Chapter 4

Establishing Causation: Legal Requirements & Scientific Evidence

Introduction

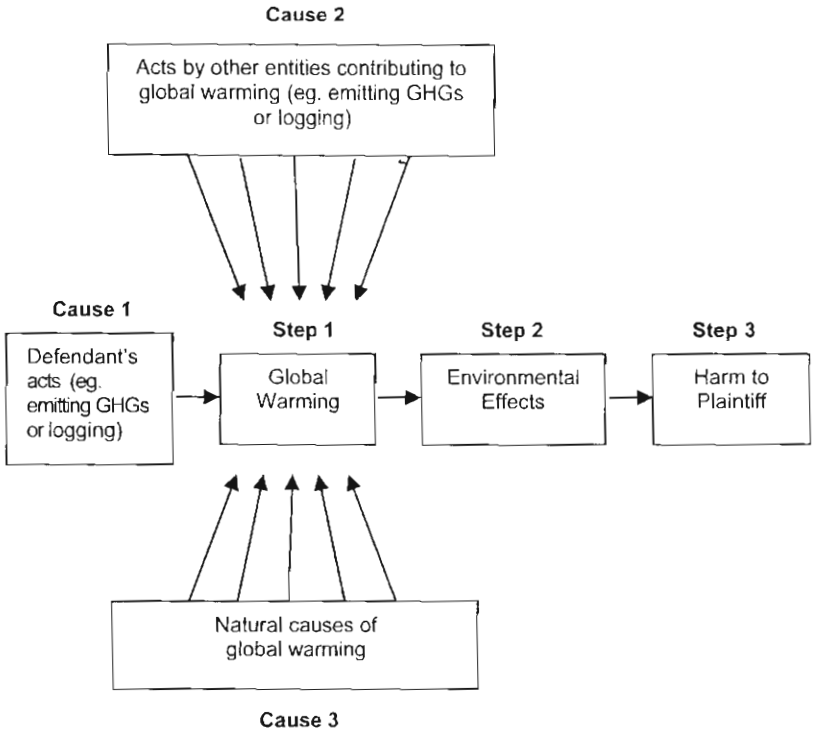
Establishing legal causation in climate change actions – that is, proving that a defendant's actions caused the harm suffered by a plaintiff – will pose the greatest obstacle for a majority of plaintiffs. The science of climate change, however, is developing rapidly and in legally significant ways. Broadly speaking, two key issues in this context will be: firstly, whether current legal tests and thresholds regarding causation and probability of causation are appropriate for, or flexible enough to accommodate, inherent complexities in the science of global warming; and secondly, whether existing scientific evidence is sufficient to support an inference of causation.

Figure 4.1 sets out a framework within which causation issues can be considered and highlights the prominence of the two issues referred to above. It provides a diagrammatic representation of the links in the causal chain that will generally need to be established by a plaintiff, beginning with a defendant's greenhouse gas polluting acts and ending with the harm complained of by a plaintiff.

The fact that factors in addition to a defendant's actions contribute to global warming (namely, natural causes and emissions by other polluters – see Causes 2 and 3) means that a defendant is not *solely* responsible for harm caused to a plaintiff. This raises a multitude of complex issues in terms of causal analysis. For example, if in the absence of anthropogenic global warming a city would experience two extreme storms but, as a result of anthropogenic climate change, experiences three such storms, it is impossible to determine whether any given storm is due to anthropogenic warming or some other contributing factor. This problem raises questions about which is the most suitable test for determining causation in climate change cases. Similarly, the fact that a plaintiff may have suffered harm in the absence of a defendant's polluting acts raises questions about how courts should assess the *probability* that a defendant's actions were responsible for a plaintiff's harm (which is only one factor amongst many that is taken into consideration by courts when determining whether a defendant's actions *in fact* caused the relevant harm in the plaintiff's particular case). These issues are addressed in Part A of this chapter.

Step 1 of Figure 4.1 demonstrates that the need to prove, firstly, that global warming is occurring and, secondly, that it is being caused partly by human activities (including those of the defendant), is critical to commencing the chain of causation. Persuading courts to accept the scientific evidence supporting the causes of global warming and, in particular, linking them with regional climatic events, will be a formidable undertaking. Part B of this chapter provides a detailed overview and critical analysis of the existing body of scientific evidence representing consensus on global warming and its causes and effects as well as counter arguments propounded by global warming sceptics.

Figure 4.1: The Chain of Causation



PART A: Legal Tests & Standards of Probability

1. Legal Tests

a. Current assessments: the common-sense approach

Under the US *Restatement (Second) of Torts*, a defendant's alleged tortious conduct is a legal cause of the plaintiff's harm if the conduct is a "substantial factor" in the occurrence of the said harm. In this context, "substantial" means that the defendant's conduct "...has such an effect in producing the harm as to lead reasonable men to regard it as a cause, using that word in the popular sense, in which there always lurks the idea of responsibility..."[1]

In Australia, the High Court has regarded questions of causation in cases of negligence as questions of fact resolved by common sense.[2] The "but for" test of causation (which asks whether a plaintiff's injuries would have occurred *but for* the defendant's negligence) has been viewed by the court as a test of limited use. Whilst the test is often a useful aid in determining issues of causation, it is not, in view of inherent limitations, an exclusive or definitive test. Application of the test is most troublesome in scenarios where multiple acts or events lead to a plaintiff's injury, as is the case in climate change cases. As Mason CJ (with whom Toohey and Gaudron J.J. agreed) said in *March v Stramere*,[3] "the test, applied as an exclusive criterion of causation, yields unacceptable results and...the results which it yields must be tempered by the making of value judgments and the infusion of policy considerations".[4] The Australian approach to questions of causation, at least in negligence cases, is that there is no single common sense criterion for answering causal questions and that a holistic perspective is needed which incorporates an evaluation of the total body of scientific evidence before the Court in the light of value judgments and public policy considerations.[5] Such an approach, which takes into account non-mechanical elements, has the potential to significantly complicate the process of establishing causation. Applying a holistic approach to causation in a climate change litigation case would be an undertaking of enormous proportions in view of the fact that a court would need to assess not only the total body of scientific evidence in relation to the action, but also the profound public policy considerations raised by global warming as well as potentially subjective value judgments.

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1 *Restatement (Second) of Torts*, § 431 cmt.a (1965), cited from D. A. Grossman, "Warming Up to a Not-So-Radical Idea: Tort-Based Climate Change Litigation", *Colombia Journal of Environmental Law*, vol. 28, 2003, pp.1-61, at p.25.

2 *Bennett v Minister for Community Welfare* (1992) 176 CLR 408, Mason C.J., Deane and Toohey, J.J. at 412-413.

3 (1991) 171 CLR 506.

4 Ibid at 516.

5 *Chappel v Hart* (1998) 195 CLR 232; *Rosenberg v Percival* (2001) 205 CLR 434.

In a discussion of the causation question,[6] Myles R Allen and Richard Lord note that Peter Stott and other researchers have used risk and probability theory in an attempt to link greenhouse gas emissions and a specific weather event, such as the European heatwave of 2003 (see further below).[7] Allen and Lord observe that, on a "but for" analysis of causation, it will almost always be impossible to say that, but for greenhouse gas emissions, the actual harm (such as an unusual weather event) would not have occurred. Citing the House of Lords case of *Fairchild v Glenhaven* (2002),[8] Allen and Lord suggest that a more appropriate test of causation in certain circumstances – and certainly climate change cases – is whether there has been a "material increase in risk".[9] *Fairchild* is of direct relevance to causation issues in climate change cases as, in that case, the House of Lords held that, where damage was caused to a plaintiff by one of two defendants in circumstances where both defendants had breached a relevant duty of care owed to the plaintiff but science did not enable it to be proven which breach in fact resulted in the harm, *both* defendants were liable (even though one of them did not cause the harm). Generally, the court indicated that causation principles may be departed from in special circumstances where the justice of the case so requires. Lord Bingham of Cornhill cited judicial opinion regarding causation from Australia, Canada and Britain which rejected a "...mechanical approach to the issue of causation..." and the idea that there is a "...uniform causal requirement for liability in tort".[10] This has clear relevance to climate change cases where a plaintiff may sue multiple defendants for harm caused by anthropogenic global warming to which they have contributed.

A test based on a material increase in risk would clearly improve the prospects of success for climate change plaintiffs. However, this benefit aside, the present authors agree that such a test for causation is highly suitable and appropriate for global warming cases in view of the complexities surrounding the science of global warming. Of course, any shift in judicial opinion towards such a test – which appears to have already commenced – will not necessarily occur as a result of climate change cases, but, rather, as part of a broader evolution of judicial opinion. Climate change cases could, however, act as a catalyst in this area.

Whilst apportionment of damage issues are outside the scope of this text, *Fairchild*[11] is also of importance regarding the question of apportionment of liability in tort cases where damage is caused by more than one person, such as in climate change suits. *Fairchild* examined authorities from several countries regarding this issue and concluded that, in most jurisdictions, such persons are held jointly and severally liable.[12] Peñalver (see following page)

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6 M.R. Allen and R. Lord, "The Blame Game: Who Will Pay for the Damaging Consequences of Climate Change?", *Nature*, vol. 432, 2 December 2004, pp. 551-552.

7 P.A. Stott, D.A. Stone and M.R. Allen, "Human Contribution to the European Heatwave of 2003", *Nature*, vol. 432, 2 December 2004, pp. 610-614.

8 [2002] UKHL 22.

9 Ibid at [12].

10 Ibid.

11 Ibid.

12 Ibid at [26]-[27].

has argued in support of holding defendants liable for damage from human induced climate change on a proportional basis according to market share for fossil fuels. In some US mass tort cases, liability has been based on market-share liability.[13] Holding defendants liable on this basis would mean, for example, that a defendant that is responsible for three per cent of global CO_2 production via fossil fuels would be held responsible for three per cent of the relevant damage (before a discount to allow for the possibility of natural causes having caused the damage is also made). This liability-splitting rule would appear to be suitable for apportioning liability although, whilst simple in theory, the calculation of world market shares could, in practice, be a costly and difficult task.

b. Review of a suggested probabilistic approach

In an article written in 1998, Eduardo Peñalver, who was at the time a third year student at Yale Law School and is now Associate Professor at Fordham University School of Law in New York, argues that the mechanistic, individualised approach to causation in climate change cases – which requires proof that a given causal factor (namely, climate change) more likely than not caused a particular injury – should be rejected, largely on the grounds that it is inconsistent with the current state of scientific knowledge.[14] An awareness of the distinction between "deterministic" and "probabilistic" accounts of causation is important to understanding Peñalver's argument. A deterministic account of causation is an account in which every action (or cause) produces a reaction (or effect) and every reaction, in turn, becomes the cause of subsequent reactions, such that the behaviour of natural phenomena can be predicted with certainty. In contrast, a probabilistic account of causation is one where phenomena can't be predicted with certainty but only within a range of probability (the central idea generally being that causes raise the probabilities of their effects). Peñalver states:

> The notion of a world governed by a web of but for causation, ordered in turn by discoverable, exceptionless laws of nature, is based upon a largely eighteenth century, corpuscularian metaphysics...Although tort law has clung to this...notion of causation, science...has largely abandoned this understanding for an indeterminate, probabilistic notion of causation...The law's failure to embrace the new scientific understanding of causation leads it to view probabilistic, epidemiological evidence as second-best, indirect evidence of "real" (that is, but for) causation.[15]

Peñalver argues that the adoption of a probabilistic approach to causation would help solve many of the problems of proving causality in complex cases,

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13 E.M. Peñalver, "Acts of God or Toxic Torts? Applying Tort Principles to the Problem of Climate Change", *Natural Resources Journal*, vol. 38, Fall 1998, pp. 563-601 at p.592. See *Sindell v Abbott Laboratories*, 607 P.2d 924, 937 (Cal. 1980); *Hymowitz v Ely Lilly & Co*, 539 N.E. 2d 1069, 1076 (NY, 1989).

