Chapter 1
Introduction

Mike Harrison, Alberto Troccoli, David L.T. Anderson, and Simon J. Mason

Humanity recognised millennia ago the importance of climate variability to the sustenance of life, whether that variability was expressed in the form of droughts, floods, heat, cold, or wind. Coping strategies, developed to handle the consequences of climate variability, helped ensure mankind's survival, although the historic record indicates that not all societies successfully overcame past challenges imposed by long-term droughts, extensive flooding, and the like. Early coping strategies included migration, invasion, appropriation and storage. In addition many, probably most, perhaps all, societies developed indigenous knowledge or belief systems that they felt enabled them to foresee or control those elements of the climate that are so critical for maintaining water and food supplies.

Much has changed for modern societies, with coping strategies such as migration, invasion and appropriation frequently constrained by international boundaries and laws. Indigenous knowledge still plays a major role in many societies, while new structures, often under the umbrellas of the United Nations or national Aid Agencies and Non-Governmental Organizations (NGOs), provide safety nets for those countries currently unable to manage the consequences of climate variability without support. In the developed world, numerous technological advances, including new crop cultivars, integrated approaches to water management, improved drugs and disease control methods, such as for malaria, have introduced major new components in the management of climate risks, although not to the extent that any country has become fully shielded. Nevertheless climate variability in the developed world is more often an irritant than a hazard to life; in fact at times it is viewed as a business opportunity. In many countries, however, climate variability may still threaten life, and, if not, might at the least pose difficult challenges in regards to economic development, individual climate events occasionally resulting

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Mike Harrison
Independent Consultant

Alberto Troccoli and David L.T. Anderson
European Centre for Medium Range Weather Forecasts

Simon J. Mason
International Research Institute for Climate and Society

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in economic consequences of magnitudes comparable to individual countries' Gross Domestic Products (GDPs), with several years of re-development often necessary in such instances.

Included amongst the technological advances that have led to increased resilience against climate variability are remarkable achievements in the understanding, monitoring and prediction of climate variability itself, in tandem with developments that significantly aid planning and management, including improved cultivars and cropping methods, new water storage and distribution methodologies, facilitation of international food transportation and storage, and so on. Technology has become an important instrument in protecting against, mitigating, planning for, as well as in the direct management of climate risks, and will continue to be so in the light of future natural and anthropogenically forced climate change. It has been suggested that while management of the risks of climate variability might be managed with current technology, and while these technologies themselves will make substantial contributions to preparations for climate change, new technologies will be required for the full future management of climate variability under a changed climate. At this time, however, for many countries the more immediate challenge is to manage current climate risks both as one key input to sustainable development and as a significant contribution to preparations for a future modified climate.

Within this book we will be focusing on one of the new technologies emerging in the search for improved management of the risks associated with climate variability, namely seasonal to interannual prediction. Prediction, used as one input to preparing for and managing the risks of climate variability, is in itself not a new concept; indigenous methods, normally based on the behaviour of local flora and/or fauna, and/or on belief systems, have flourished around the world and have provided societies with foresights over numerous centuries. Modern systems of prediction, whether based on straightforward empirical links between climate and certain slowly varying aspects of the geosystem, more often than not sea surface temperatures in tropical ocean basins, or on advanced numerical, computer-based models of the geosystem itself, are, however, relatively new, although the genesis of these models may be traced back over the past 100 years.

In principle, modern seasonal to interannual predictions are an answer to the needs of many whose activities are influenced in some manner by climate variability, whether this is in terms of creating profit through the marketing of an appropriate range of goods, or is in terms of critical decisions regarding agriculture and food security. Much of the later body of this book is devoted to exploration of the extent to which current state-of-the-art predictions address the requirements of those who have responsibilities for taking decisions in regard to climate-linked activities, to the impediments, and to the opportunities available. Various examples are provided of the way in which the systems that deliver climate prediction information have been set up and of the benefits achieved.

Earlier chapters of the book are devoted to the science and technology behind the predictions. For the science of seasonal to interannual prediction 1997 was perhaps one of the milestone years. During 1997, amongst other pertinent events, long-term operational support for the Tropical Atmosphere Ocean (TAO) array[1] was authorised by the US Congress, many prediction models of different types became available to take advantage of the information provided by the array, and one of the most significant recorded El Niño events developed to bring its particular signature of climate variability to many parts of the globe. But to understand the significance of 1997 we need to wind back a little, and to consider the lives of communities along the equatorial west coast of South America, particularly around Ecuador, Peru and northern Chile, in previous centuries.

