Chapter 2
Seasonal Forecasts in Decision Making

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A new and developing vibrant science has been born capable of providing significant benefits to humankind, from development work aimed at sustaining and enhancing the quality of life to increasing the profits of commercial activities. At the heart of this science lies an improved understanding of the climate system, of its predictability, and of its links with natural and social systems. An overview of the integrated structures of these non-independent systems within the context of the new capabilities in seasonal to interannual prediction is provided in this chapter, including the fundamental interactions between the various systems, their natural complexity, the confusion that often arises between the terms 'climate variability' and 'climate change', and the essential role climate information, including predictions, plays in the management of risks associated with climate variability and change. There follows an introduction to decision making in which climate information is involved, including discussions on decision processes and communication, a brief history of relevant climate science, and an overview of political and social issues directly linked to climate. Finally, two perspectives are provided of activities that might benefit from decision making that takes advantage of climate information: first, a predominantly end-to-end perspective in which climate information is delivered directly to a particular application; second, a perspective where the challenge is to integrate climate information into the broader context of sustainable development. These two positions, direct delivery into specific decisions for 'private' benefit and information provision for the 'public good', perhaps represent the two ends of the broad spectrum within which this new science can contribute.

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2.1 Climate Variability and Change: The Overlaps and the Differences

2.1.1 About Systems

The process that starts with the generation of a seasonal to interannual prediction and ends with someone making use of the prediction is a road that takes us from the application of pure science in physical systems to the pragmatism of real-world uncertainties, via the practicalities of operational forecasting frameworks. The latter systems are arguably more complex and unpredictable than the physical systems from which we started.

In trying to deliver on the promise offered by scientific knowledge of climate, we must deal with several 'systems' – scientific, environmental, social and economic – not only how each functions in its own right, but also how they interface, overlap and interact with each other. From the pure scientific perspective some systems are simple and driven by a single dominant force or set of independent linear forces. Such systems are generally highly predictable, e.g. planetary motion where gravity is by far the dominant force.[1] On earth, forces are rarely independent of each other and are often non-linear. Sometimes there are only a few dominant forces that give rise to chaotic outcomes; such systems exhibit some level of predictability but also often have inherent and unpredictable instabilities. At the far end of the scale there are systems with many roughly equal forces at work, which lead to random outcomes. In random systems the predictability of any individual outcome within the system is virtually impossible to assess but statistics may still tell us quite a lot about how the system will behave as a whole.

Meteorologists, ever the pragmatists, have long recognised the uncertainty in their science and that there are good reasons for limits to the predictability of explicit outcomes of the non-linear systems that generate our weather and climate (Lorenz 1963). Yet by capturing the essence of the physics, dynamics and chemistry of the system and by exploiting the 'laws' of large numbers, meteorologists and climatologists have become adept both heuristically and mathematically in stretching the levels of useful skill towards the outer limits of predictability.

[1] However, when two nearly similar gravitational pulls act on a single body then the system can become unpredictable.

2.1.2 Climate and Weather

Climate is traditionally viewed as the integration 'upwards' of the characteristics of discrete weather events and variables over time and to some extent space; occasionally climate is described as 'the statistics of weather'. The corollary is that the components of global climate change should be manifest 'downwards' on all time and space scales. This critically important concept (Fig. 2.1) has only recently been recognised by those concerned with appropriate responses to climate change. Successful adaptation to climate change will not simply be a case of adding another row of bricks to a sea wall to stem sea level rise, for example, or building another dam to catch more water in a drier climate. The consequences of 'global warming' will not just appear as an inexorably rising graph of global temperature but will also be evident through a set of complex changes in the global circulations of the atmosphere and ocean that will arise, in part, because it is expected that the warming will be greater over the land than over the sea. In turn, this means that some areas will become drier or wetter than others, but not every year – just more frequently than before. It follows that in any given year the mix of weather patterns that a decision maker will have to deal with will also change.

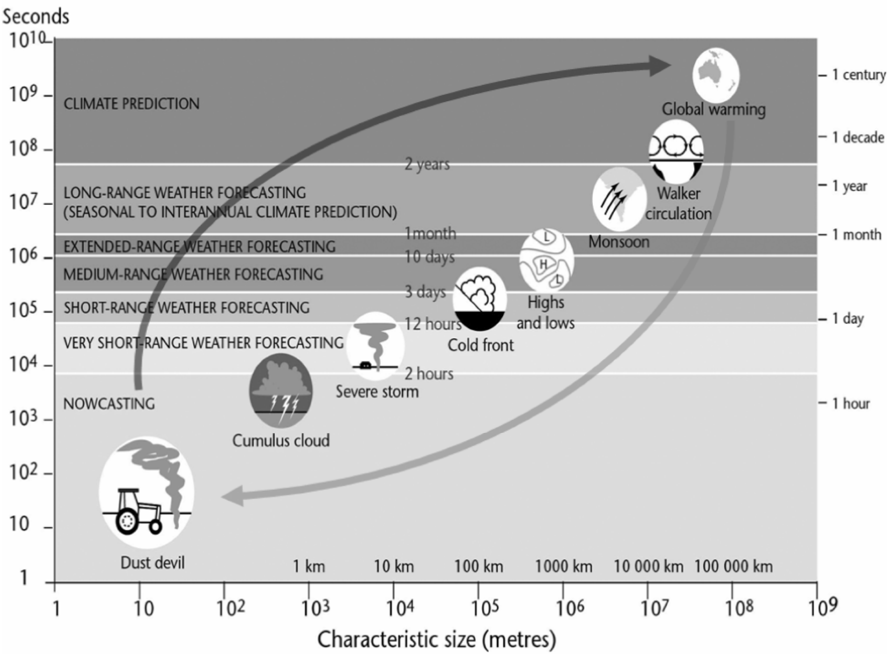

Fig. 2.1 Climate is traditionally viewed as the integration of discrete weather events and variables over time and space. The corollary is that the components of global climate change should be manifest 'downwards' on all time and space scales

Clearly then there is scope for adaptation to climate change on all time and space scales. Using the information that a seasonal to interannual forecast offers is as practical a response to climate change as it is to varying seasonal conditions.

The difficulty of distinguishing between ‘climate variability’ and ‘climate change’ has been addressed within the United Nations Framework Convention on Climate Change (UNFCCC) by constraining *climate change* to mean only that component which is directly the consequence of human activities, in particular the emissions of greenhouse gases, but also including land use transformations. All other components of change in the climate are referred to within the UNFCCC as natural *climate variability*. Note that these definitions are both independent of timescale, and thus change and variability according to the UNFCCC definition cover all scales from the very shortest to those acting over extended periods of centuries and beyond, the only difference being one of attribution, i.e. between natural and anthropogenic forcing.

This separation of change and variability is logical when viewed from a UNFCCC perspective, not least that natural climate variability cannot be ‘managed’ in the UNFCCC sense whereas management is possible to an extent for climate change as it is by definition human-induced. Two approaches to the management of climate change are envisaged within the UNFCCC: mitigation of emissions and adaptation to a changed climate. Within the UNFCCC context actions and funding regarding mitigation, with emissions taken as the main driver of change, become self-defining, and it is this perspective that provides the foundation for the UNFCCC definitions of change and variability. There is less clarity, however, when it comes to actions and funding for adaptation activities, which in the strictest UNFCCC sense should apply only to adaptation to whatever modulations on whatever timescales result purely from anthropogenic causes. In reality, such a partitioning is highly, if not totally, impractical as making a clear separation between weather and shorter scale climate fluctuations that are naturally forced from those that are anthropogenically forced cannot be made. Any adaptation responses, whether managed or endogenous, will need to factor in the integrated totality of fluctuations that have resulted from the combination of all sources. Management of the risks of climate variability on timescales of a season to a year are thus an inherent aspect of adapting to the consequences of climate change whatever the timescale. The contribution that management of short-term climate risk can make to the overall response to long-term climate change has generally been undervalued during the formative years of the UNFCCC. The broadening in recent years of the UNFCCC process beyond mitigation to embrace adaptation to a growing extent has led to a greater appreciation of the need to manage climate risks over all timescales including the vital contribution that seasonal predictions can make. Some of the tools that will assist in understanding and managing the consequences of the totality of climate variability and change, whatever the cause, are covered in this book.