14 Peñalver, above n 13, p.582.

15 Ibid pp.582-583.

such as toxic tort[16] and climate change cases.[17] However, probabilistic theories of causation are extremely complex and, in view of this, the present authors consider that an adoption of such theories as the primary basis upon which legal causation was to be established would create profound practical and jurisprudential difficulties. Whilst current approaches to causation are imperfect, probabilistic methods would likely raise at least as many problems as they solve. This section of the text considers complexities associated with a probabilistic approach to causation in order to demonstrate difficulties that would arise if such an approach were to be adopted. Some of the issues addressed below are considered in a cross-disciplinary manner and involve detailed scientific analysis. However, whilst these complex issues are unlikely to be raised in climate change cases, they warrant consideration in view of the fact that they have been raised by academic scholars.

Peñalver argues that the major conceptual difficulty regarding proof of causation in both toxic tort and tort-based climate change litigation cases arises from a mechanistic and deterministic conception of individual causation through the use of "but for" tests.[18] A "but for" analysis requires that there be a connection between a cause and its effects, so that if the cause did not occur, the effect would not have occurred either. This model derives from the "deductive nomological" model of scientific explanation, which explains phenomena by reference to invariable causal laws, or laws of nature and initial conditions.[19] Peñalver argues that the deductive nomological account of explanation, commonly employed in physics, is unsuitable for causal analysis in toxic tort and climate change cases. With respect to climate change litigation, Peñalver says that because of "background levels of the effect...it will be impossible to say with any certainty which particular lightning strikes were caused by global climate change and which ones would have occurred anyway".[20] However, whilst this may be correct in relation to lightning strikes, it can be argued in response that this problem of specificity does not arise in relation to all climatic phenomena.

Peñalver favours a probabilistic theory of causation proposed by John Dupre whose analysis, Peñalver states, is quite similar to other probabilistic definitions proposed by philosophers of science, such as Patrick Suppes who argues that "causes should be defined as those factors that raise the chances of their effects."[21] There are a number of technical models of causation based upon such probabilistic notions of causality. On this account, B is a prima facie cause of A if, and only if, B occurs earlier than A and Prob(A/B)>Prob(A). B is a spurious[22] cause of A if, and only if, B is a prima

16 Ibid p.585.
17 Ibid pp.586-7.
18 Ibid p.579-82.
19 R. Bhaskar, *The Possibility of Naturalism* (Harvester Press, Sussex, 1979).
20 Peñalver, above n 13, p.582.
21 Peñalver, above n 13, p.584. See P. Suppes, *A Probabilistic Theory of Causality* (North Holland, Amsterdam, 1970).
22 A "spurious cause" is one for which there is a statistical relation with the effect but for which there is in fact no causal link, usually because the statistical relation is caused by a third variable.

facie cause of A and there is a partition (or set) C_i (for I = 1,2,3,...) of prior events such that for all *i*, C_i is earlier than B and:

$$\text{Prob}(A/B\&C_i) = \text{Prob}(A/C_i) \quad (1)$$

B otherwise is a genuine cause. In general terms, a cause (C) is a prima facie probabilistic cause of an event (E) if, and only if, C precedes E in time and is positively relevant to E. It is a spurious cause if, and only if, there is a partition of events earlier in time than C such that C is independent of E conditional on that partition. It is a genuine cause if, and only if, it is a prima facie cause that is not spurious. Stated in its simplest form, the probabilistic analysis of causality takes a cause to be an event that precedes the effect in time, and which is positively relevant to the effect, and not one that is spurious or merely coincidental. Such an account faces the problem of showing that the partition can be specified in a logically non-circular way. The idea that the cause is independent of the effect conditional on the partition seems to require prior knowledge of causation to establish the independence condition. Spurious causes require a partition of events taking place before the cause C, such that the cause is independent of the effect E, conditional on the partition. This raises the issue of how it can be proven that a cause is independent of E conditional on the partition. To do so seems to require knowledge of which events are in the partition and those which are not. This leads to the issue of how cases of genuine causation can be distinguished from "cosmic coincidences," where events may appear to be causally related, but in reality only occur together by improbable chance. It seems that some *prior* knowledge of causation is necessary so that the independence of E conditional on the partition can be established. If prior causal knowledge is required, the probabilistic model of causality is viciously circular as a general account of causality, as it presupposes the very thing it is supposed to analyse.

2. Assessing probability of causation in multiple cause cases

When determining causation, particularly in cases where a cause is not immediately obvious, such as in climate change suits, courts base their conclusions on a range of tests and areas of knowledge such as logic, science, experience, common sense and inferences drawn from multiple strands of evidence.[23] In climate change cases, scientific evidence will play a central role in establishing causation; for example, computer models will assist in determining what human activities caused which climatic events and epidemiological studies will play a key role in providing evidence of the

23 See, eg., *Restuccia v Workers Compensation (Dust Diseases) Board* (Unreported, District Court of NSW, Geraghty J, Matter No 2172 of 2001, 12 August 2005) at <http://www.lawlink.nsw.gov.au/lawlink/district_court/ll_districtcourt.nsf/pages/dc_restuccia_v_workerscomp> viewed at 13 May 2006. For a more detailed discussion, see *Seltsam v McGuiness* (2000) 49 NSWLR 262; [2000] NSWCA 29.

likelihood or probability that a particular disease was caused by a particular agent.

When presented as evidence of individual causation, courts have viewed statistical associations based on computer models and epidemiological studies with cautious scepticism. Courts are aware that, in scenarios involving multiple or complex causes, there are often many confounding factors and intervening causative agents. As Grossman notes:

> Showing specific causation in the climate change context could be particularly difficult. First, climate change's effects involve shifts in climate activity, such as more intense and more frequent storms, not the creation of distinctive new phenomena, like the "signature diseases" of asbestosis in asbestos cases and clear cell adenocarcinoma in DES cases. Unlike those cases, the complexity of the climate system means that several factors are involved in producing climatic phenomena, making it difficult to show the probability that defendants' contributions to anthropogenic climate change caused any particular phenomenon. Second, unlike cancer or other typical toxic tort effects, the natural phenomena affected by climate change are subject to natural fluctuations in frequency and severity. The chaotic system underlying climatic effects makes it quite difficult to differentiate a particular pattern change in temperature or sea level caused by anthropogenic climate change from one caused by natural variability.[24]

These factors weigh heavily in favour of defendants and have already formed the basis of defence arguments in climate change cases. Grossman considers, however, that the obstacle of specific causation is mitigated when governments bring tort claims due to the fact that they have longer lifespans than individuals and their interests cover a wider area.[25] In principle, this increase in scope of space and time permits an aggregation of effects and hence a wider sample space for the examination of climatic events that may be genuinely attributed to human-induced climate change. For example, whilst it would be difficult for a farmer to prove that a single storm that caused damage to maple trees on his or her farm was caused by global warming, it would be relatively easier for a government to prove that a very high number of storms over an extended period that have caused widespread damage to a maple tree industry is a result of climate change.

Epidemiological studies make conclusions about whether a statistical association represents a relationship of cause and effect. However, such studies only focus on the question of whether a particular factor is capable of "causing" a disease – they do not attempt to draw conclusions about whether a particular factor in fact caused a disease in any particular case. As such, epidemiological studies only provide evidence of possibility. In view of this, a material increase in risk of injury caused by a defendant's negligence does not equate to a material contribution to the injury by the defendant's negligence. Rather, evidence of possibility is admissible in court and is taken into consideration, amongst other factors, when determining whether or not, on the

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24 Grossman above n 1, p.24.
25 Ibid p.25.

balance of probabilities, an inference of causation in a specific case could or should be drawn. Where, however, the whole of the evidence does not rise above the level of possibility, either alone or cumulatively, such an inference is not open to be drawn as the common law test of balance of probabilities is not satisfied.[26]

Epidemiological studies often provide evidence of possibility by identifying the strength of any association by a measure known as a "relative risk" (RR). A relative risk is the ratio of two risks – namely, the incidence of a disease in exposed individuals compared with the incidence in unexposed individuals. If the RR equals 1.0, the risk in exposed individuals is the same as that in unexposed individuals. If the RR is greater than 1.0, the risk in exposed individuals (for example, people exposed to the effects of global warming) is greater that the risk in unexposed individuals. A RR of 2 represents a doubling of the risk. Importantly, the magnitude of a RR does not in itself indicate any causal relationship. Rather, a RR only indicates a relative change in risk and, in doing so, provides courts with an indication of whether or not causation can be confidently inferred.

In toxic tort litigation, epidemiological data is often used to show probabilistic links between exposure to toxic substances and health defects and illnesses.[27] However, causal links in climate change cases are significantly more complex than in toxic tort and similar types of cases. The reason for this is that the climate system is one of the most complex systems known to science. There are sophisticated feedback systems, non-linear interactions and "chaos" effects whereby small events may, through feedback systems, produce disproportionately large effects (as is sometimes illustrated by climatologists through the somewhat colourful "butterfly effect" metaphor in which a butterfly in one country flaps its wings, ultimately leading to a hurricane in another distant country). In view of these complexities, computer models based on complex mathematical data and statistical equations are used to form probability relations between greenhouse gas emissions and climate effects.

It is well recognised that various statistical problems are associated with a simplistic use of RR ratios. For example, a RR can suggest that X and Y are unrelated (ie. uncorrelated directly), despite the fact that they are in fact indirectly correlated through effects of unknown confounding factors. There may also be statistical biases as a result of particular measurement methodologies. In light of these and other problems, statisticians have adopted a convention of not accepting a RR of less than 2 as being significant. Some statisticians insist on a RR of 3 and sometimes even 4. Similarly, many leading medical journals do not accept papers for publication unless they have RR findings of 3 or more. For beneficial effects, a RR of greater than 0.5 is rarely accepted by medical journals. This convention is a quality control mechanism that has been adopted in medical, and especially epidemiological, work to ensure precision of results and to attempt to eliminate findings of increases in

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26 *Seltsam v McGuiness* [2000] NSWCA 29 per Spigelman CJ at [79] - [80].

27 See S. Greenland and J.M. Robins, "Epidemiology, Justice and the Probability of Causation", *Jurimetrics*, vol. 40, Spring 2000, pp. 321-340.

risk that are in fact due to chance, statistical bias or effects of unknown confounding factors.

In the United States, there is some conjecture about what the legal threshold is for concluding that an agent was more likely than not the cause of a disease. There appears to be strong authority for the proposition that, where the only evidence bearing on cause in fact is epidemiological, the threshold is a RR greater than 2, but where evidence in addition to epidemiological evidence is presented, a lower standard may be sufficient.[28] However, in the Australian case of *Seltsam v McGuiness*,[29] Spigelman CJ conducted a comprehensive review of US case law and concluded that "[s]ome of the American cases indicate that the RR of 2.0 should not be applied as a rigid mathematical formula. Others appear to apply it in that way".[30] In relation to Australian requirements, Spigelman CJ stated:

> The predominant position in Australian case law is that a balance of probabilities test requires a court to reach a level of actual persuasion...In Australian law, the test of actual persuasion does not require epidemiological studies to reach the level of a Relative Risk of 2.0, even where that is the only evidence available to a court. Nevertheless, the closer the ratio approaches 2.0, the greater the significance that can be attached to the studies for the purposes of drawing an inference of causation in an individual case.[31]

Applying a threshold of a RR of 2 or greater to specific causes of harm within the context of climate change litigation would create significant difficulties for plaintiffs. The sheer complexity of the climatic system means that a large number of mutually interacting factors produce climatic events and it would be difficult for a plaintiff to establish that a defendant's greenhouse gas emissions specifically (as opposed to generally) contributed to the relevant harm. As Peñalver notes, plaintiffs would only recover if the incidence of the injuring climate change effect was to double due to human-caused climate change.[32] The problem with such a rule is that even very small increases in certain climatic variables, which are less than a doubling of the effect, may have major, if not catastrophic, consequences. For example, a doubling of the effects of tornadoes in regions already subject to intense tornado activity may be devastating whilst an effect that is much less than a doubling could have consequences almost as grave. In view of this, the high standards of statistical precision, as generally required by courts, will not always be appropriate in the context of climate change litigation because of the intrinsic complexities of causation involved in global warming. In situations involving such complex causal chains, a standard appropriate for the subject matter under consideration should be adopted on a case-by-case basis which, in many circumstances, may

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28 See, eg., *Re Joint Eastern and Southern District Asbestos Litigation* 964 F. 2d 92 (2nd Cir. 1992). See also the review of US authorities by Spigelman CJ in *Seltsam v McGuiness* [2000] NSWCA 29 commencing at [121].

