TITLE: Article 2 of the UNFCCC: Historical Origins, Recent Interpretations

AUTHORS: Oppenheimer, M., & Petsonk, A.

AFFILIATIONS:

Oppenheimer, Michael:

Woodrow Wilson School and Department of Geosciences, Princeton University

Petsonk, Annie:

Environmental Defense

ADDRESS FOR CORRESPONDENCE:

Michael Oppenheimer

Robertson Hall 448

Princeton University

Princeton, NJ 08544

Tel: 609-258-2338 Fax: 609-258-6082

Email: omichael@princeton.edu

Revised *19 November 2004*

Article 2 of the UNFCCC: Historical Origins, Recent Interpretations

M. Oppenheimer & A. Petsonk

Abstract. Article 2 of the UN Framework Convention on Climate Change (UNFCCC), which states the treaty's long-term objective, is the subject of a growing literature that examines means to interpret and implement this provision. Here we provide context for these studies by exploring the intertwined scientific, legal, economic, and political history of Article 2. We review proposed definitions for "dangerous anthropogenic interference" and frameworks that have been proposed for implementing these definitions. Specific examples of dangerous climate changes have been proposed that suggest limits on global warming ranging from 1 to 4^{o}C and on concentrations ranging from 450 to 700ppm CO_2. The implications of Article 2 for near term restrictions on greenhouse-gas emissions, e.g., the Kyoto Protocol, are also discussed.

1. Introduction

Until recently, the question of how to interpret and implement Article 2 of the UN Framework Convention on Climate Change received relatively cursory treatment (cf. Bodansky, 1993). Since the publication of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2001 (Houghton et al., 2001; McCarthy et al., 2001; Metz et al., 2001), a variety of governmental (Tuinstra et al., 2002; Gupta et al., 2003) and nongovernmental collaborations (Pew Center, 2001;

Diringer, 2003; Michel, 2003; SWP, 2003) have begun to examine these issues in depth.[1] At the same time, there has been no formal discussion of Article 2 by the Parties to the Framework Convention.[2]

Here we explore the history of the concept of long-term limits to climate change, emphasizing in particular the origins and development of Article 2 and evolution of the concept of “dangerous” climate change before and after the UNFCCC was adopted. We focus narrowly on scientific, legal, economic, and political developments and do not discuss apportionment of national responsibility (Baumert, 2002; Gupta, 2003), or alternative frameworks for formulating long-term objectives, such as technology-based approaches, that are not consistent with the language of Article 2.

In the climate change context, the history of an idea matters. History may illuminate the intended meaning of Article 2, and it could make apparent what notions of danger were cast aside during the debate over Article 2, and which notions have been omitted altogether. A clear understanding of the process through which the concept has evolved could help shape current efforts to reach a consensus interpretation. Since a legal definition of danger in the context of Article 2 ultimately would occur through a diplomatic process, not least important is an understanding of the roles of particular countries as well as individuals and groups (e.g., epistemic communities, Haas, 1992) in the evolution of the concept.

2. The Scientific and Policy History of Limits-to-Warming

General histories of the climate change problem (see Clark et al., 2001; Weart, 2003 and references therein; see also Hecht and Tirpak, 1995) usually begin with Arrhenius (1896) or earlier scientific studies. But it was not until the mid-1970s that a broader expert community, including policy-makers, began to focus on the questions of whether, when and how to limit warming.

In an early report of the US National Research Council (NRC, 1977), *Energy and Climate*, meteorologist J. Murray Mitchell, Jr. asked, "Can man establish which, if any, alternative scenarios would lead to "unacceptable" climatic consequences and are therefore to be avoided?" The foreword to the report, written by Philip Abelson, took a slightly different perspective (foreshadowing current discussions of economic optimization versus environmental targets noted below), asking, "What *should* the atmospheric carbon dioxide content be over the next century or two to achieve an optimum global climate?"

Antecedents of the notion of dangerous warming are found in the comprehensive analyses of human modifications of the environment in general (SCEP, 1970) and climate in particular (SMIC, 1971) that appeared in preparation for the 1972 UN Conference on the Human Environment. Specific reference to the concept of crossing a threshold of climate danger is found in Schneider (1976). Subsequent detailed assessments were spurred not only by interest in the greenhouse gases (NRC, 1977; Williams, 1978) but also by concerns about the potential effects of supersonic aircraft on climate and the ozone layer (CIAP, 1975). The global perspective on climate generated a growing list of studies of specific impacts of climate variation and climate change that eventually provided a basis for developing and interpreting Article 2 (e.g., Houghton et al., 1990; McCarthy et al., 2001 and references therein).

In a series of articles beginning in 1975, Nordhaus (1979, and references cited therein) appears to have been the first to systematically address questions like those raised by Mitchell and Abelson, and the first to attempt to model the economics of limiting carbon dioxide concentrations. Drawing on early carbon cycle models that indicated that a stable or falling atmospheric concentration could be achieved by reducing emissions, he wrote:

> Up to now there has been no serious thought of the level of standard on carbon dioxide. As a first approximation, it seems reasonable to argue that the climate effects of carbon dioxide should be kept within the normal range of long-term variation (Nordhaus, 1979).

He went on to argue that 2°C warming, comparable to what was thought to be the maximum sustained global mean temperature during the Holocene, marked the limit of "normal" and linked this change to a doubling of carbon dioxide concentrations, based on the results of early climate models. But he emphasized that "the proposed standards are deeply unsatisfactory…I am not certain that I have even judged the *direction* of the desired movement in carbon dioxide correctly, to say nothing of the absolute levels" (Nordhaus, 1979).

At the same time, some scientists ignored or were unaware of the possibility that stabilization of concentrations and climate were theoretically possible.[3] For example, Cooper (1978) asserted that "even an appreciable decrease in the rate of fossil fuel burning will only delay the time of maximum climate effect. It will not prevent it." The first comprehensive USEPA report on climate change (Seidel and Keyes, 1983) explored only options for slowing warming, rather than stabilizing carbon dioxide or climate.

2.1. EARLY POLITICAL DEVELOPMENTS

At the peak of the 1979–80 oil supply crisis, U.S. Senator Abraham Ribicoff of Connecticut learned that synthetic fuels, widely advocated as a substitute for oil and natural gas, emitted twice the CO_2 per unit of usable energy compared with conventional fossil fuels, and would lead to sharply increased atmospheric concentrations – a "Faustian bargain," in his view (Ribicoff, 1979a).[4] As a consequence, he amended the Energy Security Act of 1980 to request that the NRC conduct a comprehensive assessment of the impact of projected fossil-fuel combustion on the accumulation of CO_2 in the atmosphere (Ribicoff, 1979a, b, c; United States Senate Committee on Governmental Affairs, 1979; NRC, 1979[5]; Handler, 1979; AAAS, 1979; Pomerance, 1989). The resulting NRC report emerged in 1983, thoroughly assessing the problem, including many policy options, but not mentioning concentration limits or stabilization (NRC, 1983).

Stimulated by the same concerns over synthetic fuels as well as by the debate then underway over reauthorization of the Clean Air Act (Pomerance, 1989), the White House Council on Environmental Quality (CEQ) issued two relevant reports in 1981. The reports warned that projections of global energy use indicated that CO_2 concentrations could reach twice pre-industrial levels by the middle of the twenty-first century. According to this early view, the resulting climatic changes could "markedly affect agricultural productivity over large areas," trigger sea level rise of five meters with significant coastal flooding, and "markedly affect the less managed biosphere, including fisheries and forests." CEQ examined the energy policy implications of a range of fossil-fuel use scenarios based on limiting CO_2 concentrations to several of the values that Arrhenius had considered in the nineteenth century: 1.5, 2.0, and 3.0 times the pre-industrial level. Noting that "there are a limitless number of scenarios for burning fossil fuels that could each lead ultimately to the same level of atmospheric CO_2," CEQ nevertheless pointed out that "the more rapidly the world increases fossil fuel use now, the sooner and more rapidly it must begin its reduction in order to avoid exceeding any given CO_2 ceiling." It concluded (as had Nordhaus earlier) that CO_2 concentrations could double between 2020 and 2050 and that preventing this would require global fossil-fuel use to peak and begin declining in the 2000–2020 period (CEQ, 1981a,b). But despite these reports, the option of stabilizing concentrations remained largely unrecognized or ignored in early discussions of specific policy responses (as pointed out by Firor, 1988).

In October, 1985 (a few months after the signing of the Vienna Convention for the Protection of the Ozone Layer), the International Conference on The Assessment of the Role of Carbon Dioxide and Other Greenhouse Gases in Climate Variations and Associated Impacts convened at Villach, Austria under the auspices of the UN Environment Programme (UNEP), the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) (Bolin et al., 1986). . The conference developed an influential scientific consensus on the greenhouse gas problem. The conference statement used that consensus as a basis for suggesting that policy makers ought to grapple with climate change. The statement proposed that development of a framework convention ought to be considered, but the notion of a target was not advanced. Almost unnoticed in the conference report were a handful of emissions scenarios that resulted in stabilization of CO_2 concentrations. The Advisory Group on Greenhouse Gases (AGGG) was subsequently established by the three sponsoring organizations to advance the conference's recommendations, including consideration of a framework convention (Agrawala 1999, Andresen and Agrawala 2002). The same year, the US Department of Energy published a series of ground-breaking studies on the potential impacts of increasing concentrations of carbon dioxide (Strain and Cure, 1985; White, 1985; Ad Hoc Committee, 1985).

The summer following the Villach meeting, US Senator John Chafee of Rhode Island, then chair of the Environment and Public Works Committee, responding to the Villach report and to increasing press around atmospheric issues (Chafee, 1986), convened hearings on changes in the climate and ozone depletion, and began an effort to shape U.S.

policy. In September 1986 Senators Chafee, George Mitchell of Maine, and others wrote to Lee Thomas, administrator of the U.S. Environmental Protection Agency, requesting two studies, one of the impacts of climate change on human health and the environment, and the other of policy options for stabilization (Mitchell, Senator J. et al., 1986). While the letter referred to stabilization of *emissions*, prior and subsequent writing makes clear that Senator Chafee's concern was for stabilization of *concentrations* (Chafee, Senator J., 1986; Chafee, Senator J., et al., 1986). Chafee took significant legislative steps to clarify that U.S. policy should "identify existing and potential strategies…to stabilize global climate, and atmospheric concentrations of greenhouse gases, at current levels…" (Chafee, Senator J., 1987; Pomerance, 1989), but the mix-up complicated climate policy up to and through the adoption of the Framework Convention.

An outcome of Senator Chafee's concern was the Global Climate Protection Act of 1987, which mandated that U.S. policy should seek to "limit mankind's adverse effect on the global climate by (a) slowing the rate of increase of concentrations of greenhouse gases in the atmosphere in the near term; and (b) stabilizing or reducing atmospheric concentrations of greenhouse gases over the long term." Congress directed EPA to analyze policy options accordingly (Global Climate Protection Act of 1987). In the course of enacting this law the US Senate Foreign Relations Committee noted the threat to agriculture in particular, and stated its belief that "global warming is a potential environmental disaster on a scale only exceeded by nuclear war" (Foreign Relations Committee, 1987). Thus the U.S. Congress established that U.S. climate policy should focus on stabilizing greenhouse-gas (GHG) concentrations and preventing extremely deleterious outcomes.

