THELANCET-D-16-05691

S0140-6736(16)31335-6

The last Summer Olympics? Climate change, health, and work outdoors

Climate change threatens human health in many ways, through heat waves, extreme weather events, and shifts in disease vectors, as well as economic and social stresses on populations living in or trying to escape areas affected by seawater intrusion, drought, lower agricultural productivity, and floods.[1] In the short term, most of these impacts could be substantially ameliorated by actions to reduce background disease risks and other known causes of vulnerability. The world beyond 2050 poses increasingly difficult challenges, not only because of the inherent uncertainties in long-term predictions, but because the extent and speed of change might exceed society's ability to adapt.[2] In addition, the risk of so-called pernicious impacts—those that require trade-offs between what is generally assumed and valued as part of society and what is healthy—will rise.

Perhaps the most pernicious of these impacts is the growing expansion in season and geography of outdoor conditions (or unprotected indoor spaces) in which heavy work is no longer safe. Because more than half the planet's workforce works outdoors, primarily in construction and agriculture, society faces an increasingly serious trade-off between population health and labour productivity.[3] The risk to workers' health could be minimised if workers are allowed to sit in the shade during the hottest times of day and take breaks during hot, humid months. Otherwise, exertional heat stroke and its negative outcomes, including mortality, will become a large part of outdoor work around the world.[4] Increasingly, people will face a choice between doing what they have done for millions of years—work hard outdoors essentially any time they wish—and being safe.[5]

Heavy work outdoors is already limited in some parts of the world by heat stress—as measured by the wet-bulb globe temperature (WBGT), a combination of temperature, humidity, heat radiation, and wind—and climate change means more regions will be affected for a greater part of the year.[6]

Athletes are especially prone to heat stress in outdoor endurance events, as shown in the 2007 Chicago Marathon, which was cancelled mid-race after hundreds of heat-stricken runners required medical care.[7] In 2016, only about 70% of the elite competitors in the US Olympic Team Trials Marathon in Los Angeles finished,[8] in a race where peak temperature reached 25·6°C.[10]

The Summer Olympics represent only a small part of all outdoor work, but are iconic as the most prestigious and inclusive sporting competition in the world. Using the mean of two standard climate models, we made projections of rising temperature and humidity over the next century, assuming the high emissions RCP8·5 scenario,[11] and estimated the effects on the number and global distribution of cities eligible to host the Summer Olympic Games.

We focused only on the northern hemisphere, which contains nearly 90% of world population and allows a consistent and customary definition of summer as July to August—noting this period is not always the hottest in some countries such as India. We only included cities over 600 000 population in 2012—the lower limit among host cities since World War 2—reflecting the massive expectations in logistics and financing required

