Climate Change

and its impacts

Some highlights from the ongoing UK research programme: a first look at results from the Hadley Centre's new climate model

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Introduction

Recognising the importance of assessing the threat of future climate change and its impacts, the UK Department of the Environment, Transport and the Regions established in 1997 a series of linked research projects which predict changes in climate over the next decades and assess the potential global impact in key sectors. These sectors covered natural ecosystems, water resources, food supply and coastal areas. The first report from this study was published in December 1997 as *Climate change and its impacts*, and was distributed at the Third Conference of Parties to the UN Framework Convention on Climate Change, Kyoto.

Since then, the Hadley Centre has generated a new scenario of climate change based on predictions undertaken in 1998 from the most recent version of its climate model. The climate scenario is based on an increase in greenhouse gases according to the IPCC 'business-as-usual' emissions scenario, without changes in sulphate aerosols. As in 1997, assessment models have been used to look at the impacts arising from this greenhouse gas-only climate scenario, and the range of sectors has been extended to include human health — specifically, malaria. The assessment has concentrated on the period 2041–2070, described for convenience as the 2050s. The model has also recently been run to include in addition the cooling effect of sulphate aerosols based on a revised projection of human-made sulphur emissions. Sulphates make little difference to future warming at a global scale, but there are some differences regionally.

This report can be considered as an update of the one issued in December 1997; much of the background, many of the assumptions and caveats discussed in that report are still current. The contributions to research from the UK Public Meteorological Service programme are fully acknowledged.

Key findings

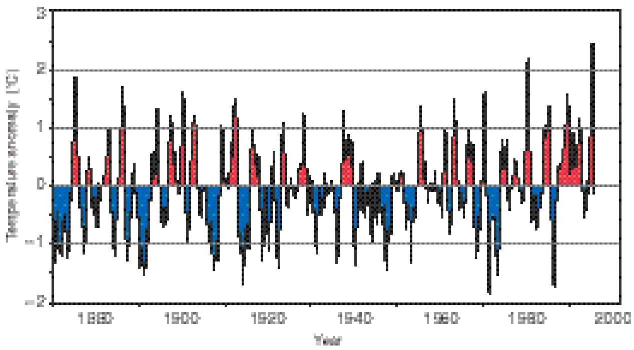
- The 1997/98 El Niño was the most extreme on record. The global mean surface temperature in 1998 is likely to exceed that in 1997 and be the highest since global instrumental records began.
- Predictions of climate change have been made using an improved climate model without corrections. IPCC 'business-as-usual' increases in greenhouse gas emissions result in a further warming of about 3 °C over the next 100 years. The inclusion of sulphate aerosols makes little difference to this global prediction.
- Comparisons of model simulations and observations, based on new statistical techniques, indicate that human-made greenhouse gases have contributed substantially to global warming over the past 50 years. Initial results also indicate that climate models can simulate reasonably well the climate change of the past 150 years, and this gives us confidence in predictions of the future.
- The new climate model has a better representation of ocean currents. Increases in greenhouse gases result in a slowing down of the North Atlantic ocean circulation, but even with this, Europe still warms.
- Based on the new climate scenario for the 2050s, tropical forests will die back in many areas of northern Brazil. In other areas of the world tropical grasslands will be transformed to desert or temperate grassland.
- Vegetation will absorb CO_2 at the rate of some 2–3 billion tonnes of carbon (GtC) per year in the first half of the next century; this compares to current human-made emissions of about 7 GtC per year. After 2050, and as a result of vegetation dieback, this will become a source of about 2 GtC per year, thereby enhancing CO_2 build up in the atmosphere. This enhancement is not yet included in climate predictions
- Water resource stresses in many of the poorest countries, already expected to increase, will be exacerbated by climate change. Due to climate change alone, some 66 million extra people will live in countries with water stress, and some 170 million people will live in countries which are extremely stressed.
- Under this climate change scenario crop yields will increase in high and mid-latitude countries such as Canada and Europe, but decrease in lower latitudes. Although globally the food system will accommodate regional variations in yields, some regions, particularly the Tropics, will experience marked reductions in yield, lower production and higher risk of hunger. Africa will be worst affected, with 18% more people at risk of hunger due to climate change alone by the 2050s.
- Global mean sea-level rise by the 2050s is predicted to be 21 cm. If coastal protection evolves as in the past, then over 20 million extra people each year will be at risk of flooding due to sea-level rise. South and South East Asia are most vulnerable in absolute terms. To manage these flood risks, proactive adaptation for sea-level rise is required around much of the world's coastal regions.
- While growth in population will itself increase the number of people at risk of malaria, climate change will increase the proportion of the world population at risk, particularly in areas where currently the disease is not endemic.

