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Briefing document on environmental stresses from climate change

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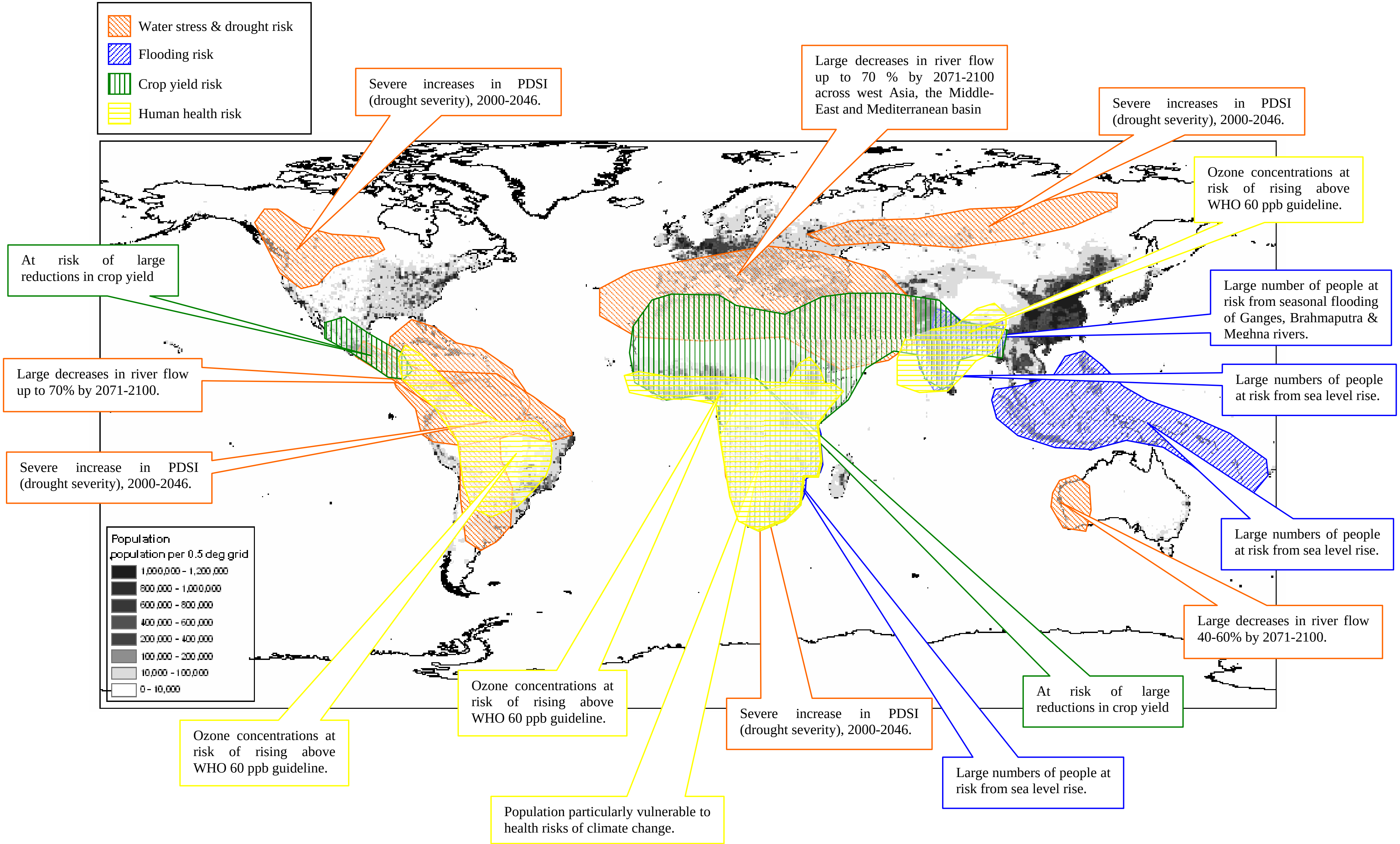
Introduction

This briefing document provides a summary of key results from detailed reports delivered for the MoD 'Defence and Security Implications of Climate Change' project (2005-2007). It focuses on climate change projections during the 21st century with particular emphasis on the 2020s and 2040s. It is structured into two main sections, the first highlighting the physical aspects of future climate change projections, and the second which identifies key regions and sectors at risk from the environmental stresses of climate change. This latter section focuses on four main environmental stress sectors; water stress and drought, coastal and river flooding, crop yield, and human health. For each point of study, general highlights are supported with focussed case studies that provide regional detail on key climate change impacts. A summary map is provided that highlights the key regions and sectors at risk from future climate changes.

It is important to note that this report does not provide a comprehensive review of the sectors and regions that are likely to be at risk from the impacts of climate change. Instead, the focus is on a few key sectors, and potential large-scale risks to these from future climate change. Many of the projections discussed in this report refer to high future population growth and greenhouse gas emissions scenarios. These are subject to large uncertainties that are not discussed here, but are detailed in an earlier report 'Uncertainties in global climate model predictions and environmental stresses' (MOEN/04/04/02/07).

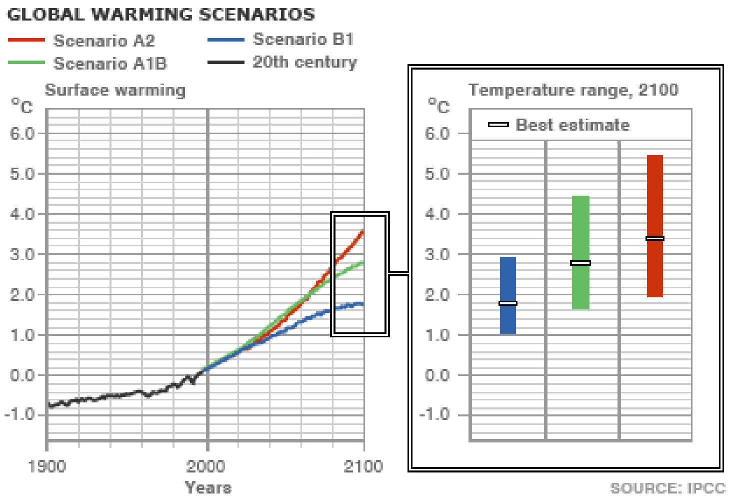
Summary of key areas at risk from climate change

Current population density used as base map for comparison



Surface air temperature

Global changes



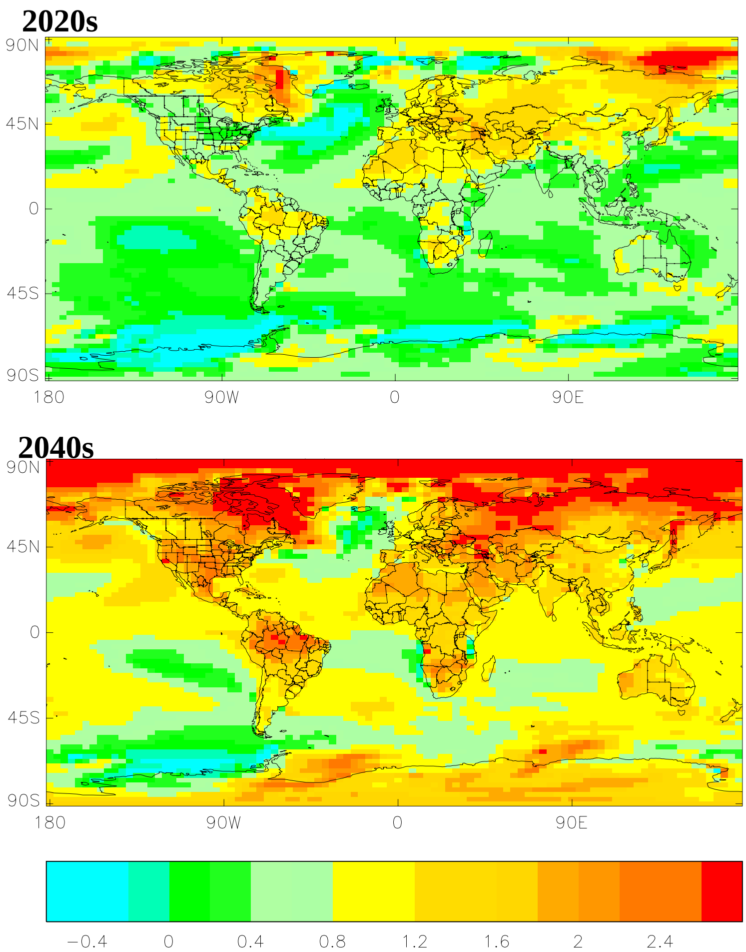
Global average surface temperature warming for 20th century observations and 3 future SRES scenarios. Right box indicates best estimate change at 2100 and the likely range based on different models (IPCC, 2007)

'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.' (IPCC, 2007).

