Abrupt changes - To what extent are tipping points a concern in coping with global change?

PRESENT PAST

Derek Lemoine
Department of Economics, The University of Arizona, Tucson, USA; dlemoine@email.arizona.edu

Tipping points have entered common discourse in a range of applications: the uprisings of the Arab Spring, the narrative of sporting events, the evolution of consumer sectors, the rhythm of political campaigns, the threat of space junk, and the collapse of financial systems. An increasingly frequent application concerns the changing climate (Russill and Nyssa 2009). Some climate tipping points irreversibly change social structures, and the form of this change determines the ultimate effect on climate damages.

Undesirable tipping points involve climate change impacts. First, consider New Orleans or Bangladesh. The infrastructure in these regions are increasingly stressed due to higher sea levels and disappearing wetland buffers. Changing conditions have made them more vulnerable to future storms that could trigger a tipping point for the local culture and economy. Or consider a climate-induced drought that shifts a livestock-based economy to less water-intensive activities. These changes become partially irreversible as economic activity, infrastructure, and communities reorganize under new constraints.

Second, and perhaps more troublingly, climate change might induce large-scale migrations due to higher sea levels, water stress, crop failures, or extreme weather events (de Sherbinin et al. 2011). Shifting populations have triggered massive changes throughout world history, and future migrating populations could trigger internal or external conflicts and bring new challenges of assimilation and adjustment. For example, climate change could enhance water scarcity in South Asia, and recent conflicts in Darfur and other parts of Africa might have been exacerbated by environmental problems.

Other societal tipping points are desirable. First, a breakthrough in low-carbon technology might be necessary to change the dynamics of the energy system (Hoffert et al. 2002). If solar cells or batteries become cheap enough, electrical and transportation systems could begin shifting to less carbon-intensive structures even without a direct policy spur. Second, enacting a greenhouse gas emission policy should create constituencies for further policy. Ambitious policies currently lack clearly defined winners to lobby for their enactment, but moderate policies could develop this constituency by coining valuable property rights in tradable permits or by nurturing low-carbon industries. Third, on the international level, a climate coalition that includes enough countries might be able to raise remaining countries' cost of holding out (Barrett 2003).

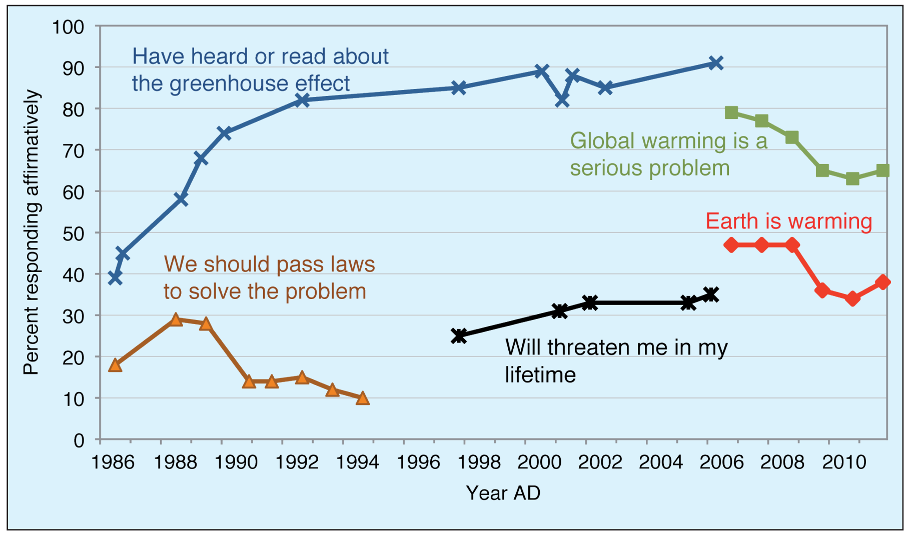

Figure 1: The response of the U.S. public to surveys' questions about global climate change (Pew Research Center for the People & the Press; Nisbet and Myers 2007).

Finally, we may still reach a further tipping point in climate awareness (see figure 1). Drawing on examples ranging from the diffusion of rumors to trends in smoking, some argue that social networks allow beliefs and behaviors to spread quickly once they reach a critical mass (Gladwell 2000). Incurring undesirable tipping points could raise public concern about the climate to such a threshold. Similar to how the first exposure to the horror of nuclear weapons has so far kept the world from further nuclear warfare, reaching the first undesirable climate tipping point may end up making future tipping points less likely by spurring preventive action.

From economic analysis of tipping points in the physical climate system, we have shown that the best policy response to a tipping possibility depends on two questions: (1) Can we affect whether a tipping point occurs? (2) If we knew a tipping point were about to occur, would we want to pursue a different policy? The first question captures our ability to prevent or spur a tipping point, while the second captures our desire to hedge against the possibility that it occurs. Because the undesirable tipping points depend on our present and future emission decisions, they provide additional incentive to reduce emissions. These undesirable tipping points also increase the payoffs to adaptation policies that reduce society's exposure to a changing climate. In contrast, desirable tipping points favor policies that make them more likely: funding research into low-carbon technology, pricing carbon sooner rather than later, and building climate awareness. If these desirable tipping points end up spurring significant emission reductions, they might even hold the key to avoiding undesirable ones.

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Dorthe Dahl-Jensen
Niels Bohr Institute, University of Copenhagen, Denmark; ddj@gfy.ku.dk

Paleoclimatic records can provide information on the operation of the climate system, including the occurrence of tipping points and the risk of abrupt changes. The deep Greenland and Antarctic ice cores are particularly well suited to study abrupt changes, because they provide a detailed and well-dated record of past climate. Prominent examples of abrupt changes are the 25 Dansgaard-Oeschger (DO) events (NGRIP 2004) that occurred during the last glacial cycle (Fig. 1).

