Examining the Decision-Relevance of Climate Model Information for the Insurance Industry

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Chapter 1

Introduction

1.1 Understanding Climate Change

"The first step to dealing with your problem is knowing your problem"

Professor Ian Stewart[1]

In order for society to develop appropriate solutions to the emerging risks associated with climate change, individuals, businesses and governments need to make rational decisions utilising the available knowledge base. Effectively communicating what is known and what is unknown about the science of climate and climate change is therefore essential in providing guidance to decision-makers. Yet there is ambiguity within the climate change discourse about the most appropriate way to define climate. Father of chaos theory, Edward Lorenz, observed that questions regarding climate and climate change can be answered either affirmatively or negatively depending on the precise definition of climate (Lorenz (1997)). In order to adapt to possible future climate states, it is therefore important to find a suitable definition of climate which is tailored towards the needs of the climate change adaptation community. Furthermore, acknowledging both the rich complexity of the physical climate system and the intricacies of the policy-making process is imperative in establishing how to provide useful information from climate model experiments to inform decision makers. The purpose of this thesis is to develop a fundamental appreciation of the meaning of climate in the context of climate change given the dynamic, nonlinear and chaotic nature of the system. Ultimately, the research aims to provide guidance for the design of future climate model experiments to better respond to the needs of the adaptation community, with a particular focus on the (re)insurance industry.

The objective of this initial chapter is to provide a broad context for the research presented in this thesis. In section 1.2, the current state of knowledge regarding climate change is described with reference to international efforts to establish a global scientific consensus. Section 1.3

[1]In an address to The Royal Society in London at a meeting titled "Handling Uncertainty in Science" held on March 22nd 2010.

explores the role of climate models in providing output to inform climate change adaptation. The arguments for investigating the behaviour of simple models are introduced in section 1.4 whilst section 1.5 outlines the reasons for the engagement of the insurance industry in climate change research. Section 1.6 lists the main questions being addressed in this thesis and describes the aims of the research. Finally, section 1.7 provides a road-map for the thesis including a brief description of each chapter and how the chapters relate to one another.

1.2 Global Warming and Climate Change

The first decade of the twenty-first century was the warmest decade globally since record began in 1880 (NASA (2010)). Global warming over the past 50 years has been widely attributed to the increasing concentration of greenhouse gases (GHGs) in the atmosphere, primarily caused by anthropogenic emissions of carbon dioxide, methane and other trace GHGs (Hegerl et al. (2007)). Global warming, due to anthropogenic emissions of GHGs, has been recognised by climate scientists as a real and potentially dangerous global issue for more than thirty years. Wallace Broecker, a scientist from Columbia University, New York, first coined the term *global warming* in a study published in 1975 where he states, “it is possible that we are on the brink of a several-decade-long period of rapid warming” (Broecker (1975)). Over the subsequent decades the science of global warming, and more generally climate change, has evolved and the issue of how to respond to twenty-first century global warming has become an issue of great concern for international, national and local policymakers.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) to compile research undertaken by the climate science community (IPCC (2011)). To date, the IPCC has produced four comprehensive assessment reports and the results provide the scientific basis for the policy debate regarding the implementation of the United Nations Framework Convention on Climate Change (UNFCCC). A vital component in each IPCC report is the presentation of climate model results. Modelling centres across the world have performed experiments to inform the analysis of past, current and future climate variability and climate change for inclusion in the IPCC assessment process. Combined with other sources of climate information, model results are used to illustrate potential future climate trajectories. The model experiments run for the Third Assessment Report (TAR) and Fourth Assessment Report (AR4) were conditioned on a set of specific emissions scenarios published in the Special Report on Emissions Scenarios (SRES). The SRES scenarios consist of alternative plausible future pathways based on assumptions about technological change and future economic development (IPCC (2000)). The AR4 report cited projections for an increase in the global mean temperature of between 1.1°C and 6.4°C by the end of the century (IPCC (2007b)). The UNFCCC relies upon the science contained within the IPCC reports to establish consensus agreements between nations which enact climate change policies and set international emissions targets.

