This article was downloaded by: [L. Phelan]

On: 05 October 2011, At: 23:16

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

Australasian Journal of Environmental Management

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tjem20>

Managing climate risk: extreme weather events and the future of insurance in a climate-changed world

L. Phelan ^a

^a Geography & Environmental Studies, University of Newcastle, University Drive, NSW, 2308

Available online: 30 Sep 2011

To cite this article: L. Phelan (2011): Managing climate risk: extreme weather events and the future of insurance in a climate-changed world, Australasian Journal of Environmental Management, DOI:10.1080/14486563.2011.611486

To link to this article: <http://dx.doi.org/10.1080/14486563.2011.611486>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Managing climate risk: extreme weather events and the future of insurance in a climate-changed world

L. Phelan*

Geography & Environmental Studies, University of Newcastle, University Drive, NSW 2308

Recent extreme weather events in eastern Australia have again raised questions in the public sphere about the nature of links between anthropogenic climate change and extreme weather events. Demonstrating that anthropogenic climate change was wholly responsible for any extreme weather event may never be possible in a system as complex as the Earth's. Yet the extent to which anthropogenic climate change increased the likelihood of some specific extreme weather events occurring can be quantified. However, this article argues that unmitigated climate change threatens not just measurable, increased likelihoods of extreme events, but over time, wholly unpredictable frequencies for extreme weather events. This article asks what the prospects might be for continued provision of insurance in a climate-changed world, for the insurance sector as well as the societies dependent on insurance as a primary tool to manage financial risks. The article argues that ultimately, the only viable way to insure against climate risks will be through effective mitigation of climate change: deep and rapid cuts in emissions now as a 'premium' to avoid uninsurable climate risks in the future.

Keywords: climatic uncertainty; environmental risk; Fraction Attributable Risk; complex adaptive systems; mitigation

Introduction

In early 2011, eastern Australian states were hit by several extreme weather events: Cyclone Yasi in Queensland, and flooding in that state and Victoria (Glynn 2011). Each event caused significant insured and uninsured financial losses. The severity of each event, with their close succession, again raised questions in the public sphere about the nature of links between anthropogenic climate change (IPCC 2007a) and extreme weather events (e.g. Insight 2011). In response to the events and their impacts, three government inquiries were established: one at Federal level, and one each in Queensland and Victoria. The Federal inquiry (Shorten 2011) focuses wholly on the adequacy of disaster insurance provisions in Australia. This article discusses the nature of the link between climate change and extreme weather events, as well as the implications for ongoing insurance provision in a climate-changed world.

An understanding of the Earth system as a complex adaptive system (Kay 2008) characterised by thresholds, feedbacks and non-linear change is well established (Lenton et al. 2008). I argue on that basis that in time, unmitigated climate change will transform the frequency of extreme weather events beyond a shift from less to more frequent, through to frequencies that are wholly unpredictable, and therefore

---

*Email: liam.phelan@newcastle.edu.au

more uncertain. Such a shift in climate risks raises significant questions for the future of insurance, a key financial risk management tool for industrialised societies (Hecht 2008). As Dlugolecki (2009, p. 1) argues, '[i]nsurers themselves have not understood the scale of the implications of global warming'.

Link between climate change and extreme weather events

Anthropogenic climate change presents a 'diabolical policy problem' (Garnaut 2008, p. xviii) and one whose mitigation requires deep and rapid cuts in emissions (Hansen et al. 2008). One possible manifestation of anthropogenic climate change has been an aggregate rise in climate change-implicated disaster events globally in recent decades. During the 1980s, an average of 400 Earth system (or 'natural') disaster events were recorded annually across the globe. In the 1990s, this increased to an annual average of 630, and then increased again to an annual average of 730 in the last ten years. In 2007, there were 960 catastrophic Earth system events, the highest number since systematic recording began in 1980. Of these events, 91 per cent were disasters in which climate change may be implicated (i.e. other than earthquakes and tsunamis) (IAIS 2008, pp. 15–16).