29 [2000] NSWCA 29.

30 Ibid at [135]. For Spigelman CJ's review of US case law, see at [121] - [135]. See, in particular, *Daubert v Merrell Dow Pharms Inc*, 43 F.3d 1311, 1321 (9th Cir 1995).

31 Ibid at [136] - [137].

32 Peñalver, above n 13, p.587.

mean a RR below 2.0 should be considered as sufficient to support an inference of causation. Such an approach is likely to be more readily accepted in jurisdictions where a RR of 2.0 is not strictly required. Achieving such an outcome in jurisdictions where a RR of 2.0 or more is required would, however, first require persuasive arguments from plaintiffs.

On a related issue, mathematico-legal writers have outlined specific difficulties associated with judicial application of the "probability of causation (PC)" formula in the context of toxic tort cases. The PC formula provides that "the probability of causation is the percentage of risk in the exposed population that is attributable to the substance under analysis".[33] In a civil toxic tort suit, a plaintiff must show that it is "more probable than not" that the exposure "causally contributed to" or "was a substantial contributing factor" to the relevant disease (ie. that the probability of causation must exceed 50 per cent).[34] Often, the probability of causation has erroneously been taken to equal the rate fraction (RF). The causal rate fraction (or relative risk) where I_1 and I_0 are the incident rates of the disease in question, with and without exposure respectively, and $IR=I_1/I_0$ is the incident-rate ratio, is given by:

$$PC = (I_1-I_0)/I_1 = (IR-1)/IR \qquad (2)$$

For $RF\equiv(IR-1)/IR$, where RF is the rate fraction (2) yields that PC=RF: the probability of causation equals the rate fraction.[35] If PC>0.5 and PC=RF then (IR-1)/IR>0.5 which implies that IR>2. However, "more probable than not" is not the same as a "rate ratio above two". As Greenland and Robins put it:

> [J]udicial applications of the formula PC=RF have been without foundation in fact. Furthermore, absent indefensible assumptions, PC and RF may be as far apart as their logical limits allow. It is possible for exposure to have causally contributed to every case of disease, even if the exposure only elevates the rate only slightly. That is, it is possible to have PC=1 even when the causal ratio IR is close to 1 and so RF is close to zero. However, the converse is false. Epidemiologic data does place a non-zero lower band on the probability of causation when RF>0. This lower bound is always less than RF when IR is constant, although under commonly used assumptions, RF approximates this lower band.[36]

Greenland and Robins conclude that biological assumptions are required to equate PC to RF.[37] Parties to climate change cases should be careful to ensure that any such erroneous applications of the formula are avoided.

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33 M. Parascandola, "What is Wrong with the Probability of Causation?", *Jurimetrics*, vol. 39, Fall 1998, pp.29-44 at p.32. A more technical consideration is S. Greenland and J.M. Robins, "Epidemiology, Justice and the Probability of Causation", *Jurimetrics*, vol. 40, Spring 2000, pp. 321-340.

34 Greenland and Robins, above n 27, at p.323.

35 Ibid p.324.

36 Ibid pp.325-326.

37 Ibid p.326.

PART B: Scientific Evidence (Consensus & Scepticism)

1. Global Warming Science

The science of climate change will be central to establishing causation in climate change lawsuits. This section outlines the state of current scientific evidence regarding global warming, including the consensus position, some of the fundamental, foundational and methodological criticisms of global warming sceptics and why, in the view of the majority of scientists, arguments propounded by sceptics are unfounded.

Scientific consensus on climate change[38] has been expressed by the Intergovernmental Panel on Climate Change (IPCC) in its 2001 assessment in the following terms:

> Human activities ... are modifying the concentration of atmospheric constituents ... that absorb or scatter radiant energy ... [M]ost of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.[39]

The use of the word "likely" is significant as the IPCC defines the term as meaning with a probability of greater than 66 per cent but less than 90 per cent.[40] If courts accept this evidence, this is enough, on a civil standard of proof (which requires a 50 per cent chance or more that an assertion be correct), to establish that global warming over the last 50 years has been due mostly to anthropogenic causes.

The conclusion drawn by the IPCC is supported by the world's major scientific bodies,[41] including the National Academy of Sciences Committee on the Science of Climate Change,[42] the American Association for the Advancement of Science,[43] the American Meteorological Society[44] and American Geophysical Union.[45] Oreskes analysed 928 abstracts published in

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38 N. Oreskes, "The Scientific Consensus on Climate Change", *Science*, vol. 306, 3 December 2004, p. 1686.

39 J.J. McCarthy (et al) (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (Cambridge University Press, Cambridge, 2001), p. 21, available through <http://www.ipcc.ch/pub/online.htm> viewed at 20 May 2006.

40 The IPCC makes the following judgmental estimates of confidence: *virtually certain* (greater than a 99 per cent chance that a result is true); *very likely* (90-99 per cent chance); *likely* (66-90 per cent chance); *medium likelihood* (33-66 per cent chance); *unlikely* (10-33 per cent chance); *very unlikely* (1-10 per cent chance) and *exceptionally unlikely* (less than 1 per cent chance).

41 Oreskes, above n 38.

42 National Academy of Sciences Committee on the Science of Climate Change, *Climate Change Science: An Analysis of Some Key Questions* (National Academy Press, Washington DC, 2001).

43 Oreskes, above n 38. See <http://www.ourplanet.com/aaas/pages/atmos02.html> viewed at 20 May 2006.

44 Oreskes above n 38.

45 Ibid.

refereed scientific journals between 1993 and 2003, listed with the keywords "climate change" in scientific databases and found that "none of the papers disagreed with the consensus position".[46]

For some global warming sceptics,[47] this merely indicates that the consensus view is being enforced as a matter of power politics and that dissenting views are not being heard within what many sceptics see as an "old boys' club" of consensus climate science.

The term "global warming scepticism" refers to the position held by some that the consensus view of climate change is incorrect or otherwise inadequate and is in need of substantial modification. Arguments propounded by global warming sceptics are, for obvious reasons, of key interest and importance to defendants of climate change lawsuits. The manner in which such arguments can be adopted by emitters was clearly demonstrated in *Western Fuels Association, Inc v Turning Point Project et al*[48] (although, in that case, which involved commercial defamation, the polluter was actually the plaintiff). In *Western Fuels Association*, which was heard in the US District Court in Wyoming, Western Fuels brought an action for commercial defamation under s.43(a) of the *Lanham Act* 15 USC § 1125. An injunction was sought to prevent the defendants publishing alleged false and misleading statements regarding the need for "an immediate shift away from the use of all fossil fuel...and the elimination of the production of electricity from coal-fired plants by the year 2050".[49] The plaintiffs argued that this claim caused damage to their commercial interests as well as those of the State of Wyoming which would be "devastated" by such a policy.[50] Western Fuels claimed that each of the defendants made false and misleading factual representations regarding the effects of carbon dioxide emissions for fossil fuel combustion and that they made "apocalyptic predictions that have no reliable scientific support".[51] This put coal in an unfavorable light and renewable energy sources in a favorable light, thereby promoting renewable energy products.

Western Fuels argued that "scientific observations reveal that the impact of carbon dioxide emissions on our environment is both modest and benign".[52] Further, it was argued that there were "demonstrated benefits of increased carbon dioxide levels"[53] and that "[t]he scientific community agrees that global warming will not be a major factor in the spread of infectious diseases and that a warmer climate is healthier than a cooler climate".[54] Such alleged positive outcomes included reduced cold-weather mortality. The

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46 Ibid.

47 A. Wildavsky, *But Is It True? A Citizen's Guide to Environmental Health and Safety Issues* (Harvard University Press, Cambridge, Massachusetts, 1995), pp. 340-374.

48 *Western Fuels Association Inc v Turning Point Project (a non-profit District of Columbia Corporation; Friends of the Earth, Earth Island Institute, Ozone Action Inc, Rainforest Action Network and International Center for Technology Assessment)* (Unreported, US District Court for the District of Wyoming, Civil Action No. 00CV-07-D, 31 March 2001).

49 Ibid p.3.

50 Ibid p.4.

51 Ibid p.6.

52 Ibid p.17.

53 Ibid.

plaintiffs alleged that the rate of malaria has fallen globally, with the number of cases falling sharply from 1983 to 1992.[55] The plaintiffs claimed that malaria was more widespread in the 19th century than the 20th century, despite the fact that average temperatures were cooler in the 19th century.[56]

In relation to computer model predictions of global warming developed by the scientific community, the plaintiffs said:

> The Defendants neglect to mention ... that the alleged villain of global warming, the amount of carbon dioxide in the air, has not moved in tandem with the earth's temperature. It is generally acknowledged in the scientific community that the computer models that depict global warming are flawed and have failed, in part, because we have insufficient knowledge of the major facts that affect the world's climate. Indeed, despite extensive studies, there is no reliable data confirming the accuracy of the computer models on which the Defendants base their claims.[57]

Further, it was alleged that the defendants "willfully ignore[d] data sets from satellites and weather balloons that show no appreciable global warming".[58] The plaintiffs disputed the sea level rise data, claiming that sea level rise slows down during periods of temperature increases due to increased evaporation from warming, resulting in increased ice accumulation in polar regions and, consequently, lower sea levels. In view of this, it was argued that moderate warming "should slow down, not accelerate, the rise of sea levels".[59] The plaintiffs also claimed that there was no evidence of the collapse of the West Antarctic ice sheet, arguing that it takes thousands of years for the ice sheets to respond to surface air temperatures. Consequently, there would need to be changes in the flow of ice streams at the bottom of the sheet, which are insensitive to surface temperature changes.[60]

None of these issues was decided at trial as the matter was dismissed for improper venue and lack of personal jurisdiction. However, the case provides a clear example of how global warming sceptic arguments are likely to be applied by defendants.[61]

The IPCC believes that the average global surface temperature of the earth has increased by about 0.6°C since the late 19th century, with 95 per cent confidence limits of close to 0.4 to 0.8°C. The IPCC identifies two periods of warming: 1910 to 1945 and 1976 to the present. The rate of warming during the 1910 to 1945 period was 0.14°C per decade, but the warming rate since 1976 has been 0.17°C per decade. This latter period has seen a faster rate of warming over land than with the oceans.[62] Cooling occurred in the northern

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55 Ibid.
56 Ibid p.19.
57 Ibid p.20.
58 Ibid p.21.
59 Ibid p.23.
60 Ibid p.24.
61 A non-technical overview of global warming scepticism in a fiction novel is given in M.Crichton, *State of Fear* (HarperCollins Publishers, London, 2004).
62 J. T. Houghton (et al) (eds), *Climate Change 2001: The Scientific Basis*, (Cambridge University

hemisphere during the period of 1946 to 1975, whereas the southern hemisphere warmed. Warming in the northern hemisphere has occurred since 1976. In its Third Assessment Report (2001), the IPCC indicates that it is more confident about the projected magnitude of global warming since the late 19th century than it was at the time of its Second Assessment Report owing to technical refinements in computer model simulations of land-surface temperatures, new studies of urban heat island effects and observed increases in land air temperature.[63] One of the many global warming sceptic arguments is that observed surface temperature increases are an artifact of measurements done in "urban heat islands" (ie. hotter city areas). The IPCC accepts that there is an urban heat island effect, but this is limited only to the relevant urban areas and does not represent larger areas. The IPCC states that

> Extensive tests have shown that the urban heat island effects are no more than about 0.05°C up to 1900 in the global temperature records used ... to depict climate change. Thus we have assumed an uncertainty of zero in global land-surface air temperatures in 1900 due to urbanization, linearly increasing to 0.06°C (two standard deviations 0.12°C) in 2000.[64]

Apart from this, data relating to changes in marine temperature and borehole temperature, along with the recession of the glaciers, which are not related to urbanisation, are consistent with the IPCC estimates of surface warming.[65] Nevertheless, the IPCC cautions that "greater urbanization influences in future cannot be discounted".[66]

The IPCC states that "the magnitude of Northern Hemisphere warming over the 20th century is likely to have been the largest of any century in the last 1,000 years".[67] Estimates of global temperature variability prior to the mid-19th century must be based upon indirect "proxy" climate indicators due to inadequacies of instrumental climate records (and also in the more remote past, due to lack of temperature measuring instruments). These indicators include

> width and density measurements from tree rings ... layer thickness from laminated sediment cores ... isotopes, chemistry, and accumulation from annually resolved ice cores ... isotopes from corals ... and the sparse historical documentary evidence available over the globe during the past few centuries.[68]

Global scale sampling of climate variations back to AD 1400 were made by the IPCC in its second report and it was concluded that summer temperatures

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63 Ibid.