Climate change science

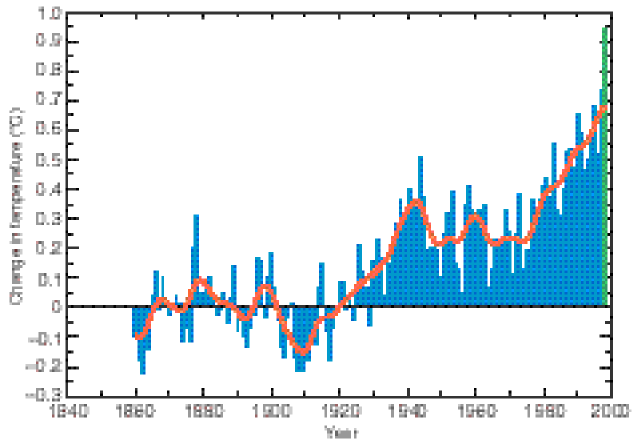
Contributors: Chris Folland, David Parker, Briony Horton, John Mitchell, Tim Johns, Christine Coughlan, Anne Keen, Nick Rayner, David Roberts, Andy Jones, Paul Jacobs, Simon Tett and Geoff Jenkins at the Hadley Centre, The Met. Office; Keith Briffa, Phil Jones, Mike Hulme and David Viner at the Climatic Research Unit, University of East Anglia

Summary

- The 1997/98 El Niño was the most extreme on record. The global mean surface temperature in 1998 is likely to exceed that in 1997 and be the highest since global instrumental records began.
- Predictions of climate change have been made using an improved climate model without corrections. IPCC ‘business-as-usual’ increases in greenhouse gas emissions result in a further warming of about 3 °C over the next 100 years.
- Comparisons of model simulations and observations indicate that human-made greenhouse gases have contributed substantially to global warming over the past 50 years. Initial results also indicate that climate models can simulate reasonably well the climate change of the past 140 years, and this gives us confidence in predictions of the future.
- The new climate model has a better representation of ocean currents. Increases in greenhouse gases result in a slowing down of the North Atlantic ocean circulation, but even with this, Europe still warms.



Changes in sea-surface temperature 1871–1998, relative to the 1961–90 average, for the eastern tropical Pacific off Peru.



Changes in the global annual mean surface temperature, relative to that at the end of the last century, are shown by blue bars, with a smoothed curve in red. The value for 1998, shown in green, includes observations up to the end of September.

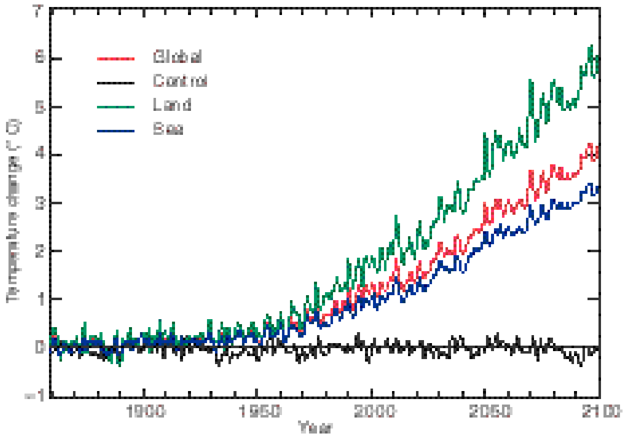
Recent observations of climate

The year since Kyoto has witnessed the largest El Niño, the warming of the eastern tropical Pacific, on record. The effects of this on global communities, from forest fires in Indonesia to torrential rains in Peru and East Africa, have been well publicised. We cannot say yet whether global warming has led to more frequent or larger El Niños. The figure alongside shows an underlying trend of rising temperatures, but also shows that large El Niños were seen at the end of the last century. The global effect of El Niño, however, demonstrates how vulnerable society is to changes in climate.

1997 was the warmest year in the global instrumental record going back to 1860. Due in part, but certainly not wholly, to the large El Niño, global surface temperatures have been at a consistently high level in 1998. Each of the first eight months of the year has been the warmest, or equal warmest, such month on record. Despite the fact that El Niño is now moving into a colder ‘La Niña’ phase, which will have a corresponding cooling effect on global climate, the annual temperature for 1998 is almost certain to be warmer than in 1997, and hence the warmest on record. However, due to natural climate variability, temperatures are not expected to rise successively each year, and it seems likely that 1999 will be cooler than 1998.

Predictions from the new Hadley Centre climate model

A climate model aims to represent all the main components of the climate system which can affect change in the future. Up to now, coupling together models of two main components of the climate system, the atmosphere and the ocean, has caused the climate model’s own simulated climate to drift away from reality. To prevent this, corrections — so-called ‘flux-adjustments’ — were introduced, and these raised issues about the confidence we had in using such models for predictions. In the third Hadley Centre coupled climate model, the ocean is represented at a much higher resolution than previously, 1.25° latitude x 1.25° longitude, which gives a greatly improved representation of ocean currents such as the Gulf Stream. This, together with improvements in the representation of processes in the atmosphere and on land, has allowed the model’s climate to remain stable without the need for flux-adjustments.