Global warming is projected to increase surface air temperatures by ~0.5ºC by the 2020s, ~1.0ºC by the 2040s and between 1.6-3.6ºC by 2100.

Until the 2040s temperature changes are largely pre-determined and vary little between future emissions scenarios.

Regional detail



Decadal average surface air temperature change (°C) between the 1990s and 2020s and 2040s, projected using the HadCM3 climate model driven by the SRES A2 emissions scenario.

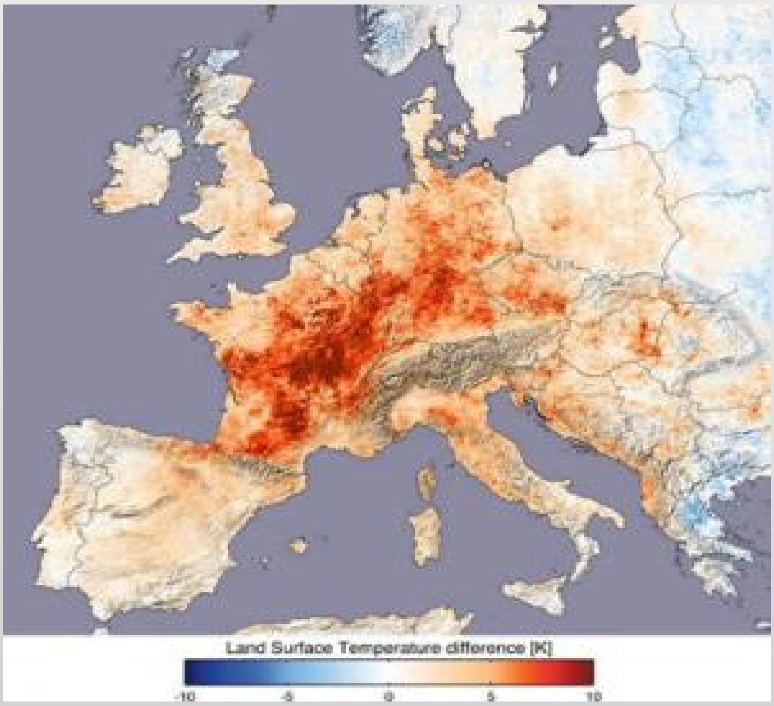
Temperature increases are projected to be highest over land and in high northern latitudes.

By the 2020s the highest regional temperature increases are between 1.2ºC and 3.0ºC, these intensify to between 2.2ºC and 3.5ºC by the 2040s.

Regions that are projected to experience the highest temperature increases are:
Russian Arctic,
Eastern Canada,
Central Amazon basin,
Eastern Europe,
North-west and southern Africa,
EasternTurkey,
The Caucases,
Northern Gulf/Near-East.

It is very likely that extreme temperatures and heatwaves will continue to become more frequent.

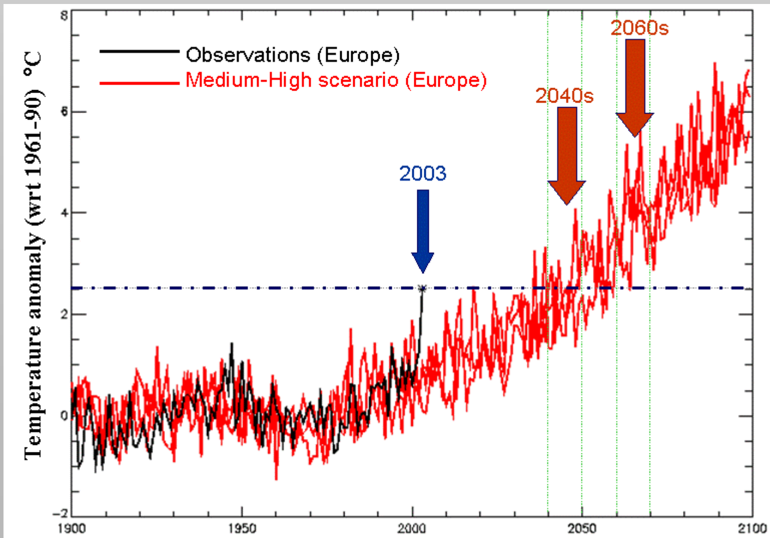
Heatwaves – Europe 2003 case study



Change in summer surface temperatures across Europe relative to the average.

The European heatwave during the summer of 2003 was the hottest on record (since 1860). Summer average air temperature over Europe exceeded the 1961-1990 average by 2.3ºC and surface temperatures were up to 10ºC above average.

The heatwave and drought resulted in over 35,000 additional deaths across Europe, significant reductions incrop yield (20% decrease in summer wheat in France) and led to severe wildfires across Portugal, Spain and France, resulting in forestry and agricultural losses of $15 billion (Munich Re, 2004).



European summer warming projected with the Hadley climate model (red) and observations (black).

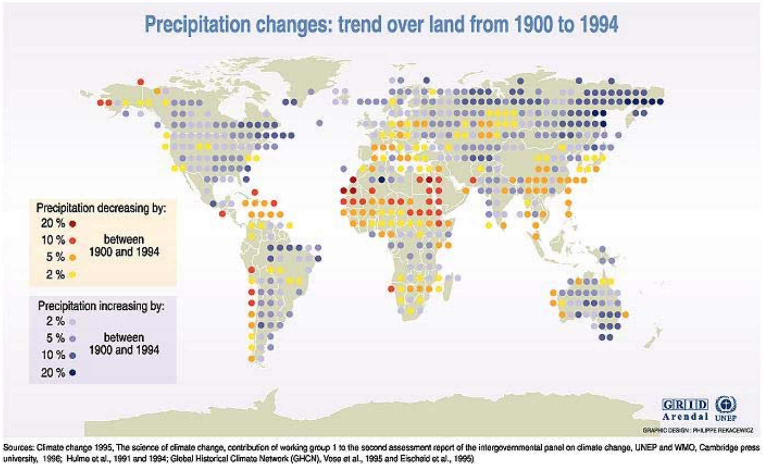
In the future, the extreme temperatures of 2003 are projected to become more frequent.

Temperature projections indicate that by the 2040s more than half of all European summers are likely to be warmer that that of 2003, and by the 2060s a 2003-type summer would be unusually cool.

Munich Re. 2004. Annual review: natural catastrophes 2003, Munich Re Group, Munich

Precipitation

Recent trends



Trends in observed precipitation over land (lack of data over oceans),1900 to 1994.

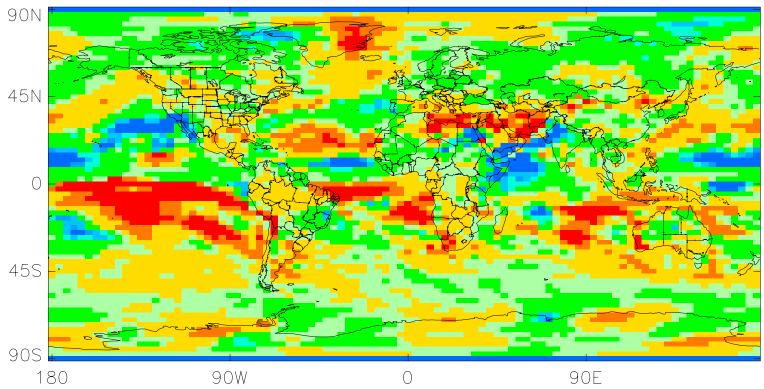
Global precipitation over land increased from 1900 to about 1960 then has decreased since 1980.

Increased precipitation has been observed over land at high latitudes of the Northern Hemisphere, especially during the cold season.

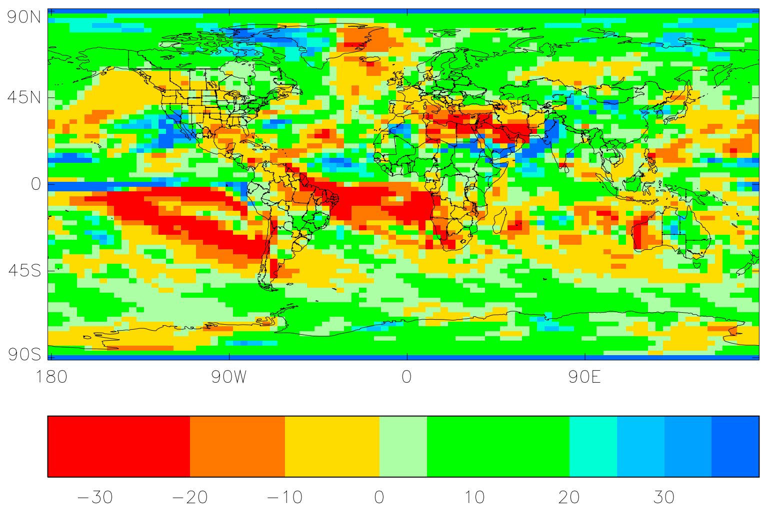
Precipitation decreases occurred in steps after the 1960s over the subtropics and the tropics from Africa to Indonesia.

