the century, 1990-2000, was related to an increased moth, *Dioryctria abietella* (Schft.), population which damages more cones during a longer growing season (see overview Tchebakova *et al.* 2009).

This study was designed to predict the possible effect of climate change on the potential and actual distributions of major conifers in the mountain Altai-Sayan ecoregion: dark-needeled *Pinus sibirica*, *Abies sibirica,* and *Picea obovata*, and light-needled *Larix sibirica* and *P. sylvestris.*

The study area, the Altai-Sayan ecoregion, is located in central Asia mainly in Russia (the northern half) and Mongolia (the southern part), with a small coverage area in Kazakhstan (in the west) and China (in the southwest). The elevation range is up to 4000 m in the central Altai. The current climate is of a continental type with cold winters and warm summers, with high annual precipitation of up to 1500-2000 mm on highlands and as little as 200-300 mm of precipitation on the foothills and the inner intermountain depressions.

In the current climate, forests dominate montane landscapes over the northern part of the Altai-Sayans (Russian part). The forests here are composed largely of four conifers (Polikarpov et al, 1986): 33.5% *Pinus sibirica* (Siberian cedar pine or Siberian cedar); 26.1% *Larix sibirica* (larch*)*; 17.5% *Abies sibirica* (fir); 6.9% *P. sylvestris* (Scots pine). *Picea obovata* (spruce) is found only in 1.8% of the mountains, mainly along streams. Hardwoods (*Betula pubescence, Populus tremula*) are found on 14.1% of the forest area and usually dominate the secondary successions after dark-needled forests are disturbed. Thus, the shade tolerant tree species Siberian cedar, fir, and spruce (referred to in Russian literature as the dark-needled species) dominate 53% of the mountain forests in southern Siberia. The light-demanding species larch and pine (commonly referenced as the light-needled conifers) thrive on 33% of the study area. Over the southern part of the Altai-Sayans (Mongolian part), drylands (steppe, semidesert, and desert) dominate over 90% of the area with 10% of forests composed of conifers: larch (66%), Siberian cedar (11%), and Scots pine (6%). Fir and spruce (1%) are found along streams. Hardwoods occupy 10% of the forest area (Bukshtynov *et al* 1981).

We determined bioclimatic envelopes (climatic limits) for major Siberian conifers from relationships between the climate and forest data deirved from different sources: 1) forest inventory; 2) common garden tests; 3) forest maps; and 4) published studies on Siberian conifers. We used three bioclimatic indices: growing degree days, base 5^{0}C, characterising plant requirements for warmth; negative degree days, base 0^0C, characterising plants' tolerance to cold; and an annual moisture index characterizing plants' drought resistance (Table 1).

Climate data from more than 200 weather stations across the Altai-Sayan Mts were used to map current climate variables. The current January and July temperatures and annual precipitation were mapped using Hutchinson's (2000) thin plate splines on a base DEM grid at a 1 km resolution. Bioclimatic indices surfaces, GDD_5 and NDD_0, were calculated from linear regressions derived from contemporary data: GDD_5 was calculated from July temperature ($R^2 = 0.90$) and NDD_0 was calculated from January temperature ($R^2 = 0.96$). AMI was calculated by dividing the growing degree days, base 5°C, surface by the annual precipitation surface.

Future bioclimatic indices for the year 2080 were calculated using climatic anomalies from the climate change scenarios A2 (a harsh scenario) and B1 (a moderate scenario) of the Hadley Center (IPCC, 2007). According to the A2 scenario, both January and July temperature anomalies will exceed 4°C resulting in mean annual temperature anomalies greater than 4°C. According to the B1 scenario, July temperature anomalies will be somewhat greater than 4°C, but January temperature anomalies will be less than 4°C resulting in mean annual temperature anomalies of 3-4°C. Precipitation anomalies were positive and up to 10% of the current values.

The dark-needled (*Pinus sibirica* and *Abies sibirica*) and light-needled (*Larix sibirica* and *P. sylvestris*) conifer distributions in current climate were mapped by coupling our conifer bioclimatic limits with current distributions of three climatic indices (Fig. 1 A). Our modeled tree species map was compared to the Landscape map of the Altai-Sayan ecoregion (Samoylova, 2001). To compare these maps, 191 classes on the actual vegetation map were combined into three classes to correspond with the three classes on the modeled map: no-forest (tundra and steppe), light-needled conifer and dark-needled conifer (Fig. 1 B). The comparison was made using kappa statistics (Monserud and Leemans 1992) which showed a fair match between the maps (with the overall kappa = 0.46); a very good match for dark-needled conifers (kappa = 0.70); and a rather poor match for light-needled taiga (kappa = 0.22). The fair values of kappa statistics confirmed that bioclimatic limits for our conifers were reasonably identified.

The dark- and light-needled conifer distributions in the 2080 climate were mapped coupling our conifer bioclimatic limits to the climate derived from the climate change scenarios A2 and B1 of the Hadley Center.

Simulations indicated that a moderate change in forest vegetation is predicted from the B1 scenario (Fig. 1 C), but more significant changes are predicted from the A2 scenario (Fig. 1 D). By 2080, forest habitats would decrease from 52% to 48% according to the moderate scenario B1 and from 52% to 38% according the harsh scenario. The portion of the dark-needled conifers would decrease 10%, and the portion of light-needled conifers increase 7% from the B1 scenario, and corresponding portions would decrease 19% and increase 6% from the A2 scenario.

In a future warm and dry climate across the Altai-Sayan mountains, all conifers could shift upwards about 500 m. Trees at the upper treeline can move only by means of migration, which is a complex and long-term process. Migration of tree species as estimated from paleoecological evidence suggests an average rate of only 300-500 m per year (King and Herstrom 1997). In the mountains, tundra may be replaced by forest more rapidly because migration rates upslope are comparable with the tundra belt width, 500 m. This distance may be covered by tree individuals in an historic timeframe. However, tree movement upslope may be tempered by poorly developed and thin soils in high mountains. Species with broad climatic niches and high migration rates conceivably could adjust to a rapidly warming climate while species with a restricted range of suitable habitats and limited dispersal are likely to disappear first.

The lower treeline is being shaped by forest fire, which rapidly promotes equilibrium between the vegetation and the climate. Extreme and severe fire seasons have already occurred in southern Siberia (Soja et al., 2007). Tree decline in a dryer climate would facilitate the accumulation of woody debris. This accumulation, paired with increased fire weather, would result in a decreased fire return interval and an increased potential for severe and large fires. In a warmer climate, following a forest fire, forest regeneration may not be possible due to increased temperature and decreased precipitation. In this scenario, grasses would replace forest. Characteristics that would permit steppe to survive and recover after frequent fires are a short life cycle and adaptation to minimal precipitation and droughts.

To conclude, the climate over the Altai Sayan mountains should be more amenable for light-needled conifers *Larix sibirica* and *Pinus sylvestris* whose habitats could expand and replace dark-needled conifers *Pinus sibirica* and *Abies sibirica* in the lowlands. In turn, dark-needled habitats are predicted to shrink and shift upslope, and Siberian cedar and fir could migrate into current tundra habitats in the highlands.

Table 1

Climatic limits for major Siberian conifers

Conifers:	Bioclimatic indices		
	Growing degree-days, 5°C	Negative degree-days, 0°C	Annual Moisture Index
Dark-needled: *Pinus sibirica*, *Abies sibirica*	> 400°C	>-3000°C	<2.0
Light-needled: *Larix sibirica*, *Pinus sylvestris*	>400°C	<-3000°C	2.0 – 3.3

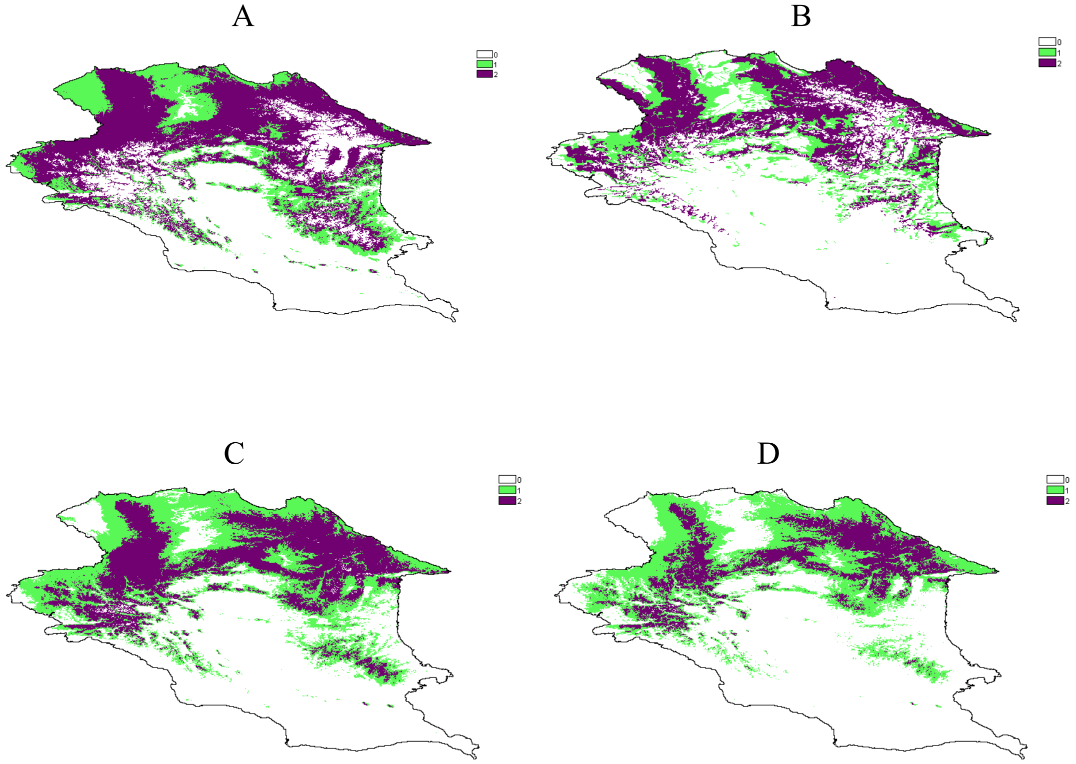

Fig.1. Major conifer distribution over the Altai-Sayan mountains in current climate (A, B) and 2080 predicted from the climate change scenarios B1 (C) and A2 (D) of the Hadley Center.

Conifer key: 1 – no-forest, 2 – light-needled (*Larix sibirica*, *Pinus sylvestris*), 3 – dark-needled (*Pinus sibirica*, *Abies sibirica*)

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4+ degrees: Ecosystem Resilience and Predictability

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The Congo basin, covering an area of ~400 million ha; harbours the second largest continuous tropical rain forest complex of the world.

Besides tropical rain forest the Congo basin harbours a second naturally abundant ecosystem type, i.e. savannas. During the last glacial maximum (~20.000 yrs. BP) most of the Congo basin was covered by savannas and the Congolian rain forests were confined to refuge areas. Later the distribution between savannas and rainforest changed with changing climate, whereby in some regions rainforest and savannas replaced each other while on some sites one vegetation type persisted Within this paper I will discuss the impacts of transient and abrupt changes in Holocene climate on the resilience of African equatorial rain forest and savannah biomes.

I will provide numerical measures of (i) the predictability of ecosystem behaviour, (ii) the entropy production, (iii) the information generation potential, and (iv) the resilience of forest and savannah biomes under past, current and future climates.

Can tropical forests survive four degrees of warming, and if so, what will their role be in the global carbon cycle?

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Tropical forests are a key component of the Earth system. They currently store almost a half of all above-ground vegetation carbon. At present, tropical forests are believed to be net sinks of carbon dioxide from the atmosphere, due to CO_2-induced fertilisation. However, they are under two pressures which could turn them into net sources of CO_2 – (a) direct deforestation and (b) climate-induced forest "die-back". The ability of tropical vegetation to continue to mitigate climate change, and, more importantly, to survive, depends on the pathway of environmental change it will face. Changes in local climate (notably temperature, precipitation and humidity) alter ecological niches and may render them less suitable for the currently inhabiting tropical species. In the framework of the Global Climate Model (GCM) this problem is conceptualised by the Dynamical Global Vegetation Model (DGVM), embedded in a land surface scheme, and being exposed to changing surface climate.

Here we focus on the issue of how uncertainty in climate predictions for the tropics (for given amounts of global warming) translates into expected future functioning of tropical rainforest. We consider the event that climate-change mitigation strategies are not achieved and global warming does reach the level of four degrees. Relevant climate uncertainty bounds were obtained from the range of IPCC AR4 GCM simulations available through the World Climate Research Programme (WCRP). Our goal is to discover climate thresholds at which the tropics no longer act as a carbon sink, and when they become a carbon source. We also consider whether the particular pathway to four degrees of warming influences the potential for die-back. This relates to the concept of "climate commitment", where climate-induced rainforest damage may be delayed due to ecological lags, and thus a false sense of rainforest robustness may initially occur for higher levels of climate change.

We achieve our goal through a new approach based on calibration of the climate pattern-scaling concept against the available AR4 climate models. This allows for exploring of the changes within a single land surface scheme exposed to many climate change pathways that mirror the behaviour of various GCMs. Our methodological framework comprises the land surface model MOSES and DGVM TRIFFID in the analogue climate model IMOGEN. The framework uses monthly patterns of the pre-industrial climate and a transient climate ('1% to 4x' experiment), derived from a given GCM, to simulate the original GCM climate data resulting from SRES emission scenarios. This is possible because local climate change (i.e. in a particular grid-box) is linked to total temperature change over land, which in turn is linked to the amount of GHG emissions (expressed as CO_2 equivalent) through a simple GCM-specific energy balance model. Moreover, such approach allows for a swift interpolation to new possible GCM-specific emission pathways. The resulting ensemble of climate change pathways is used in simulations that allow us to establish climatic thresholds leading to the change in behaviour of tropical forests (carbon sink, neutrality, die-back) as inferred from the changes in vegetation carbon.

Vulnerable People and Places

Sea level rise and impacts in a 4+° world

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The most recent scenario's for sea level rise as published in scientific literature and government policy papers be reviewed, including the ones developed in UK, Germany, Netherlands and California and other places in the world.

In order to explore the effects of sea level rise on society, such scenarios need to be combined with scenario's regarding the effects of climate change on storm surges, hurricanes/typhoons and river run-off.

Combining these scenario's can become a highly complex statistal excercise. The physical basics will be explained and examples will be given of a first order approach.

Examples will be given of the way metropolitan areas and rural areas can protect themselves from more frequent flooding taking a long term perspective. Moreover some cost estimates will be presented.

Sea level rise in a 4 degree world

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Sea level rise is amongst the potentially most serious impacts of climate change. Yet sea level changes cannot yet be predicted with confidence using models based on physical processes, since the dynamics of ice sheets and glaciers and to a lesser extent also that of oceanic heat uptake is not sufficiently understood. This is seen, e.g., in the fact that observed sea level rise exceeded that predicted by models by about 50% for the periods 1990-2006 and likewise for 1961-2003. The last IPCC assessment report did not include rapid ice flow changes in its projected sea level ranges, arguing that these could not yet be modelled, and consequently did not present an upper limit of the expected rise.

This has caused considerable recent interest in semi-empirical approaches to projecting sea level rise. These are based on using an observable that climate models can predict with confidence, namely global mean temperature, and establish with the help of observational data how this is linked to sea level. Here we present a substantial extension and improvement to the semi-empirical method proposed by Rahmstorf (Science 2007). We test it on synthetic as well as real data and apply it to obtain sea level projections for a 4-degree world.

Visualising sea-level rise projections for IPCC SRES simulations ≥ 4°C

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Several new studies have been initiated to improve the understanding and modelling of sea level rise since the AR4, including the EU funded ICE2SEA project and the US study called seaRISE. These focus on producing more credible future sea level scenarios, with land ice dynamics and ice shelves accounted for, by the time of the next IPCC assessment. One study, the Delta Committee International Scientific Assessment (Vellinga et al, 2008) specifically explored high-end climate change scenarios for flood protection in the Netherlands. In this case high-end was assumed to relate to scenarios of temperature rise of up to 6°C by 2100 with corresponding global sea level rise of 0.55-1.10m. It should be noted that our results are not directly comparable with those from this Delta report because of the differences in our definition of 'high-end' and for various methodological reasons. Other significant publications on sea level projections that have appeared since the IPCC report have focused on three key areas: Observational studies of sea level and the ice sheets, model studies based on statistical techniques and process model studies and constraints on sea level rise. In terms of observational studies the AR4 noted a rate of sea level rise between 1961 and 2003 of approximately 1.8 mm/yr, with an increase to approximately 3.1mm/yr between 1993 and 2003. Similar accelerations of sea-level rise have been observed earlier in the 20th Century but they were followed by a subsequent decrease in the rate, giving the lower long-term average. Recent measurements have provided new information on ice sheet movement, including retreat of the Amundsen Sea, rapid thinning in the past two decades of the West Antarctic Ice Sheet and increasing flow rate in the Pine Island area of Antarctica. Gravity satellite measurements from the GRACE study estimate that Greenland and Antarctica are now losing mass at a rate of about 150 cubic kilometres annually. A recent study presented at the IOP conference in Copenhagen suggests that Greenland has been losing 265 cubic kilometres annually, between 1995-2007, leading to sea level rises of 0.7+/-0.2 mm/yr (Mernild 2009). However, this must be balanced by evidence of recent slow down in a number of Greenland glaciers presented by Tavi Murray and colleagues at the AGU fall conference in 2008 (Kerr, 2009). A number of recent studies have used statistical techniques to estimate future sea level based on past changes. The most notable are Rahmstorf (2006) and Grinstead et al., (2009), with the former author providing an update on his work at the recent IOP conference in Copenhagen. These methods typically develop "transfer functions", relating past temperature change to past sea level change. By combining these functions with future temperature projections from climate models it is possible to estimate future sea level rise. The most recent Rahmstorf work concluded that 21st century sea level rise would likely be in the range 75cm to 190cm. While these type of studies do provide evidence that sea level may rise above the IPCC, 2007 projection range, they are not process based models and have a critical limitation. As Hansen (2007) points out, these types of projections assume that the balance of processes in the "tuning period", typically the 20th century and part of the 19th century, must also apply during the 21st century. Whereas, current process understanding suggests that to achieve the largest sea level rise projected by these methods will require an increase in the ice sheet contribution relative to thermal expansion. Simulating this requires a more sophisticated modelling approach. Thus, the statistical methods are of limited use in addressing 21st century sea level rise. In terms of process modelling, the volume of ice within the West Antarctic Ice Sheet available for relatively rapid collapse into the ocean has been considered as up to 6 m since the work of Mercer (1978) first raised this threat in 1978. A recent assessment of this volume using much better data, suggests that the volume available for collapse is only equivalent to 3.3 m of global sea-level rise (Bamber et al., 2009). While this reduces the available volume, it is still large enough to be of major concern, especially since the coasts of N America and the Indian Ocean would both experience a disproportionately large sea level rise due to changes in the earth's spin axis resulting from the movement of such a large volume of ice from Antarctica to the oceans. Hansen (2007) 'finds it almost inconceivable' that climate change would not increase sea level by 'the order of metres' by 2100. He believes this largely because of his understanding of the dynamics of ice sheets, involving strong non-linearities and feedback processes which are not included in current models. Such non-linearities would include warming-induced loss of buttressing ice-shelves where glaciers meet the sea. A counter argument to Hansen is found in the palaeoclimatic work of Rohling et al (2008) who examined sea level change in the last high stand of sea level about 100,000 years ago. During this period, ice masses and configuration of the ice sheets were similar to those existing today. Rohling et al find a maximum rise in sea level during this analogue period of 1.6 +/-0.8 m/century. A modelling study of the kinematics of glaciers in Greenland and Antarctica have recently placed an upper limit of 2m upon sea level rise by 2100 (Pfeffer et al. 2008). This is based on an examination of the fluxes and discharges necessary to reach various sea level rise 'targets', and assuming that the velocity of glaciers cannot exceed the upper limit of that which has so far been observed. This particular study suggests that a 0.8m sea level rise by 2100 is the most likely value. A recent study by Nick et al. (2009) applied a process based model to a single Greenland glacier, Helheim. The authors concluded that acceleration of the glacier's flow rate may be followed by a period of slower flow. From this they conclude that extrapolating recent observed increases in glacier characteristics might not give reliable sea level projections. Progress has also been made by Schoof (2007), who demonstrated a numerical technique for simulating a marine ice sheet grounding line, and predicted an instability (i.e. rapid sliding), should the bedrock slope downwards towards the ice sheet interior. Several modelling groups are now developing robust algorithms to include a two-dimensional description of the grounding line for inclusion in their general ice sheet models. Thus, while an upper limit on 21st century sea level rise of around 2m is emerging from a range of sources, there is also evidence that the most likely sea level rise might be considerably lower. Current understanding also still suggests that increases in sea level rise initiated during the 20th and 21st century are likely to continue for at least several hundred years, even with significant mitigation of emissions taking place. Understanding the impacts associated with high-end climate projections is important, alerting us to the consequences of inadequate mitigation and illustrating the range over which adaption solutions may eventually be required. In this study we have looked at the Intergovernmental Panel on Climate Change (IPCC) multi-model general circulation model ensemble (MME) of 21st century climate projections, and focused on the subset of cases where the end-of-century global average temperature rise exceeds 4ºC or more above pre-industrial levels. For each of these simulations we examined the thermal expansion, glacier and ice sheet contributions to absolute sea level change. Then we combined the absolute sea level rise with estimates of vertical land movement to provide the local relative sea level change, which enables us to highlight coastal areas around the world where potential sea level impacts are likely to be greatest. The results will also provide boundary conditions for companion studies that aim to examine a subset of locations on a finer spatial scale and account for coastal defences. Our methodology only differs from the AR4 report in that our analyses focuses purely on a sub-ensemble of the AR4 climate models that exhibit 'high-end' global temperature rise. We define 'high-end' climate change as those changes (including sea level rise) associated with a global average warming of ≥ 4°C (relative to pre industrial period 1861-90) by the 2090s. In our work we do not attempt to develop any new scenarios of accelerated ice melt. A key element of this study was the development of the a simple web-based tool for visualising the high-end sea level rise results and our presentation focuses on this new basic tool (MORSE) and its potential uses to policy and decision makers. We present examples of locations around the world where our tool shows both expected and surprising results, we discuss the reasons behind the results and highlight priorities for future work to expand its accuracy, effectiveness and usefulness.

Impacts of sea-level rise at 4 degrees and above

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The AR4 IPCC Report defined a range of sea-level scenarios for different emission scenarios encompassing the 5 and 95 percentiles of the possible rise. de Gusmao (these Abstracts) identifies those sea-level rise scenarios in this set that are associated with a >4°C rise in temperature by 2100. While not defined in the AR4 IPCC report, there is also a high impact low probability tail to the distribution of sea-level rise above these scenarios. This has been considered in the Thames Estuary 2100 Project by the H++ scenario, which explores this range of possible change using the limited information that is available. It is concluded that a 2-m rise by 2100 is not implausible.

Translating these changes into impacts is problematic, especially for the larger changes exceeding a 1-m rise where assumptions of linearity in impact models may breakdown. Here the impacts and possible adaptation responses for these scenarios will be explored using different methodologies:

- 1. GIS-based analyses of exposure to sea-level rise
- 2. An analysis of impacts and adaptation using (a) the FUND model, and (b) the DIVA model.

The potential impacts are large with 146 million people and about US $ 1 trillion dollars of GDP within 1 m of sea-level rise, based on current exposure. However, the analysis of impacts and adaptation suggests that protection would be economic in many cases. Empirical evidence from low-lying cities that have subsided up to several metres during the 20th Century supports this conclusion, as all these cities have been protected and continue to grow. Hence the actual impacts are likely to be greatly reduced.

Issues concerning the possible limits to protection and the benefits of mitigation which will reduce the likelihood that these high end rises in sea level will occur will be considered.

The impacts of sea-level rise on coastal nations with and without mitigation. An application of the DIVA and IMAGE models.

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This paper compares consequences of sea-level rise between a no-mitigation scenario, leading to about 4°C temperature increase in 2100 compared to pre-industrial, and an ambitious mitigation scenario leading to 2°C increase in 2100 compared to pre-industrial. The assessment is carried out using the two connected modelling systems IMAGE and DIVA. IMAGE is an integrated assessment model that describes processes of global change, including land use change, emissions of greenhouse gases, and changes in the bio-geochemical cycles of carbon and nitrogen. It includes an energy model whose output describes the regional demand and supply of the different energy carriers for 26 world regions. We use IMAGE to generate a set of scenarios representing socio-economic development, land-use change, temperature change and sea-level rise which are then fed into the DIVA model. DIVA is an integrated model of coastal systems that assesses sea-level rise impacts as well as adaptation to these impacts, in bio-physical, social and economic terms. In this analysis, the impacts considered are dry land loss due to coastal erosion, coastal flooding and salinity intrusion in deltas and estuaries.

As so-far the impacts of low concentration targets on sea-level rise have not been explored, several scenarios are considered that specifically look into the effectiveness of climate policy on projected sea-level rise. The 4°C scenario describes a world that develops according to medium assumptions, without any policy efforts towards mitigation of climate change. Autonomous technological progress and the worldwide diffusion of goods and services result in a convergence between world regions. The 2°C stringent mitigation scenario corresponds to the ambition of the EU and the G8 to limit global mean temperature increase to no more than 2°C. Emission reduction is achieved in various ways including increased energy efficiency, switching from coal and oil use to natural gas and increased use of non-fossil energy sources, particularly bio-energy. Carbon capture and storage is applied in stationary fossil fuel uses and non-CO_2 greenhouse gas emissions are reduced.

For each scenario, DIVA simulates impacts with and without adaptation. The adaptation options considered are increasing dike heights and nourishing beaches. In the simulations with adaptation, dikes are raised according to a demand function for safety which is increasing with GDP density and surge height and decreasing with dike cost. This means that adaptation takes place in response to both, the rising sea-level as well as the increasing wealth. Beaches are nourished based on a strategy that balances costs and benefits (in terms of avoided damages), taking into account the revenues from tourism that are attracted through maintaining sandy beaches.

Generally, the global effects of mitigation are small in the first half of this century due to the delayed response of the sea level to global warming. The magnitude of coastal impacts, however, still increases due to growing population and wealth. In the second half of the century, the differences between scenarios with and without mitigation become significant.

Under the simulations without adaptation, the number of people affected by flooding increases substantially during the century from 3.5 million per year in 2000 to 190 million per year in 2100 under the 4°C reference scenario. With adaptation the numbers are two orders of magnitude smaller and fall during the century, because the increase in wealth makes building dikes increasingly more effective and compensates for the rise in sea-level. Compared to the reference case, mitigation reduces the number of people flooded in 2100 by factor 1.6, adaptation by factor 480 and both options together by factor 560.

The total cost, defined as the sum of damage and adaptation cost, grows under all simulations. Without adaptation and mitigation, total cost grows fastest from US$ 11 billion per year in 2000 to 205 billion per year in 2100. Adaptation reduces these costs by factor 3.0, mitigation by 1.2 and both together by 4.1. Relative to global GDP and assuming no adaptation, total cost increases through the century reaching 0.1% for the 4°C scenario in 2100. Assuming adaptation, the economy grows faster than the total cost; hence the total cost relative to GDP falls during the century reaching 0.04% under the 4°C in 2100.

These figures suggest that, independent of the level of mitigation, adaptation is cost-effective and meaningful to be widely applied. Even without any sea-level rise it makes sense to raise dikes in order to provide increasing safety and lower risks as wealth increases. In contrast, the common assumption of no adaptation is very unrealistic as this would mean that people continue to dwell and accumulate assets in the coastal zone even when experiencing more and more frequent floods and higher and higher damages. For coastal impacts, it is thus more meaningful to assume adaptation to be the "business as usual scenario", although this raises the question of "how much adaptation?"

From a global perspective, these figures also suggest that adaptation is more effective in reducing impacts than mitigation and increasingly so during the century. While the benefits of both options grow during the century, the benefits of adaptation grow much faster than those of mitigation.

However, from the perspective of less-wealthier, in particular small island countries, annual costs can amount to several percent of national GDP and mitigation can lower these costs by factors 2 to 3. Furthermore, in opposition to the global picture, the economies of some of these countries grow slower than the total costs of sea-level rise even under the simulations that include adaptation. The only way to reverse this trend is stringent mitigation. Mitigation is also necessary to reduce the risk of high end sea-level rise scenarios which, while not considered in this analysis, could be catastrophic. From this perspective, climate policy is not a matter of trading-off between adaptation and mitigation. Rather, adaptation is an economic rationality to be applied irrespective of the level of mitigation and stringent mitigation is necessary in order to keep risks down at a manageable level.

Wildfire in a 4+°C World

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Recent catastrophic wildfires in southeast Australia in February 2009 and in California in May 2009 have demonstrated the vulnerability of these regions to wildfire. Extreme fire danger is associated with very high maximum temperature, low relative humidity, strong winds and extended dry conditions. Anthropogenic climate change is expected to lead to increases in the likelihood of very high maximum temperatures and reduced rainfall, increasing the likelihood of extreme fire danger conditions. An evaluation will be presented of projected increases in the frequency of extreme fire danger conditions in these regions in a 4+°C world, associated with anthropogenic climate change.