Climate change has long been expected to alter the frequency of extreme weather events (IPCC 2001, 2007b), but asking the right questions is important when exploring the links between climate change and specific extreme weather events (Allen et al. 2007). Large-scale Earth system phenomena such as the El Niño–Southern Oscillation can also lead to variations in frequencies of extreme weather events (Tompkins 2002). But such Earth system phenomena are themselves likely to change as the climate changes (Karl & Trenberth 2003). The impact of anthropogenic climate change on such phenomena pose difficult questions about the manner in which the impacts of climate change will be distributed geographically across regions and across economic sectors:

Until and unless major oscillations in the Earth System (El Niño–Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) etc.) can be predicted to the extent that they are predictable, regional climate is not a well defined problem. It may never be. (Anonymous in Henderson-Sellers 2008)

Demonstrating that anthropogenic climate change was wholly responsible for a specific weather event may never be possible in a system as complex as the Earth. However, if we step back from seeking immediate, direct connections, we can ask whether anthropogenic climate change has altered the likelihood of a specific extreme weather event occurring (Allen et al. 2007). Doing so allows quantification of anthropogenic climate change's contribution to the increased chance of a particular extreme weather event having occurred.

A gambling analogy is useful for understanding the way in which climate change is linked to specific extreme weather events. Imagine you are playing cards. The cards are shuffled and the hands are dealt. A bad hand is always a possibility and, if you receive a bad hand, that is bad luck. But what if one of your opponents is, somehow, subtly stacking the deck? Is your bad hand still all about chance? Continuing to emit

greenhouse gases means stacking the climate deck too, increasing the chance of some extreme weather events occurring.

Fraction Attributable Risk (FAR), a method borrowed from population studies in epidemiology, is applied in climate science to ask how much more likely a specific event was, given climate change (Stone & Allen 2005; Allen et al. 2007). In this way, a proportion of the probability of an extreme weather event occurring can be attributed to anthropogenic greenhouse gas emissions.

The starting point for using the FAR method is the current state of the atmosphere: the atmosphere as it is, complete with the existing anthropogenic atmospheric CO₂ equivalent burden. From here, the key question is 'how not injecting that [already emitted] amount of carbon dioxide would alter our present-day and projected future climate' (Allen et al. 2007, p. 1359). The reference conditions are defined as 'the climate that would have occurred in the early twenty-first century in the absence of specific human influences' (Allen et al. 2007, p. 1356). In fact the climate has been subject to 'specific human influences', and so those conditions can only be explored using computer simulation. The FAR method adopts the computer-simulated baseline as the 'natural', unadulterated or reference climate.

To date the FAR method has been applied to large spatial scale weather events such as heatwaves and floods. The heatwave that struck western Europe in 2003, causing around 35,000 premature deaths and at least €13.1 billion in lost agricultural production and fire damage (UK Met Office 2008) is one such event. As with the recent eastern Australian floods, this large, extreme weather event could have happened in the absence of anthropogenic climate change. However, application of the FAR method suggests human influence increased the risk of the event occurring by a factor of four to ten, with the most likely value being six (Allen et al. 2007). Put another way, human interference with the climate was responsible for perhaps 85 per cent of the risk of the heatwave occurring.

The FAR method was applied also to floods in the UK of 2000 (Pall et al. 2011). That analysis suggests anthropogenic climate change at least doubled the risk of that flood occurring. The FAR method has also been applied more broadly still, beyond individual extreme events, to analyse rainfall patterns across the Northern hemisphere (Min et al. 2011). In light of the capacity to quantify the relationship between anthropogenic climate change and some particular extreme weather events that cause significant losses, insurers' responses to increasing climate risk warrant careful attention.

Rational adaptation?

Muir-Wood et al. (2006) suggest that, after accounting for changes in population and wealth, changes in extreme weather events may be responsible for a growth in insured losses by about two per cent a year since the 1970s, and that this corresponds with rising global temperatures (Muir-Wood et al. 2006; Ward et al. 2008). The suggestion that insurers could be expected to respond to climate change through adaptive measures (including by raising premiums or even denying cover in extreme cases) has been made previously (Paterson 2001). Indeed, the current literature on insurance and climate change is almost comprehensively focussed on opportunities for adaptation (e.g. Dixit & McGray 2009; Herweijer et al. 2009; Warner et al. 2009; Botzen et al. 2010; Schwarze et al. 2010). This contrasts with hopes dating back to the Rio Summit in 1992 that the

insurance industry would provide leadership on climate change mitigation (e.g. Leggett 1993).