Much of the equatorial west coast of South America is dry in most years, with fishing, particularly for anchovies, providing major sustenance during past eons. Nowadays the story is well known of how the anchovy fisherman around the Gulf of Guayaquil noticed every few years that the fish stocks appeared to disappear for several months at a time, with resultant deleterious impacts on food reserves. At the same times heavy rainfall would strike the area, leading to flooding and wash-aways of crops and mud-built houses. Because these events typically began around Christmas, the fishermen named them ‘El Niño’, after the Christ child. But the fishermen were not the first. At least the Incas, who had never heard of El Niño, recognised its consequences for their food security. Consequently they farmed diverse stocks at different altitudes in the Andes, experience having indicated that rarely was there simultaneous failure of all stocks.

For many years the concept of El Niño was little more than a scientific novelty, studied by few. Even when in the earlier years of the 20th century Gilbert Walker undertook his ground-breaking research into the causes and prediction of the Indian monsoon, and in doing so uncovered the great ‘atmospheric see-saw’ of the Southern Oscillation, the significance of these discoveries, and their relationship to El Niño, was not appreciated. Probably the first El Niño event that drew wider attention was that of 1972/73, which was followed by several scientists building on earlier pioneering work to begin suggesting in the wider literature that El Niño was not something that just affected Ecuadorian and Peruvian anchovy-fishing communities, but was part of a much larger occasional climate anomaly that affected communities in many parts of the world. By the time the large-amplitude 1982/83 event occurred, far greater numbers of scientists were recognising that a breakthrough was being made in regard to understanding and predicting the climate system, and from then on a new ‘industry’ was born: an industry that covers the physical understanding, the consequences for predictability and prediction, and the onward use, including the politics, of the predictions, all of which are inherent in the slow changes in the planetary surfaces underlying the atmosphere.

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[1] A network of moored buoys across the tropical Pacific Ocean that delivers via satellites the monitoring information of both the atmosphere and the ocean (to 500 m depth) on which the models and predictions depend.

The basis of this burgeoning industry is that slowly varying components of the geosystem, most significantly sea surface temperatures across tropical ocean basins, can impart a ‘memory’ to the atmosphere in the vicinity of any such long-lived anomalies. And further that the atmosphere works in such a way that this ‘memory’ can be transmitted to parts of the globe remote from the originating sea surface temperature anomalies – meteorologists refer to this phenomenon as ‘teleconnections’. Thus, for instance, El Niño events are *typically* (see caveats later) associated not only with heavy coastal Ecuadorian and Peruvian rainfall, but with above-average rainfall also in northern Argentina, in East Africa, and in California. Equally, contemporaneous drought can occur in north-east Brazil, in southern Africa and over much of Australia. Climate forcing of this type is not restricted just to changes in the tropical Pacific basin, although as far as is known these are the most important; the other two ocean basins play their own, more limited, roles, as do other slowly varying aspects of the geosystem underlying the atmosphere, such as soil moisture anomalies over various continents and snow extent over Eurasia.

El Niño, and its related cousin La Niña, represent major changes in the distribution of sea surface temperatures across the tropical Pacific basin, with warmer waters spreading eastward towards South America from their usual position in the west of the basin during an El Niño. Anchovies thrive in the cold current running northwards along the west coast of South America, but during an El Niño this cold current becomes overlaid by the warmer waters, and the anchovy descend towards the colder nutrient-rich waters below.[2] For the fishermen the anchovies have disappeared; in practice they are thriving deeper within the ocean than usual, beyond the reach of any netting system.

Once scientists began to recognise the significance of events in the Pacific basin, the next stages were to understand the mechanisms involved, to model the pertinent aspects of the geosystem, and to determine if prediction might be possible based on this new knowledge. Arguments still exist over the precise mechanisms involved in El Niño events, but the basics are understood, as is demonstrated within this book. Many models of varying complexity have been built to understand the system. And many of these same models have been used to provide predictions. The advances in this field over the past 30 years are spectacular. These advances benefited enormously from the TAO array and other observing systems, both in situ and satellite-based.