The development of this dual objective by Congress occurred simultaneously with an emerging global focus on sustainable development (via the “The Brundtland Report”, World Commission on Environment and Development , 1987). The nexus between sustainable development – defined by the Commission as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” - and climate change fit naturally with the ideas of stabilizing future concentrations and preventing dangerous outcomes, and these concepts were also reinforced by the EPA reports prepared in response to the Global Climate Protection Act of 1987 (Smith and Tirpak, 1989; Lashof and Tirpak, 1990).[6]

2.2. TARGETS AND THE INTERNATIONAL REGIME

In the late 1980s, proposals to limit climate change coalesced around two very different approaches, one based on environmental objectives, and the other, on political and economic feasibility. The feasibility approach was influenced by the 1987 Montreal Protocol to the Vienna Convention on the Ozone Layer, which mandated a freeze in production and consumption of ozone-depleting chemicals followed by a 50% reduction (Montreal Protocol, 1987; Benedick, 1998; Agarwala, 1999).[7]

In 1987, science and policy experts met at two workshops in Villach and Bellaggio, respectively, and a steering committee chaired by Gordon Goodman of the Beijer Institute (later the Stockholm Environment Institute) produced a report based on the proceedings (WMO 1988). The report, a draft of which was reviewed and approved by AGGG, proposed that a target framed in terms of a *rate of warming* would provide a useful long-term objective (called a *tolerable rate*) for limiting emissions. The report recognized that both natural and social systems adjust more easily to slow than to rapid change but the ability of natural systems to adjust was much more limited. Based on the expected responses of forests and coastlines to warming and sea level rise, respectively, the report proposed a target warming rate of one-tenth degree Celsius per decade (WMO, 1988). After a broader examination of impacts, including those on coral reefs, carried out under terms of reference approved by the AGGG but completed after AGGG effectively ceased to function, the rate approach was augmented by a proposed limit of one or two degrees Celsius on total global warming (Oppenheimer, 1989; Rijsberman and Swart, 1990).[8] For an informative analysis of the roles of independent scientists, NGOs, intergovernmental organizations, and government representatives in the foregoing process, see Agrawala (1999).

The conception of targets developed during this process, based on rates and amounts of warming and sea level rise, received close attention from the Netherlands government. Based in part on what was learned during the 1987 Villach-Bellagio process, the Dutch were convinced of the plausibility of disastrous climate changes. (It is perhaps noteworthy that a participant in one of the 1987 workshops, Per Vellinga, later joined the

Dutch government and its delegation to the climate negotiations). It followed that quantitative limits for stabilization of concentrations ought to be established, and be set at levels that would avert such changes. The Dutch also believed that rapid rates of climate change would pose particular challenges for developing countries, with emphasis on the agricultural sector, and for natural ecosystems (Vellinga, personal communication).

In 1988, a different kind of target—based not on environmental objectives but on political and economic considerations (Clark and Dickson, 2001) and particular policies and measures to limit emissions such as a more efficient use of energy by the electricity sector—was introduced at an international conference in Toronto (Levy et al., 2001; Andresen and Agrawala, 2002; Clark et al., 2001). The conference participants included a mixture of individuals from governments, nongovernmental organizations, intergovernmental agencies, and the private sector. Their proposal, calling for a 20 percent reduction in *industrial countries'* emissions of carbon dioxide from 1988 levels by 2005, set in motion discussions along an entirely different track. The Toronto conferees also referred to stabilization of atmospheric concentrations, which they called "an imperative goal," and noted that its attainment in the near future would require yet larger reductions in *global* emissions – on the order of greater than fifty percent (World Conference, 1988).

While much attention globally centered on the Toronto emissions target, the Dutch government remained focused on targets based on rates and amounts of warming and sea level rise. At a 1989 ministerial conference in Noordwijk, Netherlands, the Dutch proposed that GHG concentrations should be stabilized at levels that would keep climate change within "tolerable limits," and that the Intergovernmental Panel on Climate Change (IPCC), which had been established by UNEP and WMO the preceding year, should report on options for doing so (Vellinga, 1996 and Vellinga, personal communication; WMO, 1988). Most negotiators at Noordwijk accepted the Dutch formulation. Some, however, asked for a further element, namely, that economies should not suffer, and language was included to that effect:

> *For the long term safeguarding of our planet and maintaining its ecological balance, joint effort and action should aim at limiting or reducing emissions and increasing sinks for greenhouse gases to a level consistent with the natural capacity of the planet. Such a level should be reached within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and permit economic activity to develop in a sustainable and environmentally sound manner. Stabilizing the atmospheric concentrations for greenhouse gases is an imperative goal. The IPCC will need to report on the best scientific knowledge as to the options for containing climate change within tolerable limits. Some currently available estimates indicate that this could require a reduction of global anthropogenic greenhouse gas emissions by more than 50 per cent.*

(Noordwijk Declaration, 1989)

The focus of the U.S. and Dutch governments on stabilization of concentrations may be contrasted with the German government's lack of reference to this concept in its deliberations: The 1989 Enquette Commission proposed an 80 percent reduction in fossil-fuel use by 2050 to avoid a warming of one-to-two degrees Celsius but did not mention stabilizing either concentration or temperature (Enquette Commission, 1989).

The two types of targets came together in the June 1990 report of the Response Strategies Working Group of the IPCC (IPCC RSWG, 1990; see also Hecht and Tirpak, 1995). The RSWG, chaired by the United States, had been interested in concentrations as an object of policy, and the U.S. administration's advocacy of a 'comprehensive approach' to climate policy arose in part because of that interest (Discussion Paper, 1990; Task Force on the Comprehensive Approach, 1991). Recognizing the inadequacy of existing legal instruments to address climate change, the RSWG suggested a framework convention modeled on the 1985 ozone treaty, to which subsequent protocols could be added in the future; and it asked whether a climate treaty should include, among other elements, "a provision setting any specific goals with respect to levels of emissions (global or national) or atmospheric concentrations of greenhouse gases."

The "goal with respect to levels of emissions" paralleled the kind of target that the 1987 ozone layer treaty set with regard to freezing and cutting back on production and consumption of ozone-depleting chemicals[9]. But the Montreal Protocol contains no parallel to the concept of stabilization of atmospheric concentrations of greenhouse gases.

The Montreal Protocol does contain a non-binding, hortatory goal of eventually eliminating the production of ozone-depleting chemicals (Montreal Protocol, 1987). But this language did not create an obligation to stabilize atmospheric concentrations of stratospheric ozone, although that concept had been discussed around the time the ozone accord was adopted (Titus, 1986; Fay, K., personal communication).[10]

The target-setting discussion in this time period had two other possible antecedents. One was a protocol on nitrogen oxide emissions that recently had been finalized under the UN Economic Commission for Europe's Convention on Long-range Transboundary Air Pollution (LRTAP), to which both the US and the EU subscribed (UNECE, 1979). In the 1988 Sofia Protocol Concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes (UNECE, 1988), the LRTAP parties had adopted, as a first step, a freeze on emissions of nitrogen oxides or their transboundary fluxes. But they had also agreed that subsequent control measures for NOx and volatile organic compounds (VOCs) would be premised on an "effects-based" approach, using the concept of "critical loads" based on multi-pollutant, multi-effect analysis, and covering all significant emissions sources and all environmental endpoints (photochemical pollution, acidification and eutrophication, effects on human health, the environment and materials, etc.).

Another possible antecedent was the process of standard-setting by the US Environmental Protection Agency under the US Clean Air Act. EPA officials, many of whom participated in the interagency climate change discussions at the time, were also engaged in the attempt to set air pollution standards based in part on complex calculations of the health impacts of air pollution, including the possibility of thresholds for sensitive groups. Ideas from these deliberations commingled in the process of developing a US government position for the climate change meetings then underway.

The Second World Climate Conference (SWCC, 1990), held in Geneva in November 1990 following publication of the RSWG report, was, in the words of former U.S. State Department lawyer Daniel Bodansky, a "dress rehearsal" for the negotiation of the climate treaty (Bodansky, 1993). The SWCC issued a declaration, stating, "the ultimate global objective should be to stabilize greenhouse-gas concentrations at a level that would prevent dangerous anthropogenic interference with climate" and stressing, "as a first step," the need to stabilize greenhouse gas emissions. (The "first step" language is important: while some people today (see, e.g., Inhofe, Senator J., 2003) object that the Kyoto Protocol will not solve the problem of global warming, stabilization of emissions has long been recognized as a "first step" toward the subsequent stabilization of concentrations, which would require, as was well known then, further emission reductions.)

Who was responsible for ensuring that the "ultimate global objective" language was included in the SWCC? Recollections and other evidence indicate that the Austrian delegation played a crucial role. Austria had been involved extensively in the ozone layer treaty talks, and took pride in the Vienna Convention, concluded in its national capital. The Austrian delegation was aware that neither the Vienna Convention nor the

Montreal Protocol included a measurable long term atmospheric concentration objective that would constrain future negotiations of quantitative interim targets. The delegation was determined that the Climate Treaty should not replicate this potential weakness. Moreover, while the Dutch delegation and perhaps others also played a vital role in drafting language, the Austrian delegation could maneuver with greater alacrity than the Dutch, who were bound to a time-consuming process of coordination with other EU member states. Consequently, at the SWCC, it was the Austrian delegation that introduced the long-term objective language (Crist, R., personal communication; Schally, H., personal communication).

When climate treaty negotiators met at Chantilly, Virginia, early in 1991, many focused on the kind of emissions limitation target that had been proposed at Toronto. Article 4 of the Climate Treaty, reflecting the Toronto approach, directed industrialized nations to "aim at" returning their total GHG emissions to 1990 levels by the year 2000[11]. But the Noordwijk Declaration's formulation for limiting overall climate change had also been incorporated into both the IPCC report and the SWCC. While RSWG did not endorse the notion of tolerable rates as a basis for a target (Haas and McCabe, 2001), the Austrian delegation (at one point joined by the Swiss delegation) to the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change proposed that the treaty include a long-term objective squarely premised on the concept of stabilization of concentrations in the context of ecological limits:

Long term global objective:

The long term global objective must be the stabilization of greenhouse gas concentrations in the atmosphere at a level which minimizes risks to ecosystems, ecological processes, and climatic conditions essential for the functioning of the biosphere and which will ensure sustainable development (Austrian Government, 1991; Austria/Switzerland Governments, 1991).

Building on the Austrian proposal, negotiators finally agreed on treaty language that combined elements of the Noordwijk and SWCC statements to form Article 2 of the Climate Treaty:

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a 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.*

(UNFCCC 1992, Article 2)[12]

2.3. ARTICLE 2 AND THE KYOTO PROTOCOL

Agreement on the Framework Convention led to a spate of activity in the scientific and economic communities, much of it occurring under IPCC auspices, aimed at providing a basis for interpreting Article 2 by exploring the implications that concentration stabilization would bear for allowable emissions as well as for future temperature and sea level changes (Enting, et al., 1994; Schimmel et al., 1995; Schimmel, et al., 1997; Wigley, 1995; Wigley et al., 1996; Jacoby et al., 1996). Of particular interest is an expert meeting sponsored by IPCC and held at Fortaleza, Brazil in 1994 (IPCC, 1994) in advance of the Second Assessment Report that explored the ecological consequences of warming but failed to develop a quantitative framework for analyzing the issues raised by Article 2. To a limited degree, some of these developments influenced the framing of the Kyoto Protocol, which as a "related legal instrument" is required to share the objective of the Convention.

But it was the formal reviews of progress under the Framework Convention in the mid-1990s, commenced pursuant to Articles 4.2(d) and 7 of the treaty,[13] which led the Parties to conclude that the voluntary "aim" approach was inadequate to achieve the treaty's objective, (UNFCCC COP, 1995),[14] and thus provided the legal predicate for the Kyoto Protocol. The Kyoto accord requires industrialized nations to limit their GHG emissions to a legally binding budget, or cumulative emissions, for the years 2008 to 2012, with the budget level set at an average of approximately 5 percent below their 1990 emissions levels (Kyoto Protocol, 1997).

The influence of Article 2 of the Convention on the Kyoto Protocol occurred via the concept of a "safe corridor", a set of emissions trajectories that would preserve options for stabilizing long-term concentrations at levels that would limit warming to acceptable rates and amounts. Several analyses considered a value of two degrees total warming (Dutch National Research Program, 1994; Alcamo and Kreileman, 1996a, b; EDF, 1997), and such an objective, along with a corresponding concentration target of 550 parts per million (ppm) CO_2 equivalents, received informal endorsement from the European Commission. The safe corridor concept, which arose among European scientists, had been emphasized to many governments in the period prior to the 1997 Kyoto conference.