Regional projections

2020s



2040s



Decadal average precipitation change (%) between the 1990s and the 2020s and 2040s, projected using the HadCM3 climate model driven by the SRES A2 emissions scenario.

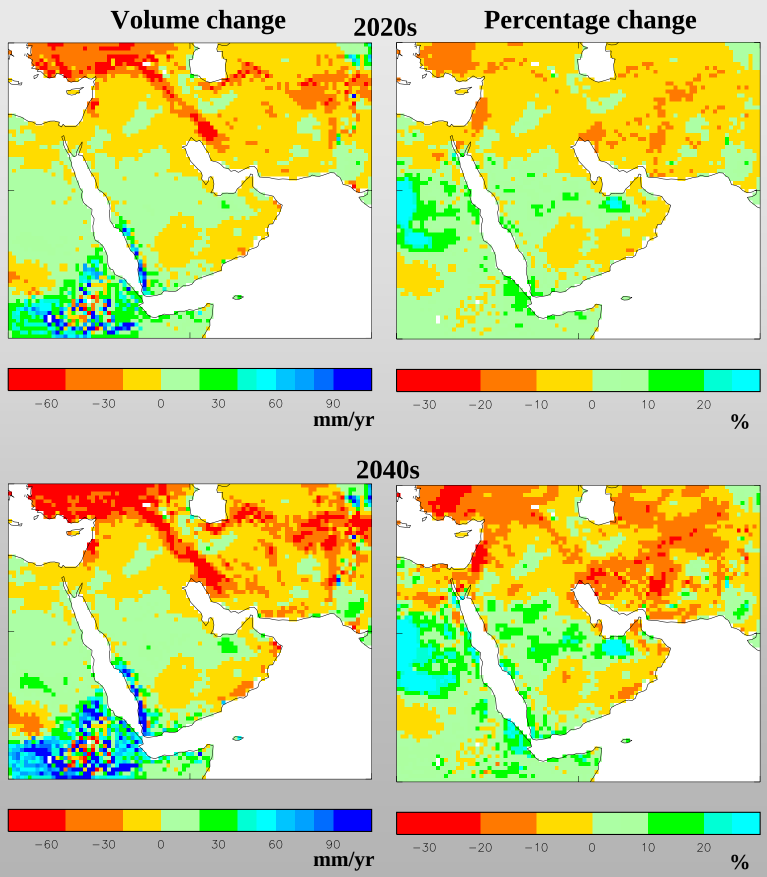
The largest percentage increases in precipitation (>30%) are projected over tropical oceans and across the southern tip of the Arabian peninsular and north-western India.

Increases in precipitation (10-20% by 2020s and 2040s) are projected across most high latitude land areas.

Projected decreases in precipitation over land are greatest (less than -30%) across the Mediterranean, northern Gulf region, southern Africa, central America, Amazon basin and western Australia.

Warmer air and oceans are likely to lead to more intense storms, particularly hurricanes and typhoons. Heavy precipitation events will likely become more frequent throughout the 21st century.

Regional precipitation changes – Middle East case study



Projected precipitation changes in volume (mm/yr) and percentage (%) across the Gulf region for the 2020s, 2040s and 2070s, relative to the 1990s.

Average precipitation is projected to decrease throughout the 21st century across the Middle-East region.

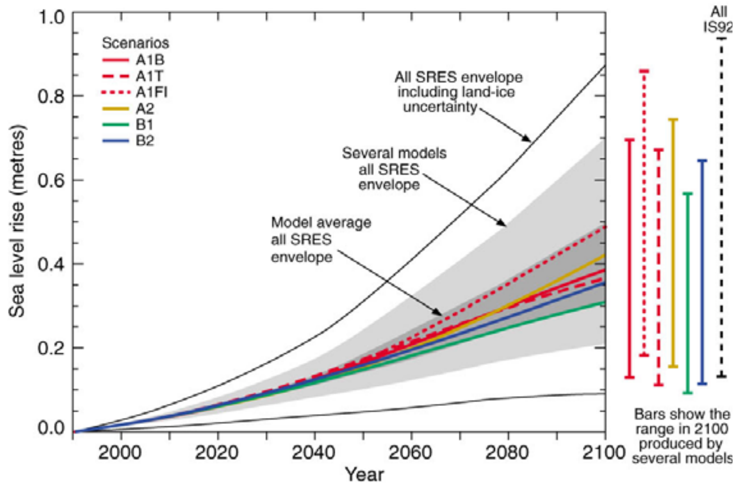
Projections indicate increases in precipitation of up to 100mm/yr (~30%) by the 2020s and 130mm/yr (~35%) by the 2040s over the Ethiopian highlands and south-west coastal fringe of the Arabian peninsular.

Decreases in precipitation of up to -100mm/yr (~-20%) by 2020s and -140mm/yr (~-30%) by 2040s are projected across Turkey, Lebanon, northern Syria, the Zagros mountain region of west Iran, the Hindu Kush region of Afghanistan and areas within central Iran and Afghanistan.

Seasonally, the largest percentage decreases in precipitation (up to -30% by 2020s, -60% by 2040s, and -80% by 2100) are projected for Turkey and the coastal regions surrounding the eastern Mediterranean during summer, southern Saudi Arabia during autumn, and central Egypt and Afghanistan during winter. The largest increases (up to 150% by 2020s and 300% by 2040s) are over central Iran during summer, and eastern Sudan during winter.

Sea level rise and storm surges

Global changes



Global average sea level projections for 1990 to 2100 using 6 SRES emissions scenarios and various global climate models (IPCC, 2001).

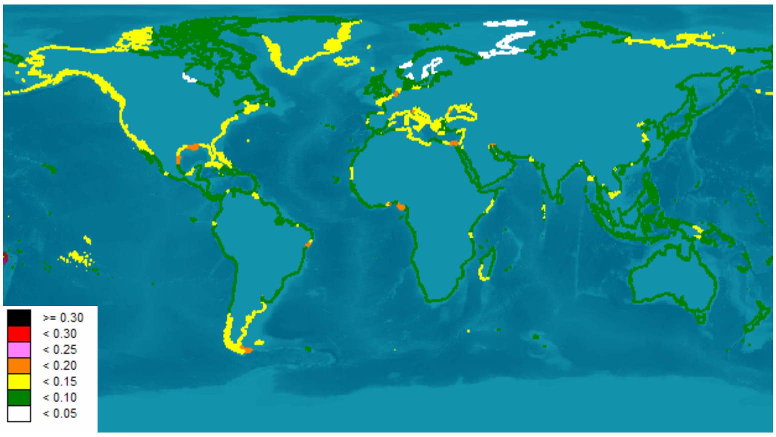
Global sea level is projected to rise by an average of 0.09m by 2030, 0.16m by 2050, and 0.39cm by 2100.

The spread in projections reflects uncertainties among global climate models and the future emissions of greenhouse gases and aerosols.

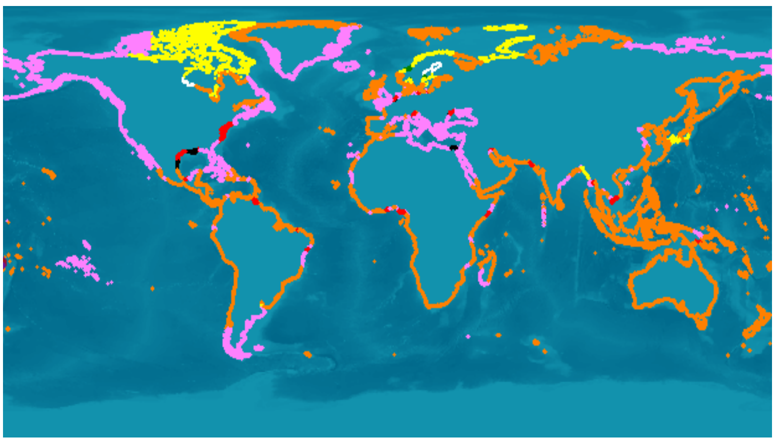
The causes of this sea level rise are: Thermal expansion of ocean water (~58%), glacial melt (~35%), Greenland ice sheet (from ~8% at 2000 to ~ 15% by 2100) and Antarctic ice sheet decreases from ~2% at 2000 to a net gain of about 5% by 2100.