Building on developments that have resulted from the recognition of the importance of, and the growing understanding of the dynamics of El Niño events, in this book we cover: overviews of the climate system and the manner in which it works; current capabilities to model and predict the climate system out to several months

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[2] During La Niña events waters along the western South American coast become colder than usual and in the eastern tropical Pacific warmer than usual. During La Niña events climate anomalies worldwide tend to be amplified in a canonical pattern roughly the reverse of that for an El Niño event, but in this case the anchovies remain near the surface.

based on the ability to simulate ocean circulations in the Pacific basin and elsewhere; the manner in which the information produced by the models is treated and delivered; and finally the ways in which this information is used in decision making in numerous activities. It is a story of success, but it is also a story of complexity in several senses, complexities that need further resolution if the full benefits of the scientific advances are to be obtained.

Complexities emerge in several ways. First, the geosystem itself is complex in the manner it works, including in the ways in which the various components interact with one another. One prime example of this complexity is that while El Niño is the major forcing known on timescales of a few seasons, it is irregular (events being separated by anything from 2 to 7 years), and, not being alone as a forcing mechanism, its influence might be overcome by other sources of forcing. Many around the Indian Ocean basin, for example, recall the 1997/98 El Niño event, sometimes referred to by meteorologists as the strongest on record, not for the canonical response expected (perhaps as during 1982/83) but for the deviations from that response. For example many areas were braced for droughts – southern Africa, India, parts of Australia – but rainfall was perfectly adequate in all of these despite the strength of the event. Equivalently in East Africa above average rainfall is the canonical response, but there was no expectation of the devastating amount of rain that fell at that time (Fig. 1.1). These differences from the best-wisdom canonical response were attributed to unusual and strong sea surface temperature anomalies across the tropical Indian Ocean, anomalies not always fully incorporated by the prediction models then available. Assumption of canonical responses with regard to climate variability is unlikely to represent the safest available approach.

Scientists have not unravelled the complexity of the geosystem in full, and models remain relatively simplified approximations of the real world. Hence any predictions from these models cannot be perfect as the models themselves are not perfect, but there is a further crucial aspect of complexity here in that the models are sensitive to various small changes in values of observations used in the initialization stages, and to aspects of their own formulation in detail, sensitivities that can lead to entirely different predictions when brought into play. Scientifically sensitivity to small differences in starting positions is known as ‘chaos’; chaos, which strictly refers to the characteristic of non-linear systems at certain (but not all) times to be markedly dependent on various relatively small differences, results in the inherent impossibility to predict the future in a deterministic sense at some, and in general for seasonal predictions at all, times – only probabilistic predictions are appropriate for chaotic systems. Most modern prediction approaches acknowledge chaos and produce probabilistic forecasts, but the delivery and interpretation of probabilistic forecasts introduces further issues. Ultimately the information produced by the models is incorporated into decision processes relevant to managed systems which themselves often have chaotic or uncontrolled aspects. The entire system is one of complexity throughout, complexities that as yet are not fully understood nor managed.