In 1996, ministers attending the UNFCCC Conference of the Parties in Geneva adopted a declaration stating their belief that "the continued rise of greenhouse gas concentrations in the atmosphere will lead to dangerous interference with the climate system," and noting IPCC findings that "stabilization of atmospheric concentrations at twice pre-industrial levels will eventually require global emissions to be less than 50 per cent of current levels" (Ministerial Declaration, 1996).[15] The chief U.S. climate treaty negotiator at the time, Undersecretary of State Tim Wirth, clearly understood the connection between dangerous impacts and rising concentrations, and in Geneva enunciated the U.S. view that while nations moved toward legally binding emission targets, they should "continue working toward a longer term concentration goal" (U.S. Statement to the COP, 1996). Shortly after the Geneva conference, leading U.S. ecologists wrote to President Bill Clinton warning that more than one degree of warming over the next century—in particular, the stabilization of CO_2 at levels above 450 ppm—could be dangerous to vulnerable ecosystems (Mooney et al 1997).

Consequently, although the Kyoto targets were developed mainly according to the feasibility criterion, and although some who participated in the negotiations regard the agreement that was struck as arbitrary, it is clear that a number of the government delegations were influenced by the ideas of stabilizing concentrations and limiting climate changes so as to avoid "danger". However, other cross-currents dominated most of the discussion of the nature of the targets.[16]

After the Protocol was signed, there was a hiatus in interest in Article 2 in the legal, political, and diplomatic communities. During this period, discussion focused largely on implementation of the Kyoto agreement. The question of what constitutes dangerous anthropogenic interference in the climate system largely proceeded on a separate track, with IPCC undertaking a scientific assessment of key vulnerabilities that would eventually form the basis of current discussions on Article 2 (Smith, et al., 2001).

3. What Does "Dangerous" Mean?

The period since Kyoto has been characterized by attempts by scientists and economists to interpret Article 2, e.g., to determine what is "dangerous anthropogenic interference", and to create frameworks for actually implementing Article 2 by determining emissions pathways consistent with various particular interpretations. As noted above, early scientific assessments of global warming often focused on the expected consequences of a constant concentration of carbon dioxide equal to a doubling of its pre-industrial level.

Because fully-transient simulations using both a time-dependent model of climate and time-varying concentrations were not published until 1988 (Hansen et al., 1988), little information was available before then on the consequences of different emissions pathways. In addressing the stabilization of concentrations, the IPCC in its first full report (Houghton et al., 1990), noted only that emissions reductions of 60 percent or more would be necessary if carbon dioxide concentrations were to be stabilized at 1990 levels.

In adopting the objective of the Framework Convention, the drafters set out the three separate principles of (a) stabilizing GHG concentrations; (b) slowing rates of climate change (as indicated by the words "in a time frame"); and (c) thus assuring that ecosystems can adapt, food production is not threatened, and nations can develop in a sustainable manner. The emphasis on ecological and social impacts means that temperature changes, rates of temperature change, amount and rates of sea-level rise, and perhaps other measures of climate change each may be important to subsequent discussions of Article 2. Although the drafters deferred selecting a numerical value and timetable for achieving the concentration target, such choices are necessary for determining emissions pathways that are effective in satisfying Article 2 (Schimmel et al., 1997).

We also note that concentration has several advantages over global mean temperature as a regulatory tool: its legal status in Article 2; the fact that it is less variable, compared to its current trend, than mean temperature; and that concentrations lead climate change while temperatures lag concentrations. The apparent advantage of temperature, that it is a more direct measure of impact, does not carry over to the global mean since local climate parameters determine actual impacts.

Over the years, even before the Framework Convention, a very broad set of phenomena were proposed as means of defining what was potentially dangerous (WMO, 1988; Rijsberman & Swart, 1990). Some dangers derive directly from geophysical changes, some from biological responses to the climate, and others from socioeconomic responses. Their impacts range from local to regional to global and they affect vulnerable human-made and natural systems ranging from infrastructure to human health to ecosystems and species, and sometimes all of the above. In some cases, the absolute level of climate change (e.g., amount of warming, sea level rise) determines the impact, whereas in other cases, the rate of change is more important.

Rather than attempt to define "dangerous", which it views as beyond its legal ambit, the IPCC in its Third Assessment Report (Smith et al., 2001) organized the vulnerabilities of individuals and socioeconomic and ecological systems in five categories called "reasons for concern" that include the relationship between global mean temperature increase and:

1. Damage to or irreparable loss of unique and threatened systems, e.g., coral reefs.
2. The probability of extreme events, e.g., droughts and floods.
3. The distribution of impacts e.g., increased crop yield in some areas but decreases in others.

4. Global aggregate damages.

5. The probability of large-scale singular events, e.g., disintegration of the West Antarctic ice sheet, shutdown of the thermohaline circulation.

The organization provided by this taxonomy, famously illustrated by figure TS-12 of McCarthy et al (2001) and figure 19-7 of Smith et al (2001), clarified the issues and must be seen as a watershed event in the evolution of thinking on Article 2.

Since the Third Assessment, five tabulations of potential dangers that are directly pertinent to Article 2 have appeared (Corfee-Morlot and Hohne 2003; Oppenheimer and Petsonk; 2003; Hare, 2003; Leemans and Eickhout, 2004; Hitz and Smith, 2004), and we can expect the list of candidate impacts to grow. Table 1 lists particular vulnerabilities that have been discussed in the Article 2 context where a specific concentration or temperature increase (above current temperature) has been proposed corresponding to the criteria of Article 2. References presented are those where the connection to Article 2 or "dangerous" climate change is made directly, rather than the underlying physical or ecological studies. In some cases, to reflect uncertainty, ranges rather than firm limits were proposed. Probability distributions have not been presented for these particular limits, although a probabilistic interpretation of the generic "reasons for concern" has been developed (Mastrandrea and Schneider, 2004).

Table 1

Proposed Numerical Values of "Dangerous Anthropogenic Interference"

Vulnerability	Global Mean Limit	References
Shutdown of thermohaline circulation	3 ^{o}C in 100 yr 700ppm CO_2	O'Neill and Oppenheimer (2002) Keller et al (2005b)
Disintegration of West Antarctic ice sheet	2 ^{o}C, 450ppm CO_2 2-4 ^{o}C, <550ppm CO_2	O'Neill and Oppenheimer (2002) Oppenheimer and Alley (2004, 2005)
Disintegration of Greenland ice sheet	1 ^{o}C	Hansen (2004, 2005)
Widespread bleaching of coral reefs	>1 ^{o}C	Smith et al (2001) O'Neill and Oppenheimer (2002)
Broad ecosystem impacts with limited adaptive capacity (many examples)	1-2^{o}C	Leemans and Eickhout (2004), Hare (2003), Smith et al (2001)
Large increase of persons-at-risk of water shortage in vulnerable regions	450-650ppm	Parry et al (2001)
Increasingly adverse impacts, most economic sectors	>3-4^{o}C	Hitz and Smith (2004)

But the IPCC taxonomy itself is by no means the sole way to categorize potential dangers, and it leads to other difficult questions. How might countries globally, in large regional groupings, or in groupings of common economic interest, agree on which reasons for concern (or individual vulnerabilities such as those in Table 1) could be used to define danger, and thereby begin the process of implementing Article 2? One plausible view is that the larger, more abrupt, less reversible, and more global the impact is, the easier may be agreement on a particular definition of danger regardless of uncertainty (O'Neill and Oppenheimer, 2002). Another is that the more certain and immediate the impact is, the easier may be agreement. The fact that these two sets of characteristics do not overlap very much for many of the impacts proposed signals some of the diplomatic difficulties that lie ahead.

For example among potential impacts of climate change, the disintegration of the West Antarctic ice sheet (WAIS) may create the greatest social and ecological danger in the long run, with the longest timescale for reversal. But because of the inadequacies of ice sheet models and the difficulty in determining WAIS's behavior in past warm epochs (Oppenheimer and Alley, 2005), there is much we do not know yet. Uncertainties include the requisite level of warming to cause the ice sheet to disintegrate, which may be quite high (~10ºC above present local Antarctic temperature) or rather modest (~2ºC above present global temperature), as well as when the disintegration might begin, which may be quite distant (millennia) or rather near (starting in about a century), according to various estimates (Oppenheimer and Alley, 2004, 2005; Vaughan and Spouge 2002; Oppenheimer, 1998). Large uncertainty also pertains to the future of the Greenland ice sheet (Hansen, 2005; Oppenheimer and Alley, 2005), which contains ice equivalent to about 7m of sea level rise and based on which a limit of 1C global warming has been proposed (Hansen, 2004, 2005).

The destruction of coral reefs through mass thermal bleaching (Hughes et al., 2003) provides a contrast: it already appears to be under way episodically and may become a permanent feature (depending on acclimation ability of corals) with the additional one or more degrees Celsius of warming that may already be locked into the climate system as a result of anthropogenic perturbation. The economic consequences of coral reef loss, restricted to various locales and the tourism and fishing industries, may be too limited to bring about political consensus on using it as a definition of danger. Of course, other ecological changes also are important in the near term (decades) and, taken together, may cause widespread concern (Hare, 2003; Leemans and Eickhout, 2004).

This example suggests that the regional distribution of impacts could prove to be a particularly contentious factor in interpreting Article 2. For example, shutdown of the thermohaline circulation, should it occur, may present a greater threat to Europe than to the United States (Vellinga and Wood 2002).   In contrast, modification of El Niño might prove more problematic for the U.S. Of course both such evaluations are based on an extremely narrow view of what "dangerous" would mean in a strongly interlinked world.

While discussions of "danger" to date have focused largely on scientific and economic considerations, social, cultural, ethical and other dimensions of warming, which are discussed in the following section, have drawn increasing, although still limited, attention (Rayner and Malone, 1998; Elzen and Berk, 2003; Gupta, 2003; Gupta at al, 2003; Adger 2001). For example, despite significant progress in understanding the psychological basis of individual views of risk (Kahneman and Twersky, 1979), there has been little discussion of how to apply this work in the context of climate change (Kasperson, et al., 1988; McDaniels et al., 1996; Sunstein, 2002; Henry, 2000).

As part of IPCC's Fourth Assessment, its Working Group II (Climate Change Impacts, Adaptation, and Vulnerability) is currently examining issues related to Article 2 for the chapter "Assessing Key Vulnerabilities and the Risk from Climate Change"; "Article 2 of the UNFCCC and key vulnerabilities" is one of seven cross-cutting themes for all the working groups (Patwardhan et al, 2003; Izrael, 2002). An expert meeting on the science related to Article 2 was held at Buenos Aires, Argentina, 18 - 20 May, 2004 (IPCC 2004), perhaps the first such workshop since the 1994 Fortaleza meeting.

4. Options for Implementing Article 2

In this section, we review various proposals to implement Article 2 on paper, that is, to convert an environmental objective into hypothetical emissions pathways (see also Patwardhan et al., 2003). The objective would be used to infer limits on climate changes as measured by one or more climate parameters, e.g., global mean or regional temperature change or rate of change; limits on climate changes must then be used to infer limits on radiative forcing and concentrations (Caldeira et al., 2003); finally, limits on concentrations must be used to infer emissions pathways (Enting, et al., 1994; Wigley et al., 1996; Schimmel et al., 1997).[17] Uncertainties abound at each step, but are probably greatest for the first (cf. WAIS example discussed above).[18]

The environmental objective would be stated in terms of some measure of climate damages and their distribution (called “numeraires” by Patwardhan et al, 2003). Among these might be cost of damages, number of people affected, number of species lost, and area of ecosystems destroyed, as well as qualitative measures like the value of loss of a unique culture. Means to compare costs and benefits of climate change with each other and with costs of action must be determined in order to assess tradeoffs. For example, since climate impacts may vary greatly across populations, what groupings of individuals ought to be considered? Among the possibilities are aggregation by geographic region (Parry et al, 2001; Arnell, 2004) or administration (e.g., country, see Smith et al 2001), gender (Lambrou and Laub, 2004), income (Tol et al , 2004), and age (Bunyavanich et al, 2003). Aside from country or geographic region, such considerations are not much reflected in the literature, or, as a result, in Table 1.

