

# Managing the risks of climate thresholds: uncertainties and information needs

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## 1 Introduction

Human activities are driving atmospheric greenhouse-gas concentrations beyond levels experienced by previous civilizations. The uncertainty surrounding our understanding of the resulting climate change poses nontrivial challenges for the design and implementation of strategies to manage the associated risks. One challenge stems from the fact that the climate system can react abruptly and with only subtle warning signs before climate thresholds have been crossed (Stocker 1999; Alley et al. 2003). Model predictions suggest that anthropogenic greenhouse-gas emissions increase the likelihood of crossing these thresholds (Cubasch and Meehl 2001; Yohe et al. 2006). Coping with deep uncertainty in our understanding of the mechanisms, locations, and impacts of climate thresholds presents another challenge. Deep uncertainty presents itself when the relevant range of systems models and the associated probability density functions for their parameterizations are unknown and/or when decision-makers strongly disagree on their formulations (Lempert 2002). Furthermore, the requirements for creating feasible observation and modeling systems that could deliver confident and timely prediction of impending threshold crossings are mostly unknown. These challenges put a new emphasis on the analysis, design, and implementation of Earth observation systems and strategies to manage the risks of potential climate threshold responses.

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## 2 Needed information

A workshop at the Aspen Global Change Institute in July of 2005 assessed the information needs posed by potential anthropogenic crossings of climate thresholds. The participants concluded that reducing key uncertainties about climate thresholds is feasible. Doing so requires enhanced efforts in mission-oriented basic science (Stockes 1997), research into the potential impacts of crossing such thresholds, and the design of strategies that could efficiently reduce the likelihood that those impacts would be experienced. The participants agreed that these efforts would be well informed by new approaches of analyzing risk management strategies, such as robust decision-making or optimal reliable strategies (Lempert et al. 2003; McInerney and Keller 2007). These new approaches are required, for example, when the applicability of the more traditional expected-utility framework cannot be assured (Lempert et al. 2003; Tol 2003). The expected utility analysis relies on a sound assessment of the economic impacts and the probabilities of the threshold responses. This information is, however, deeply uncertain at this time (Cubasch et al. 2001; Tol 2003; Yohe et al. 2006). Robust decision-making (Lempert 2002; Lempert et al. 2003) seeks to identify strategies that perform well across a wide range of plausible impacts and a wide range of plausible probability density functions. Optimal reliable strategies limit the odds of undesirable outcomes in an efficient way (McInerney and Keller 2007). Thinking in terms of risk management can help identify how and where reducing uncertainties could produce considerable social benefits (Yohe 1996; Nordhaus and Popp 1997; Keller et al. 2004). This includes exploring the high tail of the probability density function of climate sensitivity and estimating the locations of climate thresholds.

Table 1 summarizes lines of evidence that lead to these conclusions. It also indicates the degree of confidence in this evidence (Schneider and Sarukhan 2001). The subjective confidence in the threshold locations, ability for timely detection, and potential consequences are often “exploratory or speculative”. Key lines of evidence about future climate thresholds are deeply uncertain. A potential collapse of the North Atlantic meridional overturning circulation (MOC) is a case in point. Current approaches of determining the location of the relevant forcing thresholds and the possible consequences of crossing them are still exploratory. The current uncertainties make timely prediction of a potential MOC collapse extremely difficult.

## 3 A risk management approach

Potential threshold responses in natural and social systems play an important role in the interpretation of Article 2 of the United Nations Framework Convention on Climate Change [UNFCCC], wherein nations commit themselves to preventing “dangerous anthropogenic interference with the climate system” (UNFCCC 1992). Persistent deep uncertainties about climate thresholds impede the design of climate policy under the UNFCCC. They cast doubt on the location of the critical boundaries and the attribution required to connect policy levers with policy targets. They also combine with uncertainty about climate sensitivity to question our ability to link specific concentration thresholds to reducing the likelihood of “dangerous interference”.

Since the complexities of potential threshold responses undermine the applicability of expected-utility analyses, they underscore the importance of adopting more general risk management approaches. These approaches would support the design of long-term policy to avoid crossing critical thresholds of “dangerous” climate change. These would likely be specified under the UNFCCC as concentration or temperature targets and be implemented as

**Table 1** Properties of potential threshold responses. The subjective confidence is coded following (Schneider and Sarukhan 2001)