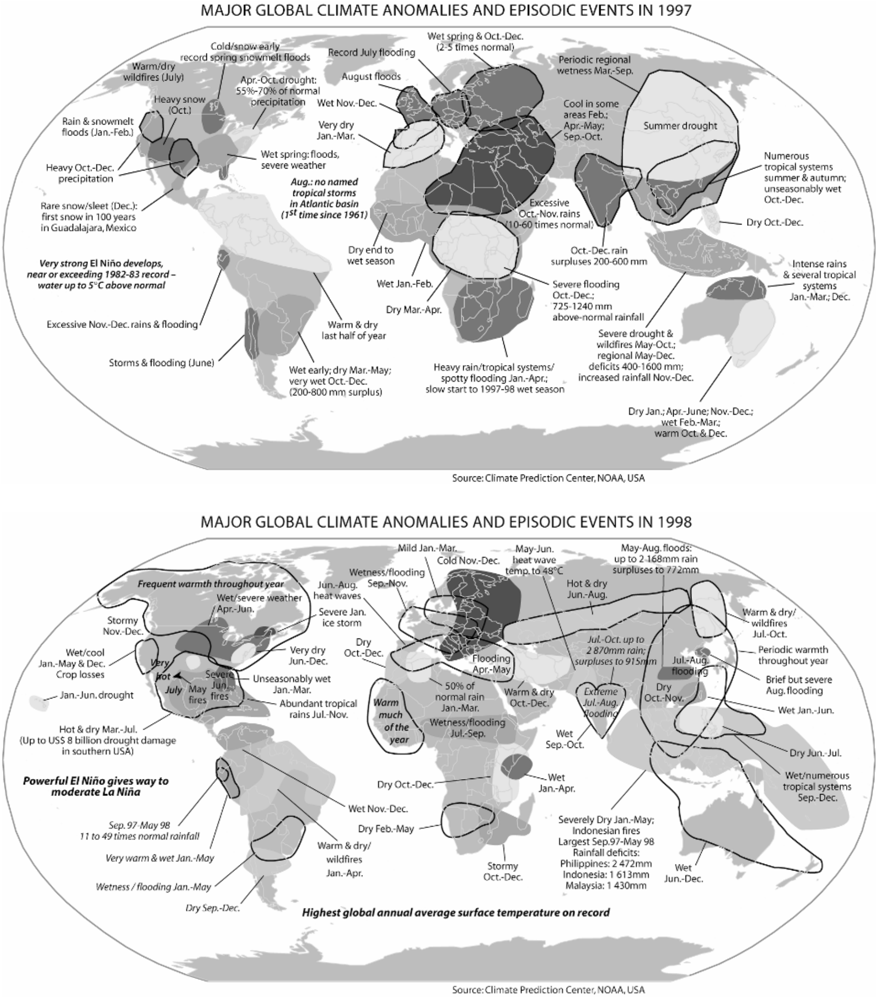

Fig. 1.1 Effects of climate variability during the years 1997 (top) and 1998 (bottom) which include (but extend beyond) the major 1997/98 El Niño event. Compare these effects with those during a 'canonical' El Niño year in Fig. 6.10. Careful comparison indicates that there were differences during the 1997/98 from those of the canonical expression, particularly around the Indian Ocean basin, including: more rainfall than typically occurs over parts of south-eastern Africa, a wet monsoon, and again more rainfall than typically occurs over northern Australia. Additionally rainfall over East Africa was far more intense than might have been expected. Strong anomalies of sea surface temperatures over the tropical Indian Ocean, contemporaneous with and perhaps related to those in the Pacific Ocean, have been identified as a possible cause (Adapted from WMO 1999, report No. 905)

Complexity is not assisted by the fact that the degree to which predictions can be made with success, even in a probabilistic sense and whether from statistical or from numerical models, varies geographically, it varies by seasons, it varies by forecast timescale, it varies by the variable being predicted, and it may exist only during specific ‘windows of opportunity’. Thus in general terms the highest predictability of atmospheric temperatures and rainfall exists across the tropical ocean basins, in particular that of the Pacific, and over certain land areas within or immediately adjacent to those basins. Predictability tends to decrease further away from the Equator and from the oceans, although some areas, such as North America, are favoured in certain seasons through enjoying higher predictability than similar regions at the same latitudes because of the manner in which teleconnections work in those areas. There is evidence that predictability in the global sense is higher during El Niño and La Niña events than otherwise, and that in some regions, such as Europe, it may not exist at times other than during these ‘window of opportunity’ events [but equally may not necessarily be high during specific individual events]. Temperature tends to be more predictable than rainfall. But even for the most predictable variable at the location with the highest overall predictability it is always necessary to provide probabilistic predictions. And with that comes the challenge of interpretation and of translation into effective decisions.

Many centres now generate predictions up to seasonal, and in some cases on longer scales, using dynamical models on either an operational or a regular research basis; many of these products are placed on either open or password-protected web sites. Dynamical models, being expensive to develop, maintain and run, are mainly the preserve of a relatively small number of meteorological organisations and universities. Broadcasting and distribution of these forecasts comes, in general but not universally, under the overview of the UN Specialised Organization, the World Meteorological Organization (WMO). WMO is coordinating the establishment of recognised Global Producing Centres as well as of Regional Climate Centres as centres of excellence to support climate services.

By comparison with dynamical models, developing and distributing predictions based on statistical approaches is relatively straightforward. Thus many national meteorological services, particularly most within Africa, that do not possess the resource to run dynamical models have created statistical modelling capabilities, either just for their own country or for wider areas, which form important bases for national prediction services. Most current evidence suggests that the qualities of predictions from statistical and numerical sources are competitive. It is possible also to combine statistical and numerical approaches, either in the prediction stage where one component is achieved through statistical means, or through the creation of a consensus of predictions from individual sources.