Another complexity arises because a large number of emissions pathways, including those that initially overshoot the ultimate target, can achieve a given concentration or global mean temperature within a particular timeframe. In practice, however, only a limited number of emissions pathways satisfy the additional constraints on rates of temperature change, rates of sea level rise, and so forth that may contribute to particular definitions of danger (O'Neill and Oppenheimer, 2004). Pathways may also be rejected due to lack of technical feasibility or high cost of implementation (Wigley et al., 1996; Metz et al., 2001).

In its most elaborate form, the simultaneous application of several criteria to limit the choice of emissions pathway is called the *tolerable window* approach (Petschel-Held et al., 1999; Toth et al., 2003). Two simplified versions that have been applied are a *population-based (*Parry et al., 2001) and a *sustainability approach* (Azar and Lindgren, 2003; Wright and Erickson, 2003; Schneider and Azar, 2001; O'Neill and Oppenheimer, 2002). The *population-based approach* (where population is a key numeraire, see Parry et al 2001), which resembles aspects of standard risk assessment, provides a means to implement avoidance of dangers falling into three of the IPCC "reasons for concern" – probability of extreme events, distribution of impacts, and global aggregate damages. Patwardhan et al (2003) reorganized the Smith et al (2001) taxonomy, and in their version, population-based dangers generally correspond to what they call Type I thresholds (which they further categorize according to distributional consequences). The distinctions we explore here provide another perspective on groupings of vulnerabilities from which to view the existing literature. All three approaches (and probably more to come) provide interesting perspectives that should be useful to policy makers.

The population approach has been used to examine the increase (or decrease, see Arnell, 2004) in populations at risk for water shortages, hunger, malaria, and coastal flooding

(Parry et al, 2001). Distributional effects and issues of equity may be made explicit including ability of a country or group to adapt to regional resource availability. A particular limitation of this approach is that although hundreds of millions of people are exposed to these risks, there is no bright line for distinguishing undesirable impacts from truly dangerous ones. In most scenarios, increasing population and secondarily, changing climate, gradually push more and more (or, in some cases, fewer and fewer) people into the risk category, so the number exposed increases (or decreases) gradually as the temperature or concentration rises.

The sustainability approach is particularly suited to implementing a definition of danger falling into reasons for concern 1 and 5, threats to unique systems (Hare, 2003; Leemans and Eickhout, 2003; Thomas et al., 2004), and threat of singular events (called Type II thresholds in the taxonomy of Patwardhan et al, 2003). The sustainability approach basically avoids many of the knotty issues of distribution by establishing a category of impacts that are so negative in terms of scope and irreversibility that almost all policy makers might seek to avoid them (Patwardhan et al, 2003). Accordingly, concerns about distribution and aggregation disappear by definition. Of course, the question of "dangerous from whose perspective" cannot be completely avoided, as should be evident from the very large range of proposed timescales for WAIS disintegration. Dangers occurring over millennia may be given little weight by some people.

With regard to sustainability, true physical and biological thresholds (Rial, 2004) may come into play,[19] potentially providing sharp distinctions among different temperatures or concentrations according to risk. Among such phenomena discussed in the context of Article 2 are shutdown of the thermohaline circulation and disintegration of the WAIS (O'Neill and Oppenheimer, 2002), forest-to-grassland transition in tropical and subtropical regions (Higgins, et al., 2002) and mass bleaching and demise of coral reefs (Hoegh-Guldberg, 1999). Although populations may well be vulnerable to the consequences of crossing such thresholds, it is the threshold property itself that provides the measure of danger. Recently, thresholds arising from the interaction of social and ecological systems have also been considered (Barnett & Adger, 2003; cf. Stipp, 2004). This arena, which reaches outside the IPCC categorization, will merit further attention in the future.

While the sustainability approach may appear to provide the sort of dividing lines that would simplify life for policymakers, in reality the uncertainties of each phenomenon are substantial, blurring the lines, as in the case of the disintegration of the WAIS, discussed above. This difficulty seriously complicates the choice of distinct climate danger zones. Problems might be circumvented by invoking the precautionary principle, for example, by determining the target based on the lowest plausible value for its temperature or concentration threshold. Using this approach, two recent studies (O'Neill and Oppenheimer, 2002; and Schneider and Azar, 2001) have argued that a plausible definition for danger is any concentration greater than 450 ppm.

The *benefit-cost framework*, which has been used to determine optimal emissions and concentration pathways (by expected utility maximization), largely originates in the work of Nordhaus and co-workers (Nordhaus, 1992; Nordhaus and Boyer, 2000; also see Keller et al., 2000). It provides a widely used means to quantitatively assess the temporal tradeoffs involved with choosing a concentration and emissions pathway in terms of a monetary numeraire. This approach, which may be particularly suitable for implementing avoidance of some dangers falling into reasons for concern 3 and 4 above, contrasts sharply with the tolerable windows approach, variants of which prescribe economic constraints on emissions pathways but without explicit optimization. Optimization provides an internally-consistent means to identify danger: Sub-optimality itself (or some magnitude of deviation from optimality) may be considered dangerous from an economic perspective.

A considerable advantage of the benefit-cost approach is that its assumptions are transparent and value judgments are rendered quantitatively. While it is true that a limited set of economic criteria are used to choose the ultimate objective, it is also true that the sufficiency of the basis of judgment can be analyzed quantitatively. In addition, this approach implicitly accounts for (quantifiable) impacts arising from the rate of climate change during the transient period before stabilization is achieved, an aspect sometimes lacking in applications of the sustainability approach (Hammitt, 1999). Shortcomings of welfare maximization in its application to the climate problem have been discussed at length (Azar and Lindgren, 2003; Tol, 2003). With regard to Article 2 in particular, distributional issues are obscured (except for the temporal dimension) because impacts and damages are aggregated globally or across different geographic regions, without taking account of whether, for example, flooding may affect residents of one locality differently than residents of another. Representation of irreversible damages (e.g., loss of species) that cannot be readily monetized (Corfee-Morlot and Höhne, 2003) is also problematic. Also generally absent is evaluation of ancillary benefits of GHG emission control measures, such as improvements in human health due to control of conventional pollutants, particularly in developing and transition economies (Metz et al., 2001; OECD, 2002; Dudek et al., 2003). One recent study highlights the potential national and global security concerns that may accompany abrupt climate changes (Stipp, 2004), yet welfare maximization has only begun to grapple with such impacts (Alley et al. 2003).

Nevertheless, progress has been made in aligning cost-benefit methods with the framework of Article 2. Previous applications yielded modest optimal emission reductions in the near-term (i.e., the next few decades; Nordhaus and Boyer, 2000) and optimal concentrations did not approach a stable value in this century. Recent studies taking into account the potential economic damages associated with crossing climate thresholds such as a collapse of the thermohaline circulation, however, suggest optimal pathways that entail significant near term reductions in allowable GHG emissions, as well as severely constrained long term concentrations (e.g., Keller et al. 2004, Alley et al, 2003).

Some studies explicitly combine optimization with an absolute constraint on concentration or temperature (Nordhaus, 1992; Keller et al., 2005a, 2005b) in order to draw on the different strengths of optimization and sustainability frameworks.

Probabilistic approaches to implementing definitions of danger in a cost-benefit framework are now being explored as well (Keller et al., 2004; Keller et al., 2005a, Mastrandrea and Schneider, 2004). All such efforts will doubtless need to be updated in light of emerging policy proposals for addressing a wider range of GHG emissions, including emissions from tropical deforestation, which currently are not addressed by Kyoto (see, e.g., Santilli et al., 2004; The Economist 2004; Folha de São Paulo, 2003).

Non-quantitative and non-utilitarian frameworks also have been proposed including consideration of distributional questions in a way that emphasizes justice, equity, and rights (Jamieson, 1997; Tonn, 2003; Gardiner, 2004; Brown, 2003). The question of tradeoffs, and whose views ought to determine what is dangerous and what tradeoffs are important, requires considerably more development. Among the possibilities are experts using risk assessment, the lay public using personal perceptions of risk as discussed in Section 3 or various groups and cultures guided by their own internal values (Gupta, et al 2003; Tyndall Centre, 2004; Dessai et al, 2004). A comprehensive complement or alternative to the benefit-cost and tolerable windows frameworks addressing such issues has yet to be developed.

Which of these frameworks did the Framework Convention Parties intend to use to determine and implement danger? The answer is unclear. One former U.S. negotiator indicated that those who wanted to ensure that danger would be defined solely in economic terms “lost” their argument when language that would have required calculation of various costs including those of societal adaptation was excluded from the mandatory text of Article 2 (Reinstein, R., personal communication).[20] Instead, language about the time frame for natural ecosystem adaptation was included. On the other hand, at least one author (Bodansky, 1993) believes that the text is neutral between adaptation and prevention, that “to the extent that adaptation to climate change is possible, such change could be viewed as benign.” Here is it worth noting that while cost-efficiency of mitigation is alluded to in Article 4 of the Convention, weighing costs and benefits is not. Yet the tension between environmental limits and optimization, apparent in the contrasting views of Mitchell and Abelson in the 1977 NRC report, remains very much alive in today’s discussions.

One option might be simply to postpone further elaboration of Article 2 until at least many of the uncertainties have been resolved. That course, however, brings into play a further set of confounding dangers. Because the problem is cumulative, delay increases the risk that particular pathways for stabilization will be effectively foreclosed (O’Neill & Oppenheimer, 2002; Oppenheimer & Petsonk, 2003). Preliminary model studies of the tradeoffs among uncertainty, learning, irreversible change, damages, and mitigation provide no definitive answers but do suggest that postponing decisions is not necessarily the optimal approach (Webster, 2002).

5. Conclusion

The long-term perspective, codified in Article 2 of the UN Framework Convention on Climate Change, has been a keystone of scientific, economic, and political components of climate policy discussions since the 1970s. With the adoption of the Framework Convention, attention in policy circles gradually shifted to the near term, particularly to the development, ratification, and implementation of the Kyoto Protocol. Until very recently, questions related to Article 2 were left largely unexplored.

Two related points emerge clearly from consideration of the history of long-term climate limits: Both U.S. and European government policy as well as U.S. and European expertise played pivotal roles in the evolution of the concepts underlying Article 2. As President Bush himself reaffirmed in 2002, the need for a long-term view, and a clear definition of Article 2, is now and has long been, a principal feature of U.S. climate policy (Bush, 2002). Renewed diplomatic attention to Article 2 may provide a route for re-engagement of the US in the international climate regime. Similarly, developing countries do not appear to have been active in discussions of Article 2, paying more attention to issues related to burden-sharing (for example, a proposal advanced by Brazil in 1997 (discussed in UNFCCC/SBSTA/2002/INF.14, 2002, and in Baumert, 2002). Yet the active engagement of these countries is a prerequisite for the emergence and implementation of any long-term target.

As to the meaning of Article 2, the political and diplomatic process through which it evolved paid much more attention to physical and biological vulnerabilities as sources of danger, and rather less attention to economic issues. Ethical and cultural considerations have been nearly absent. In the case of the latter, this neglect must surely be remedied in order for an adequate definition of danger to emerge. The history with regard to the role of economics is complex, with the concept of an optimum climate present in the earliest days of this issue. Rather than choosing a target by welfare optimization, there is successful precedent in US environmental law for giving economic considerations a secondary role in the definition of am objective, but a primary role in its implementation.[21]

Important lessons with regard to the process for building consensus can also be found in this history. Nongovernmental organizations, intergovernmental agencies of the UN, and individual experts in addition to a few governments, played key roles in the early development of the climate regime in general, and Article 2 in particular (Haas and McCabe, 2001). The impetus for interpreting Article 2 is unlikely to come in the first instance from the formal negotiation process among the Parties to the UNFCCC (Pershing and Tudela, 2003). One or perhaps several parallel private efforts, informed by the IPCC but with only modest government participation, may provide the intellectual spadework that ultimately generates governmental action (Oppenheimer and Petsonk, 2003).