Mills (2009) provides a useful survey of actions by insurance industry actors globally (insurers, reinsurers, loss modellers, brokers and regulators) that are best described as adaptive and weakly mitigative. That is, actions that allow insurers to continue to offer insurance even as the climate changes, and actions that support, promote or result in limited greenhouse gas emissions reductions only, rather than the rapid and deep cuts in emissions necessary to mitigate climate change (Hansen et al. 2008; Allen et al. 2009). Mills (2009) categorises insurers' responses to climate change as consistent with one or more of the following: (1) understanding the climate problem; (2) promoting loss prevention; (3) aligning terms and conditions with risk reducing behaviour; (4) crafting innovative insurance products; (5) offering carbon risk-management and offsets; (6) financing customer improvement; (7) investing in climate change solutions; (8) building awareness and participating in public policy; (9) leading by example; and (10) carbon risk disclosure. Plainly, there is a range of adaptive responses being implemented. As such, some in our society's primary risk management 'tool' (Hecht 2008) have shown leadership in addressing climate risk, but in terms of adaptation rather than mitigation.

One adaptive response by insurance providers to an increase in the probability of extreme events occurring would be to price climate change-implicated risks more highly. Such a move raises significant social equity issues with regard to economic access to insurance. Barnett and O'Neill (2010, p. 211) describe any 'action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups' as maladaptation. An example from Florida, a jurisdiction already well-attuned to hurricane risk, is illustrative attempts to adapt to changing climate-implicated weather risks. Loss models used by insurance firms offering hurricane insurance in Florida must be accredited annually by a government authority, the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM). The FCHLPM was created in 1995 to evaluate computer models to ensure reliable projections of hurricane losses so that rates for residential property insurance are neither excessive nor inadequate (FCHLPM 2009). That is, the FCHLPM has been given the task of ensuring that insurance premiums are neither so high as to be extortionate of consumers, nor so low as to threaten insurers' solvency. Once accredited, loss modellers can provide their models to insurers as a basis for pricing hurricane risk.

Risk Management Solutions (RMS) is the world's largest catastrophe loss modelling firm, and one that provides loss models to insurers and reinsurers providing insurance against hurricane risk in the state of Florida. In 2007, RMS submitted a US Hurricane Model (version six) to the FCHLPM that gave more weight to higher levels of hurricane activity in recent years rather than simply averaging hurricane activity over the longer term (RMS 2007). RMS gave a greater weighting to recent years because in the period since 1995 (and in comparison to the period 1970–1994), hurricane activity in the Atlantic basin has increased by 60 per cent. Additionally, the period saw an increase in intense category 3–5 storms of 120 per cent. This was the period that saw Hurricane Katrina wring devastation (in the order of US\$40b [Insurance Information Institute 2007]), notably in New Orleans. RMS' modellers made the change to their model, noting that '[a]cknowledging that the long-term historical baseline is no longer the best measure of current hurricane activity means it is

necessary to be explicit about the intended time horizon of the catastrophe model' (Muir-Wood & Grossi 2008, p. 311). This represented a marked break from the standard approach, used since the first generation of hurricane catastrophe loss models, which bases hurricane activity rates on the 'average of history' (Muir-Wood & Grossi 2008, p. 310). In practice, in the USA, the 'average of history' generally means the period since 1900.

The FCHLPM refused to accept the loss model submitted by RMS, specifically because of the increased weighting applied to recent years. Faced with the regulator's rejection, RMS then submitted a modified model that used the standard, long-term historical baseline. The FCHLPM duly accepted the modified model. Nevertheless, RMS continues to assert that the medium-term basis for projecting hurricane activity is better than the traditional long-term basis (RMS 2007).

This clash may appear unremarkable to outside observers, but it is useful in that it highlights questions over the basis for sustainable insurance provision in a climate-changed world. As the climate changes, past experience may cease to provide a reliable guide to future experience.

