Chapter 14

Services

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The enthusiasm for engaging the challenges of Seasonal to Interannual Prediction, both within the disciplines of physical and social sciences and at their interface, was well demonstrated through the energetic engagement of all during the May to June 2005 NATO ASI course, upon which this book is based. Several panel sessions were held during the course, which permitted everyone to offer views within an informal setting; some, not reflected in the main body of the book, are incorporated in this chapter. Little stays stationary in such a fast-developing field, and so, to provide the most advanced position at publication, this summarising chapter has included some of the latest development to supplement the material drawn from the course presentations and the panel discussions. Additionally, a view to the future is offered so as to provide further stimulation to those interested in the fascinating field of Seasonal to Interannual Climate.

14.1 The Science

In many communities throughout the world, economic, social and environmental development is rather more directly dependent on seasonal climate and its interannual variability than on day-to-day weather events, disasters apart. Yet, within

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the meteorological community much greater effort and expense goes into producing the daily weather forecast. At the same time, many communities are left to cope with the vagaries of climate with little effort being directed at providing the best-available climate information. Emphases are beginning to change, however, consequent on growing concerns over climate change and the recent advent of seasonal forecasting with its promising future developments, including increasing levels of skill. Seasonal forecasting not only makes climatology a ‘living and very practical science’, but also provides a most useful context for considering and valuing the daily weather forecast. It also provides a practical first step for coping with climate change: an inability to cope with climate variability as it is, does not augur well for how society might cope with the variability of some future climatic regime.

Two interrelated major scientific developments have made the progress in practical climatology possible: a vastly enriched knowledge of the physics of climate variability, achieved through enhanced global scale observing systems combined with the development of analytical and interpretative techniques; and the creation of computer-based models of the climate system – simple through to complex – that use observations to generate forecasts on timescales of a season or longer.

14.1.1 Understanding Climate Variability

Central to the enhanced understanding of climate variability lies the ever increasing knowledge of how the oceans and the atmosphere interact. In simple terms, the ocean provides a ‘long-term memory’ for the atmosphere while in turn the atmosphere helps drive the slow variations in the ocean. Furthermore, the ‘memory’ imposed by the ocean is distributed rapidly by the atmosphere, teleconnected to distant parts of the globe. The ENSO phenomenon, with its opposing maxima of El Niño and La Niña, is the strongest known modulator of climate variability on the global scale (other than the annual cycle of the sun) and provides predictability. Despite the recurrence of an El Niño phase every 2–7 years, ENSO is not an oscillatory phenomenon as such: an El Niño is not necessarily followed by a La Niña. The reason for the non-periodicity is not yet understood but several theories have been put forward, all revolving around the hypothesis that ENSO can be approximated by oscillatory systems. These theories can be divided into two main categories: (i) ENSO is a self-sustained oscillator; (ii) ENSO is a damped oscillator. In (i), the oscillator possesses a natural frequency which is perturbed by chaotic processes (weather) to be irregular, whereas in (ii), the oscillator requires some external forcing to keep the system going. The role of non-linearity and noise is markedly different in each case. Despite the attempts to provide unified theories for ENSO, the cause of the irregularity is still an open research topic.

One of the critical factors in these theories is the understanding of how ENSO events are initiated. Once an ENSO event has started, models – and therefore theories – do a reasonably good job at forecasting the subsequent evolution of the event, with lead-times up to several months. An atmospheric phenomenon called the Madden-Julian Oscillation (MJO), an intraseasonal oscillation of about 40–60 days, likely plays a major role in the initiation process and is currently the leading candidate under investigation. There is little doubt that weather can influence the evolution of ENSO events: the strengthening of the link between the weather and the seasonal to interannual climate communities is likely to be a fruitful path for research and future progress at both timescales.

Within this book there has been a focus on ENSO and its effects. ENSO is not alone, however, in forcing interannual seasonal variability. Both the tropical Indian and the Atlantic Ocean basins host processes related to rainfall variations in parts of surrounding continental masses, while the evidence for pertinent roles for extra-tropical oceans is also growing. None appears to exert the global-scale influences of the Pacific centred ENSO but nevertheless their effects are undoubtedly critical in some regions, and further understanding will lead almost certainly to improved predictions for these areas.

