COMMENTARY

Climate change: Heat, health, and longer horizons

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Public concern over climate-change impacts has mostly focused on the economic, physical, and political domains. The consequences for various industries, agriculture, livelihoods, national gross domestic product, property, infrastructure, and electoral prospects have captured most attention. In this issue of PNAS, Sherwood and Huber (1) apply a longer than usual perspective on climate change and conclude that, because of limits to human tolerance of heat, much of Earth's surface may not be habitable by 2300. Their important, related, and overarching statement is that "current assessments are underestimating the seriousness of climate change" (1). They argue that, whereas high-profile threats such as sea-level rise and economic slowdown have caused widespread anxieties, their impacts on human communities would pale into insignificance in a world that might, thermally, become partly or wholly uninhabitable by humans.

This chord needs to be struck. The world's human population is playing for higher stakes than have generally been recognized. Global climate change (along with today's other human-induced, large-scale systemic environmental changes) poses great risks to the planet's existing life-support systems and conditions. Nearly all of the adverse consequences of climate change—reduced regional food yields, freshwater shortages, increased frequency of extreme weather events, coastal population displacement, changes in the ecology and geography of infectious agents, declines in farming community incomes, and biodiversity losses with accompanying disruption of ecosystem functions—will converge adversely on human biology and health. Climate change, ultimately, is a threat to our biological health and survival (2).

There are four main threads to the authors' argument about future heat extremes. (*i*) When the modifying effect of humidity on perceived (i.e., physiologically experienced) heat is allowed, the present range of extreme climatic conditions around the globe is actually rather limited: the hottest places tend to be dry, so that wet-bulb temperatures (T_W) essentially never exceed 31 °C. (*ii*) For reasons of physiology and physics, T_W values above 35 °C cannot be tolerated even under ideal conditions of shade, ventilation, and rest; therefore, there is little leeway. (*iii*) Climate modeling suggests that increases in global mean temperatures will give rise to similar increases in maximum T_W, in a ratio of at least 3 °C T_W for every 4 °C of global warming. (*iv*) Global mean temperatures may well rise by more than 10 °C, probably not this century but within the coming three centuries.

The authors may seem—at least on current thinking—to have stretched the limits of plausibility (1). To date, we have not had to think seriously about a foreseeable future world that is 10–12 °C warmer than today. However, as they point out, such temperature increases are not off the predictive scale if current trajectories continue and if full consequent global heating is realized over the next three centuries. Furthermore, given inherent scientific uncertainties about the future behavior of the climate system under changing conditions, recent modeling is as likely to have underestimated future changes as to have overestimated them. Indeed, much recent trend data indicate just that type of disparity between previous forecasts and actual geophysical outcomes (3, 4).

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Stretching the Time Horizon

Most of the prevailing discussion and modeling of climate change extends only to 2100 or even earlier, whereas this paper looks out further to 2300. This extension is important and necessary. First, as Sherwood and Huber (1) point out, climate change will not stop in 2100 if emissions continue. Therefore, because the trajectory beyond 2100 will depend largely on what is done or not done in this century, the longer vision should guide us now. Second, the further into the future our outlook, the more serious it gets—potentially, catastrophic. Climates that differ drastically from the present are well within the long experience of Earth but well outside human experience. However, such climatic conditions are not impossible in the relatively near future.

Within the wider arena of research and policy on climate change, there is now an increasing focus on the need for adaptive strategies. Human-induced climate change is almost certainly already occurring, and more of it is in the pipeline regardless of the actions that we might take today. While the world community struggles to agree on and implement effective international reductions in greenhouse gas emissions (mitigation), adaptive responses are becoming increasingly necessary and important, especially for areas of high risks and populations of high vulnerability.

Sherwood and Huber (1) argue, however, that mass dependence on increasingly intensive air conditioning in a seriously overheated future world, even if affordable and equitably available, would overload any currently imaginable energy-supply system. However, might there be science fiction-type solutions to counter such extremes of future heat, given today's rapid and accelerating technological changes? After all, 300 years ago, the height of technology was wind power (steam power was first applied in 1712), and high-speed transportation was by stagecoach. Although living enclosed in glass cool-houses might appeal to some, that straw is far too distant to grasp at and is one that only a minority would probably be able to grasp if and when the time came. Trusting in future fantasy would be foolish, futile, and perhaps, fatal.

