Extended Abstract Submission
Avoiding Dangerous Climate Change
Met Office, Exeter, UK, 1-3 Feb. 2005

Paper Title: Probabilistic Assessment of “Dangerous” Climate Change and Emissions Scenarios

Keywords: Dangerous Climate Change, Climate Sensitivity, Probabilistic Analysis

Authors: Michael D. Mastrandrea*‡ and Stephen H. Schneider*†

Affiliations: * Center for Environmental Science and Policy, Stanford University
† Department of Biological Sciences, Stanford University, Stanford, CA 94305-5020
‡ Corresponding Author

Contact Information:
Michael D. Mastrandrea
Center for Environmental Science and Policy
Encina Hall East, E415
Stanford, CA 94305-6055
mikemas@stanford.edu
Voice: +1 650 224 2070
Fax: +1 650 725 4387

Stephen H. Schneider
Department of Biological Sciences
Stanford, CA 94305-5020
shs@stanford.edu
Voice: +1 650 725 9978
Fax: +1 650 725 4387

Probabilistic Assessment of “Dangerous” Climate Change and Emissions Scenarios

Michael D. Mastrandrea* and Stephen H. Schneider*†
* Center for Environmental Science and Policy, Stanford University
Encina Hall East, E415, Stanford, CA 94305-6055
† Department of Biological Sciences, Stanford University, Stanford, CA 94305-5020

Abstract

Successful compliance with Article 2 of the United Nation Framework Convention on Climate Change, prevention of “dangerous anthropogenic interference with the climate system” (DAI), is dependent on the climate policy decisions driving future greenhouse gas mitigation efforts and stabilization levels. The likelihood of avoiding a given threshold for DAI is in part dependent on the range of uncertainty for climate sensitivity. We combine a set of probabilistic global average temperature metrics for DAI with probability distributions of future climate change produced from published climate sensitivity distributions and a range of proposed emissions pathways, including stabilization pathways differing in both stabilization level and approach trajectory—such as overshoot scenarios. These joint probability distributions represent a “likelihood framework” to differentiate future emissions pathways with regard to their potential for preventing DAI.

1. Introduction

1.1: Article 2 and climate policy

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) states its ultimate objective as: “Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” This level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner [1]. Thus, the criteria for identifying “dangerous anthropogenic interference” (DAI) may be characterized in terms of the consequences (or impacts) of climate change [2]. While these impacts, and precise definition of “DAI,” are subject to considerable uncertainty, a plausible uncertainty range can be quantified from current scientific knowledge [3]. We argue that climate change policy decisions should be conceptualized in terms of preventing or reducing the probability of DAI, a risk-management framework familiar to policymakers, and an outcome to which over 190 signatories to the UNFCCC have committed.

Due to the complexity of the climate change issue and its relevance to international policymaking, careful consideration and presentation of uncertainty is important when communicating scientific results [4,5,6,7]. Policy analysis for climate change necessarily requires decision-making under uncertainty [8,9,10]. As expressed in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR), the scientific community can provide essential information needed for decisions on what constitutes DAI [11]. Further, the scientific community can provide specific probabilistic guidance on the implications of different policy choices and their likelihood of avoiding “dangerous” climate impacts. We present a probabilistic framework for assessing the likelihood of DAI under a range of greenhouse gas emissions scenarios, including climate mitigation scenarios resulting in stabilization of atmospheric greenhouse gas concentrations, with and without overshoot of the stabilization concentration.

2. DAI metrics

2.1: Aggregate metric

In Mastrandrea and Schneider [12], we presented a cumulative density function (CDF) of the threshold for "dangerous" climate change, based on the IPCC "Reasons for Concern about Climate Change" [3; here, Fig. 1]. Each column in the figure represents a "reason for concern" about climate change in this century based on dozens of IPCC lead authors' examination of climate impacts literature, thus representing a "consensus estimate" of DAI. We construct our CDF by assigning data points at the threshold temperature above which each column becomes red (solid black line in Fig. 1), and assume that the probability of DAI increases cumulatively at each threshold temperature by a quintile—making the first threshold the 20th percentile. This CDF is a starting point for our analysis of DAI; it facilitates a concrete sensitivity analysis of future climate change scenarios and the likelihood of exceeding various thresholds of "dangerous" climate change. The median, 50th percentile threshold for DAI in this metric is 2.85ºC [12].