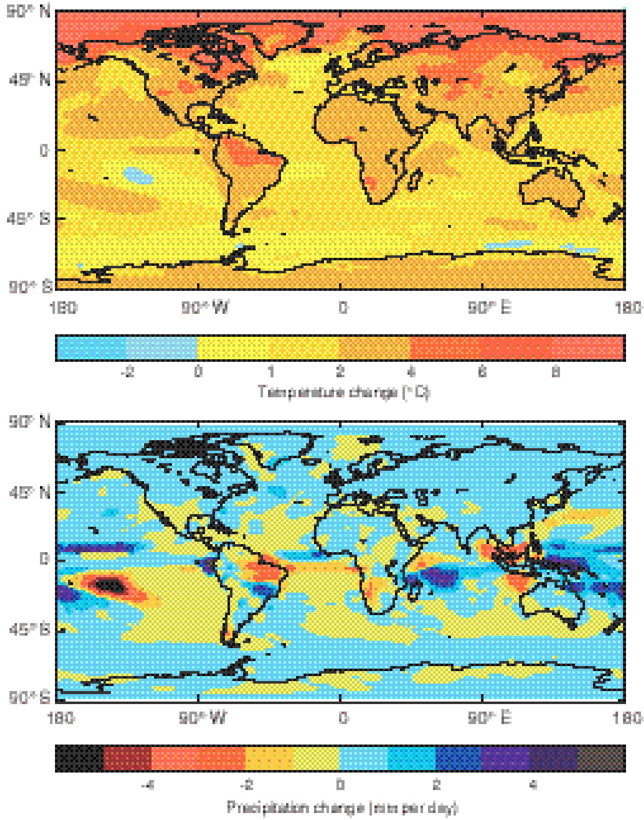


Changes in land, sea and global mean surface temperature from the new Hadley Centre model driven with changes in greenhouse gas concentrations (without sulphate aerosols): observed to1995 and IPCC 'business-as-usual' to 2100. The black line shows the low climate drift of the unperturbed model.

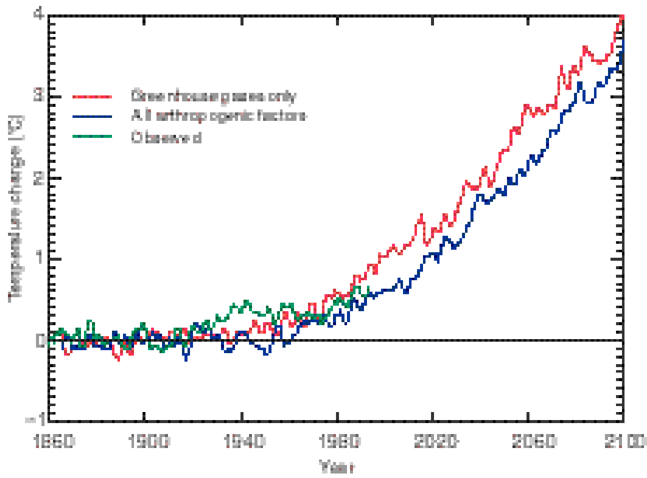
The new model has been used to make simulations and predictions of climate over the period 1860–2100, and some of the results are shown on this page. When driven by observed increases in greenhouse gases to the present, and IPCC-projected increases in the future, the model predicts that a rise in global temperature of about 1 °C should have occurred already, and a further rise of about 3 °C is to be expected by 2100; rises over land (where the main impacts are expected) will be almost twice as fast as those over sea.

The regional patterns of change are also shown on this page; high-latitude winters will warm faster due to feed-back from the melting of sea-ice, and there will be some ocean areas where rises are quite limited. Rainfall changes will be most marked in tropical regions. These patterns, and the global mean rises, are not very different from those previously predicted with flux-adjusted models. Using the new model we see relatively large decreases in rainfall over Amazonia and parts of Africa, but this may be due to changes in the model other than omitting flux-adjustment. Predictions from the new model have been used to investigate impacts on a number of socio-economic areas, and these are described in later sections of this report.

The new climate model has, very recently, also been run including changes in sulphate aerosols from revised projections of SO_2 emissions — about a half of those used in IPCC 1995. Although the direct cooling effect of sulphate aerosols is much reduced, we also now include cooling from the indirect effect via changes in cloud brightness. The diagram alongside shows how the simulation of change to date is in broad agreement with the observed temperature rise. Other factors, such as changes in solar output and volcanic activity, will be included in future simulations, and are expected to give better agreement in mid-20th century. However, natural variability means that simulated and observed temperatures will not always agree. Because total global sulphur emissions are not expected to change substantially in future, the warming over the next 100 years is much the same as without sulphate aerosols — about 3 °C (see figure below). There are some differences in regional detail, however.



The patterns of change in northern winter temperature (top) and precipitation (bottom) for the 2050s, compared to the present day, when the climate model is driven with IPCC 'business-as-usual' changes in greenhouse gases only.



The global mean surface temperature change when the model includes the effect of greenhouse gases (red), and also including the direct and indirect effects of sulphate aerosols (blue). Observations are shown in green.

Uncertainty in climate change predictions

Recent work at the Hadley Centre has shown that, when driven by all the observed changes in climate forcing factors (natural and human-made), the climate model does reasonably well at simulating changes in climate over the last 140 years, taking into account the vagaries of natural internal climate variability. It is also able to mimic changes in the more distant past, for example during the warm period some 6,000 years ago. This limited model validation gives increased confidence in predictions of future climate change.

Rapid changes in ocean circulation

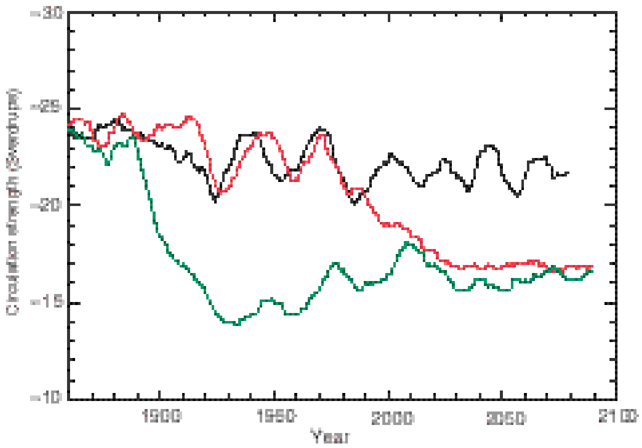
There is considerable interest in how stable ocean thermohaline circulation (the 'conveyor belt') will remain in the face of rises in greenhouse gas concentrations. The possibility has been raised of a southwards movement in the Gulf Stream leaving Europe exposed to a colder climate. The improved representation of the ocean currents in the new Hadley Centre model has allowed us to investigate this with more realism. We find that, even when CO_2 is increased at an unrealistically rapid rate of 2% per year, and then stabilised at four times the present concentration, the strength of the Atlantic ocean circulation decreases by about 25% (see diagram alongside). This slowdown does decrease the amount of heat transported into north-west Europe, but this is more than offset by direct greenhouse warming, so that temperatures in Europe still rise. However, changes in ocean circulation do alter warming patterns in the North Atlantic, and hence will contribute to changes in European weather, including, for example, storminess. Some other climate models show a more drastic reduction in ocean circulation, and the reason for this range of responses is not fully understood.