Regional detail

2020s



2040s



Spatial distribution of Sea Level Rise (meters) by 2020s and 2040s for the average of 5 global climate models and 4 SRES emissions scenarios. Land uplift and subsidence estimates are included.

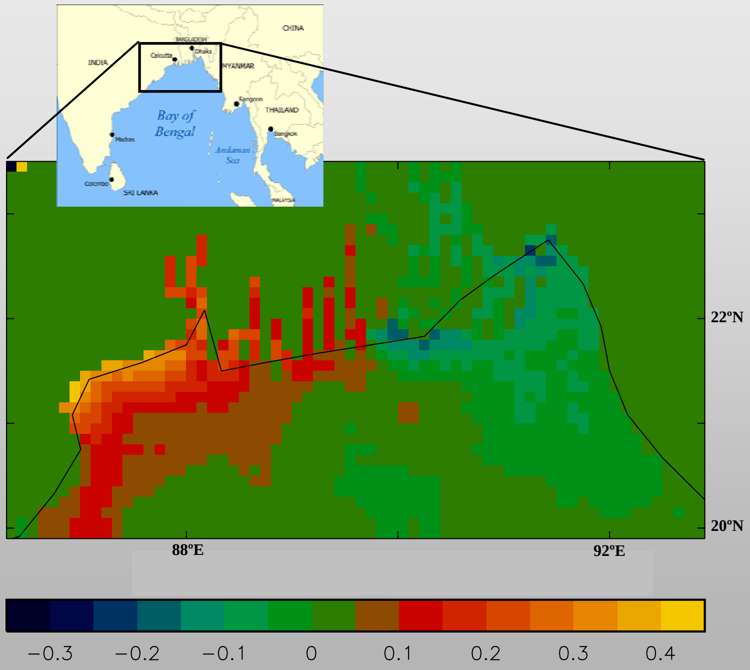
Sea level rise (relative to the coastline) is projected to be highest along the eastern seaboard of USA, Gulf of Mexico, southern tip of South America and Falkland Islands, Netherlands, and at many of the deltas of large rivers, including the Mississippi, Rio Grande, Rhone, Nile, Euphrates, Tigris and Niger.

Regions experiencing the highest sea level changes are projected between 0.14m and 0.24m of rise by 2030 and between 0.24m and 0.35m by 2050.

By 2050 the highest sea level rise (greater than 0.3m) is projected for the Gulf of Mexico and Nile delta regions.

However, the impact of sea level rise is highly dependent on the vulnerability of coastal regions, i.e. population density, low-lying land area and sea defences (see section on ‘coastal flooding’).

Storm surges – Bay of Bengal case study



Projected change in extreme (99.99 percentile) water levels in the northern Bay of Bengal between 1961-1990 and 2071-2100 using the B2 SRES emissions scenario.

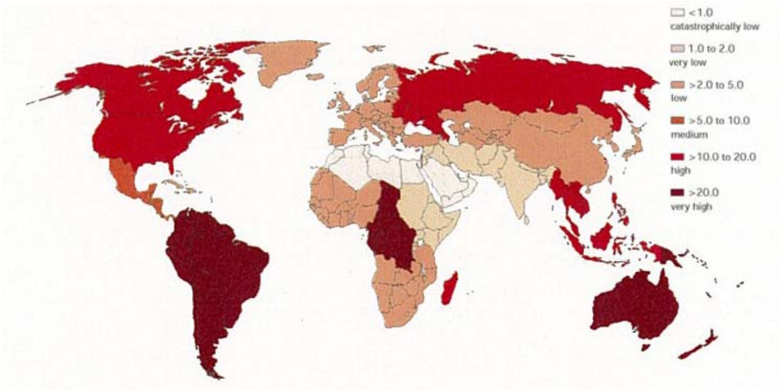
The shallow northern coastline of the Bay of Bengal is particularly vulnerable to high storm surges that are driven by tropical cyclones.

The number of tropical cyclones is projected to increase in the Bay of Bengal region under future climate change.

Increases in storm surges in the north-west of the Bay of Bengal are projected to increase water levels by over double that of global sea level rise projections.

Environmental Stresses of Climate Change

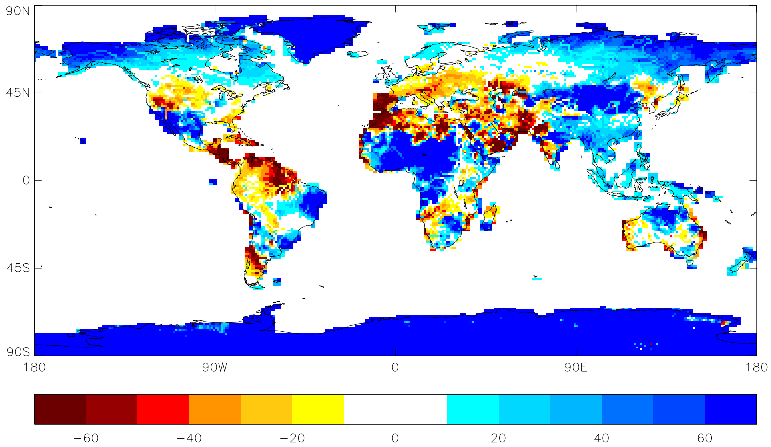
Water stress and drought



Current water availability measured in terms of 1,000m³/capita/year (GEO-3, 2002).

In the mid-1990s approximately 1.7 billion, one third of the world's population, were considered to live in water stressed countries, and 20 % of these lacked access to safe drinking water (UNEP, 2000). Most of these people are in Africa and Asia.

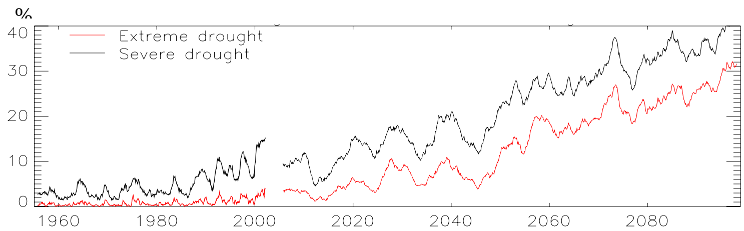
According to the Global Environment Outlook (GEO-3, 2002) more than half the population in the world could be living in severely water-stressed areas by 2032. West Asia, including the Arabian Peninsula, is likely to be the worst affected with well over 90 % of the population likely to be living in areas with "severe water stress" by 2032.



Predicted changes in average global river flow (%) between 1961-1990 and 2071-2100 for the A1B SRES emissions scenario (Falloon & Betts, 2006).

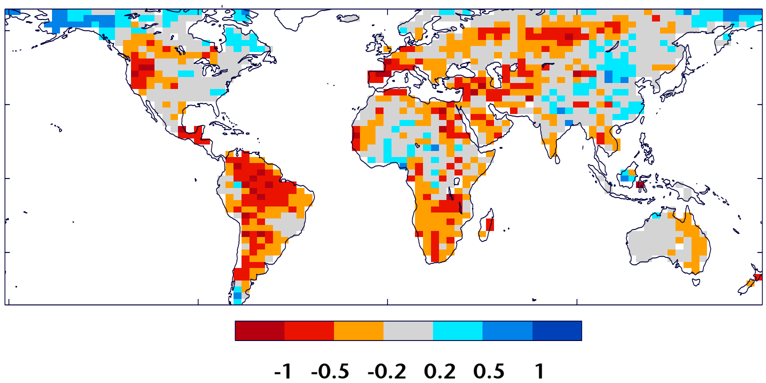
Future projections of river flow also indicate large decreases in water availability across west Asia the Middle-East, central America and the Mediterranean and Amazon basins. In these regions, river flows are projected to decrease by up to 70% by 2071-2100.

The largest increases in river flow are projected across the boreal regions, northern China and central-west Africa.



Proportion of land surface in drought each month. Drought is defined as extreme and severe relative to 1% and 5%, respectively, of the land surface in drought under present-day condition (Burke et al., 2006).

Land area exposed to severe and extreme droughts is projected to increase during the 21st century from ~10% to 20 % by 2050 and to 40 % by 2100.