2.1.3 *Adaptation, Climate Variability and Change*

Even if separating adaptation to climate variability from adaptation to climate change becomes problematic, as it will be in many practical instances, what are the main pathways for adaptive responses? Figure 2.2 suggests that climate science can tell us how 'forcing' within the climate system will produce or induce changes in weather and longer term climate patterns. Such outcomes will have their consequences or 'impacts', the severity of which will be determined by the level of vulnerability of a society or ecosystem that is sensitive to weather and climate. If the impact is sufficiently strong to elicit a response within the community, that response may take several forms. In the case of a serious or severe event that leads to a disaster, for example, the normal human response will be one of providing emergency relief to affected communities as quickly as possible. Experiencing an impact might lead one to attempt to do something about future levels of the undesired forcing. Experimenting with cloud-seeding to prevent damaging hail is one example of such a response on the shortest timescale. Efforts at mitigation or abatement of greenhouse gas emissions to forestall further global warming lie at the other end of the time spectrum. A further "lesson learned" response is to take adaptive measures that build resilience to future occurrences of similar events. Such responses would include building sturdier houses to withstand storm-force winds or even adding that extra row of bricks on the sea wall.

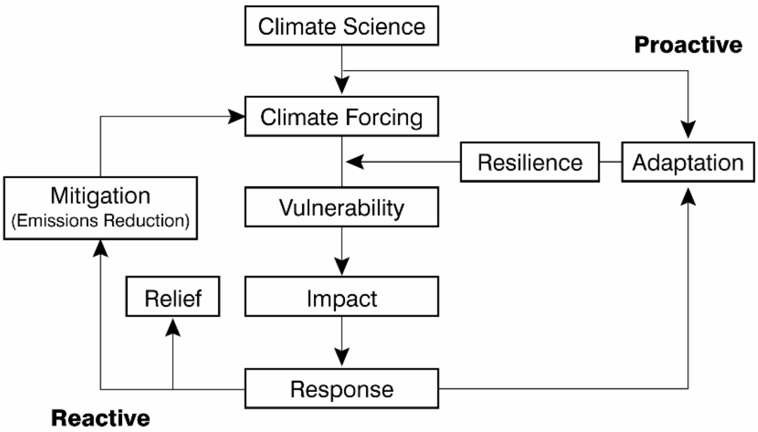

Fig. 2.2 Pathways for responding to climate variability and change. The central axis represents the sequence of a climatically forced event. The side arms provide optional actions to reduce the negative impacts of such events, either proactively with the application of scientific understanding or, in a more reactive sense, when the consequences of an event have already been experienced

So far, however, all the actions or responses discussed have been ‘reactive’, and follow once an event has occurred or begun to occur. Figure 2.2 suggests that climate science has the potential for providing a more proactive pathway to adaptation. Such a pathway provides opportunities for building resilience and hence reducing vulnerability to an event before it occurs. It is important to recognise that while reliable and useful prediction is a highly desirable tool to have at one’s disposal on this pathway it is not always necessary for deriving effective adaptation strategies. Even in the absence of any predictive capacities, statistical information about how the climate varies in time and space can be a powerful planning tool, at least so long as one is confident that the past climate is a good model for future climate.

2.1.4 Forecasts, Predictions, Projections and Scenarios

The rapidly growing societal awareness of climate change highlights a degree of terminological confusion within the broader climate community, not only among those interested in response and adaptation measures but also among climate scientists. Not entirely at one on how best to define the term ‘climate’ as it relates to the past and to the present, climatologists are faced with the need to describe what it means when one is talking a bout climate and climatic events into the future. The term ‘climate forecast’ seemed to suggest an extension of explicit weather type forecasts out to climate timescales, something that, as we have seen, is clearly not possible; the addition of the pre-fix ‘long-range’, as in “long-range weather forecasts”, did little to resolve the confusion on the shorter climate timescales. In fact the use of synonymic terms to define a range of very different concepts has left many scrambling to sort out the details, e.g. ‘projection’ as something distinct from a ‘forecast’ or a ‘prediction’, along with the now almost hackneyed term ‘scenario’. Figure 2.1 provides one attempt at a rational nomenclature, but the inclusion of climate projections and scenarios on this figure would probably require a third axis. Those with a sceptical bent on the climate change issue rose quickly to exploit some of this terminological confusion, despite the best efforts of the Intergovernmental Panel on Climate Change to have everyone reading from the same glossary (IPCC 2001).

In essence, all expressions of what the future may hold, whether they are called forecasts, predictions, projections or scenarios, embody degrees of uncertainty. Consequently, from a practical or even a basic conceptual point of view, it is the level of uncertainty that matters and not so much the exact meaning of the term being used.

2.2 A History and Status of Seasonal to Interannual Predictions in Decision Making

2.2.1 Introduction

From a practical perspective, there is only one reason for undertaking research and development to advance seasonal to interannual predictions and for investing in the infrastructure to produce and deliver them. That reason is to assist whatever decision processes are of concern to those who might make use of them. To be of real and measurable value, prediction information must be readily assimilable into the decision processes of recipients. In practice this goal may represent the ideal more than the complex reality, but it implies nevertheless that coordination between supplier and recipient is essential for the derivation of optimal benefit from the prediction information. Such optimal benefit is difficult to achieve in seasonal prediction:

- When information is couched in language that recipients find difficult to interpret – jargon such as "chaos", "probabilities", "terciles" and so on
- When the provider does not have a clear view of the needs of the recipient
- When the recipient does not have a clear view of the uncertainties inherent in the information
- Without adequate and ongoing coordination and dialogue between provider and recipient

The process of dialogue and coordination has been building for many years, but there remains much to be done in order to achieve optimal support for decision making.

Following the global emergence of seasonal forecasting after the commissioning of the Tropical Atmosphere Ocean (TAO) array, the first approach taken was to disseminate seasonal to interannual predictions in an "end-to-end" way. This process generally involves one or more forecast producers delivering predictions to one or a group of recipients within a specific sector, an approach adopted initially by both the World Meteorological Organization's Climate Information and Prediction Services (CLIPS) initiative and by the International Research Institute for Climate and Society (IRI).[2] This end-to-end process has been the traditional approach taken in the delivery of short-range weather forecasts, and therefore seemed a logical way forward. In practice end-to-end has proven often to be sub-optimal for seasonal to interannual predictions because of the intrinsic difficulties in linking the probabilistically framed predictions to many practical decision processes. The outcome to date, by and large, has been a mosaic of small projects,

[2] Originally named the International Research Institute for Climate Prediction.

with few that can be regarded as seminal to a more generalised approach. Translation of results between projects/sectors/geographical areas has proved to be difficult.

Recognising these difficulties, some organisations have developed strategies built around the concept of focussed solutions within particular sectors. In this approach attention is placed on the coordination of all activities within the delivery and application chain in order to develop a comprehensive decision making package that will benefit the stakeholders within a specific sector. For example, one pilot IRI project covered the management of water resources in two dams in Ceará (Brazil). Water from these dams was used for hydropower generation, for irrigation (during the greater part of the year when rain is not expected) and for general purposes, including industrial and personal, consumption. The project involved the generation of predictions on various timescales, the convening of several committees of users and water managers, the application of market forces, involvement of the insurance sector, and the creation and delivery of a tailored information package to all stakeholders. While not yet commissioned operationally, this project provides a cogent example of the type of innovative solution that might be applied elsewhere.