Estimating human population health impacts in a 4 degree world

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Climate change will have significant impacts on human population health and wellbeing. Physical scientists are able to estimate the impacts of +4°C on the cryosphere, oceans, and river flows using past analogues. However, projecting impacts on the human species, with biological and ecological relations enmeshed in complex and region-specific culture and governance, has not been seriously attempted. Key thresholds (or tipping points) for human and social *systems* are likely at global mean temperatures well below those estimated for the biophysical systems – and several important thresholds would arise before +4°C.

The projection of population health risks from climate change typically entails extrapolation of climate-health relationships observed under recent/present variations in climate, ecological, social and demographic conditions. Pathways of health impact include:

- Flooding and other extreme events
- Water availability
- Loss of ecosystem services, including crop yields
- Communicable (including vector-borne) diseases
- Social disruption, migration, conflict

Increases in health burdens from urban heat-waves and the geographical extension of some communicable diseases have been quantified. Growth of many pathogens is temperature sensitive. Where there are well defined temperature thresholds for transmission of communicable diseases, the geographic changes in climatic suitability for transmission can be estimated (however, this is not equivalent to a prediction that disease prevalence will necessarily increase in these areas). For many vector borne diseases and other health outcomes, no simple climatic thresholds are apparent, reflecting the more complex causal pathways involved. For diseases transmitted by mosquito vectors such as malaria and dengue, ambient temperature affects the development of both vector and parasite, while rainfall and humidity affect vector populations.

Communicable diseases – simple biological thresholds

In several European countries, there is a linear association between temperature and salmonellosis cases above a threshold of approximately 6°C (Kovats et al, 2004). In Alaskan coastal waters, a threshold of about 15°C facilitates a sustained summer gastroenteritis risk (McLaughlin et al, 2005). Diarrhoeal illness was associated with variations in rainfall and temperature in several studies. In Bangladesh, there was no apparent threshold in the relationship between non cholera diarrhoea and temperature, (Hashizume et al 2007). In Zambia, there was no threshold in the relationship between cholera and temperature (Fernandez et al, 2009). Ciguatera (fish poisoning) is most common where sea surface temperatures exceed 29°C (Llewellyn, 2009). This may reflect disturbance of coral ecosystems, including coral bleaching, above this temperature (Hoegh-Guldberg et al, 2007).

Climatic thresholds for non communicable diseases

Associations between daily health events (hospital admissions, mortality) and daily temperatures are nonlinear and exhibit locally specific thresholds, reflecting social adaptation to local climate. In a multi-country study, the threshold for heat-related deaths ranged from 16°C to 31°C (McMichael et al, 2008). Heat thresholds were generally highest in cities with high annual mean temperatures. Unusually high temperatures, particularly if prolonged, can have severe impacts, as demonstrated by the mortality impacts of the European heatwave of 2003.

More complex dose-response relationships are likely for other types of extreme climate event, such as floods, droughts and storms. Coastal flooding due to sea level rise will lead to population displacement. Water scarcity and a projected reduction of food yields in poor countries would impair nutrition and child development. Effects of climate change on food security and nutrition are locally variable and strongly contingent upon social responses such as importation.

Estimates of future impact

There are relatively few quantitative estimates of health impact relevant to a 4°C temperature increase. Parry et al, (2001) estimated populations at risk of hunger, malaria, flooding and water shortage following global average temperature increases of 1.5 to 3°C (Figure, based on Parry et al, 2001). With a 4°C increase in global average temperature in the 2080s, substantial changes are projected in populations at risk of malaria in Africa (Tanser et 2003) and dengue fever globally (Hales et al, 2002).

As climate patterns alter beyond the range of historical experience, simple extrapolation of health risks observed at lower global average temperature rises becomes increasingly inappropriate. Most major pathways of health impact related to climate change are complex and multi causal. Current adaptations to local climate (for example, through design of buildings and settlements, water supply infrastructure, ecosystem management, crop varieties, livelihoods) reduce or prevent adverse health effects of contemporary climate variability. Eventually, if unchecked, climate trends will pass social tipping points, leading to social breakdown and migration. However, the relationships between environmental factors and population displacement are locally specific and generally not well quantified.

Conclusions

Our ability to adapt to climate change is dependent on ecosystem services as well as continued social stability. As climate change progresses beyond a 2°C global average, limits to adaptation, as well as "mal-adaptive" responses (eg. fossil fuel powered air conditioning, desalination) are likely to be encountered. Tipping points in social as well as natural systems could lead to a collapse of social adaptive capacity, and rapid worsening of health impacts at global scale.

Current evidence can inform us of the health effects of large increases extreme weather events, and large scale discontinuities causing social upheavals, population movement, hunger, starvation, and conflict. These processes and their consequences would become dominant influences on health, disease and survival in a +4°C world.

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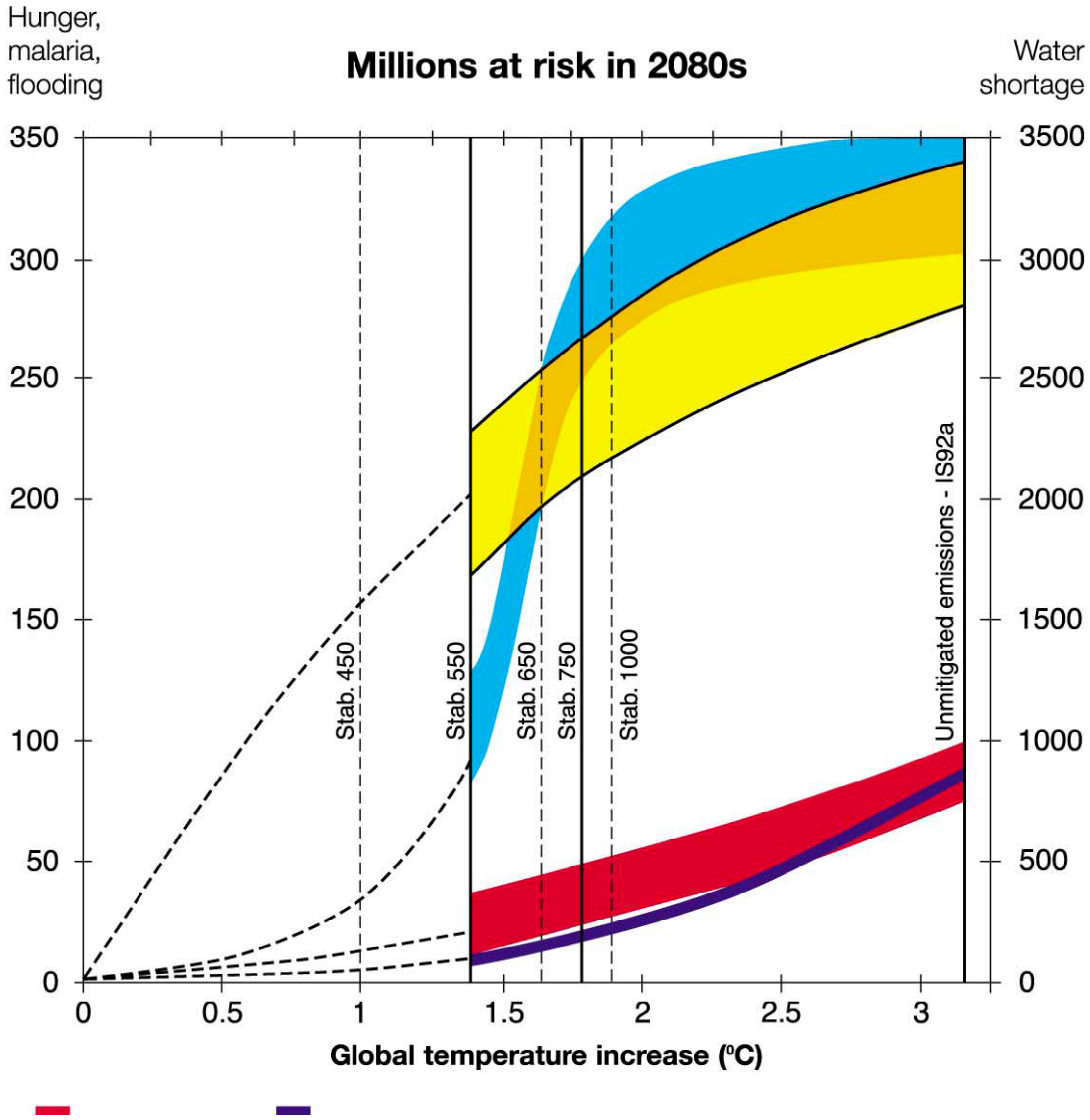
Hunger, malaria, flooding
Millions at risk in 2080s
Water shortage
350
300
250
200
150
100
50
0
3500
3000
2500
2000
1500
1000
500
0
Stab. 450
Stab. 550
Stab. 650
Stab. 750
Stab. 1000
Unmitigated emissions - IS92a
0
0.5
1
1.5
2
2.5
3
Global temperature increase (ºC)

Climate-Induced Population Displacements in a 4°+C World

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Massive population displacements are now regularly forecasted as one of the most dramatic possible consequences of climate change. Most forecasts and estimations adopt a deterministic approach based the number of people living in regions that will be affected by sea-level rise, and conclude that about 150-200 million people could be displaced by 2050 as a result of climate change. Such forecasts, however, triggered wide controversy amongst the scholarly community, and were often criticised for being too environmentally deterministic and not sufficiently rooted in empirical evidence. Indeed, such forecasts took little account of vulnerability patterns and demographic trends, and did not factor in the development of possible adaptation strategies.

Recent empirical studies, such as the EACH-FOR project (*'Environmental Changes and Forced Migration Scenarios'*), have shown however that environmental factors were increasingly important drivers of migration movements, both forced and voluntary. Such environmental factors could be very diverse, such as extreme weather events, slow-onset land degradation, or sea-level rise. They can lead to brutal or long-planned migration, and might or might not allow the possibility for people to return to their homes eventually.
These studies have also highlighted how migration was not necessarily the result of failure of adaptation strategies, but could be one of possible options for populations to cope with the impacts of climate change. In such cases, associated migration patterns will often be temporary or seasonal, as migration is envisioned as a risk-reduction strategy for the family. Finally, another striking empirical finding is that the most vulnerable people are often unable to migrate when confronted with environmental degradation, because they lack the financial resources and social capital to do so. As a result, migration cannot be used as an adaptation strategy by the people who would most need it.

Current forecasts and projections show that regions that would be impacted by such population movements are low-lying islands, coastal and deltaic regions, as well as Sub-Saharan Africa. Such estimates, however, are consistent with a 2°C temperature rise. In the event of a 4°C + temperature, not only is it likely that climate change-associated population movements will be more important, but their patterns might also be significantly different, as people might react differently to temperature changes that would represent a threat to their very survival.

Different studies have been conducted on the way ecosystems would respond to different temperature changes. Similar studies, however, have not yet been conducted with regard to the impacts of population. This paper puts forward the hypothesis that a greater temperature change would not only affect the magnitude of associated population movements, but also – and more importantly – the characteristics of the population movements and therefore the policy responses that can address such movements. In order to test the hypothesis, the papers reviews and compares different cases of migration flows triggered by environmental changes. In particular, it highlights the differences in migration patterns between cases of mild environmental degradation and cases of massive environmental disruption. This comparison yields the conclusion that migration could hardly be used as an adaptation strategy when populations were confronted with massive environmental disruptions, as it is expected to be the case with a 4°C + temperature change. This result can be explained by two different and opposed factors: in many cases, migration was simply a survival strategy, and no other choice was left to the migrants. In some other cases (droughts in particular), resources of the households will be primarily affected to meeting primary, subsistence needs, rather than being used for migration. This results in a decrease of migration flows at times of environmental crises.

Such observations appeal different policy responses. So far, migration policies have largely been environmentally blind, neglecting climate change as a migration driver. No international protection regime exists to assist those who will be displaced by climate change. As for environmental policies, they have mostly considered migration as a last resort strategy. Thus they have focused on strategies that would mitigate the impacts of climate change, in order to reduce the migratory pressure. In a 4°C + world, however, the adaptive capacities of many regions are likely to be overwhelmed by the impacts of climate change, and it will most likely be crucial to enhance the migration options of those who will be affected by the impacts, so that migration can be a key element of the affected populations' adaptive capacity. This will require the enabling of pro-active migration policies, both at the internal and international levels, as well additional resources transfer to the countries and regions that will be most impacted. In the likely hypothesis where the development gap would not be closed by 2050, developing countries would lack the capacities to bear the financial burden of migration, and transfer mechanisms would need to designed, taking into account equity considerations.

Adaptation strategies should also be directed towards to destination regions, so that they can cope with additional influxes of migrants. Migrants represent an additional demographic pressure for regions often already affected by resources scarcity. In order to avoid migration to lead to security risks, as it has sometimes been the case in the past, the adaptive capacities of destination regions will need to be strengthened as well.

As both adaptation and migration policies would need to evolve significantly in the face of a 4°C + climate change, discussions on such evolutions should not be confined in the framework of climate talks, but should be mainstreamed in the debate on global governance of migration as well.

Social Vulnerability and Adaptation Possibilities for Vietnam in a 4+°C World

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A 4°C increase in global mean temperature has the potential to threaten human security and quality of life in a manner unprecedented in recent history. This paper assesses the current state of knowledge on vulnerability and adaptation to these forecasted changes in the country of Vietnam, based on field research in the coastal regions of the Red River Delta and urban Ho Chi Minh City, as well as research with national policy-makers. Our ongoing research has focused on 1) assessing localized vulnerability; 2) determining adaptation options already being weighed; and 3) understanding the institutional framework that enables adaptation actions and policy. The goal of our project is to use Vietnam as a case study to determine the main institutional and human challenges facing poor and highly affected countries in a 4°C world.

Vietnam is likely to be one of the most impacted nations, due to its very long coastline, dependence on agriculture, relatively low levels of development, and location of the largest urban center in a low-lying coastal area (Ho Chi Minh City). Vietnam has been identified as one of the top 15 countries in the world already vulnerable to natural hazards like drought and storms in terms of number or people and scale of exposure (Dilley et al 2005), and a 4°C increase will exacerbate this condition to levels previously not experienced. Vietnam has already begun to feel the effects: the average surface temperature has risen 0.7°C since 1950, the typhoon and flood seasons are longer than they used to be, and storms are tracking into new coastal areas (Carew-Reid 2008; Ho Long Phi 2008). The regional changes that are predicted under most future scenarios for 2100 indicate Vietnam will have millions of people impacted by an increase in rainfall in wet seasons and decrease in dry of around 10% or more, increased intensity and frequency of storms and floods, and a likely sea level rise of at minimum 1meter (MONRE 2008).

While the Government of Vietnam is increasingly recognizing the threats facing the country from climate change, there have been limited research programs focused on identifying social vulnerability and addressing adaptation. Vietnam adopted in December 2008 a National Target Program for Climate Change (NTP), but the document has little to say about how adaptation will take place and who will be the most vulnerable populations beyond noting a few biophysical zones (coastal areas and mountains are presumed to be the most vulnerable places) (MONRE 2008). Currently, government plans for vulnerability and adaptation assessment in the NTP tend to be focused on sector-wide and quantitative vulnerability assessment needs for the whole country, and on solutions that the government can implement through policy or financial planning. The main adaptation measures mentioned in the NTP are 'hard' adaptation measures (sea dykes, reinforced infrastructure, more durable buildings) with some other measures, like resettlement, storm warning systems and mangrove planting (MONRE 2008). Little attention has been paid to social vulnerability or 'soft' adaptation measures like increasing institutional capacity or the role of local action and social capital in building resilience and adaptive capacity.

Our ongoing fieldwork has been focused on this latter question, by understanding how individual households, communities and policymakers have adapted to previous climate events, particularly the extreme floods that have occurred in the recent past, as even in the absence of pressures from climate change, livelihoods of people in Vietnam have long been subject to natural disasters. For example, from 1976 to 2003 floods in the Red River Delta killed 15,835 people, inundated 2.7 million of ha of agricultural land, with economic damage estimated at 3.5 billion USD (Dang 2004). Ho Chi Minh City is subject to twice-daily tidal flows, and in 2007, high tides inundated 556 ha of the city, causing several hundreds of thousands of dollars in damage (Ho Chi Minh City 2008).

Localized vulnerability is important to understand as regional downscaling of long-term climate forecasts needs to be supplemented with detailed assessments of who in geographically vulnerable regions (as most coastal areas are assumed to be) are the most socially and physically vulnerable (Adger 1999). Currently, the Red River Delta in the North and the Mekong Delta in the South are protected by two kinds of dyke systems: river dykes along the Red River and Dong Nai/Mekong River system and tributaries; and coastal sea dykes and mangrove areas. However, these infrastructure systems are delicate, suffering from poor construction (most dikes are dirt or stone), poor drainage and weak pumping infrastructure. Additionally, much land which was designed for agricultural production in the two deltas has been converted into industrial or urban uses without flood prevention measures. Related problems include the loss of forests around the two deltas which no longer retain water, leading to greater volumes accumulating in flood prone areas. A lack of attention to long term climate issues in land planning is common across all levels.

Preliminary findings from local fieldwork indicate that while flooding in general happens every year in the two deltas, the patterns are variable in terms of where the flood waters accumulate, and where damage is highest. Furthermore, natural events (such as heavy rains) are compounded by poor local water management (such as inadequate pumps or release of water from a reservoirs). Floods also do not consistently affect the same production sectors. For example, in the Red River Delta, in one coastal research site (Thai Binh province), rice, aquaculture and cash crops have all been affected in different years by flooding. In an inland riverine area (Ha Tay Province) floods primary affect the livestock sector. Similarly, in some areas poor households appear to the be the most vulnerable, while in other areas it is the better off, who have more to lose financially in flood damage. These varying vulnerabilities make it very difficult to put forth comprehensive national-level plans, and indicate downscaled, community-level assessments are likely to be most useful.

Localized adaptation to climate change is already visible in some rural areas in particular. Change in housing style is the most common adaptation strategy, as 1-story houses made of dirt and thatch are giving way to 2-story concrete structures for those who can afford them. Changes in household production activities are also noticeable to adjust to rising flood waters and seasonality of floods. Households now generally use shorter-term rice varieties to shorten the crop season as a precaution against disasters. A number of households reported that they have turned their most often-flooded rice fields into aquaculture areas. Taking non-farm jobs is another way households have adapted, as it allows them to get alternative sources of cash to reduce risks. There have been very few ‘hard’ adaptation measures taken by individuals surveyed to protect their farmland from floods, such as building small impoundments and drainage systems. The lack of finances available, both in capital and loans, likely limit these options. Social capital however does remains a strong point for adaptation possibilities; relatives are the first line of defense for households that have been affected by storms; they seek shelter in relatives’ houses; they rely on relatives to help them clean up afterwards; and to provide loans if financial assistance is needed. These social capital ties remain strong, and are one bright spot of hope as informal institutions that may help to buffer some of the effects of climate changes.

In terms of a formal institutional framework, community and national-level climate measures play a very limited role in adaptation, and are instead primarily aimed at disaster preparedness for one-off events. The current government policy on climate change (the NTP) did not formalize an overall structure for adaptation action, only setting up an advisory committee made up of several government ministers. In the absence of new formal mechanisms for adaptation guidance, the Central Committee for Flood and Storm Control (CCFSC) remains the major national government entity actively involved in adaptation-type actions. The CCFSC, which includes representatives of all major line ministries, is supposed to gather data and monitor flood and storms and issue warnings and forecasts, and offices of the CCFSC at each province are tasked with coordinating local measures such as dyke protection and post-flood recovery efforts (Chaudry and Ruysschaert 2007). However, institutionally the CCFSC is aimed more at short-term forecasting, and not long term adaptation. While the government structure to respond to climate disasters is clear and well-coordinated, it lacks flexibility to take on the new challenges posed by climate change. There is also no new funding for climate adaptation currently available from the Government. The Prime Minister of Vietnam attended the Poznan, Poland, meetings of the UNFCCC, where he called for an international fund for the five countries to be most effected by sea level rise (Vietnam, Bangladesh, the Bahamas, Egypt and Surinam), but such a fund may be several years away, if ever implemented (VNA 2008). This remains an institutional challenge for affected countries like Vietnam, particularly when faced with the rapid changes that are expected in a 4°C world.

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Predicting temperatures within buildings and the heat stress on occupants under substantial climate change

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The level of future climate change is still uncertain and depends upon many social and political factors to mitigate the extent of climate change. Estimates of the extent of future climate change can be obtained from the latest set of UK Climate Impacts Program projections (UKCP09) [1]. The projections include a range of possible values for each emissions scenario allowing and estimation of likelihood and risk to be made. The measured timeseries of recent carbon emissions indicate that the levels of climate change experienced could be greater than projected by the IPCC A1FI emissions scenario [2], so it seems prudent to examine the upper percentiles of the CDF probabilities included in the UKCP09 projections.

Currently many existing buildings exhibit levels of overheating close to the maximum allowed by the building regulations of the country in which they are located. It is highly likely that such designs will breach the regulations under even modest amounts of climate change [3]. As the events in Paris 2003 showed, such overheating can have severe consequences for human health, productivity and performance. We show that a simple metric the 'climate change amplification coefficient' C_T [4] can be used to estimate the internal conditions of a building for any realistic amount of climate change irrespective of temporal range, emissions scenario or probability level. Only two thermal simulations are required to calculate C_T thus simplifying the otherwise daunting number of possible climate change projections. This allows a rapid estimation of the internal environment and its impacts on human health as well as rational comparison between different design and construction choices. While the effects of different levels of climate change on the built environment can be calculated relatively easily, the effects of those environmental conditions on human thermoregulation are more complex.

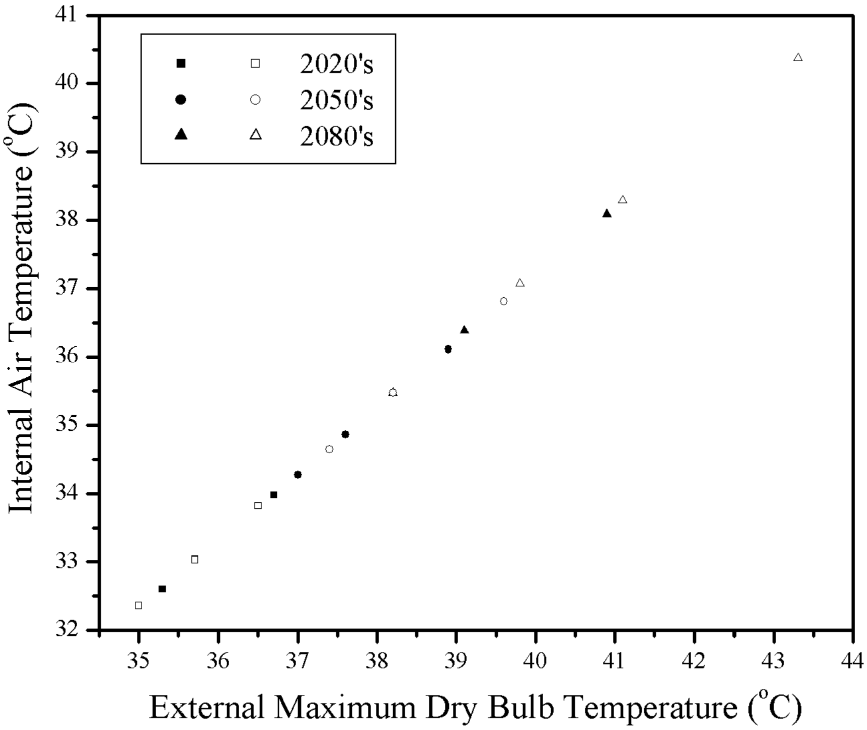

Figure 2 Plot of resultant internal maximum temperatures versus maximum external Dry Bulb Temperature. Shown are the 50th, 70th and 90th percentiles for the medium (solid symbols) and high (open symbols) emissions scenarios for different temporal ranges.

Future weather files can be created using the morphing method [5] and the UKCP09 climate anomalies. Here we focus on only the medium and high emissions scenarios (IPCC: A1B and A1FI respectively) at the 50th, 70th and 90th percentiles. These files can be used to perform detailed whole building dynamic thermal simulations taking into account solar gains, ventilation, metabolic and anthropogenic heat loads. Figure 1 shows the results of thermal simulations of a small rest home for different levels of climate change. Note the linear response of the internal temperature to changes in the external climate. The gradient of a linear fit to the data is the 'climate change amplification coefficient' C_T [4] and can be used to estimate the internal temperature for any amount of climate change without the need to perform a full simulation.

Air temperature is an important factor when considering thermal comfort and heat stress but other climatic variables are also important such as mean radiant temperature, humidity and air speed. Other non-climatic variables also have to be considered such as clothing insulation levels, acclimatisation, fluids intake and metabolic rate, which is dependent on factors such as age and weight. In heat stress, the body temperature may rise, this leads to increased blood flow within the skin and sweating if necessary. These mechanisms provide a greater potential for heat loss to maintain body temperature. If these mechanisms are insufficient to maintain the core body temperature heat storage can occur. The overall physiological response for continued heat storage is therefore vasodilation to increase skin temperature and then sweating leading to profuse sweating. As core body temperature continues to rise and the skin is completely wet a reduction in sweating may occur due to blocking of the sweat glands in the wet humid conditions. The decrease in sweating promotes a further, often rapid increase in core body temperature to beyond 38-39 °C where collapse may occur to above a rectal temperature of 41 °C where heat stroke may occur. There will be mental confusion, failure in central thermoregulation, sweating and death with eventual denaturing of body proteins. There is a large individual variability in the mechanisms of the response to heat stress, depending upon age, gender, body fat and drugs as well as factors such as clothing, hydration and acclimatisation. One of the most vulnerable groups to the effects of heat stress are the elderly, since the ability to sweat diminishes with age [6] also there is a tendency to not drink adequate fluids, resulting in higher than expected rectal temperatures.

The predicted heat strain method describes two factors, E_{req} the required evaporation rate and E_{max} the maximum possible evaporation given by:

$$E_{req} = M - W - C_{res} - E_{res} - C - R - \delta S_{eq},$$
$$E_{max} = \frac{(P_{sk,s} - P_a)}{R_{tdyn}}.$$

Required heat loss E_{req} is a balance between metabolism (M), mechanical work (W) respiratory convective and evaporative heat flow (C_{res}, E_{res}), convective and radiative heat flow (C, R) and the remainder as heat stored (δS_{eq}). Detailed equations for each of these heat loss mechanisms can be found in the international standard ISO7933 [7]. The maximum possible heat loss E_{max} is the difference between water vapour pressure, skin temperature ($P_{sk,s}$) and water vapour pressure of the surroundings (P_a) divided by the dynamic evaporative resistance of the clothing (R_{tdyn}). If $E_{req} > E_{max}$ the heat is stored in the body δS_{eq} which leads to a rise in core body and rectal temperatures. Details of the method for calculating the core and rectal temperatures from the difference between E_{req} and E_{max} can be found in ISO7933.

To estimate the effects of future heat strain on building occupants a thermal model of a small rest home was created. All constructions within the model conform to 2002 UK building regulations. A rendering of the model is shown in figure 2, it is a single storey building with the entrance and a conservatory facing south.

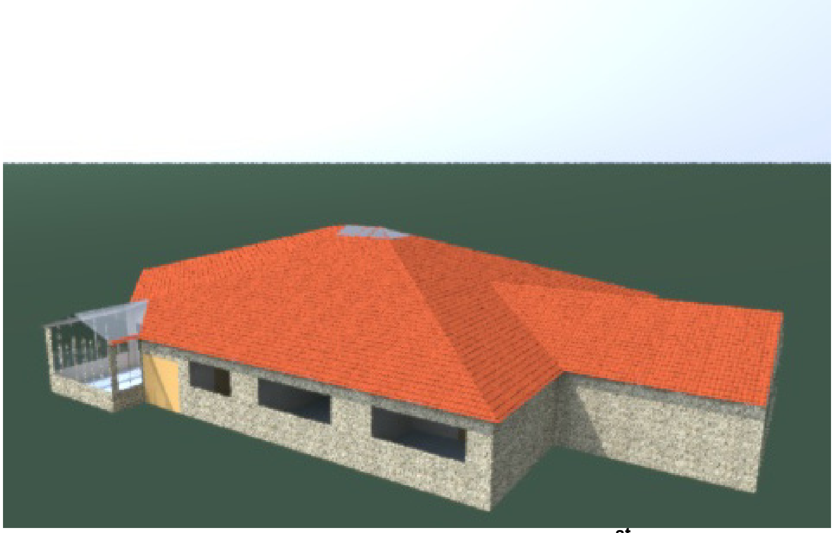

Figure 3 Rendering of the thermal model in this study on the 21st of July.

For the calculation of the rectal temperature of occupants of the rest home a typical subject was created. Clothing insulation and levels of activity (metabolic rate) are typical of elderly rest home occupants. A computer program based upon ISO7933 used hourly data for the climatic variables: air temperature, mean radiant temperature, relative humidity and air velocity output by the thermal model for the month of July. These data are read into the program and the final core and rectal temperatures are calculated. Occupants were assumed to be unacclimatised but able to drink freely. Figure 3 shows a plot of the air temperature within a room and the rectal temperature of the subject exposed to these conditions.