Not all seasonal variability is attributable to atmosphere-ocean interactions, and evidence is mounting that other sources of predictability exist. These sources include amounts of soil moisture across the continental masses, the distributions of continental snow and polar ice, atmospheric aerosol distributions, and even stratosphere/troposphere interactions.

There will remain always some seasonal variability not attributable to the phenomena discussed above; some climatologists might place this unexplained portion of the variability, which varies according to region, in the bin labeled ‘noise’, stating that it is not predictable – at least, with current models. Hopefully research breakthroughs, currently unforeseen, will prise some of the ‘noise’ from that bin and place it into a category bearing promise of improved predictions, thereby improving the predictability of the climate system.

14.1.2 Models

There are two basic approaches to seasonal to interannual predictions – statistical and dynamical – and both have progressed substantially over the past decades.

Dynamical models of the climate system are appealing tools for learning about the climate and for attempting to predict it. The appeal stems from the fact that these models are based on physical principles, as expressed by their mathematical formulation. Moreover, since model resolution may be modified with minimal effort and also the level of complexity can be usually adjusted in a modular way (e.g. a model of sea ice can be included or not depending if one is interested in high latitude phenomena), such models can be all the more attractive, and versatile.

The drawback is the large cost, both in financial terms (including computational, in a proportional way to resolution and complexity) and human resource terms and, therefore, their development is normally the prerogative of major research centres. These models have allowed considerable improvement in the quality of operational seasonal forecasts and will most likely contribute to further improvements in the future. However, even the most sophisticated model only gives an approximate representation of the very complex climate system. For example, resolution of current operational seasonal forecast models is not normally sufficient to resolve important phenomena such as the MJO in a satisfactory way. More crucially, however, atmospheric convection in the tropics, upon which also the MJO is dependent, is a weak point of most, if not all, models. Thus, the full potential of numerical models is far from being achieved and a vigorous model development phase is still underway through: improvement in the representation of critical physical processes such as atmospheric convection and oceanic coastal upwelling; increase in the level of model complexity; increase in model resolution; representation of model uncertainties via the use of multi-models and/or the implementation of stochastic processes.

Although dynamical models have numerous advantages over statistical models, and offer greater prospects for long-term improvements in performance, statistical models remain in wide use, and are likely to do so for years to come. Much of the popularity of statistical models comes from practical considerations, such as their minimal demands on computational resources and their relative simplicity. For these reasons statistical models are used extensively in developing countries. However, even in countries such as the United States, statistical models constitute an important input to the mix of operational forecasting systems for the simple reason that they continue to outperform dynamical model forecasts in some instances. With the establishment in November 2006 of Global Producing Centres, dynamical model predictions are being made increasingly available to forecasting centres that do not have the resources to run their own models, and so an upsurge in the application of statistical models to downscale and recalibrate dynamical model predictions is beginning. This process should enable most countries to take advantage of both approaches.

The output of dynamical and statistical models is increasingly used in a variety of decision making frameworks. Model enhancements, as well as increases in dynamical model resolution, will advance the science of seasonal forecasting in the long term. Additional practical benefit will be gained from greater flexibility in the interpretation of, and enhanced information supplied by, all types of models. For example, more detailed predictions in both the spatial and temporal senses, is the *sine qua non* for all who prepare and use seasonal forecasts, with information regarding the start of rains in seasonal regimes being prominent amongst the latter. Modellers so far have given limited attention to these problems, mainly on the grounds that these details fall into the area of unpredictable noise, but also because of resource limitations. Nevertheless, there are encouraging signs that advances will be made, not only through higher resolution models, but also through post-processing of the global model forecasts, either through empirical means or by embedding regional climate models capable, in principle, of providing information at higher spatial and temporal scales. It is likely that development and beneficial use of this information will need close coordination between providers and users.