However, even this approach, which is still essentially end-to-end in concept, and similar such approaches, may not be sufficient to tackle the larger issues. As already mentioned, prediction, when available, is just a single, albeit important, tool in the management of climate risks. In a broader context the potential contribution of predictions lies in the need to manage climate risks on all timescales. This broader context includes the management of risks arising from climate change and desertification and, in a more political/social framework, the achievement of objectives such as the Millennium Development Goals (MDGs). It covers additionally incorporation and melding of sources of risk other than climate *per se*, and aspects of management of the totality of those risks, including development and administration of appropriate policies. All approaches require an outcome-oriented perspective of interaction of all involved disciplines with all users.

2.2.2 Decision Making

The decision is everything: without serving as a basis for decisions, seasonal to interannual prediction would be little more than a stimulating intellectual challenge. Yet providing information for possible use in making a decision is not of itself enough; that information should enlighten a new decision, confirm the validity of a decision already made, or cause the recipient to adjust a previous decision, if it is to have *value*. Without providing value, even the stimulating intellectual challenge is at risk.

The value obtained in practice can be determined in numerous ways, including through (but not restricted to) the form and quality of individual decision processes and the degree to which predictions are customised to those decision processes. High order predictions, such as ones for total agricultural production in a region, in principle offer the greater potential value as compared to those at lower orders, say the number of growing degree days during a season, or those at lower orders still, such as mean temperature and rainfall anomalies over a period. Most seasonal predictions currently offer only the lowest order of climate predictions, typically of mean temperature and rainfall anomalies, although there is expanding activity to support higher order predictions in certain geographical regions and sectors.

While predictions tend to possess a relatively monochromatic character, decisions in a complex environment come in a vibrant spectrum of forms and approaches. Few decisions are independent of others, and most are based on a range of information streams. Climate will generally be only one factor under consideration – see the example of Food Security in Fig. 2.3 – and may be perceived as not even particularly important. Predictions of first order variables such as rainfall and temperature, unless perceived, or ideally proven, to be of a quality sufficient to provide value, may receive less attention than basic climatic data, and less attention than other data streams informing a decision. Yet, in practice, relevant climate and other data are only infrequently supplied alongside the predictions themselves as part of a climate service. Similar arguments apply to predictions of second and third order variables.

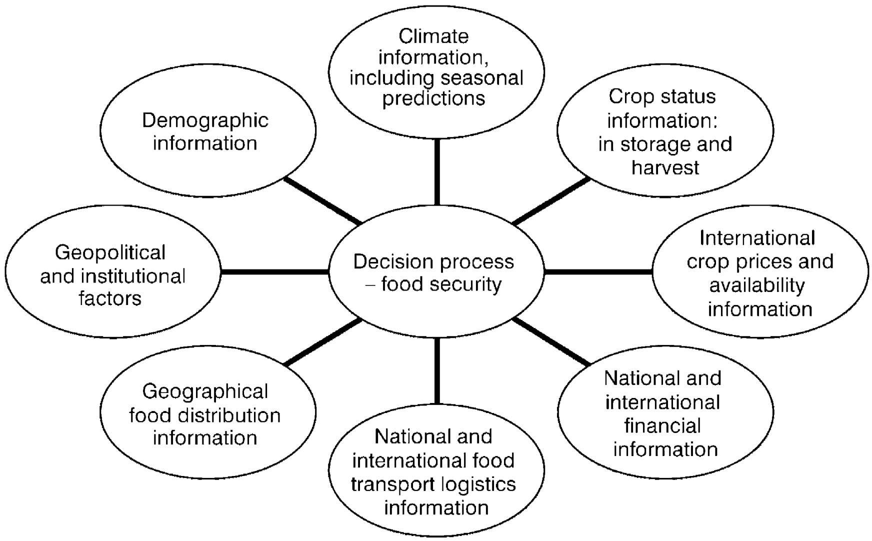

Fig. 2.3 A simplified example of information streams that might be used in a single decision process related to food security

Decisions are made within a rich continuum of overlapping domains involving sectors, cultures, economics and politics, as well as timescales. Numerous sectors are affected by climate variability, and indirect interactions can extend those affected into surprising areas. For example, most of the eight MDGs, even those not explicitly related to climate, can be detrimentally or beneficially influenced respectively by climate variability that undermines or supports the economic and/or political and/or physical infrastructure of a country. MDG No. 8, Develop a Global Partnership for Development, which covers mainly international trade and finance issues, is but one example. Most cultures approach decision making through their own time-honoured traditions, with many continuing to use indigenous knowledge developed over centuries to guide their day-to-day decisions. The economic, political and statutory backdrop to any decision can influence both the manner and the outcome of specific decisions. All such issues should be considered in order to deliver seasonal to interannual predictions tuned according to pertinent decision processes.

Even the matter of timing proves complex, as decisions are made on a wide variety of timescales, with a variety of lead-times, few of which will correspond neatly to the scales and lead-times common to contemporary prediction capabilities. There is often a tension between the window of opportunity for seasonal prediction that comes from sea surface temperature anomalies and the real requirements of the decision maker. It is this tension that organisations such as the IRI, the Australian Bureau of Meteorology (BoM) and the Queensland Department of Primary Industries (QDPI), for example, are attempting to address.

2.2.3 Communication

Effective communication between provider and recipient is an essential prerequisite for maximising the benefits from short-range climate predictions. Good communication, in both verbal and visual forms, needs to be appropriate to all stages of the process, starting with the initial introduction of predictions in specific decision making contexts, continuing through the period of forecast use, and then extending to the support necessary for further development in their application. Like most scientists, climatologists tend to use the jargon peculiar to their field. Recipients also tend to belong to particular disciplines or sectors, each with its own vernacular. The inevitable consequence is scientist-recipient communication at a sub-optimal level. This language problem certainly is not restricted to climate, but attention within the climate context could break down some of the perceptual barriers that cause predictions to be discounted or used ineffectively. Hence climate scientists have a fundamental responsibility to understand how their information is to be used, and to communicate their information in the language of that use. It helps if the recipients also have some understanding of climate jargon, but in practice this may not be necessary provided there is confidence in the information being received, a confidence more likely to grow given communication primarily in the vernacular of the recipient. Confidence is linked in context to credibility, credibility being gained through numerous processes including extensive experience of the quality of the predictions or of receipt of persuasive information confirming that quality, a requirement again demanding communication in a form suitable to the recipient. Unfortunately most training activities to date have focused on teaching recipients climate jargon, rather than on teaching climate scientists the essential language of recipients and the nature of their decision making processes.

Sitting alongside verbal communication is the powerful tool of visual communication. Data visualisation techniques have developed rapidly in recent years, particularly through the use of computers, and have made substantial contributions to the advancement of all sciences. Data visualisation can also be a potent means of communicating science and scientific information to the layperson. It is regrettable, therefore, that novel methods of communicating visual information on seasonal to interannual climate predictions that are readily accessible to recipients have been slow to develop and that, in general, visual presentations remain tied to the perceived communication needs of the climate scientist rather than to the actual needs of recipients.