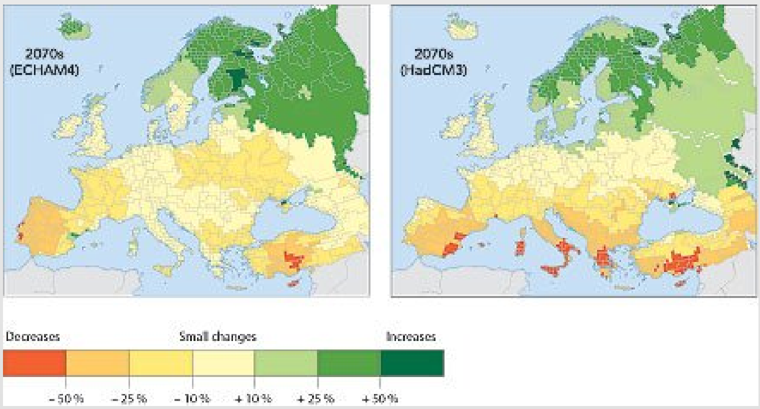


Trend in the Palmer Drought Severity Index per decade for the period 2000-2046 projected using the HadCM3 climate model and A2 SRES scenario (Burke et al., 2006).

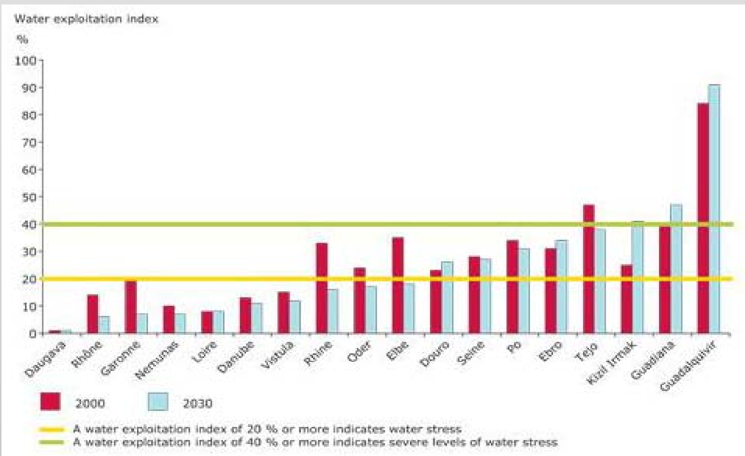
Severe increases in drought (represented by the Palmer Drought Severity Index) are projected for the Mediterranean basin, Gulf, southern Africa and South and Central America (particularly the Amazon basin.

Burke EJ, Brown SJ & Christidis N. 2006. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. Journal of Hydrometeorology 7, 1113-1125.
Falloon PF & Betts RA. 2006. The impact of climate change on global river flow in HadGEM1 simulations. Atmospheric Science Letters 7, 62-68.

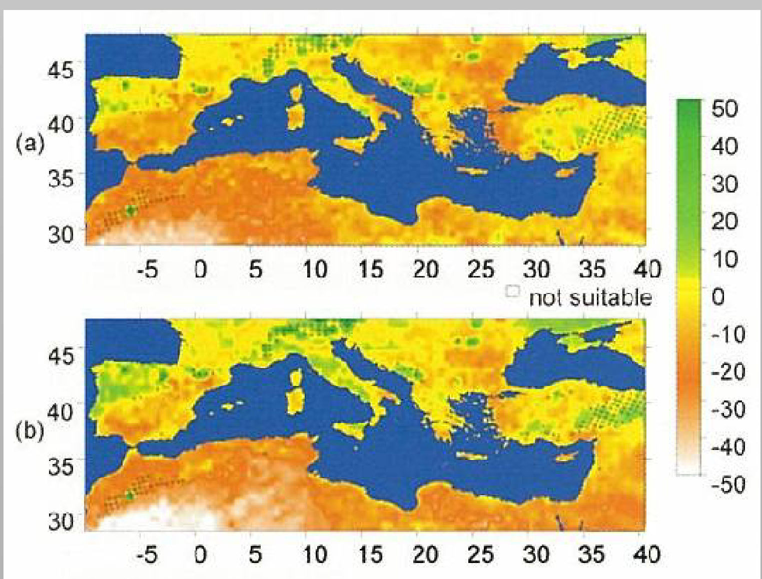
Water stress – Mediterranean case study



Mediterranean areas already experiencing water deficit, particularly Spain, Portugal, Italy, north Africa during summer, are expected to experience more severe conditions in the future.



In southern Europe reduced rainfall and increased evaporation are likely to reduce runoff in many river basins in Greece, southern Italy and Spain, and parts of Turkey by 10% or more by 2030.



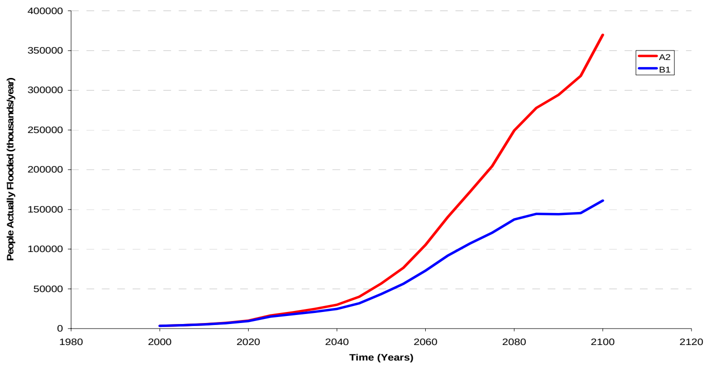
Percentage change (2070-2099 minus 1961-1990) in summer crop yield across the Mediterranean region as a result of climate change with the (a) A2 and (b) B2 SRES scenario (MICE final report).

Increasing water stress and higher temperatures, especially during crop development, are projected to reduce summer crop yield across the Mediterranean by as much as -30%.

Decreases in crop yield are expected to be particularly acute in North Africa.

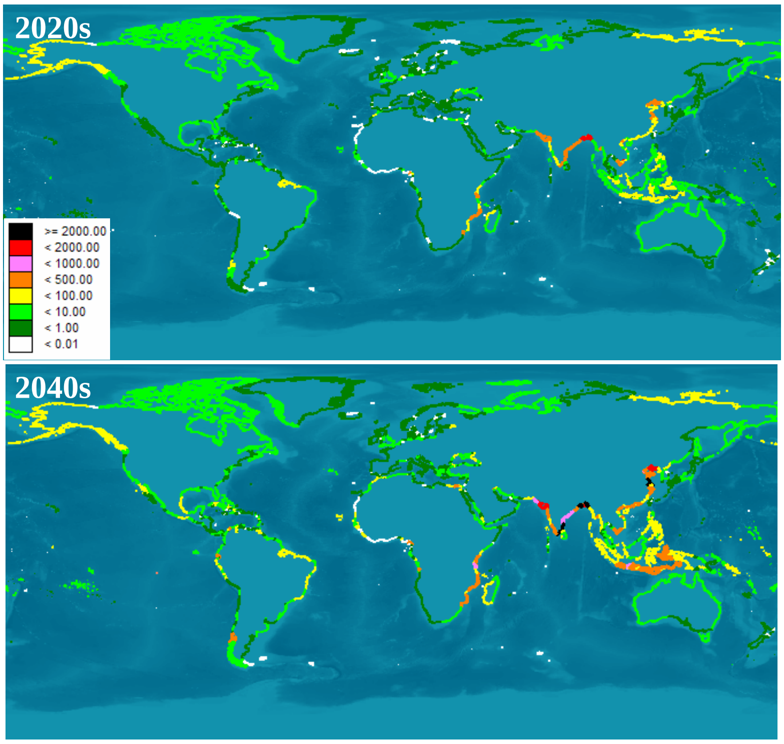
Coastal and river flooding

Sea level rise



Projected time series of People Flooded (thousands per year) globally between 2000 and 2100 with population change according to the A2 (high) and B1(low) SRES scenarios. These simulations assume no change in current coastal defences.

The global number of people flooded each year is projected to increase from less than 5 million to ~20 million by 2030, ~50 million by 2050 and between ~160 million (low emissions scenario) and 370 million (high emissions scenario) by 2100.



Spatial distribution of People Flooded (thousands per year) by 2030 and 2050 for the average of 5 global climate models and 4 SRES emissions scenarios. Future population increases are assumed to be in line with the A2 SRES scenario.

The largest coastal agricultural land areas at risk of flooding from sea level rise are in Pakistan, India, Indonesia and the east coast of Africa. These regions have relatively expansive low lying coastal agricultural regions and low current dike heights.

The largest populations at risk from sea level rise are located in Bangladesh, India, Pakistan, eastern China, southern Indonesia, the Maldives and Java.

Other populations at risk of flooding are along the east coast of Africa, southern tip of Chile and in the Nile delta. These risks result from high coastal floodplain population densities and low sea dike heights.