64 Ibid p.106. See also D.E. Parker, "Large-Scale Warming is Not Urban", *Nature*, vol. 432, 18 November 2004, p. 290 where Parker shows that "globally, temperatures overland have risen as much on windy nights as on calm nights, indicating that the observed overall warming is not a consequence of urban development ... The reality and magnitude of global-scale warming is supported by the near-equality of temperature trends on windy nights with trends based on all data".

65 Houghton (et al) (eds.), above n 62.

66 Ibid.

67 Ibid p.102.

68 Ibid p.130.

in the northern hemisphere were the warmest for at least six centuries. Technological developments in proxy climate indicators have enabled the IPCC to conclude that 20th century temperatures are the warmest in the last 1,000 years. Isotope information from ice cores has been particularly relevant here,[69] as have lake and ocean sediment samples and borehole measurements.[70]

Many global warming sceptics[71] respond to the claim by the IPCC that the 20th century is "likely" (meaning with a probability of greater than 66 per cent but less than 90 per cent) to have been the warmest of any century in the last 1,000 years with what they claim to be contradictory evidence of a "Little Ice Age" and a "Medieval Warm Period". The Little Ice Age occurred during the 17th to 19th centuries and the Medieval Warm Period during the 11th to 14th centuries. The IPCC interprets the available scientific evidence to indicate that these temperature effects were regional rather global.[72] Although the 15th to 19th centuries were the coldest in the northern hemisphere in the last 1,000 years, from a global temperature perspective this cooling was, relative to late 20th century figures, a cooling of only less than 1°C. This regional temperature variability is thought to be due to changes in atmospheric circulation patterns, with increased flows of continental air from the north.[73] Temperatures in the Medieval Warm Period, from the 11th to 14th centuries are only 0.2°C warmer than temperatures from the 15th to 19th centuries and these temperatures are still below temperatures of the mid-20th century.[74] As stated earlier, the Medieval Warm Period was a regional phenomenon with there being no evidence of a warming in the tropics or the southern hemisphere.[75] The Medieval warming was restricted to areas in and around the North Atlantic.[76]

Another important body of evidence supporting the theory of human-induced global warming relates to changes in the 20th century of various temperature-related variables. The IPCC states that there has been a substantial retreat of alpine and continental glaciers due to 20th century warming.[77] The principal glaciers that are advancing at present are in maritime regions of New Zealand and Norway. This is due to an increase in precipitation because of atmospheric circulation changes.[78] Lake-ice and river-ice cover in the northern hemisphere has decreased by an average of two weeks over the 20th century.[79] Northern hemisphere snow cover has decreased by approximately 10 per cent since 1966.[80] The extent of Arctic spring and summer sea-ice has reduced by 10 to 15 per cent since the 1950s, although there is scant evidence of a reduction in the extent of Arctic sea-ice during

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69 Ibid p.131.
70 Ibid p.132.
71 See, eg., the argument of W. Kininmonth, *Climate Change: A Natural Hazard* (Multi-Science Publishing Co, Essex, 2004).
72 J. T. Houghton (et al) (eds), above n 62, p.133.
73 Ibid p.135.
74 Ibid.
75 Ibid.
76 Ibid.
77 Ibid p.102.
78 Ibid.
79 Ibid.
80 Ibid.

winter even with temperature increases.[81] Recent submarine data shows a 40 per cent decline in Arctic sea-ice thickness in the summer or early autumn period of 1958 to 1976 and the mid-1990s. This decrease is about 4 cm per year, although other evidence indicates a smaller decrease of approximately 1 cm per year.[82] NASA satellite photographs taken in September of 2005 show a shrinking of the summer Arctic ice cap relative to satellite records from 1979 at the same time of the year. From 1978 to 2000, the sea ice area averaged 7 million square kilometres, but at September of 2005, the Arctic sea ice area had dropped to 5.31 million square kilometres. According to additional shipping data, the September 2005 ice cover is the least amount of Arctic ice in the past century. NASA stated in October 2005 (when it released the photographs) that, at the present melting rate, the summer-time Arctic could be ice-free in less than a century.[83]

The IPCC states that with regard to Antarctic sea-ice extent, there may have been an initial decrease in the mid-1970s but "Antarctic sea-ice extent has stayed almost stable or even increased since 1978".[84] A number of non-scientific global warming sceptic websites cite the likely increase in Antarctic sea-ice extent as a refutation of the IPCC reports without any apparent awareness that the main IPCC scientific report, *Climate Change 2001: The Scientific Basis,* accepts that such an increase is occurring. This is a danger of political and other critics who base their criticisms upon summaries and newspaper reports without reference to primary scientific literature.

More recently, David Vaughan and co-workers of the British Antarctic Survey have published a study using aerial photographs over the past 50 years of all 244 marine glaciers on the western side of the Antarctic Peninsula.[85] Most glaciers are in retreat because of climate change, although the changes are so rapid that atmospheric global warming may not be the sole factor, with changes in the movement of ocean currents perhaps playing a role. Over the past 50 years, 87 per cent of all 244 marine glaciers on the west side of the peninsula have been in retreat, with the retreat speed having increased since the year 2000. There has been an average shrinkage of 600 metres in 212 retreating glaciers. For example, the Widdowson Glacier retreated at a rate of 1.1 kilometres a year and the Sjogren Glacier has retreated over 13 kilometres since 1993. Glacial retreat began about 50 years ago at the warmer northern tip and then moved south. In the past 50 years, the Antarctic Peninsula has been the fastest warming region on earth with an average air temperature increase of approximately 2°C since the 1950s. Aircraft and satellite laser

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81 Ibid.

82 Ibid. Some scientists believe that the Arctic may have crossed a critical threshold of warming, where the Arctic region is beginning to absorb more heat from the sun due to rapidly melting ice, thus setting up a feedback mechanism of continuous melting and heating. See S. Connor, "Global Warming 'Past the Point of No Return'", *The Independent* (on-line), 16 September 2005 at <http://news.independent.co.uk/world/science_technology/article312997.ece> viewed at 20 May 2006.

83 See <http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16689> viewed at 20 May 2006.

84. Houghton (et al) (eds.), above n 62, p.102.

85 A.J. Cook, D.G. Vaughan (et al), "Retreating Glacier Fronts on the Antarctic Peninsula Over the Past Half-Century", *Science*, vol. 308, 22 April 2005, pp. 541-544.

altimeter surveys of the Amundson Sea sector of West Antarctica have shown a discharge rate from local melting glaciers of around 250 cubic kilometres of ice per year into the sea: a discharge rate sufficient to raise sea levels by around 0.2 mm per year. About half of the present rise in the global sea level of approximately 1.8 mm per year is due to the melting of terrestrial ice. A worst-case scenario arising from these changes is a possible collapse of the Western Antarctic ice sheet which lies on a part of the continental shelf that is below sea level. If the entire ice sheet slid into the sea, it has been estimated that the global sea level would rise by about 5 metres even if the ice did not melt.[86] Although the IPCC rejects the notion that a collapse of this ice shelf is occurring, some researchers, such as Chris Rapley, director of the British Antarctic Survey, believe that there is some evidence that such a collapse is beginning to take place, based on the simultaneous melting of three of Antarctica's largest glaciers that collectively drain about a third of the ice sheet.[87] The cause could be natural variation but global warming is a more likely suspect. Rapley believes that the collapse of the western ice sheet within a few hundred years could destabilise the eastern Antarctic ice sheet, which in turn could raise sea levels by a catastrophic 50 metres.[88]

Various newspaper reports have commented on the need of the European ski industry to move higher into Alpine regions because of an earlier ice melt.[89] In 2005, for example, the high altitude ski run at Val Senales in Alto Adige, near Italy's border with Austria, closed for the first time in its 30 year history. High altitude ski runs closed in August 2005 in the Tonale Pass and at Marmolada in Italy's Dolomites. Walter Maggi, a geologist at Milan University, is reported to have hypothesised that this melt was due to low rainfall in the northern spring and high temperatures in June and July 2005, with a deeper cause being global warming.[90] However, as science writer Fred Pearce has recently pointed out, it would be a mistake to assume a mechanical connection between shrinking glaciers and global warming, without considering other factors.[91] Mountain glaciers have been shrinking since the 19th century, so the connection is more complex than a simple inference that rising air temperatures are causing the glaciers to melt. Changes in cloud cover, the timing of snowfalls and changes in humidity, all of which could be related to global climate change, may be factors.[92]

In the summary of the IPCC position above, it is stated that the IPCC found that the 20th century shows the most dramatic temperature rises of the past millennium. Michael Mann, of the University of Virginia, established

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86 "West Antarctic Ice Sheet on the Slide", *New Scientist*, 12 February 2005, p. 9.
87 Ibid.
88 Ibid.
89 I. Traynor, "Higher and Higher: Ski Resorts in Fight to Survive Global Warming", *The Guardian*, 26 March 2005 at <http://www.guardian.co.uk/climatechange/story/0,12374,1445899,00.html> viewed at 20 May 2006.
90 "Off Piste: Glacial Meltdown Has the Ski Slopes on the Run", *The Australian*, 12 August 2005, p. 8.
91 F. Pearce, "The Flaw in the Thaw", *New Scientist*, 27 August 2005, pp.26-30.
92 Ibid p.28.

what is now known as the "hockey stick" graph.[93] This is a graph of the past millennium's temperature that is generally flat until about 1900, then rises like the blade of a hockey stick. Mann's work has become a particular target of climate change sceptics as the sceptics believe that if Mann is refuted, the IPCC position is seriously damaged. However, the IPCC accepts the hockey stick hypothesis as being "likely" but not "certain". Further, even if there was shown to be greater climate variability in the past, this conjecture is consistent with enhanced global warming occurring in the 20th century. What it would mean is that the global climate is even more chaotic and sensitive to fluctuations than was previously thought. It is a logical mistake to infer from that conjecture alone that the global warming hypothesis is refuted solely on that basis.

Mann's analysis is based on palaeoclimatic data sets from ice cores, coral and tree ring data and thermometer readings in the more recent past. Mann and other coworkers extended their analysis back over a period of 2,000 years. The result of the analysis is that global mean temperatures significantly rose in the early 20th century, the rise coinciding with the production of CO_2 and other greenhouse gases from industrial activity.

Major critics of Mann's work include S. McIntyre and R. McKitrick.[94] McIntyre and McKitrick's critique focuses on Mann's principle component analysis (PCA). Principle component analysis is a mathematical technique that can summarise data in a body of "noisy" records, so that the most common patterns of the data are described and physically significant components are characterised. McIntyre and McKitrick argue that Mann's PCA convention used in the analysis of North American tree ring data selects for the hockey stick shape, so that the graph becomes a mere statistical artifact. Mann examined whether tree ring data exhibited significant differences from the 20th century calibration period. In this way, data was normalised so that the mean over the 20th century period was zero, emphasising data with the largest positive or negative differences. The underlying data would be likely to have a hockey stick shape because what was being sought was whether or not there were significant differences in the tree ring data from the 20th century calibration period. It does not follow from this that the raw data examined for such differences must, as a matter of statistical artifact, show a hockey stick shape as it is at least logically possible that the tree ring data would show no significant differences from the 20th century calibration period.[95]

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93 M.E. Mann (et al), "Global-Scale Temperature Patterns and Climate Forcing Over the Past Six Centuries", *Nature*, vol. 392, 1998, pp. 779-787; M.E. Mann and J. Park, "Oscillatory Spatiotemporal Signal Detection in Climate Studies: A Multiple-Taper Spectral Domain Approach", *Advances in Geophysics*, vol. 41, 1999, pp. 1-131; M.E. Mann (et al), "On Past Temperatures and Anomalous Late 20th Century Warmth", *Eos*, vol. 84, 2003, pp. 256-258.

