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RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Introduction

The ENSEMBLES project (contract number GOCE-CT-2003-505539) is supported by the European Commission's 6th Framework Programme as a 5 year Integrated Project from 2004-2009 under the Thematic Sub-Priority "Global Change and Ecosystems". This assessment of health impacts is part of Workpackage 7.3 of RT7 (Research Theme 7) coordinated by Dr Roberto Roson at FEEM, Italy.

This paper reports the Milestone M7.4 – The estimates by region of the impacts of climate change on mortality and morbidity with a brief description of the methods. More detailed description of the methods and sensitivity analyses are available in the relevant journal papers. .

Climate scenarios

ENSEMBLES required a global and regional assessment and therefore the populations in different climates needed to be taken into account. Climate-health relationships are determined by climate as well as by socio-economic and other environmental determinants. We estimated the impacts of climate change for 21 World Regions, which are aggregated to 6 major regions (as defined by the World Health Organization).

Table 1. Region characteristics, based on climate zones with at least 5% of the regional population

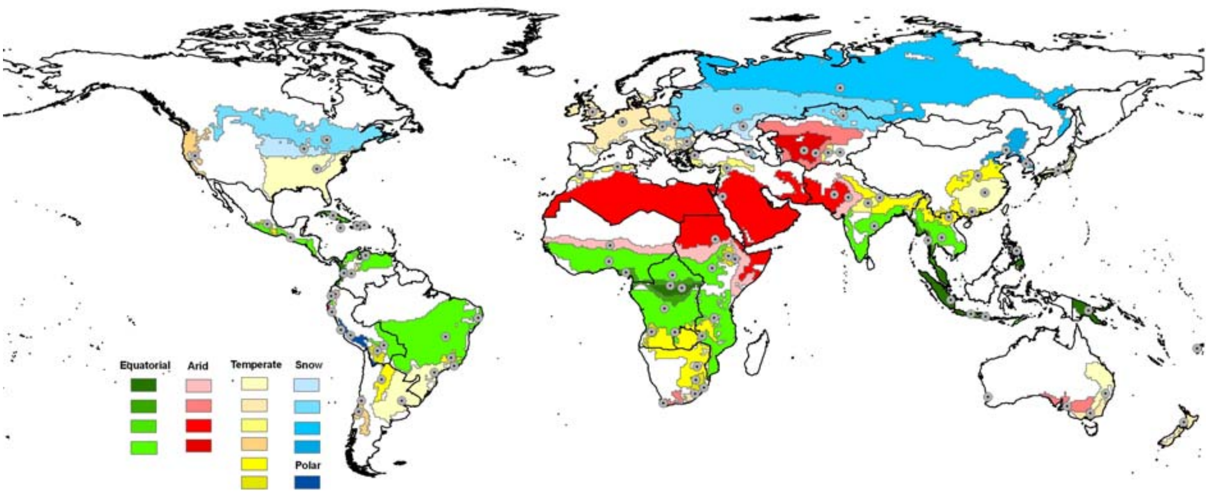
World Region	Main climate types* (% population in the region)	Number of climate grid points	% of population represented
1. Asia Pacific, High Income	warm temperate, fully humid, hot summer (63%) snow, winter dry, hot summer (11%)	2	74%
2. Asia, Central	warm temperate, summer dry, hot summer (13.2%)	6	52%
3. Asia, Eastern	warm temperate, fully humid, hot summer (33%) warm temperate, winter dry, hot summer (27%) snow, winter dry, hot summer (11%)	4	79%
4. Asia, South	equatorial, winter dry (34%) warm temperate, winter dry, hot summer (27%) hot steppe (11%)	5	86%
5. Asia, South East	equatorial, fully humid (24%) equatorial, winter dry (20%)	7	76%
6. Australasia	warm temperate, fully humid, hot summer (35%) warm temperate, fully humid, warm summer (26%) warm temperate, fully humid, warm summer (16%)	5	91%
7. Caribbean	equatorial, winter dry (32%) equatorial, winter dry (28%) equatorial, fully humid (15%)	4	83%
8. Europe, Central	warm temperate, fully humid, warm summer (63%) snow, fully humid, warm summer (19%)	3	90%
9. Europe, Eastern	snow, fully humid, warm summer (71%)	3	83%
10. Europe, Western	warm temperate, fully humid, warm summer (49%) warm temperate, fully humid, warm summer (16%)	2	64%
11. Latin America, Andean	equatorial, winter dry (14%) warm temperate, fully humid, warm summer (10%)	7	58%
12. Latin America, Central	warm temperate, winter dry, warm summer (15%) equatorial, winter dry (15%) equatorial, winter dry (14%)	5	55%
13. Latin America, South	warm temperate, fully humid, hot summer (51%) cold steppe (10%)	4	76%
14. Latin America, Tropical	warm temperate, fully humid, hot summer (33%) equatorial, winter dry (29%)	5	80%