If the authors (1) are approximately right, then reliance on adaptation must not be allowed to engender complacency about the primary need to reduce atmospheric CO_2 concentrations. Meanwhile, adaptation is a necessary transitional strategy now, and pleasingly, many adaptive strategies will also enforce the immediate strengthening of currently deficient public-health and related social/infrastructural programs in many countries (5).

Acclimatization to Heat: Biological Limits

Within the more usual time horizon, spanning only decades of climate change, there has been discussion about the possibilities of physiological acclimatization in response to future increased exposures to extreme heat (6). Further, that discussion has often been predicated on the

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likely future increases in climatic and weather variability that are anticipated to accompany climate change. Sherwood and Huber (1), however, focus particularly on the prospect and consequence of substantial changes in mean temperature conditions over several centuries along with accompanying changes in the distribution of maximum temperatures. Even if variability changes little, a higher mean temperature implies more frequent exceeding of physiologically tolerable thermal limits. For mean temperature increases of 4–6 °C or more, it is implausible that human biology, as currently constituted, could adapt physiologically.

It is instructive, therefore, that the authors (1) remind us of the time frame of biological evolutionary processes. As they point out, the fossil record shows that the evolutionary changes evoked by the slow fluctuating processes of global cooling over the past 65 million years have typically yielded increases in warm-blooded mammalian body size, thereby reducing heat dissipation to the external environment. Thus, we human mammals cannot expect to undergo any useful heritable biological adaptation during the evolutionary nanosecond of just the next several centuries. The genus *Homo* has a particularly high rate of biological evolution, in part because of behavioral drive (7), and this is well-illustrated by the emergence and spread of the lactase allele within the last 10,000 years in response to the novel inclusion of dairy foods in the human diet (8). Indeed, the rate of genetic evolution in humans has been extraordinarily rapid over this time (9).

Admittedly, we are in unknown territory here, given that the unprecedented size of today's human population has grown from millions to billions within the historical, not the geological, past. A larger gene pool allows more rapid response to environmental changes, as does an increase in interbreeding between regional genetic strains. Furthermore, "a population that suddenly increases in size has the potential for rapid adaptive change" (9). Even so, biological evolutionary adaptation to a warmer climate would seem likely to require scores or even hundreds of generations, not just several hundred of years.

Also, the authors (1) note that a much hotter world would not only be less tolerable and less livable but would be a world wherein economic productivity would fall, both because of the disrupted production processes in nature (agriculture, forests, and fisheries) on which we depend and the impaired work capacity under overheated conditions (10). There has been negligible recognition of this latter category of impact in the climate-change science literature. Indeed, major international bodies such as the World Bank and the United Nations Development Program have yet to adequately acknowledge this basic consequence of climate change and impaired work capacity, and they do not include it in their projections and plans for social and economic development.

Reinforcing the Case for Action, Now

This paper helps broaden the vista of questions that human health researchers (11), anthropologists (12), and social scientists in general should now explore. Estimations of economic impacts in dollar terms, a checklist of climate-endangered (nonhuman) species, anticipated proportions of coastline inundated—these are all easily and intuitively understood, and they are very important. Beyond those, however, the greater challenge is to understand, quantify, and communicate the many adverse impacts on human health that will result from plausible scenarios of climate change. Whereas that may seem an unduly anthropocentric priority, in reality it will help to spur international action to abate climate change, which in turn will protect other species. Anyway, having got ourselves into this quandary, we humans are both obliged and entitled to ask what the consequences for us might be and how we should resolve the problem.

Although this paper focuses on just one key climatic exposure (future thermal stress), it provides a clear warning that we need to acquire a better and fuller understanding of the stakes that we may ultimately be playing for over several centuries. It, thereby, invites equivalent research questions in other areas of climate-change risk assessment: are there similar limits to compensatory food production, freshwater generation, and disease control in a much warmer world beyond 2100? Political discussion to date has toyed with the goal, probably already wishful thinking, of averting even the 2 °C rise that is the recognized indicative guardrail against dangerous interference with the climate system. Consideration of longer-term, more severe impacts should serve to focus attention on what now, ominously, seems to be a more likely outcome and with a more absolute limit beyond which we must not go.

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