Well-designed visualisations could play a vital role within the framework of specific decision processes:

- To help explain the science
- To provide climatological and other information
- To provide the predictions themselves of whatever type
- To provide information on the quality of the predictions (i.e. verification)
- To place climate information within the context of other information required for a decision

As yet, many predictions, together with any accompanying verifications, are made available in formats that do little to assist decision makers. Frequently complementary explanations are written in the jargon of the scientist rather than the language of the recipient. While it may be a difficult and slow process to improve the quality of the predictions themselves, much could be done now to improve the communication of them and their current levels of skill in ways that facilitate their incorporation into decision processes, with consequent rapid gains in the value of the predictions. Equally, well designed visualisations can be used to communicate to the climate scientist how decisions in recipient communities are made. Communication through an effective mix of enhanced verbal and visualisation techniques offers outstanding potential for major advances in targeting and improving the value of the forecasts.

2.2.4 A Brief History

Climate prediction, at least that covering the next few seasons, is one of the oldest professions, with known examples stretching back millennia. Life depends on climate, and decision making to sustain life requires methods of foreseeing climate aberrations that threaten life. The extant wealth of indigenous knowledge, built over many generations, has resulted in a complex of information still frequently used and implicitly trusted in many parts of the world. Not surprisingly this indigenous knowledge universally tends to be derived around seasonal changes in local flora and fauna, plus astronomical observations. Religion and other belief structures (including dictums and maxims) are added to the mix in many countries. Wherever indigenous knowledge is considered fundamental then the usefulness of any new information source naturally will be first judged against this; it is conceivable, of course, that such comparisons may be biased. Nevertheless the existence of a culture of indigenous knowledge provides an opportunity for the climate scientist to introduce new techniques in a sympathetic and synergistic manner.

While a rich global history exists of attempts to predict weather in coming seasons, it is generally agreed that modern seasonal to interannual prediction originated in the work of Sir Gilbert Walker, tasked while Director of the Indian Meteorological Service in the early years of the 20th century with predicting the monsoon in order to bolster food security for the subcontinent. Indian food security in practice has come through the coordinated planning of resources over a few years, rather than through Walker's work. However Walker's legacy lives on through both the world's longest-running statistical seasonal prediction system, as maintained by the Indian Meteorological Department (IMD), and his identification of the Southern Oscillation, the great "see-saw" in atmospheric pressure differences between the South Pacific and the Indonesian region. It was to be several decades before the relevance of Walker's work was to be recognised in full, but his work provides the observational foundation for most modern approaches.

By the 1970s a few scientists were beginning to recognise the relationship between the Southern Oscillation and El Niño (to be discussed in Chapter 3), a periodic warming of sea surface temperatures along the equatorial Pacific South American coast, and further to acknowledge the societal impacts of individual El Niño events. With that progress came evidence of the general potential for sea surface temperature anomalies, primarily but not uniquely tropical, to influence remote climates on seasonal timescales. Although the 1972/73 event created a stirring of interest, it was the 1982/83 event, with its "classic global climate anomaly configuration" (also known as teleconnection pattern and shown in Fig. 6.10 later in the book – compare it to the main climate anomalies for the 1997/98 ENSO event in Fig. 1.1), that propelled El Niño into global prominence. That event transformed the agenda of the First International Conference on Southern Hemisphere Meteorology, coincidentally held during August 1983 in a Brazil feeling the full impacts of the event from flood rains in the south to drought in the northeast. The event also set in train an industry building statistical prediction models based on links between rainfall and anomalous sea surface temperature patterns, an industry that continues today alongside the sophistication of the global coupled climate models, the former providing benchmarks for skill assessments of the latter.

Gilbert Walker worked from an entirely pragmatic base, and that same pragmatism has been the main driver for new investment in prediction infrastructure. Certainly influential theoretical work, such as that undertaken in the USA through the 1980s and 1990s by Peter Lamb and associates (Mjelde et al. 1993, and references therein), suggested that the financial returns to be expected from seasonal prediction could be substantial. Practical experience, such as that gained in the 1990s using seasonal predictions in the Nordeste region of Brazil, an area with some of the highest seasonal rainfall predictability anywhere, supported the theory.

A further boost to information delivery was given by the major 1997/98 El Niño event, which happened to coincide with the commissioning of the TAO array of moored buoys straddling the equatorial Pacific, with the maturation of the numerous ocean prediction models using TAO data, and with the first of the Regional Climate Outlook Forums (RCOFs), held to deliver information into tropical countries most influenced by El Niño events.

However progress since has been more constrained than appeared to have been promised by these early successes. A number of dramatic predictions of the consequences of the developing El Niño event openly and widely broadcast in 1997, often taking advantage of the emergence of the Internet, were felt to have been incorrect. The 1997/98 event, although unarguably one of the largest on record in terms of its intensity and effects, failed to impose the 1982/83-style "classic global climate anomaly configuration" on which these predictions were based. Confidence was eroded and questions were raised concerning the free and open distribution of independent and sometimes contradictory predictions. Scientists pressed the need for presenting predictions as probabilities, a concept that immediately raised a barrier to understanding and acceptance for some users. And recipients did not always gain the assurance necessary to incorporate this new prediction information into their decisions; many recognised that a false decision might have long-term effects that might be difficult to reverse. In the worst cases gambler's ruin beckoned. The initial positive results from the Brazilian Nordeste proved difficult to duplicate even in this same region, with later spectacular forecast failures in the region severely denting confidence (Lemos 2003; Meinke et al. 2006).

The science has now entered perhaps a period of consolidation. There is no doubt that the predictions have measurable skill in the technical sense, and experiments such as PROVOST and DEMETER have demonstrated certain levels of technical skill beyond the preliminary expectations of participating scientists (for example over Europe, where earlier research had indicated minimal, if any, predictability). Prediction models continue to be improved, new sources of prediction skill are being examined – in part through the COPES (Coordinated Observation and Prediction of the Earth System) experiment in which research into seasonal predictability originating in land surface soil moisture, ice cover and stratospheric circulations is being assessed – and new activities generated to introduce prediction information to additional user groups and sectors. Yet, as indicated earlier, it remains unclear that maximum value is being extracted from the current skill levels of the predictions. In part the apparent lack of value in seasonal forecasts almost certainly results from non-optimal incorporation of climate information into the decision matrix of climate-sensitive enterprises. Therein lies a key to the delivery of the societal benefits inherent within the science.

2.3 Climate-Related Decision Making Under Uncertainty

The proposition that, from the societal point of view, decision making is the ultimate goal of seasonal to interannual climate prediction has been emphasized already. It has also been highlighted that climate predictions – and climate information in general – will be just one component in most decision making processes (see Fig. 2.3). Most important of all, however, is the fact that climate prediction is inherently probabilistic in nature and probabilities always indicate uncertainty in the final outcome (this fact will be stressed many times throughout the book). Decision makers who make use of such predictions need to factor in this intrinsic uncertainty. Defining a practical framework for taking uncertainty into account in order to assess the level of risk associated with decision making processes is the subject of this section.[3] Such a framework is based on decision analysis, a subject developed under the discipline of decision theory.

Decision theory is a body of knowledge and a related set of analytical methods of different levels of formality designed to assist decision makers in choosing a course of action from among a set of alternatives through a careful consideration of the possible consequences of each alternative. In turn, decision analysis is essentially concerned with breaking complex problems into manageable parts, by adopting the 'divide and conquer' approach. A large body of work has been developed in the field of decision analysis, and only its surface will be scratched here. A good reference for a deeper understanding of the subject is provided by Goodwin and Wright (2003).

Two of the most important tools in decision analysis are decision tree diagrams and influence diagrams. These are two tools that attempt to model the decision making process by illustrating graphically the alternatives, uncertainties, risks and

[3] The concepts of risk and uncertainty, while related, are very different: uncertainty involves variables that are constantly changing, whereas risk involves only the uncertain variables that affect or impact the system's output directly (Mun 2004). Note, however, that not everyone finds uncertainty, and its associated probabilities, easy to incorporate into their decision making processes.

objectives of the problem at hand. By offering a visual representation of the decision problem, these tools are helpful in clarifying the various steps in the decision process in ways that can lead to creative thinking and to the identification of issues not previously considered. These features make these two diagrammatic approaches appealing to decision makers faced with complex decisions. Decision making in general involves multiple objectives as well as multiple stakeholders. In order to simplify the treatment, only a single objective and a single stakeholder are considered here.