14.1.3 Assessment of the Skill of the Models

Because seasonal forecasts are expressed as probabilities, they cannot be assessed as 'right' or 'wrong' in any simplistic way. While it is possible to assess the accuracy of deterministic forecasts, for probabilistic forecasts other attributes such as reliability and resolution are more appropriate. None of these attributes can be communicated in a single score, although regrettably there continues to be undue reliance on scores without recognition of the limited information that such scores can communicate. There are detailed diagnostic techniques that have been devised to provide comprehensive assessments of the quality of the forecasts, but a major limitation is that large sample sizes are generally required. Sample sizes of seasonal forecasts are small compared to those for weather forecasts, for example, and so robust estimates of forecast quality are lacking. Very few assessments of the quality of seasonal forecasts have been performed for the simple reason that these forecasts (and hindcasts) have been produced only since the early 1990s, providing sample sizes of only about 15 years.

Partly to address the problem of limited sample size, considerable effort has been invested in generating hindcasts, and projects such as DEMETER have been invaluable in obtaining realistic estimates of operational performance. Perhaps the main conclusion from these forecasts/hindcasts is that although seasonal forecasts of parameters such as the NIÑO3.4 index or of 200 hPa heights can be predicted with impressive skill, parameters of more direct interest to potential users of such forecasts, such as near-surface air temperatures and precipitation, are much harder to predict. Nevertheless there is considerable information content in the forecasts of temperature and precipitation at certain times of year and for some areas, mostly within the tropics and sub-tropics. Temperature forecasts are notably better than precipitation, although recent attempts to focus on the frequency of precipitation, rather than on total precipitation, are yielding promising results.

14.1.4 Conversion of Model Forecasts into Useable Form

Despite the major investment required to generate a prediction from a dynamical model (whether a coupled ocean-atmosphere model, or an atmosphere-only model), generating the model output is only one step in an involved process for generating a seasonal forecast. Dynamical models are far from perfect, and the differences between model and observed climates can result in substantial errors in forecasts. Because these errors are systematic, they can usually be removed using relatively simple statistical procedures. However, best results are obtained when systematic spatial displacements of the model's climate features are considered, and these spatial corrections require more advanced procedures.

Even without systematic errors, some form of post-processing of the model output is usually required to make forecasts relevant at spatial scales and locations of interest to specific users. Predictions straight out of a dynamical model are generally representative of large spatial averages, and "downscaling" procedures are required to translate the resolution of the forecasts to a more practically useful scale. Downscaling procedures have also been developed to provide statistics about the intraseasonal characteristics of weather. The dynamical models are useful for providing predictions of seasonally averaged conditions, but their current representations of weather variability are insufficiently realistic to be used directly. Downscaling (both temporal and spatial) can be performed using either statistical techniques or with limited-area, high-resolution dynamical models. The latter are expensive to run, and despite some promising results, there have still been no clear indications that they can outperform the statistical procedures.

Regardless of the temporal and spatial resolution of the forecasts desired, there is overwhelming evidence that the best forecast can be made by considering outputs from a suite of models. This multi-model approach can be justified on the basis of improved representation of the uncertainties in the forecast arising from imperfections in the models. Multi-model approaches are effective whether the individual models are dynamical, statistical, or a combination of both. However, there is still some debate about the best ways to combine the predictions from the different models. It seems intuitively appealing to weight the better models more highly than the ones with less skill, but in practice the limited sample sizes available make it virtually impossible to estimate differences in the skill of models robustly. As a result, simple averaging of the predictions from different models remains a very competitive procedure.

14.2 Communication and Integration

Developments in the underlying science need to be matched by improvements in the way climate information is communicated and integrated into societal structures. The current focus of seasonal to interannual prediction research is on the development of forecast systems, and particularly on dynamical models. Coupled models, perhaps the most promising long-term solution for predictions at the global scale in the maximum possible detail and with the highest quality, are complex and expensive to develop and maintain, as are the observing networks required to support them. Rightly, there is continuing investment in these models. But commensurate investment is required also in all downstream aspects, including delivery systems, interpretation and decision making approaches, management and mainstreaming, which ultimately determine the levels of societal benefit achieved. Benefit, or value, is not achieved through forecast quality alone. More consideration is required in building the case for increasing the funding of research in these latter areas.