94 S. McIntyre and R. McKitrick, "Corrections to Mann et al 1998 Proxy Data Based on Northern Hemisphere Average Temperature Series", *Energy and Environment*, vol. 14, 2003, pp. 751-771; "Hockey Sticks, Principle Components, and Spurious Significance", *Geophysical Research Letters*, vol.32, L03710, doi:10.1029/2004GL021750, 2005.

95 See also E. Zorita (et al), "Testing the Mann et al (1998) Approach to Palaeoclimate Reconstructions in the Context of a 1000-yr Control Simulation with the ECHO-G Coupled Climate Model", *Journal of Climate*, vol. 16, 2003, pp. 1378-1390; S. Gerber (et al),

One of the core empirical arguments of global warming sceptics has been that there is a discrepancy between warming occurring at the earth's surface and satellite measurements of the lower troposphere (the lower layer of the atmosphere) which show a cooling. Analysis of the satellite data which originally identified this discrepancy was conducted by John Christy of the University of Alabama in Huntsville.[96] This discrepancy generated considerable scientific debate for a number of years.[97] Recently, three papers published in *Science* journal have argued that the discrepancy is only apparent, being due to problems with the data.[98] A research team of Sherwood (et al) examined weather balloon data obtained from studies of global warming. Measuring devices in the balloons, called radiosonde, have thermometers which cannot be effectively shielded from direct sunlight, so a correction factor is added to the analysis by scientists to compensate for temperature bias errors that occur. Sherwood (et al) argued that there was an over-correction in the data which reduced the apparent temperature below the actual temperature. Weather stations across the world tend to release their balloons simultaneously. Accordingly, some measurements are taken in daylight, some at night. Sherwood (et al) found that night-time temperatures in the troposphere had risen but day-time temperatures had dropped, indicating over-correction of the day-time data.

Other scientists, Mears and Wentz, have examined satellite measurements of tropospheric temperatures.[99] Satellite temperature measurements of the troposphere must take into account the temperature effects of the stratosphere (which is the layer of air above the troposphere). It is necessary for the satellite to take measurements at the same time each day over the same spot on the earth's surface. However, over a satellite's lifetime, its orbit decays due to friction with the outer atmosphere. As a result, after a few years, measurements were taken at 5 pm instead of 2 pm which yielded lower temperatures due to a time bias. When this bias was corrected, the data showed that the troposphere was warming, not cooling. Santer (et al) have also argued that the discrepancy between surface temperatures and tropospheric temperatures was due to data errors;[100] they conducted an analysis of various computer models which all predicted that the troposphere should be warming rather than cooling.

"Constraining Temperature Variations Over the Last Millennium by Comparing Simulated and Observed Atmospheric CO2", *Climate Dynamics*, vol. 20, 2003, pp. 281-299.

96 J.R. Christy (et al), "Reducing Noise in the MSU Daily Lower-Tropospheric Global Temperature Dataset", *Journal of Climate*, vol. 8, 1995, pp. 888-896.

97 Q. Fu, "Contribution of Stratospheric Cooling to Satellite-Inferred Tropospheric Temperature Trends", *Nature*, vol. 429, 6 May 2004, pp. 55-58.

98 S. Sherwood (et al), "Radiosonde Daytime Biases and Late 20th Century Warming"; C.A. Mears and F.J. Wentz, "The Effect of Diurnal Correction on Satellite-Derived Lower Tropospheric Temperature"; B.D. Santer (et al), "Amplification of Surface Temperature Trends and Variability in the Tropical Atmosphere", *Science*, published online 12 August 2005; Sherwood (et al), *Science*, DOI: 10.1126/science.1115640; Mears and Wentz, *Science*, DOI: 10.1126/science. 1114772; Santer (et al), *Science*, DOI: 10.1126/science.1114867

99 Mears and Wentz, above n 98.

100 Santer (et al), above n 98.

Christy, who was the first researcher to notice the alleged discrepancy, has accepted that there were flaws in the satellite data. Christy re-analysed his results and concluded that the earth is warming at a rate of about 1.23°C per century, whereas Mears and Wentz believe that the rate is about 1.9°C. The Christy figure is below the IPCC range of 1.5°C to 6°C per century, whereas the Mears and Wentz figure is within the range but at the lower end. Christy has said that "[w]e all agree that warming is related to human effects, but it's not as dramatic as models say." Sherwood is in agreement, stating "I don't think we have resolved the controversy over global warming. But there is no longer any data contradicting the predictions of global warming models".[101]

The International Scientific Steering Committee of the International Conference on Stabilization of Greenhouse Gases – Avoiding Dangerous Climate Change[102] has, on the basis of further scientific data than that which was available at the time of the IPCC Third Assessment Report, concluded that climate change risks are more serious than previously thought. One area of concern is the increasing acidity of the oceans as over one third of all CO_2 entering the atmosphere from human activity ultimately dissolves in the oceans forming carbonic acid. At present CO_2 emission trends and assuming no emission cuts, the pH (acidity) of the ocean will fall by 0.4 units by 2100 and 0.77 units by 2250. Apart from threatening an array of sea organisms, such changes could have an unexpected feedback effect upon climatic systems, including changes to the ocean carbon cycle and nitrification processes which, in turn, would disrupt marine ecosystems.[103] The Steering Committee states:

> A number of critical temperature levels and rates of change relative to pre-industrial times were noted. These vary for the globe, specific regions and sensitive ecosystems. For example, a regional increase above present of 2.7°C (this would be associated with a global temperature rise of about 1.5°C) may be a threshold that triggers melting of the Greenland ice-cap, while an increase in global temperatures of about 1°C is likely to lead to extensive coral bleaching. In general, surveys of the literature suggest increasing damage if the globe warms from about 1 to 3°C above current levels. Serious risk of large scale, irreversible system disruption, such as reversal to the land carbon sink and possible destabilisation of the Antarctic ice sheets is more likely above 3°C. Such levels are well within the range of climate change projections for the century.[104]

In a worst case scenario, of a temperature rise of 3°C above present levels, few existing ecosystems would adapt and there would be a risk of a loss of up to 60 per cent of species by 2100.[105] A large loss of migratory bird habitats will occur and alpine species will approach extinction. At a temperature change of

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101 Z. Meroli, "Sceptics Forced into Climate Climbdown", *New Scientist*, 20 August 2005, p. 10.

102 See *Report of the International Scientific Steering Committee* (10 May 2005), presented at International Symposium on the Stabilization of Greenhouse Gases - Avoiding Dangerous Climate Change, Hadley Centre, Met Office, Exeter, UK, 3 February 2005, <http://www stabilisation2005.com/Steering_Commitee_Report.pdf> viewed at 1 May 2006.

103 "Oceans Become More Acid", *New Scientist*, 12 February 2005, p. 11.

2.5 to 4°C, crop failures would rise from 50 to 75 per cent.[106] A disintegration of the West Antarctic ice sheet, raising sea levels by 4 to 6 metres, would also be likely to occur.[107] Even with a stabilisation of greenhouse gas levels in the year 2000, global mean temperatures will continue to rise another half degree. Oceanic thermal inertia will cause an additional 320 per cent sea level rise by the end of the 21st century.[108] Jason Lowe, of the Hadley Centre for Climate Prediction and Research in the United Kingdom, and co-researchers believe that an annual average warming of 2.7°C may be sufficient for the deglaciation of Greenland, which may be irreversible.[109]

A scientific team of Cox (et al) has analysed results of a computerised climatic model which involves carbon-cycle feedbacks.[110] The model shows that, under a business-as-usual scenario without CO_2 reductions, the terrestrial biosphere would act as a carbon sink until around 2050 before becoming a source releasing CO_2. There is palaeoclimatic evidence supporting this hypothesis.[111]

Another area where recent scientific work has led to a more sceptical conclusion than that of the IPCC Third Assessment Report is the probability of

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106 Ibid, Table 2a: Impacts on human systems due to temperature rise, precipitation change and increases in extreme events. See generally P.M. Cox (et al), "Amazonian Forest Dieback Under Climate-Carbon Cycle Projections for the 21st Century", *Theoretical and Applied Climatology*, vol. 78, 2004, pp. 137-156; J. Halloy and A.F. Mark, "Climate Change Effects on Alpine Plant Biodiversity: A New Zealand Perspective on Quantifying the Threat", *Arctic, Antarctic and Alpine Research*, vol. 35, 2003, pp. 248-254; L. Hannah (et al), "Conservation of Biodiversity in a Changing Climate", *Conservation Biology*, vol. 16, 2002, pp. 264-268; R. Leemans and B. Eickhout, "Another Reason for Concern: Regional and Local Impacts on Ecosystems for Different Levels of Climate Change", *Global Environmental Change*, vol. 14, 2004, pp. 219-228; M. Parry (et al), "Millions at Risk: Defining Critical Climate Change Threats and Targets", *Global Environmental Change*, vol. 11, 2001, pp. 181-183. Unexpected ecosystem collapse is also possible; "catastrophic" transitions may "occur typically quite unannounced, and 'early warning signals' of approaching catastrophic change are difficult to obtain", M. Scheffer (et al), "Catastrophic Shifts in Ecosystems", *Nature*, vol. 413, 11 October 2001, pp.591-596, at p.591.

107 B.C. O'Neill and M. Oppenheimer, "Dangerous Climate Impacts and the Kyoto Protocol", *Science*, vol. 296, 14 June 2002, pp. 1971-1972.

108 G.A. Meehl (et al), "How Much More Global Warming and Sea Level Rise?", *Science*, vol. 307, 18 March 2005, pp. 1769-1772; T.M.L. Wigley, "The Climate Change Commitment", *Science*, vol. 307, 18 March 2005, pp. 1766-1769; M. Parry, "Avoiding Dangerous Climate Change: Overview of Impacts", Avoiding Dangerous Climate Change Conference, Met Office, Exeter, UK, 1-3 February 2005, available through <http://www.stabilisation2005.com> viewed at 20 May 2006.

109 J. Lowe (et al), "The Role of Sea-Level Rise and the Greenhouse Ice Sheet in Dangerous Climate Change and Issues of Climate Stabilization", Avoiding Dangerous Climate Change Conference, Met Office, Exeter, UK, 1-3 February 2005, available through <http://www.stabilisation2005.com> viewed at 20 May 2006.

110 P.M. Cox (et al), "Acceleration of Global Warming Due to Carbon-Cycle Feedbacks in a Coupled Climate Model", *Nature*, vol. 408, 9 November 2000, pp. 184-187.

111 G.R. Dickens, "Hydrocarbon-Driven Warming", *Nature*, vol. 429, 3 June 2004, pp. 513-515; H. Svensen (et al), "Release of Methane From a Volcanic Basin as a Mechanism for Initial Eocene Global Warming", *Nature*, vol. 429, 3 June 2004, pp. 542-545; W.M. Loya and P. Grogan, "Carbon Conundrum on the Tundra", *Nature*, vol. 431, 23 September 2004, pp. 406-408.

the shutdown of the thermohaline circulation (THC).[112] The THC is a global circulation system in the world's oceans consisting of warm surface currents and cold saline deep currents connected in high latitudes of the Atlantic and Antarctica where ocean-to-atmosphere heat transfers occur. Poleward flowing currents in the North Atlantic warm Northwestern Europe by about 10°C relative to North American temperatures at the same latitude. The North Atlantic part of the circulation system is highly vulnerable to changes in atmospheric temperature and the hydrological cycle. The shutdown of the THC is a high impact and low probability event, although how low is not clear. Stephen Schneider predicts a shutdown of THC at 700 parts per million CO_2 and a 3°C rise over the present global average temperature within 100 years.[113] The scientific team of Challenor (et al) put the probability of THC collapse at 0.30, which is 10 times greater than the previous IPCC consensus.[114] The scientific team of Schlesinger (et al)[115] predict, based on their own mathematical model, that, on a business-as-usual emissions scenario, the probability of THC collapse in the next 200 years is greater than 2 chances in 3 and that there is a 1 in 4 chance of THC collapse under "even the most rigorous immediate climate policy".