Sting in the tail

Some changes in the Earth system are better understood as thresholds that are crossed, rather than as linear, orderly and progressive change (Lenton et al. 2008). Earth system science suggests a number of key, globally significant Earth system 'boundaries', of which climate change is one (Rockström et al. 2009). Examples of non-linear (and faster-than-predicted) climate changes include the Greenland ice sheet melt and sea level rise (Oppenheimer & Alley 2005, p. 258; Rahmstorf et al. 2007). Prediction and even detection of Earth system thresholds is highly challenging and not always possible before thresholds are crossed (Keller et al. 2008; Lenton et al. 2008). Such circumstances of increasing uncertainty raise profound implications for the ongoing viability and accessibility of insurance. One example is insurance providers responding to threats to their ongoing profitability by withdrawing from markets in which risk levels appear to have changed, such as the hurricane insurance market in Florida (Mills 2007, p. 2).

A changing climate therefore carries a sting in the tail for climate risk management, and one for which adaptive measures alone are inadequate. Increases in extreme weather events' frequencies has been long anticipated, and over time may mean climate risk insurance moving from being more affordable to less so. Eventually, a changing climate may lead to a shift in climate risks, from relative predictability to relative unpredictability. Under such circumstances, insurance for climate risks would move again, beyond less affordable to incalculable.

Capacity to calculate risk is central to this issue. Insurance for weather risks works in part because past human experience of the climate is a reliable guide to future experience (Phelan et al. 2011a). Terms such as 'a one-in-a-100-year flood' reflect that reliability: while we cannot predict exactly when such a flood will occur, the term assumes with some confidence that such a flood will happen, on average, every 100 years or so. Anticipating the frequency of loss-causing events is needed to calculate likely losses, and therefore to set appropriate premiums.

This remains possible as long as the Earth (including its climate) stays in a stable though dynamic state, one that is familiar to humans through the course of human

history. Anthropogenic climate change means shifting the state of Earth, perhaps relatively suddenly, from its familiar state into an alternative – and perhaps radically different – state. Such a shift may render the state of the Earth system unstable and characterized by unpredictable change (Roe & Baker 2007). Etkin (2010, p. 404) argues that anthropogenic atmospheric CO₂ concentrations are driving a radical shift outside the ‘well-defined domain’ the Earth’s state has occupied for the past 420,000 years. Etkin (2010, p. 404, footnote 2) further notes that ‘[o]ther data suggests this pattern has existed for a million years, through ten ice-age cycles’. Albrecht and Rapport (looking beyond climate change to consider sustainability overall), argue that ‘the world of relative predictability, with respect to reliability of ecosystem functions, has by degrees been transposed to a world of relative chaos in which surprise dominates, often with severe human consequences’ (Albrecht & Rapport 2002).

Another possibility is that the Earth system has shifted to an alternative state that is also stable, but unfamiliar. One example would be an ice-free planet. In that scenario, we would have no reliable experience to rely on for calculating weather risks in a way that would support provision of insurance. That is, we would be without a reliable past record for calculating future probabilities. This too may mean climate change-implicated weather risks may become uninsurable in a conventional sense. Under such conditions, it is difficult to imagine insurance, whether provided by the private industry or by governments, operating as it does now.

Insurance: relied upon by societies, threatened by climate change

Insurance has a long-established role in facilitating economic activity, dating back to antiquity (Trennery 1926; Pfeffer & Klock 1974, p. 27). As Pfeffer and Klock (1974), p. 272) put it, ‘[s]hips do not sail and capital is not deployed abroad without adequate insurance protection’. Insurance is a key element of contemporary industrialised societies and provides societies with a measure of economic security (Knights & Vurdubakis 1993, p. 734). As the world’s largest industry and valued at US\$5 trillion in 2007 (Mills 2009), insurance now plays a key role in the global economy: insurance is a key tool for managing financial risks in contemporary industrialised economies (Hecht 2008).