The DO events are characterized by abrupt warming followed by a gradual cooling. The isotopic composition of the nitrogen (N_2) in air bubbles trapped in Greenland ice and the stable water isotopes of oxygen (^{18}O) and hydrogen (deuterium, D) of the ice itself show that the abrupt warmings represent surface temperature changes in the order of 10-15°C (Landais et al. 2005). Annually dated ice core sections covering the two most recent DO events reveal the actual rapidity of the changes. Some proxies, like the deuterium excess ($d=\delta D-8*\delta^{18}O$), changed level over just a few years (Steffensen et al. 2008). The deuterium excess reflects the temperature at the moisture uptake region for the precipitation. Its step-like changes in Greenland ice cores suggest that the atmospheric circulation regime shifted substantially and irreversibly basically from one year to the next (Masson-Delmotte et al. 2005). Following the atmospheric regime shift, temperatures over Greenland warmed more gradually over some decades by 10-15°C, as shown by the $\delta^{18}O$ record (Steffensen et al. 2008). These observations prove that the climate system did, and therefore can, tip and reorganize internally within years and cause strong and fast regional temperature changes.

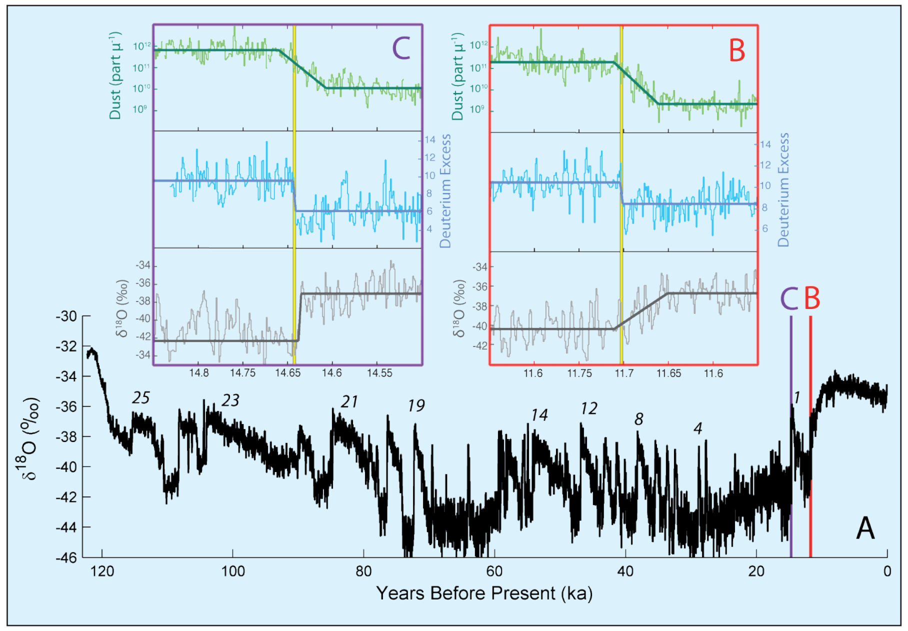

*Figure 1: High-resolution records from the Greenland ice core NGRIP. Panel **A** shows stable water isotopes ($\delta^{18}O$) in 20-year resolution. Numbers mark the most prominent of the 25 Dansgaard-Oeschger events. Panels **B** and **C** zoom in on two 300-year intervals during the transition from the last glacial to the Holocene. Shown are records of $\delta^{18}O$, deuterium excess and the unsolvable dust at 1-year resolution. The solid lines highlight the transitions in the records; the vertical yellow lines mark the steps in deuterium excess over just a few years. (Figure based on Steffensen et al. 2008).*

How and why did the abrupt climate changes happen? Studies from all latitudes based on ice cores from Polar Regions, marine sediments, stalagmites, corals and other paleoclimatic archives allow us to piece together a broader picture of the DO events and to deduce a sequence of causes and effects. During the cold phases preceding the abrupt warmings, vast volumes of ice were discharged into the ocean from the large glacial ice sheets including the North American Laurentide ice sheet, causing sea level to rise by several tens of meters (Siddall et al. 2003). The overturning circulation and associated northward heat transport in the Atlantic slowed down. This warmed the South and cooled the northern polar region further and may have resulted in a southward shift of the Intertropical Convergence Zone (ITCZ; Partin et al. 2007).

What caused the abrupt warmings? This is less well understood and requires investigation of the (very sparse) near-annually dated records. The studies from the Greenland ice cores suggest that the sudden rearrangement of the northern atmospheric circulation might have been initiated by a sudden shift of the ITCZ in the low latitudes. A sudden decrease of the dust concentration in the ice indicates that the wetness of the source area for the dust (related to the position of the ITCZ) had shifted (Steffensen et al. 2008). Perhaps the warming of the south finally pushed the ITCZ north again?

Can such tipping points of temperature and sea level change happen in the coming decades and centuries? The DO events during the last glacial seemed to be initiated by surges from big glacial ice sheets. Such large Ice sheets are not present nowadays, but other triggers that could cause the system to tip are plausible. Increased precipitation and melting of ice sheets and glaciers could increase the fresh water supply to the Arctic and the North Atlantic Ocean and alter the intensity of the ocean circulation. This would tip the energy distribution between the North and South in a similar way as happened during the glacial DO events. Rapid mass loss of the West Antarctic Ice Sheet, of which major parts lie more than 1 km below the present sea level, could cause an abrupt sea level rise of several meters.

State-of-the-art simulations with complex Earth System models do not project abrupt climate changes for this century. However, based on our understanding of the past DO events we conclude that abrupt changes of temperature and sea level cannot be ruled out entirely for our future world.

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