15. North America, High Income	warm temperate, fully humid, hot summer (43%) snow, fully humid, warm summer (18%) snow, fully humid, hot summer (10%)	4	80%
16. North Africa – Middle East	hot desert (37%)	5	63%
17. Oceania	equatorial, fully humid (62%)	2	71%
18. Sub-Saharan Africa, Central	equatorial, winter dry (55%) equatorial, winter dry (12%)	6	92%
19. Sub-Saharan Africa, East	equatorial, winter dry (25%) hot steppe (10%)	6	66%
20. Sub-Saharan Africa, South	warm temperate, winter dry, hot summer (42%) warm temperate, winter dry, warm summer (19%)	5	87%
21. Sub-Saharan Africa, West	equatorial, winter dry (61%) hot steppe (22%)	3	91%

*Only types with ≥10% of regional population are listed; type appears more than once within a region if non-contiguous zones of the same type are present.

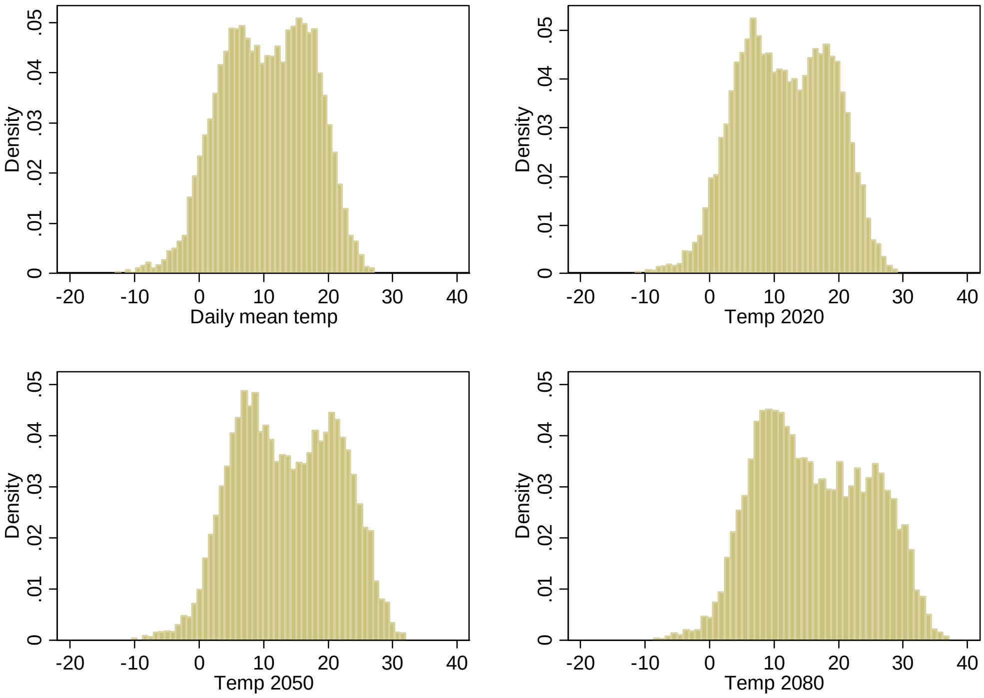
We selected grid cells (from the climate model grid) representative of the main climate types in which people live within each region, based on the Köppen climate classification [1]. A Geographic Information System (GIS) was used to allocate the proportion of the regional population (year 2000) to each climate zone, using the Gridded Population of the World version 3 (GPW v3) [2]. We then selected the climate zones in which at least 5% of the regional population resided (Table 1). A population-weighted centre point was calculated for each of these climate zones and the climate grid cell in which this was located was then chosen. This gave a total of 93 grid cells (Figure 1).

Figure 1. Location of population-weighted centroids of climate zones which were matched to climate modelling points within the 21 world regions (regional boundaries shown as black borders on map).