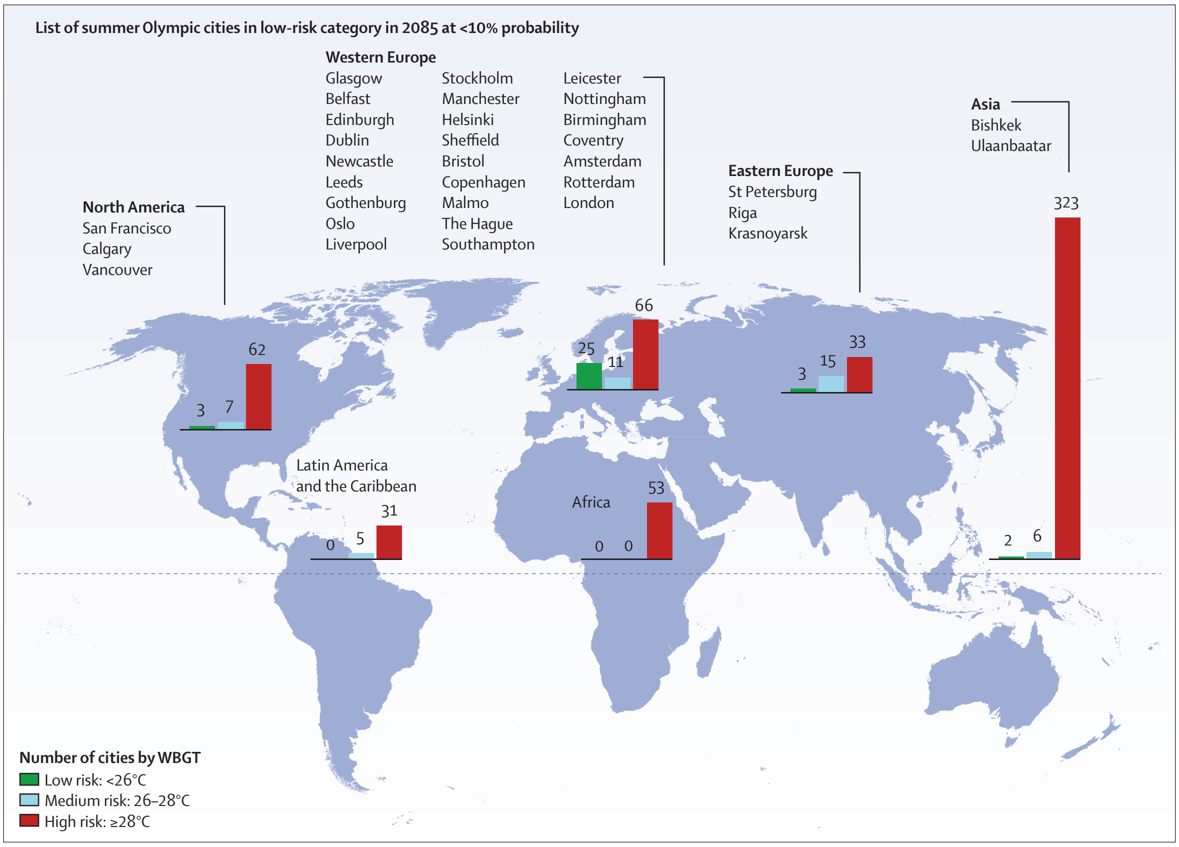

***Figure:* Summary of all 645 northern hemisphere cities in 2085 capable of mounting the Summer Olympics**
Bar charts organise the number of cities in each region by whether their estimated summer WBGT will put them at low (~5% globally), medium (~7%), or high (~88%) risk. Cities in low-risk category in 2085 are listed, only eight of which are outside western Europe.

for a city to run the Olympics. These expectations have escalated even faster than has the average city size. Given the problems of high altitude (low air resistance and low oxygen partial pressure) that became apparent at the 1968 Mexico City Olympics, we included only cities below 1600 m (1 mile) in elevation.

The marathon (42·2 km) is the most demanding endurance event, and thus provides a fair indication of whether conditions are likely to be safe for any other Olympic event.[12] We assumed 26°C WBGT in the shade as the low-risk limit to run the marathon, but also examined 28°C WBGT as the medium-to-high-risk threshold.[13] As most events will probably be run at least partly in sunlight, the full WBGT is almost certainly higher.

Risk of unpredictable disruption of an event that involves billions of dollars, years of planning, hundreds of thousands of people, and massive global media attention would greatly reduce the attractiveness of a venue, particularly if the disruption is required to avoid serious risk to the athletes. We assumed that any venue with more than a 10% chance of having to cancel the marathon at the last minute owing to exceedance of the safe WBGT limit would not be a viable choice to hold the Games as they are structured today. We also examined the implications of accepting an approximate 25% probability. A 10% criterion has previously been used to judge venues for the Winter Olympics in terms of prospects for cold nights and sufficient snow.[14]

We used temperature and humidity data from the outputs of two well-known climate models[15,16] that represent the upper and lower estimates of future climate change to calculate WBGT in the shade for each city in 2085. Conservatively, the lowest estimate for the 10% warmest day was used for the analysis—ie, the WBGT of the third-hottest day during the cooler of the two summer months. For approximately 25% probability, the estimate is the WBGT of the seventh-hottest day.

By 2085, only eight (1·5%) of 543 cities outside of western Europe would meet the low-risk category

(<10% probability of ≥26°C WBGT; figure).[17–19] If the threshold were lifted to 28°C WBGT (medium risk), only 33 (6·1%) more cities would be included, totalling 41 (7·5%) viable cities. The remaining 502 cities would be in the high-risk category (≥10% probability of ≥28°C). If the probability of exceeding the WBGT thresholds is substantially raised to approximately 25%, 76 (14·0%) cities would qualify. Western Europe, however, shows a different pattern with 25 (24·5%) of 102 cities meeting the strictest risk criteria (<10% probability of ≥26°C) and 49 (48·0%) meeting the least constrictive requirements (<25% probability of ≥28°C). Projections out to the early 22nd century, which carry even more uncertainty, suggest the last cities in the northern hemisphere with low-risk summer conditions for the Games will be Belfast, Dublin, Edinburgh, and Glasgow.

The Games might be run entirely indoors, in winter, or without the marathon and other heat-sensitive endurance events, but they would then be quite different from what the world has come to consider the Summer Olympics. High-visibility international athletic events such as the Summer Olympics represent just a small fraction of heavy exertion outdoors, but increasing restrictions on when, where, and how the Games can be held owing to extreme heat are a sign of a much bigger problem. If the world's most elite athletes need to be protected from climate change, what about the rest of us?