Technology for information delivery is in reasonably good shape. Modern communications systems, satellites, the Internet and mobile phones offer the opportunity for rapid dissemination of information of all forms on the global scale. Even in the more remote areas where most advanced communications systems have not as yet penetrated, there are developments such as the RANET[1] project providing viable options that are progressively extending into more geographical areas. There is no technological reason in principle why, within the foreseeable future, even the most remote user might not have rapid access to some form of past, current and future climate variability information, should they so wish. The physical difficulties of delivery are being surmounted.

Delivery, however, is not simply a matter of providing the necessary technical facilities, but covers also the information delivered, its content and the manner in which it is presented. Communication with users is a key component of the forecasting system and particular focus should be devoted to this aspect in the near future. People often tend to think and view life in more or less deterministic terms (B is a result of A, or A causes B) but coping with unavoidable uncertainty or ‘risk’ demands more complex thought processes and a greater degree of prudence in order to cope with the possibility of making what might be seen in hindsight as a ‘wrong’ decision. Major efforts are required, possibly using familiar instances of probabilistic forecasting (as betting on horse racing and other uncertainties) to find ways of raising awareness in people towards managing seasonal risk, so that they can make best use of seasonal forecasts.

Ideally, the entire delivery system should be designed to assist decision processes, however individual. Here advances have also been made in recent years. An example is the approach adopted by APSRU[2] in delivering information in a utilisable manner, information that not only covers past and future climate variability but also, within the Australian farming context, multiple related information streams presented in a form that assists decision making. The Australian Bureau of Meteorology has also led in the production of user-friendly web sites.[3]

Whereas the APSRU approach is predominantly a service delivered through the Internet, face to face communication was pioneered in the Regional Climate Outlook Forums (RCOFs). Since their initiation during 1997, these Forums have

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[1] RAdio and InterNET for the Communication of Hydro-Meteorological and Climate Related Information. See: http://www.ranetproject.net/

[2] Agricultural Production Systems Research Unit. See: http://www.apsru.gov.au/apsru/

[3] See: http://www.bom.gov.au/silo/

continued in many parts of the developing world.[4] And they continue to flourish with the first such event for continental Asia having been held in April 2005 in Beijing. The Forums, in their original form, are expensive to run, and in some regions there are concerns over sustainability. Regardless of sustainability, RCOFs have most certainly provided a stimulus to the introduction of climate services, including seasonal predictions, in many parts of the world. The nascent Regional Climate Centres, a project of WMO, will likely support future communication with stakeholders.

Finally, numerous pilot projects have probed the difficulties and the value obtainable from climate services. Within the current volume are examples of leadership by the National Meteorological Service of Morocco, and by Florida State University. There are other examples from Australia, Africa, the USA and the South Pacific. Various projects run under the banner of climate change, such as some within AIACC,[5] in practice tend to address climate variability rather than climate change *per se*.

Hence there has been a wealth of activity over recent years to promote the dissemination and uptake of the forecasts. But, despite this progress, there are still few clear demonstrations of consistently achievable value obtainable through the use of the developing prediction technology. What has been progressively recognised over the last few years are the outstanding issues of delivering services, within all of the technological and cultural contexts that that entails, as discussed below.

As has been argued in numerous places in this book, central to achieving value is both the decision process itself and the delivery of information appropriate to each decision. The decision process is the pivot around which information and knowledge are converted into value. The decision process is a growing area of research within the context of seasonal forecasts and requires substantially further attention. Improved understanding of decision processes, especially those processes that lie at the nexus of multiple information streams (such as those with economic, environmental and social components) will provide substantial benefits in designing climate information to achieve optimal benefit. A start was made in 2006 at the WMO International Conference on “Living with Climate Variability and Change”.[6] More is needed, however.