The decision tree diagram is a flow diagram that includes the timing of decisions, coverage of uncertainties, and quantification of each possible decision. Once the objective of the decision has been identified, the decision tree analysis requires five steps:

1. Determine all possible options and risks related to the problem
2. Calculate the consequences of all options
3. Determine the uncertainty associated with each option
4. Generate a tree diagram using the information from the first three steps
5. Assess the best course of action

In societies that are driven mainly by economic considerations, the numerical quantity that expresses the objectives of the situation, and summarises the outcomes of all the options, is money. In principle, however, there is no reason why other quantities could not be used; for instance the number of people at risk of starvation due to a possible drought, or measures that are problematic to quantify, such as the effects on the environment of particular management options (e.g. desertification, salination, erosion, etc.).

The graphical representation of a decision tree diagram is made up of activity forks or decision nodes (a square) and event forks or chance nodes (a circle). The use of a triangle to terminate a branch in the tree is customary. An activity fork is used when a definitive decision amongst two or more options is required, whereas an event fork is used when the option is subject to uncertainty. Given the complete tree diagram, the best course of action is determined by considering the implications of each option starting from the right of the diagram and moving to the common start of the tree, towards the left. This process of evaluation of the best action plan decision is referred to as “folding back” or “pruning” the tree.

Referring to the food security example (Fig. 2.3), it is possible to construct a highly simplified decision tree diagram by considering only three information streams: “Crop status information”, “Climate information, including seasonal prediction” and “International crop prices and availability information”. Imagine the following situation: one million people may be at risk of starvation – the risk is dependent on the amount of food in the reserves and on the predicted climate conditions. In order to decide on the best course of action (i.e. to reduce the risk of starvation by providing the population with sufficient food for the coming season) a decision tree diagram might be built, as in Fig. 2.4. If the crop reserves are sufficient, then no action is required.[4] However, if reserves are insufficient available options need to be assessed. It is assumed here that the only two accessible additional pieces of information are a seasonal climate prediction and international crop prices. The climate prediction offers a 30% chance that rainfall will be sufficient to produce enough crops to meet national demands. For crop prices there are two options: one is to buy crop in advance, the other is to buy it after the cropping season has started. In the former case the cost is, say, €10 million, in the latter €30 million. So, for unfavourable predicted climate conditions, the options are to buy now and spend €10 million or buy later and spend three times as much. In the case of favourable conditions, the options are to buy now or to hedge, e.g. by purchasing insurance or by buying part of the crop that might be needed. In the case of hedging, it is assumed that costs of either alternative are €2 million.

The best course of action is then given by the branch with the associated lowest expense or, in the commercial parlance, the largest profit. By "pruning" the branches of the tree, one obtains the monetary values as presented. The only value which needs some explanation is €7.6 million. At each node, the value before that node is calculated by considering the probability of each branch following the node. This probability is multiplied by the amount on the corresponding branch and then summed over the contributions from all branches. In this case there are

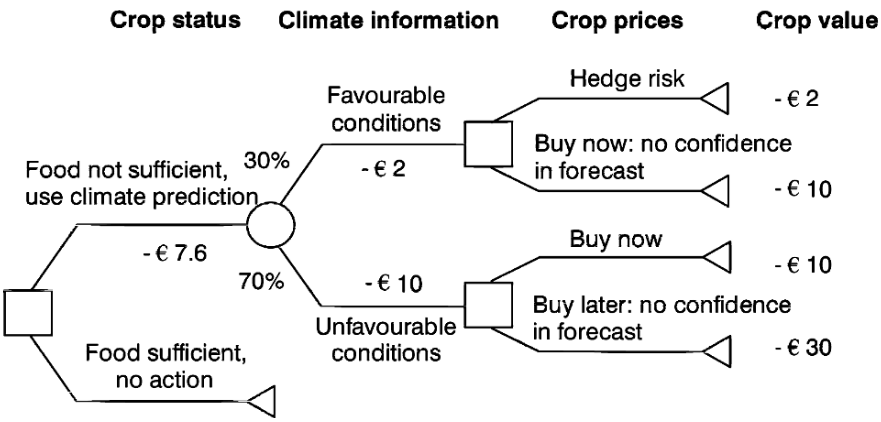

Fig. 2.4 Example of a decision tree diagram with reference to the food security application of Fig. 2.3. Squares represent decision nodes and circles chance nodes. The use of a triangle to terminate a branch is customary. Amounts are in million of euros. This is a highly simplified decision tree, purposely constructed to focus on its mechanics (see text for details)

[4] For simplicity, options such as building national food reserves or generating foreign income through sales have been ignored.

only two branches after the (single) chance node and so the value before that node is (€2 × 0.3 + €10 × 0.7) million = €7.6 million. In evaluating this problem, it has been assumed that the decision maker is risk-neutral. The results generalise however to arbitrary risk attitudes of the decision maker, whether they are risk averse or risk seeking. The attitude to risk may be assessed by eliciting a utility function.

In the present example, it is straightforward to assess what is the most convenient action when food reserves are not sufficient, and this is to spend €2 million to hedge the risk given a favourable prediction, or to buy now otherwise. However, it is also true that only a single estimate of costs was provided. In practice, because uncertainty generally exists in the various options forming the decision tree, sensitivity analyses are conducted with the aim of providing error estimates associated with all possible outcomes. A more meaningful evaluation of the risk associated with the selected course of action would thus be obtained. It is important to note that the use of expert advice or judgment – seasonal prediction in this case – in event forks generally sharpens the uncertainties associated with the options in that particular fork. Probabilities would be equal in the absence of any information, including of historical records,[5] i.e. 50–50% instead of the 30–70% (see Fig. 2.4) coming from the knowledge of climate information. The procedure used to incorporate expert advice in the decision making probability assessment is referred to as the Bayesian approach. A discussion of Bayesian theory is given in Chapter 9.

In practice, situations tend to be rather more complex than that shown in Fig. 2.4, as can be inferred from the number of entries in Fig. 2.3. The number of possible options would grow substantially were the simple decision tree of Fig. 2.4 generalised to take into account all the entries in Fig. 2.3. The rapid growth of complexity represents a drawback of tree diagrams as they can become difficult to follow or to validate.

The decision making problem is further complicated when different entries in the tree are interdependent; for example in the food security case above the act of issuing a public climate forecast may affect crop prices directly. At first glance tree diagrams appear to represent an end-to-end process, in that they flow sequentially from left to right; a closer examination shows, however, that a diagram can become highly interactive due to the interdependence of the various processes.

An alternative approach to decision trees is the use of influence (or relevance) diagrams. The high-level (compact) visual representation of influence diagrams makes them particularly valuable for the structuring phase of problem solving, and for visually representing large, intricate problems. The complexity of the details present in decision trees becomes embedded into the general structure of influence diagrams, structure which clearly calls attention to the relationships between the

[5] In practice, it is virtually impossible not to be able to have access to some additional prior information. Any such information would modify the prior 50–50% probability.

various elements of the problem. As a consequence, influence diagrams can cope with situations in which there is substantial sophistication and complexity. All these features make influence diagrams easier to interpret and overall more powerful than tree diagrams. Indeed, some authors contend that decision trees should only be used as a teaching device for beginners. Note that a 'properly' formed influence diagram can always be converted into a decision tree (Howard 1990, explains the rules to build a 'proper' influence diagram).