These "catastrophic" scenarios[116] have featured in a Pentagon paper by Peter Schwartz, a CIA consultant, and Doug Randall, a business consultant.[117] They argue that 8,200 years ago climate change brought widespread crop failure, famine, disease and mass migration of populations.[118] Developing the most extreme high impact and low probability scenarios, they project that, without adequate preparation over the next 20 years, climate change could result in major conflicts as populations fight over dwindling food and water resources. Whilst such a report is perhaps more relevant to a political, rather

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112 R.K. Pachauri, "Avoiding Dangerous Climate Change – 2nd Keynote Address", Avoiding Dangerous Climate Change Conference, Met Office, Exeter, UK, 1-3 February 2005, at <http://www.stabilisation2005.com> viewed at 20 May 2006.

113 S.H. Schneider, "Overview of 'Dangerous' Climate Change", Avoiding Dangerous Climate Change Conference, Met Office, Exeter, UK, 1-3 February 2005, available through <http://www.stabilisation2005.com> viewed at 20 May 2006.

114 P. Challenor (et al), "The Probability of Rapid Climate Change", Avoiding Dangerous Climate Change Conference, Met Office, Exeter, UK, 1-3 February 2005, available through <http://www.stabilisation2005.com> viewed at 20 May 2006.

115 M. Schlesinger (et al), "Reducing the Risk of a Collapse of the Atlantic Thermohaline Circulation", Avoiding Dangerous Climate Change Conference, Met Office, Exeter, UK, 1-3 February 2005, available through <http://www.stabilisation2005.com> viewed at 20 May 2006.

116 See generally R.A. Posner, *Catastrophe: Risk and Response* (Oxford University Press, Oxford, 2004).

117 P. Schwartz and D. Randall, "An Abrupt Climate Change Scenario and Its Implications for United States National Security", The Pentagon, October 2003.

118 Some researchers have placed the cause of the "great dying" – a mass extinction which occurred around 250 million years ago, which wiped out 90 per cent of sea life and three quarters of land-based life – to be global warming. The standard theory is that a large asteroid or meteor hit the earth, a theory which these researchers dispute. See: K. Ravilious, "Extreme Volcanism Doomed the Dinosaurs", *New Scientist*, 20 August 2005, p. 11; D. Dawson (et al), "Effect of Maturation on the Indigenous δD Signatures of Individual Hydrocarbons in Sediments and Crude Oils from the Perth Basin (Western Australia)", *Organic Geochemistry*, vol. 36, no. 1, January 2005, pp. 95-104.

than a legal, debate about global warming issues, it paints a picture of the broader types of social harms to which climate change could lead.

2. Climate Modelling

Climate models are used by scientists to make projections of future climate and will form a key part of scientific evidence presented by plaintiffs. This section considers key climate modelling techniques, their application in the context of predicting climate change as a result of global warming and some of the key criticisms aimed at these techniques by global warming sceptics.

a. Atmospheric modelling techniques

Modelling of the atmosphere is generally done using "numerical models" (equations consisting of constants, coefficients, terms or elements represented by numbers) based on fundamental physical equations (typically differential equations) that describe the physics of the atmosphere by a mathematical representation of movements and processes. The physical processes are described by mathematical algorithms and parameters which parameterise (or, in other words, mathematically represent) these processes.[119] The equations in these systems are partial differential equations which are "non-linear". An equation is said to be linear if all non-constant terms are of degree 1. For example, the equation $y=x$ is a linear equation but $y=x^x$ is non-linear, for y and x being variables ranging over real numbers. A problem with non-linear partial differential equations is that they lack an analytic closed form solution (in other words, an "exact" solution) and they must be mathematically solved using discrete approximation methods, such as the finite difference method which involves discrete approximations to continuous partial derivatives. In non-technical terms, this means that there is, in principle, no *exact* mathematical solution to the basic equations used in atmospheric modelling techniques. The equations can only be approximated by various mathematical methods using computers. Consequently, some degree of unpredictability and uncertainty cannot be eliminated. Further, small changes in climatic variables may have unpredictably large long term effects. As such, there is an intrinsic degree of unpredictability which, in turn, introduces a level of uncertainty into the basic climate equations. The IPCC recognises that, in the non-linear aspect of climate systems

> there is no simple proportional relation between cause and effect. A complex, non-linear system may display what is technically called chaotic behaviour. This means that the behaviour of the system is critically dependent on very small changes of the initial conditions.[120]

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119 See W.M. Washington and C.L. Parkinson, *An Introduction to Three-Dimensional Climate Modeling* (Oxford University Press, Oxford and New York, 1986); J. Houghton, *Global Warming: The Complete Briefing* (Cambridge University Press, Cambridge, 2004) at p.80; K.E. Trenberth (ed), *Climate System Modeling* (Cambridge University Press, Cambridge, 1992).

120 J.T. Houghton (et al), *Climate Change 2001: The Scientific Basis* (Cambridge University Press, Cambridge, 2001) at <http://www.ipcc.ch/pub/online/htm>, at p. 91 viewed at 20 May 2006.

General Circulation Models (GCMs) are the most general types of computer climate models. There are two types of GCMs: Atmospheric General Circulation Models (AGCM) and Oceanic General Circulation Models (OGCM). As the names indicate, AGCMs analyse atmospheric effects and OGCMs analyse oceanic effects. For example, an OGCM will analyse the effects ocean currents have upon the temperature of the atmosphere. Technical mathematical differences exist between the models; however, both represent dynamic processes on a three dimensional grid of points. The horizontal resolution of AGCMs are usually 250 kilometres and, in the vertical resolution, there are 10-30 levels of the atmosphere. OGCM models usually have a horizontal resolution of 125-250 kilometres, with a resolution in the vertical of 200 to 400 metres. Steps of 30 minutes are taken to determine time-dependent behaviour.[121] More complex models can be produced by "coupling" models which incorporate the carbon cycle and aerosol processes to produce Atmosphere-Ocean General Circulation Models (AOGCMs). Realistic GCMs need to couple the atmosphere and the oceans because the energy balance of the climate system is determined by this coupling. The oceans, for example, store and exchange large quantities of carbon dioxide and heat and influence the hydrological cycle.[122] Consideration of the role of aerosols (liquid or solid particles suspended in the air) is also important because of their "radiative forcing" properties, scattering and absorbing atmospheric solar and infrared radiation. Some researchers believe that these particles have a "global dimming" effect; that is, a cooling effect from particles in the atmosphere which has masked the earth's vulnerability to greenhouse gases. However, the IPCC has noted that aerosols "have short atmospheric lifetimes and therefore cannot be considered simply as a long-term offset to the warming influence of greenhouse gases".[123] Aerosols have a number of interactions with clouds by altering "warm, ice and mixed-phase cloud formation processes by increasing droplet number concentrations and ice particle concentrations".[124] A major research project currently under way is to parameterise GCMs with respect to clouds and aerosol interactions.[125] An understanding of clouds, especially on a regional scale, is a major challenge which is being addressed by further scientific research and advances in computer modelling.[126]

The IPCC says that "the very complexity of climate models means that there are severe limits placed on our ability to analyse and understand the model processes, interactions and uncertainties".[127] As such, "it is always possible to find errors in simulations of particular variables or processes in a climate model".[128] Models are, after all, idealisations of reality. This does not

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121 Houghton (et al) above n 120, p.94.
122 Ibid.
123 Ibid p.291.
124 Ibid.
125 Ibid p.292; J.E. Penner, "The Cloud Conundrum", *Nature*, vol. 432, 23/30 December 2004, pp. 962-963.
126 Houghton (et al), above n 120, p.474.
127 Ibid.

mean, however, that models are "unusable" in investigating climate phenomena as this would mean that a scientific understanding of climate (ie. a mathematical representation via a model) is not possible at all which clearly is not the case (for example, models used for weekly weather predictions are generally accurate). Models can be refined over time to reflect an increasing degree of realism about underlying physical and dynamic processes. Multiple models are often used – and mutually tested against empirical data – in an attempt to reduce scientific uncertainty.[129] Whilst there are various aspects of scientific uncertainty associated with climate models, the degree of uncertainty is manageable and is likely to reduce as scientific research progresses. Certainly, the level of uncertainty should not prevent the models from being presented as evidence in court.

b. Methodological criticisms of sceptics

Global warming sceptics have made a number of methodological criticisms of climate modelling techniques, often in an attempt to discredit their value as evidence in court. A core argument of sceptics is that "uncertainty" associated with climate change computer models renders predictions of global warming spurious. This argument is widely used by global warming sceptic internet writers.[130] The Third Assessment Report of the IPCC acknowledges and addresses the issue of uncertainty in a number of places. The following concise statement on the issue is made by Working Group III:

> There are many uncertainties regarding the magnitude of future climate change, its consequences and the costs, benefits and implementation barriers of possible solutions. Future emissions to the atmosphere are inherently uncertain and can only be explored on the basis of scenarios. The change in concentration of GHGs [greenhouse gases] that would result from a given emission rate is much less certain. But the timings, extent and distribution of climate change and sea level rise for a given concentration of GHGs is not known due to limitations in modeling climate change at the regional level. The impacts of climate change on ecosystems and humanity is known with limited certainty. The potential for an unspecified, low-probability, but catastrophic turn of events haunts the problem.[131]

A degree of uncertainty is inherent in advanced work in the physical sciences and cannot realistically be eliminated. Climatology is not a precise science, like many others. It is in the nature of empirical science that models and theories stand open to criticism and revision, but this does not provide grounds

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129 T.F. Stocker, "Models Change Their Tune", *Nature*, vol. 430, 12 August 2004, pp. 737-738; D. A. Stainforth, "Uncertainty in Predictions of the Climate Response to Rising Levels of Greenhouse Gases", *Nature*, vol. 433, 27 January 2005, pp. 403-406

130 See, eg., B. Peiser, "A Space for Climate Change Sceptics: A Response to David King", 10 May 2005 at <http://www.opendemocracy.net/xml/xhtml/articles/2490.html> viewed at 20 May 2006.

131 Report of Working Group III of the Intergovernmental Panel on Climate Change, *Summary for Policymakers: Climate Change 2001: Mitigation* (Cambridge University Press, Cambridge, 2001) at <http://www.ipcc.ch/pub/online.htm>, at p. 608 viewed at 20 May 2006.

for rejecting them entirely. Global warming sceptics often require inappropriately high standards for the acceptance of climatic models and theories.

i. Theoretical inadequacy of computer models

One of the most important methodological criticisms made by climate change sceptics centres around the alleged methodological inadequacy of computer models.

William Kininmonth is perhaps Australia's highest profile global warming sceptic and has published a book, entitled *Climate Change: A Natural Hazard*,[132] expressing his scepticism. Kininmonth is a meteorologist and was a member of Australia's delegation to the Second World Climate Conference 1990 and the intergovernmental negotiations for the Framework Convention on Climate Change (1991-1992). Kininmonth's core claim is that the IPCC model of the climate system is inadequate for future climate control planning and maintains that global warming is a function of the climate system, rather than human activities, and that climate change is a real but natural hazard for humans. Kininmonth believes that computer models are at a "rudimentary stage of development", with major deficiencies in the representation of physical processes, energy processes and transport. Kininmonth argues that the IPCC models have errors regarding poleward net energy transport and net longwave radiation and makes the empirical claim that atmospheric CO_2 increase is in advance of carbon usage by humans.