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[4] See: http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

[5] Assessments of Impacts and Adaptation to Climate Change. See: http://www.start.org/project_pages/aiacc.html

[6] See: http://www.livingwithclimate.fi

14.3 Getting There

It is essential that the objectives for any service delivery intended to provide value are recognised and incorporated as that service is created. According to one leading institute that works to build bridges between climate scientists and climate information stakeholders, the IRI,[7] the prerequisites for future services built on seasonal to interannual predictions include:

- Recognising stakeholders' needs, both real and perceived
- Identifying viable decision options that are sensitive to climate variability and to forecast content
- (in reflection of the preceding) Focussing on those aspects of stakeholders' activities with viable decision options
- Building effective and appropriate communication
- Generating sustained support by institutions and favourable policies (including at government level)

This is a valuable opening list of essential prerequisites; each is fundamental and each raises its own challenges. However it could be argued that "effective and appropriate communication" is the most fundamental aspect of all. Communication is necessary between all involved, throughout the forecaster to decision maker chain, to recognise stakeholder needs, to identify viable decision options, and to develop and deliver forecasts that address viable decision options. Communication is necessary also to build institutional commitment and to introduce the conditions suitable for the creation of favourable policies, including government policies, where they do not exist. To date, it is debateable whether there has been effective universal broadcasting of the benefits potentially but realistically available from the forecasts, and equally whether there has been effective communication between providers and stakeholders in all contexts. It is certainly debateable whether many products currently available freely through the Internet provide the level of communication of climate information in all regards that is necessary.

It is in regards to communication that the most significant advances may be made in the next few years. Compared with the steady evolution expected in forecasting systems, short-term benefits are readily available through improved communication and decision making. Most certainly there will be advances in our understanding of climate processes, our ability to observe the environment in numerous regards, and our ability to model and predict the environment, and benefits from these will unquestionably reach those attempting to manage under climate variability. But the most tangible stakeholder benefits are most likely to originate first in the delivery of information through protocols more amenable to

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[7] http://iri.columbia.edu/outreach/publication/report/06-01/report06-01.pdf

stakeholder understanding and to incorporation into decision processes than is often the case today.

One of the main difficulties at present is in converting climate information directly into information of assistance in decision making in terms of agricultural production, malaria incidence, water resource levels, and so on. And few, if any, of these applications possess linear transfer functions from climate information to the application-related response. Approaches have been tested whereby model output is fed subsequently into sectorial models, such as for crop prediction or dam management. These approaches might be referred to as 'two-tier sectorial' models whereby coupled models provide the climate input, or 'three-tier sectorial' models when separate ocean and atmosphere components are used. Increasingly comprehensive 'single-tier sectoral' climate models are being developed, currently more specifically in regard to climate change, where such additional factors are being incorporated directly with the atmospheric model itself. This approach ensures climate feedbacks are simulated dynamically and guarantees overall consistency of predictions. These more comprehensive models most likely will find a role in ensemble seasonal prediction, and will later be extended to embedded regional climate models. Inevitably adoption of this approach will raise new issues regarding the validation of these extended models within the framework of interannual climate variability, and introduce new contexts of predictability, and challenges with linking to decision processes.

Regarding the interface between producers and stakeholders, one issue is that only a relatively small number of decision processes are neatly aligned to the timescales and lead-times associated with current prediction technology. There is an argument to adjust technical development away from the focus on improvement of predictions within the known window of predictability, towards development of information requirements dependent upon timescales appropriate to the decision processes themselves. That approach would require more imaginative use of climate information (which at times is neglected in the rush to use forecasts), more creative interpretation of the predictions themselves, and incorporation of other pertinent non-climate information, in order to provide a focussed complex designed to facilitate individual decision processes. Such an approach would focus all available information onto the specific requirements of individual decisions. The importance of decision processes is being recognised increasingly, with conferences such as "Living with Climate Variability and Change" mentioned in the previous section. One object of this conference was to transfer some research focus from 'skill/quality' to 'decision processes'. This and similar conferences may well assist in guiding the design of future research and operational programmes.