Daily data (24-hour averages) were extracted for these climate grid cells for the years 1960 to 2100 for two climate scenarios: A2 and B2 from the HadCM3 climate model [3]. These climate scenarios are derived from specified emissions scenarios that project future economic growth and technological development within a consistent storyline[4]. The A2 scenario assumes a high population growth and medium rapid economic development and therefore represents a moderately "high" emissions scenario. The B2 scenario assumes that greenhouse gas emissions are reduced through technological change and that there is more emphasis of governments addressing environmental problems through policy implementation. The increase in global mean temperature by the 2080s from pre-industrial levels is projected to be 3.4 °C (range 2.4 to 6.4) and 2.4 °C (range 1.4 to 3.8) for A2 and B2, respectively [5].

Figure 2. Changes in daily temperature distribution for a specified mid-latitude grid cell [HadCM3] under scenario A2 for 4 different time periods (30 years).



As with rainfall, the humidity output of climate models is less robust than the temperature data. Models work out surface moisture parameters using a surface flux model, so that there is a balance between the fluxes of energy from different parameters. The fluxes in HadCM3 were revised to give better comparisons with observations but this decreases the confidence in the projections of humidity. It is difficult to assess quality of the grid cell level humidity measure. We used the daily output for relative humidity to generate a temperature-humidity index (WBGT) (see paper Kjellstrom et al. on productivity). For the other outcomes (diarrhoeal disease and cardio-respiratory mortality), only temperature data were used.

Population scenarios and health futures

An important component of health impact assessment is the estimates of the baseline mortality. In the context of climate change, this entail robust estimates of current and future baseline (i.e. no climate change) disease rates. There is no information in the SRES on future disease burdens, but there are estimates of population growth (but not population ageing).

WHO has produced mortality projection to 2030 for the Global Burden of Disease project [6,7], the current burden of mortality was derived from the Global Burden of Disease assessment for mortality in 2002, published in the World Health Report 2004. These are the best available projections of mortality and are used in this assessment. Figure 3 summarise the cause and age-specific burdens for 2002 and 2030 by world region.

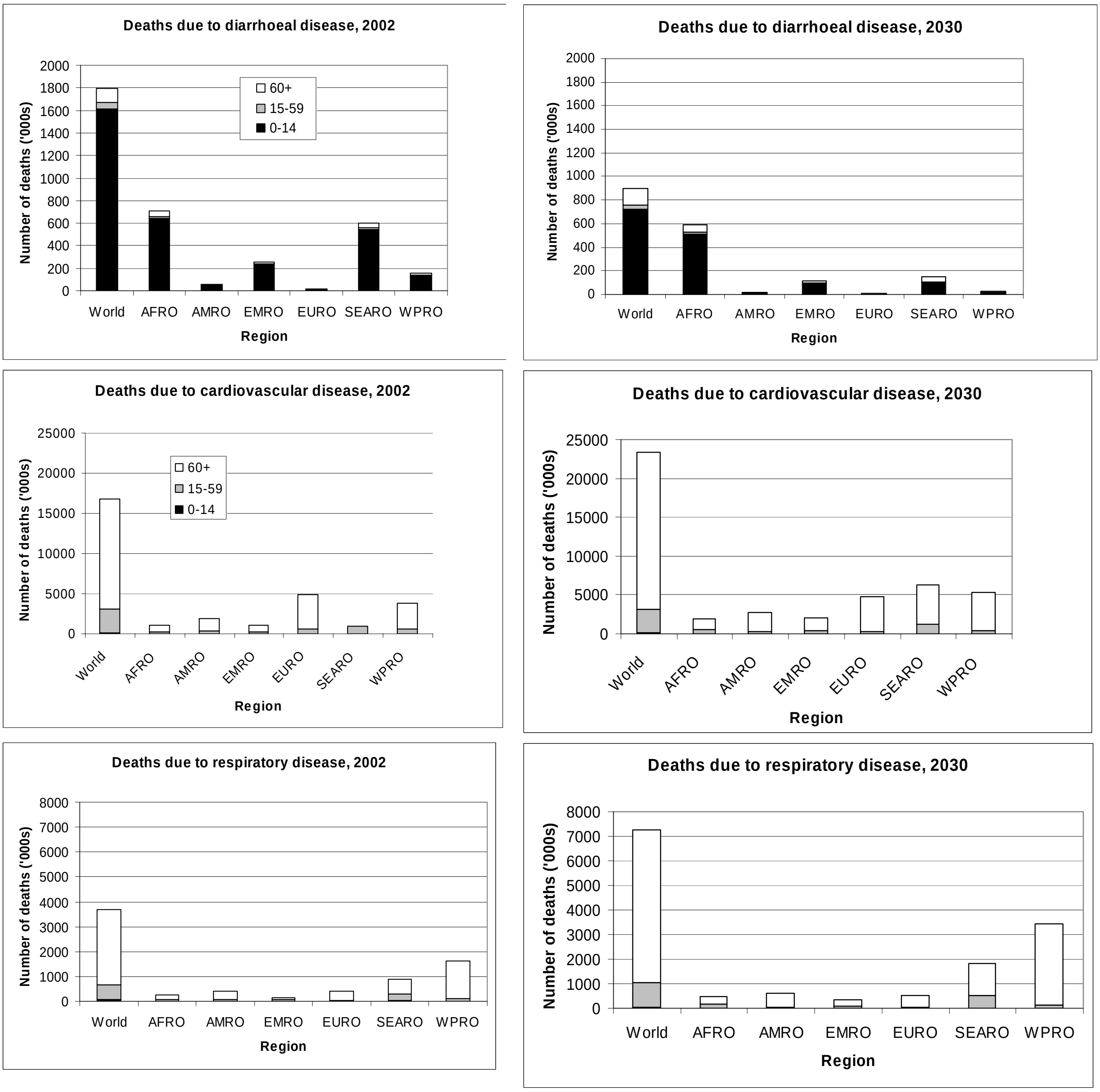
Briefly, these projections incorporate the following assumptions (under the baseline scenario):