Kininmonth's most important theoretical criticism of the IPCC models is that they are based on "flat earth physics" and that the "radiation forcing" hypothesis used by the models cannot be sustained, except in the most qualitative terms. Kininmonth describes the IPCC radiative forcing model in the following manner:

> [The] climate system is made up of space, an atmospheric layer (the troposphere) and the earth's surface. Incoming solar radiation at the top of the atmosphere is balanced by the sum of the outgoing longwave radiation emitted by the earth's surface, cloud tops and greenhouse gases in the atmosphere, and of solar radiation reflected from the earth's surface, clouds and atmospheric aerosols.[133]

Increased atmospheric CO_2 reduces longwave radiation emission to space causing positive forcing or warming. Kininmonth criticises the radiation forcing hypothesis by saying that, subject to a few technical exceptions, a true radiation balance at the top of the atmosphere, as predicted by the IPCC radiative forcing model, does not exist. Kininmonth says:

> Most of the incoming solar radiation is intercepted in the tropics where, in magnitude, it far exceeds emissions of longwave radiation to space. Over polar

132 W. Kininmonth, *Climate Change: A Natural Hazard* (Multi-Science Publishing Co, Essex, 2004).

> regions the emission of longwave radiation to space exceeds the intercepted solar radiation, especially during the darkness of winter. As a consequence, nowhere is the earth's surface temperature a function of local radiation characteristics alone.[134]

Kininmonth concludes:

> The complexity of the climate system and its interacting energy processes underscore the inadequacy of the IPCC's simple theoretical framework of radiative forcing. The atmosphere and oceans are fluids in motion that interact and whose variability has time constraints extending out to a thousand years and more. As a consequence, the IPCC assertions that the climate system has limited internal variability and that increased concentrations of greenhouse gases in the atmosphere will lead to dangerous climate change are simplistic and erroneous.[135]

However, the IPCC is clear that the radiative forcing, one-dimensional model of the heat budget of the atmosphere and ocean is an idealisation and pedagogical tool and has stated that

> radiative forcing of climate change is a modeling concept that constitutes a simple but important means of estimating the relative impacts due to different natural and anthropogenic radiative causes upon the surface-tropospheric system.[136]

This one-dimensional model is only one of many models used by the IPCC. Three-dimensional AOGCMs build in the horizontal processes that Kininmonth describes. The IPCC claims that three-dimensional AOGCM experiments

> show that the radiative forcing continues to serve as a good estimator for the global mean surface temperature response but not to a quantitatively rigorous extent as in the case of the one-dimensional radiative-convective models.[137]

Kininmonth's principal critique of the human-enhanced global warming hypothesis is that climate change is a natural phenomenon that has taken place since long before humans evolved and will continue to occur in the future. Kininmonth minimises the role of humans in causing climate change by highlighting the very substantial changes in climate and sea levels over long geohistorical periods. On Kininmonth's philosophical anthropology, human beings are only minor players on the surface of the earth.

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134 Ibid p.7.

135 Ibid p.54. Professor Bob Carter, marine geophysicist at James Cook University, Queensland, also disputes the idea that human activity is the cause of recent historical rises in global temperatures, maintaining that atmospheric carbon dioxide is a primary forcing agent for such temperature changes: B. O'Keefe, "Ice Cores Show Warming 'Natural'", *The Weekend Australian*, 7-8 January 2006, p.4.

136 Houghton (et al), above n 120, p.353.

137 Ibid p.354.

Climate scientist, William Ruddiman, expresses an alternative position to that of Kininmonth.[138] Ruddiman argues that an "incipient ice age" should have begun several thousand years ago in parts of northeastern Canada. However, about 8,000 years ago CO_2 levels began to rise, even though natural trends would indicate that they should have dropped. Methane levels began to rise about 3,000 years ago. Ruddiman hypothesises that natural cooling trends were reversed when humans discovered agriculture. Ruddiman rejects the idea that these increases in gases were due to natural factors, such as the loss of carbon-rich vegetation, because during four previous interglacial periods gas concentrations had fallen, not risen.[139] A new phenomenon must therefore be hypothesised to account for this change and the rise of human agriculture coincides with the period of gas increase. Agricultural activities generate CO_2 and methane, particularly the cultivation of rice paddies which are good methane producers. Deforestation, which began in Europe and China about 8,000 years ago, is a source of CO_2 production. Ruddiman, in conjunction with Stephen Vavrus and John Kutzbach of the University of Wisconsin-Madison, has used a computer model to predict the present day temperature without any human-produced greenhouse gases and found that the global average temperature would be 2°C cooler than at present. In a sense, human-produced greenhouse gases may have benefited humankind in the past. Nevertheless, as Ruddiman notes:

> [I]f so few humans with relatively primitive technologies were able to alter the course of climate so significantly, then we have reason to be concerned about the current rise of greenhouse gases to unparalleled concentrations at unprecedented rates.[140]

ii. Complexity of climate precludes reliable modelling

Christopher Essex and Ross McKitrick are well known critics of the consensus view of climate change and McKitrick, as we have seen, has challenged Mann's hockey stick curve. Their major work that is critical of the consensus view of climate change is *Taken by Storm: The Troubled Science, Policy and Politics of Global Warming*.[141] Essex and McKitrick argue that the consensus view on global warming, as epitomised by the IPCC, is wrong:

> It appears ... that a lot of well-meaning people get locked unwittingly into a game that requires them to speak as if they are absolutely certain about matters upon which certainty is inherently impossible. Many prominent players have staked their reputations on positions that cannot be supported by science or sound policy analysis. Consequently, a debate in a free and open marketplace

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138 W.F. Ruddiman, "The Anthropogenic Greenhouse Era Began Thousands of Years Ago", *Climate Change*, vol. 61, no. 3, 2003, pp. 261-293, "How Did Humans First Alter Global Climate?", *Scientific American*, vol. 292, March 2005, pp. 35-41, *Plows, Plagues and Petroleum: Howe Humans Took Control of Climate* (Princeton University Press, Princeton, in press).

139 Ruddiman, "How Did Humans First Alter Global Climate?", above n 138, p.38.

140 Ibid p.41.

141 C. Essex and R. McKitrick, *Taken by Storm: The Troubled Science, Policy and Politics of Global Warming* (Key Porter Books, Toronto, 2002).

> of ideas can't happen. Instead, what we can get looks more like a fortress, heavily defended by an arsenal of authoritarian pronouncements designed to intimidate outsiders into staying away.[142]

Essex and McKitrick raise many empirical challenges to the consensus view, such as urban heat island biases and allegedly conflicting satellite and balloon data. Their major challenge, however, is to the science and mathematics of modelling. Essex and McKitrick's principal argument is that the complexity of climatic phenomena precludes reliable predictions. For example, thunderstorms involve turbulence and a mathematical understanding of turbulence is, they argue, an intractable problem. Thunderstorms are not dealt with in climate models as they are sub-grid scale phenomena (ie. phenomena that are on such a localised meteorological scale that they are not within the dimensions used for analysis in computer models). They claim that ignoring these sub-grid scale phenomena would produce absurd results as the importance of these phenomena, viewed together as a group, is substantial. Use is made of parameterisation to produce empirical rules describing such phenomena. As these empirical rules are based upon meteorological observations, Essex and McKitrick argue that

> use of such parameterizations means the resulting computer calculation procedures are *models* and not computations of basic *theory*. Climate models do not represent a theory for climate. There is no comprehensive scientific theory for climate...Therefore, forecasting climate change with a model, in lieu of a theory, is a dicey proposition.[143]

There is, however, a strong counter-argument: it does not follow that, because there are outstanding mathematical difficulties in understanding turbulence and other such phenomena, there is no "comprehensive scientific theory for climate". Outstanding mathematical difficulties are present in most foundational fields of science, such as in relation to reconciling quantum mechanics and relativity.[144] Turbulence is of concern in areas other than just climate science – for example, it is a general problem in engineering.[145] Taken to its logical conclusion, Essex and McKitrick's argument could invalidate many other areas of science. They anticipate this objection, arguing that engineering parameterisations

> are tested experimentally for each regime to which the model is applied...But climate forecasting is no engineering problem. We can't test climate models over all the conditions they are meant to apply to. We have only the current climate on which to test parameterizations.[146]

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142 Ibid p.10.

143 Ibid p.16.

144 See N. Maxwell, "Discussion: On Relativity Theory and Openness of the Future", *Philosophy of Science*, vol. 60, 1993, pp. 341-348.

145 See P.A. Libby, *Introduction to Turbulence* (Taylor and Francis, Washington DC, 1996); J. Banks (et al), *Chaos: A Mathematical Introduction* (Cambridge University Press, New York, 2003).

146 Essex and McKitrick, above n 141, p.16.

It is arguable, however, that it is the current climate, rather than hypothetical climates, that is of core concern to climate scientists and, as such, a testing of parameterisations with respect to present observations is satisfactory. Many other models in physics and science, such as evolutionary biology and cosmology, face similar limitations, yet this does not mechanically invalidate them.

Arguably, Essex and McKitrick operate within an overly narrow conception of scientific theories where "in the physical sciences, it is only theory that is relentlessly tested by controlled experiments. In contrast, models are constructed to fit only some observations and metaphors need have little to do with experiments."[147] It could be argued that such a narrow conception of scientific theories would, for example, require scientists to view evolutionary theory and various aspects of cosmology as models or mere metaphors. This would appear to be an unreasonably "high" redefinition of "scientific theory" because it is well established that scientists accept that these disciplines constitute, or incorporate, scientific theories.

iii. Concept of global temperature

Essex and McKitrick argue that metaphors, such as "global warming" and "global temperature", have served as replacements for both theory and models and have confused the discussion about climate change. In relation to "global temperature", they argue against the cogency of such a concept. Generally, their argument is that there is no such thing as a global temperature because the world is not in thermodynamic equilibrium; rather there is a global temperature statistic. "Average temperature" is as meaningless as the "average" phone number because:

> Numerically, you can add up a bunch of temperatures and take some average, but it has no physical interpretation. Temperature only means something locally, because the thermodynamic conditions vary from point to point.[148]

The authors illustrate this proposition through a dialogue involving "Professor Thermos" – an imaginary scientist and teacher – and his students. Thermos refutes student objections to his scepticism about the concept of a global temperature by engaging them in an exercise in which they are asked to determine the average temperature of their classroom. Thermos puts a thermometer in ice water stored in the room, then under his tongue and then in various other places. The students object that these places are not representative of the room temperature. Thermos replies that, if such places are excluded, there is no end because there "is no place in this room that is not affected by heat or cold to a lesser degree".[149] As the room is not in thermodynamic equilibrium, there exists an infinity of "room temperatures" or

147 Ibid p.62.
148 Ibid p.103.
149 Ibid p.105.

a temperature field. Temperature is a "condition of a physical system in terms of how energy is distributed over physical states".[150] Temperature as such cannot be reduced to a single number by way of an average. To be scientifically meaningful, the average, as in the average height of a population, has to have a real physical connection to the matter under scientific investigation. "Total temperature", however, does not have a physical meaning, Essex and McKitrick argue.

However, "local areas" are, when looked at from a molecular perspective, quite large and themselves embrace a range of thermodynamic conditions. Essex and McKitrick's analysis would arguably lead to the conclusion that the concept of temperature only has a very limited application in relation to very small regions of space with a few air molecules. The concept of an average temperature is, as Essex and McKitrick note, a statistical artifact but it is still physically meaningful. If, for example, the global average temperature rises by 5°C, this tells us that, generally, local temperatures around the world are, on the whole, rising. From this perspective, it would be difficult to argue against the proposition that the average global temperature statistic is not physically meaningful.

Professor Thermos says that in the context of global warming, public concern is not about a rise in average temperature; rather, concern is about physical changes, such as sea level rises and the frequency and severity of storms. Thermos says that these climate phenomena "have little to do with temperature, and certainly less to do with some official global temperature statistic".[151] Even if the official global temperature statistic is "nailed down and completely fixed, all these worrisome things could still happen!".[152] However, it is because of the occurrence of "worrisome" climatic phenomena that climate scientists have come to be concerned about global warming and have attempted to measure its extent within existing scientific limits. It would be a bold argument to claim that climatic change does not bear a relationship to the official global temperature statistic.