A bundle of questions remain about the theory and mechanics of defining and implementing Article 2: What generic risks, and what specific impacts, should guide long-term policy? What geographic scope is important? Populations of what size should be of concern? In what way should the distribution of impacts geographically, or among socioeconomic or cultural groups, be taken into account, as opposed to total human welfare? How much should natural ecosystems weigh in this accounting? Should costs and benefits be weighed quantitatively to define "dangerous" or should environmental criteria supplemented by bounds on implementation costs be employed, as in the tolerable window approach? What does a target for a global quantity actually mean, and how would responsibility for its attainment be apportioned and enforced? To what extent can a decision to follow one pathway be adjusted in the future in light of further learning? How much time do nations have to deliberate these questions before feasible pathways for avoiding dangerous climate changes are foreclosed?

The difficulty of resolving these issues will continually lead policy makers and others to ask: Does near term policy really need to be guided by Article 2? Can incremental measures, strung together, produce a desirable outcome? And, finally, could policies guided by technological goals rather environmental goals (Edmonds & Stokes, 2003) achieve such a result? With greenhouse gas concentrations rapidly approaching levels that are dangerous according to one or more of the proposed criteria, outcomes of the great geophysical experiment (Revelle and Seuss, 1957) may prevent us from completing the socio-political experiment which could answer these questions.

Acknowledgments

The authors are indebted to Dan Bodansky for sharing his file on the negotiation history of Article 2. We also acknowledge input and thoughtful comments from Shardul

Agrawala, Dan Bodansky, Renate Christ, Dan Dudek, Kevin Fay, Alexander Golub, Klaus Keller, Brian O'Neill, Hugo Schally, Pier Vellinga, Jonathan Wiener, and an anonymous reviewer.

Notes

[1] The COOL dialogue (Tuinstra, 2002) initially focused on effects, assessing the case for stabilizing concentrations at 450 ppm. The reports prepared under COOL ended up focusing on means of implementing a 50-80% emissions reduction in the Netherlands by 2050. (Berk et al. 2002) In 2003, the UK committed to a 60% reduction by 2050 (Blair, Prime Minister T., 2003), while Germany announced its commitment to seek to limit warming to not more than two degrees over the next century (Trittin, Minister J., 2003). Moreover, in late November 2003 the world's third-largest oil company, BP, announced that "based on our understanding of the range of the uncertainty around the scientific views, we've come to the judgment that to avoid serious impact upon societies or the environment it is necessary to stabilise atmospheric concentrations of greenhouse gases at around 500-550 parts per million" (Browne, Lord J., 2003). And in his February 2004 Speech from the Throne, Canada's new prime minister, Paul Martin, signaled that it is time to take a long-term perspective, as the UK and other EU member states are doing (Anderson, Minister D., 2004).

[2] Lack of discussion of Article 2 reflects in part the objections of the Group of 77 developing countries and China to anything that might lead to emissions caps for them (Corfee-Morlot & Höhne, 2003); the United States has supported the G-77 position in declaring such discussions "premature" (Pew Center, 2002; Peel, K., personal communication). Neither the 2002 Delhi Declaration (UNFCCC Eighth Conference, 2002), nor the decisions adopted by the Ninth Conference of the Parties to the UNFCCC in Milan in 2003 makes any explicit reference to Article 2 (Corfee-Morlot & Höhne, 2003; UNFCCC COP-9 Decisions, 2003).

[3] Depending on assumptions made about the carbon cycle, stabilization of concentration might require enhancement of sinks, e.g., geologic sequestration, or approaching zero emissions over a multi-century time scale. But at least temporary stabilization of concentration over the timescale of policy consideration, one or two centuries, was certainly plausible given finite CO_2 emissions, based on models of the time (and today).

[4] "Mr. President, the United States faces a serious dilemma. Our efforts to reduce our dependence on imported oil may include some exceptional dangers to our environment….The problem is the increased accumulation of carbon dioxide in the atmosphere caused by the use of fossil fuels" (Ribicoff, 1979a).

[5] "We believe it to be important that the phenomenon of increasing carbon dioxide (CO_2) concentration in the atmosphere be widely understood as a major consideration in discussions of future energy policy….The CO_2 problem arises from both the total amount of CO_2 added to the atmosphere and the rate at which it is being added. If the rate were sufficiently slow, most of the CO_2 would be taken up by the oceans and there would be little effect on the atmosphere. If the rate is rapid and increasing geometrically, as has been the trend for the past 30 years with the ever increasing worldwide use of fossil fuels, a large fraction of the added CO_2 remains in the air. If this trend continues, the CO_2 content of the air will be doubled before the middle of the next century. By the year 2000, the projected increase over the present value of 335 parts per million will be much smaller, about 30 to 60 parts per million….We recognize that a synthetic fuel program based on coal is a major energy supply option. If, in the future, it appears that continuing increases in atmospheric CO_2 are likely to have significant deleterious effects, then it may be necessary to shift to other alternatives which introduce less CO_2 into the atmosphere. We therefore urge that provisions be made now to assure that such other alternatives will be available if and when they are needed" (NRC, 1979).

[6] These concepts appear in the recommendations of the World Conference on the Changing Atmosphere in Toronto in 1988 (World Conference, 1988), the declaration of the Noordwijk Ministerial Conference on Atmospheric Pollution and Climate Change in November 1989 (Noordwijk Declaration, 1989; Bodansky, 1993), and the declaration of the Second World Climate Conference in Geneva in 1990 (SWCC, 1990), discussed further below.

[7] The Montreal Protocol's initial targets of a freeze followed by a 50% cut in production of ozone-depleting chemicals by industrial countries by the year 1999 were understood at the time to be scientifically rather arbitrary. The initial targets were politically and economically feasible, given the relatively few companies manufacturing ozone-depleting chemicals and the economic incentives that the protocol created for marketing more ozone-friendly substitutes. But immediate stabilization of stratospheric ozone concentrations at then-current levels would have required, according to USEPA, an immediate 85 percent production cut (Hoffman, 1986; Benedick, 1998; Benedick, 1999).

[8] For additional discussion of the role played later by the AGGG targets, see Haas and McCabe, 2001.

[9] See note (7) above.

[10] Moreover, the understanding that the ozone hole first appeared when total chlorine exceeded atmospheric concentrations of roughly 2 parts per billion, while never formalized as a goal of the Montreal Protocol, nevertheless guided negotiations that led ultimately to a mandatory phase-out of ozone-depleting chemicals, with a 10-year grace period for developing countries (Montreal Protocol, 1987, as amended; Fay, K., personal communication).

[11] Although President George H.W. Bush had announced as early as November 1989 that the United States had agreed with other industrialized nations that "stabilization of carbon dioxide emissions should be achieved as soon as possible," and that it was "timely to investigate quantitative targets to limit or reduce carbon dioxide emissions" (White House 1989), at the insistence of the United States, the "return to 1990 levels" provision of Article 4.2 of the Framework Convention was made voluntary (UNFCCC, 1992).

[12] Notwithstanding the increased focus on concentrations, a 1992 National Research Council report on the policy implications of greenhouse warming, like the NRC's 1983 report, contained virtually no analysis of concentration limits or stabilization scenarios (NRC, 1992).

[13] Article 4.2(d) of the Convention requires the Conference of the Parties to review the "adequacy" of Convention commitments. Article 7.2(a) of the Convention requires the Conference of the Parties to "Periodically examine the obligations of the Parties and the institutional arrangements under the Convention, in light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge."

[14] This was the famous Berlin Mandate, which committed the Parties to adopt, not later than the end of 1997, a "protocol or another legal instrument", but which also provided that the new instrument would contain no new commitments for developing nations. The "no new commitments" language differed sharply from the approach taken, for example, in the Montreal Protocol on the Ozone Layer, where developing country commitments to freeze and phase out CFCs were paced with a ten-year lag from industrialized country commitments.

[15] The Geneva Ministerial Declaration was acclaimed with applause by many at the time, but because of objections of a number of countries, including OPEC nations, it was never formally adopted by consensus as a COP decision.

[16] Specifically, US negotiators were largely preoccupied with the political and economic feasibility of binding emissions caps, while European negotiators advanced a suite of regulatory initiatives. The two different approaches reflected in part their differing forms of government. At the EU level, the

Commission's advocacy of "policy and measure" formulations could be partly traced to the tension between the EU and its member states over competencies; the legal imperative to avoid implementation schemes that would distort internal trade; and the fact that treaties could be adopted by member states without simultaneous adoption of implementing legislation. In the US, by contrast, the constitutional requirement that treaties be approved with the advice and consent of a two-thirds majority of the Senate, and the passage in the summer of 1997 of a Senate resolution advising the administration that a Kyoto Protocol that failed specific economic and participation tests would be dead on arrival in the Senate, served to concentrate the minds of U.S. negotiators on the economic and political feasibility of the accord.

[17] To remind the reader, while natural variations of GHG concentrations are generally small in the time frame of interest here, climate does vary randomly over such periods and also because of changes in solar intensity and in Earth's volcanic dust veil (which reflects sunlight). Natural and social systems influenced by climate also vary independently of climate. In addition, anthropogenic land-use changes and emissions of reflective particles affect climate. How to account for these fluctuations in determining what levels of greenhouse forcing are dangerous present critical, but as yet not much studied, issues.

[18] Quantitative assessment of the regional impacts of particular climate changes on natural and social systems is still early in development. Limited geographic resolution and other uncertainties in global climate models prevent accurate forecasts of many impacts following from particular GHG concentrations that occur on spatial scales on the order of a few thousand kilometers or smaller. Quantitative estimates of the relation between emissions and concentrations, provided by carbon cycle models, have a broad range of uncertainty, due to relatively poor understanding of many important processes (like the absorption of carbon by forested ecosystems under varying carbon dioxide concentrations, temperatures, and precipitation rates).

[19] See Levy et al (2001) for a discussion of the history of the use of thresholds for regulating other environmental problems.

[20] Hortatory text was included in the famous "Principles". See UNFCCC Article 3.3 ("The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible climate change, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.")

[21] See, e.g., the U.S. Clean Air Act, which mandates that EPA set targets for criteria pollutants based on health considerations, not net benefits; and that economic considerations be considered only in determining how best to meet the health-based standards (Reitze, 1999).

References

AAAS: 1979, 'Proceedings of the AAAS Climate Program Workshop on Consequences of Climatic Changes, Annapolis, Maryland,' *Archives of the AAAS: Climate (1975-1989).*

Ad Hoc Committee on the Relationship between Land Ice and Sea Level: 1985, 'Glaciers, Ice Sheets, and Sea Level: Effect of CO2-induced Climate Change', Washington, D.C., U.S. Department of Energy DOE/ER/60235-1.

Adger, W.N.: 2001, 'Scales of Governance and Environmental Justice for Adaptation and Mitigation of Climate Change.' *J. Int. Devel.* **13**, 921-931.

Agrawala, S.: 1999, 'Early Science-policy Interactions in Climate Change: Lessons from the Advisory Group on Greenhouse Gases.' *Global Environmental Change* **9**, 157-169.

Alcamo, J., & Kreileman, E.: 1996a, 'The Global Climate System: Near Term Action for Long Term Protection.' *Background Report prepared for the Workshop on Quantified Emissions Limitation Reduction Objectives (QUELROS) at the Third Meeting of the Ad Hoc Group on the Berlin Mandate of the Framework Convention on Climate Change.* Report 481508001, National Institute of Public Health and the Environment (RIVM), Bilthoven, The Netherlands.

Alcamo, J., & Kreileman, E.: 1996b, 'Emissions Scenarios and Global Climate Protection.' *Global Environmental Change,* **6,** 305-334.