*Kirk R Smith, Alistair Woodward, Bruno Lemke, Matthias Otto, Cindy J Chang, Anna A Mance, John Balmes, Tord Kjellstrom

School of Public Health, University of California, Berkeley, CA, USA (KRS, JB, AAM); School of Population Health, University of Auckland, Auckland, New Zealand (AW); Nelson Marlborough Institute of Technology, Digital Technology, Nelson, New Zealand (BL, MO); Department of Orthopaedics and Department of Family & Community Medicine, University of California, San Francisco, CA, USA (CJC); and Centre for Technology Research and Innovation, Limassol, Cyprus (TK)
krksmith@berkeley.edu

We declare no competing interests.

1 Woodward A, Smith KR, Campbell-Lendrum D, et al. Climate change and health: on the latest IPCC report. *Lancet* 2014; **383:** 1185–89.
2 King D, Schrag D, Dadi Z, Ye Q, Ghosh A. Climate change. A risk assessment. Cambridge: Cambridge Centre for Science and Policy, 2015.
3 UNDP. Climate change and labor: impacts of heat in the workplace. Geneva: CVF Secretariat, United Nations Development Programme, 2016.
4 Meade RD, Poirier MP, Flouris AD, Hardcastle SG, Kenny GP. Do the threshold limit values for work in hot conditions adequately protect workers? *Med Sci Sports Exerc* 2016; **48:** 1187–96.
5 Kjellstrom T. Impact of climate conditions on occupational health and related economic losses: a new feature of global and urban health in the context of climate change. *Asia-Pac J Public Health* 2015; **28:** S28–37.
6 Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. *Glob Health Action* 2009; published online Nov 11. DOI:10.3402/gha.v2i0.2047.
7 Davey M. Death, havoc and heat mar Chicago race. *New York Times* (New York), Oct 8, 2007: A1.
8 Butler SL. After Olympic marathon trials, athletes question how officials handled heat and hospitality. *Runner's World* (Emmaus, PA), Feb 25, 2016: http://www.runnersworld.com/olympic-trials/after-olympic-marathon-trials-athletes-question-how-officials-handled-heat-and (accessed Aug 3, 2016).
9 Baxter K. Galen Rupp, Amy Cragg win US Olympic marathon trials. *Los Angeles Times* (Los Angeles). Feb 13, 2016: http://www.latimes.com/sports/sportsnow/la-sp-sn-us-olympic-marathon-trials-live-updates-20160213-story.html (accessed Aug 3, 2016).
10 Virgin C. Virgin on running: US Marathon Trials 2016. American Running Association, 2016. http://www.americanrunning.org/w/article/virgin-on-running-us-marathon-trials-2016 (accessed Aug 3, 2016).
11 van Vuuren DP, Edmonds J, Kainuma M, et al. The representative concentration pathways: an overview. *Clim Change* 2011; **109:** 5–31.
12 Roberts WO. Determining a "do not start" temperature for a marathon on the basis of adverse outcomes. *Med Sci Sports Exerc* 2010; **42:** 226–32.
13 Parsons K. Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance, 3rd edn. Boca Raton, FL: CRC Press, 2014.
14 Scott D, Steiger R, Rutty M, Johnson P. The future of the Winter Olympics in a warmer world. Ontario: University of Waterloo, 2014.
15 Jones C, Hughes J, Bellouin N, et al. The HadGEM2-ES implementation of CMIP5 centennial simulations. *Geosci Mod Dev* 2011; **4:** 543–70.
16 Dunne JP, John JG, Shevliakova E, et al. GFDL's ESM2 global coupled climate–carbon earth system models. part II: carbon system formulation and baseline simulation characteristics. *J Climate* 2013; **26:** 2247–67.
17 Inter-Sectoral Impact Model Intercomparison Project. About ISIMIP. https://www.isimip.org/about/ (accessed Aug 3, 2016).
18 CRU. TS3.23: Climatic Research Unit Time-Series, Version 3.23 of high resolution gridded data of month-by-month variation in climate (Jan, 1901–Dec, 2014). http://ckan.data.alpha.jisc.ac.uk/dataset/273f64b7-3bfc-40e1-b038-86eaed359d08 (accessed Aug 3, 2016).
19 Brinkoff T. City population: statistics and maps of the major cities, agglomerations and administrative divisions. 2010. http://www.citypopulation.de (accessed Aug 3, 2016).