River	Maximum monthly outflow and month (m^3s^{-1})		Change in maximum monthly outflow (%)
	1961-1990	2071-2100	
Brahmaputra, Bangladesh	70590 (Sep)	83620 (Aug)	18.5
Changjiang/Yangtze, China	63440 (Oct)	84850 (Oct)	33.7
Congo (Zaire), Congo/Zaire	51990 (Jan)	70540 (Jan)	35.7
Ganges, Bangladesh	43880 (Sep)	59070 (Sep)	34.6
Irrawaddy, Myanmar	40120 (Sep)	56700 (Sep)	41.3
Sao Francisco, Brazil	37700 (May)	57420 (Apr)	52.3
Xi/His (Pearl), China	30270 (Aug)	41640 (Aug)	37.6
Kolymy, Russia	12760 (Jun)	22580 (Jun)	76.9
Niger, Nigeria	9541 (Sep)	22590 (Oct)	136.8
Chari/Shari, Chad	3527 (Oct)	14290 (Oct)	305.0

Changes in maximum monthly river flow for 10 rivers showing the largest increases. Values are based on averages for the 1961-1990 and 2071-2100 periods with the future A2 SRES scenario (Falloon & Betts, 2006).

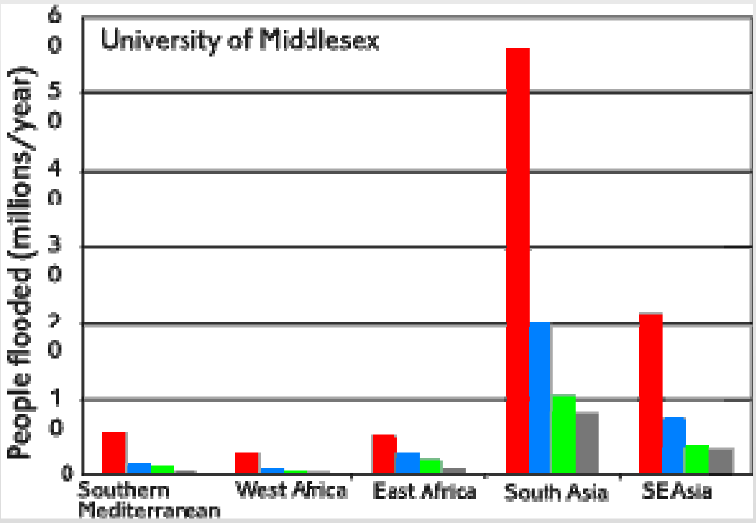
Globally, river flows are projected to increase about 4-8% by 2071-2100.

More frequent and severe flooding is likely in areas where peak river flows increase significantly.

Large increases in maximum river flows of between 18% and 305% are projected for rivers in central Africa (Chad, Nigeria and Congo), Russia, China, Brazil, Myanmar and Bangladesh.

Falloon PF & Betts RA. 2006. The impact of climate change on global river flow in HadGEM1 simulations. Atmospheric Science Letters 7, 62-68.

Flooding – South Asia case study



Average annual number of people flooded for five vulnerable continental regions in the 2080s under the three emissions scenarios: unmitigated (red), stabilisation at 750 ppm (blue) and stabilisation at 550 ppm (green). Also shown is the case of no climate change (grey) (Nicholls).

With 0.4m sea level rise (average 2080 projection with high emissions scenario), the number of people flooded globally is estimated to increase from 13 million per year to 94 million per year. 60 % of these will occur in South Asia (from Pakistan, through India, Sri Lanka and Bangladesh to Myanmar).

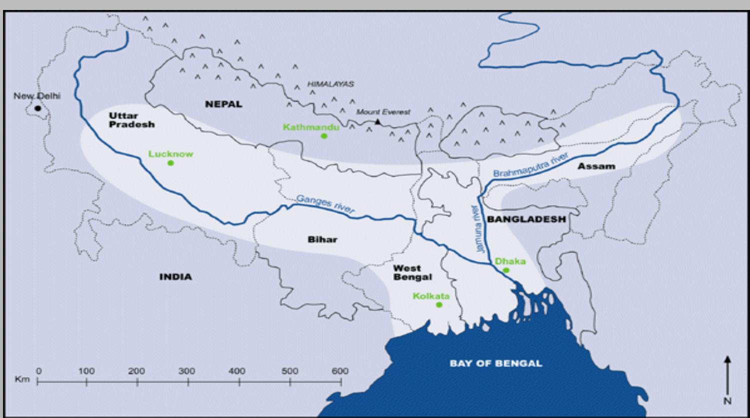
By stabilising future greenhouse gas emissions the number of people flooded from sea level rise could be significantly reduced (green and blue bars in figure).

Country	Sea-level rise	Potential Land Loss		Population Exposed	
	(cm)	(km^2)	(%)	(millions)	(%)
Bangladesh	45	15,668	10.9	5.5	5.0
Bangladesh	100	29,846	20.7	14.8	13.5
India	100	5,763	0.4	7.1	0.8
Pakistan	20	1,700	0.2	n.a.	n.a.

Potential land loss & population exposed in India, Bangladesh & Pakistan for selected magnitudes of sea-level rise, with no adaptation measures (Modified from IPCC (2001) Table 11-9, p.569).

Projections of land loss and number of people exposed to flood risk from sea level rise in Bangladesh, India and Pakistan highlight the vulnerability of Bangladesh to coastal flooding.

With sea level rise of 45cm and 100cm Bangladesh could loose ~11% and 21% of land area and 5% and 13.5% of the population may be exposed to coastal flooding.



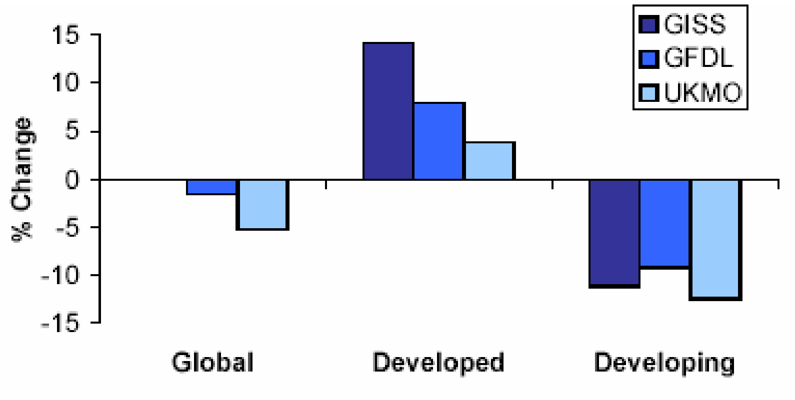
Brahmaputra and Ganges River basins.

Future projections indicate increases in the risk of flooding of the rivers flowing through Bangladesh.

For a 2ºC global temperature rise (~2050s) and high emissions scenario, average flood discharge for the Ganges, Brahmaputra and Meghna rivers could be as much as 15%, 6% and 19% higher, respectively (Mirza et al, 1998)

Robert Nicholls. http://www.bdix.net/sdnbd_org/world_env_day/2002/current_issues/sea_label_rise/middlesex-univ.htm
IPCC, 2001. Climate Change: Impacts, Adaptation and Vulnerability. Cambridge University Press. 1032pp.
Mirza MQ, Warrick RA, Ericksen NJ & Kenny GJ. 1998. Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna basins in South Asia. Hydrological Sciences Journal, **43**, 845-858.