Alley, R.B., Marotzke, J., Nordhaus, W.D., Overpeck. J.T., Peteet, D.M., Pielke, R.A. Jr., Pierrehumbert, R.T., Rhines, P.B., Stocker, T.F., Talley, L.D., Wallace, J.M.: 2003, 'Abrupt Climate Change,' *Science* **299**, 2005-2010.

Andersen, Minister D.: 2004, Remarks on Prime Minister Martin's Speech From The Throne Regarding the Kyoto Protocol, live transcript available at http://www.cbc.ca/insite/AS_IT_HAPPENS_TORONTO/2004/2/3.html, Part II, starting at Minute 24:00.

Andresen, S. & Agrawala, S.: 2002, 'Leaders, Pushers, and Laggards in the Making of the Climate Regime,' *Global Environmental Change* **12**, 41-51.

Arrhenius, S.: 1896, 'On the Influence of Carbonic Acid in the Air Upon the Temperature of the Ground,' *Philosophical Magazine* **41**, 237-76.

Arnell, N.W.:2004, 'Climate Change and Global Water Resources: SRES Emissions and Socio-economic Scenarios', *Global Environmental Change* **14**, 31–52

Austrian Government: 1991, Paper No. 27, Submission of the Government of Austria to the Intergovernmental Negotiating Committee, copy on file with the authors.

Austria/Switzerland Governments: 1991, Paper No. 2, Open Paper, elaborated by some experts in their personal capacity, submitted by Austria and Switzerland. Shopping List: Main Elements for Inclusion in a Framework Convention on Climate Change or Related Protocols, copy on file with the authors.

Azar, C., and Lindgren, K.: 2003, 'Catastrophic Events and Stochastic Cost-benefit Analysis of Climate Change,' *Climatic Change* **56**, 245-255.

Barnett, J., and Adger, W.N.: 2003, 'Climate Dangers and Atoll Countries,' *Climatic Change* **61**, 321-337.

Baumert, K.A., ed.: 2002, 'Building on the Kyoto Protocol: Options for protecting the climate,' Washington, DC, World Resources Institute.

Benedick, R.: 1998, *Ozone Diplomacy: New Directions in Safeguarding the Planet*, Harvard University Press, Cambridge, Mass.

Benedick, R.: 1999, 'The Indispensible Element in the Montreal Ozone Protocol', *Earth Matters,* Columbia Earth Institute, September.

Berk, M.M., van Minnen, J.G., Metz, B.,Moomaw, W., den Elzen, D M.G.J., van Vuuren, P., and Gupta, J.: 2002, *Climate Options for the Long Term (COOL), Global*

Options Synthesis Report, RIVM report 490200003 2001/2002, NOP report 410 200 118, text available at http://www.rivm.nl/bibliotheek/rapporten/490200003.pdf.

Blair, Prime Minister T.: 2003, 'Concerted International Effort Necessary to Fight Climate Change,' (February 24), text available at http://www.number-10.gov.uk/output/Page3073.asp.

Bodansky, D.: 1993, 'The United Nations Framework Convention on Climate Change: A Commentary,' *Yale Journal of International Law* **18,** 451-467.

Bolin, B., et al. (eds.): 1986, 'The Greenhouse Effect, Climatic Change, and Ecosystems,' SCOPE Report No. 29. Chichester, John Wiley.

Brown, D.A.: 2003, 'The Importance of Expressly Examining Global Warming Policy Issues Through an Ethical Prism', *Global Environmental Change*, **13**, 229-234.

Browne, Lord J.: 2003, 'Climate Change,' Speech to the Institutional Investors Group, Gibson Hall, Bishopsgate, London. Text available at: http://www.bp.com/genericarticle.do?categoryId=98&contentId=2015334

Bunyavanich, S., Landrigan, C., McMichael, A.J., Epstein, P.R.: 2003, 'The Impact of Climate Change on Child Health,' *Ambulatory Pediatrics* **3**, 44-52.

Bush, President G.W.: 2002, Remarks at the National Oceanic and Atmospheric Administration, text available at http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html.

Caldeira, K., Jain, A.K., and Hoffert, M.I: 2003, 'Climate Sensitivity Uncertainty and the Need for Energy without CO_2 Emission', *Science* **299**, 2052-2054.

Chafee, Senator J.: 1986, 'Our Global Environment: The Next Challenge', in Titus, J.G. (ed.), *Stratospheric Ozone: Effects of Changes in Stratospheric Ozone and Global Climate*, Proceedings of the United Nations Environment Programme (UNEP)/Environmental Protection Agency (EPA) International Conference on Health and Environmental Effects of Ozone Modification and Climate Change, Washington, D.C., U.S. Environmental Protection Agency.

Chafee, Senator J., Garn, Senator J., and Leahy, Senator P.: 1986, Colloquy For the Record in the Debate on House Joint Resolution 738 (Continuing Resolution), Vol. 132 Cong. Rec. Senate Part 19 (99th Cong., 2d Sess.) 27982-3, October 2.

Chafee, Senator J.: 1987, Statement introducing Amendment No. 934 to S. 1394, the Foreign Relations Authorization Act, reprinted at Vol. **133** Cong. Rec. Senate Part 19 (100th Cong., 1st Sess.) 27053-4, October 8.

Clark, W.C., Jaeger, J, Cavender-Bares, J., and Dickson, N.M.: 2001, ‘Acid Rain, Ozone Depletion, and Climate Change: An Historical Overview,’ in W.C. Clark, J. Jaeger, J. van Eijndhoven, and N.M. Dickson (eds.), *Learning to Manage Global Environmental Risks - A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain*, MIT Press, Cambridge, MA.

Clark, W.C., and Dickson, N.M.: 2001, ‘Civil Science: America’s Encounter with Global Environmental Risks,’ in Social Learning Group, *Learning to Manage Global Environmental Risks: A Comparative History of Responses to Climate Change, Ozone Depletion, and Acid Rain*, MIT Press, Cambridge, MA., pp. 259-294.

Climate Impact Assessment Program (CIAP): 1975, *Impacts of Climatic Change on the Biosphere, Monograph 5, Part 2 – Climate Effects*, Washington, D.C., Institute for Defense Analysis, US Department of Transportation.

Cooper, C.F.: 1978, ‘What Might Man-Induced Climate Change Mean?’, *Foreign Affairs* **56**, p. 500.

Corfee-Morlot, J., and Höhne, N.: 2003, ‘Climate Change: Long-term Targets and Short-Term Commitments,’ *Global Environmental Change* **13**, 277–293.

Council on Environmental Quality (CEQ): 1981a, *To Breathe Clean Air*. Washington, DC: US Government Printing Office.

Council on Environmental Quality (CEQ): 1981b, *Global Energy Futures and the Carbon Dioxide Problem.* Washington, DC: US Government Printing Office.

Dessai, S Adger, W. N., Hulme, M., Turnpenny, J., Kohler, J., Warren, R.: 2004, 'Defining and Experiencing Dangerous Climate Change,' *Climatic Change*, **64**, 11-25.

Diringer, E. (ed.): 2003, *Beyond Kyoto: Advancing the International Effort against Climate Change*, Pew Center on Global Climate Change, Arlington, Virginia, USA.

Discussion Paper: 1990, 'A "Comprehensive" Approach to Addressing Potential Global Climate Change,' presented at the Informal Seminar on U.S. Experience with "Comprehensive" and "Emissions Trading" Approaches to Environmental Policy', Washington, DC, February 3, 1990, pp. 1-6, copy on file with the authors.

Dudek D., Golub, A., and Strukova, E.: 2003, 'Ancillary Benefits of Reducing GHG Emissions in Transition Economies,' *World Development* **31**, 1759-1769.

Dutch National Research Program on Global Air Pollution and Climate Change (NRP): 1994, 'Report of International Review Meeting IMAGE 2.0, NRP Report 00-09', available by permission at http://sedac.ciesin.org/mva/NRP/NRP.html.

The Economist: 2004, 'Local Resources and Global Assets: Saving the Rainforest', July 22.

Edmonds, J., and Stokes, G.: 2003, 'Launching a Technology Revolution,' in Michel, D. (ed.), *Climate Policy for the 21st Century: Meeting the Long-Term Challenge of Global Warming,* Center for Transatlantic Relations, Johns Hopkins University, pp. 153-186.

Elzen, M. d., and Berk, M.: 2003, 'How Can the Parties Fairly and Effectively Establish Future Obligations Under Long-Term Climate Objectives?' in Michel, D. (ed.), *Climate Policy for the 21st Century: Meeting the Long-Term Challenge of Global Warming,* Center for Transatlantic Relations, Johns Hopkins University, pp. 113-151.

Enquette Commission: 1989, 'Protecting the Earth's Atmosphere: An International Challenge,' *International Report of the Study Commission of the 11th German Bundestag*, Bonner Unversitats-Buchdruckerie (Deutscher Bundestag Ed.).

Enting, I.G., Wigley, T.M.L., and Heimann, W.: 1994, 'Future Emissions and Concentrations of Carbon Dioxide: Key Ocean/Atmosphere/Land Analysis,' Technical Paper No. 31, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Atmospheric Research, Aspendale, Australia.

Environmental Defense Fund (EDF): 1997, 'Failure at Kyoto: A Narrow Time Window For Reductions, And A Steep Price For Delay,' Policy paper prepared for the 1997 Third

Conference of the Parties to the UN Framework Convention on Climate Change (copy on file with the authors).

Firor, J.: 1988, 'Public Policy and the Airborne Fraction,' *Climatic Change* **12**, 103-105.

Folha de São Paulo: 2003, 'Amazon Proposal,' November 30 (editorial).

Foreign Relations Committee: 1987, Senate Report No. 100-75, June 18, p. 18.

Gardiner, S.M.: 2004, 'Ethics and Global Climate Change', *Ethics* **114**, 555-600.

Global Climate Protection Act of 1987, Title XI of the Foreign Relations Authorization Act, Fiscal Years 1988 and 1989, P.L. 100-204, 101 Stat. 1331, reprinted at 15 U.S.C. sec. 2901n, P.L. 100-204, Title XI, secs. 1101 to 1106, December 22, 1987, Stat. 1407.

Gupta, J.: 2003, 'Engaging Developing Countries in Climate Change,' in Michel, D. (ed.), *Climate Policy for the 21st Century: Meeting the Long-Term Challenge of Global Warming*, Center for Transatlantic Relations, Johns Hopkins University, pp. 233-264.

Gupta, J., Berk, M., and van Asselt, H.: 2003, 'Defining Dangerous,' in *Report of the Annex I Workshop on Article 2 of the Climate Convention*, Institute for Environmental

Studies, Report number W-03/35, Amsterdam, Netherlands, 20 November, copy available at www.vu.nl/ivm.

Haas, P.M.: 1992, 'Obtaining International Environmental Protection through Epistemic Consensus,' in Rowlands, I.H. and Greene, M., *Global Environmental Change and International Relations*, MacMillan.

Haas, P.M., and McCabe, D.: 2001, 'Amplifiers and Dampeners: International Institutions and Social Learning in the Management of Global Environmental Risks', in Social Learning Group, *Learning to Manage Global Environmental Risks: A Comparative History of Responses to Climate Change, Ozone Depletion, and Acid Rain*, MIT Press, Cambridge, MA., p. 335.

Hammitt, J.K.: 1999, 'Evaluation Endpoints and Climate Policy: Atmospheric stabilization, Benefit-Cost Analysis, and Near-Term Greenhouse-Gas Emissions,' in *Climatic Change* **41**, 447-468.

Handler, P.: 1979, Letter from Dr. Philip Handler, President, National Academy of Sciences, to Senator Abraham Ribicoff, November 1, 1979, reprinted in Congressional Record (Senate) **125:23**, pp. 30682-30683.

Hansen, J., Fung, I., Lacis, A., Rind, D., Lebedeff, S., Ruedy, R., and Russell, G.: 1988, 'Global Climate Changes as Forecast by Goddard Institute for Space Studies Three-Dimensional Model', *J. Geophys. Research*. **93**, 9341-9364.

Hansen, J.: 2004, 'Defusing the Global Warming Time Bomb', *Sci. Amer.*, **290**, 68-77.