Regarding melding producer and stakeholder perspectives, the approach of developing full information and decision making packages for specific applications adopted by, for example, the IRI and APSRU is likely to begin to replace the original end-to-end concept that was taken at the outset, not least by CLIPS and the IRI, and that is still predominantly in use. That is not to say that end-to-end processes are inappropriate on all occasions – business uses are one example where the end-to-end model may in general be best (notwithstanding the fact the coordinated and cooperative decision making can lead frequently to optimal outcomes, even in the business world). The new comprehensive approach should be encouraged, but it retains nevertheless the disadvantage of producing solutions that tend to be culturally, sectorally and geographically specific.

Scientific advances will only produce benefit provided there is conversion of new information into value. A more coordinated approach would be beneficial in achieving this in regard to seasonal to interannual prediction, and the engagement of some form of international process would stimulate the coordination needed in all regards of defining research needs across the board, incorporating stakeholders at all levels, mainstreaming into policy, and delivering improved decision processes.

14.4 Goodbye Cinderella, Hello “Seamless Future”

For many years climate was the preserve of geographers, statisticians and historians. The emergence of meteorology during the mid-20th century as a ‘hard’, scientific discipline steeped in the mathematics of thermodynamics and fluid dynamics saw climate take on an almost ‘Cinderella’ role. Climatologists were more or less relegated to the task of archiving the data gathered for the sole purpose of predicting tomorrow’s weather. During the latter part of the century that retreat to the background begun to reverse, with the mass of data collected beginning to reveal that climate, hitherto thought of as static except over very long periods, was anything but static. The 30 years needed to ‘define’ the climate of a locality did little more than define the climate of that 30 year period, with the climate of successive 30 year periods differing, and often markedly so. Hence the notion of climate variability was born.

As knowledge of the causes of climate variability grew, led by the rush to understand El Niño, then so too did the capacity to model the climate system. By coupling components replicating processes in the oceans and over the land surface to what was already being modelled in the atmosphere, one could begin to model the whole climate system, and indeed that broadening path continues with notions of ‘earth system’ modelling.

The imperative to understand the human imprint on climate began to rise around the same time, and indeed for a period has subsumed to a large extent the importance of modelling and predicting ‘natural’ climate variability. In reality the distinction is somewhat artificial since any effort to predict the climate of the future must perforce take into account all processes in play, both human and natural, to the extent that they are significant on the timescale of the prediction. Thus climate variability is now a prime area in which to develop a career, and its importance to society and the contribution that its science can make are now mostly recognised.

Yet the study of climate variability has not yet fully shrugged off its ‘Cinderella’ image, as the quality of seasonal predictions, the putative rationale for research in the area, are perceived as failing to live up to the expectations set by short range weather forecasts. As we have seen throughout this book, for reasons that have as much to do with understanding human perceptions as with understanding the fundamental physical science, bridging the weather-climate predictability gap is not a trivial task.

Nonetheless, the notion of a ‘seamless’ forecasting system with lead times from minutes to centuries is an attractive concept and possibly one that will eventuate as a reality in time. Already we are beginning to see ‘unified’ models that are capable of being run in various timescale modes and spatial resolutions, along with the application of ensemble predictions and multi-model schemes to the challenges of weather forecasting, seasonal prediction, and climate projections.

In reality, however, the journey has barely started with decision making still mostly compartmentalised on the supply side by practical distinctions between weather and climate forecasting activities, and on the demand side by a host of factors that have little to do with weather and or climate. Seamless forecasting systems promise as yet little information that is not already available in the separate formats. So the paradigm remains unfulfilled, viz. that of a ‘seamless forecasting system’ linked into a ‘seamless decision making system’, with clear challenges remaining for both sides of the divide.

Undoubtedly, a major driver for progress lies in what the science of climate variability offers by way of an opportunity for learning to adapt to climate change, with the seasonal forecast models providing a basis for validating climate change models, as well as offering a bridge to weather forecasting models. Adaptation and modelling together, in both seamless decision making and forecasting contexts still seems a logical path forward.