In conclusion, some of the primary methodological criticisms of leading sceptics of global warming, many of which are likely to be used by defendants in climate change suits, are open to rebuttal. Generally, it is arguable that, like sceptics on philosophical matters, sceptics regarding methodological issues operate with an unreasonably high epistemic standard which, if applied to other areas of science, would render them impossible.

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150 Ibid p.106.
151 Ibid p.111.
152 Ibid.

3. Linking Global Warming to Specific Regional Climate Change

Plaintiffs who suffer harm from global warming will be concerned about specific harms to themselves which will usually be a product of specific regional climatic changes. If courts reject general global warming scepticism and accept the scientific consensus position that most global warming over the past decades has been due to anthropogenic causes (and it is not unreasonable to assume that this will occur in view of the overwhelming body of evidence supporting this proposition), a more limited sceptical argument, possibly of greater relevance to global warming lawsuits, could still be advocated. A defendant may argue that *specific* regional climatic changes cannot be linked with more *general* global climatic change, as regional climatic changes may be a matter of natural climate variation. In a civil action, a plaintiff will need to prove that, on the balance of probabilities (ie. to a standard of probability greater than 50 per cent), the *specific* climatic event was due to anthropogenic global warming.

The issue of linking specific regional climate changes with global warming was addressed in detail by Dr David Legates, a climate expert, in a declaration he made in a brief for the US Government in *Friends of the Earth Inc et al v Peter Watson et al*.[153] Legates stated that he believes that the climate has been warming since the mid-1800s before significant industrial contributions to greenhouse gases were made.[154] Further, Legates stated that

> model spatial resolutions are far below that required to describe many atmospheric and land-surface processes...and other important processes (including, for example, the representation of surface topography) such that even model simulations of present-day conditions do not represent well the current climate and have not been able to adequately reproduce the climate of the past thirty years.[155]

Legates concluded that *specific* climatic phenomena, such as changes in the frequencies of droughts and floods, cannot be directly related to rising concentrations of greenhouse gases. Legates accepted that, since 1900, global average air temperature has risen by between approximately 0.6°C, with a margin of error of 0.2°C, and that this is partly due to human activities. However, Legates concluded that "significant questions remain" regarding the extent to which anthropogenic causes have contributed to this rise. The first of three reasons provided by Legates for this uncertainty was the fact that "global air temperatures have been rising since the mid-1800s, long before significant

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153 US District Court, Northern District of California, San Francisco Division Civ No. 02-4106 (JSW), 29 April 2005. See also E. Kintisch, "Global Warming Skeptic Argues US Position in Suit", *Science*, vol. 308, 22 April 2005, p. 482.

154 Declaration of Dr. David R. Legates in Support of Defendants' Reply to Plaintiffs' Opposition to Defendants' Motion for Summary Judgment at p. 4, <http://www.climatelawsuit.org/documents/legates_declaration.pdf> viewed at 1 May 2006.

155 Ibid.

increases in anthropogenic greenhouse gas concentrations have been documented"[156] (however, regardless of the hypothetical causal mechanism, one way in which such a claim can be challenged has already been addressed in relation to the work of William Ruddiman – namely, that the adoption of greenhouse gas emitting agriculture by humans coincides with the period of gas and temperature increases). Legates also raised the issue of urban heat islands which has also been addressed earlier in this chapter. Legates concluded that:

> due to the complexities of the climate system, it is impossible to connect emissions of greenhouse gases from any specific source or group of sources to an increased risk of any particular outcome. Linkages between an anthropogenic increase in greenhouse gas concentrations and climate outcomes are difficult to make (e.g. it is difficult to argue for changes in storminess or flood/drought frequencies since it is affected by many factors other than global air temperatures); attributing a climate-based cause to non-climate outcomes (such as polar bear extinctions or the demise of the maple syrup industry) is even more tenuous. The underlying theme of our understanding of climate science is that the system is both wildly complex and inherently stable – throughout the millennia, life has survived and thrived, despite widely changing solar, air temperature, and atmospheric gas concentrations.[157]

The final words of Legate's declaration are:

> In general, our climate has and will continue to exhibit intricate patterns not reliably reproduced by global climate simulations, thus underscoring their scientific incompleteness. Thus, a reliance on climate model projections of the future that is inherently flawed is unwise.[158]

The IPCC, in discussing regional climate information,[159] accepts that a high degree of uncertainty characterises information regarding specific climatic events due to the complexity of processes controlling regional climate change and "the difficulty in extracting fine-scale regional information from course resolution coupled with Atmospheric-Ocean General Circulation Models (AOGCMs)".[160] Present day AOGCMs have a horizontal resolution (ie. the horizontal land distance covered) of around 300 to 500 kilometres but regional climates are typically affected by events occurring at the sub-AOGCM horizontal grid scale. This appears to be the general thrust of the Legates critique of the IPCC: that computer models of the climate are too crude to capture fine-scale climate information.

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156 Ibid, p.5.
157 Ibid pp.10-11.
158 Ibid p.33.
159 J.T. Houghton (et al), *Climate Change 2001: The Scientific Basis* (Cambridge University Press, Cambridge, 2001) at <http://www.ipcc.ch/pub/online/htm> viewed at 20 May 2006, Chapter 10 by F. Giorgi (et al).
160 Ibid p.587.

However, the IPCC observes that coupled AOGCMs can be supplemented by regionalisation techniques which include what it refers to as:

(1) high resolution and variable resolution Atmosphere GCM experiments;
(2) nested limited area (or regional) climate models (RCMs); and
(3) empirical/statistical and statistical/dynamical methods.[161]

High resolution and variable resolution experiments are simulations for a shorter time period than the usual period of centuries used to analyse the global climate. This may involve a period of only a few decades so that simulations within the order of 100 kilometres globally, or with variable resolution models of 50 kilometres, may be conducted.

Nested regional climate modelling techniques use data derived from GCMs – including greenhouse gas emission rates, aerosol forcing along with initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions[162] – to produce RCMs. RCMs aim to encompass sub-GCM grid scale forcing (ie. relatively small-scale phenomena that have a climatic impact), such as complex topographical features of surfaces, to give a more precise simulation of atmospheric conditions.

Finally, as the regional climate is conditioned by both the global climate and local physiography, such as topography, use can also be made of empirical/statistical and statistical/dynamic downscaling. The IPCC indicates that this involves

> first determining a statistical model which relates large-scale climate variables (or "predictors") to regional and local variables (or "predictands"). Then the predictors from an AOGCM simulation are fed into this statistical model to estimate the corresponding local and regional climate characteristics.[163]

Statistical models include various regression models, neural networks and various other statistical-dynamic techniques.[164] Local climatic information can be fed into these statistical tools to establish statistical relationships for present day climate.

These regionalisation techniques all have technical limitations. For example, most statistical downscaling techniques have limitations on projectionability, meaning that present day statistical relationships about climate patterns cannot necessarily be projected for future climates. Uncertainties are associated with the representation of climatic and physico-chemical processes and, according to the IPCC, these "limitations" are

> due to the numerical approximation of the model's equations, simplifications and assumptions in the models and/or approaches, internal model variability,

161 Ibid.
162 Ibid p.590.
163 Ibid p.591.

> and inter-model or inter-method differences in the simulation of climate response to given forcings.[165]

Nevertheless, the IPCC does not consider these technical problems as an insuperable barrier to the advancement of regional climatic knowledge. The IPCC believes that, with improvements in computing power, some of the existing limitations may be overcome.

Evidence cited by the IPCC, that the increases in temperature are human caused, consist of a number of propositions. First, 20th century warming is unusual in the context of palaeoclimatic reconstructions over the past 1,000 years. Temperature records prior to the intense industrial activity of the past two centuries show relatively stable, and possible decreases, in temperature with natural variability, including changes in solar radiation and volcano emissions, contributing at most only several tenths of a degree per year. As the IPCC puts it:

> [C]onclusions on the detection of an anthropogenic signal are insensitive to the model used to estimate internal variability. Recent observed changes cannot be accounted for as pure internal variability even if the amplitude of simulated internal variations is increased by a factor of two or more.[166]

In other words, the probability that natural variability alone can explain 20th century warming is unlikely (meaning a 10-33 per cent chance) to very unlikely (1-10 per cent chance). Anthropogenic factors do, however, provide an explanation of changes in the global climate over the 20th century, with models detecting a response pattern to the emission of anthropogenic greenhouse gases. As natural causes cannot explain 20th century warming, the IPCC concludes that human activities remain as the only scientific cause of that warming.

Strong arguments can be made that global warming sceptics are mistaken in proposing that specific weather events cannot be attributed to human-induced global warming. In a paper published in December of 2004,[167] one scientific research team examined the European summer of 2003, which was the hottest in Europe since AD 1500 and during which there were large numbers of heat-related deaths, to see if its heat irregularity was due to global warming. The authors do not argue on the basis of a simplistic "but for" deterministic model that "but for" past greenhouse gas emissions the heatwave would not have occurred. The proximate cause of the heatwave was an anticyclone over northwestern Europe. Any such weather event viewed in isolation could be caused by "chance in an unmodified climate".[168] Rather, through the construction of a probability model created to provide estimated likelihood functions for anthropogenic and natural contributions to European summer temperatures, the authors demonstrate that the probability is greater

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165 Ibid.

166 Ibid p.730.

167 P.A. Stott (et al), "Human Contribution to the European Heatwave of 2003", *Nature*, vol. 432, 2 December 2004, pp. 610-614.

168 Ibid p.610.

than 90 per cent that over half the risk of (ie. on the balance of probabilities) such a heatwave was attributable to anthropogenic causes.[169] This is one of the first times that a specific weather event having substantial health implications has been scientifically attributed to anthropogenic global warming. Clearly, this is highly significant for climate change plaintiffs seeking to establish causation based on existing scientific evidence.

In conclusion, it is clear that establishing causative links on the balance of probabilities between global warming and specific regional climate change poses a significant obstacle for climate change plaintiffs in view of the sheer complexity of causation in the climate system and the presence of multiple causes of climatic events. The fact that the IPCC itself accepts that there is a high degree of scientific uncertainty characterising information regarding specific climatic events suggests that defences based on such acknowledged uncertainty would be on stronger legal and scientific grounds than those based on defences that question the entire foundation of the consensus view of climate change. However, on-going refinements to computer models and climate modelling techniques are addressing aspects of the scientific uncertainty associated with linking global warming to specific regional climate changes. With improvements in computing power and technology, the IPCC believes that current uncertainties will be reduced in the future. There is already a growing scientific literature linking climate change to specific regional climatic events.[170] On this basis, the prospects of successfully establishing causation between the two are likely to improve as research continues.

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169 Ibid p.612. See also S.F.B. Tett (et al), "Causes of Twentieth Century Temperature Change Near the Earth's Surface", *Nature*, vol. 399, 1999, pp. 569-572.

170 See, eg., M. Allen, "Liability for Climate Change", *Nature*, vol. 421, 2003, pp. 891-892; P. A. Stott, "Attribution of Regional-Scale Temperature Changes to Anthropogenic and Natural Causes", *Geophysical Research Letters*, vol. 30, July 2003, 1728, DOI10.1029/2003GLO17324; D. J. Karoly (et al), "Detection of a Human Influence on North American Climate", *Science*, vol. 302, 2003, pp.1200-1203; F. W. Zwiers and X. Zhang, "Toward Regional-Scale Climate Change Detection", *Journal of Climate*, vol. 16, March 2003, pp.793-797; M. den Elzen (et al), "Analysing Countries' Contribution to Climate Change: Scientific and Policy-Related Choices", *Environmental Science and Policy*, vol. 8, no. 6, December 2005, pp. 614-636; H. Graβl (et al) (German Advisory Council on Climate Change), *World in Transition: Towards Sustainable Energy Systems*, (Earthscan, London, 2004).