- GDP growth as projected by the World Bank, approximately 3% per annum for most regions after 2015
- Mid-range UNPD population growth scenario of 7.1 billion in 2015

- Relationship between socio-economic development (GDP) and mortality in poor countries is unchanged in the future.
- Tobacco smoking increases (as a cause of respiratory disease) but no other specific risk factors are considered.

The burden of communicable diseases, (including diarrhoeal disease) are projected to decline in the future, whereas the burden of non-communicable diseases is projected to increase.

Figure 3. Summary of mortality (total number of deaths) for 2002 and 2030 by cause of death and age group for the major world regions.



Diarrhoeal disease mortality

Diarrhoeal disease is one of the most important causes of global ill-health in low income countries. It is recognised to be highly sensitive to climate and weather factors[8]. Diseases associated with water are varied and cover multiple environmental pathways. However, there are no published associations in the literature that quantify the link between climate, water availability and diarrhoeal disease. Although the recent paper by Lloyd et al.[9] indicated that diarrhoeal disease morbidity is higher in arid areas, this is insufficient evidence on which to base a global risk assessment. Therefore, this assessment uses published epidemiological time series studies that have shown associations between environmental temperature and diarrhoeal disease outcomes (reported diarrhoeal episodes or hospital admissions)[10].

Methods

A review of the published literature was undertaken to identify published quantitative estimates of an association between temperature, rainfall and diarrhoeal disease (mortality or morbidity). Previously, the WHO CRA results were based on two papers that quantified the short term association between temperature and diarrhoeal disease[11,12]. More recent work in Europe has quantified the effect of temperature on reported cases of salmonella. We restricted the assessment to the effect of increasing temperatures on the incidence of all-cause diarrhoea, making no prediction of the effect of changing rainfall patterns.

In all, 14 published studies were found that met our criteria literature (Kovats, forthcoming).. Temperature was found to increase the risk of diarrhoeal disease (non-specific) and bacterial diarrhoeal disease (salmonella, cholera, etc). The majority of the studies were generally of high quality. The exposure (climate) data were recorded at local meteorological stations, and can be considered to have negligible measurement error at the population level. The time-series methods used independently controlled for seasonal variations and long-term trend, imparting high confidence in to the observed effect of temperature on the outcome recorded. All studies report the short term association between temperature and diarrhoeal disease. All studies reported estimates of the change in risk per degree change in temperature (weekly or monthly). Extrapolation of this relationship to the future assumes that there is no change in the temperature-disease relationship. This is unlikely. Further, there is potential bias: if the temperature-responsiveness is indeed greater at low temperatures, extrapolation of an average value will tend to underestimate effects in areas which are on average colder, and overestimate in hotter regions.

A range of pathogens are responsible for diarrhoeal disease (in addition to the non-infectious causes) (Table 3). Viral agents (e.g. rotavirus) typically peak in the winter seasons (in temperate countries) and in rainy seasons (in tropical countries). However, these are excluded from the assessment as the evidence for an increase in temperature is relative weak. The effect of temperature on campylobacteriosis is also weak and this outcome is also excluded from the assessment.