2.2: Stakeholder metrics

There are many ways that DAI could be interpreted from this figure, or from other sources. Each "reason for concern" could provide its own probability distribution for DAI, each "reason for concern" could be given its own "weight" based on some definition of its relative importance, or other categories or metrics for assessing DAI other than those displayed could be used. The evaluation of DAI is informed by scientific evidence and analysis but is ultimately a normative decision influenced by value judgments determined by socio-political processes and considering factors such as development, equity, sustainability, uncertainty, and risk. The perceived definition of DAI will likely be different depending on geographical location, socio-economic standing, and ethical value system. Our first attempt at this definition [12] uses the simplest possibility—equal weight for all five categories. As the temperature increase exceeds the orange-to-red threshold of more categories, we believe a greater number of people will agree that "dangerous" change is occurring or would likely occur. Thus, we use all "reasons for concern" instead of just one, assuming equivalence of the "danger" from each category. We present a traceable account [13] of our assumptions in creating this definition, and we believe a similar account should be made each time such a definition is created by any analyst, as others, such as Wigley [14], have done.

To represent other possible DAI metrics, we produce a set of three new CDFs, based on individual "reasons for concern" categories, which reflect certain policy perspectives commonly presented by generalized stakeholders in the international climate debate. An Alliance of Small Island States (AOSIS) member may focus their definition of DAI on Column I, risks to unique and threatened systems, which in part represents temperature change associated with risks to unique human settlements such as small island nations or vulnerable coastal states like Bangladesh. A high-latitude nation such as Canada, or a nation with high adaptive capacity, such as the United States, may be most concerned with abrupt nonlinear climate changes, and may base their definition of DAI on Column V, risks from future large-scale discontinuities. An economic policy analyst, or a government making decisions based on such analysis, may base their definition of DAI on Column IV, aggregate impacts of goods and services valued by market transactions. We acknowledge that the "reasons for concern" categories are not completely independent. For example, extreme climate events (Column II) may induce impacts to unique or threatened systems (Column I) or increase distributional impacts (Column III). However, these "reasons for concern" were specifically designated by the IPCC as impacts related to the evaluation of DAI, and each category represents an established impact "numeraire" for DAI. Other numeraires for evaluating impacts have been suggested (e.g., the "five numeraires" in [15]), but are not developed here, though any such set could be applied to this framework.

3. Emissions scenarios

3.1: SRES scenarios

We apply our DAI metrics to two categories of greenhouse gas emissions pathways. The first category is a subset of the illustrative scenarios from the IPCC Special Report on Emissions Scenarios (SRES) [16]. We choose the illustrative scenarios A1FI (fossil intensive) and A1T (technology), two scenarios from the A1 family which reflect significantly different technological development pathways that induce very different greenhouse gas emissions profiles. These emissions scenarios do not extend beyond the year 2100, and were not created specifically as stabilization pathways. However, while A1FI emissions stray far above scenarios reaching commonly proposed atmospheric stabilization concentrations, A1T emissions are consistent with such stabilization pathways [17], and could be construed as a “climate policy-like” scenario, at least for evaluating differential consequences of emissions choices on DAI.

3.2: Stabilization scenarios

The SRES scenarios incorporate emissions projections for all significant radiatively active trace gases and aerosols. O’Neill and Oppenheimer [18] produce stabilization pathways which also include this array of relevant emissions profiles, generating scenarios which reach a range of CO_2-equivalent stabilization levels through three approach categories: slow approach, rapid approach, and overshoot. These differ from previous stabilization scenarios in that they consider radiatively active gases beyond CO_2 and aerosols, and a wider range of approach pathways. We apply our DAI metric to representative scenarios from these approach categories for 500 ppm and 600 ppm CO_2-equivalent stabilization levels.

