Abrupt climate change in the Arctic

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COMMENTARY:

Abrupt climate change in the Arctic

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Semantic arguments about the definition of 'tipping points' are distracting attention away from the causes and impacts of climate change in the Arctic.

In 1992, the United Nations established the Framework Convention on Climate Change (UNFCCC) with the aim of "preventing dangerous anthropogenic interference with Earth's climate system". Two decades later we are confronted with arguably the first signs of dangerous climate change in the Arctic region. Dangerous climate change was defined implicitly by the UNFCCC as that precluding ecosystem adaption, jeopardizing food production or preventing sustainable development. In the Arctic, the rate of climate change is now faster than ecosystems can adapt to naturally[1], and Inuit communities are experiencing compromised food security and health, and threats to traditional cultural activities[2]. The Intergovernmental Panel on Climate Change lists five main concerns related to dangerous climate change, all of which are now being experienced in the Arctic (Table 1).

Table 1 | Evidence for the presence of all five reasons for concern that characterize dangerous climate change[12] in the Arctic region.

Reasons for concern with Arctic climate change	Evidence	References
1. Risks to unique and threatened systems (Risk of losing unique ecological and social systems)	Decline of ice-associated biota (polar bears, seals, walruses, ice algae) and Arctic copepods	1, 13
	Rapid changes in landscapes due to permafrost thawing and thermokarst activity	14, 15
	Threats to Inuit cultural practices	2, 16
2. Risk of extreme weather events (Extreme events with substantial consequences for societies and natural systems)	Peat fires in the subarctic regions	17, 18
	Severe winter in northern temperate regions	19
3. Distribution of impacts (Spatial scale of impacts)	Changes in sea-level rise	20
	Altered heat budgets	21, 22
	Changes in freshwater discharge and ocean circulation	23, 24
	Greenhouse-gas emissions	25
	Reduced oceanic carbon dioxide uptake	26
4. Aggregate damages (Monetary damages or monetary losses, and lives affected or lives lost)	Impacts to Inuit well being, health, safety and culture	2
	Risks to security from territorial disputes	27
5. Risks of large-scale discontinuities (Likelihood of reaching tipping points)	Destabilization of the Greenland ice sheet	28, 29
	Peat fires in the subarctic region	30
	Methane emission from thawing methane hydrates	31, 32
	Slowed global thermohaline circulation	33
	Reduced oceanic carbon dioxide uptake	34

The Arctic therefore presents a test of our capacity as scientists, and as societies, to respond to abrupt climate change. But this response is being delayed because parts of the scientific community and the media have descended into semantic debate over whether Arctic sea ice has a 'tipping point'[3]. We argue here that this is distracting attention from the urgent need to focus attention on developing early warning indicators of abrupt change, addressing its anthropogenic causes, and rebuilding resilience in climate, ecosystems and communities.

Tipping points

Perhaps the most dangerous aspect of Arctic climate change is the risk of passing tipping points (Fig. 1a). Tipping points have been defined as critical points, in forcing or some feature of a system, at which a small perturbation can qualitatively alter its future state. Tipping elements are those large-scale components of the Earth system that can exhibit a tipping point[4]. The Arctic region arguably has the greatest concentration of potential tipping elements in the Earth system, including Arctic sea ice, the Greenland ice sheet, North Atlantic deep-water formation regions, boreal forests, permafrost and marine methane hydrates[4]. Recent analyses have added several more candidates[5] (Fig. 1a).

The array of tipping elements in the Arctic are not independent — they are causally connected to one another, and to other areas for concern. Warming of the Arctic region is proceeding at three times the global average, and a new 'Arctic rapid change' climate pattern has been observed in the past decade. Loss of Arctic sea ice has been tentatively linked to extreme