Identifying the causes of recent climate change

The change seen over the past 140 years, shown earlier, amounts to some 0.6 °C. Is this due to human activities such as the burning of fossil fuels? There are many factors that influence climate, and distinguishing the human-made signal from background natural climate variability is a challenge. To do this we use advanced statistical techniques which look at changes in patterns of temperature, both at the surface of the earth and through the depth of the atmosphere, giving greater importance to those areas where natural variability is low and vice versa. This statistical analysis indicates that, over the past 50 years, human-made greenhouse gases have contributed substantially to global warming. There is still considerable uncertainty in this estimate, but this recent study supports and strengthens the IPCC 95 statement that the balance of evidence suggests a discernible climate change due to human activities. Although it is still not possible to unambiguously assign recent change to human activity, we are working towards a more robust assessment through better model simulations, better observations, and better estimates, from models and observations, of the natural variability of climate.

Making better estimates of climate change

The reason why climate predictions are so uncertain is that, once climate change begins, consequential changes will feed back, either positively or negatively, on the original warming. These feedbacks are poorly understood. Although we believe the most important feedbacks in the atmosphere, ocean, land surface and sea-ice are already included (albeit imperfectly) in the climate model, there are others which should be taken into account, and this can only be done by including all components of the climate system in a fully interactive model. Most recently we have included a sulphur cycle which creates sulphate aerosol from natural and industrial SO_2 emissions. The next step is to add the carbon cycle and chemistry; climate change has the potential to disturb the natural carbon cycle in such a way as to alter atmospheric concentration of CO_2, and to disturb the chemistry of the atmosphere so as to alter concentrations of other greenhouse gases such as ozone and methane. Sub-models currently under development will be incorporated (over the next few years) in the main model to form the first Hadley Centre Earth Systems Model. Ultimately we plan to include feedbacks from socio-economic sectors such as agriculture and energy use.



The strength of the Atlantic circulation is seen to decrease substantially as greenhouse gas concentrations rise at 2% per year to four times the pre-industrial value (green). The black line shows the unperturbed circulation, and the red line the change when greenhouse gases follow the IPCC 'business-as-usual' emissions scenario.

Impacts of climate change on natural vegetation

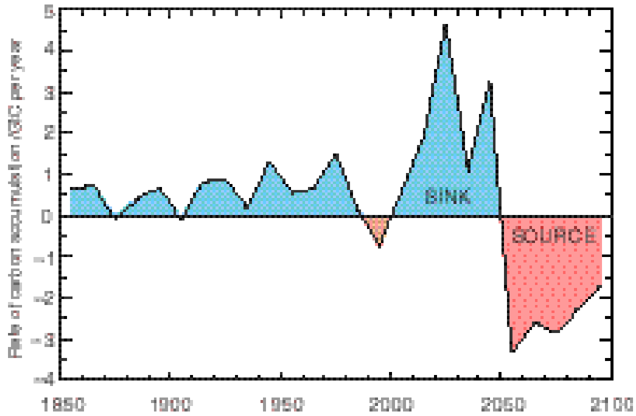
Contributors: Andrew White, Andrew Friend and Melvin Cannell, NERC Institute of Terrestrial Ecology (ITE), Edinburgh.

Summary

- Under the latest climate scenario for the 2050s, tropical forests will die back in many areas of northern Brazil. In other areas of the world, tropical grasslands will be transformed into desert or temperate grassland.
- Vegetation will absorb CO_2 at the rate of some 2–3 GtC per year in the first half of the next century; this compares to current human-made emissions of about 7 GtC per year. After 2050, and as a result of vegetation dieback, this will become a source of about 2 GtC per year, thereby enhancing CO_2 build-up in the atmosphere. This enhancement is not yet included in climate predictions

