Mind the gap

MARK NEW, DIANA LIVERMAN AND KEVIN ANDERSON

Policymakers must aim to avoid a 2 °C temperature rise, but plan to adapt to 4 °C.

Reducing greenhouse gas emissions soon and fast enough to prevent a global average temperature rise of more than 2 °C above the pre-industrial level — commonly regarded as the threshold for 'dangerous climate change' — was always going to be tough. As we approach the end of the first decade of the twenty-first century and emissions continue to increase, keeping below 2 °C with any reasonable probability will be possible only with urgent and stringent mitigation measures. In practice, this will necessitate almost immediate emissions reductions by rich nations, followed soon after by reductions from developing nations[1,2].

As the challenge of keeping below 2 °C increases, the likelihood of reaching higher temperatures becomes correspondingly larger. At the worst end of the scale, with continued intensive fossil fuel use, temperatures could rise 4 °C by the 2070s, or even as early as 2060 if there are strong positive feedbacks in the carbon cycle[4]. The situation is bleaker still once political inertia is considered. Moderate-emissions scenarios, including those arising from weak climate agreements, still result in a significant probability of exceeding 4 °C by the end of the century or early in the next century[5]. As nations delay on agreeing a global climate treaty, it seems essential to explore the terra quasi-incognita of a world in which the average temperature is 4 °C above the pre-industrial level, and to understand the implications for nature and society.

BRAVE NEW WORLD

A world where the average temperature was 4 °C higher than in pre-industrial times would be very different from the one we now inhabit, and even from one with 2 °C of warming. Studies suggest that 2-4 °C of warming would trigger the permanent break-up of the Greenland ice sheet, causing sea level to rise by up to seven metres in the long term[6]. With warming of 3 °C, the Arctic Ocean would most likely be ice-free in summer[7]. At 4 °C, most reef-building corals would be unable to adapt to changes in ocean temperature and acidification, in which case tropical coral reefs would die out or become far less diverse[8]. While thresholds or tipping points in other systems are less well known[9], the risk of major shifts in ecosystems such as tropical forests increases as global temperature rises from 2 to 4 °C.

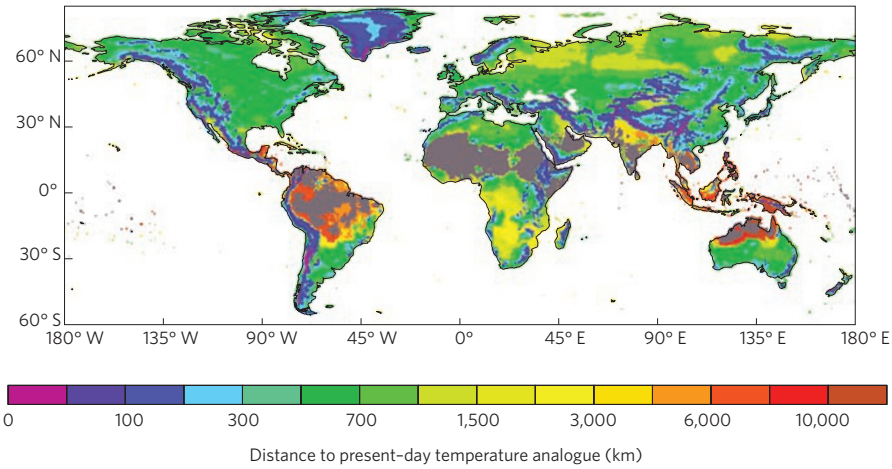

Figure 1 Spatial shifts at 4 °C. The distance (in kilometres) that the world's current temperature zones would shift under 4 °C of global warming. Areas in grey would be hotter on average than any region on the planet today. For other areas, colours indicate the minimum distance to a location whose present-day mean annual temperature is equivalent to the coloured region's expected future temperature in a 4 °C world. Present-day temperatures are based on the CRU 0.5° latitude–longitude climatology[18]. Future temperatures are estimated by combining the multi-model mean temperature change from 14 global climate models under a moderate-emissions scenario.