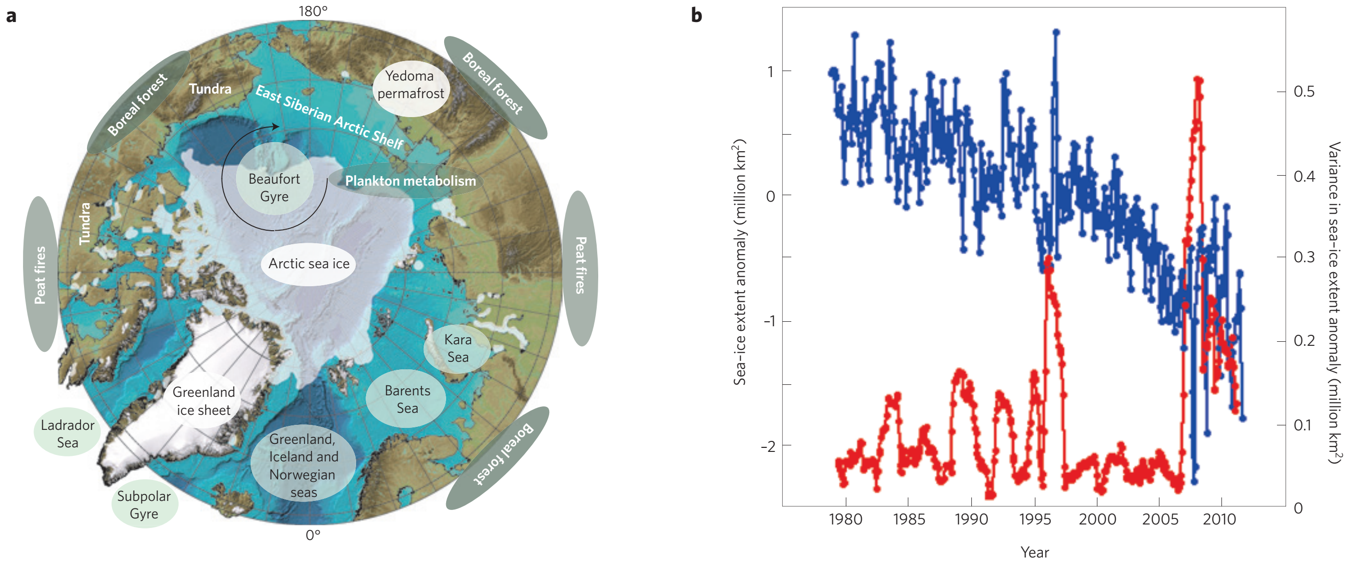

Figure 1 | Arctic climate change. **a**, Map of potential Arctic climate tipping elements. Systems ringed are suggested tipping elements. Tipping elements are: those that involve ice melting (white); those that involve changes in ocean circulation (often coupled to sea ice and/or atmospheric circulation) (aqua green); and those that involve biome change (dark green). **b**, Monthly anomalies in Arctic sea-ice extent (blue line) relative to the monthly averages for the period November 1978–July 2011 and the average variance in sea-ice-extent anomaly over 16-month running windows (red line). Data taken from ref. 35.

cold winters in Europe (another reason for concern, namely risks of extreme weather events). Near complete loss of the summer sea ice, as forecast for the middle of this century, if not before, will probably have knock-on effects for the northern mid-latitudes, shifting the jet streams and storm tracks. Several tipping elements have already been set in motion and changes are accelerating (Table 1). But, are they about to reach their tipping points?

Semantic confusion

Shrinkage of the summer Arctic sea-ice cover has accelerated faster than predicted by models, with the five lowest minima on record occurring during 2007–2011 (Fig. 1b). Before any of these recent events occurred, it was argued that a tipping point had already been passed. Within a decade hence, summer sea ice could be largely confined to north of the coasts of Greenland and Ellesmere Island — the only location where substantial multi-year ice will be found[6]. By mid-century, an ice-free summer Arctic Ocean looks likely, and this transition to a purely seasonal cover of first-year ice could involve a tipping point. But other scientists strongly disagree, and the media have recently taken up their cause.

Early last year, a paper showing that modelled summer ice loss can be quickly reversed[3] led to headlines such as 'Tipping point not likely for Arctic sea ice'. And in August, the BBC (and a suite of websites) announced that Arctic tipping points may not be reached, based on a study in which the term 'tipping point' was not even mentioned[7]. At the heart of the disagreement is a semantic confusion; the assumption that a 'tipping point' is synonymous with passing a bifurcation point, which must inevitably lead to irreversible change. Instead, we argue that tipping points do not have to be points of no return[8]. On the contrary, several tipping points, such as the loss of summer sea ice, may be reversible in principle, though hard to reverse in practice. Different types of tipping phenomena have been recognized, including reversible 'noise-induced' transitions between different attractors of a system.