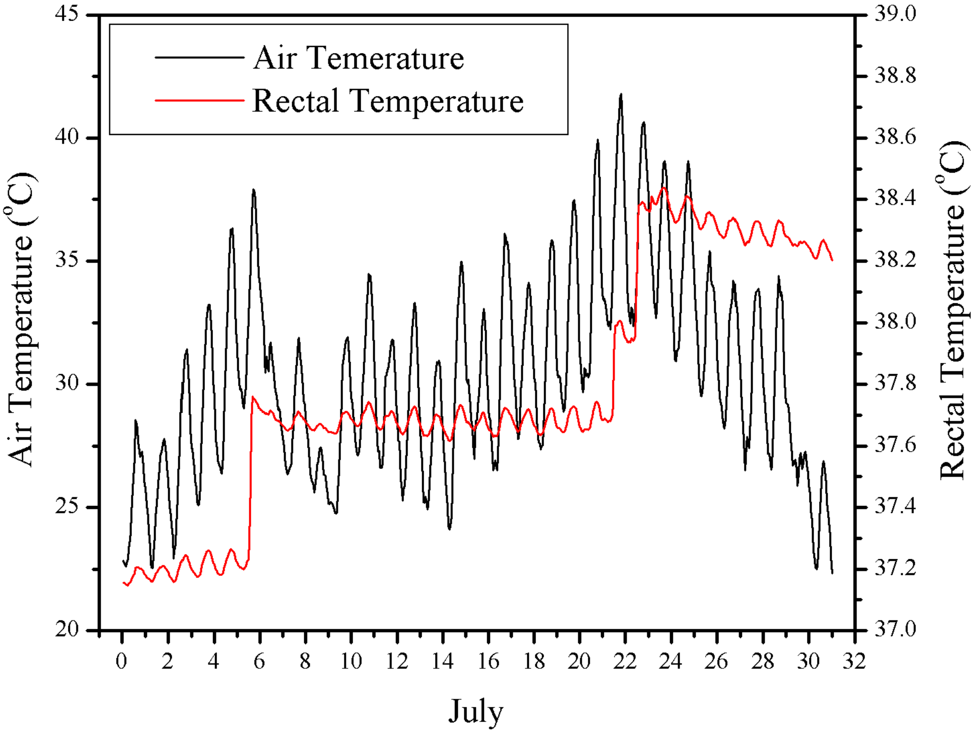

Figure 4 Plot of internal air temperature for the month of July generated from future weather for London 2080 high emissions scenario. Also shown is the rectal temperature of a subject exposed to these climatic conditions.

As shown in figure 3 there are points of higher air temperature at which the subjects are unable to cool themselves adequately and there is a rapid increase in rectal temperature. The magnitude of the air temperature does not allow the rectal temperature to fall before the next period of high air temperature around the 21st July. This increases the rectal temperature well above the 38 °C limit imposed by the WHO [8] for prolonged daily exposure. Here we see the rectal temperature still above 38 °C for the next 7 days despite a rapid decrease in air temperature over the same period, indicating that the human body is slow to respond to environmental cooling. Note that despite the metabolic rate and activity levels adjusted to represent elderly rest home occupants there is no inclusion in the model of age or infirmity, all occupants are treated as fit and healthy. Hence the results shown in figure 3 should be treated as a lower limit.

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Adaptive coping strategies in a four degree world

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As humanity's ability to adapt physically to a warming globe will depend in part on how well people adapt psychologically, this paper considers how humans might adjust to or cope with the threat associated with a world under a radically transformed climate. While varying among individuals and societies, many people will experience threats related to: the well-being and survival of descendants; the state of the planet, including its natural wonders and biological diversity; and the stability and progress of the societies in which they live. In short, the threat of climate change is a threat to one's conception of how the future will unfold. Extensive social scientific research into human reactions to threats provides some insights into the psychological strategies humans are likely to adopt. These "coping strategies" are designed to defend against or manage the unpleasant emotions that are associated with "waking up" to the dangers of a warming globe. The emotions include fear, anxiety, guilt, anger, anguish, sadness, depression and helplessness. These unpleasant emotions arise in part because the threat of warming may also destabilise an individual's identity or sense of self—threatening one's life plans, reminding one of the fact of eventual death, challenging the morality of ecologically destructive (or apathetic) behaviours, or subverting one's internalised expectations of the future.

We group the coping strategies that people are likely to use in the face of global warming into three types.

1. **Denial strategies**. These aim primarily at suppressing anxiety associated with predictions of climate disruption by not allowing the facts to be accepted into the conscious mind. By denying the reality of the facts, no emotions need be felt. The most prominent form of denial can currently be seen in "climate sceptics" for whom acceptance of climate science and the response it calls for conflict with one of more of their fundamental beliefs. A more "casual" form of denial is also engaged in by many members of the public. Anxiety can be reduced simply by restricting exposure to distressing information, such as by skipping news stories about climate change or disengaging from conversations, or telling oneself that "scientists are often wrong" or "they are exaggerating".

2. **Maladaptive coping strategies**. In these cases, the facts about global warming are acknowledged and accepted to some extent, but the emotional experience is such that the person needs somehow to blunt some aspects of the facts or the associated emotions. As such, these methods of coping can be maladaptive or unhelpful both to the individual and to the situation because they impede appropriate action. They include: reinterpreting the threat by reducing the scale of it; diverting attention from anxious thoughts through minor behaviour changes; disengaging morally by shifting blame onto others; cultivating indifference or apathy; and, engaging in wishful thinking.

3. **Adaptive coping strategies**. These strategies are deployed when the person accepts both the facts and the accompanying emotions, and then tries to act on the basis of both. They are adaptive in the sense of promoting psychological adjustment to new circumstances and stimulating actions appropriate to the new reality. They include: expressing and controlling emotions, allowing deep feelings of anger, depression and despair to be felt, communicated and then transcended; problem solving through finding out more about climate change and working with others on mitigation and adaptation measures; and, promoting more intrinsic value-orientation through sustained and considered reflection on mortality.

In short, denial suppresses both facts and emotions, maladaptive coping strategies admit some of the facts and allow some of the emotions, both often in distorted form, and adaptive coping strategies accept the facts and allow the emotions to be felt, thus promoting more positive behaviours. The three groups of coping strategies may be considered to be sequential in the sense that moving from the first to the second and the second to the third requires that obstacles be overcome.

While it is beyond the scope of this paper to consider how societies and their institutions will respond to climate disruption, it is important to stress that the way individuals cope will be influenced by how their societies react to the new environment. For example, the present distress felt by the small minority who use more adaptive forms of coping (allowing in the full facts and emotions associated with the climate threat) may be intensified because of their isolation.

At some point, governments, non-government institutions and professional organisations will recognise the benefits of promoting and supporting adaptive coping strategies. They may do so by actively encouraging such strategies and acting in ways that promote a shift to intrinsic values. The latter have particular relevance for a world under four degrees of warming as there is a real danger that threats to survival will stimulate a retreat to maladaptive strategies of apathy, pleasure-seeking, blame-shifting and derogation of out-groups. The research literature on death reflection (the more thoughtful and prolonged engagement with death) suggests that an open and wide-ranging public debate over questions of mortality and survival would make recourse to maladaptive coping strategies less attractive. More conscious reflection on mortality would also encourage more pro-social and less materialistic goals.

Vulnerable Areas and Vulnerable Peoples: A Case Study of Sundarbans of Bangladesh and India

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I. Introduction

Since 2007, with the publication of International Panel for Climate Change (IPCC) Report no.4, award of Nobel Prize in 2007 jointly to Chairman to this panel R.K.Pachauri and the noted environmentalist and US. former Vice President, Al Gore and simultaneous expression of similar environmental concerns about the effects of global warming in the near future, the problem of climate change has emerged as one of the most vital problems of the 21st century. Though it is a global problem and almost all parts of the world and the human society will be more or less affected by this event, yet some areas and some people will be more affected than others as a consequence of this. It has been estimated that there is a possibility of global warming in the present century to the extent of 2-5^{0}C unless something is done to mitigate the present process of rise in global warming. The scientists are afraid, if this warming cross the threshold level of 4^{0}C, then the ice-caps of the two polar regions are likely to get melted and the sea levels throughout the world will probably go up nearly by two meters. In this unprecedented situation, never experienced in human history, all the low level coastal areas of the world and especially in the tropical region will become vulnerable to submergence from rising sea water causing great danger to the people living in such regions.

II: Nature of Vulnerability of the Coastal Regions and the Inhabitants of Such Places

So far India is concerned, the effects of climate change may be quite severe for her as she possesses a long coastal region at both eastern and western frontiers of it. In fact, the environmentalists have specified the equatorial region of the world i.e. in between the lines of tropic of cancer and tropic of capricorn as the most vulnerable region susceptible to the adverse effects of the global warming; some countries like Maldives and some coastal regions of India, China, Malaysia Indonesia and other countries are likely to face the incidence of submergence in a big way. The Sunderban delta region on the eastern boundary of India and Bangladesh is likely to face the incidence of submergence in a big way and also likely to experience sea-changes in its geographical features as a consequence of this. It may be mentioned here that there is a chance under the present situation that the country Maldives may be totally wiped out from the map of the world. The large portion of Sunderban which is the largest mangrove forest of the world and extends over both the countries India and Bangladesh is likely to lose a significant portion of it as a result of submergence. Sunderban being the habitat of large number of flora and fauna including the world famous Royal Bengal Tiger and now a habitat of large number of people also will lose their habitat as a consequence of it. It may be mentioned that some parts of Sunderban are fragile and not suitable for human habitat as they are still in the making but a large number of people being ousted from different areas due to various reasons (in fact, there is a new term in the literature of development economics called development oustees) had to take shelter in this fragile and vulnerable region being fully aware of the danger which will vary from region to region depending upon the natural endowments and the readiness of the authorities to protect these people by creating infrastructure to manage the disaster. It is for this reason, the high income countries of the world face such natural calamities with increased resistance with very few casualty of the life of vulnerable people.

III: Special Features of Vulnerability of Sunderbans and the People There

We have already noted that the vulnerable regions of Sunderbans are not only fragile but also unsuitable for human habitation. This makes such people living there doubly vulnerable to the adverse effects of climate change; both India and Bangladesh are low income economies and the later is included in the category of least development countries. It is quite unlikely that the governments of these two countries will take adequate steps to protect these people from natural calamities as in most cases their settlements are temporary. High density of the population also makes it difficult to arrange for their adequate rehabilitation whenever they unfortunately become the victims of fury of the nature. The scientists predict that the behavior pattern of weather system has undergone unexpected changes in these years as a consequence of global warming. More over India and (the erstwhile East Pakistan) Bangladesh being separated by partition in 1947 and Bangladesh being gone through several phases of military rule, there is almost no cooperation between them to adopt some joint measure to protect the Sunderban and her people though this region extends substantially in these two countries.

IV: Official Policies to Mitigate Impacts of Climate Change including Rehabilitation of Affected People with Suggestions

We have already noted that India and Bangladesh being two independent countries, never take any joint and concerted efforts in this matter. Sunderban is classic example of cross boundary cooperation in the matters of environment protection and disaster management which became more important in the context of climate change in recent years. Better result may be obtained if they undertake studies to find out respective sources of green house gas emission while the IPCC Report says that energy supply and fossil fuel consumption with transport account for 39% of these sources. Such policies may lead to accurate estimation of the magnitude of this problems and adoption of appropriate policies. Alternative sources of energy like animal power may also be used more fully and effectively in appropriate areas to reduce their fuel consumption especially in large low income populous countries which are still predominantly rural and heterogeneous in their energy use. In the transport sector, a substitution of fuel consuming cars and bikes with cycle may boost up domestic demand and employment with a reduction in green house gases also. All the issues are sought to be analyzed with examples from economies of India and Bangladesh which are now following unsustainable energy intensive western model of development leading to increase in CO_2 emission and global warming over time.

Climate Change in Mediterranean Region: Vulnerability and Adaptation Opportunities

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As a cross boundary issue, Climate Change (CC) is seen as an avoidable challenge for scientists, economists as well as policy makers. Mediterranean region is one of the most vulnerable places in term of CC. It is also extremely vulnerable to global changes due to it geo-strategic position in the world. Together, global and climate changes affect seriously sustainable development in this region. It is a heterogeneous space embracing both developed and developing countries, with diverse social, economic and political systems. Though land use intensity and water scarcity are among it main characteristics, it has underwent a long history of intensive anthropogenic activities relied mostly on natural resources. These special features make the Mediterranean region as model area for integrated research and policies into change-related impacts at global level.

Vulnerability:
As IPCC 3rdAR (2001) stated strong evidences that human activities are the main cause of CC, today anthropogenic behaviour have a strong influence in determining the future potential responses and adaptations to CC. Thought Mediterranean region slightly contributes to CC (about 6 to 7%); it is among vulnerable places on earth to be affected by global warming. The IPCC (WGI, 3rdAR) indicates substantial drying in the Mediterranean region. Among possible impacts listing water scarcity, wildfire, heat waves, desertification, drought, new pest/diseases and sea level rise. Under this climate threats, no sustainable development can be seen in short-medium terms.

In this region, regional and global anthropogenic emissions amplify the impacts of local CC. Thus reducing regional emissions of Mediterranean countries is one of the opportunities to mitigate the consequential impacts. The paper submitted to Klima2009 by El Ouahrani A. & Merzouki A., (not published yet) highlights CO2 emission from fossil fuel in the Mediterranean region. It revealed the accelerating CO2 emission from south/eastern-rim countries (SERCs), largely from Turkey and Egypt, which due mainly to fast growing economy and population. Spain and Italy are leading in this regards in northern-rim countries (NRCs). It revealed that by 2050 SERCs emissions will overcome those of NRCs if no mitigation measurements have been admitted. The authors urge for conscientious dialogue within Mediterranean countries to adopt appropriate (flexible) policy decisions able to uphold green economy in the region without harming SERCs development.

Nowadays, climate change manifesting well in the Mediterranean region by dryness that affect mostly Mediterranean forests which are possibly one of the most vulnerable forest ecosystems on earth. It featured by it fragility and instability due to massive anthropogenic pressure and harsh climatic conditions that prevent recovering of natural vegetation, in addition to roughly lack of integrated management. Among extreme events, wildfires seem threaten strongly Mediterranean forests. In fact, wildfires are one of the forest issues that have been most studies regarding to CC change in the Mediterranean region (Yves B., 2009). Global worming seems to be major factors driving wildfires all over the world. Society behaviour, land use change, and landscape management are also part of defining future wildfires patterns. Therefore, we should helping society to coexist with wildfire through participatory approach that leads to awareness campaign previous fire season will be the best strategy to prevent forest fires. Thereby, promoting cooperation and networking between NRCs and SERCs, more vulnerable to wildfire, could help reaching good outcomes through transfer of knowledge, experiences and help building capacities aiming at conserving and recovering Mediterranean forests mainly in SERCs.

4Degree & Beyond

The IPCC scenarios (SRES) highlight some of the impacts of CC in the Mediterranean region. In this context, M. de Castro et al,. (2004) elaborate response strategies focused on adaptation and mitigation opportunities. He stated that global climate modelling results throughout 20th century and focus on the Mediterranean region corresponding to two IPCC emission scenarios (SRES: A2 & B2).

For the last third of the 21st century, the highest warming simulation in summer corresponds to **6°C** in A2 and above **5°C** in B2. In the winter season the projected temperature rise is about **1** to **2°C** less intense then in the summer. The max warming in winter season is localised in southern inland Mediterranean regions. While in the summer it is rather localised in European countries. Generally, warming will be less intense in coastal areas. Precipitation regimes show uniform decrease all over the Mediterranean zones. However, the seasonal quantity of showers will increase in both northern and western regions for A2 and B2. On the other hand, A2 scenario shows sever decrease in precipitation compared to B2. For the 2nd half of 21st century temperature variability will be generally higher than nowadays in most regions of the Mediterranean (more remarkable in A2). However, precipitation variability is spatially less uniform and likely to be reduced in areas where decrease of seasonal precipitation is predicted.

Adaptation opportunities

After development of more reliable scenarios that predicted the impacts of global warming, the Fourth Assessment Report of the IPCC (2007) concluded that even with stringent mitigation efforts, climate change impacts is unavoidable. Therefore, investing in adaptation options become crucial mainly in the post-2012 negotiations. To start, we need to improve our scientific knowledge on vulnerability and adaptation, fostering pragmatic adaptation strategies applicable to various scales, contribute to international discussions based on resulted scientific data. Among cross boundary Initiatives in the Mediterranean, I highlighted here; Plan Bleu, Circe (Climate change and impact research: The Mediterranean environment), a European project on climate change and adaptation strategies, INVULNERABLe, bring together scientific communities with private business to talk on climate change scenarios and its impacts on socio-economic sectors, EFIMED focus mainly on climate change impacts on Mediterranean Forests. These and other climate change induced networking could be seen as fruitful opportunities to build adaptation capacity in the Mediterranean region. Mediterranean region is mostly populated by rural communities (notable in SERCs) which are relying mainly on natural resources particularly sensitive to climate variability. Hence, rural communities seem to have less option capacities to endure or adapt to climate change impacts. However, some recent studies on vulnerability and adaptation capacity to climate changes (Glwadys and Claudia, august 2009) showed that most vulnerable regions to climate change have also higher adaptation capacity. They seen vulnerability to climate change more linked to intrinsic social and economical development, and hence an opportunities to boot development in such regions.

Conclusion:

This paper attempts to urge all stakeholders in Mediterranean regions, to work in close synergy mainly north-south partnership, to avoid local and therefore global warming of 4degree and beyond meanwhile reducing the cost of climate change adaptation. To start, we need to improve our scientific knowledge on vulnerability and adaptation opportunities, fostering integrated adaptation strategies applicable to various scales, contribute to international discussions based on resulted scientific data. Investing in adaptation options "now" becomes crucial to success in the post-2012 negotiations and beyond.

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Poverty reduction and climate change adaptation in worst case scenario – Synergies & Challenges

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Eastern state of Orissa is one of the most economically backward states in India and ranks 11th out of 15 major states in India in Human Development Index. More than 40% of Orissa's population lives below poverty line. Orissa is already affected by climate extreme events like heat waves, cyclone, floods or droughts, which have increased in frequency over last decade. In the last four years, calamities have claimed more than 30,000 lives[1]. It is expected that a 4+^{0}C rise in temperature would only exacerbate the situation in Orissa and put millions of rural poor in peril.

Climate change phenomena is being addressed broadly in three ways: (i) through mitigation measures, (ii) through adaptation processes, or (iii) through acceptance and continued suffering (coping). Mitigation measures are long-term and require constant effort and global consciousness. Adaptation through various coping mechanisms to build in resilience towards climatic vagaries is an on-going process, focusing on sustainable management of natural resources and livelihood diversification. Whereas coping refers to the immediate actions in the face of an event or changes and ability to maintain welfare, adaptation here refers to long-term adjustments to the framework within which coping takes place.

The concepts of adaptation, adaptive capacity, vulnerability, resilience, exposure and sensitivity are interrelated. Currently at international level there is no agreement over reducing or stabilizing the greenhouse gas emissions which is the main cause of global climate change. However, it is widely believed that climate change adaptation is a must especially for the developing countries where most of the world's poor live. Whereas efforts to reduce emissions have a global perspective, the adaptation measures are planned and delivered at local levels and are meant to cater to the households in a particular region. Adaptation of the communities and their increased resilience towards climate change is a broad based endeavour and is not only restricted to activities of Climate Change Adaptation (CCA) specific projects. Mainstream development projects impact CCA by the communities and are important given the scale and wider application of such projects in comparison to CCA specific projects. Mainstream development projects become much more important given the delay in coming out with a specific CCA related agreement at international level. During the interim period till more funding is available for CCA at the national and international levels, mainstream development funding could be assessed vis a vis its impact on CCA. Moreover, even if large scale CCA specific funding is made available, it is doubtful that this will be adequate for continuously CCA work. It is therefore imperative that the mainstream projects are screened for their positive or negative impacts on CCA.

Traditional areas of development funding and interventions are closely related to reducing community's sensitivity to climate variations. There are various approaches doing rounds in

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[1] http://www.cseindia.org/programme/geg/pdf/orissa.pdf

India that work on development of rural communities especially in the marginalized regions. Various such approaches like employment guarantee, Self-Help group, micro-credit, afforestation and conservation of forests, watershed development etc have large budgets and are funded by both internal and external sources. These approaches, strategies and activities under these schemes have an impact on the vulnerability and adaptive capacity of the communities towards climate change. However, an increased focus on such strategies is necessary in the present time because the climatic changes are becoming more rapid and frequency and intensity of extreme events may also increase in future.

Abject poverty fans socio-economic vulnerability towards not only fluctuations in the market but also towards changes in the climate. Addressing such vulnerability requires a large amount of financial resources. Channelizing overseas development assistance towards fighting climate change could be an option but the Government of India is not in favor of linking climate funding and general overseas development assistance.
In the light of such conflicting policy opinions and limited availability of resources for addressing vulnerability issue in climate change it is imperative to understand inherent synergy and/or conflict in the programme design and outcomes of ongoing development programs vis a vis climate vulnerability.

Taking the case of DfID supported Western Orissa Rurual Livelihood Project (WORLP) in Orissa, this paper attempts to explore **current approaches to development in marginalised rural areas** and **assess whether these approaches satisfy the need for climate change adaptation** in a +4 degrees world.

The project area of WORLP lies in an area of India where the mean temperatures are seen to be rising, and where the community's vulnerability profile places it among the highest risk in the country. The climate risks that have been identified in the project area pertain to (i) High variability of rainfall, leaving people with two peak periods of food stress (ii) Drought and dry spells and (iii) Flash floods

The project logical framework indicates clearly that this project was not designed with any climate change objectives or indicators to measure this, and indeed no major environmental impact was envisaged other than that which might be expected through the enhancement of natural resource assets. Nonetheless, the goals of the project are such that it might well be expected to contribute to climate change adaptation.

A recent study of the project indicates that the adverse effects of climate variability may have lessened through natural resource interventions, where groundwater tables have risen, land use patterns have altered, and levels of crop diversification and production have increased. In the farm, off-farm and non-farm sectors, livelihoods have become increasingly diversified and thus more resilient. Much effort has gone into participatory planning and capacity building processes, and community level organisations mainly in the form of SHGs have grown in both number and strength, with increasing levels of federation. The increased stock of social capital that has thus been generated has seemingly gone a long way to ensuring quicker reactions, and responses which are both better informed and more appropriate in stress situations. People in the project area, in particular women, now appear to be better prepared for, and adapted to, extreme weather events and variability. Vulnerability for the poorest has been reduced, and their strategies for coping rendered more confident.
A general framework is emerging from the study of impact of WORLP project on the adaptive capacity of the target population. This framework is based broadly on three pillars of

social, economic and environmental aspects. A further pillar of political aspect is added though not empirically gained from the WORLP. Political here means the structures, institutions and entitlements that are necessary for reducing vulnerability and improving adaptive capacity of the community. A further disaggregation of these aspects is done and a checklist is developed which could provide a basic assessment tool for development projects that want to assess a particular project’s suitability to the Climate Change Adaptation.

A View From the Top: Vulnerability and Adaptation in Mountain Systems

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Abstract:
Mountain ecosystems are among the most vulnerable to climate change and in the frontline of adaptation to extreme warming scenarios. On the Tibetan Plateau, for example, the average temperature increase per decade over the last 50 years was in the range of 0.2 to 0.6 degrees C. Similar figures exist for the Andes and other high mountain environments. These extreme increases are not only projected to have major repercussions for regional hydrological systems through advanced glacial melting but they will also transform mountain livelihoods. These livelihoods are already among the most marginal and stressed, and the prospects of large-scale warming are likely to overwhelm existing coping mechanisms of local populations.

This paper proposes to develop a vulnerability assessment tool for these mountain livelihoods, building on the IPCC components of vulnerability: exposure, sensitivity, and adaptive capacity. The tool will identify and apply a mountain-specific set of vulnerability dimensions and criteria, based on Jodha's framework on mountain specificities. The latter highlights the particular conditions and constraints for sustainable development in mountain regions, and calls for tailored development interventions. In a similar vein, we will make a case that successful adaptation in these high-risk environments will depend on a sound assessment of mountain-specific climate vulnerabilities.

Mountain Environments

Mountains are fragile ecosystems that are globally important as the source of most of the Earth's freshwater, repositories of biological diversity, destinations for recreation and tourism, cultural diversity, knowledge and heritage. Mountains also provide food, energy, timber, flood and storm protection, and erosion prevention. Globally, mountains cover almost 40 million km^2 (approximately 30% of the Earth's surface). Mountains occur on all continents, in all latitude zones, and within all the world's principal biome types (IMR, n.d.). Mountains are the home of almost 17% of the world's population. In 2000, the number of people living in mountainous regions was estimated to be more than 1.1 billion. Total rural population in developing and transitioning economy was 490 million out of this 245 million are vulnerable population (IMR, n.d.).). In general, both poverty and ethnic diversity are higher in mountain regions, and people are often more vulnerable than people elsewhere (Korner and Ohsawa, et al.,2005).

Mountains influence climate mainly in four ways: through their altitude, continental position, latitude and topography (Price and Barry, 1997). At the same time, mountains are most sensitive to all climatic changes in the atmosphere. The Global Climate Change Models (GCMs) provide various scenarios and their consequent impacts. The A1FI is one of them and used for projecting extreme warming; fossil fuel intensive world of rapid economic growth, low population and rapid introduction of new and more efficient technologies (Korner and Ohsawa, et al.,2005). Based on this scenarios, Nogues-Bravo et al. (2007) suggest that population pressures and urbanization are increasing stress on mountain regions.

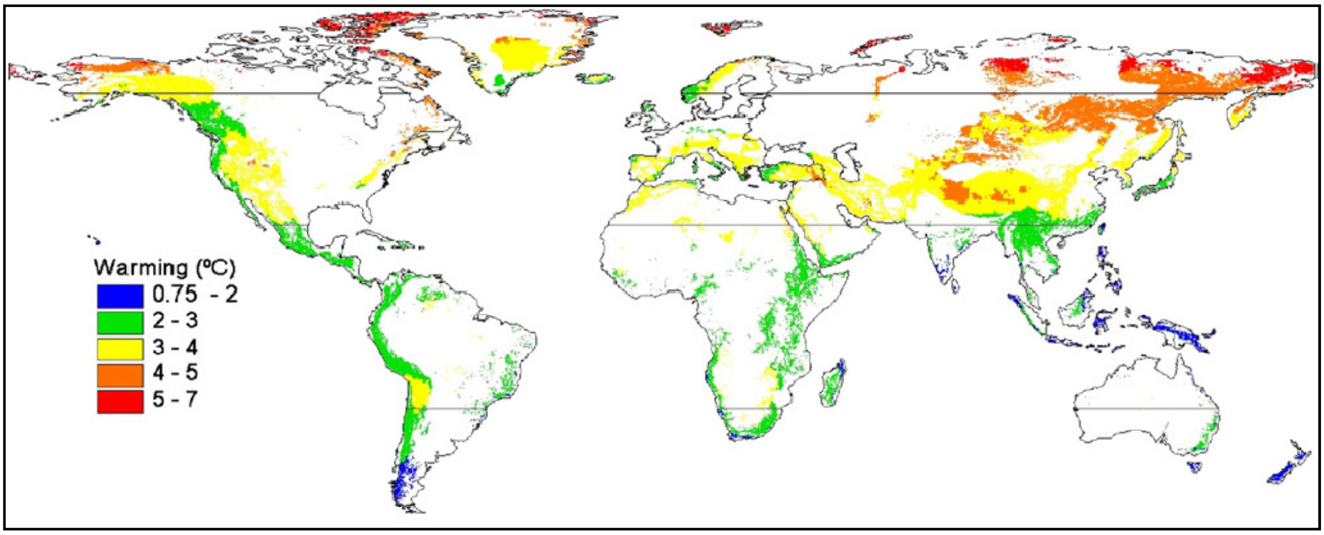

Fig 1: Projected warming of A1FI for year 2055 (Nogues-Bravo et al. 2007: 426)

This projection clearly shows that globally all mountains will experience warming but high-latitude mountains of Asia will have greater increase in temperature ranging from 3 to 7 degree centigrade. Ironically, this region is one of the most populated mountain regions of the world and majority of them are vulnerable to food insecurity (Huddleston, Ataman, et al., 2003).

Vulnerability Frameworks

The poster presents a vulnerability assessment framework building on work by Chambers on livelihoods and poverty, Jodha's observations on "mountain specificities" and the IPCC framework of vulnerability.

A review of the literature on poverty, vulnerability and climate change reveals that Chambers seminal piece (1983) on the dimensions of deprivation and vulnerability is still significant and relevant. It helps us to understand the interactions of poverty, vulnerability and overall development needs. According to Chambers, deprivation is a complex situation at the crucible of five drivers: poverty, isolation, physical (health) weakness, powerlessness and vulnerability. These drivers interact with each other at different scales and magnitudes.

For people living in mountainous regions, these drivers are very pronounced. Also, due to environmental degradation and climate change impacts these drivers are getting intensified. For example, food insecurity, malnutrition and disease, water scarcity induced by climate change are contributing to the poverty, physical (health) weakness. In addition, climatic hazards, such as storm, floods, landslides etc. are reinforcing isolation. Demographically, mountainous people are diverse and live in scattered settlements. Their demography and settlement pattern coupled with mountain terrain make them politically marginalized in decision making process and representation. Migration, induced by environmental degradation and climatic variability, from mountainous region is more pronounced than ever. People who stay there experience marginalization, isolation, and powerlessness relatively more than the people in plain or those who have migrated. Interestingly, according to Chambers, vulnerability is exposure to risk, shocks and stress from environmental and climatic factors (Chambers, 1983).