A 4 °C, the world would probably be warmer than any time in the last 800,000 years[10] and certainly the last 18,000 years, the period in which modern humans evolved. Moreover, the rate of climate change would be as fast as or faster than any previously experienced. Because land areas warm faster than the ocean and higher latitudes more than lower latitudes, temperature increases would exceed 4 °C in many regions. Approximately 13 per cent of land — including the Amazon, the Sahara-Sahel-Arabia region, India and northern Australia — could experience average temperatures for which there are no spatial analogues in today's climate (Fig. 1); in other words, the temperature in these regions would be higher than the average at any place on Earth today. Correspondingly, present-day climates in the tropics and subtropics would shift short distances to higher elevations or in some cases several thousands of kilometres polewards.

The implications of a 4 °C world for society are not well understood, as most assessments have focused on changes of around 2 °C or, at most, 3 °C. Even with a 2 °C global warming, in most African nations 80 per cent of the land area would develop climatic conditions unsuitable for crops currently grown there[11]. Present-day analogues elsewhere in Africa could, however, offer the potential for adaptation through regional trade and international movement of crop varieties. At 4 °C, the number of climate analogues on the African continent would become very small and solutions might require growing entirely different crops, shifting to livestock or breeding new varieties — all of which would pose great cultural, ecological and technological challenges[12]. Present-day patterns of water stress would be increasingly exacerbated as the global temperature rose from 2 to 4 °C. In the

most water-stressed regions of the world, currently home to one-fifth of the global population, a 4 °C temperature rise could reduce water availability for 50 per cent of residents and increase availability to only 35 per cent[13].

Some recent estimates of sea level rise exceed previous projections by the Intergovernmental Panel on Climate Change, suggesting increases of more than one metre in a 4 °C world by 2100 if recent contributions from melting land ice continue[14]. Deltas and other low-lying coastal regions would be particularly vulnerable. Over 136 port cities with present-day populations greater than 1 million would be at risk[15], requiring protection or translocation of over 500 million people. The cost of maintaining current safety levels in the coastal zone could be as much as $50 billion a year by about 2020.

The implications of 4 °C of warming for health raise distinctive concerns because of the uncertainties in how vector-borne diseases might shift and evolve[16], in how extreme events would affect health and mortality, and in how climate change would affect other factors important for public health, such as water and food security, conflict and migration. Managing exposures of new populations to diseases like malaria, planning buildings for efficient cooling, and shifting up the scale of disaster response and vulnerability reduction become much more immediate priorities if 4 °C is indeed a real possibility within 50 to 60 years.

Substantial changes in the structure and function of ecosystems, including disturbance by fires and insects, are very likely for temperatures above 2 °C. Recent assessments of faunal change based on relatively low-emissions scenarios suggest that increased temperatures, including regional changes of up to 4 °C, could result in local loss of at least ten per cent of endemic vertebrates in the Americas and the replacement of 90 per cent of species in the tundra, Central America and the Andes[17]. Although ecosystems and species can be resilient, a 4 °C world would require unprecedented interventions regardless of whether the choice is to maintain the current portfolio of conservation areas or to plan new conservation areas suitable for a changed climate.

A PERFECT STORM

While adapting to a 2 °C temperature rise may mostly involve adjustments of existing practices, a world at 4 °C presents large and complex challenges that are likely to require fundamental socioeconomic and technological transformations, rather than adjustments — assuming such transformations are achievable through planning at all. Moving from 2 to 4 °C would also bring, for any particular location, an accumulating load of increasingly severe impacts. While one or a few impacts considered in isolation may be manageable, a 'perfect storm' of multiple severe impacts may be catastrophic.

The ongoing climate negotiations offer little to suggest that sufficient collective will currently exists to meet this mitigation challenge.

Some decisions with long lead times or enduring implications — such as restructuring urban, water and transport infrastructure, or improving coastal protection and forest investments — cannot wait until we know the level of future mitigation efforts. Proactive adaptation therefore faces two possible missteps: expensive over-adaptation if mitigation is successful or costly under-preparation if a 4 °C world does materialize. For adaptation decisions that need shorter lead times, such as rethinking water allocation and switching agricultural practices, early proactive investments in technology innovation such as water reuse or new crop species will ensure that effective solutions are available when needed.