A reliable and accessible insurance system is essential for economic stability. As such, states are generally loathe to see insurers fail. The ramifications from the failure of HIH Insurance in Australia in early 2001 – Australia’s biggest corporate collapse – rippled through the Australian economy, inspiring headlines such as ‘HIH collapse threatens economy’ (McIlveen 2001), and triggering a Royal Commission (Commonwealth of Australia [HIH Royal Commission] & Owen 2003). A key early part of the United States’ Federal Reserve Bank’s response to the 2008 global financial crisis was to bailout the AIG, the world’s largest insurer (Federal Reserve Bank of New York 2008).

Some elements in the insurance industry were alert to the potential for climate change to impact on financial losses as early as the 1970s (e.g. Munich Re 1973). While some in the insurance sector have responded adaptively and weakly mitigatively to climate change, effective mitigation remains essential. Extreme weather events that cause insured and uninsured financial losses, such as the recent floods and cyclone in Eastern Australia, will continue to occur; so, too, the mopping up afterwards. Climate change has long been expected to cause an increase in such

events, and climate change's contribution to the likelihood of some specific events occurring can now be quantified. Without effective climate change mitigation, their frequency may even become wholly unpredictable. Climate change adaptation measures are essential given that climate change impacts are already manifest. However, adaptation measures alone are insufficient, in that they do not address the loss, over time, of Earth system stability caused by climate change.

Anthropogenic climate change presents a threat to reliable and accessible insurance provision (Phelan et al. 2011b). This suggests that in the medium- and long-term, ongoing financially viable and accessible insurance depends on effectively mitigating climate change. Yet effective climate change mitigation remains a wicked policy problem (Rittel & Webber 1973; APSC 2007); that is, one characterised by complexity, interdependencies, and one that is continuing to evolve. It is a problem without a clear solution, but one for which any effective solution will surely require behavioural change.

Serious efforts to mitigate climate change effectively and justly have been underway for decades: at the international level the United Nations Framework Convention on Climate Change (United Nations 1992) dates back to 1992. The highly anticipated 15th Conference of the Parties to the Framework Convention at Copenhagen in late 2009 failed to deliver a fair, ambitious and binding target (Phelan 2010), and though the negotiations remain live, subsequent meetings (e.g. the 16th Conference of the Parties in Cancún) have resulted in little further progress. Meanwhile, global CO₂ emission rates and atmospheric concentrations continue to rise well beyond (rather than reduce to within) biogeophysical limits: '...the acceleration of both CO₂ emissions and atmospheric accumulation [in the period 2000–2007] are unprecedented and most astonishing during a decade of intense international developments to address climate change' (Global Carbon Project 2008). Domestically, an effective carbon price (i.e. one that would drive deep and rapid cuts in greenhouse gas emissions) remains a work in progress.

Conclusion

Unmitigated climate change threatens more than a simple increase in extreme weather event frequency. Climate change threatens the Earth system's familiar stability, and therefore the reliability on which climate risk probabilities are calculated. In essence, this is a shift from relative predictability to relative unpredictability. Such a shift would radically undermine the basis for provision of insurance for climate risks. In the absence of effective climate change mitigation, insurance may cease to be a useful tool for managing financial risks impacted by climate change. The point is surely worthy of consideration in the Australian Federal government's current review of the adequacy of disaster insurance.

Much of the world's population functions currently with limited or no access to insurance. As such, a radical undermining of the basis for insurance for climate change-implicated weather risks does not herald the end of the world as we know it. Nevertheless, as the world's largest industry, insurance plays a key role in the modern global economy. Ultimately, the only viable way to insure against climate risks is through mitigation: deep and rapid cuts in emissions now as a 'premium' of sorts, to insure against increased, then unpredictable, financial losses in the future. Such a conclusion may appear unremarkable in the literature on climate science, which has

conclusively established the scientific basis for anthropogenic climate change. But it is remarkable in the context of the literature on insurance and climate change, which focuses almost exclusively on adaptation options.

Acknowledgments

Thank you to the editors and an anonymous referee for very helpful and much appreciated comments on an earlier draft.