Hansen, J.: 2005, 'A Slippery Slope: How Much Global Warming Constitutes "Dangerous Anthropogenic Interference"', *Climatic Change*, in press.

Hare, W.: 2003, 'Assessment of Knowledge on Impacts of Climate Change – Contribution to the Specification of Article 2 of the UNFCCC: Impacts on Ecosystems, Food Production, Water and Socio-economic Systems,' Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen, Berlin, text available at: http://www.wbgu.de/wbgu_sn2003_ex01.pdf.

Hecht, A.D., and Tirpak, D.: 1995, 'Framework Agreement on Climate Change: A Scientific and Policy History,' *Climatic Change* **29,** 371-402.

Henry, A. D.: 2000, 'Public Perceptions of Global Warming', *Human Ecology Review*, **7**, 25-30.

Higgins, P.A.T., Mastrandrea, M.D., and Schneider, S.H.: 2002, ‘Dynamics of Climate and Ecosystem Coupling: Abrupt Changes and Multiple Equilibria,’ *Philos T Roy Soc B* **357** (1421), 647-655.

Hitz, S. and Smith, J.: 2004, ‘Estimating Global Impacts from Climate Change’, *Global Environmental Change* **14**, 201-218.

Hoegh-Guldberg, O.: 1999, ‘Climate change, Coral Bleaching and the Future of the World’s Coral Reefs,’ *Marine and Freshwater Research,* **50,** 839-866.

Hoffman, J.S.: 1986, ‘The Importance of Knowing Sooner,’ in Titus, J.G. (ed.): *Stratospheric Ozone: Effects of Changes in Stratospheric Ozone and Global Climate,* Proceedings of the United Nations Environment Programme (UNEP)/Environmental Protection Agency (EPA) International Conference on Health and Environmental Effects of Ozone Modification and Climate Change, Washington, D.C., U.S. Environmental Protection Agency.

Houghton, J.T., Jenkins, G.J., and Ephraums, J.J. (eds.): 1990, *Climate Change: The IPCC Scientific Assessment*, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., and Xiasou, D. (eds.): 2001, *Climate Change 2001: The Scientific Basis,* Contribution of Working Group

I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, NY..

Hughes, T. P. et al.: 2003, 'Climate Change, Human Impacts, and the Resilience of Coral Reefs,' *Science* **301**, 929-933.

Inhofe, Senator J.: 2003, 'The Facts and Science of Climate Change,' distributed at the Ninth Conference of the Parties to the UN Framework Convention on Climate Change, Milan, Italy (copy on file with the authors; copies available from Senator Inhofe's office).

Intergovernmental Panel on Climate Change Response Strategies Working Group (IPCC RSWG): 1990, *Climate Change: The IPCC Response Strategies*, Island Press.

Intergovernmental Panel on Climate Change: 1994, Proceedings of the IPCC Special Workshop on Article 2 of the United Nations Framework Convention on Climate Change, Fortaleza, State of Ceará, Brazil, October 17-21, copy on file with the authors.
Intergovernmental Panel on Climate Change: 2004, IPCC Expert Meeting on The Science to Address UNFCCC Article 2 Including Key Vulnerabilities, Buenos Aires, Argentina, 18 – 20 May, available at http://www.ipcc-wg2.org/

Izrael Yu. A.: 2002, 'Scoping Paper for Levels of Greenhouse Gases in the Atmosphere: Preventing Dangerous Anthropogenic Interference with Climate System', IPCC, Geneva, copy on file with authors.

Jacoby, H.D., Schmalensee, R., and Reiner, D.M.: 1996, ‘What Does Stabilizing Greenhouse Gas Concentrations Mean?’, in Proceedings of the International Petroleum Industry Environmental Conservation Association (IPIECA) Symposium on Critical Issues in the Economics of Climate Change, Paris, October 8-11, copy on file with the authors.

Jamieson, D.:1997, ‘Global Responsibilities: Ethics, Public Health, and Global Environmental Change’, *Indiana J. Global Legal Studies* **5**, 1-16.

Kahneman, D., & Tversky, A.: 1979, ‘Prospect theory: An Analysis of Decisions under Risk’, *Econometrica* **47**, 313-327.

Kasperson, R.E. et al.: 1988, ‘The Social Amplification of Risk: A Conceptual Framework,’ *Risk Analysis* **8**, 177-187.

Keller, K., Tan, K., Morel, F.M.M., Bradford, D.: 2000, ‘Preserving the Ocean Circulation: Implications for Climate Policy,’ *Climatic Change* **47**, 17-43.

Keller, K., Bolker, B.M., and Bradford, D.F.: 2004, ‘Uncertain Climate Thresholds and Economic Optimal Growth,’ *Journal of Environmental Economics and Management* **48**, 723-741.

Keller, K., Hall, M., Kim, S.-R., Bradford, D.F., and Oppenheimer, M.: 2005a, 'Avoiding Dangerous Anthropogenic Interference with the Climate System', submitted to *Climatic Change.*

Keller, K., Kim, S-R., Baehr, J., Bradford, D.F.,, and Oppenheimer, M.: 2005b, 'What Is the Economic Value of Information about Climate Thresholds?', submitted for publication in Schlesinger, M. (ed.), *Integrated Assessment of Human-Induced Climate Change.*

Kyoto Protocol on Climate Change: 1997, text available at http://www.unfccc.int.

Lambrou, Y. and Laub, R.: 2004, 'Gender Perspectives on the Conventions on Biodiversity, Climate Change and Desertification', Gender and Climate Network, http://www.gencc.interconnection.org/.

Lashof, D.A. and D.A. Tirpak (eds.), 1990: *Policy Options for Stabilizing Global Climate*, Report to Congress, U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Washington, DC.

Leemans, R., and Eickhout, B.:2004, 'Another Reason for Concern: Regional and Global Impacts on Ecosystems for Different Levels of Climate Change', *Global Environmental Change*, **14,** 219-228.

Levy, M.A. et al.: 2001, ‘Goal and Strategy Formulation in the Management of Global Environmental Risks,’ in Clark, W.C., Jaeger, J. van Eijndhoven, J. and Dickson, N.M. (eds.), *Learning to Manage Global Environmental Risks - A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain*, MIT Press, Cambridge, MA.

Mastrandrea, M.D. and Schneider, S.H.: 2004, ‘Probabilistic Integrated Assessment of “Dangerous” Climate Change’, *Science*, **304**, 571-575.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., and White, K.S., eds.: 2001, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, NY.

McDaniels R, Axelrod, L.R., Slovic, P.: 1996, ‘Perceived Ecological Risks of Global Change: A Psychometric Comparison of Causes and Consequences,’ *Global Environmental Change* **6**, 159-171.

Metz, B., Davidson, O., Swart, R., and Pan, J., eds.: 2001, *Climate Change 2001: Mitigation*, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, NY.

Michel, D. (ed.): 2003, *Climate Policy for the 21st Century: Meeting the Long-Term Challenge of Global Warming*, Center for Transatlantic Relations, Johns Hopkins University.

Ministerial Declaration: 1996, Ministers and other heads of delegations present at the second session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, adopted July 18, 12:00, copy on file with the authors.

Mitchell, Senator J., Chafee, Senator J., Gore, Senator A., Baucus, Senator M., Leahy, Senator P., Stafford, Senator R., Durenberger, Senator D., and Humphrey, Senator G.: 1986, Letter to EPA Administrator Lee Thomas, September 12, 1986, reprinted at Vol. 132 Cong. Rec. Senate Part 19 (99th Cong., 2d Sess.) 27982-3, October 2.

Montreal Protocol on Substances that Deplete the Ozone Layer: 1987, reprinted in 26 I.L.M. 1550, text available at www.unep.org.

Mooney, H.A., et al.: 1997, Letter to President William J. Clinton (copy on file with the authors).

National Research Council (NRC): 1977, *Energy and Climate*, National Academy of Sciences, Washington, DC.

National Research Council (NRC): 1979, 'A Statement on CO_2 and Energy Policy, July 19, 1979,' cited in Congressional Record (Senate), 96th Congress, 1st Session, **125:16,** pp. 20831-5, July 26.

National Research Council (NRC): 1983, *Changing Climate*, Report of the Carbon Dioxide Assessment Committee, edited by the Commission on Physical Sciences, Mathematics, and Resources of the National Research Council Board on Atmospheric Science and Climate, National Academy of Sciences, Washington, DC.

National Research Council (NRC): 1992, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base*, Panel on Policy Implications of Greenhouse Warming, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, Washington, DC.

Noordwijk Declaration on Atmospheric Pollution and Climate Change: 1989, reprinted in December 13, 1989: *International Environmental Reporter* **12**, p. 624, Bureau of National Affairs; and in 1990: *American University Journal of International Law & Policy* **5**, pp. 592-594.

Nordhaus, W.D.: 1979, 'Strategies for the Control of Carbon Dioxide,' in *The Efficient Use of Energy Resources*, Yale University Press, New Haven.

Nordhaus, W.D.: 1992, ‘An Optimal Transition Path for Controlling Greenhouse Gases,’ *Science*, **258**, 1315-1319.

Nordhaus, W.D. and Boyer, J.: 2000, *Warming the World: Economic Models of Warming*, MIT, Boston.

O’Neill, B.C. and Oppenheimer, M.: 2002, ‘Dangerous Climate Impacts and the Kyoto Protocol,’ *Science* **296**, 1971-2.

O’Neill, B.C. and Oppenheimer, M.: 2004, ‘Climate Change Impacts Sensitive to Concentration Stabilization Path’, *Proc. Nat. Acad. Sci*. **101**, 16,411-16,416.

Oppenheimer, M.: 1989, ‘Developing Policy for Responding to Climatic Change,’ *Climatic Change* **15**, 1-4.

Oppenheimer, M.: 1998, ‘Global Warming and the Stability of the West Antarctic Ice Sheet,’ *Nature* **393**, 325-332.

Oppenheimer, M. and Alley, R.B.: 2004, ‘The West Antarctic Ice Sheet and Long Term Climate Policy,’ *Climatic Change*. **64**, 1-10.

Oppenheimer, M. and Alley, R.B.: 2005, ‘Ice Sheets, Global Warming, and Article 2 of the UNFCCC’, *Climatic Change*, in press.

Oppenheimer, M., and Petsonk, A.: 2003, 'Global Warming: Formulating Long Term Goals,' in Michel, D. (ed.), *Climate Policy for the 21st Century: Meeting the Long-Term Challenge of Global Warming*, Center for Transatlantic Relations, Johns Hopkins University, pp. 79-112.

Organization for Economic Cooperation and Development (OECD): 2002, *Ancillary Benefits and Costs of GHG Mitigation: Policy Conclusions*, OECD, Paris.

Parry, M., Arnell, N., McMichael, T., Nicholls, R., Martens, P., Kovats, S., Livermore, M., Rosenzweig, C., Iglesias, A. and Fischer G.: 2001, 'Millions at Risk: Defining Critical Climate Change Threats and Targets,' *Global Environmental Change* **11**, 181-183.

Patwardhan, A., Schneider, S.H., and Semenov, S.M.: 2003, 'Assessing the Science to Address UNFCCC Article 2' (IPCC Concept Paper), text available at http://www.ipcc.ch/activity/cct3.pdf.

Pershing, J., and Tudela, F.: 2003, 'A Long-Term Target: Framing the Climate Effort,' in Diringer, E. (ed.): 2003, *Beyond Kyoto: Advancing the International Effort against Climate Change*, Pew Center on Global Climate Change, Arlington, VA.

Petschel-Held, G., Schellnhuber, H-J. , Bruckner, T., Toth, F.L., and Hasselmann, K.: 1999, 'The Tolerable Windows Approach: Theoretical and Methodological Foundations,' *Climatic Change* **41**, 303-331.

Pew Center on Global Climate Change: 2001, Proceedings of a Workshop on the Timing of Climate Change Policies, Washington, DC, 11 to 12 October, Pew Center on Global Climate Change, Arlington, Virginia, text available at www.pewclimate.org.