The symbols used for influence diagrams are similar to those for decision trees, but with some differences. A decision node, drawn as a rectangle, represents a variable under the control of the decision maker; an uncertainty node, drawn as an oval, represents a variable not directly controlled by the decision maker; a deterministic node, drawn as a double oval, represents an uncertainty that is functionally determined by the variables influencing it; and a value node, drawn in many ways, including a hexagon or a diamond, represents the variable to be optimised by the decision. The nodes are connected to each other via arrowed arcs, which generally indicate 'relevance'. An example of an influence diagram with reference to the food security application of Fig. 2.3 is shown in Fig. 2.5.

This example is just one of the many possible combinations for linking the various variables or options of Fig. 2.3. It is important to recognise that decision tree diagrams and influence diagrams are never unique in the sense that they aim to 'model' the experts' natural thought processes. It is therefore crucial to elicit information for the specific problem at hand from as many experts as possible, also to try to ensure that wider economic, social and environmental considerations (i.e. the three pillars of sustainability) are taken into account. For example, in Fig. 2.5

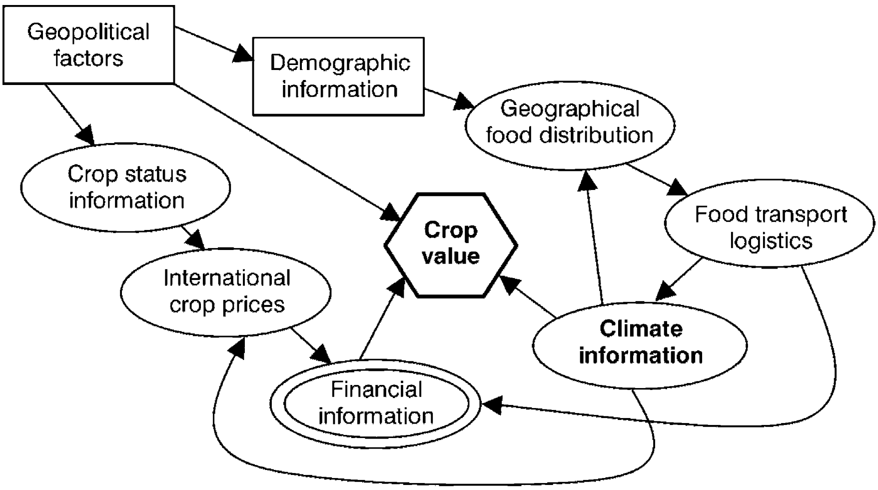

Fig. 2.5 Example of an influence diagram with reference to the food security application (see Fig. 2.3). For the sake of clarity not all the dependencies have been represented in this diagram (e.g. the link between 'crop status information' and 'climate information')

the customary choice to assign certainty to the “Geopolitical factors” and “Demographic information” variables has been made, and the variable to be optimised is “Crop value”, as in the decision tree of Fig. 2.4, but this problem could be stated in other ways.

To summarise, the two most relevant concepts highlighted by Fig. 2.5 are:

1. Climate information is just one of the components in the decision making process
2. Climate information enters the decision process under several facets through its interdependency with other information streams

2.3.1 A Holistic Approach to Seasonal Climate Prediction

A direct corollary to the decision analysis presented in the previous section is that climate information has to be considered within its broader context, especially the social and economic aspects. This holistic approach, defined as *Climate Affairs* by Glantz (2003), is helpful not only in understanding and managing the many ways in which climate variability influences human activities and environmental processes, but also in identifying how societal and environmental issues not related to climate may act as confounding factors to the climate information in the decision making process. Indeed, the concept of Climate Affairs was developed with the aim of placing climate and climate-related factors on the list of items that decision makers should take into consideration. Climate Affairs consists of the following component fields:

- *Climate science*: the description of the components of the physical climate system, including the role of human activities as forcing factors to the system
- *Climate impacts*: the impacts of the climate on both societies and ecosystems
- *Climate politics*: the process needed to produce climate-related regulations and laws
- *Climate policy and law*: the legal and regulatory aspects of climate–society–environment interactions
- *Climate economics*: the financial aspects of the climate, including cost-assessments carried out in order to assist in the decision making process
- *Climate ethics and equity*: the set of principles of right conduct and the state of being just, impartial, and fair in the context of climate-related impacts (e.g. the poor generally have fewer options than the rich in tackling climate-related harmful events)

Food security, as discussed in the previous section, is one of the sectors that would greatly benefit from a holistic approach, especially in regions with large interannual climate variability. By definition, climate-related issues are crucial in such areas, but many problems also arise because of the pressure to exploit these areas, as well as through other human choices and *perceptions* of acceptable risks.

It is worth noting that the concept of Climate Affairs goes beyond mere applications to decision making. Its other purposes are to encourage education and communication on climate-society-environmental issues, and to improve understanding of how climate variability affects society and the environment. Despite the feasibility of assessing risks attributable to climate in a physical sense (e.g. probability of a drought, a quantity directly usable in decision analysis), there are also many societal aspects which are difficult to quantify, and thus subjective judgment often plays a significant role in decision making. It is through focussing on education and by developing appropriate communication approaches that the level of arbitrary subjectivity of decisions may be reduced.

The subjective role of climate information was emphasised by the use of the word *perception* above. The perception of the climate (and of its prediction) is often distinct from its physically measured characteristics. A prediction for a colder winter than normal, for example, can be interpreted in many different ways, depending on the person to whom this prediction is addressed. A perception is often related to the association a person makes to his/her most memorable cold winter. Thus perception relates more to the psychology of the decision maker rather than to ignorance or lack of information[6] (Weber 2001; Loewenstein et al. 2001). The notion of perception is critical to any decision making process is further explored in Chapter 11.

In the following specific perceptions of climate by society are discussed briefly. There are three non-exclusive ways in which climate may be perceived by society: as a hazard, as a resource and as a constraint (Glantz 2003).

The hazard component is probably the most common way in which society tends to view climate, especially when high impact events, such as devastating floods or persistent droughts, hit the headlines. The hazard perception is particularly strong for governments, since climate-related harm to a population may have repercussions on a government's duration in power or on its likelihood of re-election. For governments, it may be more relevant therefore to be concerned with climate-related disasters than with enhancing climate as a resource.

Despite the perceived presence of this sword of Damocles, societies around the world view climate as a resource too. In fact people's lives and activities, including commerce, are adjusted in general to the expected flow of the seasons in order to take advantage of local climate conditions.

There are also environments in parts of the globe to which humans are less able to adapt. These environments are characterised by conditions where climate is seen as a constraint, an impediment to productivity or even to survival. Such is the case in marginal agricultural areas, for example, where annual rainfall averages are low and interannual climate fluctuations in precipitation are so large that production may be meagre in some years, at which times it may be accompanied by

[6] A linked issue is that of legitimacy, which concerns the perception that the system is being provided in the interests of the stakeholders and those of the providers.

economic losses or even starvation. When such constraints are occasionally relaxed, e.g. in the rare 'good' years of the semi-arid tropics, decision makers are presented with opportunities that need to be exploited: in the rain-fed wheat systems of Australia, for instance, 70% of profits are made in 30% of the years.

Certain global phenomena, such as the seasons or ENSO, may lead to all three perceptions of the climate across diverse locations. ENSO, for instance, is perceived as a hazard in some regions, as its occurrence is associated variously with droughts and floods. Similarly, ENSO may be seen as a resource in those regions where its outcomes are beneficial (e.g. warmer winters in Florida during La Niña events; see Chapter 12). Finally, ENSO is a constraint on productivity and/or security in places where resources are not sufficient to cope with its consequences. The objective of factoring seasonal to interannual predictions into decision making processes is then one of modifying perceptions towards reducing losses related to the hazard and constraint components, and to increasing gains related to the resource component.