The future burden of diarrhoeal disease due to climate change is calculated indirectly by estimating the proportion of infections due to “hot weather” under current and future climates. Region-specific exposure-response relationships and thresholds were assumed, following the methods developed in the Global Burden of Disease assessment [8].

Not all pathogens are temperature-sensitive. The distribution of pathogens varies by country and age group. Based on community based surveys of diarrhoeal disease in children in developing countries, it was estimated that[13]:

- approximately 20% of infections are due to pathogens, such as rotavirus, that are thought to be not sensitive to temperature effects,
- approximately 30% of infections are due to pathogens which are sensitive to temperature effects
- the remaining 50% of infections are of unknown aetiology.

Results

We estimated the additional burden of diarrhoeal disease due to climate warming, assuming no specific adaptation measures (but assuming improvements in adaptive capacity due to economic growth). The additional burden due to climate change is the temperature-attributable burden under the 2030s climate (averaged over the 10 year period surrounding 2030) compared to the temperature attributable burden estimated under the current climate (averaged for 1961 to 1991).

Table 3. Estimated burden of mortality due to climate change (temperature) impacts on diarrhoeal disease, by major world region.

World Region	Deaths due to diarrhoeal disease (all ages) (2002)	Deaths due to diarrhoeal disease 2030 (all ages)	Additional deaths due to climate change in 2030 A2	Additional deaths due to climate change in 2030 B2
AFRICA	707657	590,103	19,325	18,601
AMERICAS	56394	16,353	321	319
EASTERN MEDITERRANEAN	258718	111,853	5,943	6,191
EUROPE	16457	5,223	161	219
SOUTH EAST ASIA	603342	147,133	3,734	4,381
WESTERN PACIFIC	154269	27,725	575	523
WORLD	1797972	898,390	30,059	30,234

Heat-related cardio-respiratory mortality

Heat is a natural hazard and much is known about the effects of high temperatures on the human body. Episodes of extreme temperature can have significant impacts on health and present a challenge for public health and civil protection services. One of the most certain impacts of future anthropogenic climate change will be an increase in heat waves in many populations, and such heat waves will be more intense [5].

Methods

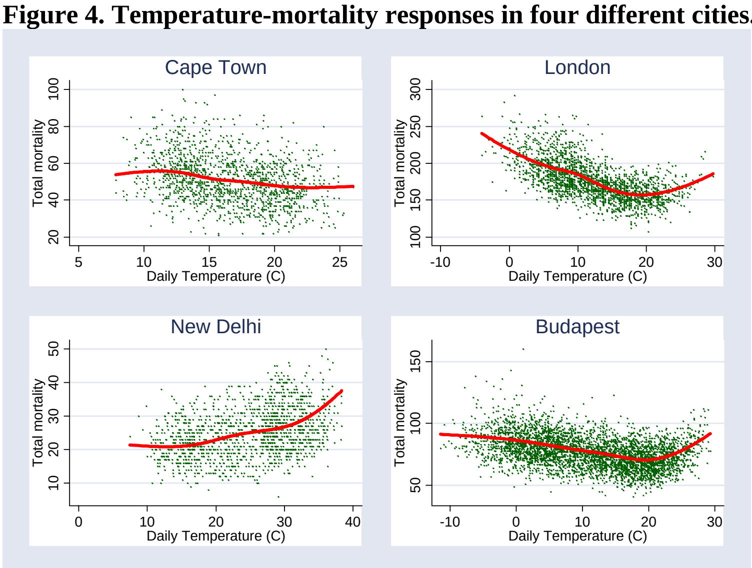
Models that estimate the annual temperature attributable mortality have been generated based on observed short term associations between temperature and mortality. Temperature-mortality relationships are locally specific, and show significant heterogeneity [14]. A review was undertaken to identify studies that quantified the relationship between temperature (heat) and cardio-respiratory mortality. The criteria used to select studies for deriving the modelled estimates were:

- Study uses daily time series methods to quantify the relationship between daily mean temperature and mortality.
- Study reports a coefficient from log linear regression that estimates the % changes in mortality per degree Centigrade changes in temperature above and below reported threshold temperature.

Daily temperature distributions for each region were estimated for each climate scenario (A2, and B2) using the method describe above. An exposure-response relationship and Tcutoff was applied within each region for cause and age-specific mortality. The number of days above ("hot days") this temperature were calculated for baseline climate and the 2 climate scenarios in 2030.