Jodha (1992, 2005) in his extensive work in Himalayan regions has proposed that inaccessibility, fragility, marginality serve as drivers of vulnerability, whereas the diversity and “niche nature” of mountain system can enhance adaptive capacities. The IPCC Technical Assessment Reports defines vulnerability as a function of exposure, sensitivity and adaptive capacity. A deeper analysis of this definition reveals that exposure, sensitivity and adaptive capacity broadly accommodate socio-economic and bio-physical drivers as explained by Chambers.

Mountain Vulnerability Assessment

With the background of Chambers’ work which broadly encapsulates Jodha’s proposition of mountain ‘specificity’ and IPCC’s definition of vulnerability, we examined the key elements and correlated underlying meanings and propose a vulnerability assessment framework.

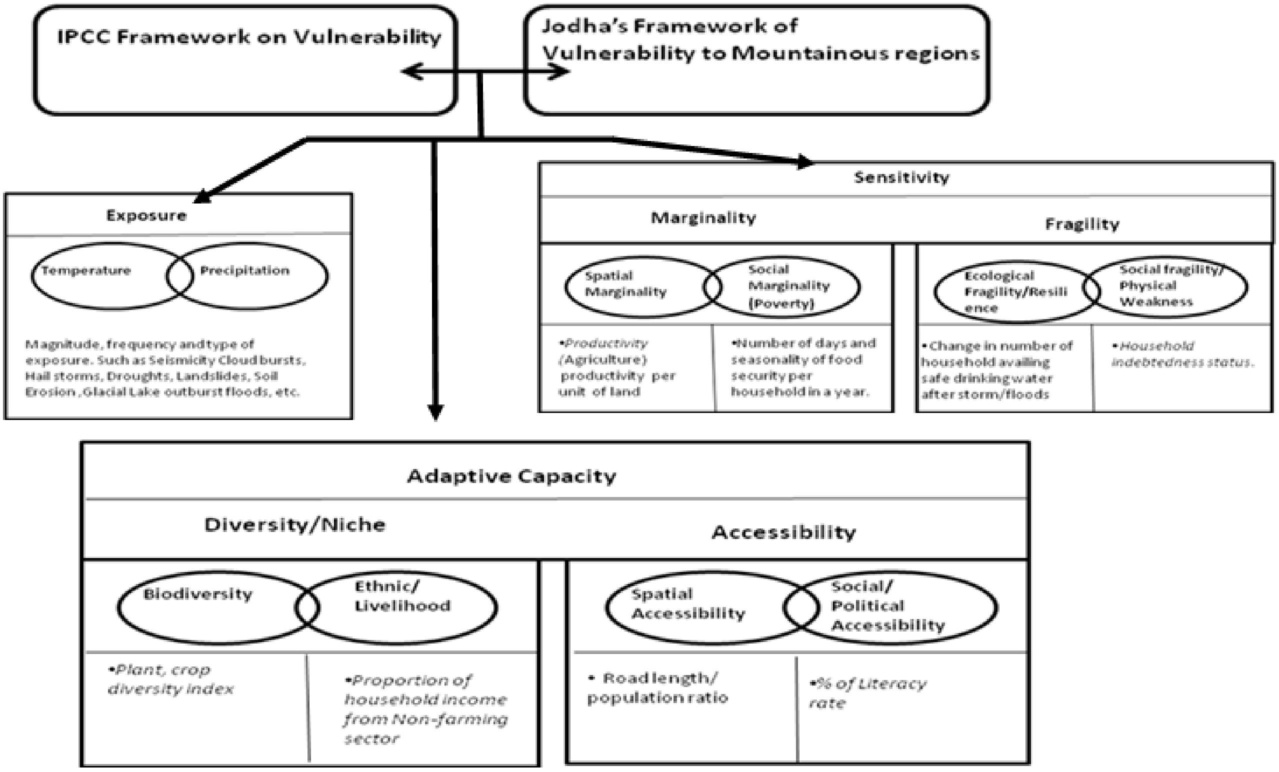

Fig 2: Mountain Vulnerability Assessment Framework

According to the IPCC Exposure is, **“**the nature and degree to which a system is exposed to significant climatic variations.” In the case of Mountain the exposures are generally due to Seismicity Cloud bursts, Hail storms, Droughts, Landslides, Soil Erosion, Glacial Lake outburst floods, etc.

Again, according to the IPCC, sensitivity is, “the degree to which a system is affected, either adversely or beneficially, by climate-related *stimuli”.* It is closely associated with the Jodha’s notions of marginality and fragility. Marginality and fragility explain the degree of productivity and resilience of the mountain system. Adaptive capacity is, “the ability of a system to adjust to climate *change (including climate variability and extremes) to Moderate potential damages, to take* advantage of opportunities, or to cope with the consequences.

Here, it is strongly driven by the type and character of diversity/niche and further influenced, positively or negatively, by the accessibility; socially and spatially.

In this poster we propose a few indicative indicators (highlighted in italics), distinguishing between bio-physical and social dimensions, and their interactions. For example, spatial marginality can be measured by *Productivity (agriculture) per unit area of land* and social marginality by the n*umber of days and seasonality of food security per household in a year*. Fragility is related to resilience of ecosystem and community to cope the shocks and stress. An indicator for ecological fragility/resilience is the *change in number of household availing safe drinking water after storm/floods* and for social fragility the *household indebtedness status*.

Diversity/Niche has two dimensions which cover, biodiversity, and livelihood diversity. For biodiversity a *plant/crop diversity index* can be used, whereas livelihood diversity can be captured by the *proportion of household income from the non-farming sector.* Accessibility, also, has spatial and social dimensions: Spatial accessibility can be measured by *Road length/ population ratio* and socio-political accessibility by the *literacy rate*

Conclusions

This framework indicates that vulnerability is dynamic in nature and its assessment must not be considered static, and should be updated as new data becomes available. Continual reassessment allows the tracking of change trajectories and reclassification of vulnerable populations. To adapt to the changing environment we need a context specific, well tailored vulnerability assessment. Also, vulnerability assessment and adaptation strategies should be embedded into overall development of the mountain ecosystem and communities. Hence, adaptation strategies need to be integrated as a crosscutting poverty reduction intervention and development strategies.

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Sea level response and impacts of a 1°C to 7°C prescribed temperature rise by 2100

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Introduction

An inevitable consequence of an increase in global temperatures is sea-level change. The effect of this change for most low-lying coastal areas will be an increase in susceptibility to flooding events and land loss due to submergence or erosion (Hoozemans et al. 1993; Nicholls 1995). As these areas are often occupied by areas of high population density, important infrastructure, and land with high value for agriculture and biodiversity, significant impacts should be expected. Projected increases in population and wealth, and therefore development, can only increase these impacts.

Increases in temperatures drive sea-level rise, and by investigating a range of temperature and sea-level scenarios, the magnitude of potential impacts can be investigated and adaptation options assessed. The QUEST-Global Scale Impacts project (QUEST 2009; QUEST-GSI 2009) has undertaken work constructing prescribed sea-level scenarios with a temperature rise of 1°C to 7°C by 2100. Using the DIVA (Dynamic Interactive Vulnerability Assessment), an integrated modelling tool, this research examines the number of additional people flooded per year due to sea-level rise and storm surges (McFadden et al. 2007; Vafeidis et al. 2008).

Methods

An A1B sea-level rise scenario from the IPCC AR4 MAGICC 4.2 dataset (Raper and Cubasch 1996; Cubasch et al. 2001; Meehl et al. 2007; Raper et al. 2001; Randall et al. 2007) was created using the ensemble mean values of thermal expansion and temperature. This projects a 3°C rise in temperature by 2100, creating a 0.40m rise in sea-level, with respect to the 1961-1990 baseline. Prescribed scenarios, where a certain temperature is expected at a set time, were derived by scaling the sea-level components (thermal expansion, ice sheets and ice caps). Temperatures were prescribed between 0.5°C and 4.0°C in increments of 0.5°C in 2050, producing eight new sea-level scenarios. Global temperature rise ranged between 1°C and 7°C by 2100, equivalent to 0.13m to 1.09m of global sea-level rise at this time (Figure 1). These results represent central values for sea-level rise and population, so do not indicate uncertainties. Prescribed scenarios are beneficial as they allow for a range of temperature inputs, and thus sea-level rise impacts. However, the rate of sea-level rise lags a rise in temperature, so the worst impacts will probably occur beyond 2100.

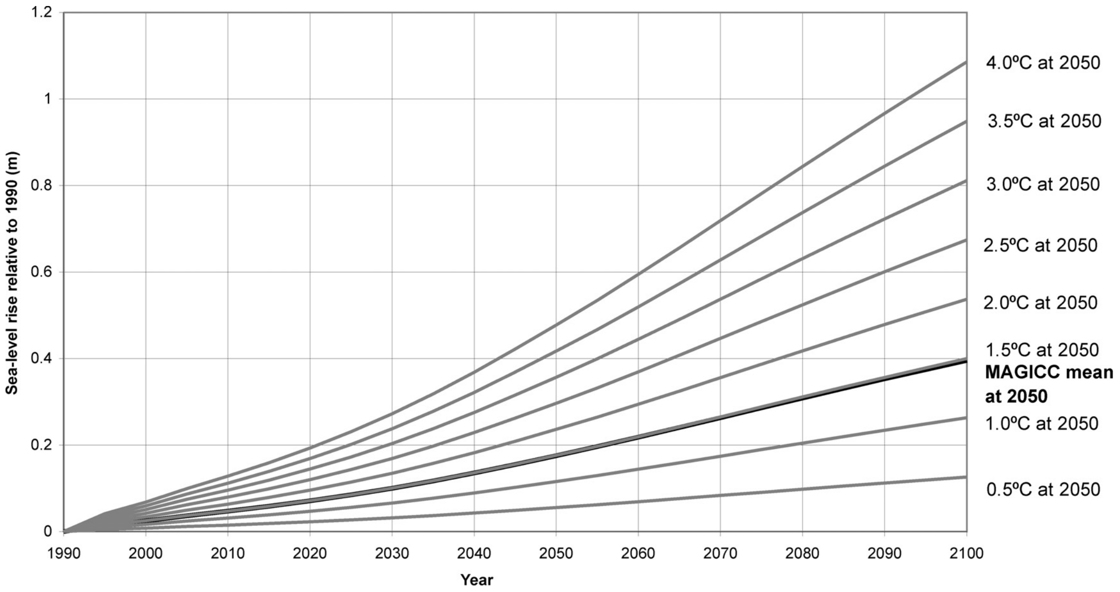

Figure 1. Sea-level rise scenarios based on the ensemble MAGICC mean, for prescribed temperature changes between 0.5ºC and 4ºC (at 0.5ºC intervals) at 2050. Prescribed sea-level rise ranges from 0.13m to 1.09m in 2100.

The DIVA model assesses biophysical and socio-economic impacts of sea-level rise and socio-economic development. DIVA downscales global sea level rise projections, and combines it with local uplift and subsidence, to produce a rate of relative sea-level rise. Combing the A1B social-economic scenario including land-use, coastal population and GDP growth from IMAGE 2.2 (IMAGE Team 2002), with relative sea-level rise, the number of people subject to flooding for return periods of a 1-in-1 to a 1-in-1000 year storm event have been calculated. Impacts also depend on adaptation strategies and two strategies were assessed here: (1) with adaptation (including a cost-benefit analysis where costs and avoided damage is balanced with dike building and beach nourishment), and (2) without adaptation (where dike heights are maintained at 1995 levels and no beach nourishment is undertaken).

Results

Figures 2 and 3 illustrate the number of people flooded from 1990 to 2100 under the MAGICC ensemble mean and eight prescribed scenarios against year and temperature respectively. The MAGICC mean ensemble scenario has a similar rate of sea-level rise to the prescribed scenario of 1.5ºC rise in temperature in 2050. Broadly, as time progresses and temperatures rise, so do the additional number of people flooded (populations decrease after 2050, explaining the decrease in number flooded at high temperatures). The MAGICC ensemble mean scenario predicts that for a 3ºC increase in 2100, a 0.40m sea-level rise will result in 89 million people flooded per year if defences are not adapted and upgraded to cope with the changing conditions. If temperature predictions are lower, and sea levels rise only by 0.13m by 2100, only 18 million people will be flooded per year. However, if temperatures rise at a faster rate, producing a 4.0ºC rise by 2050, leading to a 7ºC rise by 2100, this figure would increase to 204 million people per year. Hence impacts increase with temperature rise, and growing numbers of people are threatened without adaptation. It is important to anticipate the magnitude of future sea-level rise and plan appropriate adaptation measures, such as the raising of sea dikes or land use planning to encourage retreat.

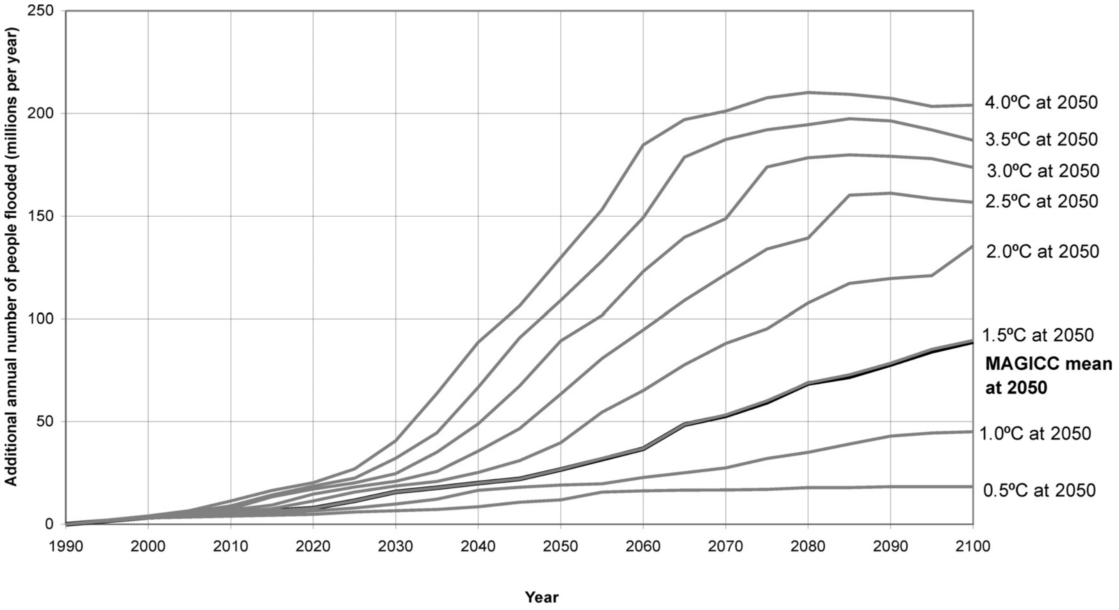

Figure 2. Additional number of people flooded per year due to storm surges and sea-level rise from 1990 to 2100.

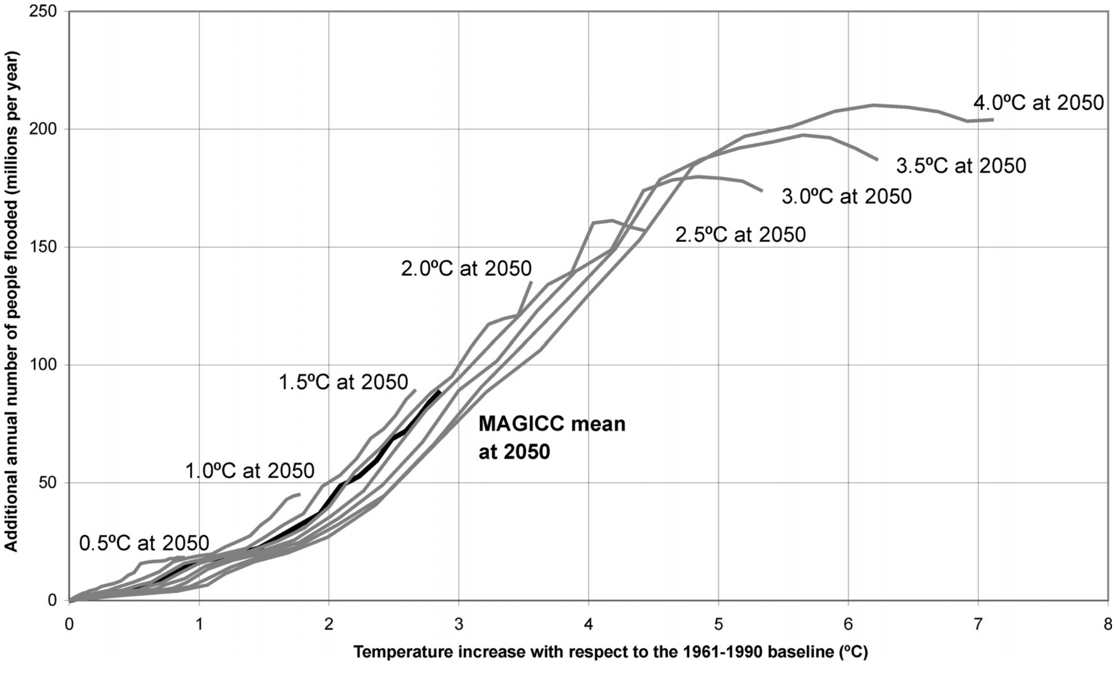

Figure 3. Additional number of people flooded per year plotted against the rise in temperature between 1990 and 2100.

Discussion

Globally it is projected that many millions of people will be affected by sea-level rise, but these impacts will not be evenly spread. Variations in population density and the ability to adapt to a changing environment mean that certain regions are more at risk than others. For instance, under the MAGICC ensemble mean projection of a 3ºC rise by 2100, 29 million people will be expected to be flooded annually (34% of the global total) along the East Indian Ocean coast (comprising Pakistan, India, Sri Lanka, Bangladesh and Myanmir), followed by the East Asia coast (comprising China, Korea and Japan) with 18%. With a 1.09m sea-level rise by 2100 (corresponding to a 7ºC rise), 50% of the annual number of people flooded will also be in these two regions.

Whilst South and East Asia have the highest populations, small islands have a high relative level of vulnerability from sea-level rise and storm surges. Under the MAGICC ensemble mean sea-level scenario, up to 175 times more people per year may be flooded compared with present levels. However, this increase is also due to the expanding population base compared with the initial population. Continued inundation of sea-water would cause loss of land, crops and freshwater supplies posing risk to stability and island security. For instance, for the low-lying Pacific island of Tuvalu, forced migration to New Zealand is or will become a reality (Mortreux and Barnett 2009). As their adaptation is potentially limited, for large temperature rises small islands everywhere are highly threatened.

Globally, despite the high risk of living in the coastal zone, it is probable the coast will remain a magnet for housing, industry and wealth over the 21st century, unless planning measures are enforced. Developing countries are particularly vulnerable as they have a reduced ability to respond and adapt. Climate change will exacerbate their problems (Leatherman and Nicholls 1995). This situation could be worsened if cyclones increase in intensity, thus increasing storm surge and flood height (Meehl et al. 2007). This has not been investigated here, but is a likely consequence of rising temperatures. Effective flood protection will continue to be vital to reduce risk, allowing the coastal zone to be perceived as a safe and attractive place. Using a cost-benefit approach to coastal defence, the annual number of people flooded could be reduced for the MAGICC ensemble mean scenario from 89 million per year to 0.2 million per year at a cost of 17 billion US dollars per year in 2100. However, perfect adaptation is unlikely to happen and the challenge is to promote effective adaptation measures.

Conclusions

This study shows that for an increase in global temperature, global sea-levels will also rise. From a 3ºC rise in temperature producing a 0.40m rise in sea-level by 2100 using the A1B scenario from the MAGICC dataset, prescribed scenarios suggest for a 7 ºC increase in 2100, a sea-level rise of 1.09m could result. Using the DIVA model, it is anticipated that 89 million and 204 million additional people would be flooded per year in 2100 with a 3ºC rise and 7ºC rise in temperatures respectively. The East Asia, East Indian Ocean coast would be particularly at risk due to high populations in low-lying areas, and small low-lying islands would also have a relativity high risk.

Vulnerability can be reduced by adapting to sea-level rise, such as through the protect, accommodate and retreat options. However, as competition for land in the coastal zone is already high and this is expected to rise with population and wealth, adaptation options should be appropriately engineered according to localised conditions.

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&beyond
4degrees

Adaptation

One Two Three More: Challenges to Describing a Warmer World

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Our visions of warmer worlds are formed by a mix of firm century-old science and evolving state-of-the-art model output. The clarity of this vision when restricted to numerical models is limited, even for a zero degree warmer world. Various reasons for this are well known within the modelling community; these reasons are each sufficient to cloud our view, and we are unlikely to resolve all of them on the timescale on which critical policy decisions will be made. The implications for our determining the implications of a global climate change of 4+ degrees for people, ecosystems, and the Earth-system itself will be discussed and illustrated. Our inability to see details of a 4+ degree warmer Earth would in no way decrease the extreme impacts that such a change would bring us and the Earth-system.

When interpreting model output in a naive-realism mode, the strongest rational arguments available to us suggest that our models reflect planets "similar to the Earth" but not the details of our Earth.

Nevertheless our models provide robust results we expect to be shared by any planet roughly like ours, even one, say, with no long, high north-south mountain ridges. Our insights lie within this collection of "similar Earths" where the details of sub-gridscale parameterisations are not critical to the big picture: and that big picture defines and limits the results models can support as being robust. Once the details of the implementation matter (that is, the details of how some phenomenon or object is represented within a model), then we know we do not know; the insight provided by our models is not just uncertain, but unreliable, and we are dealing not with probability due to model uncertainty but ambiguity due to model inadequacy. To a large extent, today's robust results are supported by the models and, semi-independently, by climate science itself. We have high confidence that doubling CO2 will significantly warm the Earth, as it would any planet similar to our Earth.

It would be of great value if climate scientists would clearly communicate explicit limits (in spatial resolution and in temporal resolution, as a function of lead time) of where current model output is believed to be robust. Where does insight fade? Where does model noise dominate? Where are we in an uncertain transition? Such limits would be of value not only to policy makers, but also to other specialist scientists considering impacts and adaptation. Alternative, softer, methods of communicating the limitations of our insight (such as including a **lower-bound** on structural model error in a pie chart, or presenting temperature anomalies as if they were temperatures) overstate our confidence, are likely to degrade decision making due to over-confidence, and threaten the credibility of the science in the longer term.

Such limits to robustness will also, of course, be a function of the particular evolution a particular model run follows (that is, its trajectory in time), not just a function of space and time and lead-time. How do we best interpret models of warmer and warmer worlds as realistic visions of what a warmer Earth would look like, knowing that each trajectory carries a greater chance of a "Big Surprise" as the model moves farther and farther from our observations and insights of this Earth. Quantifying this chance, using the science to evaluate the likelihood that today's model-visions of a warmer planet seriously misinform us, would be a significant value in decision support and policy making. Quantifying the probability of a “Big Surprise” is always an aid to model-based decision support, regardless of the application. In the case of climate policy, it might prove of more value than a detailed description of warmer model-worlds, if our aim is to inform rather than to motivate. A scientific presentation of a potential future is incomplete without some estimate of the probability that it is significantly misleading. This presentation offers an appeal for such calculations, it does not present them.

Climate science argues on physical grounds that some models are not expected to yield realistic results (defined, say, as "decision relevant" results), when they reach temperatures significantly greater than that model's "current" global mean value, a value which itself often differs significantly from that of the Earth. Current state-of-the-art model-worlds have global mean temperatures that fall within a range of about 3 degrees K. By construction, every model has an anomaly temperature of zero over the period used to define the anomaly, and that period varies depending on the results presented; often the anomaly is defined over 1900-1950 when discussing the last century, while when extrapolating into the future the period is often 1960-1990. Plotting anomalies clarifies agreement in "changes", both local and global, and gives the impression that the models agree. At the same time, local feedbacks (crops dying, ice melting, and so on) respond to the actual model-temperature, not the anomaly, and in this way agreement in anomalies might convey over-confidence in likely local effects and will not reflect the response of physics-based feedbacks in the model.

Planets similar our Earth, but where Iceland or Britain, Indonesia or Mallorca do not exist, or where the Andes are a kilometre shorter, are expected to have similar global responses to a similar increase in levels of greenhouse gases, at least for small increases. For a civil servant or decision maker to view model output as suggestive of what our Earth would look like at 4+ degrees, what it would look like locally in OX1 1DW, in England, or across Europe based upon today’s climate models, today’s scientists must have some rational expectation that the global models provide high fidelity at that resolution and those global temperatures. The alternative is to accept that we know we do not know the details; few would recommend over-interpreting model noise. At longer lead times, feedbacks from differences in the eastern South America due to a low Andes range, for example, would be expected to have significant impact elsewhere in the world. Downscaling adds relevant details **only** under the assumption of fidelity on the large scales. At 4+ degrees, when might we expect "small scale" feedbacks to remain unimportant?

With the caveats above, and those below, we can examine the variability among model-worlds which share the same global mean temperature. It will be seen that the available ensembles of model-worlds show wide variety in regional changes for the same global mean temperature, regions the size of the Central United States or Europe for example. Further, there is significant overlap in local changes in the same region in a +3 degree model-world and in a +5 degree model world. The take-home message for policy makers is that for regions as small as most countries, knowing the global mean temperature leaves significant uncertainty in the local response. And in politics, arguably, all climate is local.

For informed decision making, our current climate models have limited skill at the resolution of most countries even under current conditions, our knowledge of vulnerability to natural variability comes more from observations and science than from modelling. Noting that this is the case for a zero degree warmer world, and accepting that the “climate signal” for *large* *scale average* changes will soon come out of the noise (if it has not already), we can embrace the fact that our models are not very informative regarding what will actually be observed *on the length scales of countries* for even 2 or 3 degree warmer worlds. Decision relevant information on local impacts need never come “out of the noise” regardless of how clearly the “climate signal” does. The fact that 4+ degree warmer worlds would almost certainly initiate both known and unexpected feedbacks, feedbacks that are known not to be in today’s models, sits uncomfortably with knowledge that most of the feedbacks discussed are positive and would lead to more warming globally-on-average. The policy question is whether or not we wish to explore these 4+ degree worlds empirically, given our limited vision of just how dangerous they might prove to be.

Can we improve our vision of 4+ degree worlds short of driving our Earth to these temperatures? The fact that details of the trajectory determine its reliability means that interpreting ensembles as a probability distribution (in any Monte Carlo fashion, whether Bayesian or other) is fundamentally misguided. The diversity of our models simply fails to reflect the uncertainty in our future, even when a specific emissions scenario and other future non-climate drivers are fully specified. Determining global temperature at which a model should disqualify itself (becoming a "more" with no further quantitative information on even global mean temperature) is an open question for climate science. As the title of this presentation suggests, that number might be uncomfortably low, requiring decisions to be made under deep uncertainty.

How adaptation decision-making is affected by the potential for 4C and beyond

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There is widespread acceptance that, however fast the world starts to reduce greenhouse gas emissions, we are very likely to experience at least 2°C global warming over the coming 50 years (Van Vuuren *et al.* 2008). As a result of uncertainties both in human decision-making (will the global governance of greenhouse gas emissions be achieved rapidly given the past decade's data suggesting otherwise? Rahmstorf *et al.* 2007) and in the earth system (do a variety of tipping points mean that even with strong mitigation we may have passed thresholds in critical feedback processes? Lenton *et al.* 2008), higher levels of global warming are now being seriously contemplated, to and beyond 4°C global warming (this conference). Our short thesis is that this increase in the range of prospective futures by itself increases the costs of (beneficial) proactive adaptation for a particular class of adaptation decisions, regardless of the costs of adaptation at any specific level of warming. Examining this thesis raises a number of important questions about how humanity responds to the current trend of increasing uncertainty about our future.

The assessment of the implications of scenarios of future change for adaptation tends to concentrate on the direct costs and benefits of specific adaptation options for a particular future projection. However the history of the successive four IPCC Assessments shows that our improving understanding of the earth system has in fact led to a progressive increase in the range of future possible global temperatures, both as a result of including a wider range of societal responses, and due to a growing appreciation of what we do *not* know about earth system feedbacks. Growing concerns about tipping points (Lenton *et al.* 2008), and observations of the fact that global emissions, atmospheric CO_2 concentrations, temperature and sea level rises are tracking at or above the highest level contemplated in the IPCC emission scenarios (Raupach *et al.* 2007; Rahmstorf *et al.* 2007) mean that this trend is likely to be continued in the next IPCC Assessment. Recognition that uncertainty pervades our view of the future is leading to an increasing need to think about how to make decisions in the face of this uncertainty (e.g. Dessai *et al.* 2008).

However, not all decisions are equal. Decisions with short latencies (that is, that have implications for only a short period of time) need not generally take account of this uncertainty – for example, the colour we paint our house roofs can be readily and cheaply re-assessed in a few years time, and adjusted if today's choice turns out to have been wrong. By contrast, decisions with long latencies, such as building major infrastructure, the location of new suburbs, the large-scale establishment of new industries, design of landscape architectures for conservation and production, and the planting of long-lived keystone forest species, need to consider the uncertainty among alternative futures. There are other decisions with medium latencies which have different implications – for example, there may be the option to choose deliberately to build infrastructure cheaply with a shorter design lifetime so there is an opportunity to revisit choices when more is known about the future. Such decisions depend on the opportunities for (and costs of) trading off shorter 'disposable' lifetimes with more temporal flexibility.