2.4 Identifying the Users and the Uses

For seasonal to interannual forecasts to be of benefit to society it is imperative to identify clearly the users as well as the context of each use. Numerous users are likely to be interested in decision-making processes for which seasonal forecasts might be relevant, sometimes beyond those directly affected by climate variability. One example is that of crop switching (e.g. planting sorghum instead of cotton) or by using superior drought-adapted varieties when water-deficient conditions are expected. Here we give a brief overview of some potential direct uses of predictions; in the following section a more focused discussion from the perspective of the developing world is provided. Where possible examples are provided, firstly, of ground-level decision processes, and secondly of decision processes at national and international level. Note that while the list given below may offer the impression of independence, some of the sectorial examples nevertheless may be interconnected: thus there is a need for appropriate interaction amongst sectors if optimal decisions are to be attained. A second factor to recognise is that, while all examples in the following are quoted within positive contexts, seasonal forecasts may be used, say by traders, to the disadvantage of those unfortunate to live and work in negatively affected (e.g. drought) areas.

2.4.1 Agriculture

Agriculture, including both plant cultivation and livestock production, is a sector heavily dependent on climate, such as in the amount and timing of rainfall, the occurrence of damaging frosts, the length of the growing season, and the number of growing degree-days. Seasonal forecasts would therefore assist pre-emptive actions, such as the use of varied crop species, or the altered composition and/or allocation of browsing herds for more effective exploitation of marginal areas. Thus improved use of climate information in agriculture could increase profitability and sustainability by allowing farmers to match cropping decisions to expected climatic conditions (Stern and Easterling 1999). At the national, regional and international levels, matters of food security, of international crop yield estimation and food flows, and of food marketing can be informed through climate services. Practical examples of the uses of seasonal forecasts in agriculture are discussed in Chapter 12.

2.4.2 Disaster Forecasts and Prevention

Natural disasters associated with extreme climate events, resulting in the loss of life, destruction of shelters and food reserves, disruption of food production and transportation systems, and health risks are situations faced by large parts of the world population. General systems of emergency preparedness and response, such as early warning systems, might benefit and avoid costly damages (see Chapter13). Seasonal forecasts could play a role in warning systems in cases in which their skill was judged to be at levels sufficient for alerts. International preparations for disaster response might also take advantage of climate information.

2.4.3 Energy

Most forms of energy production (e.g. gas and hydropower) and the level of energy consumption are, to varying degrees, affected by climate conditions. Using seasonal forecasts as input for load-balance models could potentially decrease the overhead necessary to maintain the agreed baseline energy availability, thus helping to optimize the matching of supply and demand. They might also be used for planning international energy transfers.

2.4.4 Finance and Insurance

Climate information can be used in the financial sector to optimize capital requirements, and to hedge the risk of financial losses due to climate-related events. For example, seasonal forecasts can be used by an energy company to optimize the use of climate-linked financial products designed to reduce the potential impact of adverse weather conditions on the company's balance sheet, or by an insurance company to assess its exposure to climate-related risk. Insurance is now being tested in response to climate risk management in the developing world.

2.4.5 Fisheries

Fish population fluctuations, whether due to climatic factors or to harvesting or to other reasons, are by their nature more difficult to analyse. As a consequence, for fishing management, which normally aims at constraining both biological and economic overfishing, it might be more challenging to use forecast information effectively. One notable exception might be that of Peruvian anchovies whose population is highly influenced by El Niño events.

2.4.6 Food Security

Food security is naturally related to the agricultural examples given earlier. Droughts, floods and cyclones are some of the essential factors in determining the quantity and quality of food supply, also referred to as food security. Food security is particularly an issue in regions where the interannual climate variability, especially in rainfall, is large and local production is the main food supply. For such regions, rainfall forecasts could help alleviate problems in low rainfall years. It must be noted, however, that climate is only part of the story in food-hardship periods; confounding factors such as political situation or locust infestation may contribute to exacerbate the problem (e.g. the 2005 food crisis in Niger).

2.4.7 Health Management

Human health is sensitive to several types of climatic variations. For some diseases close direct and indirect links with climate conditions exist (e.g. malaria epidemics). In such cases, climate forecasts might give public health systems early warning of the likelihood of epidemics. For instance, tropical disease risk management is an application in which the use of climate information is receiving increasing attention. Health planners need information on the predicted level of risk for malaria, meningitis, or cholera epidemics to develop. International strategies for improving health and for relevant pandemic responses would benefit from an enhanced use of climate information.

2.4.8 Hydrology and Water Resource Management

Water managers may benefit from rainfall forecasts for the planning of irrigation systems, surface water storage, groundwater pumping capacity and trans-basin diversion. Such forecasts might also contribute to a more effective deployment of emergency flood management and relief operations. Information on climate variability, including predictions, can form an important knowledge source in decisions on water security, facility development, and cross-border basin management.

2.4.9 Policy Making and Public Authorities

Relevant public institutions have the potential to influence the way in which individual users (e.g. a farmer) respond to climate forecasts. Such institutions may act via, for instance, proper dissemination of the forecast or by offering incentives, the latter possibly coupled with some form of insurance to spread the risk of responding to probabilistic forecasts.

2.4.10 Retailing Industry

The impact of the climate variability is seen across many areas of the retailing industry (e.g. ice creams, refreshing beverages or air conditioning units, summer or winter clothes). By taking climate forecasts into account, customer demand could be better predicted. In turn, this would mean making the most out of sales and reducing waste through efficient delivery, staffing and stock control. Climate forecasts may influence decisions about provisioning of a particular product, for instance coffee imported from Indonesia rather than Brazil or Central America, or vice versa, although such decisions can be detrimental to the livelihoods of the coffee-growers and their communities.

2.4.11 Transport and Tourism

Climate information is potentially useful for planning in the operation of leisure facilities as well as strategic planning and investment. Predictions of tropical cyclone activity or anomalous climate conditions could, for instance, be used by transport planners and resort owners to prepare for potential impacts such as for storm damage. Equally, these predictions could be used to inform tourists of the likely risks they would incur by travelling to specific regions. Current thinking has it that using climate forecasts for leisure planning may involve risks of litigation (e.g. by resort facility owners or washed-out tourists). It should be noted, however, that the main difference with the sectors mentioned earlier is that in this case information is provided to the general public also. As with the issuing of weather forecasts, experience needs to be built on ways to communicate climate forecasts, along with their uncertainties, to wider audiences.

2.5 The Importance of Climate in Key Development Sectors[7]

Three top priority development sectors are particularly sensitive to climate variability, namely agriculture, water resources and health. The situation is most critical in Africa where the livelihoods of hundreds of millions of people are extremely vulnerable to climate variability. Much improved climate risk management is essential to support more effective development and to help mitigate disasters.

Climate exerts a profound influence on the lives of poor people who depend on agriculture for their livelihoods and sustenance, who are unprotected against climate-related diseases, who lack secure access to water and food, and who are vulnerable to hydro-meteorological hazard. For vulnerable communities, developing flexible, proactive responses to climate variability that enhance resilience is both a crucial step toward achieving the MDGs by 2015, and a foundation for coping with the uncertainties of a changing climate into the future. Furthermore, because climate has a confounding influence on many development outcomes, attention to climate variability is essential for evaluating real progress.