Note

1. This paper synthesises and extends on elements of three earlier pieces: Phelan et al. (2010, 2011a, 2011b).

References

- Albrecht, G & Rapport, DJ 2002, 'Taking LIFE insurance seriously: a revolutionary role for the global insurance industry in achieving sustainability', Healthy Ecosystems Healthy People [conference], International Society for Ecosystem Health in association with the Center for Applied Biodiversity Science and Conservation International, Washington, DC.
- Allen, M, Pall, P, Stone, D, Stott, P, Frame, D, Min, S-K, Nozawa, T & Yukimoto, S 2007, 'Scientific challenges in the attribution of harm to human influence on climate', *University of Pennsylvania Law Review*, vol. 155, pp. 1353–1400.
- Allen, MR, Frame, DJ, Huntingford, C, Jones, CD, Lowe, JA, Meinshausen, M & Meinshausen, N 2009, 'Warming caused by cumulative carbon emissions towards the trillionth tonne', *Nature*, vol. 458, pp. 1163–1166.
- APSC 2007, *Tackling wicked problems: a public policy perspective*, Australian Public Service Commission, Canberra.
- Barnett, J & O'Neill, S 2010, 'Maladaptation', *Global Environmental Change*, vol. 20, no. 2, pp. 211–213.
- Botzen, WJW, van den Bergh, JCJM & Bouwer, LM 2010, 'Climate change and increased risk for the insurance sector: a global perspective and an assessment for the Netherlands', *Natural Hazards*, vol. 52, pp. 577–598.
- Commonwealth of Australia HIH Royal Commission & Owen, NJ 2003, *The failure of HIH Insurance*, Commonwealth of Australia, Canberra.
- Dixit, A & McGray, H 2009, *Paying the premium: insurance as a risk management tool for climate change*, Washington, DC, World Resources Institute.
- Dlugolecki, AF 2009, 'The climate change challenge', *Risk management: research on risk management, assessment and prevention*, vol. 45, no. SC1, pp. 1–12.
- Etkin, B 2010, 'A state space view of the ice ages – a new look at familiar data', *Climatic Change*, vol. 100, pp. 403–406.
- FCHLPM 2009, *Florida Commission on Hurricane Loss Projection Methodology*, viewed 15 June 2009, <<http://www.sbafla.com/methodology/>>.
- Federal Reserve Bank of New York 2008, *Statement by the Federal Reserve Bank of New York regarding AIG transaction*, media release, New York, 29 September, viewed 21 July 2010, <<http://www.newyorkfed.org/newsevents/news/markets/2008/an080929.html>>.
- Garnaut, R 2008, *Garnaut climate change review*, Cambridge University Press, Port Melbourne.
- Global Carbon Project 2008, *Growth in the global carbon budget*, media release, Global Carbon Project, 25 September, viewed 13 May 2009, <http://www.globalcarbonproject.org/global/pdf/Press%20Release_GCP.pdf>.
- Glynn, J 2011, 'Reinsurance costs in Yasi, Queensland floods trigger Australian dollar surge', *The Australian*, viewed 4 August 2011, <<http://www.theaustralian.com.au/business/markets/reinsurance-costs-in-yasi-queensland-floods-trigger-australian-dollar-surge/story-e6frg94o-1226031290450>>.