Our focus here is on the class of decisions with long latencies, for which a scenario-based risk assessment can lead to a number of different types of options, as illustrated in the following brief examples. Consider the case of a decision-maker assessing three future scenarios: an overshoot scenario where the climate is expected to eventually recover after peaking around 2°C (the '*recovery*' scenario, e.g. MEP2010 scenario, Sheehan *et al.* 2008), a stabilisation scenario where the climate stabilises at around 3°C ('*stabilisation*', e.g. MEP2030), and, the focus of this conference, a scenario of continuing change where the climate is expected to exceed at least 4°C warming ('*runaway*', e.g. A1FI).

For some decisions the effects of uncertainty are monotonic (although not necessarily linear). For example, the implications of sea-level rise on how close to current sea levels new buildings should be allowed is essentially a question of what level of precautionary principle to apply, itself a cost:benefit analysis related to factors such as the longevity of the buildings, damage functions and ease with which they can be later moved. A wider range of credible possible futures should cause the threshold to be set at an increasing height; consequently the cost of proactive adaptation essentially rises in proportion to how severe the *runaway* projection is considered to be.

However, other decisions may require different and incompatible responses under each scenario. For example, long-lived forest trees may take a century to mature to provide microclimate, nesting hollows and the physical structure that sustains a desirably-functioning ecosystem, so that decisions about management after fire today have a long latency (Steffen *et al.* 2009, Box 9). A response to a *recovery* scenario would be to nurse existing populations through the next two centuries by protecting them from fire, weeds and other threats; by contrast the response to a *stabilisation* scenario might be to promote the establishment of a species with a higher temperature optimum, whilst in the face of the *runaway* scenario the best management may be to simply facilitate ecosystem change by maximising connectivity with other parts of the landscape. Each of these three scenario response strategies would be significantly sub-optimal (or disastrous) if either of the other scenarios actually comes to pass. Hence the risk management strategy here should be to risk hedge against the alternatives by managing different parts of the landscape differently. This imposes a greater adaptation cost since multiple alternative adaptations must be undertaken rather than a single one; it also implies a much greater residual impact since, in this case, two-thirds of the landscape will have sub-optimal management, although we do not at this stage know which two-thirds. In general, as the range of alternative futures expands, the cost imposed on this class of decisions increases disproportionately.

There are many other examples of this class of decisions with long latency that require risk hedging (Parry *et al.* 2007). For example, water storage dams for irrigation are a useful adaptation for modest levels of climate change that causes regional drying; but may be a wasteful or even dangerous response to a *runaway* scenario that either dramatically decreases runoff, or increases flood extremes beyond the dam's design tolerance. In agriculture, moderate climate change scenarios that cause some increase in climate variability but still permit wheat cropping would encourage the establishment of greater grain storage infrastructure in current grain growing regions to ensure there are adequate reserves for dry periods and to cater for larger crops in the high yielding years. But a *runaway* scenario that means farming needs to move to new regions would instead suggest investing in this infrastructure elsewhere or later, and possibly using costly portable infrastructure that can be moved at need but which is less effective. In this case a decision might be taken to trade off increased flexibility over efficiency and longevity by investing in the expensive moveable infrastructure, again increasing the costs of proactive adaptation.

In general, it is important to disaggregate different types of decisions. First, decisions with short latency are amenable to incremental improvement as the future becomes clearer, and should be consciously planned this way. Second, decisions with long latency need to be considered in terms of the range of possible futures; appropriate adaptations for these decisions can then be classified into precautionary as opposed to risk hedging responses. In both cases increasingly severe scenarios of possible climate change increase the costs of ideal proactive adaptation; however, costs increase more rapidly for the risk hedging decision class. Perversely, for these it would be better to *know* for sure that global warming will result in 4°C warming, than to face the uncertainty of a wide range of possible futures!

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Nature conservation in a 4+ degree world: a luxury or a necessity?

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A four degree plus temperature rise raises the spectre of extremely serious impacts on the natural environment. Coping with this would require a substantial increase in our efforts to conserve the natural environment. But a four degree rise would also have huge implications for human health, safety and wellbeing. In this sort of world, can we afford the luxury of trying to save “the birds and butterflies”? Won’t there be much more pressing issues to deal with?

We argue that, in fact, we cannot afford ***not*** to conserve the natural environment. Protecting and strengthening ecosystems safeguards the services they provide and is one of our best defences against environmental change and its effects; this will become more, not less, important under extreme change. We present evidence to support this view, using four examples from England. We also briefly discuss some of the challenges that must be addressed for sustainable adaptation to be achieved.

The role of trees and woodlands. England is one of the least forested countries in Europe, with only about 9% tree cover compared with 37% in the EU as a whole (Forestry Commission 2008). Tree planting and appropriate woodland management would make an effective and sustainable contribution to achieving a wide range of climate change objectives.

Woodland can help manage important environmental risks, which will increase with climate change, such as soil erosion, agricultural runoff, rise in water temperature and consequent declines in water quality, and flooding (Caissie 2006; Conlan *et al*. 2007; Sudgen *et al*. 2008). Trees also help regulate local climate and provide shelter from wind and storms to protect crops, livestock and soils, as well as supporting important pollinating insects (Sugden *et al*. 2008; Escobedo *et al*. 2009; Merckx *et al*. 2009a, 2009b). Growing trees to produce timber or woodfuel could help farmers spread the social and financial risks from climate change (Sugden *et al*. 2008). All these services are likely to become more important to society under the extreme climatic changes that four degrees would bring especially as flooding, water pollution, heatwaves, droughts and unpredictable conditions become more frequent and severe (Murphy *et al*. 2009).

Trees may play an increasingly important role for human health and recreation in a 4+ degree world. In cities, there could be potentially vital shade and temperature regulation benefits for people by increasing the number and area of trees in urban landscapes (Gill *et al*. 2007; Escobedo *et al*. 2009). In the countryside, woodland areas may become increasingly important as cool places where people can enjoy the outdoors, away from the summer heat.

In addition to its adaptation benefits, woodland provides a major carbon sink by sequestering carbon within its timber and maintaining soil carbon stores (Choudrie *et al*. 2008). In some cases mitigation may be best achieved by sustainable timber harvesting for fuel and materials (Nabuurs *et al*. 2007).

All these benefits can be realised in ways sympathetic to nature conservation interests. For example mixed species woodland provides advantages over monocultures as it spreads the risks of susceptibility to new pests and diseases and a range of extreme events.

Keeping blanket bog in good condition. Blanket bog is found in the English uplands where high rainfall and poor drainage frequently result in waterlogged conditions; the largest areas are in the Pennine hills. The waterlogging, together with cool temperatures, result in low rates of decomposition and the formation of deep peat. Blanket bog provides a number of ecosystem services with a direct bearing on the quality of human life (O'Brien *et al*. 2007); two of the most important are carbon storage and water supply. The peat is a substantial store of carbon, which has built up over thousands of years and healthy bog continues to steadily remove carbon from the atmosphere, although there may be small releases of methane through decomposition (Thompson 2008). Catchments covered with blanket bog are a major source of water supplies for large numbers of people in the Midlands and north of England. They are also areas which can support low intensity sheep grazing and contribute to a highly valued landscape with a well developed tourist industry (Usher & Thompson 1988).

Blanket bog can be degraded by a range of factors including drainage, over-grazing and air pollution (O'Brien *et al*. 2007). In a degraded state, soil erosion leads to the release of carbon and a changed hydrology with poorer quality and more variable water supply and increased risk of flooding downstream. Climate change is likely to exacerbate this degradation particularly if summer droughts become more frequent. Restoring blanket bog safeguards service provision and increases resilience of these services to climate change as well as protecting conservation interests. There are already efforts being made to block grip drains and increase water levels in some moorland areas to improve bog condition in order to maintain carbon storage and water resources, but in a 4+ degree world, urban populations neighbouring these upland areas may have a greater imperative to increase the area of blanket bog in currently drained upland areas.

Management of rivers and catchments Appropriate management of rivers and catchments is crucial to both the provision of clean water and the management of flood risk, along with a range of associated services. Climate change projections (Murphy *et al*. 2009) suggest that we will see both an increase in summer droughts and in extreme flooding events and these are likely to be increasingly severe as we approach a 4+ degree world.

Where rivers have been degraded by channelisation, pollution, excessive water abstraction and destruction of riparian vegetation, they will be less able to provide the services society requires, especially under the harsher conditions imposed by a 4+ degree world. Restoration of floodplains with healthy natural ecosystems improves their ability to store and absorb large flooding events, protecting built-up areas and reducing the scouring impacts of large water flows down rivers (Wheater 2006). Restoring riparian vegetation can guard against water pollution, the risk of which is likely to increase with climate change (Caissie 2006; Sugden *et al*. 2008) Elements of natural floodplain ecosystems such as wetlands also have the potential to store water at times of excess and gradually release it back into the environment, reducing the effects of drought.

Managed realignment of coastlines. In a 4+ degree world, sea-levels may rise substantially, threatening large parts of England's coastal areas with inundation, particularly those on the eastern and south-eastern coasts. Hard defences, such as sea-walls will be very expensive and potentially unsustainable, against the continued erosive forces of the sea. By working with nature, using saltmarsh and other coastal habitats to create more storage space for high tides and to reduce the energy of the sea before reaching such defences, costs can be reduced and sustainability increased (Defra 2005).

Managed realignment involves breaching sea walls and letting the sea advance to cover the land behind it. In most cases, new flood banks are constructed behind the wall that is breached; the sea covers the land between the old and new defences and intertidal habitats are gradually established (Dixon *et al.* 2008). There have been over twenty realignment projects in the UK designed either for habitat conservation or flood risk management or both, the largest of which, at Alkborough on the Humber estuary, protects 90,000 hectares of land and 300,000 properties from sea level rise. In addition, it has produced new recreation opportunities to benefit the local community both directly through increased tourism, as well as significant conservation benefits (Environment Agency undated; Dixon *et al*. 2008).

These examples demonstrate the importance of protecting ecosystem services, but there is still much debate about the relationship between ecosystem services and maintenance of high levels of biodiversity – the traditional goal of nature conservation. Do we need to conserve a wide range of species to maintain the full range of ecosystem services?

For a small number of services, such as pollination, particular species provide the service directly. In such cases it is sensible risk management to maintain a range of species that can contribute to providing the service. In many other cases (e.g. water purification, erosion regulation, greenhouse gas regulation) the service is provided at the ecosystem level, rather than species level. There is nevertheless a strong link between some key species and ecosystem function; for example many of the properties of blanket bog are associated with *Sphagnum* moss (O'Brien *et al*. 2007). There is an insurance effect of having high levels of species diversity as different species respond differently to fluctuating conditions (Tilman & Downing 1994; Yachi & Loreau 1999; Cottingham *et al*. 2001; Dang *et al*. 2005). There is also evidence that some ecosystem processes, such as productivity or decomposition, increase as diversity increases (Tilman *et al*. 1997; Hooper *et al*. 2005; Balvenera *et al*. 2006; Hector & Bagchi 2007; Scherrer-Lorenzen 2008). The provision of multiple services is also likely to require the presence of multiple species and more complex ecosystems (Hector & Bagchi 2007).

In promoting the value of nature conservation as a means to ensure the multi-functional benefits of the natural environment within the context of extreme climate change, there will be socio-economic and political issues to be resolved. In particular, pressure on land in England may become intense in a 4+ degree world and we will need to find the appropriate balance between the different services society requires or demands, including the need for food production and renewable energy production. We will need to better understand the costs and benefits (not just monetary but ecological and social) of trade-offs between different services and to develop decision-making models to help us make the optimal choices. In the evaluation of these trade-offs, it will be important to recognise the cost-effective benefits that natural environments provide and will increasingly provide in a 4+ degree world.

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The implications of 4+°C warming for adaptation strategies in the UK: time to change?

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A change in global temperature above 4°C will bring considerable impacts to the UK. Although such a level of change may be considered as a ‘high consequence, low probability’ outcome, the application of sensible, precautionary planning suggests that appropriate adaptation responses must be considered to avoid the type of impacts projected (e.g. Parry et al 2008). In this paper, we consider existing adaptation approaches in the UK to explore how current efforts and approaches compare with what might be needed in the face of 4°C of warming.

The UK has an impressive resource of conceptual and practical advice on adaptation processes, but much of the focus has been on what is achievable, rather than what may ultimately be needed. Driven by the need for policy integration and efficiency, adaptation is progressed through mainstreaming and the identification of ‘no-regret’ or ‘win-win’ options. For valid reasons adaptation has mainly been framed as an activity that requires only a minimal disruption to current activities and approaches with a focus on “efficiency and effectiveness” (Eakin et al 2009, p217). However it remains unclear to what extent the need for “transformative adaptation” (Jones 2003) will be recognised through such an approach. According to Defra:

> *“Assessing climate change risks and opportunities should become ‘business as usual’– part of normal risk management, and business planning.”*[2]

However will it be possible for businesses and government to operate as usual if warming is greater than 4°C?

At all scales of governance in the UK there has been considerable emphasis on mainstreaming adaptation into existing decision-making frameworks; adaptation becomes another criterion to be included within existing decision-making processes. Mainstreaming adaptation is an appealing concept but policy integration is difficult to achieve; experiences in sustainable development show limited progress which might serve as a warning for efforts to do the same with adaptation (Kok & de Coninck 2007). Alongside mainstreaming there is also considerable awareness of the need to ensure an integrated response across sectors and scales of governance as uncoordinated actions may result in maladaptation. Integration is one of the ambitions of the Governments’ Adaptation Policy Framework which stresses that one of the Governments’ roles is providing the evidence and tools necessary to enable adaptation.[3]

In the UK public sector, coordinated efforts in adaptation have been greatly facilitated by the publication of official UK climate change scenarios (e.g. Hulme & Dessai 2008, Gawith et al 2009). To date, almost all adaptation strategies within national and local government have built upon ‘reasonable’ scenarios of climate change and have not considered low-probability, high-consequence scenarios with worst-case outcomes.

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At the National level the Climate Change Risk Assessment is being developed to support the development of national policy on adaptation in a manner consistent with the existing policy appraisal framework. The existing framework is based on an assessment of costs and benefits and where feasible attributing monetary values to all impacts of any proposed policy. There remains a danger with such an approach that short term or more ‘likely’ issues are favoured over longer term, more uncertain ones.[4] Focusing on a narrow range of climate possibilities may not be fully effective in the longer term if warming exceeds 4°C; it is possible that some of the decisions being made now may lead to maladaptation and the investment in unsustainable options.

At the local level an important step towards achieving the Governments aim of protecting the public from immediate risk[5] was the introduction of an adapting to climate change indicator (NI 188) in the Performance Framework for Local Government. The ultimate aim of the indicator is to “ensure that assessing the risks and opportunities from climate change is embedded across decision making, services and planning.” [6] However defining and monitoring a process may not guarantee successful outcomes if the type of impacts are more in line with those projected at 4°C rather than 2°C warming. While there is increasing evidence that Local Authorities are adopting risk management approaches more widely than in the past, it remains unclear as to the progress local authorities have made towards addressing climate based risks but this is also very challenging to measure.[7] This in part reflects a tension at the local level between the identification of risks and the ability to respond to risks; for example legal or mandatory requirements for certain types of action from seemingly unrelated areas. Climate impacts require long-term management as the nature of the risk faced by organisations will change over time. This may clash with existing business models and planning horizons.

However if it seems our current approaches to adaptation are limited and maybe inadequate in the face of warming greater than 4°C then it is certain that changing this approach faces considerable barriers. Firstly, there are considerable organisational and cultural challenges of putting adaptation into practice. Adaptation as a process is tied up with the organisational context in which it is played out. It is this context that largely determines an organisations response to climate change (Berkhout et al. 2006). Uncertainty is a very important issue both in terms of the extent of the impacts but also the nature of responses and adjustments required. Decision-makers tend to have particular requirements for information that may be at odds with that which can be provided by science. This is typified by this quote from a user survey on UKCIP02:

“it is frustrating that no ‘prediction’ is available for actual use in routine studies…For example, how much mean sea level rise in 100 years? It could be anywhere between a few centimetres and a metre...What is a coastal engineer supposed to do in design of a seawall?” [8]

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An additional problem has been termed the ‘adaptation myth’; identifying the potential or capacity to act is does not mean that adaptation will happen (Repetto 2008). Even in European countries where traditional measures suggest ‘high’ adaptive capacity this does not lead directly to action (O’Brein et al 2006); perceived adaptive capacity may be a more useful measure for understanding when the potential for action will be realised (Grothmann & Patt 2005).

Alternative approaches include ‘robust decision-making’ and ‘adaptive management’ which focus on “strategies that are robust against a wide range of plausible climate change futures” (Lempert & Schlesinger 2000, p.391) and ‘learning by doing’ (Schreiber et al 2004) respectively. However research in the UK into the application of robust decision-making suggests that being robust to climate change uncertainties usually means higher costs. Because the trade-offs between costs and robustness are context specific, it is difficult to find general lessons as to the applicability of the method beyond those sectors that traditionally take a long term planning perspective (Dessai and Hulme 2007).

However there are examples of adaptation planning and theory that illustrate the type of thinking that may be required if warming is greater than 4°C.

The risk of increased flooding (storm surge, sea level rise and fluvial flow) to London is a major concern for the Environment Agency; the UK body responsible for flood risk management. A major project (TE2100) was commissioned to explore how best to plan for a changing climate against a background of aging infrastructure and changing uses of the estuary. The project adopted a ‘scenario neutral’ approach to climate change impacts and focussed on potential options as the starting point. Different ‘bundles’ of potential options could be assembled and then assessed to see how effective they would be against different projections of climate change. This was based on a series of identifiable thresholds extracted from the scenario analysis. The implementation of this adaptive management approach - phasing in different options when required - will be dependant on monitoring the actual rate of climate change and ensuring sufficient implementation lead times are identified.

The Institute of Mechanical Engineers (IME) released a report in that considered possible climate changes over the next 1,000 years and the adaptation potential of four key sectors: energy, water, buildings and transport. The recommendations from the report include the need to consider the long-term viability of “many settlements, transport routes and infrastructure sites, planning for either their defence or ordered abandonment” and that there should be a greater focus on adaptation based on a recognition that the “global effort on mitigation, to date, has been less than successful” (2009 p.6)

Adaptation is now becoming a mainstream issue and may no longer be the “Cinderella of climate change”[9]. In the UK developments such as the Climate Change Bill will encourage a wider range of organisations to consider the need for adaptation beyond the traditional ‘early-movers’ such as water companies and the insurance industry. However for many organisations developing the adaptation agenda (moving towards ‘action’) seems to present a number of problems. Most organisations seem to fairly quickly grasp the issue of potential climate change impacts but for adaptation it seems harder to know what to do and how to do it. If these current problems are seen in perspective against the possibility of warming of 4°C or more then this suggests a considerable gap in our level of preparedness.

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Notes

1. see http://www.defra.gov.uk/environment/climatechange/adapt/pdf/adapting-to-climate-change.pdf
2. See http://www.defra.gov.uk/environment/climatechange/adapt/pdf/adapting-to-climate-change.pdf
3. However see “Accounting for the Effects of Climate Change Supplementary Green Book Guidance” June 2009: http://www.defra.gov.uk/environment/climatechange/adapt/pdf/adaptation-guidance.pdf
4. http://www.defra.gov.uk/environment/climatechange/adapt/index.htm
5. http://www.defra.gov.uk/environment/localgovindicators/ni188.htm
6. A Risk Management Benchmarking Survey of Local Authorities conducted by ALARM and the Audit Commission in 2006 found that 78 percent of respondents say risk management is clearly embedded in strategic plans, while 81 percent report that it is explicit in their financial planning.
7. Expressed preferences for the next package of UK climate change information. Final report on the user consultation. December 2006
8. From speech by Joan Ruddock (Parliamentary under-secretary for state: climate change) on 19th May 2008. Text available from: http://www.defra.gov.uk/corporate/ministers/speeches/joan-ruddock/jr080519.htm

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4degrees &beyond

Avoiding Large Climatic Changes

4°C: The emission reduction challenge

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While there remains uncertainty over the precise conditions that could trigger abrupt or irreversible changes in the earth system, the probability of such events occurring is higher for a global mean warming of 4°C above pre-industrial levels than it is for a 2°C warming. Furthermore, the sizeable negative impacts on the human system (for instance to health, food and water supply) associated with a global average temperature rise of 4°C have been documented for many geographical regions.

Recently the G8 adopted an aim of limiting global warming to no more than 2°C, in-line with the EU target. With the Climate Change Act the UK has put into law the need to significantly reduce emissions over coming decades. The Committee on Climate Change proposed initial emission budgets out to 2022 which are based on scenarios that lead to an 80% UK emission reduction, and a 50% global emission reduction by 2050.

In this work we:

- Use results from the AVOID programme to show the size of emission reductions needed to move from a pathway likely to exceed 4°C towards one more consistent with 2°C of global warming, including discussing some of the avoided consequences.
- Discuss the possibility of recovering back to lower temperatures in a usefully short time if a 2°C target warming is exceeded.
- Discuss some of the challenges of making such large emission reductions.

Avoiding dangerous climate change

The AVOID programme (which is led by the Met Office Hadley Centre and includes the Tyndall Centre, Walker Institute and the Grantham Institute for Climate Change) is delivering information on the science and economics of avoiding dangerous climate change to DECC and other Government stakeholders. The first phase has developed a set of emission scenarios and is now examining the climate change, climate impacts, costs of impacts and cost of mitigation for these scenarios. The scenarios are defined in terms of pre-peak emissions, the timing and height of the emissions peak, the post peak reduction rate for emissions and the long-term "emissions floor" (which corresponds to emissions that we might not be able to eliminate). An example time series of warming and its uncertainty for a scenario in which emissions peak in 2016 is shown in Figure 1 below.

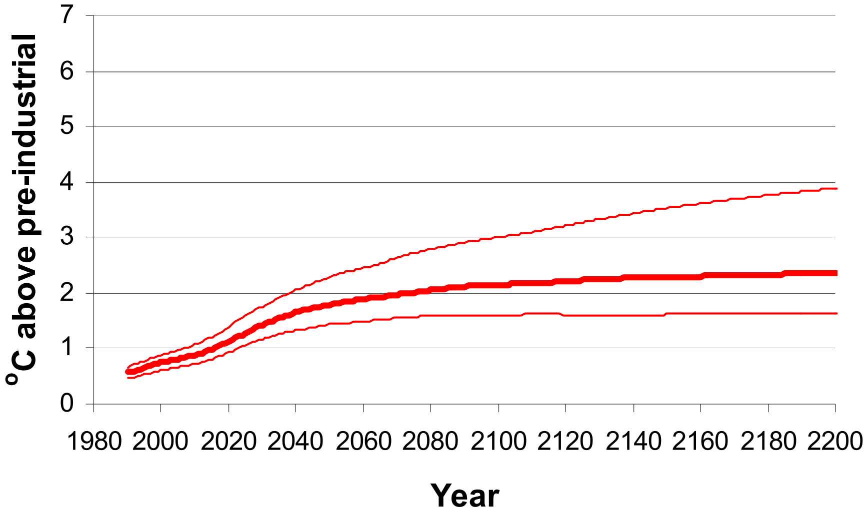

Figure 1: Showing the global mean temperature rise for an example mitigation scenario that peaks emissions in 2016. The solid red line is the median outcome. The thin lines show the 10th to 90th percentile range of warming.

The temperature rise at 2100 in these mitigation scenarios depends most strongly on the timing and height of the emissions peak and the post peak reduction rate. We also note a sensitivity of the peak warming to future aerosol forcing reduction rates. Like earlier work we conclude that limiting warming to 2°C above pre-industrial levels will require very large emission cuts relative to business-as-usual cases. Our lowest warming (to 2100) scenario corresponds to an emissions peak in 2014, a long term emissions reduction rate of 5% per year and an eventual fall in emissions to zero. This gives a median simulated warming above pre-industrial levels of less 2°C.

The “emissions floor” is important for long-term climate change, with zero values allowing temperatures to eventually decline slowly, and the non-zero values we considered typically leading to post 2100 warming. This is consistent with findings in recent work by Matthew and Caldeira (2008), House et al. (2008) and Allen et al. (2009).

The possibility of recovering if a 2°C target is exceeded

If a desired temperature target were to be exceeded but then mitigation efforts continued, how long would it take to return to the target level? A growing number of recent studies (for instance, Solomon et al., 2009; Lowe et al., 2009) have considered the maximum rate of decline in atmospheric CO_2 concentration and temperature following a peak level of warming. The results from a HadCM3LC earth system model simulation in which emissions were zeroed at either 2012, 2050 or 2100 (a set of highly idealised cases) are shown in the Figure 2 below. For the case in which CO2 concentrations peak at around 550ppm, the rate of CO_2 concentration reduction after the peak is around 45 ppm/century, and there is little evidence of a temperature decrease by 2100.

The amount of time spent over a particular temperature target appears to depend on several factors, including the long term rate of atmospheric CO_2 concentration reduction, and the amount of forcing from more rapidly removed greenhouse gas species. Faster temperature decline rates might be possible using geo-engineering methods.

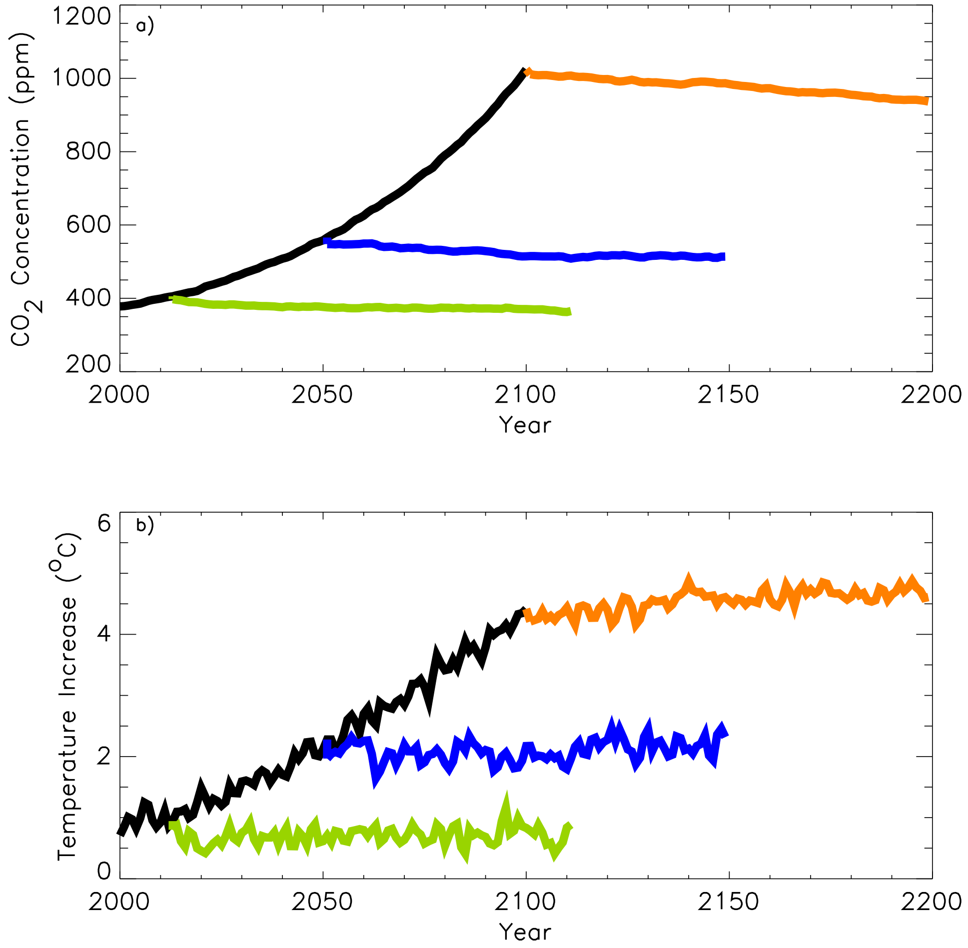

Figure 2. Projected atmospheric CO2 concentration (upper panel) and temperature increase above pre industrial levels (lower panel) simulated with the HadCM3LC model. The black curves show the SRES A2 (CO2 only) emissions forcing reference case. The green, blue and orange curves show the mitigation experiments in which emissions were zeroed at years 2012 (scenario "2012E0"), 2050 ("2050E0") or 2100 ("2100E0").

Some of the challenges of making large emission reductions

The last IPCC Working Group 3 assessment catalogued a range of technically viable methods of reducing greenhouse gas emissions, and also looked at their economic impacts. Other recent assessments, for instance by the Committee on Climate Change in the UK, have also shown how significant emission reductions might be made. Questions remain over the optimum balance of different mitigation measures, with considerable interest still focused on the role of changes in land use and deforestation (e.g. Wise et al., 2009).

We conclude our analysis by highlighting that while reducing peak warming from 4°C to 2°C does avoid many climate impacts, some significant residual impacts will still occur. Thus, even with sizeable emission reductions during the 21st century there is still likely to be a need for large amounts of adaptation, especially for those most vulnerable to climate change.