	Threshold for initiation	Ability for timely detection	Possible consequences	Key references
Greenland Ice Sheet melting	≈ 1.5 °C <sup>a</sup>	Difficult, as threshold may be close <sup>b</sup>	≈ 7 m sea-level rise <sup>c</sup> Possible MOC weakening <sup>b</sup> Damages depend on melting rate <sup>a</sup>	(Gregory et al. 2004) (Hansen 2005)
Coral bleaching	≈ 1.5 °C <sup>b</sup>	Difficult, as the threshold may be close <sup>b</sup>	Ecosystem changes <sup>c</sup> Food production <sup>c</sup> Tourism <sup>c</sup>	(Hughes et al. 2003) (Keller et al. 2005) (Knowlton 2001)
El-Niño Southern Oscillation changes	Deeply uncertain <sup>d</sup>	Difficult <sup>a</sup>	Precipitation and temperature changes <sup>d</sup> Ecosystem changes <sup>d</sup> Food production <sup>d</sup> Flooding <sup>d</sup>	(Fedorov and Philander 2000) (Philander and Fedorov 2003) (Timmermann et al. 1999) (Timmermann 1999)
MOC weakening	Very low <sup>b</sup>	Likely feasible <sup>a</sup>	Precipitation and temperature changes <sup>d</sup> Fisheries <sup>d</sup> Terrestrial ecosystems <sup>d</sup>	(Gregory et al. 2005) (Higgins and Vellinga 2004) (Latif et al. 2004) (Link and Tol 2004) (Vellinga and Wood 2004)
MOC collapse	≈ 2 to > 5 °C <sup>d</sup>	Very difficult <sup>d</sup>		(Fichefet et al. 2003) (Hargreaves and Amman 2006) (Rahmstorf and Zickfeld 2005) (Schmittner and Stocker 1999) (Vellinga and Wood 2002) (Zickfeld and Bruckner 2003)
West Antarctic Ice Sheet disintegration	≈ 2.5 °C <sup>d</sup>	Very difficult, fingerprints are uncertain and difficult to observe <sup>d</sup>	≈ 5 m sea-level rise <sup>c</sup> Possibly severe <sup>d</sup> Damages depend on melting rate <sup>a</sup>	(Oppenheimer 1998) (Oppenheimer and Alley 2004) (Vaughan and Spouge 2002)

The temperature thresholds in the second column refer to the approximate changes in globally averaged surface temperatures relative to pre-industrial conditions. Note that some values (e.g., Oppenheimer and Alley 2004) are based on a precautionary interpretation of the available evidence (Keller et al. 2005). The “timely detection” (third column) refers to an actionable warning sign for the threshold response (as opposed to the crossing of the approximate temperature or carbon dioxide concentration threshold) that would enable reversing the anthropogenic forcing to reduce the risk of the threshold response to low levels. The references given in the last column are a subset of key publications, more detailed analyses can be found in the references cited therein

<sup>a</sup>Established but incomplete

<sup>b</sup>Competing explanations

<sup>c</sup>Well established

<sup>d</sup>Exploratory or speculative

emissions targets. These long-term targets should be adjusted over time as new information becomes available. The risk management approach also sheds light on how to design near-term policies that are consistent with “moving long-term targets”. Near-term policies could be framed as a hedge against the costs of policy adjustments. These could be implemented either by limiting the likelihood of crossing the thresholds (Keller et al. 2000; McInerney and Keller 2007; Yohe et al. 2006) or by maintaining the feasibility of specific concentration or temperature limits (Yohe et al. 2004, 2005). Indeed, slowing the pace of climate change, even modestly, is a potentially efficient way of increasing the likelihood of confident and timely prediction of threshold crossings, even though this strategy might make the signal more difficult to detect. To be economically efficient, though, the adjustment process must be predictable and transparent, much like the predictable rules that define the anticipations of adjustments by markets in the conduct of monetary policy in countries such as the United States.

Textbooks (Stiglitz and Walsh 2002) tell us that the Federal Reserve makes periodic short-term adjustments within the boundaries of long-term targets for growth in the money supply, even as research continues into defining the best policy targets in an uncertain world (Jensen 2002; Walsh 2003). The former chairman of the Federal Reserve Board Alan Greenspan (Greenspan 2004) stated that these adjustments and the specifications of long-term targets are tempered by “crucial elements of risk management” (p. 37). More specifically, the former Chairman wrote (p. 37): “For example, policy A might be judged as best advancing the policymakers’ objectives, conditional on a particular model of the economy, but might also be seen as having relatively severe adverse consequences if the true structure of the economy turns out to be other than the one assumed. On the other hand, policy B might be somewhat less effective under the assumed baseline model but might be relatively benign in the event that the structure of the economy turns out to differ from the baseline.” His words and the continuing debate over policy design can be cast into the context of how best to respond to the threat of climate thresholds. Hedging against even speculative descriptions of what might be “intolerable” impacts of crossing a threshold can make sense. The efficacy of such “act-as-you-learn” hedging can be improved by better information and further investigations of how to design adaptive mitigation strategies.

#### 4 Implications for the design of research portfolios

Climate thresholds pose deep intellectual challenges at the interface of pure and policy-relevant science. Reducing the risk of future surprises requires a balanced and diversified research portfolio that analyzes the range of possible thresholds. Possible elements of such a research portfolio that are likely to pay dividends include: (i) refining the probabilistic analysis of paleo-events to improve predictions of future climate change; (ii) characterizing the connections between monitoring and early prediction of threshold crossings; (iii) reducing the uncertainty of decision-critical parameters, such as climate sensitivity; (iv) estimating the impacts of threshold crossings; (v) analyzing strategies to reduce the risk of threshold crossings; and (vi) investigating ways of representing and communicating key uncertainties to decision-makers, stakeholders and the general public. It is important that the research portfolio covers many potential thresholds, ranked according to their importance. Currently, the threshold of a potential weakening or collapse of the MOC is drawing much of the attention, but it is not clear that it poses the most imminent or most dangerous threat.

While the current understanding of potential climate thresholds is uncertain, crucial information needs and research strategies for addressing them are becoming clear. Improving our understanding of the impacts associated with a growing list of possible thresholds and our understanding of how anthropogenic forcing affects their likelihoods is crucial to enhancing our ability to select long-term policy objectives and to craft short-term hedges for the effective management of climate risks.

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