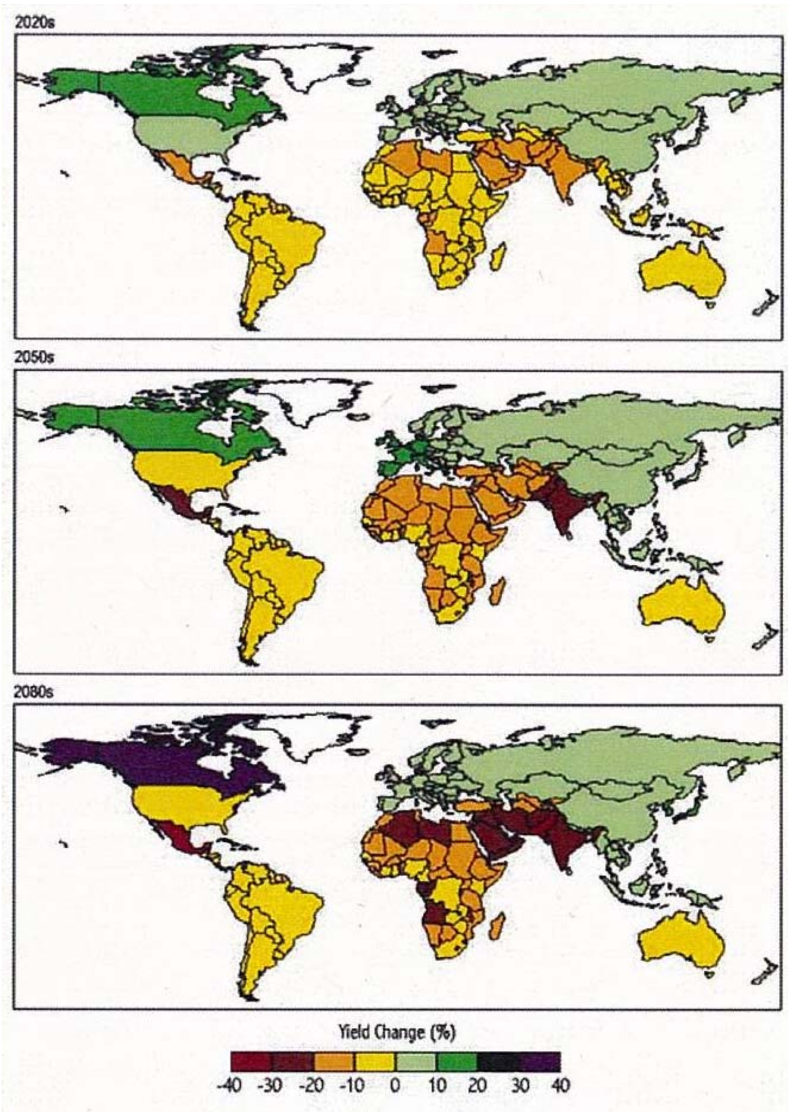
Crop yield



Change in cereal production in developed and developing countries for a doubling of CO_2 (equivalent to ~3ºC global warming) simulated with three climate models (GISS, GFDL and UKMO Hadley Centre) (in Parry et al., 2005).

The impact of climate change on crop yield varies greatly according to the species and site characteristics.

Cereal production in developing countries is projected to decrease by ~-10% under a doubled CO_2 climate. This results from a pole-ward shift in the most suitable growth conditions for cereals into developed countries.



Percentage change in average crop yield for wheat, maize and rice using the HadCM3 climate model. Influence of CO_2 on plant growth is included.

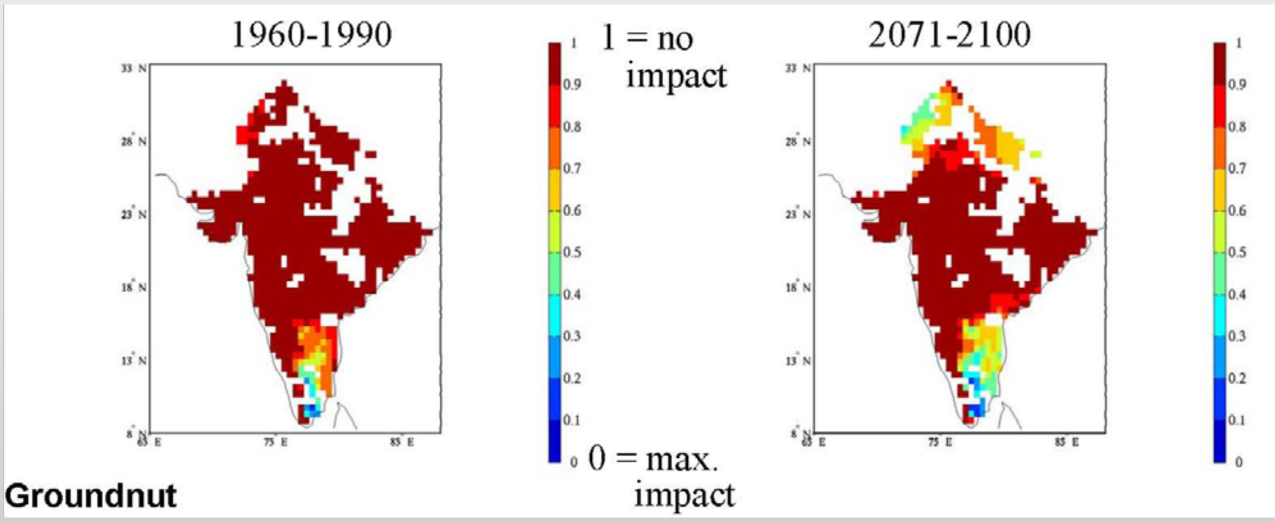
Temperate and boreal zones (USA, Canada, northern Europe and northern Asia) are generally projected increases in crop yields with moderate warming to 2020s and 2050s. This is the result of warmer temperature and enhanced atmospheric CO_2 increasing photosynthesis.

In tropical regions where some crops are near their maximum temperature threshold and in water limited agricultural regions (S. America, Africa, Middle East, SE Asia and Australia) yields are projected to decrease under climate change.

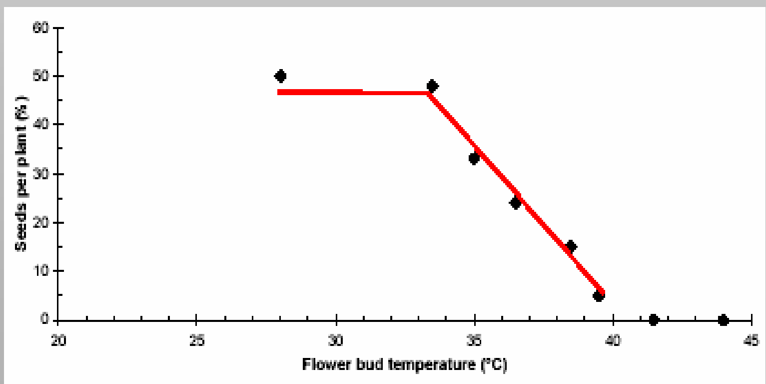
Crop yields in India, Pakistan, countries across the Gulf, north-west Africa, south-west Africa and central America are projected to experience the largest decreases, up to -40%.

Parry, M.L, C. Rosenzweig, and M. Livermore. 2005 Climate change, global food supply and risk of hunger. Philosophical Transactions of the Royal Society B **360**, 2125 – 2136

Food security – India case study



Change in water and temperature stress at flowering of Groundnut across India between 1960-90 and 2071-2100 under climate change driven by the A2 SRES scenario (Challinor et al., 2005).



Yield loss caused by high temperature in groundnut (peanut) in India (Vara Prasad et al., 2001).

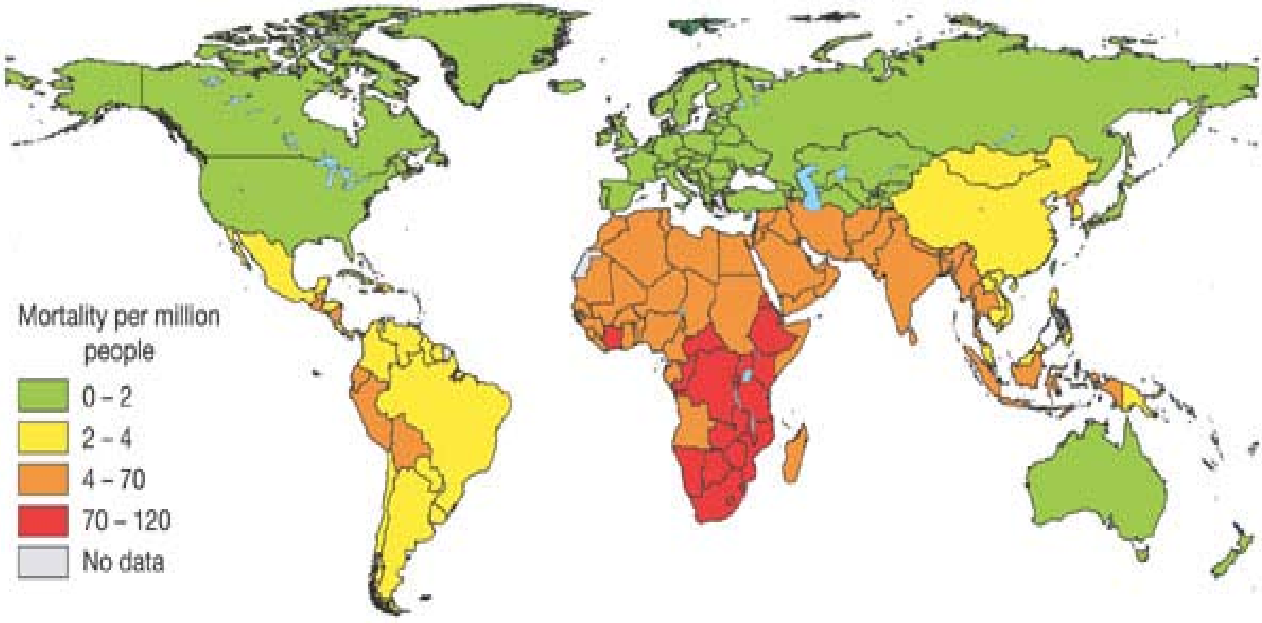
Groundnut yield in India is projected to decrease under climate change as a result of enhanced water stress in the south and temperature stress in the north.