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What will it take to avoid 2, 3 and 4+ degrees? The importance of cumulative emissions

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The eventual equilibrium global mean temperature associated with a given stabilization level of atmospheric greenhouse gas concentrations remains uncertain, complicating the setting of stabilization targets to avoid dangerous levels of global warming. Similar problems apply to the carbon cycle: observations currently provide only a weak constraint on the response to future emissions. Here we use ensemble simulations of simple climate-carbon-cycle models constrained by observations and projections from more comprehensive models to simulate the temperature response to a broad range of carbon dioxide emission pathways. We find that the peak warming caused by a given cumulative carbon dioxide emission is better constrained than the warming response to a stabilization scenario and hence less sensitive to underdetermined aspects of the analysis. Furthermore, the relationship between cumulative emissions and peak warming is remarkably insensitive to the emission pathway (timing of emissions or peak emission rate). Hence policy targets based on limiting cumulative emissions of carbon dioxide are likely to be more robust to scientific uncertainty than emission-rate or concentration targets. Total anthropogenic emissions of one trillion tonnes of carbon (3.67 trillion tonnes of CO2), about half of which has already been emitted since industrialization began, results in a most likely peak carbon-dioxide induced warming of 2oC above pre-industrial temperatures, with a 5-95% confidence interval of 1.3-3.9oC. In this talk we explore how the risks of higher levels of carbon-dioxide-induced warming scale with cumulative carbon dioxide emissions and demonstrate the need for adaptive mitigation strategies to minimize the risk of dangerous levels of warming.

Beyond 4 Degrees: should we reconsider our options?

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The possibility of more rapid and extreme climate changes than currently assessed by the IPCC cannot be excluded, linked to earth system feedbacks and thresholds. Do today's policy makers have to take these into account, and if so, are the policy options to address extreme changes different from those considered now? The paper briefly summarizes the types of extreme climatic changes noted in the literature and then evaluates the options to address them. Different from other studies, which usually look at only one type of measure, we consider a portfolio of options: an international "crash" emissions reduction programme, drawing greenhouse gases from the atmosphere, "emergency cooling" through influencing the radiative balance of the atmosphere, and finally adaptation options beyond those considered seriously today.

We use four sets of criteria to assess these options: effectiveness, feasibility, earth system risks, and socio-economic and governance implications. When confronted with extreme climate change, political leaders will have to decide on the choice or mix of "emergency" measures. Research can ensure that such decisions are based on sound and timely scientific information. If, through concerted international efforts to mitigate greenhouse emissions, low stabilization levels could be reached, such emergency decisions may never have to be made. However, research for some form of a "plan B" may be warranted, focusing on those options that combine potential effectiveness and feasibility with limited environmental and political risks.

The role of international transportation sectors in climate stabilization

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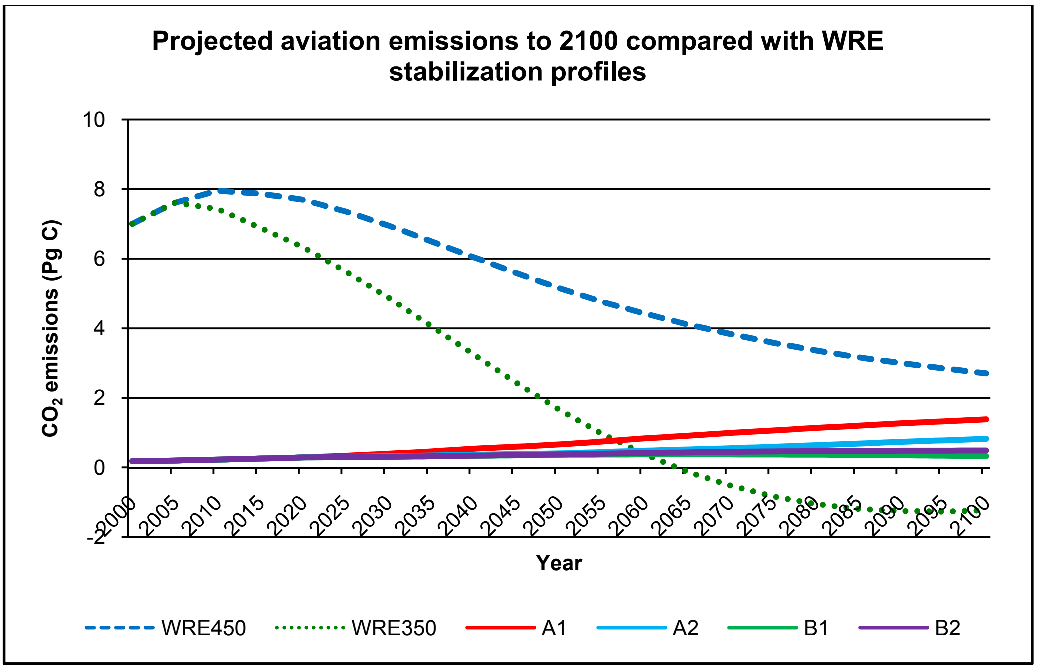
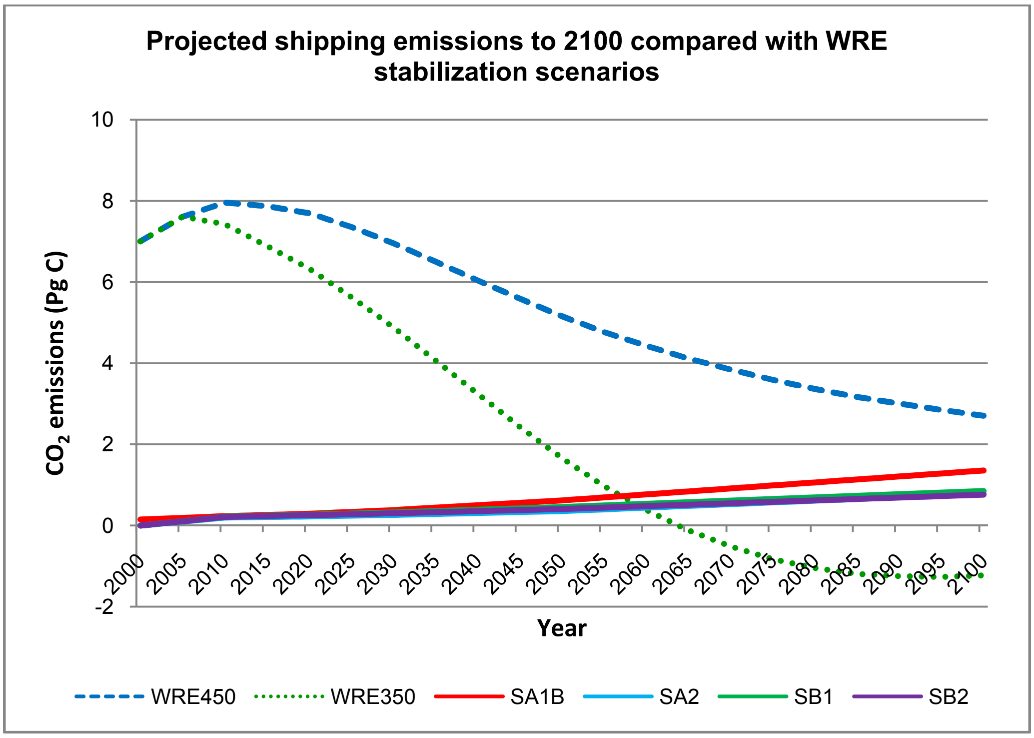
The set of stabilization scenarios in current usage (e.g. WRE [1] and GGI [2]) define emissions trajectories over the 21st century that are needed in order to either achieve CO_2 concentration stabilization levels in the atmosphere (e.g. 450 ppm), or some statistical probability of not exceeding a global average temperature increase over the pre-industrial period (e.g. 2 °C). International transport emissions of CO_2 have been increasing rapidly over the past few decades, particularly from international aviation and shipping which currently represent 2.5 and 3.3% of global CO_2 emissions, respectively, and updated projections of emissions from these sectors, based on SRES-type assumptions, indicate strong increases by 2050 [3, 4]. In order to examine the potential role of international transportation within climate stabilization, we use a climate response model, tailored to account for the CO_2 and non-CO_2 effects of aviation and shipping [3,5,6,7]. A range of SRES emissions to 2100 are used to illustrate how much these projected emissions from aviation and shipping will 'consume' of global carbon budgets under various stabilization assumptions. This will help guide thinking over what sort of emissions expectations the sectors might have, and the reductions via various technology, operational and market-based instruments that might be necessary.

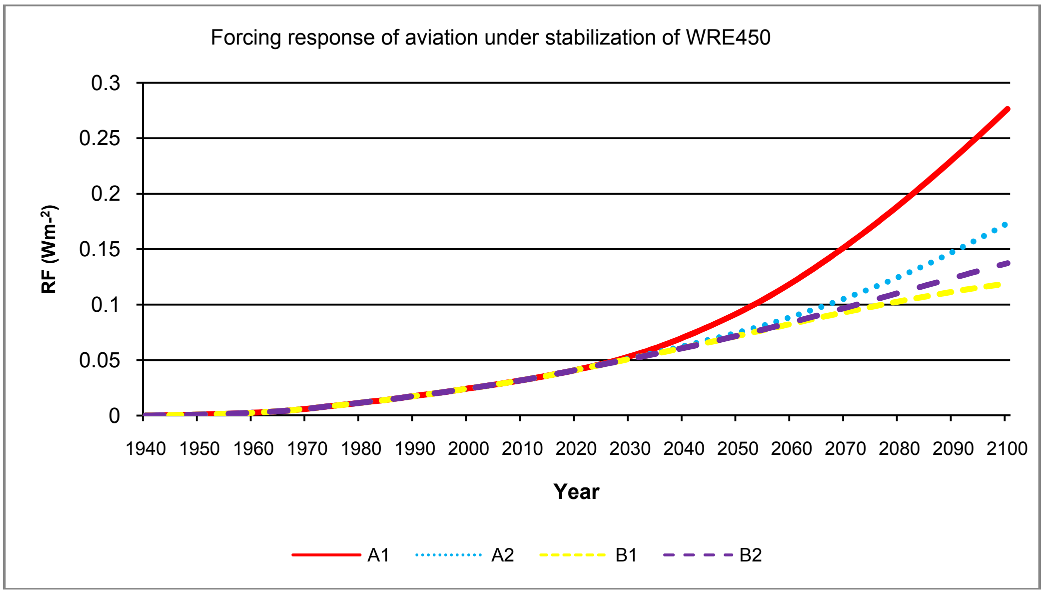
From previous preliminary work, we have shown that aviation could consume a disproportionately large fraction of global emissions, CO_2 concentrations and temperature response, if the expectation is that aviation continues to grow at expected rates to 2050 [5]. Comparing aviation emissions under climate stabilization policies, the CO_2 emissions of 4 aviation scenarios (based upon storyline assumptions generated from data taken from the European Commission's 6th Framework Project QUANTIFY whereby SRES-based scenarios were developed in a consistent manner for the whole transport sector) [8] were plotted with the emissions profiles of the WRE450 and WRE350 stabilization scenarios (see below).

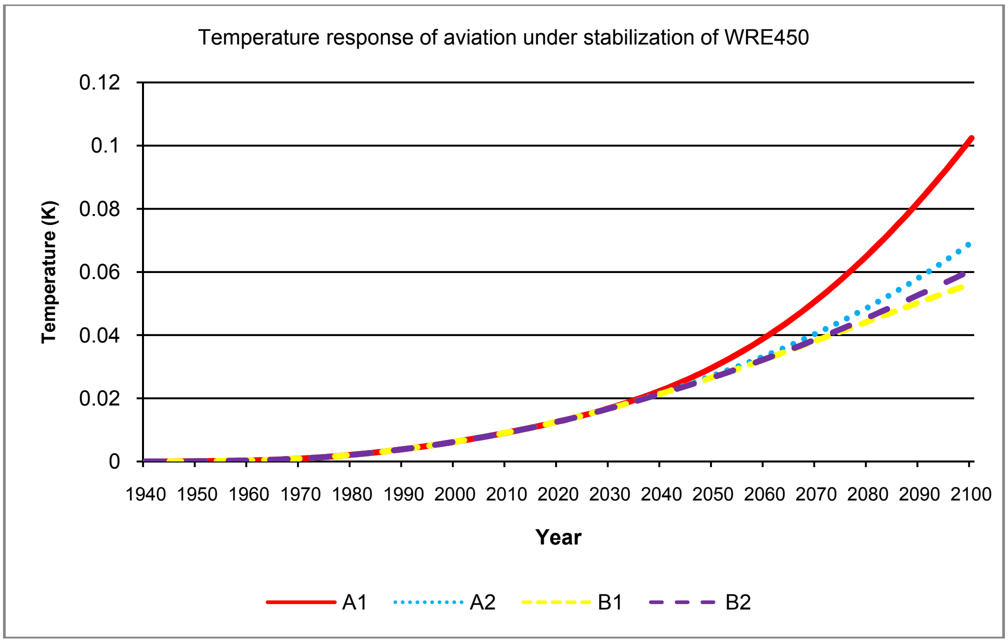


The graph demonstrates that the emissions from the aviation sector will be taking an increasingly significant proportion of the emissions under stabilization at 450ppmv, and under 350ppmv. The outlook is clearly unsustainable as there is the requirement for negative emissions and aviation's emissions are set to continue to increase. Consequently, if aviation emissions were to take the path the scenarios project, and if climate policies are based on an even more stringent stabilization target than 450ppmv, then there is a clear incompatibility. A similar outlook has also been shown to be the case for shipping, as shown below.



To further investigate aviation's climate impact, the forcing and temperature response of aviation CO$_2$ emissions under climate stabilization at 450ppmv was evaluated. The emissions for the 4 scenarios were run in LinClim, a linear climate response model [9]. See below:





The plots demonstrate that the aviation industry will have an increasing impact on the climate (one which varies depending upon the emissions pathway the industry takes).

It is important to note that the stabilization scenarios do not prescribe where emissions reductions must come from to meet the stabilization of atmospheric CO_2; rather they demonstrate what emissions reductions would be required to do so. If the principle of stabilization is to continue to be used as a basis of climate policies, then it will be important to address where the emissions reductions will come from, and to what extent.

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Avoiding a 4+°C World: A Challenge for Democracy

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1. Introduction

Climate change is an emblematic example of how humankind is now influencing the workings and dynamics of the planetary machinery. While the study of such an "anthropogenic drift" of Earth System is grounded in natural sciences, social sciences have highlighted critical issues regarding its human dimensions. Yet I am not sure that some threats to democracy are not underexplored when coming to the dénouements of the dramas arising from this human-environment interaction.

2. The features of the "4+°C carbon equation"

Climate science suggests a 97-99 % chance of not exceeding a warming of 4°C relative to the pre-industrial for a stock of greenhouse gases stabilised at 450 ppm CO2e (Wigley and Raper, 2001; Murphy et al., 2004). If some studies are more pessimistic (see Meinshausen, 2006), there is for Stern (2007, p.333) 'a very high chance of staying below 4°C' at 450ppm CO2e'. Yet stabilisation at 450ppm CO2e is likely 'to be very difficult and costly' (Stern, 2007, p.338). On the one hand the stock of greenhouse gases in the atmosphere 'is already at 430 ppm CO2e and currently rising at roughly 2.5 ppm every year' (Stern, 2007, p.219). On the other hand, there is 'high agreement and much evidence that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades' (IPCC, 2007, p.7).

An illustrative emissions path to stabilise at 450 ppm CO2e without overshooting is that global emissions would peak in 2010 and then fall at some 7% per year, reaching 70% below 2005 values by 2050 (Stern, 2007, p. 227). This result is of course indicative but provides a crucial illustration of the scale of the challenge: emissions should peak within the very next few years with massive decarbonisation of the global economy from thereafter. According to Stern (2007, p. 234), even if emissions from OECD, Russian Federation and Eastern European countries could be reduced to zero in 2050, the rest of the world would still need to cut emissions by almost 80% from BAU to stabilise at 450 ppm CO2e! If carbon sinks were to weaken, future emissions would need to be cut even more rapidly…

So hitting 450ppm CO2e appears very difficult to achieve. Edenhofer et al. (2006) point out that some of the models simply cannot find a way to achieve this. For Anderson and Bows (2008), 'it is increasingly unlikely that any global agreement will deliver the radical reversal in emission trends required for stabilization at 450ppmv carbon dioxide equivalent (CO_2e)'. Overshooting paths are an option, but they are likely to involve greater risks, and assuming that any overshoot could be clawed back it would be unwise. This suggests that the timing and scale of the necessary mitigation are beyond anything we have been prepared to face.

3. We are racing to the brink of an abyss

We know that a catastrophe is about to happen regarding climate change, but incredulity prevents us from taking action. We face an ‘impossibility of believing that the worst is going to occur’, Dupuy (2009) says. This is striking when considering successive alarming reports of the IPCC, which include for now more than a decade the best available (yet uncertain) scientific knowledge. This paradox may be a consequence of either cognition or metaphysics.

A first cognitive example deals with discounting and preference reversals. Evidence suggests that people repeatedly prefer small rewards arriving soon to larger rewards arriving later, even though the constant choice of the latter would maximize their overall gain, and exhibit inconsistent behaviour over time (impatience in the short term, patience in the long run) (Fehr, 2002). This provides a possible explanation for why we fail to act in time to prevent foreseeable catastrophes. A second cognitive example involves misconceptions of climate dynamics. Sterman (2008) shows how even highly educated students exhibit widespread misunderstanding of the laws of physics, presuming wrongly that climate change can be reversed should harm become evident. Such a belief (implying that a bathtub filled faster than it drains will never overflow) could explain procrastination and low support to mitigation.

A more philosophical ground involves the ontological weakness of the catastrophe in the future. Dupuy (2009) suggests that even when we know what is likely to occur the catastrophe is not credible because our current implicit metaphysics of temporality leads to a conception of the future as unreal. He draws upon Bergson to explain the paradox that something can appear ‘at one and the same time as probable and as impossible’ and claims that the catastrophe is ‘characterized by a temporality that is in some sense inverted. As an event bursting forth out of nothing, the catastrophe becomes possible only by making itself possible while becoming real.’ In the words of Sartre: ‘The Future is not, it is possibilised’. Regarding climate change, it turns out that this instinctive metaphysics of temporality could well be the major stumbling stone to the mitigation of greenhouse gases.

These two features suggest that neither scientific evidence nor unprecedented levels of awareness will necessarily result in action to preclude climate change. As a consequence, there is *a fortiori* no reason for any mitigation to be democratic-driven.

4. A tale of two possible threats to democracy

I have reframed the challenge of avoiding a 4+°C climate change by focusing on two salient issues, namely the laws of physics and some features of our human condition. I shall now sketch two authoritarian scenarios of climate change mitigation drawing upon Jonas (1984).

A first scenario involves an arbitrative delineation between (assumed legitimate) needs and (assumed illegitimate) desires along the lines of a strictly normative definition of sustainability by experts or policy-makers. That is to say that an extreme form of rationing could for instance be decreed under some ‘benevolent tyranny’. A government deciding to turn to drastic wartime-style rationing to fight climate change could materialise such a scenario. For instance, and although this idea would certainly give rise to resistance and social disorders, people could become rationed to some quantity of meat and milk a week. Beyond the albeit necessary need to compromise in the pursuit of superior values and common good, arbitrary moves like these could involve stringent reductions in liberty and freedom within liberal democracies, without proper justification nor legitimacy.

Another authoritarian scenario involves an (in this way much less Jonassian) immoderate runaway towards massive technological fixes for climate change. Various schemes to control climate have been proposed to offset global warming by fertilizing the oceans with iron; brightening clouds over the marine atmospheric boundary layer with reflective sea-salt aerosols; spreading sulphur dioxide in the stratosphere to reflect away solar energy or even building a sunscreen in space... As emissions of greenhouse gases continue to rise, there is a growing interest in such technologies supposed to provide 'silver bullets' to avoid catastrophic climate change. Obviously, it is not clear which environmental impacts these options might have (all of them would have side effects that probably cannot be anticipated). Yet we also should wonder if adopting any of them could ever be politically acceptable. That is to say a hubris-inspired radical technocracy or unilateral geo-engineering initiatives change could *de facto* rule out democracy and politics in fighting climate.

Of course, these two scenarios are speculative. Yet Jonas (1984) suggests that some authoritarian form of power would be less ill-equipped than democracy under dire urgencies such as the "Perfect Storm" of climate change. And it may be that some 'enlightened' people might soon get desperate enough to consider seriously the former or the latter option.

5. Conclusion

Howsoever urgent may be the need to tackle climate change, my point is that we have to find a way to do it without sacrificing democracy. The opposite option would be a dangerous example of what I call an 'intangible threat' of climate change.
Firstly, we should perhaps set aside delusions of blind faith in 'techno-fixes' and realise that the most sensible and cost effective option is certainly to cut emissions. Secondly we should overtake the diagnosis of Jonas (1984) that democracy structurally lack responsibility from the conjunction of the 'hedonism' of modern culture and the so-called free market forces. What we have to do is to make use of a powerful weapon of democracy: the tax system. Introducing carbon prices with a tax embodied on greenhouse gases emissions is a perfect example of what modern democracies should handle. We have to take this gamble.

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Greenhouse Gas Contributions and Mitigation Potential of Agriculture: Creating Incentives within the Existing Carbon Trading Agreements

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Agriculture is one of the major sources of greenhouse gases (GHGs) emissions. In 2005, it accounted for 10-12% of total global emissions (Smith et al. 2008). If indirect emissions are also taken into consideration, agriculture accounts for somewhere between 17 and 32% of all global human-induced GHG emissions (Bellarby et al. 2008). An interesting aspect of GHG emissions from agriculture is that approximately 80 percent of total emissions from agriculture, including deforestation, are from developing countries (World Bank 2008a). Agriculture accounts for 13% of total GHG emissions in Africa, 14% in East Asia, 13% in East and Central Asia, 20% in Latin America, and 26 % in South Asia (World Bank 2008b). What makes GHG emissions from agriculture troubling is the fact that these emissions have been rising rapidly. From 1990 to 2005, methane (CH_4) and nitrous oxide (N_2O) emissions from agriculture sector increased by 17% globally. Due to the increased use of fertilizers in agriculture and livestock, Food and Agriculture Organization estimates increase in N_2O emission up to 35-60% and CH_4 emissions up to 60% by 2030.

As emissions from agriculture mostly originate from the developing world, there is a real opportunity to contain the rapid growth in GHG emissions from agriculture with improved management practices. However, achieving this meaningful GHG reduction without jeopardizing livelihood and food security of the poor is a real challenge. Agriculture cannot only be regarded as the sector with huge GHG mitigation potential because it is also the sector on which livelihood and food security of the millions of poor in the developing world is dependent upon. For the rural poor that make up approximately 70% of the World's poor, agriculture is a major source of income and sustenance (World Bank 2003). It accounts for approximately 70% of full-time employment in Africa (Cook 2009). Sixty percent of the labor force in South Asia is dependent on agriculture (World Bank 2008b).

Given such a high dependence on agriculture, motivating resource-poor smallholder farmers in the developing countries to adopt management practices, which may require substantial deviation from their current practices, is not going to be easy. At least not till the long-term guarantee of sustained benefits that will out-weigh their current gains are clear. Past evidence show that resource users invest in practices that increase carbon pools only when benefits exceed alternative use of their land, labor, and capital (Franzel 1999).

There are many agricultural practices that can potentially increase carbon pool and mitigate GHG emissions from agriculture. Among them, the most significant include: cropland and pasture management, restoration or degraded lands, livestock management and manure management.

1. Cropland and pasture Management

The total carbon (C) sequestration potential of the world cropland is about 50% of annual emission by deforestation and other agricultural activities (Lal and Bruce 1999).

2. Livestock and Manure Management

Livestock contribute to global warming through emissions of CH_4. With increase in population, the demand for livestock is going to increase in the coming decades. The growth in livestock also means an increase in methane emissions. If CH_4 emission is allowed to increase in direct proportion to the increase in the numbers of livestock, livestock-related methane emissions will go up to 60% by 2030. With the rapid increase in judicious use of nitrogen fertilizer in developing countries, N_2O emissions from agriculture are projected to increase up to 35-60% by 2030 (FAO 2003).

3. Restoration of degraded lands

Land degradation is a global problem. It is highly variable and discontinuous and could result from different causes such as excessive disturbance, erosion, organic matter loss, salinization, acidification crusting and structural decline, and pollution and contamination (Mortimore 1998; Foley et al. 2005; Lal 2008). Restoration of degraded lands is crucial in terms of achieving the real GHG emission reduction potential. The restoration of 100 million ha of degraded crop lands in different eco-regions through conversion to biofuel production could alone lead to below ground C sequestration of 0.025 Pg C/yr (Lal and Bruce 1999).

Benefits of Agricultural Mitigation

Even though the global technical potential of GHG mitigation in agriculture is estimated to be somewhere between 4500 and 6000 MtCO2- eq/yr by 2030 (Caldeira et al. 2004; Smith et al. 2008), social, economic, technical, and institutional barriers make it difficult to realize the estimated potential. Lack of capital assets makes it extremely hard for resource-poor smallholder farmers to participate in soil carbon projects. Most of the smallholder farmers have very little or no education, no investment or savings, no formal property rights, and often have limited social networks and institutional access. Some of the barriers that need to be eased in order for soil carbon projects to make the real difference in terms of GHG mitigation are: (a) high start-up and transaction costs (b) land tenure.

(a) High start-up and transaction costs

The transaction cost has a substantial effect on participation in carbon contracts (Antle and Stoorvogel 2009). High start-up and transaction costs associated with small scale soil carbon projects make these projects really unattractive to the resource-poor smallholder farmers. As the amount of money that farmers receives will be the market price less the brokerage cost, the money that poor smallholder farmers may receive for participating in soil carbon projects in most cases may not outweigh the costs incurred. For example, the brokerage costs of crop insurance alone could amount to 25% of the market price if it requires grouping of many farmers and sold to one insurance agent (Smith et al. 2008).

(b) Land Tenure Issues

In many poor developing countries, the prospects of implementation of soil carbon projects may actually turn out to be lot more difficult than anticipated because of the pervasiveness of land tenure. The land tenure issue is highly complex as the farmer's perception about it varies considerably from one region to another (Unruh 2008). In the absence of secured land tenure, farmers are less likely to adopt the proposed mitigation practices.

Conclusion

Soil carbon projects should take into consideration the historical relationship of the local population with the land and current trends of management and use. For some farmers, land is more than a means of production. As land is passed on from one generation to another in many developing countries, it is considered a cherished gift. For farmers to abandon the practices, which in some cases may have been practices for generations, some sort of guarantee of sustainability of these projects in the face of ongoing changes in climate, market fluctuations, local land use and population change is necessary.

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The role of sectoral characteristics in designing mechanism for participation of developing countries.

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Introduction

In December 2007 the international community agreed upon the Bali Road Map at the COP in Bali. The road map aims at coming to a comprehensive international agreement on climate change by the end of 2009 and it defined four basic building blocks which guide the negotiations: mitigation, adaptation, financing and technology transfer. On the mitigation side this includes commitments on the side of developed countries (Annex I parties under the Kyoto protocol) but also requires an increasing participation by developing countries (non-Annex I parties under the Kyoto protocol), especially the group of newly industrialized countries. Currently a range of proposals are on the table for involving developing countries more actively. A big group of these has been commonly summarized under the broad concept of 'sectoral approaches'. Various studies have been published on the general concept of such approaches. Yet one of the most important factors, the implications particular approaches will have on certain sectors, has been largely ignored. Due to the diverse characteristics of sectors it is necessary though to take a close look at the suitability of specific approaches to given sectors.

Methodology

In our research we looked at four of the most prominent concepts under the term 'sectoral approach'. In order to evaluate sector specific implications we then applied these approaches to two sectors – the cement and the transport sector. For each concept we developed concrete proposals for a sector specific design. We then evaluated these proposals using widely accepted criterias such as economic efficiency and environmental effectiveness. We paid special attention to the issues of technology transfer and Measurement, Reporting and Verification (MRV) as these are commonly regarded as specially crucial issues for the success of any approach. To give an order of magnitude of the potentially achievable emission reductions we made an attempt to give some first order estimates on the achievable emission reduction potential for each of the four concepts.

Concepts of Sectoral Approaches

According to Watson (Watson et al. 2005) reasons for considering sectoral approaches for the broader involvement of developing countries are broad. For developing countries they are a way of learning by doing as they cover only a few sectors and not all national emissions. Furthermore they address competitiveness concerns of energy intensive, internationally competing industries. The economic activities (and underlying technical processes) that are covered are comparable within and among countries. And last but not least they are based on a realistic evaluation of mitigation potential at a sector level.

Consequently they have played an ever increasing role within the UNFCCC negotiations process. Besides being mentioned in the Bali action roadmap, where "cooperative sectoral approaches and sector-specific actions" were recognised as a possible way for nationally appropriate mitigation actions by non-Annex I countries, various parties have submitted documents expressing their view on sectoral approaches. These include South Korea, China and the EU. This reflects that approaches that are based on sectoral characteristics will play an ever increasing role.

There is a large variety of possible design options. Terminology and the underlying concepts are becoming clearer, but are still often vague and ambiguous. Therefore a transparent classification of the different approaches is necessary. Even small variations in design can have large impact on the evaluation of an approach, for example on environmental impact, distributional effects or simplicity of negotiation. For this reason the following analysis focuses only on the most-discussed approaches. These are also summarised and discussed in Höhne et al. 2008.

We have focused on four approaches. Crucial to the broad concept of *transnational approaches* is the central role of industry in negotiating its design. At the core of the *country-specific crediting approach* is the voluntary commitment of a country to keep emissions of a sector below a certain level (baseline) that is agreed a priori at the international level. (see www.sectoral.org). Under advanced *technology standards* governments commit to achieve certain predefined best available technology (BAT) for new installations and best practice (BP) for existing plants in selected sectors. In the *policy-based approach* developing countries pledge to implement certain policies in a given sector.