- Hansen, J, Sato, M, Kharecha, P, Beerling, D, Berner, R, Masson-Delmotte, V, Pagani, M, Raymo, M, Royer, DL & Zachos, JC 2008, 'Target atmospheric CO₂: where should humanity aim?', *Open Atmospheric Science Journal*, vol. 2, pp. 217–231.
- Hecht, SB 2008, 'Climate change and the transformation of risk: insurance matters', *UCLA Law Review*, vol. 55, no. 6, pp. 1559–1620.
- Henderson-Sellers, A 2008, 'The IPCC report: what the lead authors really think', *Environmental Research Web*, viewed 21 December 2008, <<http://environment.alresearchweb.org/cws/article/opinion/35820>>.
- Herweijer, C, Ranger, N & Ward, RET 2009, 'Adaptation to climate change: threats and opportunities for the insurance industry', *The Geneva Papers on Risk and Insurance: Issues and Practice*, vol. 34, pp. 360–380.
- IAIS 2008, *Global reinsurance market report 2008*, International Association of Insurance Supervisors, Basel.
- Insight 2011, La Niña, Special Broadcasting Service, viewed 23 April 2011, <<http://news.sbs.com.au/insight/episode/index/id/346/La-Ni-a#overview>>.
- Insurance Information Institute 2007, *Insurance claims payment process in the Gulf Coast after the 2005 hurricanes*, Subcommittee on Oversight and Investigations of the House Committee on Financial Services (Robert P. Hartwig representing the Insurance Information Institute). Government Printing Office, Washington DC, viewed 17 January 2008, <<http://purl.access.gpo.gov/GPO/LPS82645>>.
- IPCC 2001, *IPCC third assessment report: climate change 2007 (TAR)*, Cambridge University Press, Cambridge.
- IPCC 2007a, *Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
- IPCC 2007b, *IPCC fourth assessment report: climate change 2007 (AR4)*, Cambridge University Press, Cambridge.
- Karl, TR & Trenberth, KE 2003, 'Modern global climate change', *Science*, vol. 302, no. 5651, pp. 1719–1723.
- Kay, JJ 2008, 'An introduction to systems thinking', 3–13, in D Waltner-Toews, JJ Kay & N-ME Lister (eds), *The ecosystem approach: complexity, uncertainty, and managing for sustainability*, Columbia University Press, New York.
- Keller, K, Yohe, G & Schlesinger, M 2008, 'Managing the risks of climate thresholds: uncertainties and information needs', *Climatic Change*, vol. 91, no. 1/2, pp. 5–10.
- Knights, D & Vurdubakis, T 1993, 'Calculations of risk: towards an understanding of insurance as a moral and political technology', *Accounting, Organizations & Society*, vol. 18, no. 7/8, pp. 729–764.
- Leggett, J 1993, *Climate change and the insurance industry: solidarity among the risk community?*, Amsterdam, Greenpeace.
- Lenton, TM, Held, H, Kriegler, E, Hall, JW, Lucht, W, Rahmstorf, S & Schellnhuber, HJ 2008, 'Tipping elements in the Earth's climate system', *Proceedings of the National Academy of Sciences of the USA*, vol. 105, no. 6, pp. 1786–1793.
- McIlveen, L 2001, 'HIH collapse threatens economy', *The Australian*, 2.
- Mills, E 2007, *From risk to opportunity 2007: insurer responses to climate change*, Ceres, Boston.
- Mills, E 2009, *From risk to opportunity 2008: insurer responses to climate change*, Ceres, Boston.
- Min, S-K, Zhang, X, Zwiers, F & Hegerl, GC 2011, 'Human contribution to more-intense precipitation extremes', *Nature*, vol. 470, pp. 378–381.
- Muir-Wood, R & Grossi, P 2008, 'The catastrophe modeling response to Hurricane Katrina', 296–319, in HF Diaz & RJ Murnane (eds), *Climate extremes and society*, Cambridge, Cambridge University Press.
- Muir-Wood, R, Miller, S & Boissonade, A 2006, 'The search for trends in a global catalogue of normalized weather-related catastrophe losses', Workshop on climate change and disaster losses: understanding and attributing trends and projections, Hohenkammer, 25–26 May.
- Munich Re 1973, *Flood inundation*, Munich Re, Munich.