4. Temperature projections

4.1: Climate sensitivity uncertainty

Using general circulation models (GCMs), the IPCC has long estimated the climate sensitivity—the equilibrium global mean surface temperature increase from a doubling of atmospheric CO_2—to lie somewhere between 1.5ºC and 4.5ºC [19] without indicating the relative probability within this range. Recent studies produce distributions wider than the IPCC range, with significant probability of climate sensitivity above 4.5ºC [20,21, e.g.]. The likelihood of avoiding any given temperature threshold for DAI is extremely sensitive to the uncertainty associated with climate sensitivity, as demonstrated by Mastrandrea and Schneider [12]. Differences in climate sensitivity given an emissions scenario will lead to very different temperature profiles. The IPCC TAR presents future global average temperature profiles induced by the SRES illustrative scenarios, including A1FI and A1T, by forcing a simple climate model tuned to several complex Atmosphere-Ocean GCMs (AOGCMs) [19]. Each “tuning” employs a different climate sensitivity, resulting in the temperature ranges presented in the TAR for each illustrative scenario. O’Neill and Oppenheimer also use a simple climate model of the type used in the TAR to produce temperature profiles based on their stabilization pathways, and choose three climate sensitivities within the IPCC range to produce a sensitivity analysis. Neither of these sources conduct a full investigation of the range of uncertainty in climate sensitivity, and the implications for the emissions scenarios they employ. Further, they do not relate their emissions scenarios, which implicitly or explicitly require climate mitigation policy decisions, to the likelihood of avoiding DAI, the current ultimate goal of international climate policy (O’Neill and Oppenheimer do compare the future temperature profiles generated by their emissions scenarios to thresholds for individual climate impacts that may be considered “dangerous”).

In our analysis, we use three probability distributions from two published sources [20,21], the same as those used in our previous work [12]. Use of these probability distributions allows us to sample a more full range of uncertainty in climate sensitivity.

4.2: Probabilistic temperature time series

To generate consistent temperature time series for application of our DAI metrics, and to explore the probabilistic range for future temperature change implied by uncertainty in climate sensitivity, we use the radiative forcing time series for the scenarios described above to force a simple two-box climate model [22]. We do not recommend that our quantitative results using this simple model be taken literally, but we suggest that our probabilistic framework and methods be taken seriously: they produce relative trends and general conclusions that are more robust than estimates made without probabilistic presentations of outcomes, and our threshold metrics for “DAI” offer a risk-management framework for discussion of future climate change that can be applied to results at all levels of model complexity or for alternative numeraires to evaluate “dangerous” impacts.

For the SRES scenarios, which only provide emissions until the year 2100, we generate transient temperature time series from 1990 to 2100 and using initial conditions for temperature and radiative forcing consistent with those provided by the IPCC TAR [19]. For the stabilization scenarios, which extend to the year 2300, we generate temperature time series from 1990 to 2300, with identical initial conditions.

For each scenario, we generate temperature time series under a range of climate sensitivities sampled from our climate sensitivity distribution. Thus, we generate probability distributions for future temperature change based on the uncertainty in climate sensitivity.

5. DAI Analysis

5.1: Probabilistic DAI analysis

We apply our aggregate metric and stakeholder metrics for DAI to probability distributions for global average temperature increase in 2050 and 2100 for each emissions scenario. For each distribution, we will indicate the number of outcomes exceeding a range of DAI thresholds from our aggregate CDF for DAI. This analysis and those described below are currently being executed. We include Figure 2, a result from [12] which represents the type of probability distribution these analyses will produce. Figure 2 indicates the percentage of outcomes exceeding our median threshold for DAI, 2.85°C, from our aggregate DAI metric. This was the first step in a probabilistic analysis using a range of temperature thresholds for DAI from our CDF. Here, we will conduct similar analyses (though the temperature profiles and distribution under analysis are produced by specified emissions scenarios instead of emissions profiles determined through an optimization framework, as in [12]).