Pew Center on Global Climate Change: 2002, 'Conference of the Parties 8 (COP 8) Climate Talks in New Delhi,' text available at http://www.pewclimate. org/what_s_being_done/in_the_world/cop_8_india/index.cfm.

Pomerance, R.: 1989, 'The Dangers from Climate Warming: A Public Awakening,' in Abrahamson, D.E. (ed.), *The Challenge of Global Warming*, Island Press, Washington, DC, pp. 259-69.

Rayner, S. and Malone, E.L. (eds): 1998, *Human Choice and Climate Change*, Vol 1, The Societal Framework, Battelle Press, Washington DC.

Reitze, A.W. Jr.: 1999, 'The Legislative History of U.S. Air Pollution Control,' *Houston Law Review* **36**, p. 679.

Revelle, R., and Suess, H.E.: 1957, 'Carbon Dioxide Exchange between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 during the Past Decades,' *Tellus* **9**, 18-27.

Rial, J.A., et al.: 2004, 'Nonlinearities, Feedbacks, and Critical Thresholds within the Earth's Climate System', *Climatic Change*, **65**, 11-38.

Ribicoff, A., Senator: 1979a, 'Statement to the U.S. Senate Committee on Governmental Affairs,' Congressional Record, Senate 96th Congress, 1st Session, **125:16**, pp. S20831-5 (July 26).

Ribicoff, A., Senator: 1979b, 'Statement on Amendment No. 564 to the Defense Production Act,' Congressional Record, Senate, 96th Congress, 1st Session, **125:23**, pp. S30682-3 (November 1).

Ribicoff, A., Senator: 1979c, 'Statement on Amendment No. 564 to the Defense Production Act,' Congressional Record, Senate, 96th Congress, 1st Session, **125:23,** p. S31212 (November 7).

Rijsberman, F. & Swart, R. (ed.): 1990, 'Targets and Indicators of Climate Change', Report of Working Group II of the Advisory Group on Greenhouse Gases, WMO/UNEP. Stockholm Environment Institute: Stockholm.

Santilli, M., Moutinho, P., Schwartzman, S., Nepstad, D., Curran, L., and Nobre, C., 2004: 'Tropical Deforestation and the Kyoto Protocol: An Editorial Essay', submitted to *Climatic Change*.

The Study of Critical Environmental Problems (SCEP): 1970, *Man's Impact on the Global Environment*, MIT Press, Cambridge, Mass.

Schimmel, D. et al.: 1995, 'CO_2 and the Carbon Cycle,' in Houghton, J.T. et al., eds., *Climate Change 1994: Radiative Forcing of Climate Change and Evaluation of the IPCC IS92 Emissions Scenarios*, Cambridge University Press, Cambridge, UK.

Schimmel, D. et al.: 1997, 'Stabilization of Atmospheric Greenhouse gases: Physical, Biological, and Socio-economic Implications,' IPCC Technical Paper III, Intergovernmental Panel on Climate Change, Geneva.

Schneider, S. H.: 1976, *The Genesis Strategy: Climate and Global Survival*. Plenum Press, New York, p. 11.

Schneider, S. & Azar, C.: 2001, 'Are Uncertainties in Climate and Energy Systems a Justification for Stronger Near-term Mitigation Policies?,' paper presented at the Pew Center Workshop on the Timing of Climate Change Policies, Washington, DC, 11 to 12 October, Pew Center on Global Climate Change, Arlington, Virginia, text available at www.pewclimate.org.

Second World Climate Conference (SWCC): 1990, Declaration of the Second World Climate Conference, reprinted in J. Jäger and H.L. Ferguson, eds., *Climate Change: Science, Impacts and Policy - Proceedings of the Second World Climate Conference,* Cambridge University Press/WMO 1991.

Seidel, S. and Keyes, D.: 1983, ‘Can We Delay a Greenhouse Warming?,’ (2nd, Corrected Ed.). Washington, DC: Environmental Protection Agency.

The Study of Man’s Impact on Climate (SMIC): 1971, *Inadvertent Climate Modification,* MIT Press, Cambridge, Mass.

Smith, J., Schellnhuber, H.-J., and Mirza, M.Q., et al.: 2001, ‘Vulnerability to Climate Change and Reasons for Concern: A Synthesis,’ in McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., and White, K.S., (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, and New York, NY.

Smith, J.B. and Tirpak, D.A. (eds.):1989, *The Potential Effects of Global Climate Change on the United States*. EPA-230-05-89, Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency, Washington, DC.

Stiftung Wissenschaft und Politik (SWP): 2003, 'High-level Transatlantic Dialogue on Climate Change', sponsored by The Brookings Institution and The German Institute for International Security Affairs (SWP), October 16-18.

Stipp, D.: 2004, 'Climate Collapse: The Pentagon's Weather Nightmare,' *Fortune Magazine*, January 26.

Strain, B.R. and Cure, J.D.: 1985, 'Direct Effects of Increasing Carbon Dioxide on Vegetation,' US Department of Energy DOE/ER-0238.

Sunstein, C.R.: 2002, *Risk and Reason*, Cambridge University Press, Cambridge, UK.

Task Force on the Comprehensive Approach to Climate Change: 1991, 'A Comprehensive Approach to Addressing Potential Climate Change,' U.S. Department of Justice, Environment and Natural Resources Division, Washington, DC, pp. 16-34, copy on file with the authors.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., Ferreira De Siqueira, M., Grainger, A., Hannah, L., Hughes, L., Huntley, B., Van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Peterson, A.T., Phillips, O.L., & Williams, S.E.: 2004, 'Extinction Risk from Climate Change', *Nature* **427**, 145-148.

Titus, J.G. (ed.): 1986, *Stratospheric Ozone: Effects of Changes in Stratospheric Ozone and Global Climate,* Proceedings of the United Nations Environment Programme (UNEP)/Environmental Protection Agency (EPA) International Conference on Health and Environmental Effects of Ozone Modification and Climate Change,Washington, D.C., U.S. Environmental Protection Agency.

Tol, R.S.J.: 2003, 'Is the Uncertainty about Climate Change too Large for Expected Cost-Benefit Analysis?', *Climatic Change* **56**, 265-289.

Tol, R.S.J., Downing, T.E., Kuik, O.J., and Smith, J.B.:2004, 'Distributional Aspects of Climate Change Impacts', *Global Environmental Change*, **14,** 259–272.

Tonn, B.: 2003, 'An Equity First, Risk-based Framework for Managing Global Climate Change', *Global Environmental Change*, **13**, 295-306.

Toth F. L., Bruckner, T., Füssel, H.-M., Leimbach, M., and Petschel-Held, G.: 2003, 'Integrated Assessment of Long-term Climate Policies: Part 1 – Model Presentation', *Climatic Change* **56**, pp. 37-56.

Trittin, J.: 2003, Speech on German-Brazilian Environmental Cooperation, Latin American Regional Preparatory Conference for 'Renewables 2004', (Brasilia, October 30, 2004), copy on file with the authors.

Tuinstra, W., Berk, M., Hisschemöller, M., Hordijk, M., Metz, B., Mol, A.P.J. (eds.): 2002, 'Climate OptiOns for the Long Term (COOL),' Final Report, Volume A – Synthesis Report, NRP report 954281, Wageningen, text available at http://www.wau.nl/cool/reports/COOLVolumeAdef.pdf.

Tyndall Centre: 2004, *Perspectives on Dangerous Climate Change*, Report of a Workshop organized by the Centre for Environmental Risk and The Tyndall Centre for Climate Change Research, June 28-29, University of East Anglia.

United Nations Economic Commission for Europe (UNECE): 1979, Convention on Long-range Transboundary Air Pollution (LRTAP).

United Nations Economic Commission for Europe (UNECE):1988, Protocol concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes, Sophia, Bulgaria.

United Nations Framework Convention on Climate Change (UNFCCC): 1992, text available at http://www.unfccc.int.

United Nations Framework Convention on Climate Change (UNFCCC) Eighth Conference of the Parties (COP-8).:2002, Decision 1/CP.8, Delhi Ministerial Declaration on Climate Change and Sustainable Development, text available at www.unfccc.int.

United Nations Framework Convention on Climate Change (UNFCCC), First Conference of the Parties (COP-1): 1995, 'Berlin Mandate of the Conference of the Parties to the Framework Convention on Climate Change', Decision 1/CP.1, paragraph 6 (FCCC/CP/1995/7 Add.1), text available at www.unfccc.int.

United Nations Framework Convention on Climate Change (UNFCCC) Ninth Conference of the Parties (COP-9): 2003, COP-9 Decisions, Milan, text available at www.unfccc.int.

United Nations Framework Convention on Climate Change (UNFCCC) Document FCCC/SBSTA/2002/INF14, 16 October 2002: 'Methodological Issues: Scientific and Methodological Assessment of Contributions to Climate Change.'

United States Senate Committee on Governmental Affairs: 1979, 'Carbon Dioxide Accumulation in the Atmosphere, Synthetic Fuels, and Energy Policy: A Symposium,' 96th Congress, 1st Session, U.S. Government Printing Office, Washington, D.C.

United States (U.S.) Statement to the Second Session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change: 1996, July 18, copy on file with the authors.

Vaughan, D. G., and Spouge, J. R.: 2002, 'Risk Estimation of Collapse of the West Antarctic Ice Sheet,' *Climatic Change* **52**, 65-91.

Vellinga, P.: 1996, 'Climate Change: From Science to Global Politics,' in: *Environmental Policy in International Context*, New York: Wiley.

Vellinga, M and Wood, R.A.: 2002, 'Global Climatic Impacts of a Collapse of the Atlantic Thermohaline Circulation,' *Climatic Change* **54**, 251-267.

Vienna Convention for the Protection of the Ozone Layer: 1985, text available at www.unep.org.

Weart, S.: 2003, *The Discovery of Global Warming*, Harvard University Press, Cambridge, MA.

Webster, M.: 2002, 'The Curious Role of Learning in Climate Policy: Should We Wait for More Data?' *The Energy Journal* **23**, 97-119.

White, M.R., ed.: 1985, 'Characterization of Information Requirements for Studies of CO_2 Effects: Water Resources, Agriculture, Fisheries, Forests, and Human Health,' US Department of Energy DOE/ER-0236.

White House, 1989: Statement on Climate Change (7 November 1989), quoted in Revkin, A., 'Climate Plan Is Criticized as Optimistic,' *The New York Times*, February 26, 2002, p. 1.

Wigley, T.M.L.: 1995, 'Global Mean Temperature and Sea Level Consequence of Greenhouse Gas Concentrations Stabilization,' *Geophys. Research Letters* ***22***, 45-48.

Wigley, T.M.L, Richels, R., and Edmonds, J.A.: 1996, 'Economic and Environmental Choices in the Stabilization of CO2 Concentrations: Choosing the "Right" Emissions Pathway', *Nature* **379**, 240-243.

Williams, J., ed.: 1978, 'Carbon Dioxide, Climate, and Society', Proceedings of an IIASA workshop, Pergamon, Oxford, February 21-24.

World Commission on Environment and Development: 1987, *Our Common Future*, UN General Assembly Document A/42/427, 4 August 1987.

World Conference on the Changing Atmosphere: 1988, Statement on Implications for Global Security, Toronto (June 27-30 1988), reprinted as World Meteorological Organization and United Nations Environment Program WMO/OMM Doc. 710 (1989), and reprinted in American University Journal of International Law and Policy **5**, p. 515.

World Meteorological Organization (WMO): 1988, ‘Developing Policies for Responding to Climatic Change, A Summary of the Discussions and Recommendations of the Workshops Held in Villach (28 September–2 October 1987) and Bellagio (9-13 November 1987) under the Auspices of the Beijer Institute, Stockholm’, WMO/TD no. 225, Geneva.

Wright, E.L., and Erickson, J.D.: 2003; ‘Incorporating Catastrophes into Integrated Assessment: Science, Impacts, and Adaptation,’ *Climatic Change* **57**, 265-286.