Dessler and Parson (2006) divide the available responses to deal with climate change into three broad categories. Mitigation policies aim to address the rise in the concentration of GHGs through efforts to reduce GHG emissions or enhance GHG sinks. Geoengineering policies aim to actively manipulate the radiative balance of the climate system and offset the effects of the GHG forcing. Finally, adaptation policies are focussed on managing the physical impacts of climate change. This thesis is primarily concerned with the use of climate model output to inform adaptation policy but the implications of the research also have relevance for the design of model experiments to guide mitigation and geoengineering policy.

1.3 Model Guidance for Adaptation to Climate Change

Despite efforts to reduce the emissions of anthropogenic GHGs to mitigate against projected future warming, concentrations of GHGs in the atmosphere continue to rise and further warming of the planet is considered by many to be largely inevitable (IPCC (2007b)). As a result, policymakers are no longer concerned only with policies designed to reduce GHG emissions but also in enacting adaptation strategies to enable society to cope with the impacts of climate change. As the focus of climate change policy shifts from mitigation to adaptation, different forms of climate information will be required to guide policy decisions.

Climate models have been used extensively to inform the mitigation debate by providing estimates in the range of global and regional changes in climate variables, such as temperature and precipitation. However, policy responses have largely been centred on "best estimates" and mean values, particularly in relation to projected changes in the global mean temperature. For example, the European Commission (EC) has advocated a target of minimising the increase in global mean temperature to 2°C above the pre-industrial value (European Commission (2008)). The EC acknowledges that such a target will not avoid many of the adverse impacts of climate change but state that a higher rise in global mean temperature "will result in increasingly costly adaptation and considerable impacts that exceed the adaptive capacity of many systems". Conversely, when considering climate change adaptation, policy responses are likely to be dependent on the entire range of projected outcomes. As noted by Stainforth et al. (2007a), "most if not all decision support is sensitive to more than the mean". The distinction between what information is required for mitigation and adaptation decisions largely reflects the contrasting nature of the policy debates; the mitigation discourse primarily focuses on the global mean temperature because this variable is used to anchor negotiations on emissions reductions.

As the primary tool for assessing the future impacts of climate change, global circulation models (GCMs) enable scientists to test hypotheses and make predictions of future climate change subject to a number of assumptions. However, producing reliable and believable projections for informing adaptation decisions is fraught with uncertainty. Whilst climate models have been instrumental in attributing twentieth century global and regional warming to anthropogenic greenhouse gas forcing (Hegerl et al. (2007)), models show considerable disagreement when predicting future climate changes at the spatial and temporal scales that interest decision makers. Oreskes et al. (2010) note that there is much less agreement between models regarding local changes in climate when compared to global mean changes, questioning the value of the current generation of climate model projections to guide adaptation. Presenting and communicating results which are subject to large uncertainty therefore poses a critical challenge to the climate modelling community. Similarly, interpreting highly uncertain model results which are conditional on a number of crude assumptions is problematic for decision makers.

Recently, modelling centres around the world have begun developing their capabilities in *Climate Services* to improve the communication and presentation of climate information, especially in aiding climate change adaptation. The emergence of Climate Services originates from a WMO meeting[2] held in 2009 where attendees discussed the need for suitable national-level provision of climate information relevant for adaptation decisions. The UK Met Office[3], the US National Oceanic and Atmospheric Administration[4] (NOAA) and the German Climate Service Center[5] (CSC) are all examples of institutions that have recently established a Climate Service to provide advice for customers, primarily within their respective nations. The central focus of each Climate Service is on translating climate model projections into usable formats to inform a wide range of decisions and applications.

In order to provide usable climate model information, many groups have advocated the use of higher spatial resolution modelling (both horizontal and vertical) to improve the realism of model results and produce more reliable information; especially in acknowledging the needs of the insurance sector (Strachan (2007b), HM Treasury (2009)). However, given the complexities of the system under investigation, there is no guarantee that higher resolution information will reduce uncertainty in climate model projections. As noted by Allen et al. (2000), it is possible that uncertainty may increase when resolving finer scale processes by reducing the number of modelling assumptions. Maintaining a dialogue between climate modellers and the user community is therefore essential to ensure that users understand how uncertainty arises and why future generations of climate models might increase, rather than decrease, the uncertainty. Moreover, any apparent reduction of uncertainty resulting from increased model resolution may be a consequence of limited computing capacity available to explore uncertainty.