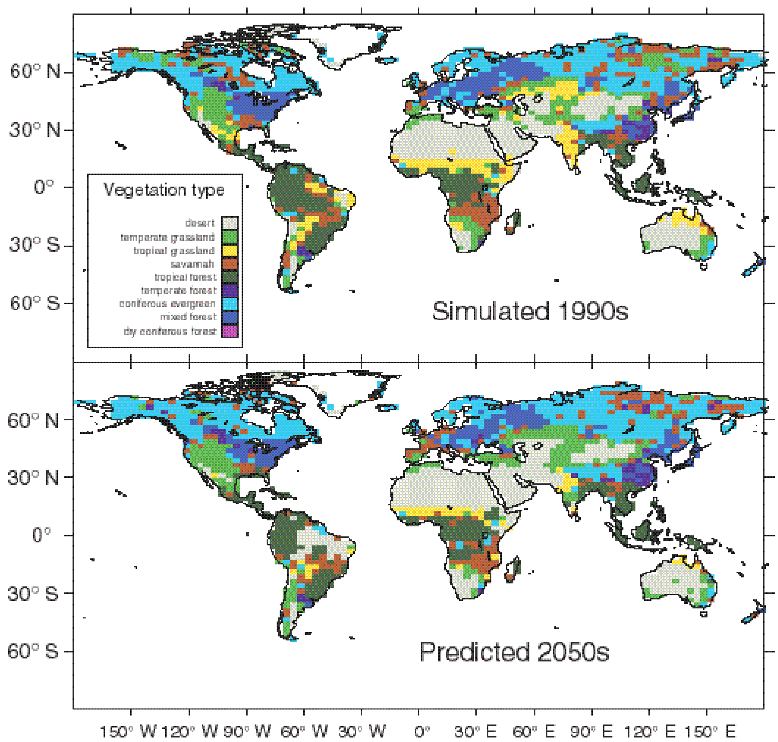
Climate predictions from the new Hadley Centre model with increases in greenhouse gases only, for the period 1860–2100, together with projections of increasing CO_2 concentration and nitrogen deposition, were used to drive the ITE ecosystem model, a model which has been well tested and peer-reviewed. The maps below show the global distribution of desert and eight vegetation types predicted by the ecosystem model for the present day and for the 2050s. Many regions which currently support tropical forests are predicted to change to savannah, grassland or even desert. The ecosystem model predicts that this dieback will occur over vast areas of northern Brazil, beginning in the 2040s, resulting from decreases in rainfall of up to 500 mm per year and increases in temperature of up to 7 °C. Many regions of tropical grassland will be transformed into desert or temperate grassland, in areas of India, Africa and North America. Temperate grassland will also expand into regions of Europe and North America which are currently dominated by temperate or coniferous forest, resulting in a significant loss of productivity and biomass. By contrast, there is a northwards expansion of coniferous and temperate forest in both North America and Asia, and a large area where these forest types remain dominant. In these regions, the forests grow faster and increase in biomass, as a result of the enhancement of photosynthesis by CO_2, more favourable temperatures and nitrogen deposition.

The ecosystem model was also used to predict the rate of changes in the amount of carbon stored in global vegetation and soils over the period 1860 to 2100. The model predicts that the land acts as a weak carbon sink until about 1990, after which the sink will increase to sequester around 2–3 billion tonnes of carbon (GtC) per year between 2000 and 2050. (For comparison, current emissions of CO_2 due to human activity are about 7 GtC per year.) After 2050, and as a result of vegetation dieback and change, primarily in Amazonia, Europe and North America, the terrestrial land surface becomes a source of carbon, releasing approximately 2 GtC per year into the atmosphere. Consequently, after 2050, changes in natural ecosystems predicted by the model will enhance the build-up of CO_2 in the atmosphere. This enhancement is not yet included in climate models.



Predicted changes in the rate of increase in the carbon store on land, showing when the land is a source or sink of carbon.

Global distribution of vegetation types predicted by the ITE ecosystem model for the present day and for the 2050s.



Impacts of climate change on water resources

Contributor: Nigel Arnell, University of Southampton

Summary

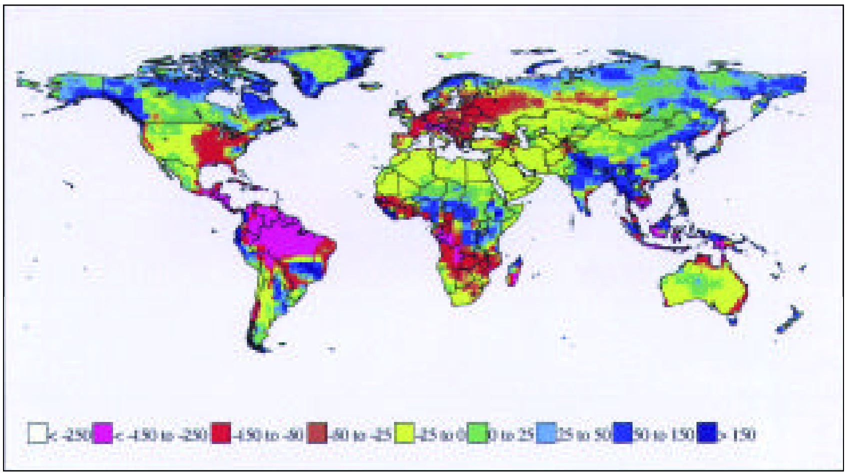
- Water resource stresses in many of the poorest countries, already expected to increase, will be exacerbated by climate change. Due to climate change alone, some 66 million extra people will live in countries with water stress, and some 170 million people will live in countries which are extremely stressed.

One of the greatest potential impacts of climate change on human society is through its effect on water resources. At present, approximately one third of the world's population live in countries experiencing water stress, and it has been forecast that by 2025 as much as two thirds of a much larger world population could be exposed to water stress, simply due to the increase in population. Climate change has the potential to exacerbate further these stresses in some parts of the world.