This semantic confusion masquerading as scientific debate, although providing excellent media fodder, is distracting from the urgent need to tackle abrupt change in the Arctic.

Early warnings

The fact that sea ice has almost recovered to its full areal extent in the winters following recent minima does not imply that the ice loss has been fully reversed. The thickness of the ice cannot be rebuilt over one winter following summer minima. Indeed, the sensitivity of Arctic sea ice to climate warming depends on the thickness of the ice[6]. Although records of Arctic sea-ice thickness are far less robust than those of its areal extent, they show unambiguously that Arctic sea-ice volume has declined dramatically over the past two decades. Most of the sea-ice area present in the spring now represents first-year ice, prone to melting during summer. As a consequence, the variability of Arctic ice extent has increased dramatically since 2006 relative to the period 1979–2006 (Fig. 1b)[5,8].

This increase in variability could represent an early warning of an approaching tipping point[9]. Complex, nonlinear systems typically shift between alternative states in an abrupt, rather than a smooth manner. These states can be pictured as neighbouring valleys, and the initial behaviour of a system can be pictured as a ball rolling around in one of the valleys. If the resilience of a state is being eroded, that valley is getting broader and shallower. As this happens, the ball will undertake larger and longer excursions from the bottom of the valley. If there is enough 'noise' in the system the ball may even start to make excursions to the other valley. These are both causes of increased variability. Recent analysis suggests that the acceleration of sea-ice decline around 1996 was preceded by an increase in sea-ice variability nearly a decade beforehand[8].

As well as Arctic sea ice, we must consider the resilience of Arctic marine ecosystems whose fate is clearly connected to that of the sea ice. Reduced ice extent is expected to change the size and species composition of plankton in an irreversible manner, with significant ramifications for harvestable production, key fish species, ice-bound fauna and air–sea carbon dioxide exchange[5]. These ecosystem changes may carry their own early warning signals.

Solutions

We suggest a systematic effort should be made to look for early warning signals of further abrupt changes in the Arctic. This would aid the development and deployment of adaptive strategies, and could contribute to a more pre-emptive, precautionary policy approach. Unfortunately, time series on the dynamics of environmental and biological tipping elements other than sea ice are patchy at best[1]. A major collaborative effort to compile time series through data-rescue programmes and to maintain observation capacity of key tipping elements needs to be developed[5]. Arctic ozone-monitoring efforts represent an excellent example of such an international collaborative programme.

To reduce the risk of near-term abrupt changes in the Arctic, short-lived radiative forcing agents should be mitigated. The deposition of black carbon (soot) on Arctic snow and ice is making a large contribution to warming and ice melt[10]. Yet the technology to mitigate soot emissions from coal-burning power stations or biomass-burning stoves is uncomplicated and readily accessible. Methane and the tropospheric ozone produced from it are also significant contributors to Arctic warming. Encouragingly, around 40% of global anthropogenic methane emissions could be mitigated at zero cost or with net economic benefit (the stumbling block being that the benefits are shared by everyone, whereas the mitigation costs are borne by only a few). Of course in the long term, restricting cumulative emissions of carbon dioxide is essential for safeguarding slow tipping elements such as the Greenland ice sheet.

The perception of present danger is such that the Arctic Council is already discussing regional geoengineering options. Reduction in tropospheric sulphate aerosols has been a major contributor to recent Arctic warming; hence, it has been proposed to replace them with deliberately injected stratospheric aerosols. Modellers have begun simulating whether such deliberate sunlight reflection can prevent, for example, irreversible melting of the Greenland ice sheet[11]. Whether such methods can reduce the risk of further dangerous Arctic climate changes warrants research. But in the meantime, we should stop debating the existence of tipping points and start managing the reality of dangerous climate change in the Arctic. ❐