2.5.1 Agriculture in Africa

All current initiatives for development in Africa emphasize the overriding importance of agriculture, both for eliminating hunger, and also as a local and national economic driver. The Millennium Project proposes major scaled-up interventions to enable smallholder agriculture to develop and sustain itself throughout the poorest regions of Africa. These interventions then are designed to be coupled with a 'safety net' to protect communities and local economies in disastrous years, so that gains made in better years are not wiped out by unfavourable seasons, as happens so often at present. Such an ambitious programme, designed to bring a

[7] This section is derived largely unaltered, with permission of IRI, from text originally produced for their Position Paper entitled 'Sustainable Development: Is the Climate Right', that was published in 2005 and in which a predominantly African perspective was taken; nonetheless this section can be read within a wider geographical context.

hundred million people out of poverty by 2015 in sub-Saharan Africa, explicitly recognises the importance of climate variability in its proposals.

2.5.1.1 Subsistence Farmers

For too many people in Africa, subsistence agriculture is a desperate form of poverty akin to slavery that requires major effort for relatively little return. With reduced fallow periods, smaller farm size, declining soil fertility, lower yields, increasing indebtedness and isolation from markets, such farmers have relatively few choices even before rainfall variability, crop pests and diseases, malaria, AIDS and emigration of young labour make their lives even more onerous.

2.5.1.2 Cash Crop Farmers

Farmers that engage more with local markets and dealers, can also access credit and buy inputs (improved seeds, fertiliser, sprays for pest and disease control) to increase the value of their labours. Such farmers tend to be less risk averse and more proactive in their management choices, and as such, are in more of a position to access and take advantage of weather and climate information, particularly in their choice of seeds and other agricultural inputs.

2.5.1.3 Risk Benefit

Communities who depend on rain-fed farming for sustenance and livelihood in high-risk environments are among those most affected by climate variability, but conversely are also often particularly well poised to benefit from improved management of climatic risk through appropriate use of climate information. It is important to empower rural populations to better manage risk and exploit opportunity by (a) providing relevant, timely information to the target populations; (b) fostering and guiding adaptive management responses; and (c) addressing resource constraints to adaptive responses.

2.5.1.4 Managing the Rural Economy

Without a healthy rural economy, farming communities cannot get the inputs they need to cope better with climate variability and so the cycle of poverty is perpetuated. There are many ways that governments can improve the rural economy (see the Millennium Project proposals for example) in ways that are sensitive to prevailing conditions. For example, modern methods of monitoring crop production from satellite are now routinely used in most regions of Africa. Coupled with seasonal climate prediction, these enable early yield estimation, extend the lead-time of food stock or relief decisions, and facilitate timely implementation of measures to help ensure local food security or cope with harvest surpluses. And knowing in advance the risk of food shortfall/surplus is very important information for central government economic advisers, and local government planners, in order to make contingency arrangements.

2.5.2 Water

Improved water management is recognised as a fundamental requirement for development. In the Africa Water Vision for 2025 the key problems identified are:

1. The multiplicity of transboundary water basins
2. Extreme spatial and temporal variability of climate and rainfall, and climate change
3. Growing water scarcity

It is of prime importance for people in Africa today, and tomorrow, that water from rainfall is managed more effectively. In order to achieve this, the most important step is to ensure that rainfall variability is not simply accepted as an inescapable ‘fate from the gods’. Rather, rainfall needs to be regarded as an environmental variable that is influenced by increasingly well-understood physical processes. As such water supplies can and must be managed better by a whole host of decision makers in the diversity of economic and social domains affected by fluctuations in availability.

2.5.2.1 Transboundary River Systems

Much ocean induced climate variability affects large areas of Africa and its effects are particularly noticeable at the scale of transboundary river basins. Attempts are being made through the African Network of Basin Organisations to improve management and decision making in all transboundary river systems, to encourage greater cooperation between stakeholders, and to mitigate flooding and reduce competition and conflict over access to water. To achieve these objectives effectively, it is absolutely essential to incorporate knowledge of seasonal water variability into decision making, and where appropriate, early warning through seasonal forecasting. Capacity building in water authorities to enable people to use these increasingly powerful tools is essential.

2.5.2.2 Reservoir Management

Reservoirs are designed to hold significant amounts of seasonal runoff to mitigate the effects of upriver rainfall variability. The Aswan dam in Egypt provided irrigation through 10 years of drought and sub-normal rainfall over Ethiopia in the 1980s. Very often, however, there are conflicting demands on reservoir managers to provide water for hydropower, irrigation and to manage flood and base flows for the health of lower river communities and ecosystems. Without knowledge of future rainfall, reservoir managers inevitably tend to be conservative. With reliable indicators of future rainfall quantities, reservoir managers are in a better position to make best use of the limited stored water available. Such decisions involve risk, and managing risk is an essential component of making the best of a scarce and highly variable resource such as water.

2.5.2.3 Summary

Climate variability not only affects the design and management of water and sanitation infrastructure, but also plays an important role in the planning and design of water resource systems. It is essential that knowledge of climate variability be incorporated in water management strategies at all timescales, as an integral part of knowledge-driven decision-making: optimal system management is impossible without it.

2.5.3 Health Management

The European heat wave of 2003 had a dramatic impact on mortality causing an excess of about 15,000 deaths in France of which about 1,000 were in Paris alone. The consequences of unusual warm years in Africa pass largely undocumented. We all know from direct personal experience that dry-season illness tends to be different from wet season diseases. But how much does the overall incidence of disease, and hence death rates, depend on climate variability, and hence fluctuate from season to season and year to year? The answer is ‘climate has an enormous impact on health’ and many diseases are recognised by the World Health Organization (WHO) as being climate sensitive. These include: influenza, diarrhoeal disease, cholera, meningitis, dengue fever, chikungunya, avian flu, Rift Valley fever, leishmaniasis and malaria.

2.5.3.1 Malaria

Malaria is widely appreciated as the most important of the climate-sensitive diseases in the world. It is seen as a major impediment to socio-economic development particularly in Africa where 90% of the 1–3 million deaths it causes each year occur. If we are serious about reducing malaria, and associated maternal and child mortality as part of the Millennium Development Goals, then information on the seasonality of climate and its variability must be taken into account when planning and implementing routine health campaigns and epidemic preparedness.

It is estimated that more than 110 million people in Africa live in regions prone to malaria epidemics. The populations affected have little acquired immunity to malaria and are therefore vulnerable to explosive epidemics that can cause high case fatality rates among all age groups. In spite of the severity and the magnitude of the problem, understanding of epidemic malaria is very limited and almost nothing is known of the economic burden of malaria epidemics in sub-Saharan Africa.

For malaria climate is the primary factor in determining at least some epidemics.

- **Temperature** influences development rates of both the malaria parasite and its mosquito host. Higher temperatures, but only up to about 40°C, shorten the parasite extrinsic incubation period and increase the stability of disease transmission
- **Increased rainfall** in semi-arid areas increases availability of breeding sites and therefore augments malaria vector populations if temperature is favourable. It is also associated with increases in air humidity that result in higher adult vector survivorship and therefore greater probability of disease transmission

Epidemics frequently occur when periods of drought (during which people can lose immunity to the disease) are followed by a return to normal or above normal rains in the more arid regions. Combining information on malaria trends and vulnerability with rainfall information can provide warnings for high transmission years prior to the peak malaria season. For example, the case of Botswana has demonstrated a strong impact of December–February rainfall on malaria incidence anomalies, which make it possible to alert the Ministry of Health of increased risk of an epidemic before the peak transmission period of March and April. Seasonal climate forecasts can supply even earlier warning of changes in malaria risk. A seasonal climate forecast in November can provide information about the expected extent of the next malaria transmission period 5 months before the peak of the malaria season and 3–4 months earlier than warnings that are issued based on observed rainfall. Prime interventions include planning integrated vector management; awareness raising campaigns allied to education, as well as timely procurement of drugs.