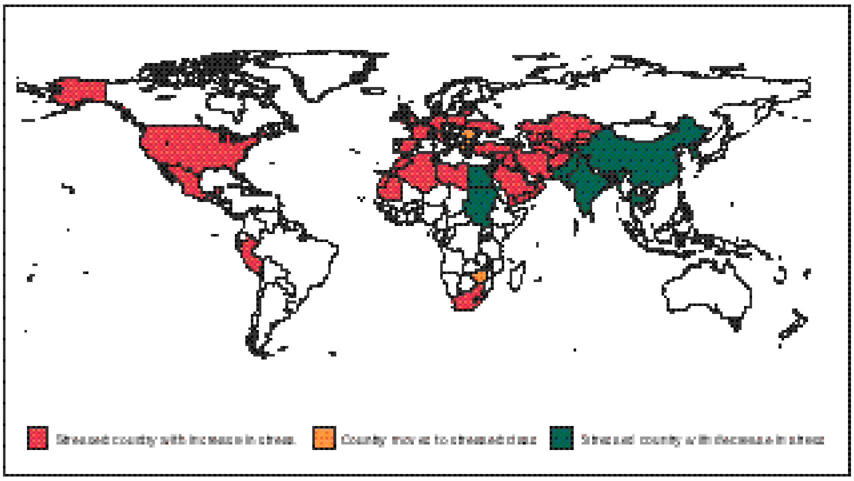
The implications of the new Hadley Centre climate scenario for water resources stress were assessed by first simulating river runoff with a macro-scale hydrological model, calculating changes in national water resource availability (taking into account imports from upstream), and comparing the estimated volume of water available for use with the amount withdrawn by water users. The baseline water availability and use data, together with the scenarios for future water use, were taken from work undertaken for the 1997 Comprehensive Assessment of the Freshwater Resources of the World.

The first map shows the estimated change in 30-year mean annual runoff by the 2050s as compared with the baseline period 1961 to 1990. Runoff increases in high latitudes, South East Asia and some equatorial regions, but decreases substantially in Europe, most of Africa, the Middle East, eastern North America, and much of the Amazon basin. These changes can be very large in percentage terms. The rise in temperature will also affect the timing of streamflow through the year, with particularly large changes in those parts of the world — eastern Europe, the northern United States, and parts of east Asia — where the higher temperatures mean that a much smaller proportion of winter precipitation falls as snow to be stored on the land surface until the spring melt. In these areas, winter flows will increase and spring flows decrease.

One measure of national water resource stress is the ratio of water used to water available (although this hides within-country variations and the risk of stress during drought conditions), and countries using more than 20% of their total annual water supply are generally held to be exposed to water stress. The second map shows the effect of climate change on water stress by the 2050s, relative to the effects of population growth, and indicates that water resource stresses in many of the poorest countries would be exacerbated by climate change. Climate change would lead to an additional 66 million people living in countries using more than 20% of their total potential resource by 2050, and an additional 170 million people would be living in countries using more than 40% of their resources.



Estimated change in 30-year mean annual runoff (millimetres per year) by the 2050s, compared with the baseline period.



Change in water stress, due to climate change, in countries using more than 20% of their water resources.

Impacts of climate change on food supply

Contributors: Martin Parry and Matthew Livermore, Jackson Environment Institute, University College London;
Cynthia Rosenzweig, Goddard Institute for Space Studies, USA;
Ana Iglesias, Cuidad Universitaria, Spain; Gunther Fischer, International Institute for Applied Systems Analysis, Austria

Summary

- Due to changes in climate and CO_2 crop yields are expected to increase in high- and mid-latitude countries but decrease in lower latitudes. Although globally the food system will accommodate regional variations in yields, some regions, particularly in the Tropics, will experience marked reductions in yield, lower production and higher risk of hunger. Africa will be worst affected, with 18% more people at risk of hunger due to climate change alone.

Dynamic crop growth models are used to simulate the effects of climate change, as projected by the new Hadley Centre climate model, and increased atmospheric CO_2, on the yield of major cereal crops. A world food trade model is then used to simulate the economic consequences of changes in yields and thus estimate the changes in world food output, in world food prices and in the number of people at risk from hunger. All models and methods used in this analysis have been validated and peer-reviewed.

Changes in crop yields predicted for the 2050s are shown below. Decreases in yields are seen by the 2020s in Russia, and in Canada by the 2080s. Western Africa and tropical South America appear worst affected. Yields in some regions, such as Canada and Australia, may initially increase then decrease through the decades, due to the changing balance between positive effects of CO_2 'fertilisation' and the negative effects of moisture stress. This clearly has implications for adaptation policies.

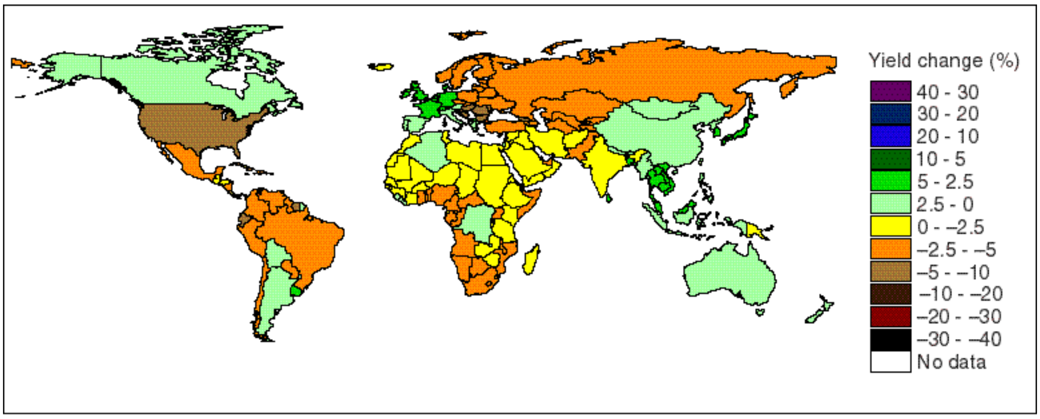
The world food model incorporates climate responses as changes in average national or regional yield per commodity as described above. Economic adjustments include changes in agricultural investment, allocation of land to different crops, land reclamation and prices. A 'risk of hunger' index is based upon methods developed by the UN Food and Agricultural Organization.