A 4 °C temperature rise within the lifetime of many people alive today is an alarming scenario, and one that becomes more likely with each year that emissions continue to rise. The severe and catastrophic impacts that will accumulate if temperature rises beyond 2 °C constitute, by any measure, an escalation in the level of 'dangerous anthropogenic interference' with the climate system. Warming of 4 °C or more would have consequences that might be beyond the ability of humankind to cope, particularly if those consequences are allied with other stresses. Even affluent communities would see substantial and unprecedented changes to how they live, while for the majority, fundamental transformations might be necessary for survival.

The challenges involved in reducing emissions soon and fast enough to have even a small chance of keeping temperatures below 2 °C are much larger than most people realize, requiring unprecedented collective will among the governments of both the developed and developing world. Ongoing climate negotiations offer little to suggest that sufficient collective will currently exists to meet this mitigation challenge. Yet aiming to reduce emissions to keep the average temperature below 2 °C remains a crucial political objective. To try and possibly fail at achieving this goal is better than to renounce the effort, as the larger the gap between the 2 °C target and the final temperature change, the more catastrophic the consequences. The risk of allowing the world to experience 4 °C of warming this century demands both accelerated efforts at effective mitigation and serious planning for adaptation to changes that may be larger than those usually considered.

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References

1. Anderson, K. & Bows, A. *Phil. Trans. R. Soc. A* **366,** 3863-3882 (2008).
2. Clarke, L. *et al. Energy Econ.* doi:10.1016/j.eneco.2009.10.013 (2009).
3. UK Committee on Climate Change. *Building a Low-Carbon Economy: the UK's Contribution to Tackling Climate Change* (The Stationery Office, London, 2008); http://bit.ly/5VP8zS
4. Betts, R. A., Collins, M., Hemming, D. L., Lowe, J. A. & Sanderson, M. in *Hadley Centre Technical Notes* No. 80 (2009).
5. Rogelj, J. et *al. Nature Rep. Clim. Change* doi:10.1038/climate.2009.53 (2009).
6. Charbit, S., Paillard, D. & Ramstein, G. *Geophys. Res. Lett.* **35,** L12503 (2008).
7. Boe, J. L., Hall, A. & Qu, X. *Nature Geosci.* **2,** 341–343 (2009).
8. Hoegh-Guldberg, O. *et al. Science* **318,** 1737–1742 (2007).
9. Lenton, T. M. *et al. Proc. Natl. Acad. Sci. USA* **105,** 1786–1793 (2008).
10. Jouzel, J. *et al. Science* **317,** 793–796 (2007).
11. Burke, M. B., Lobell, D. B. & Guarino, L. *Glob. Environ. Change* **19,** 317–325 (2009).
12. Jones, P. G. & Thornton, P. K. *Environ. Sci. Pol.* **12,** 427–437 (2009).
13. Heinke, J., Gerten, D. & Frieler, K. in *4 Degrees and Beyond* (Oxford, 2009); http://bit.ly/54Yeqp
14. Rahmstorf, S. in *4 Degrees and Beyond* (Oxford, 2009); http://bit.ly/54Yeqp
15. Nicholls, R. J. *et al. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates.* OECD Environment Working Paper 1, ENV/WKP(2007)1 (OECD, Paris, 2007); http://bit.ly/7Ravnf
16. Lafferty, K. D. *Ecology* **90,** 888–900 (2009).
17. Lawler, J. J. *et al. Ecology* **90,** 588–597 (2009).
18. New, M., Hulme, M. & Jones, P. *J. Clim.* **12,** 829–856 (1999).

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Mark New is at the School of Geography and Environment at the University of Oxford. Diana Liverman is at the Environmental Change Institute at the University of Oxford and the Institute of the Environment at the University of Arizona in Tucson. Kevin Anderson is at the School of Mechanical, Aerospace and Civil Engineering at the University of Manchester, UK. All authors are affiliated with the UK Tyndall Centre for Climate Change Research. e-mail: mark.new@ouce.ox.ac.uk