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References

1. Wassmann, P., Duarte, C. M., Agusti, S. & Sejir, M. *Glob. Change Biol.* **17,** 1235–1249 (2011).
2. Ford, J. D. *Environ. Res. Lett.* **4,** 024006 (2009).
3. Tietsche, S., Notz, D., Jungclaus, J. H & Marotzke, J. *Geophys. Res. Lett.* **38,** L02707 (2011).
4. Lenton, T. M. *et al. Proc. Natl Acad. Sci. USA* **105,** 1786–1793 (2008).
5. Duarte, C. M. *et al. AMBIO* http://dx.doi.org/10.1007/s13280-011-0224-7 (in the press).
6. Wadhams, P. *AMBIO* http://dx.doi.org/10.1007/s13280-011-0222-9 (in the press).
7. Funder, S. A. *Science* **333,** 747–750 (2011).
8. Carstensen. J. & Weydmann, A. *AMBIO* http://dx.doi.org/10.1007/s13280-011-0223-8 (in the press).
9. Lenton, T. M. *Nature Clim. Change* **1,** 201–209 (2011).
10. Ramanathan, V. & Carmichael, G. *Nature Geosci.* **1,** 221–227 (2008).
11. Irvine, P. J., Lunt, D. J., Sonte, E. J. & Ridgwell, A. *Environ. Res. Lett.* **4,** 045109 (2009).
12. Smith, J. B. *et al. Proc. Natl Acad. Sci. USA* **106,** 4133–4137 (2009).
13. Post, E. *et al. Science* **325,** 1355–1358 (2009).
14. Jorgenson, M. T., Shur, Y. L. & Pullman, E. R. *Geophys. Res. Lett.* **33,** L02503 (2006).
15. Lawrence, D. M., Slater, A. G., Tomas, R. A., Holland, M. M. & Deser, C. *Geophys. Res. Lett.* **35,** L11506 (2008).
16. Laidler, G. J. *et al. Climatic Change* **94,** 363–397 (2009).
17. Zoltai, S. C., de Groot, W. J., Morrissey, L. A. & Livingston, G. P. *Environ. Rev.* **6,** 13–24 (1998).
18. Yurganov, L. *et al. Atmos. Chem. Phys.* **11,** 12207–12250 (2011).
19. Petoukhov, V. & Semenov, V. A. *J. Geophys. Res.* **115,** D21111 (2010).
20. Yin, J. *et al. Nature Geosci.* **2,** 262–266 (2009).
21. Perovich, D. K. *et al. Geophys. Res. Lett.* **34,** L19505 (2007).
22. Spielhagen, R. F. *et al. Science* **331,** 450–453 (2011).
23. Dickson, B. *et al. Nature* **416,** 832–837 (2002).
24. Peterson, B. J. *et al. Science* **298,** 2171–2173 (2002).
25. IPCC *Climate Change 2007: The Physical Science Basis* (eds Solomon, S. *et al.*) (Cambridge Univ. Press, 2007).
26. Cai, W. J. *et al. Science* **329,** 556–559 (2010).
27. Borgerson, S. G. *Foreign Aff.* **87,** 63–77 (2008).
28. Rignot, E., Box, J. E., Burgess, E. & Hanna, E. *Geophys. Res. Lett.* **35,** L20502 (2008).
29. Pritchard, H. D. *et al. Nature* **461,** 971–975 (2009).
30. Huntington, H. P., Goodstein, E. & Euskirchen, E. AMBIO http://dx.doi.org/10.1007/s13280-011-0226-5 (in the press).
31. Archer, D., Buffett, D. & Brovkin, V. *Proc. Natl Acad. Sci. USA* **106,** 20596–20601 (2009).
32. Shakhova, N., Semiletov, I. & Gustafsson, O. *Science* **327,** 1246–1250 (2010).
33. Hofmann, M. & Rahmstorf, S. *Proc. Natl Acad. Sci. USA* **106,** 20584–20589 (2009).
34. Siegenthaler, U. & Sarmiento, J. L. *Nature* **365,** 119–125 (1993).
35. Fetterer, F. *Sea Ice Index* (National Snow and Ice Data Center, 2002, updated 2009).

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COMMENTARY:

Higher standards for sustainable building materials

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Certification criteria for sustainable building materials need to be rationalized to avoid confusion in the marketplace.

The market for building construction in the United States is estimated to be worth nearly US$1 trillion per year[1], representing around 13% of the gross domestic product. Buildings account for approximately 42% of US energy consumption[2], 67% of electricity consumption[3] and 39% of carbon dioxide emissions[4]. Buildings and the building industry have an enormous potential impact on global climate change — improving the sustainability of building practices and materials can have an equally great effect on mitigating its severity.