Assuming no change in climate, world cereal production is estimated to grow from about 1,800 mmt (million metric tonnes) in 1990 to about 3,500 mmt in 2050, matching global food requirements throughout the period. Food prices are estimated to rise but the relative risk of hunger will decrease. These projections are consistent with those of FAO. They assume a 50 per cent liberalisation of trade by 2020 and an annual increase in cereal yields of just under one per cent.

The climate change scenario leads to world cereal production being progressively reduced from projections without climate change — by the 2050s the world could be experiencing a shortfall of 90 mmt compared to the reference scenario. Food prices increase by 17 per cent above the level they otherwise would have been, and the number of people at risk of hunger is projected to increase due to climate change by 30 million by the 2050s.

The global estimates presented above mask important regional differences in impacts. In general, small decreases in yield and production are compensated for by socio-economic developments. However, regional disparities are evident. Yield decreases at lower latitudes, and in particular in the arid and sub-humid Tropics, lead to production decreases and an increase in the risk of hunger, effects that may be exacerbated where adaptive capacity is lower than the global average. For example, in Africa cereal productivity is estimated to be reduced by about 10 per cent from the reference case by 2050, and place 18% more people at risk of hunger.

In especially vulnerable areas and over short periods (e.g. in spells of drought or flooding) many of the effects of climate change will be more adverse than those indicated above.



Potential change in yields of cereals (wheat, maize, rice) for the 2050s, including effects of CO_2.

Impacts on coastal communities

Contributor: Robert Nicholls, Middlesex University, London

Summary

- Global mean sea-level rise by the 2050s is predicted to be 21 cm. If coastal protection evolves only according to Gross Domestic Product (GDP), as in the past, then over 20 million extra people each year will be at risk of flooding due to sea-level rise.
- The coasts of the southern Mediterranean, West and East Africa, east Asia and, most particularly, south and South East Asia are most vulnerable in absolute terms. The islands of the Caribbean, and the small islands of the Indian Ocean and Pacific Ocean, are also vulnerable in terms of large relative increases in flood risk.

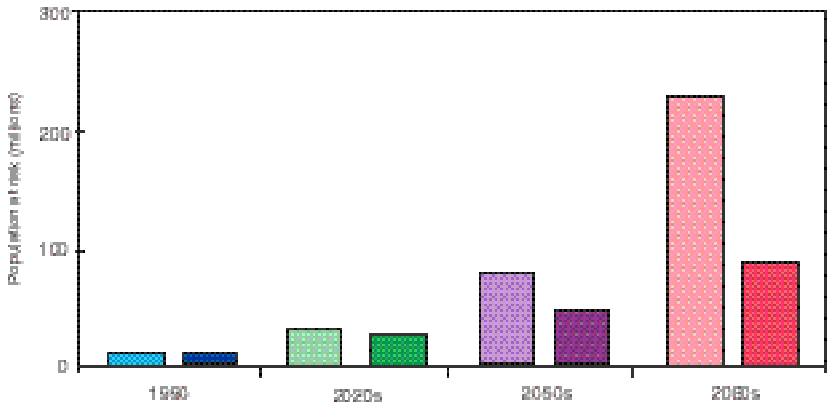
Sea-level rise increases the risk of coastal flooding if the other factors determining flood risk (storminess and flood defences) remain the same. Recent estimates are that 21% of the world's population live within 30 km of the coast, and these populations are growing at twice the global trend, so increases in flood risk could have significant human impacts. The new Hadley Centre climate model predicts a global rise in sea level of 21 cm by the 2050s due to rises in greenhouse gases from human activities. This estimate includes direct prediction of thermal expansion combined with estimates of land-based ice-melt, using a model developed by the University of Utrecht driven by the predicted climate change; an improvement on earlier estimates. Sea-level rise will not be the same everywhere; in some areas it could be up to twice this global mean, in other areas relatively little; later estimates of coastal impacts will include this variation.

The number of people at risk, defined as the average number of people flooded per year by storm surge, is estimated for this sea-level rise scenario. Storm climatology is assumed to remain constant and population growth in the coastal zone is assumed to be double the national increase. The standard of protection from flooding in the 1990s is estimated using GDP, in the absence of suitable global data. Results are presented for two cases: constant protection (no change with time) and evolving protection (where protection is upgraded in line with increase in GDP, but with no specific allowance for global sea-level rise). The way in which protection is assumed to evolve is in line with historical developments.

The impacts produced by sea-level rise are shown in the diagram alongside. With constant protection and no further sea-level rise, the model predicts an increase in the annual number of people at risk of flooding from 10 million people in 1990 to 32 million people in the 2050s; taking into account sea-level rise this increases to 78 million, i.e. an extra 46 million people at risk. Three quarters of these people are concentrated in a few vulnerable regions, particularly south and South East Asia, where there are many densely populated deltas, and West Africa, where the coastal population is growing rapidly. In addition, there are relatively large increases in the numbers of people at risk in all the regions comprised of small islands: the Caribbean, the Indian Ocean and the Pacific Ocean.