Sectoral Characteristics – Transport Sector

The transport sector is highly complex and includes rail, road, navigation and aviation that can be split into freight and passenger transport. In general term and emission-wise it is one of the fastest growing sectors worldwide and reductions potentials are large. The emission reduction measures in the sector can be split into four large groups: efficiency improvements, modal shifts, activity level reduction and reduction in the carbon content of fuels. A first group of emission reduction measures through efficiency improvements and reductions in the carbon content is relatively easily quantifiable and frequently included in mitigation potential studies (see for instance Hoogwijk et al. 2008). A second group of measures within the categories activity level reduction and modal shift can not be easily quantified and are highly sensitive to national circumstances. This later group is more complex to implement and measure, often requires a larger group of actors and may conflict with different interest groups. Yet the emission reduction potential in this later group are large.

Sectoral Characteristics – Industry: Cement Sector

Cement production is a an energy-intensive, homogeneous production process. Geographically the production is highly concentrated, with China being by far the largest cement producer. The amount of relevant options to reduce emissions is with a total of five options manageably small. These are the use of alternative raw materials for clinker production (clinker adaptation), improvement of efficiency of the kiln, fuel switch, a decrease electricity use in grinding and blending as well as an increase in the share of additives to cement other than clinker (clinker cement ratio).

The reduction potential in the sector is relatively well-known. In its Energy technology perspectives report the IEA for instance estimates that adopting best practice in energy efficiency globally at 2005 production levels would result in 322 Mt CO_2 or 15% less emissions (IEA 2008) . Furthermore, due to a the highly concentrated structure of the sector and the existence of a well established international forum, the Sustainable Cement Initiative, methodology development and data gathering are far advanced. Summarizing, the cement sector has a much lower degree of complexity than the transport sector.

Evaluation – Methodology

There are four principal criteria for evaluating environmental policy instruments which are reported in the literature and commonly used to evaluate climate policy approaches (e.g. IPCC 2007). These are: environmental effectiveness, economic efficiency, equity and distributional issues, technical and institutional feasibility**.**

Environmental effectiveness concerns the extent to which the approach can contribute to the global greenhouse gas reduction effort. *Economic efficiency* analyzes whether an approach is cost-effective, referring to the extent, to which a policy can achieve its objective at a minimum cost. *Equity and distributional* evaluates the distributional effects of a policy, including dimensions such as fairness and equity and the aptness of an approach to ensure “common but differentiated responsibilities”. We paid special attention to implications on technology transfer and its utility for developing country participants, as this topic is seen crucial in the climate negotiations (compare Ockwell 2008).*Technical and institutional feasibility* of the approaches in the sectors was regarded with respect to the applicability to the UNFCCC process, while we paid special attention to the issue of monitoring reporting and verification (MRV).

Evaluation Results – Transport Sector

From our evaluation we conclude that a *policy-based approach* is probably best suited for the sector. The reason for choosing this most flexible yet also least concrete approach lies in the complexity of the sector. Hence some of the approaches are only suited for subsectors, while a policy based can adapt to national circumstances and include a large part of the potential emission reductions. Focussing only on subsectors decreases the potential abatement by neglecting modal shift and activity reduction options. Furthermore such an approach allows for the consideration of the sustainable development objectives of the country.

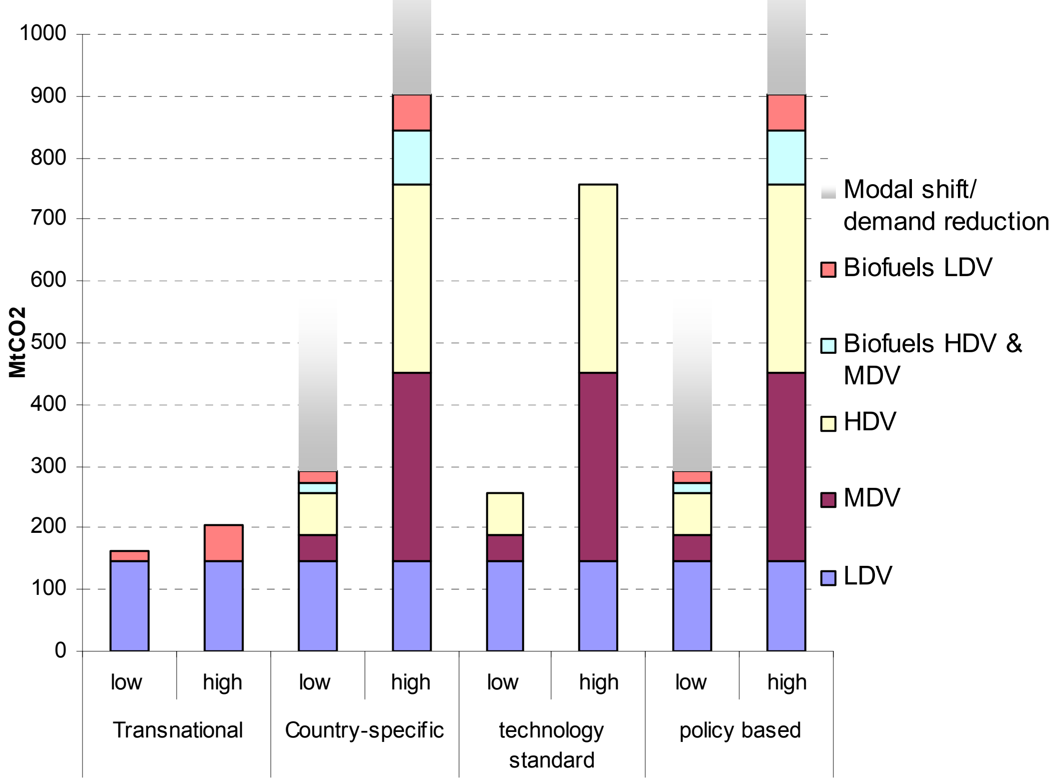

Illustration B Reduction potentials in the transport sector covered by the sectoral approaches (Source: own analysis and Hoogwijk et al. 2008)

Evaluation results - Cement sector

The analysis indicates that for cement the country-specific crediting approach is very likely the best option, since it covers all reduction potentials, enables the consideration of national circumstances and there is a high readiness of the sector regarding methodology and data. Transnational standards could potentially ‘level the playing field’, but cost effectiveness is doubtful and high competitiveness is likely to hamper technology transfer. Technology standards could be an option for less developed countries, not capturing all potentials, but requiring less capacity for negotiation and implementation.

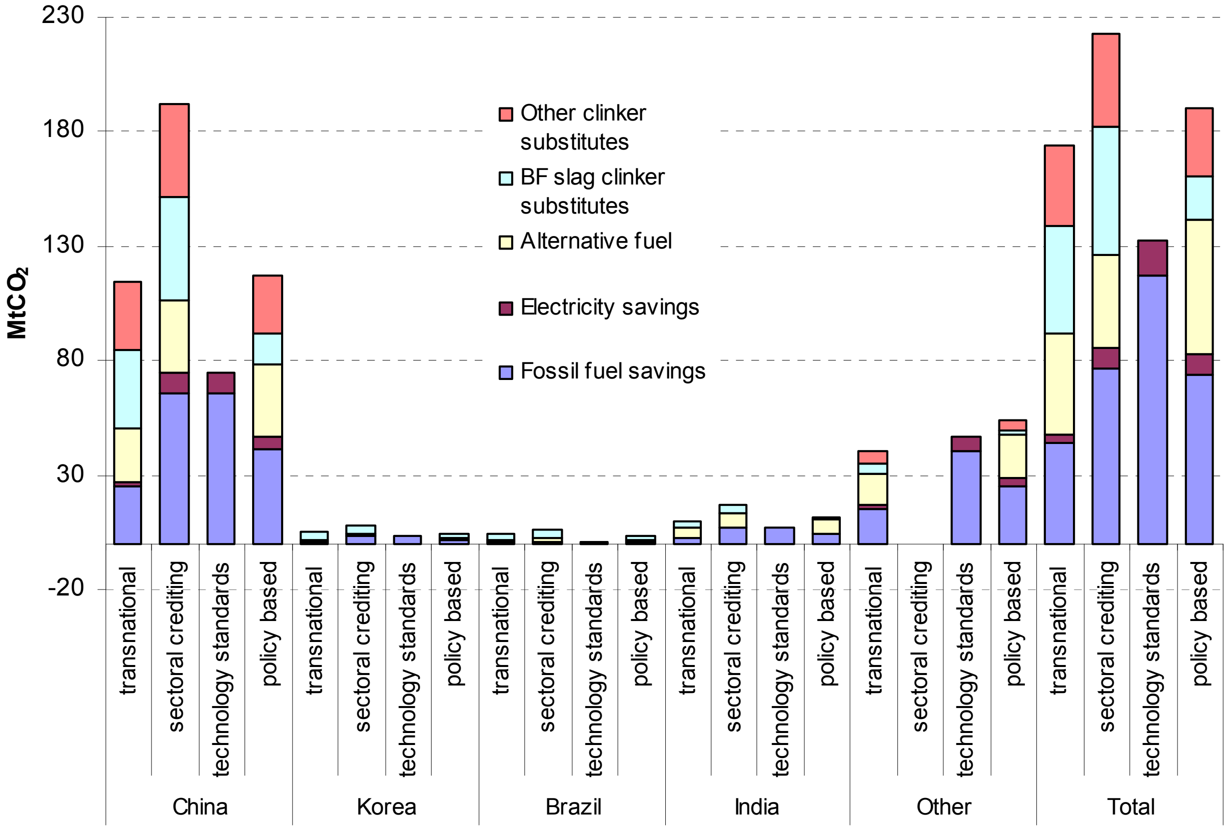

Illustration A Reduction potentials in the cement sector covered by the sectoral approaches (Source: own analysis and IEA/OECD 2008)

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Backcasting for low carbon transport

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[1]*Oxford University, Oxford, United Kingdom,* [2]*Halcrow Group, London, United Kingdom*

1. Introduction

Transport is a major user of carbon-based fuels, and is increasingly being highlighted as the sector which contributes least to CO2 emission reduction targets. This paper reports on the findings of the recent VIBAT (Visioning and Backcasting for Transport) series of studies (www.vibat.org) which explore the options of the transport sector in reducing CO2 emissions in various contexts. The case studies discussed are in Europe (London, UK) and Asia (Delhi, India). The analysis considers the common objectives for transport CO2 reduction, but the very different baselines, targets and pathways towards sustainability.

Strategic direction:

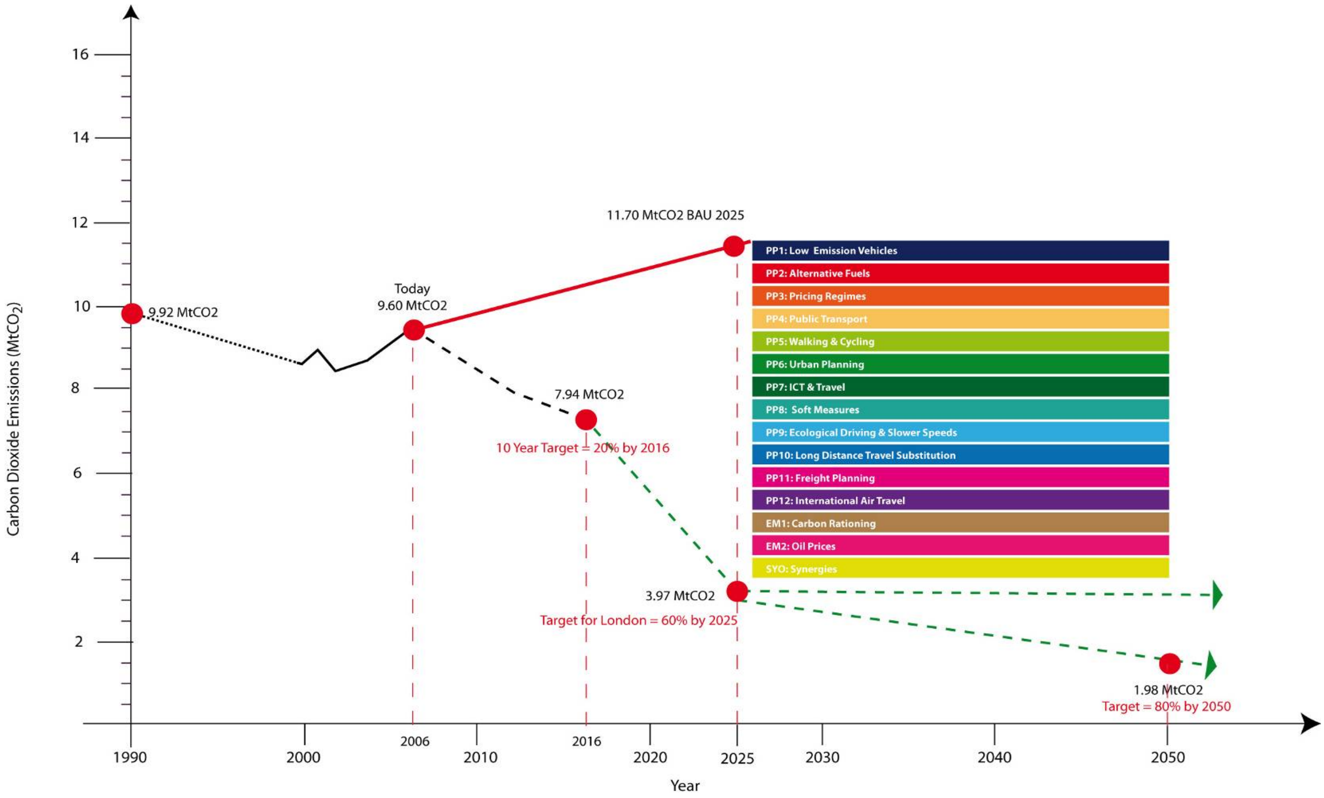
- A peak in emissions within 10 years
- Global reduction in CO2 emissions of 50% from 1990 levels (from over 50 GtCO2e now – to 20 GtCO2e)
- Developed countries: an 80% reduction in CO2 emissions on 1990 levels – to 2 tonnes per capita per annum – by 2050 (UK has this as a target – Climate Change Act 2008)
- Say transport accounts for 25% of CO2 emissions – aiming for 0.5 tonnes per capita within transport
- Issues: An equitable target (and budget?) for all cities/jurisdictions? With some tradeable element?

2. Case Study: London

Objective: mapping the pathways towards a 60% reduction in CO2 emissions in the transport sector in London by 2030 and 80% by 2050

- A range of policy packages
- Level of application
- Target achieved/ achievable?

Figure 1. Baseline and Projection (London Transport Sector)



Potential Scenarios

- **BAU 2030:** This future is an extension of existing trends over the next 20 years – some investment in public transport, limited change in the efficiency of the car stock and in the use of alternative fuels, but there is no coherent strategy for accelerated change.
- **Scenario 1: Lower carbon driving:** Seeks an approx. 40% reduction in transport CO2 emissions, on 1990 levels. However, this is reliant on an ambitious implementation of technological measures (low emission motor vehicles and alternative fuels - 95gCO2/km).
- **Scenario 2: More active travel:** Seeks an approx. 40% reduction in transport CO2 emissions, on 1990 levels. However, it is less optimistic about the potential implementation of low carbon vehicles and relies more on public transport, walking and cycling and smarter choice investment.
- **Scenario 3: Sustainable travel:** This scenario combines the best technological and behavioural application of scenarios 1 and 2 to deliver an approx. 80% reduction in transport CO2 emissions, on 1990 levels. It is very optimistic about levels of application of policy levers.

Figure 2. Passenger Km (London)

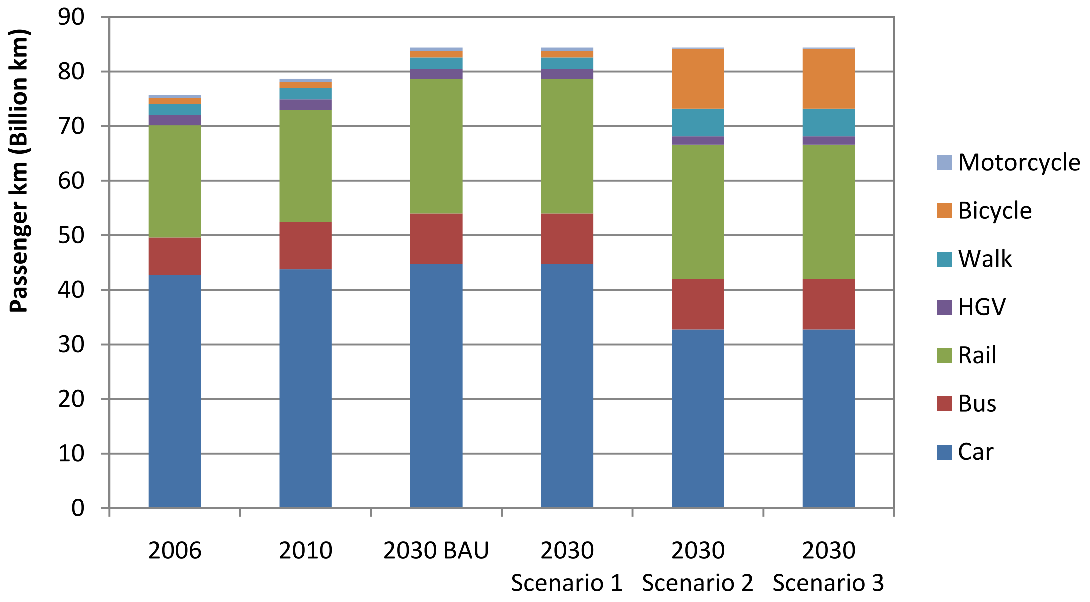
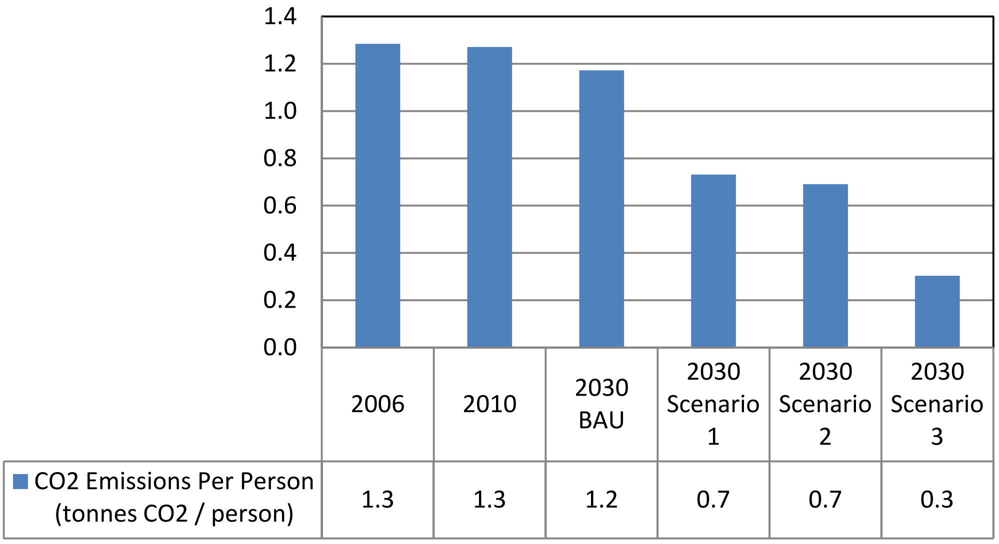


Figure 3. Transport Per Capita CO2 Emissions (London)



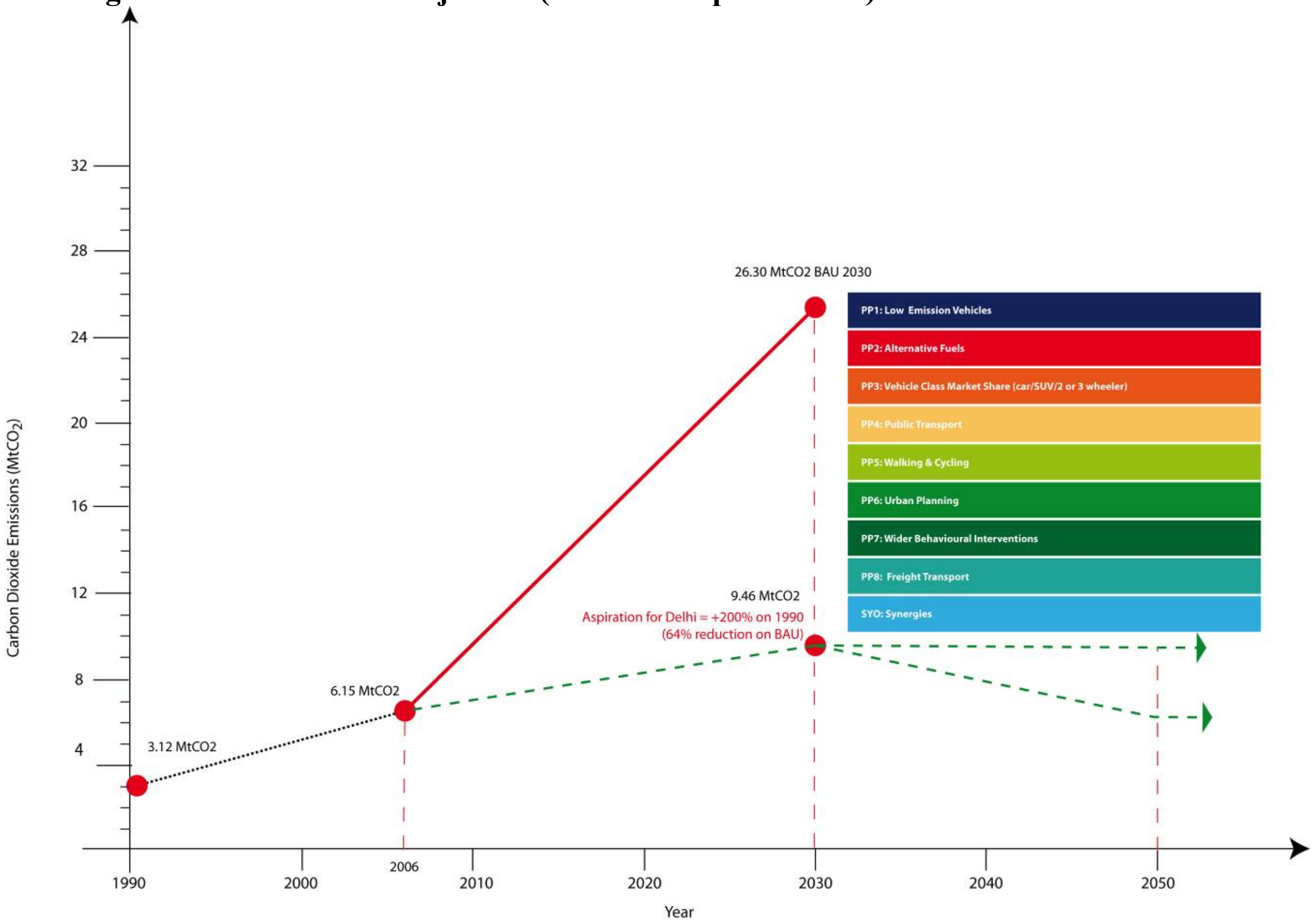
	2006	2010	2030 BAU	2030 Scenario 1	2030 Scenario 2	2030 Scenario 3
CO2 Emissions Per Person (tonnes CO2 / person)	1.3	1.3	1.2	0.7	0.7	0.3

3. Case Study: Delhi

Objective: mapping the pathways towards reducing the projected growth in CO2 emissions in the transport sector in Delhi by 2030 and 2050

- A range of policy packages
- Level of application
- Target achieved/ achievable?

Figure 4. Baseline and Projection (Delhi Transport Sector)



Potential Scenarios

- **BAU 2030:** This future is an extension of existing trends over the next 20 years – some investment in public transport, limited change in the efficiency of the car stock and in the use of alternative fuels. Large projected growth in traffic.
- **Scenario 1: Lower carbon driving:** A strong and successful push on technological innovation, including low emission vehicles, alternative fuels and smaller vehicle types. Seeks an approx. 500% increase in CO2 emissions on 1990 levels (BAU is 700% increase)
- **Scenario 2: More active travel:** Less optimistic about the potential implementation of low carbon vehicles and relies more on public transport, walking and cycling investment and behavioural measures. Seeks an approx. 300% increase in CO2 emissions on 1990 levels (BAU is 700% increase)
- **Scenario 3: Sustainable travel:** This scenario combines the best technological and behavioural application of scenarios 1 and 2 to deliver an approx. 200% increase in transport CO2 emissions, on 1990 levels. It is very optimistic about levels of application of policy levers.

Figure 5. Passenger Km (Delhi)

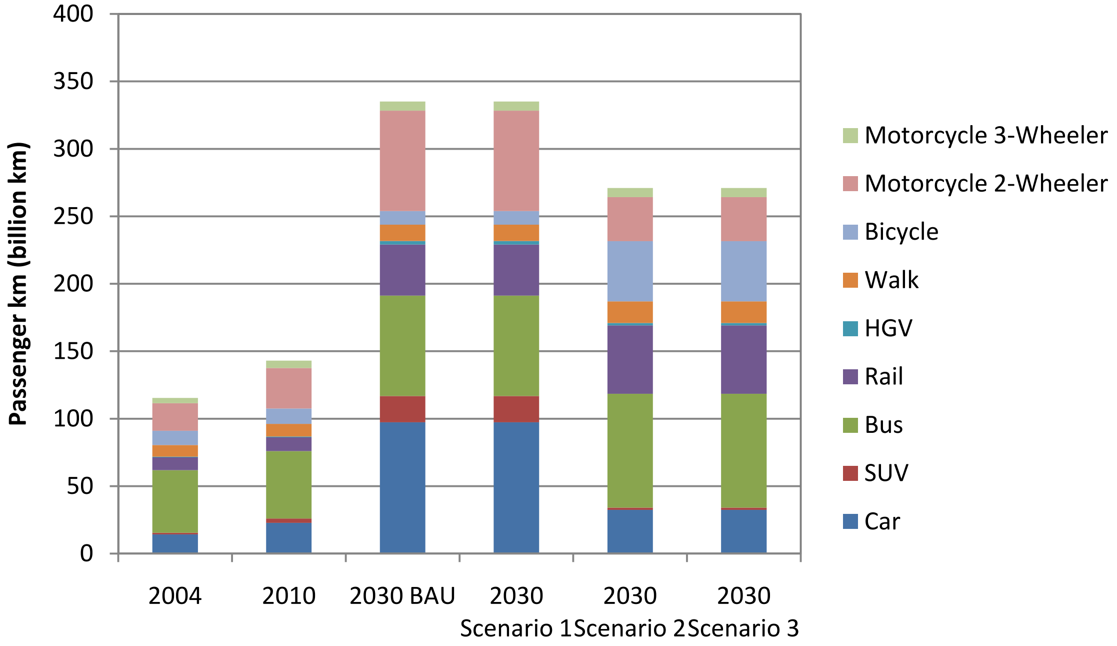
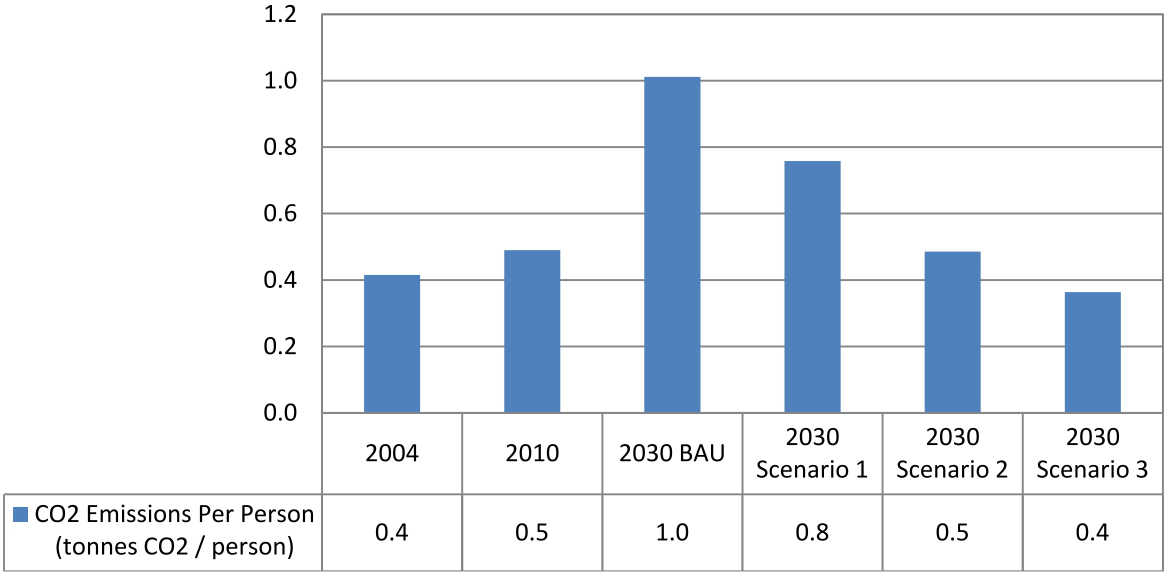


Figure 6. Transport Per Capita CO2 Emissions (Delhi)



4. Conclusions

Different packages of measures are selected for each city consistent with equitable [and deep] emission reduction objectives. London can deliver deep tonne per person reductions on current transport CO2 emission levels; Delhi can break the huge projected rises in transport CO2 emissions. A backcasting study approach is used, testing the likely impacts of alternative images of the future for 2030 and 2050. A transport and carbon simulation model (TC-SIM) is also developed for London. Within this, users are able to consider a series of potential policy packages - low emission vehicles, alternative fuels, pricing regimes, public transport, walking and cycling, etc - and select variable levels of application to help achieve strategic CO2 emission reduction targets.