By the late 21st century increases in both the mean and variability of temperature are expected to exceed the critical threshold for Groundnut growth more frequently, resulting in reduced yields.

Challinor A.J., Wheeler T.R., Slingo J.M., Hemming D. (2005). Quantification of physical and biological uncertainty in the simulation of the yield of a tropical crop using present day and doubled CO2 climates. Philosophical Transactions of the Royal Society B, 360, 2085-2094.
Vara Prasad, P.V., P.Q. Craufurd, V.G. Kakani, et al. 2001. Influence of high temperature on fruit-set and pollen germination in peanuts. Australian Journal of Plant Physiology **28**, 233.

Human health

Currently, the World Health Organisation (WHO) estimates over 150,000 deaths and approximately five million 'disability-adjusted life years' (DALYs) per year can be attributed to climate changes since the mid-1970s. The majority occur in developing countries as a result of increasing incidences of diseases such as diarrhoea (temperature effects only), malaria and malnutrition.



Climate change related increases in human mortality based on cardiovascular diseases diarrhoea, malaria, inland and coastal flooding, and malnutrition, for 2000. Climate change projections are made using the business as usual 'IS92a' scenario and the HadCM2 Hadley Centre global climate model and are compared to the baseline 1961-1990 levels (Patz et al., 2005).

Disease/Illness	Annual Deaths	Climate change component (death / % total)
Diarrhoeal diseases	2.0 million	47,000 / 2%
Malaria	1.1 million	27,000 / 2%
Malnutrition	3.7 million	77,000 / 2%
Cardiovascular disease	17.5 million	Total heat/cold data not provided
HIV/AIDS	2.8 million	No climate change element
Cancer	7.6 million	No climate change element

Source: WHO (2006) based on data from McMichael et al. (2004). The numbers are expected to at least double to 300,000 deaths each year by 2030.

WHO estimates of extra deaths from climate change in 2000 (in Stern, 2007).

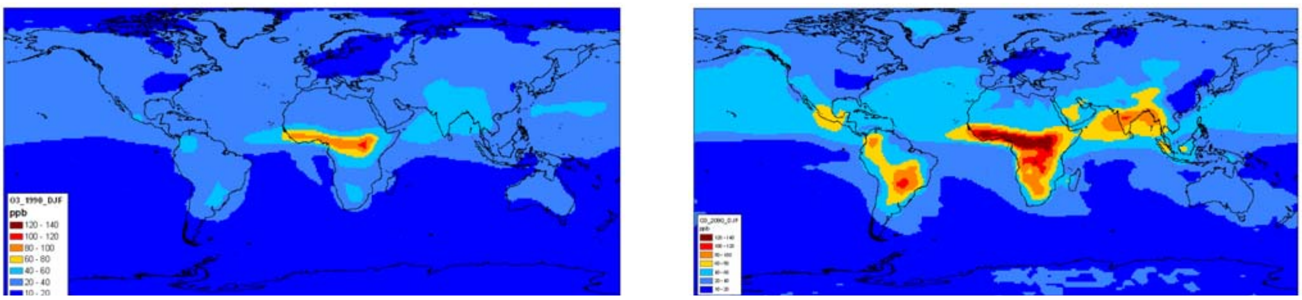
WHO projections of the health impacts from future climate change indicate current mortality will more than double by 2030 (McMichael et al., 2004).

Health risks from climate change are expected to be most acute for populations across Africa, the Middle-East, south Asia and parts of central and south America.

Flood related mortality is projected to rise significantly (see section on coastal and river flooding) and modest increases are projected in diseases including malaria, malnutrition and diarrhoea with future climate change.

Heatwaves are predicted to intensify and become longer in duration (see case study on the European heatwave).

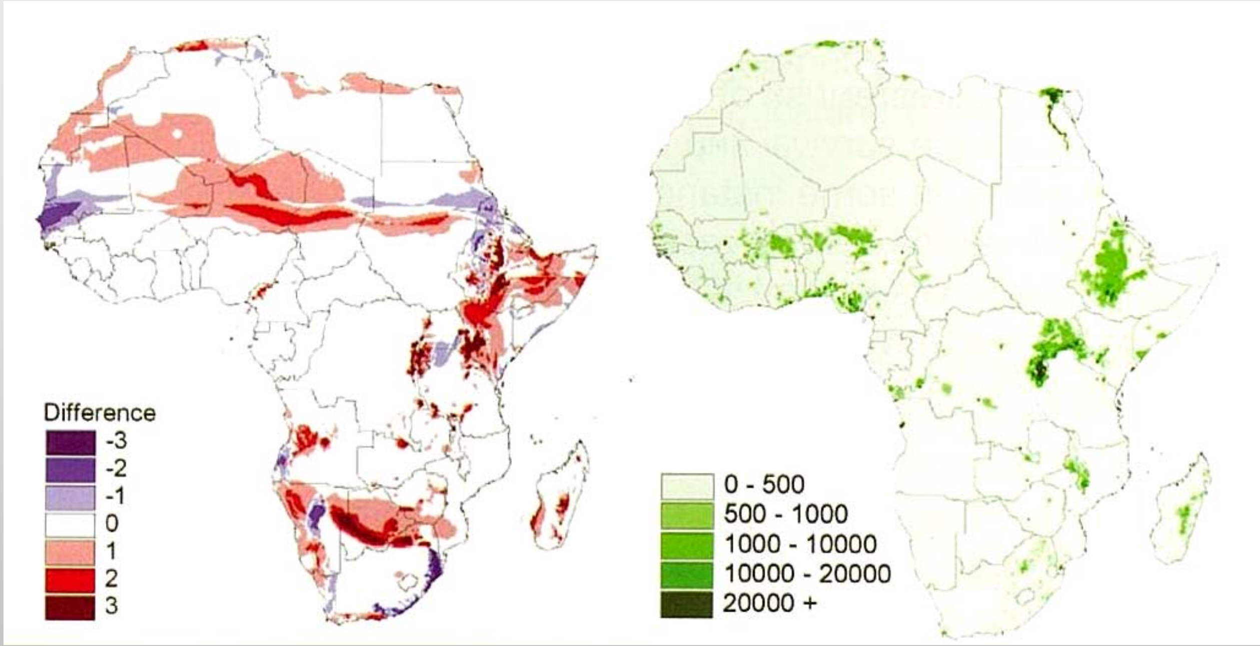
Low-level ozone is projected to increase significantly in some regions and seasons under climate change to concentrations that exceed the WHO 8 hour human exposure maximum guideline concentration of 60 parts per billion.



Winter average low-level ozone concentrations for a) 1990 and b) 2090 estimated using the Hadley Centre climate model HadCM3 coupled to the STOCHEM tropospheric chemistry model. Zones coloured in orange/red highlight concentrations above 60 ppb (Sanderson et al., 2003)

Patz JA, Campbell-Lendrum D, Holloway and Foley JA. 2005. Impact of regional climate change on human health. Nature 438, 310-317.
Stern N. 2007. The Economics of Climate Change. Cambridge University Press. 770 pp.
McMichael, A. J. et al. in Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors (eds Ezzati, M., Lopez, A. D., Rodgers, A. & Murray, C. J. L.) Ch. 20, 1543–1649 (World Health Organization, Geneva, 2004)
Sanderson MG, Jones CD, Collins WJ, Johnson CE and Derwent RG. Effect of climate change on isoprene and surface ozone levels. Geophysical research letters 30(18).

Human health – Malaria in sub-Saharan Africa case study



Change in climate suitability class (red = more suitable: blue = less suitable) across Africa between 2005 and 2030 as a result of climate change (left figure). The right figure shows projected population growth over the same period allowing visualisation of the population areas most at risk of malaria (Brownlie et al., 2006).

Climate change is one of several drivers that control the changes in risk of human populations to infectious diseases

In Africa, climate change alone is projected to increase the population at risk from malaria by 13% by 2015 and 14.5% by 2030. However, human population growth is predicted to increase the population at risk from malaria by a greater amount; 22% by 2015 and 61% by 2030.

The MARA (Mapping Malaria Risk in Africa) project estimates an increase of 16-28% in the number of people exposed per month to malaria risk by 2100, excluding any increase in population (Patz et al., 2005).

Brownlie J, Peckham C, Waage J, Woolhouse M, Lyall C, Meagher L, Tait J, Baylis M & Nicholl A. 2006. Forsight. Infectious Diseases: preparing for the future. Future Threats. Office of Science and Innovation, London83pp.
Patz JA, Campbell-Lendrum D, Holloway and Foley JA. 2005. Impact of regional climate change on human health. Nature 438, 310-317.