Finally, for the stabilization pathways, we will apply our DAI metrics to the probability distribution of equilibrium temperatures implied by each stabilization level, and provide the additional transient warming above the equilibrium level implied by the overshoot stabilization pathways. (As all these codes are functional, it will be possible to have a large set of results analyzed well before the conference).

5.2: Irreversibility and path-dependence

The response of the complex climate system to external forcings may include abrupt nonlinear climate changes and other impacts irreversible on time scales relevant to human policymaking. Paleoclimatic data and scientific understanding of current components of the climate system indicate that such changes are possible in the future due to anthropogenic forcings. We examine stabilization scenarios which vary in their approach to the final stabilization level. While overshoot pathways may reduce the mitigation costs of reaching a given stabilization level [23,24], they may also increase the climate change impacts associated with a given stabilization goal [18,25]. Further, the additional transient warming induced by overshoot stabilization pathways may exceed temperature thresholds for irreversible, abrupt nonlinear climate changes or impacts (like species extinctions), which will persist long after the temporary threshold exceedence. This phenomenon would increase the likelihood of DAI for overshoot pathways compared to other pathways reaching the same stabilization level.

Such additional “overshoot impacts” largely fall under categories represented by Columns I and V of the “reasons for concern.” Therefore, using our individual DAI metrics, we will calculate the increased likelihood of DAI implied by overshoot pathways compared to alternate approach pathways.

---

1. *United Nations Framework Convention on Climate Change* (UNFCCC, 1992; http://www.unfccc.de).
2. A. Patwardhan, S.H. Schneider, S.M. Semenov, “Assessing the science to address UNFCCC Article 2” (IPCC Concept Paper, http://www.ipcc.ch/activity/cct3.pdf).
3. J.B. Smith *et al.*, in *Climate Change 2001: Impacts, Adaptation, and Vulnerability - Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, K.S. White, Eds. (Cambridge Univ. Press, Cambridge, UK, 2001) chap. 19.
4. S.H. Schneider, *Environ. Model. Assess.* **2**, 229 (1997).
5. M.G. Morgan, M. Henrion, Eds., *Uncertainty: a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge Univ. Press, New York, NY, 1990).
6. R.N. Pittock, R.N. Jones, C.D. Mitchell, *Nature* **413**, 249 (2001).
7. S.H. Schneider, B.L. Turner, H. Morehouse Garriga, *J. Risk Res.* **1**, 165 (1998).
8. A.S. Manne, R.G. Richels, *Energy J.* **16**, 1 (1995).
9. J.K. Hammitt, R.J. Lempert, M.E. Schlesinger, *Nature* **357**, 315 (1992).
10. M.D. Webster, *Energy J.* **23**, 97 (2002).

---

11. D.L. Albritton *et al.*, in *Climate Change 2001: Synthesis Report, Summary for Policy Makers - Contribution of Working Groups I, II, and III to the IPCC Third Assessment Report*, R.T Watson, Ed. (Cambridge Univ. Press, Cambridge, UK, 2001) pp. 37-43.
12. M.D. Mastrandrea, S.H. Schneider, *Science* **304**, 571 (2004).
13. R.H. Moss, S.H. Schneider, in *Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC*. R. Pachauri, T. Taniguchi, K. Tanaka, Eds. (World Meteorological Organization, Geneva, 2000) pp. 33–51.
14. T. Wigley, *Clim. Change*, *In press*.
15. S.H. Schneider, K. Kuntz-Duriseti, C. Azar, *Pac. and Asian J. Energy* **10**, 81 (2000).
16. N. Nakicenovic, *et al*. (2000) *Special Report on Emissions Scenarios* (Intergovernmental Panel on Climate Change, Cambridge Univ. Press, Cambridge, U.K.).
17. T. Banuri *et al.*, in *Climate Change 2001: Mitigation – Contribution of Working Group III to the IPCC Third Assessment Report*, R. Pachauri, Ed. (Cambridge Univ. Press, Cambridge, UK, 2001) Summary for Policy Makers.
18. B.C. O'Neill, M. Oppenheimer, *Proceedings of the National Academy of Sciences* **101**, 16411 (2004).
19. U. Cubasch *et al.*, in *Climate Change 2001: The Scientific Basis, Summary for Policy Makers - Contribution of Working Group I to the IPCC Third Assessment Report*, J.T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, UK, 2001) Chapter 9.
20. N.G. Andronova, M.E. Schlesinger, *J. Geophys. Res.* **106**, 22605 (2001).
21. C.E. Forest, P.H. Stone, A.P. Sokolov, M.R. Allen, M.D. Webster, *Science* **295**, 113 (2001).
22. S.H. Schneider, S.L. Thompson, J. Geophys. Res. **86**, 3135 (1981).
23. J.K. Hammitt, *Clim. Change* **41**, 447 (1999).
24. R. Swart, J. Mitchell, T. Morita, S. Raper, *Global Environ. Change* **12**, 155 (2002).
25. T.M.L. Wigley, *Benefits of Climate Policies: Improving Information for Policymakers* (Organization for Economic Cooperation and Development, Paris, 2004).