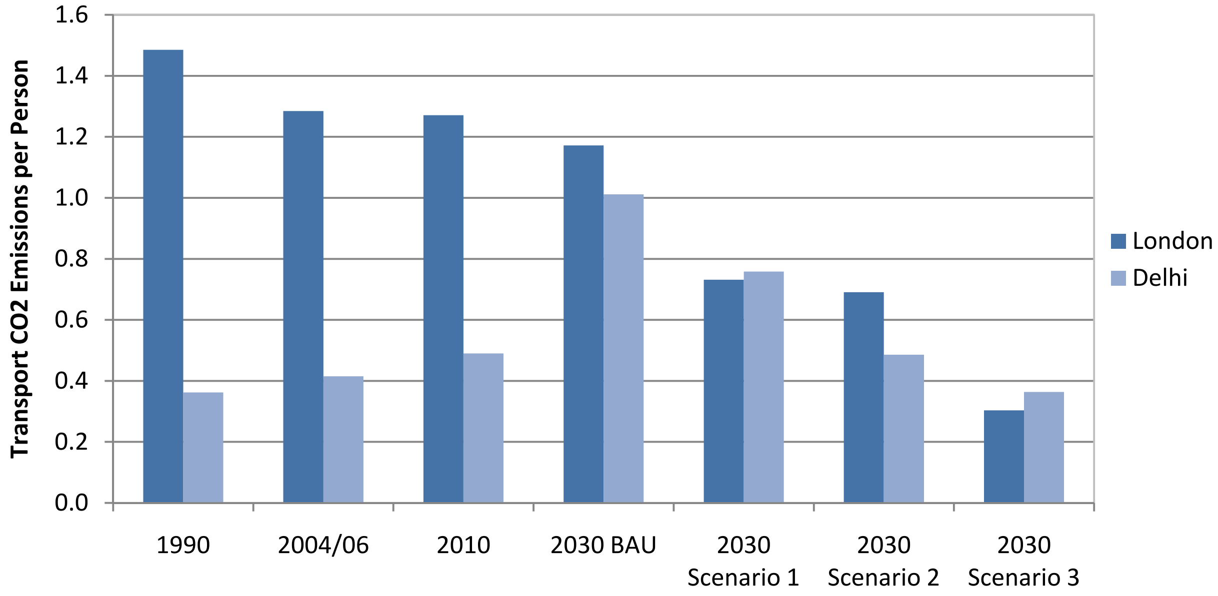
In Practice

- Within UK and elsewhere: much debate – but little action – the transport sector needs to URGENTLY ACCELERATE its efforts
- Some cities, such as London, providing a lead.
- [60-80%] [per capita] target is very ambitious: little understanding of pathways to achieve these

Wider Contexts

- LTP3 and transport/urban strategy preparation
- National and city contributions to global agreements
- Enhancing discussion and ownership – involving decision-makers and the public (simulation gaming/modelling)

Figure 7. Different Contexts; Common Futures



Optimised future policy packages are defined for 2030 and 2050 and a working methodology that can be applied to wider cities. A deep reduction in transport CO2 emissions is theoretically possible in all cities, yet practically very difficult to achieve. The main perceived problem is in engendering an interest in the public to change consumer purchases and behaviours.

The huge challenge is to map out and widen the debate on potential pathways, enabling a level of consumer and behavioural change consistent with strategic aspiration.

UK marginal abatement cost curves for the agriculture and land use, land-use change and forestry sectors out to 2022, with qualitative analysis of options to 2050

Dominic Moran[1], Michael MacLeod[1], Eileen Wall[1], Very Eory[1], Guillaume Pajot[2], Robin Matthews[2], Alistair McVittie[1], Andrew Barnes[1], Bob Rees[1], Andrew Moxey[3], Adrian Williams[4], Peter Smith[5]

[1]Scottish Agricultural College, Edinburgh, United Kingdom, [2]The Macaulay Institute, Aberdeen, United Kingdom, [3]Parento Consulting, Edinburgh, United Kingdom, [4]Cranfield University, Cranfield, United Kingdom, [5]Aberdeen University, Aberdeen, United Kingdom

Greenhouse gas (GHG) emissions from agriculture, land use and land use change and forestry (ALMF) are a significant percentage of UK emissions. The sector has been relatively neglected in discussions on both mitigation and adaptation. The UK Government is committed to ambitious targets for reducing emissions and all significant sources are coming under increasing scrutiny. Emissions reductions need to be achieved in an economically efficient manner, i.e. measures that provide the most cost-effective ways of reducing emissions should be implemented first. In order to identify cost-effective measures, and the potential emissions reductions from ALMF, marginal abatement cost curves (MACC's) have been developed for the Committee on Climate Change (CCC). This paper describes the methodology used in developing MACC's and highlights the difficulties faced, and the strategies adopted to overcome them. We discuss the abatement potentials identified by the MACC exercise and outline the relevant technologies required to deliver them by 2050. This discussion also highlights the relevant policy instruments. The MACC approach provides one template to demonstrate how an emissions budget can be derived for a biologically complex sector.

Landscape responses to future climate change in glaciated mountains

Jasper Knight, Stephan Harrison

University of Exeter, Exeter, United Kingdom

Glaciers are currently in long-term decline particularly at their climatic limits on mid- and low-latitude mountains. Glacier and permafrost melting are contributing to land surface destabilisation on mountains and in the high-latitudes. Increased frequency of natural hazards (rockfall, landslides, solifluction, mudflows, floods) is a typical paraglacial response to ice retreat in these areas. Important downstream effects include changes in sediment, meltwater and nutrient supply to rivers, floodplains and fronting coasts.

With global warming, glacier retreat is accelerating and larger areas of mountains and high-latitudes are falling under paraglacial process domains as unstable land surfaces are exposed to subaerial erosion. Here we argue that paraglaciation is replacing glaciation as the dominant geomorphological regime of mountain and high-latitude areas, until the start of the next global glaciation. Under global warming, this means that the current phase of enhanced paraglacial sediment supply will be the last for geological time periods. This will play a primary control on sediment and water supply in glaciated catchments, and with implications for natural hazards, biodiversity, agricultural production and coastal erosion.
Under a 4°C warming by 2100, the global distribution and area of glacial and periglacial domains will shrink dramatically. Glaciers in continental interiors will decrease in volume most rapidly due to regional albedo and continentality, with significant negative effects on glacier-fed water supply in central Asia, central America and Africa. Glaciers in coastal mountains will likely persist longer and be most strongly precipitation-limited.

Spatially and temporally variable landscape responses result from nonlinear impacts of climate forcing on sensitive mountain systems. Landscape evolution models do not well-represent glacier and paraglacial landscape responses, or downstream impacts on land surface stability, ecosystems and water resources. Instrumentation of glaciated catchments is needed to monitor paraglacial sediment exhaustion alongside standard monitoring of glacier and permafrost retreat.

Applications of pattern scaling for probabilistic assessment of regional climate impacts

Katja Frieler[1], Ben Poulter[2], Nadine Braun[2], William Hare[1,3], Malte Meinshausen[1]

[1]Potsdam Institute for Climate Impact Research, Potsdam, Germany, [2]Technische Universität Berlin, Berlin, Germany, [3]Climate Analytics, Potsdam, Germany, [4]Swiss Federal Institute for Forest, Snow and Landscape Research, Zürich, Tajikistan

Greenland is one key region in the world with potentially severe climate change impacts (e.g. Lenton et al., 2008). Sea level rise due to increasing loss of the ice mass strongly depends on regional changes in temperature and precipitation. We present a new methodology of getting probabilistic climate change projections taking into account the variability of regional climate patterns, varying from one GCM to another. We show results for Greenland under a 4 degree global warming scenario in comparison to scenarios in which global mean temperature change is limited to 2 degrees – following the climate targets envisaged within the international climate change negotiations.

Based on the whole set of AR4 AOGCM simulations we present a new statistical scaling methodology providing ensemble projections of regional climate change under a four degree global warming. The method utilizes the AOGCM based linear relation between global mean temperature changes and regionally averaged changes in temperature and precipitation. While the linearity of this link function is already established for temperature and to a lesser degree (depending on the region) also for precipitation (Santer et al. 1990; Mitchell et al. 1999; Mitchell, 2003; Solomon et al., 2009), we especially focus on the quantification of the uncertainty of the associated scaling coefficients. Based on a linear mixed effects model (e.g. Bates and Pinheiro, 2001) we estimate ensemble mean scaling coefficients (so called "fixed effects") and separate standard deviations for the inter-model, the inter-scenario and the inter-run variability around them (so called "random effects"). In comparison to other statistical scaling approaches our approach has the following advantages; first, the explicit estimation of the inter-scenario variability especially allows to verify the basic assumption of pattern scaling, that inter-scenario is generally small in comparison to other disturbances - a fact that allows us to calculate regional changes under a global warming of 4 degrees relatively independent of the specific pathway.

And secondly, instead of fitting separate models for the temperature and precipitation data we apply a two-dimensional model. This approach allows us to estimate correlations between the temperature and precipitation component of the random effects. Thus, we explicitly account for the fact that models (scenarios or runs) showing an especially high temperature increase may also show high precipitation increases or vice versa. Multiplying the two-dimensional distribution of the scaling coefficients by a global mean temperature change of 4 (and 2) degrees finally provides a two dimensional uncertainty distribution of regional changes in temperature and precipitation, where both components might be correlated. Taking these correlations into account is especially interesting because many impacts as e.g. changes in the surface mass balance of the Greenland ice sheet critically depend on the interaction of the temperature and precipitation component of climate change: Increasing precipitation may at least partly balance the loss due to increasing temperatures (see below).

Based on the described scaling approach regional warming reaches 5.8 (±1.2) degrees over Greenland when global mean warming is assumed to be 4 degrees. The standard deviation is calculated taking into account the four sources of uncertainty considered here: 1st uncertainty

of the estimated ensemble mean (fixed effect), 2nd inter-model deviations from the ensemble mean, 3rd inter-scenario and 4th inter-run variability of the scaling coefficients. In fact, for Greenland the standard deviation of the inter-scenario variability of the scaling coefficients turns out to be relatively small (0.12) while the standard deviation of the inter-model variability is larger (0.28). Similar results are also found for other regions as for example the Amazon Basin (lat: -15 to 0 degrees; lon: -70 to -50 degrees) where the scaling coefficient for temperature is slightly lower than in Greenland (1.29 in comparison to 1.44) while the inter-scenario variability is very small (0.05) and the inter-model variability reaches 0.21.
The precipitation signal is relatively strong for Greenland where models consistently show increasing precipitation, while overall there is only a slightly positive non significant trend for the Amazon region with models disagreeing with respect to the sign of the coefficient. Temperature and precipitation increases are highly correlated for Greenland: Models showing an especially high temperature increase also show high precipitation increases reflected by a correlation coefficient of 0.88 for the inter-model random effects of both components. That is not a general feature: For the Amazon region the correlation is estimated to negative (-0.65).

Figure 1 and 2 show samples of the bivariate uncertainty distributions of regional climate changes for Greenland under a global warming of 2 and 4 degrees. These samples provide the input for a regional specific impact function based on Gregory et al., 2006. It allows us to calculate changes in sea level rise due to changes in Greenland's surface mass balance in dependence of regionally averaged changes in temperature and precipitation. Their model uses the integrated sum of expected positive degree days, based on yearly averages of temperature, and different degree-day factors (DDFs) for snow and ice to calculate surface melt and the following runoff. It was applied to calculate the change of surface mass balance for a range of regional climate changes ΔT and $\Delta P/P_0$, where changes in surface mass balance are expressed as a contribution to changes in global-average sea level in mm/y. An increasing precipitation produces a negative sea level contribution, because of higher accumulation rates. Increasing temperatures produce a positive contribution, because of accelerated melting rates. The calculations do not account for sea level rise due to dynamical losses which could add to loss in surface mass balance providing significantly higher changes in sea level rise as presently observed (Pachauri and Reisinger, 2007). Figure 1 and Figure 2 include the isolines for different values of sea level rise associated with different levels of regional temperature and precipitation changes. Calculating the fraction of sample points that lie above one of these lines allows to estimate the probability of exceeding certain limits of changes in sea level rise under a global warming of 2 and 4 degrees. The resulting probabilities for exceeding 0 mm/y is in both cases 100%, exceeding 1 mm/y for 4 degrees is 21.95% and 0% in case of 2 degrees. The point where surface mass balance becomes negative corresponds to a sea level rise of 0.62 mm/y (as estimated by Gregory et al., 2006). The exceedance probability for this isoline is equal to zero under a 2 degree global warming and equal to 68.6% in case the case of 4 degrees global warming.

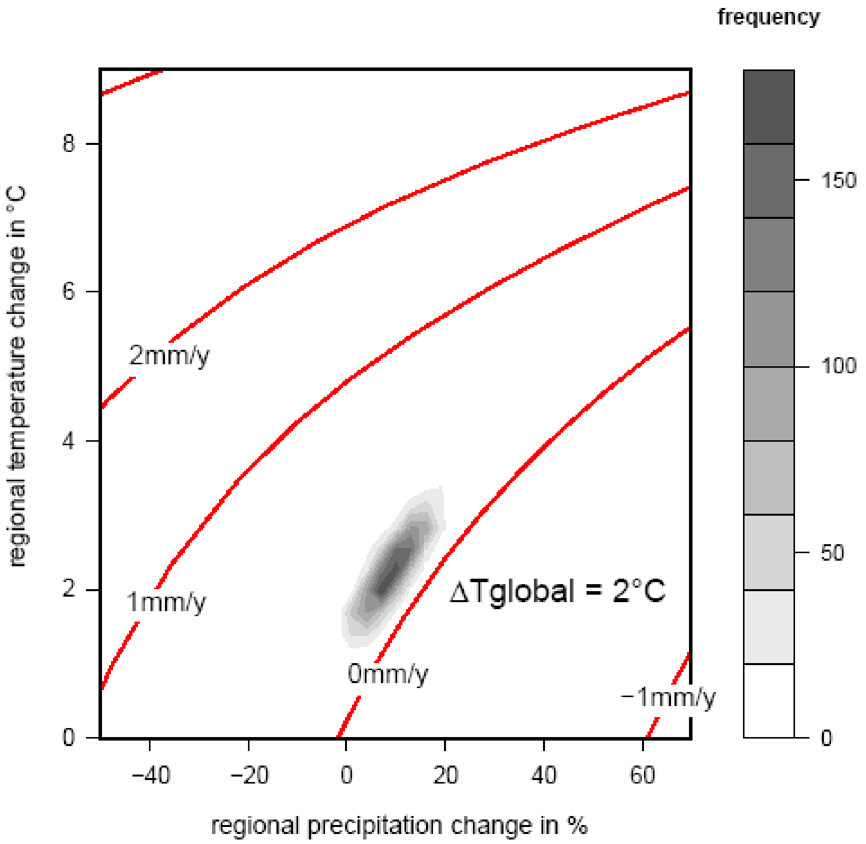


Figure 5: Bi-dimensional uncertainty distribution for regional temperature and precipitation changes (with respect to the reference period 1961-1990) over Greenland under a global warming of 2 °C (above pre-industrial values). Isolines represent changes in sea level rise due to changes in Greenland's surface mass balance.

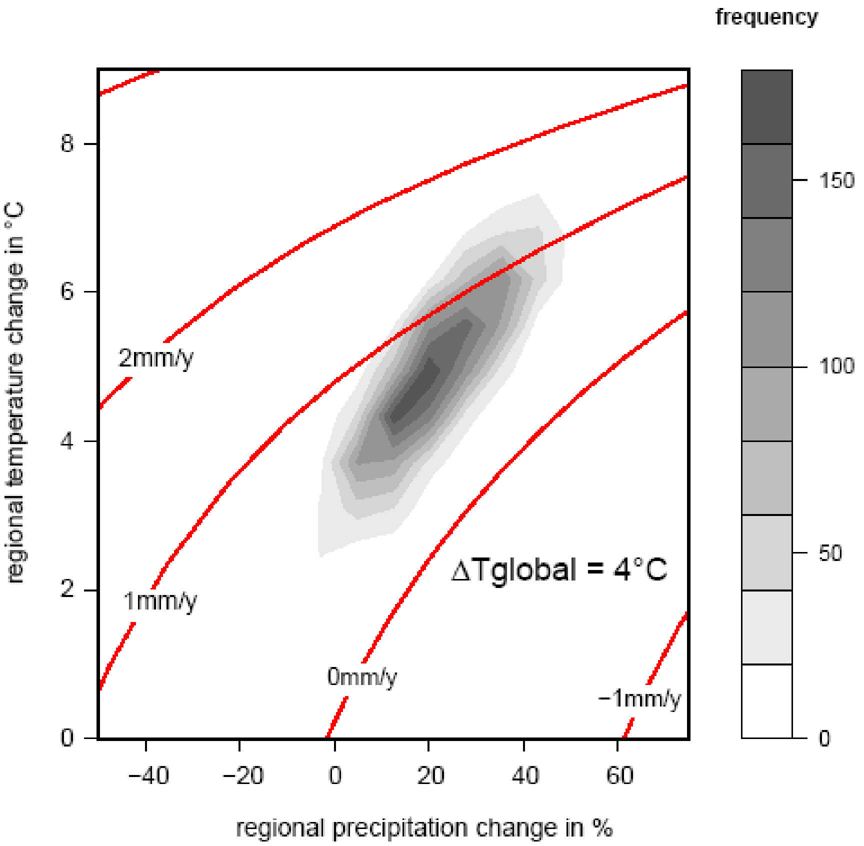


Figure 2: Bi-dimensional uncertainty distribution for regional temperature and precipitation changes (with respect to the reference period 1961-1990) over Greenland under a global warming of 4 °C (above pre-industrial values). Isolines represent changes in sea level rise due to changes in Greenland's surface mass balance.

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&beyond
4degrees

Conference Agenda

4degrees &beyond

International Climate Conference
28-30 September 2009, Oxford, UK

Implications of a global climate change of 4+ degrees
for people, ecosystems and the earth-system

Conference Agenda

Monday 28 September 2009

09:00 – 10:45	Registration and coffee
Session 1	Conference Opening Chair: Dr Mark New
11:00 – 11:15	Welcome
11:15 - 11:45	Keynote Address: Terra quasi-incognita: beyond the 2°C line Prof John Schellnhuber, Potsdam Institute for Climate Impact Research, Germany
11:45 - 12:10	4 degrees of global warming: regional patterns and timing Dr Richard Betts, Met Office Hadley Centre, UK
12:10 - 12:35	Beyond 4°C: impacts across the global scale Prof Nigel Arnell, University of Reading, UK
12:35 - 12:50	Questions
12:50 - 14:00	Lunch: St Anne's Dining Hall Room check-in for residential delegates
Session 2	Agriculture, Food and Water Security 1 Chair: Dr Richard Betts
14:00 - 14:25	Keynote Address: 4 degrees plus: what might this mean for agriculture in sub-Saharan Africa? Dr Philip Thornton, International Livestock Research Institute, Nairobi
14:25 - 14:45	Adapting African food systems to a 4 degree world Dr Polly Ericksen, University of Oxford, UK
14:45 - 15:05	What would happen to barley production in Finland if the global temperature increases above 4°C? A model based assessment Dr Reimund Rötter, MTT Agrifood Research, Finland
15:05 - 15:25	4+°C: A drastic reduction in the renewable energy potential of sugarcane Mr Rasack Nayamuth, Mauritius Sugar Industry Research Institute, Mauritius
15:25 - 15:45	Questions
15:45 - 16:25	Coffee and Poster Session 1: Hartland Room

Session 3	Agriculture, Food and Water Security 2 Chair: Prof Nigel Arnell
16:25 - 16:45	Crop yield and adaptation under climate change: implications of warming Dr Andrew Challinor, University of Leeds, UK
16:45 - 17:05	Risked posed to global water availability by a 4 degrees climate change Dr Fai Fung, Tyndall Centre for Climate Change Research, University of Oxford, UK
17:05 - 17:25	Limits to adaptation: implications of global temperature changes beyond 4°C for water supply in southern England Dr Matthew Charlton, Walker Institute for Climate System Research, University of Reading, UK
17:25 - 17:45	Basic mechanism for abrupt monsoon transitions Prof Anders Levermann, Potsdam Institute for Climate Impact Research, Germany
17:45 - 18:05	Questions
18:05 - 19:00	Drinks Reception: Foyer B, Ruth Deech Building
19:00 - 21:00	Dinner: St Anne’s Dining Hall

Tuesday 29 September 2009

Session 4	Ecosystems and Ecosystem Services Chair: Dr Mark New
09:00 - 09:30	Keynote Address: Tropical forests in a 4+°C World Prof Yadvinder Malhi, Environmental Change Institute & School of Geography and the Environment, University of Oxford, UK
09:30 - 09:50	Changing climate, land use and fire in Amazonia under high warming scenarios Prof Wolfgang Cramer, Potsdam Institute for Climate Impact Research, Germany
09:50 - 10:10	Living with uncertainty – UK forestry in a 4°C world Prof Andy Moffat, Forest Research, UK
10:10 - 10:30	Projections of regional impacts of a 4°C global warning in the semi-arid land of Northeast Brazil Jose Marengo, Earth System Science Center-National Institute for Space Research, Brazil
10:30 - 10:50	Questions
10:50 - 11:20	Coffee and Poster Session 2: Hartland Room
Session 5	Vulnerable People and Places 1 Chair: Prof Diana Liverman
11:20 - 11:50	Keynote Address: Sea-level rise and impacts in a 4+°C World Dr Pier Vellinga, Wageningen University, The Netherlands
11:50 - 12:10	Sea-level rise in a 4 degree world Prof Stefan Rahmstorf, Potsdam Institute for Climate Impact Research
12:10 - 12:30	Visualising sea-level rise projections for IPCC SRES simulations ≥ 4°C Mr Diogo de Gusmao, Met Office Hadley Centre, UK
12:30 - 12:50	Impacts of sea-level rise at 4 degrees and above Prof Robert Nicholls, University of Southampton, UK
12:50 - 13:10	The impacts of sea-level rise on coastal nations with and without mitigation. An application of the DIVA and IMAGE models Dr Jochen Hinkel, Potsdam Institute for Climate Impact Research, Germany
13:10 - 13:30	Questions
13:30 - 14:30	Lunch: St Anne's Dining Hall
Session 6	Vulnerable People and Places 2 Chair: Dr Chris West
14:30 - 14:50	Wildfire in a 4+°C world Prof David Karoly, University of Melbourne, Australia
14:50 - 15:10	Estimating human population health impacts in a 4°C world Dr Simon Hales, World Health Organisation, Switzerland

15:10 - 15:30	Climate-induced population displacements in a 4°+C world Dr Francois Gemenne, Institute for Sustainable Development and International Relations, Sciences Po Paris, France
15:30 - 15:50	Social vulnerability and adaptation possibilities for Vietnam in a 4+°C world Dr Pamela McElwee, School of Global Studies, Arizona State University, USA
15:50 - 16:10	Questions
16:10 - 16:40	Coffee and Poster Session 3: Hartland Room
Session 7	Panel Discussion
16:40 - 17:40	4 degrees of climate change: alarmist or realist? Diana Liverman, Mark Lynas, Kevin Anderson, James Painter, Ian Noble
17:40 - 18:30	*Depart St Anne's for Exeter College* *Walking time: 10-15minutes (see map)*
18:30 - 19:15	Drinks Reception: Exeter College – Rectors Lodgings
19:15 - 22:30	Dinner: Exeter College – Dining Hall

Wednesday 30 September 2009

Session 8	Adaptation Chair: Prof Diana Liverman
09:00 - 09:20	One two three more: challenges to describing a warmer world Prof Leonard Smith, London School of Economics, UK
09:20 - 09:40	How adaptation decision-making is affected by the potential for 4 degrees and beyond Dr Mark Stafford-Smith, Australian Commonwealth Scientific and Research Organisation, Australia
09:40 - 10:00	Nature conservation in a 4+°C world - a luxury or a necessity? Dr Michael Morecroft, Natural England, UK
10:00 - 10:20	The implications of 4+°C warming for adaptation strategies in the UK: time to change? Ms Lisa Horrocks, AEA, UK
10:20 - 10:40	Questions
10:40 - 11:10	Coffee and Poster Session 4: Hartland Room
Session 9	Avoiding Large Climatic Changes 1 Chair: Dr Kevin Anderson
11:10 - 11:30	Keynote: 4+°C: the emissions reduction challenge Dr Jason Lowe, Met Office Hadley Centre, UK
11:30 - 11:50	What will it take to avoid 2, 3 and 4+ degrees? The importance of cumulative emissions Dr Myles Allen, Department of Physics, University of Oxford, UK
11:50 - 12:10	Beyond 4°C: should we reconsider our options? Dr Rob Swart, Wageningen University and Research Centre, The Netherlands

12:10 - 12:30	The role of international transportation sectors in climate stabilization Ms Holly Preston, Manchester Metropolitan University, UK
12:30 - 12:50	Questions
12:50 - 13:50	Lunch: St Anne's Dining Hall
Session 10	Avoiding Large Climatic Changes 2 Chair: Dr Mark New
14:00 - 14:30	Keynote Address: Global emission pathways: balancing Annex 1 mitigation with non-Annex 1 development Prof Kevin Anderson, Tyndall Centre for Climate Change Research, UK
14:30 - 14:50	Avoiding a 4+°C World: A Challenge for Democracy Prof Bertrand Guillaume, Troyes University of Technology, France
14:50 - 15:10	Greenhouse gas contributions and mitigation potential of agriculture: creating incentives within the existing carbon trading agreements Dr Hari Dulal, The World Bank, USA
15:10 - 15:30	Questions
15:30 - 16:10	Conference Roundup Synthesis and implications for Copenhagen Prof Diana Liverman
16:10 - 16:40	Coffee and Poster Session 5: Hartland Room
	Conference Ends

Poster Presentations

Agriculture, Water and Food Security	
Prof R Ponce-Hernandez Trent University, Canada	A model-based approach to predicting the effects of global warming four degrees and beyond on ecosystem primary productivity, land degradation and food security at national scale: Case Study Ethiopia
Dr Helena Kahiluoto MTT Agrifood Research, Finland	Implications of 4+°C global warming on potential of carbon trading for mitigation and food security - analytical framework and an Ethiopian case
Dr Yasuaki Hijioka National Institute for Environmental Studies, Japan	Implications of 4+°C in Japan. Quantitative analysis of sectoral impacts of climate change in Japan using an integrated assessment model.
Mr Jens Heinke Potsdam Institute for Climate Impact Research, Germany	Implications of extreme global warming scenarios for global water availability
Mr Robert McSweeney Atkins Water & Environment, and University of East Anglia, UK	Stochastic and perturbation techniques to assess the influence of climate change-induced multi-seasonal drought on water resource vulnerability at Weir Wood Reservoir, North Sussex, UK
Ecosystems and Ecosystem Services	
Dr Humphrey Crick Natural England, UK	Ecosystem-based conservation in a 4+ degree world
Dr Elena Parfenova Forest Institute, Russian Federation	Conifer trees of the south Siberia mountains in a changing climate of XXI Century
Dr Stephan A. Pietsch University of Natural Resources and Applied Life Sciences, Austria	4+ degrees: Ecosystem Resilience and Predictability
Mr Przemyslaw Zelazowski Environmental Change Institute & School of Geography and the Environment, University of Oxford, UK	Can tropical forests survive four degrees of warming, and if so, what will their role be in the global carbon cycle?
Vulnerable People and Places	
Dr Matthew Eames University of Exeter, UK	Predicting temperatures within buildings and the heat stress on occupants under substantial climate change
Prof Clive Hamilton Australian National University	Adaptive Coping Strategies in a Four Degree World

Dr Raj Kumar Sen Rabindra Bharati University, India	Vulnerable Areas and Vulnerable Peoples: A Case Study of Sundarbans of Bangladesh and India
Mr Abdeltif El Ouahrani University Abdelmalek Essaadi, Morocco	Climate Change in Mediterranean region: vulnerability and opportunities
Mr Jayesh Bhatia NR Management Consultants, India	Poverty reduction and climate change adaptation in worst case scenario – Synergies & Challenges
Dr Gernot Brodnig World Bank, USA	A View From the Top: Vulnerability and Adaptation in Mountain Systems
Dr Sally Brown University of Southampton, UK	Sea level response and impacts to a 1ºC to 7ºC temperature rise by 2100
Avoiding Large Climate Changes	
Mr Markus Hageman Ecofys GmbH, Germany	The role of sectoral characteristics in designing mechanism for participation of developing countries
Dr Robin Hickman University of Oxford, UK	Backcasting for low carbon transport
Dr Dominic Moran Scottish Agricultural College, UK	UK Marginal Abatement Cost Curves for the Agriculture and Land Use, Land-Use Change and Forestry Sectors out to 2022, with Qualitative Analysis of Options to 2050
Dr Jasper Knight University of Exeter, UK	Landscape responses to future climate change in glaciated mountains
Dr Katja Frieler Potsdam Institute for Climate Impact Research, Germany	Applications of pattern scaling for probabilistic assessment of regional climate impacts