The proportion of temperature-attributable deaths were calculated using the heat mortality coefficients from the published literature. Climate change attributable deaths were calculated as the change in proportion of temperature-attributable deaths (i.e. heat-attributable deaths plus cold-attributable deaths) for each climate scenario compared to the baseline climate and each climate zone. In regions with predominantly temperate and cold climates, reductions in cold-related mortality are likely to be greater than increases in heat-related mortality. Climate scenarios show a net benefit on mortality in these regions, consistent with previous assessments. In these results, we present heat-related mortality only.

Figure 4. Temperature-mortality responses in four different cities.



Results

Table 4. Estimated burden of cardiovascular mortality due to climate change (temperature) impacts on cardio-respiratory mortality disease, by major world region.

World Region	Heat-related mortality 2002 (all ages)	Additional deaths due to climate change in 2030 A2	Additional deaths due to climate change in 2030 B2
AFRICA	38	46	34
AMERICAS	224	243	439
EASTERN MEDITERRANEAN	394	590	486
EUROPE	2771	5576	5616
SOUTH EAST ASIA	416	1449	1597
WESTERN PACIFIC	862	784	889
WORLD	4703	8688	9060

Direct effects on labour productivity

Global climate change will increase outdoor and indoor heat loads, and may impair health and productivity for millions of working people. We developed a method to estimate the direct impact of climate change on labour productivity, using physiological evidence about effects of heat, climate guidelines for safe work environments, climate modelling and global distributions of working populations.

Methods

WBGT is calculated from measurements of the natural wet bulb temperature (Tnwb), the globe temperature (Tg) and the dry bulb air temperature (Ta). WBGT outdoors is 0.7 Tnwb + 0.2 Tg + 0.1 Ta, and WBGT indoors is 0.7 Tnwb + 0.3 Tg. Tnwb and Tg outdoors are likely to be much higher than Tnwb and Tg indoors because of the influence of solar radiation. The specialised measurements for WBGT are not available from routine weather stations, and various formulas have been developed to estimate WBGT from routinely collected data (Ta, relative humidity, etc.). The Australian Bureau of Meteorology [15,16] proposes a method for estimating "WBGT" from air temperature (Ta) and relative humidity (RH), assuming moderately high heat radiation level in light wind conditions (approximately outdoor work in hot calm environments with some, but not extreme, sun exposure or indoor work with some local heat source).

We applied the method of estimating WBGT suggested by the American College of Sports Medicine in 1985[16]. Using 24-hour average temperature and relative humidity from the HadCM3 global climate model [3], we calculated WBGT using the Australian Bureau of Meteorology equations:

$$WBGT = 0.567 \times Ta + 3.94 + 0.393 \times E$$

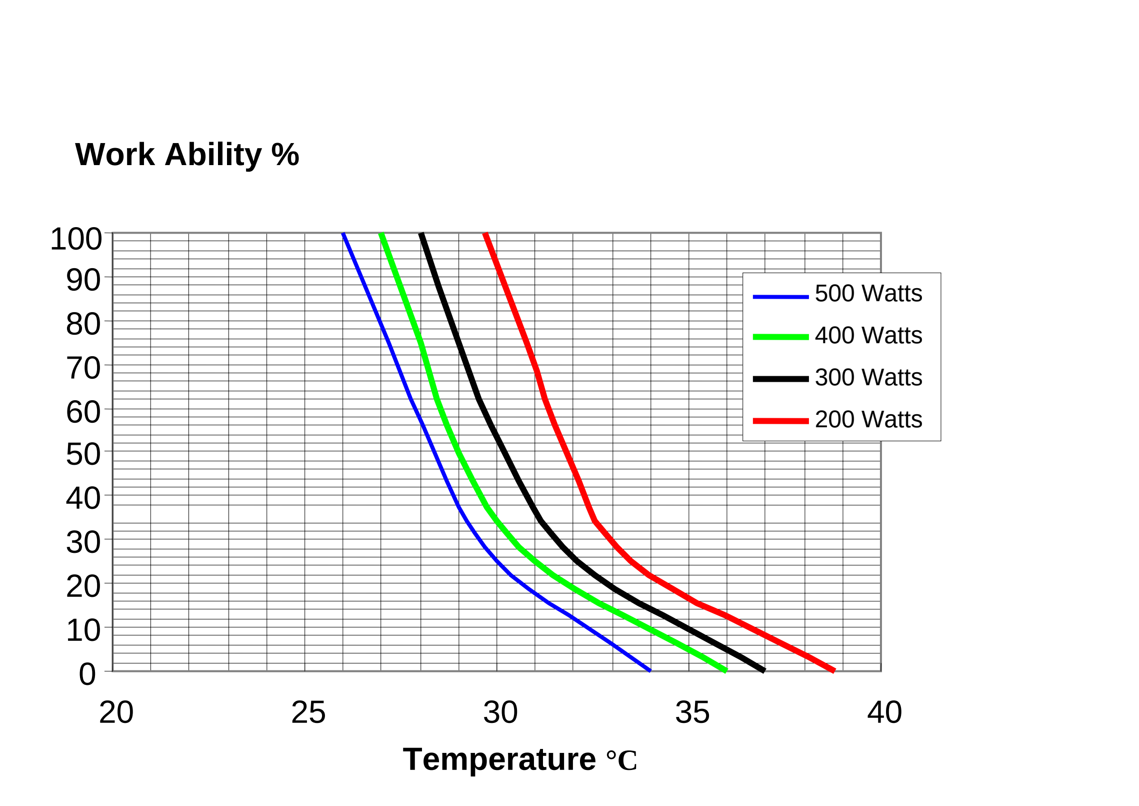
$$E = RH/100 \times 6.105 \times \exp(17.27 \times Ta / (237.7 + Ta))$$