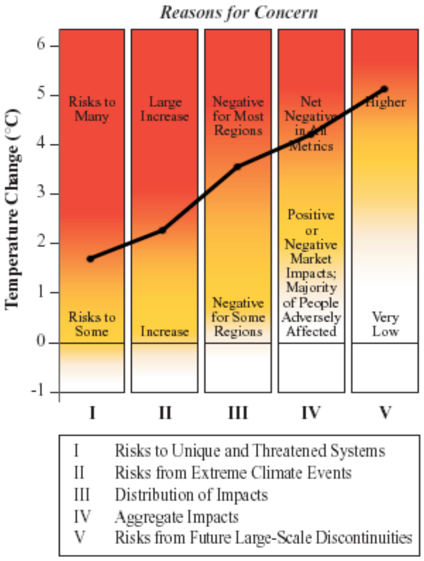

Fig. 1. An adaptation of the IPCC Reasons for Concern figure from [12], with the thresholds used to generate our CDF for DAI. The IPCC figure conceptualizes five reasons for concern, mapped against climate change through 2100. As temperature increases colors become redder, indicating increasingly widespread and/or more severe negative impacts. We use the transition-to-red thresholds for each reason for concern to construct a CDF for DAI.

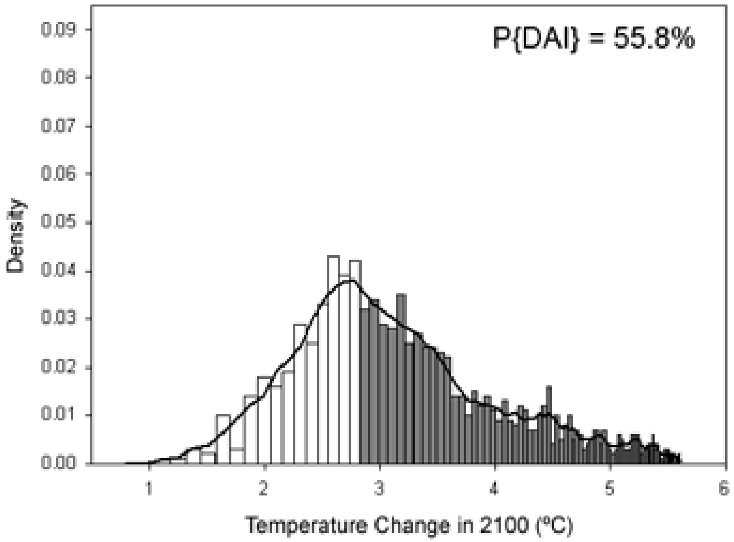

Fig. 2. Sample probability distribution for future climate from [12], generated by sampling from the uniform climate sensitivity distribution from [21] and assuming business as usual emissions from the Dynamic Integrated Climate and Economy (DICE) model [see 12 for methods]. Gray shading indicates outcomes which exceed the median threshold for DAI from our aggregate metric, 2.85ºC. Such probability distributions provide the first step in a probabilistic analysis of the implications of climate policy decisions and pathways to stabilization of atmospheric concentrations.