The advance towards higher resolution models is driven, in part, by the belief that higher resolution models are able to better represent extreme weather. Given the relevance of information about extremes to many decision makers concerned with adaptation to climate change, improving the theory of how extreme weather will be affected in a changing climate is clearly a worthwhile endeavour. The IPCC has recognised the need to focus on extreme events and in a future special report[6], the IPCC will specifically address the management of

[2]World Climate Conference 3: Geneva, Switzerland, 31 August to 4 September 2009. Available at http://www.wmo.int/wcc3

[3]Available at http://www.metoffice.gov.uk/services/climate-services

[4]Available at http://www.climate.gov/#climateWatch

[5]Available at http://www.climate-service-center.de

[6]Further details available at http://www.ipcc-wg2.gov/AR5/sr.html

extreme risk with reference to the latest available science (IPCC (2009)). However, increasing model resolution to improve projections of extreme events inevitably leads to escalations in computational expense so a balance needs to be struck between resolving small scale processes and the need for large ensembles to explore uncertainty. This thesis aims to inform the debate regarding the tension between the need for increased model resolution and the need for a more rigorous exploration of uncertainty.

1.4 Modelling by Analogy

Key to aiding the communication process, not only between modellers and policymakers but also amongst climate scientists, is establishing a conceptual basis for understanding the meaning of climate under climate change. Given the complexity of GCMs, let alone the complexity of the real climate system, insights from simpler models may therefore help in illustrating the notion of climate in a model which exhibits climate change. In this thesis, low-dimensional models, which have features analogous to the climate system, are investigated to provide insights to inform the analysis of the more complex models that are used routinely to guide adaptation decisions.

Climate models will never include all of the physical processes that can influence the evolution of the climate system. Ultimately, there will never be a perfect model of the climate system and in reality, all models are wrong (Smith (2000)). The best climate modellers can do is select the dominant processes and model them at the relevant spatial and temporal scales to provide information which is fit for purpose. By doing this, it ought to be possible to determine for which phenomena and on which time scales climate models might reflect reality (Smith (2002)).

Climate model projections inherently provide imperfect and incomplete information but used appropriately, models can be an important tool to inform the decision making process. Understanding the ability of complex climate models to explore uncertainty is therefore crucial in establishing what constitutes the appropriate use of climate model projections. By understanding and interpreting the behaviour of the simple analogous models, one can begin to understand the capacity of complex, computationally expensive models to sample the different sources of uncertainty associated with climate change prediction. It follows that analysing low-dimensional nonlinear dynamic models makes it possible to develop hypotheses regarding the predictive capabilities of more complex climate models of much higher dimensionality. Smith (2002) states:

> "While it is unreasonable to expect solutions to low dimensional problems to generalise to million dimensional spaces, so too it is unlikely that problems identified in the simplified models will vanish in operational models."

The use of simple models in this thesis therefore has a dual purpose: providing a means to develop a conceptual understanding of climate under climate change and also to explore the role of different types of uncertainty in the predictability of the climate system.

1.5 The Insurance Industry

Insurance provides a financial mechanism for individuals and businesses to protect themselves against risk. Policyholders pay a premium to an insurance company which indemnifies (compensates) the policyholder in the event of an incurred loss. The insurance industry is the world's largest industry worth an estimated $4.1 trillion in revenues in 2009 (TheCityUK (2010)). The success and sustainability of insurance therefore has significant implications for society and the global economy.

Mills (2005) stresses the importance of climate change to the sector, explaining that virtually all insurance business lines are vulnerable to the impacts of climate change. As the industry attempts to understand the consequences of climate change for specific business practices, insurers are becoming increasingly interested in the ability of climate science to provide information to estimate changes to weather- and climate-related perils. Given the large loss potential associated with insurance portfolios which cover extreme weather events, such as Atlantic Hurricanes, insurers and reinsurers (who effectively insure insurance companies) are particularly concerned with the trends in the frequency and magnitude of extremes and rare events. (Re)insurers are therefore beginning to develop partnerships with academic institutions and climate scientists to further understand the uncertainties and challenges associated with providing usable information to inform insurance decisions[7].