Where Ta = 24-hour average shaded dry bulb air temperature in °C; E = 24-hour average absolute humidity (water vapour pressure) in hPa, hector Pascal; RH = 24-hour average relative humidity in %. The factor 3.94 represents impact of WBGT from radiated heat, and we found that this formula produces too high WBGT values. In our (TK) analysis of hourly data we noted that the difference between 24-hour averages and daytime means in hot places were generally between 3 and 5 °C. As a compromise we assumed that the WBGT values calculated from 24-hour values would represent the daytime mean WBGT outdoors.

Daily work WBGT estimates were made for the current climate (years 1961-1990) and three future 30-year time periods centred on the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099). In order to take into account indoor heat exposures for industrial and service sector workers, we used the approximation that indoor WGBT = outdoor WBGT – 4, based on a deduction of the radiation exposure factor 3.94 from the formula above.

The distributions of the number of days at different work WBGT values within each future time slice period were calculated. To provide a single estimate of the daily WBGT distribution for each world region, we combined the distributions for regional cells using population weighting. Using the ILO and NIOSH standards for acclimatized persons, Kjellstrom[17] produced a graph of "work ability" as the maximum percentage of an hour that a worker should be engaged working (Figure 5). The four curves represent four different work intensities. We assume that 200 W corresponds to office desk work and service industries; 300 W to average manufacturing industry work and 400 W to construction or agricultural work. 500 W corresponds to very heavy labouring work and is not considered in this analysis. Work ability rapidly diminishes within a 10-20 degree range.

Figure 5. Association between work ability and WBGT for four work intensities. Source: [17], based on recommendations by NIOSH [18].



The working population of each region was categorised into three sectors: service, industry and agriculture using World Bank data for 1990-2005 [19]. In each region, any country without labour data was assumed to have the same distribution pattern as the country with the nearest GDP for which labour data were available. Country data were combined using population-weighted averages to give estimates of labour distributions for each region.

Assuming the different work intensities for each sector, we estimated regional labour productivity as a weighted average based on the distribution of work activities across the three sectors within each region. We assumed that labour patterns change over time consistent with economic growth projected under the A2 and B2 emission scenarios[4,20]. North America was kept constant and all other regions converged towards this pattern as per capita income increased. Globally, GDP growth is higher under B2, and therefore more rapid convergence to the high income distribution occurs under this scenario than under A2.

We then calculated the number of days with reduced work ability for each day during each 30 year period using the WBGT work ability relationships in Figure 5. The loss in work ability for each day was added up for each 30 year period. The reductions in work ability are presented for the baseline climate (we assume this to be 1961-1990 as it the standard now used for climate impact studies). For the two climate modelling scenarios and three future time periods, the additional reductions in relation to the reference period (no climate change) were calculated. As sensitivity analyses, we performed the same calculations assuming both constant climate and constant labour patterns over time.

Results

Table 5: Impact of climate on labour productivity, as percent days lost and incremental loss relative to baseline, by region[1] for A2 and B2 scenarios, assuming changes in labour patterns.