While there is a relatively small number of forecast producers, those interested in taking advantage of the predictions are globally widespread. Given that prediction skill tends to be highest overall at lower latitudes, with active advantage of that fact taken in Australia, the greatest concentration of users (Australia excepted) might be expected in developing countries, users with responsibilities ranging from international management of development, including issues such as food and water security, through all levels down to those taking decisions in the field. Climate-sensitive commercial interests are growing in the developing world, including from businesses based in the developed world. The three classic areas of interest (but numerous others exist) are agriculture, water resources and health, all of which are covered in this book in some detail. At higher latitudes, where skill levels tend to be lower, the greatest number of users are probably those with commercial interests, with government planners a second important interested group. In all cases the available evidence suggests that the costs of developing and maintaining the forecasts are significantly outweighed by the benefits produced.

The book is laid out in five parts. In Part 1, a background to the science and to the use of the predictions in decision making is provided, in part through this introduction chapter. The scientific core is discussed in Part 2, in which focus is given to the workings of the climate system and to approaches to prediction, both dynamical and statistical. Methodologies for adjusting the prediction information that emerges from the various models so that that information is better tuned for later decision making, is covered in Part 3. Decision making and some specific uses of the prediction information are discussed in Part 4, while loose ends and views to the future are drawn together in Part 5.

To an extent the structure of this book is reminiscent of an end-to-end approach to the production, delivery and use of the prediction information. In other words it might be viewed as outlining a unidirectional system in which predictions are fed through necessary delivery stages for ultimate use in applications. There is nothing new in such an end-to-end approach, this having been the principal model for delivery of weather forecasts over many decades. The end-to-end principle was assumed in first attempts to deliver seasonal predictions in the 1990s and the early 2000s, it was the underlying paradigm for the creation of WMO's Climate Information and Prediction Services (CLIPS) and the US-based International Research Institute for Climate and Society (IRI), and it remains the assumed principle for a large body of forecasters and service providers. Experience has indicated, however, that because of the complexities of the systems involved throughout, the end-to-end approach is non-optimal, and new approaches/paradigms are being sought.

These new approaches are based on steadily improving understanding of the decision processes involved in the use of climate information. Decision processes vary significantly to the extent that a simple one-size-fits-all, end-to-end, approach to the delivery of climate services is frequently, in practice, unsatisfactory. From the most broad-brushed perspective, decision processes, and therefore the manner in which climate information should be delivered, vary between the developed world and the developing world, between commercial and development contexts, between sectors (agriculture, water, health and so on), and between the various levels at which decisions are made (from intergovernmental down through to the field level). End-to-end delivery of information might be appropriate in, say, commercial contexts, whereas different approaches are necessary for social and economic development contexts within the developing world.

The necessity for climate information providers to be sensitive to the specific decision needs within each context places an onus on those providers for customisation of services, an onus that requires close cooperation with those taking specific decisions. The IRI has changed its strategy to approach this challenge through integrated assessment of all information needs (not limited simply to climate information) within each context, with the expectation that lessons learned will ultimately lead to greater facility in optimisation of information delivery across countries, sectors, and so on. But this raises the question of identification, and nomenclature, of these decision makers. From the perspective of the end-to-end model the concept was simply one of delivery to 'end users' for use in their 'applications'. The new paradigm, covering intermediaries/recipients/decision makers/decision takers/stakeholders/end users, at the full range of levels, with responsibility for numerous decisions that often do not conform to the straightforward concept of 'application', has not yet generated an appropriate nomenclature that places all involved and their actions into clear context. Within this book the nomenclature used is variable as a result, although we try to be as consistent as possible, but should throughout be considered within the context of the new, evolving, paradigm. As will be seen, the learning process in service delivery is still at an early stage and is not covered in full within this book; the examples provided give insight, nonetheless, into contexts within which climate information is being provided and used. Undoubtedly service delivery is one area demanding active and creative consideration from those engaged within it.

The potential readership of this book is broad, covering numerous disciplines and levels of expertise. Climatologists with interests specific to atmospheric dynamics and numerical modelling cannot be expected to be expert in issues of communication nor of the behaviour of *Anophe les* mosquitoes and its links to climate and malaria. Equally agriculturalists may not be interested in the detailed structure of climate models. In order to assist those with the limited expertise in the contents of specific chapters, each chapter begins with a summary of its contents written in such a way as to be accessible to all readers. A list of references is provided at the end of the book, including a separate list for further reading of interest to both specialists and non-specialists. Also, two glossaries have been included to assist all readers, the first dealing with acronyms and the second with terminology.

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