- Oppenhiemer, M & Alley, RB 2005, 'Ice sheets, global warming and Article 2 of the UNFCCC', *Climatic Change*, vol. 68, no. 3, pp. 257–267.
- Pall, P, Aina, T, Stone, DA, Stott, PA, Nozawa, T, Hilberts, AGJ, Lohmann, D & Allen, MR 2011, 'Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000', *Nature*, vol. 470, pp. 382–85.
- Paterson, M 2001, 'Risky business: insurance companies in global warming politics', *Global Environmental Politics*, vol. 1, no. 4, pp. 18–42.
- Pfeffer, I & Klock, DR 1974, *Perspectives on insurance*, Englewood Cliffs, NJ, Prentice-Hall.
- Phelan, L 2010, 'What to make of COP 15? A ringside report', *Air Quality and Climate Change*, vol. 44, no. 1, pp. 14–15.
- Phelan, L, Henderson-Sellers, A & Taplin, R 2010, 'Climate change, carbon prices & insurance systems', *International Journal of Sustainable Development & World Ecology*, vol. 17, no. 2, pp. 95–108.
- Phelan, L, Henderson-Sellers, A & Taplin, R 2011a, 'Reflexive mitigation of the Earth's economy: a viable strategy for insurance systems', in W Leal Filho (ed.), *The economic, social and political elements of climate change*, Berlin, Springer Verlag, pp. 81–98.
- Phelan, L, Taplin, R, Henderson-Sellers, A & Albrecht, G 2011b, 'Ecological viability or liability?: insurance system responses to climate risk', *Environmental Policy & Governance*, vol. 21, no. 2, pp. 112–130.
- Rahmstorf, S, Cazenave, A, Church, JA, Hansen, JE, Keeling, RF, Parker, DE & Somerville, RCJ 2007, 'Recent climate observations compared to projections', *Science*, vol. 316, p. 709.
- Rittel, HWJ & Webber, MM 1973, 'Dilemmas in a general theory of planning', *Policy Sciences*, vol. 4, no. 2, pp. 155–169.
- RMS 2007, *RMS announces estimated hurricane activity rates for 2008 to 2012*, media release, Risk Management Solutions, 20 November, viewed 21 July 2009, <http://www.rms.com/NewsPress/PR_112007_HU_2008_2012.asp>.
- Rockström, J, Steffen, W, Noone, K, Persson, Å, Chapin, I, Stuart, F, Lambin, EF, Lenton, TM, Scheffer, M, Folke, C, Schellnhuber, HJ, Nykvist, B, de Wit, CA, Hughes, T, van der Leeuw, S, Rodhe, H, Sörlin, S, Snyder, PK, Costanza, R, Svedin, U, Falkenmark, M, Karlberg, L, Corell, RW, Fabry, VJ, Hansen, J, Walker, B, Liverman, D, Richardson, K, Crutzen, P & Foley, JA 2009, 'A safe operating space for humanity', *Nature*, vol. 461, pp. 472–475.
- Roe, GH & Baker, MB 2007, 'Why is climate sensitivity so unpredictable?', *Science*, vol. 318, pp. 629–632.
- Schwarze, R, Schwindt, M, Weck-Hannemann, H, Raschky, P, Zahn, F & Wagner, GG 2011, 'Natural hazard insurance in Europe: tailored responses to climate change are needed', *Environmental Policy and Governance*, vol. 21, no. 1, pp. 14–30.
- Shorten, B 2011, *National disasters insurance review*, media release, 4 March, Assistant Treasurer, Commonwealth of Australia, viewed 23 April 2011, <<http://assistant.treasurer.gov.au/DisplayDocs.aspx?doc=pressreleases/2011/039.htm&pageID=003&min=brs&Year=&DocType=0>>.
- Stone, DA & Allen, MR 2005, 'The end-to-end attribution problem: from emissions to impacts', *Climatic Change*, vol. 71, pp. 303–318.
- Tompkins, H 2002, 'Climate change and extreme weather events: is there a connection?' *Cicerone*, vol. 3, pp. 1–5.
- Trennery, CF 1926, *Origin and early history of insurance*, London, P.S. King & Son.
- UK Met Office 2008, *Extreme temperatures on the rise*, media release, 26 March, viewed 21 April 2009, <<http://www.metoffice.gov.uk/corporate/pressoffice/2008/pr20080326.html>>.
- United Nations 1992, *United Nations Framework Convention on Climate Change*, Geneva, United Nations.
- Ward, RET, Herweijer, C, Patmore, N & Muir-Wood, R 2008, 'The role of insurers in promoting adaptation to the impacts of climate change', *The Geneva Papers on Risk and Insurance: Issues and Practice*, vol. 33, pp. 133–139.
- Warner, K, Ranger, N, Surminski, S, Arnold, M, Linnerooth-Bayer, J, Michel-Kerjan, EO, Kovacs, P & Herweijer, C 2009, *Adaptation to climate change: linking disaster risk reduction and insurance*, Geneva, United Nations International Strategy for Disaster Reduction Secretariat (UNISDR).