With evolving coastal protection and no sea-level rise, the number of people at risk amounts to some 27 million people by the 2050s; when the effects of sea-level rise are included, this rises to 50 million people, i.e. an additional 23 million people. The same six regions contain most of these people, but under this scenario the majority are concentrated in one region: south Asia. The areas with many small islands again experience large relative increases in the number of people at risk.

While adaptation is feasible in many of these vulnerable areas, it will involve long-term planning and substantial costs. The Netherlands exemplifies one approach to controlling flooding in deltas, depending on well developed institutions and a large amount of infrastructure. Many small islands have inherently more limited indigenous resources for adaptation than larger islands and continental settings.



Annual number of people at risk under the sea-level rise scenario, assuming constant flood protection (LH bar) and evolving protection (RH bar)

Impacts of climate change on human health: malaria

Contributors: Pim Martens, International Centre for Integrative Studies, The Netherlands; Anthony McMichael and Sari Kovats, London School of Hygiene and Tropical Medicine; Matthew Livermore, Jackson Environment Institute, University College London.

Summary

- While growth in population will itself increase the number of people at risk of malaria, climate change will increase the proportion of the world population at risk, particularly in areas where currently the disease is not endemic.

Climate change is likely to have various adverse impacts on human health. One direct impact is likely to be changes in the distribution and activity of the insect, tick and rodent carriers of certain human diseases. There is a long history of using mathematical models to understand the transmission of mosquito-borne infections, such as malaria, in humans. Predicting the human risk of disease is far more difficult than predicting changes in the geographical range distribution of carriers and of the viability of the infectious agent. This is because human activities do much to influence the risk of disease. For example, in many countries, malaria has been eradicated or controlled.

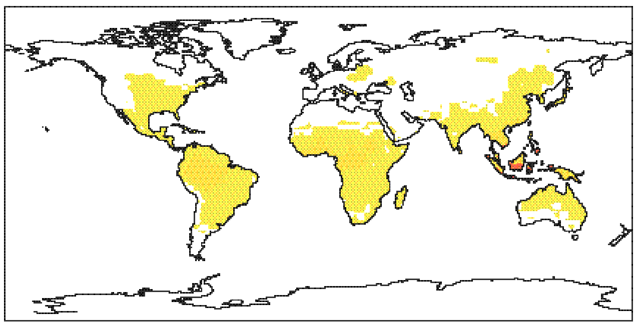
An assessment of impact of climate change on potential malaria transmission has been made using the peer-reviewed MIASMA model developed in the Netherlands. The term 'potential' is here used to refer to the model's predictions of where malaria could occur, based on climatic factors. The model does not take into account local demographic, socio-economic and technical circumstances that could limit transmission. The capacity of the environment to sustain malaria transmission is the key factor in the assessment of how changes in ambient temperature and precipitation patterns would affect malaria risk. A high capacity to sustain transmission of the disease indicates that, despite a smaller or less efficient mosquito population, the disease may remain endemic in a specified area. There is much diversity around the world in how local mosquitoes and local populations behave in relation to the transmission of malaria. As a first approximation, global level modelling necessarily assumes standard behaviours for the mosquito species.

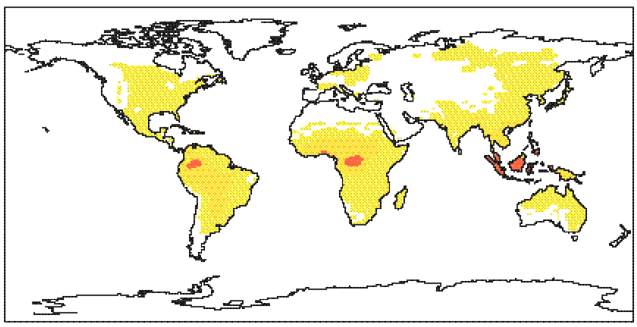
Although it is difficult to validate the highly aggregated global model outcomes (due to lack of data, for example), the MIASMA model has been validated at the country level and for certain specific regions.

Global estimates of the potential for malaria transmission were made based on predictions using the new climate change scenario from the Hadley Centre. The global maps below show the potential transmission of *P.falciparum* malaria, firstly under baseline climate conditions (1961–1990) and, secondly, under the climate scenario for the 2050s.

The largest changes in transmission potential are forecast at the latitudinal and altitudinal fringes of current risk areas. The minimum temperature for parasite development is the limiting factor for malaria transmission in many highland areas. At higher altitudes, such as the eastern highlands of Africa, or in the Andes region of South America, an increase in temperature of several degrees Celsius could increase the transmission potential sufficiently to convert initially malaria-free areas into areas that experience seasonal epidemics. In such non-endemic areas, populations have little or no immunity to malaria and epidemics in these regions are characterised by high morbidity (sickness) and mortality (death) in both children and adults.

The map shows that the greatest changes in potential malaria risk relative to baseline climate are forecast to occur in temperate zones. However, malaria is unlikely to be reintroduced into developed countries which have adequate surveillance systems and maintain control programmes. Malaria is the world's most prevalent mosquito-borne disease; at present approximately 40% of the world's population is at risk of infection. On a global scale, there is a projected increase of the population at risk of malaria. High rates of population growth in endemic areas already entail an increase in population at risk in the absence of climate change. However, climate change superimposed on this pattern of population growth will increase the population at risk of malaria even further.





High
Medium
Low
No transmission

Potential malaria *(P. falciparum)* risk areas for baseline climate conditions (1961–90) and for the climate in the 2050s.

Further information

Further information on the topics covered in this report can be obtained from the contacts below.

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