Region	Impact	Baseline	2020s		2050s		2080s	
			A2	B2	A2	B2	A2	B2
AP_HI	%days lost	0.3%	0.2%	0.5%	0.5%	0.9%	2.0%	1.7%
	Increment		-0.1%	0.2%	0.2%	0.6%	1.7%	1.4%
As_C	%days lost	0.1%	0.4%	0.3%	0.5%	0.6%	1.1%	0.2%
	Increment		0.3%	0.1%	0.4%	0.4%	0.9%	0.1%
As_E	%days lost	10.1%	9.7%	11.3%	10.5%	7.7%	16.4%	10.4%
	Increment		-0.4%	1.2%	0.4%	-2.4%	6.3%	0.3%
As_S	%days lost	25.2%	30.1%	22.9%	29.6%	22.8%	32.7%	28.4%
	Increment		4.9%	-2.3%	4.4%	-2.4%	7.5%	3.2%
As_SE	%days lost	42.1%	38.2%	42.7%	44.1%	50.3%	59.1%	46.2%
	Increment		-3.9%	0.6%	2.0%	8.2%	17.0%	4.1%
Au	%days lost	0.0%	0.1%	0.1%	0.2%	0.2%	0.3%	0.3%
	Increment		0.0%	0.0%	0.2%	0.1%	0.3%	0.3%
Ca	%days lost	11.3%	12.3%	13.1%	19.1%	12.6%	25.3%	18.4%
	Increment		1.0%	1.8%	7.7%	1.2%	14.0%	7.1%
Eu_C	%days lost	0.1%	0.2%	0.4%	0.1%	0.1%	0.4%	0.3%
	Increment		0.0%	0.3%	0.0%	0.0%	0.3%	0.1%
Eu_E	%days lost	0.1%	0.2%	0.2%	0.5%	0.1%	0.2%	0.1%
	Increment		0.2%	0.2%	0.4%	0.0%	0.1%	0.1%
Eu_W	%days lost	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
	Increment		0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
LA_A	%days lost	1.8%	2.8%	2.7%	5.0%	2.9%	13.2%	6.7%
	Increment		1.0%	0.9%	3.2%	1.2%	11.4%	5.0%
LA_C	%days lost	15.5%	23.0%	22.9%	34.1%	19.9%	42.4%	31.5%
	Increment		7.5%	7.4%	18.6%	4.4%	26.9%	16.0%
LA_S	%days lost	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.2%
	Increment		0.1%	0.1%	0.1%	0.0%	0.2%	0.1%
LA_T	%days lost	11.9%	13.0%	13.3%	5.8%	3.6%	8.9%	6.0%
	Increment		1.2%	1.5%	-6.0%	-8.3%	-3.0%	-5.9%
NA_HI	%days lost	0.8%	2.1%	2.0%	4.2%	3.4%	9.0%	5.9%
	Increment		1.3%	1.2%	3.4%	2.6%	8.2%	5.1%
NA_ME	%days lost	0.0%	0.2%	0.1%	0.6%	0.3%	0.5%	0.1%
	Increment		0.2%	0.1%	0.6%	0.3%	0.5%	0.1%
Oc	%days lost	58.9%	50.8%	58.9%	62.0%	64.8%	61.8%	40.6%
	Increment		-8.0%	6.0%	3.1%	-18.2%	2.9%	-5.5%
SSA_C	%days lost	33.6%	41.1%	40.9%	34.5%	22.6%	38.2%	30.3%
	Increment		7.5%	7.3%	0.8%	-11.0%	4.6%	-3.3%
SSA_E	%days lost	6.3%	9.3%	10.4%	10.3%	9.8%	16.8%	11.0%
	Increment		3.0%	3.4%	4.0%	2.8%	10.5%	3.9%
SSA_S	%days lost	2.2%	3.4%	2.2%	1.8%	3.3%	3.1%	1.2%
	Increment		1.2%	1.1%	-0.4%	-1.1%	0.9%	-0.3%
SSA_W	%days lost	40.3%	47.0%	40.3%	43.8%	47.1%	49.6%	32.1%
	Increment		6.7%	6.8%	3.4%	-8.2%	9.3%	1.6%

[1]AP_HI: Asia Pacific, High Income; As_C: Central Asia; As_E: East Asia; As_S: South Asia; As_SE: South East Asia; Au: Australasia; Ca: Caribbean; Eu_C: Central Europe; Eu_E: Eastern Europe; Eu_W: Western Europe; LA_A: Andean Latin American; LA_C: Central Latin America; LA_S: Southern Latin America; LA_T: Tropical Latin America; NA_HI: North America, High Income; NA_ME: North Africa/Middle East; Oc: Oceania; SSA_C: Central Sub-Saharan Africa; SSA_E: Eastern Sub-Saharan Africa; SSA_S: Southern Sub-Saharan Africa; SSA_W: Western Sub-Saharan Africa.

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