The research conducted in preparation of this thesis was supported by Lloyd's of London. In collaboration with the Emerging Risks team at Lloyd's, research was undertaken to understand the long-term strategic issues facing the industry which could be informed by the appropriate interpretation of climate model output. As a facilitator for the London insurance market, individual syndicates benefit from the impartial research conducted by Lloyd's, which is made available to the entire market.

1.6 Research Aims

In combining research into the fundamental principles associated with climate predictability, provided by the experiments on simple dynamic models, with research into the use of climate model information by the insurance industry, and more generally the adaptation community, this thesis attempts to contribute to the bridging of scientific endeavours with societal needs. Specifically, this thesis aims to address the following questions:

- What are the climate model information needs and desires for strategic decision-making

[7] Examples include the Willis Research Network (see http://www.willisresearchnetwork.com/) and the Lighthill Risk Network (see http://www.lighthillrisknetwork.org/).

within the insurance industry and are the current generation of climate model experiments capable of providing such information?

- How should climate be defined to best address the needs of the climate change adaptation community?
- Is the ergodic[8] assumption valid for a climate system subject to altered forcings?
- Is the future climate dependent on the pathway of the forcings?
- How should climate model experiments be designed to explore the full range of climate change uncertainties?

While exploring these specific research questions, this thesis investigates both the conventional paradigm in which long-term climate prediction is treated purely as a boundary value problem (as opposed to an initial condition problem) and the justification of the ergodic assumption inherent in the current design of climate model experiments. The analysis presented in later chapters is designed to provide insight regarding these two distinct notions. In the idealised model experiments, situations in which the ergodic assumption breaks down are illustrated and the relevance of these findings for understanding the validity of the ergodic assumption in climate prediction are discussed. Furthermore, by exploring the role of IC uncertainty in low-dimensional models, results support the view that climate prediction ought to be treated as both an initial value problem and a boundary condition problem for time scales relevant to climate change adaptation.

Given the broad scope of the research topic, this thesis does not attempt to provide answers which apply to all climate change adaptation applications and all business lines within the insurance sector. Nevertheless, it does represent an important step in re-focussing the attention of the climate modelling community in providing model output which is fit for purpose and addresses user needs.

1.7 Thesis Outline

This thesis consists of six further chapters. Chapter two provides background information and a literature review, related to the aims described and the themes outlined in this introductory chapter. In chapter three an analysis of the Lorenz-63 model is presented to generate insight regarding the meaning of climate under climate change. The experiments conducted explore the impact of fluctuating model parameters and initial condition (IC) specification. Chapter four extends the methodology to the Lorenz-84 model. Building on the concepts explored in the previous chapter, the analysis focuses on the impact of transitive[9] and intransitive[9] behaviour in the modelling of climate. Experiments using the Lorenz-84 model coupled to the Stommel

[8]Definition in section 2.1.4 and in the glossary.
[9]Definitions provided in relevant chapters and in the glossary.

ocean box model are presented in chapter five to further extend the analogy to the climate system, combining two dynamical systems operating on different time scales. The notions of ergodicity and transitivity are again explored in the context of climate predictability for climate defined as distribution of model states. Chapters three to five contain the body of results which are used in determining the necessity of exploring IC uncertainty in climate prediction. Chapter six however, focusses on the policy dimension of the research. The narrative attempts to address the needs of insurers, tasked with responding to climate change, with the insights gained from the exploration of climatic uncertainties using analogous simple dynamical models. The chapter includes a case study illustrating the potential application of Bayesian Networks (BNs) to translate climate model output into a usable format for addressing insurance decisions, specifically in relation to the emerging area of index-based microinsurance. Finally, chapter seven provides a discussion of the thesis results. The discussion centres on the appropriate design of climate model experiments to address user needs, particularly in the insurance sector, whilst acknowledging the multiple sources of climate change uncertainty explored in this thesis.