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Exchanges

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Conference Special

Applications of CLIVAR Science

CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

WCRP Climate

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European Centre for Medium-Range Weather Forecasts

This issue has been sponsored by the European Centre for Medium-Range Weather Forecasts

Editorial

Welcome to this edition of Exchanges. I am indeed grateful to ECMWF for agreeing to sponsor its printing As you will see from the front cover, this edition is timed to coincide with the First International CLIVAR Science Conference. In particular it is intended to complement the Thursday afternoon session on the 'Application of CLIVAR Science to Society'. As David Legler points out below, this is increasingly a key topic for programmes like CLIVAR. It also represents an important challenge for us. The papers in this edition cover a variety of such applications, including those to farm, livestock management, and crop yield (and indeed to agriculture more generally), food distribution and food security, health, including disease transmission, water resources, flood and precipitation forecasting and electricity demand. The use of wave climatologies in the design of ocean structures are also touched on. A range of applications is therefore covered, relevant to both the developing and the developed world.

An important application of CLIVAR science is, of course to the policy implications of the increase in the concentration of greenhouse gases in our atmosphere and here CLIVAR can make a key contribution through input to the IPCC. The announcement on the following page provides one opportunity to do this. Enabling this sort of coordinated effort is a primary aim for CLIVAR as well as for WCRP more widely.

One additional paper covers the upcoming North American Monsoon Experiment of VAMOS as an internationally coordinated joint CLIVAR/GEWEX process study. It complements Edition 29 of Exchanges (sponsored by the China Meteorological Administration through the Chinese Academy of Meteorological Sciences), which covers the highly successful South American Low level Jet Experiment (SALLJEX). We look forward to seeing the fruits of NAME in due course.

The Conference will provide a real opportunity to review the breadth of CLIVAR science and how it is being applied as it has developed over the last 5 years or so. We are grateful indeed to the sponsors of the Conference as well as to a number of people who have worked tirelessly to make this Conference a success. David Legler has played a pivotal role and has taken time out from a very busy schedule to write the guest editorial below to help set this edition in perspective. Over to you, David.

Howard Cattle

The role of applications in CLIVAR

David M. Legler, Director U.S. CLIVAR Office

In research we often measure our success by the number and quality of refereed papers, presentations, products, students, and the advancement of knowledge. By these measures, CLIVAR has been "successful" in several areas of scientific discovery, including understanding and simulating in models the mechanisms that govern the physical climate system. Moreover, CLIVAR has helped characterize the predictability of some aspects of the physical climate system, and improved prediction capabilities for phenomena such as the monsoons and ENSO. CLIVAR will also continue to advance the quality of climate forecasts, identify and quantify other sources of predictability of the climate system, detect and describe changes in our climate, and improve the quality of climate system models used to develop future projections of climate changes and simulations of past changes. However, as the scientific community continues making strides in research, interest likewise increases at the local, regional, national, and international levels to utilise improved climate forecasts, refined projections, and new products to explore mitigation options in practices and policies for reducing the potential deleterious impacts of future adverse conditions and to take advantage of favourable conditions.

Increasingly programmes like CLIVAR are expected to contribute more directly to the application of climate information for societal benefit. This is a priority of the national climate research effort in the U.S. for example. Thursday's Conference application session includes demonstrations on how CLIVAR science can lead to improved agricultural productivity and more efficiently managed water resources. Other tantalizing presentations include exploring the connection between climate and ecosystems in the N. Pacific, and analyzing how the NAO is related to heart disease mortality in England. The motivation for CLIVAR to develop and communicate helpful knowledge, capabilities, and products to decision-makers has never been clearer.

Anecdotal evidence of the value of climate forecasts abound. However, broader and more systematic uses of climate science information require considerable and often detailed knowledge of information pathways, management practices, and adaptation and decision-making processes within the affected sector/activity - knowledge that falls outside the realm of most physical climate scientists. In order to develop even more robust linkages to those in the decision-making communities, CLIVAR needs to explore partnerships with individuals and programs that can supply these capabilities. Centers such as IRI (http://iri.columbia.edu/) in the U.S. (see the article on page 5) and WMO efforts to improve climate services (see the CLIPS article on page 4) are helping to break new ground in the area of climate forecast applications. Four international climate changes programmes, including the WCRP, have begun to establish a framework, the Earth System Science Partnership (ESSP - http://www.ess-p.org/) to promote an integrated study of the Earth System and the implications of climate changes for global sustainability. More information on ESSP and about CLIVAR's role within this framework will be forthcoming in the months ahead.

Announcement: Opportunity to participate in climate model analyses leading towards the IPCC Fourth Assessment Report

Climate modeling groups around the world have been charged with performing an unprecedented set of coordinated 20th and 21st century climate change experiments, in addition to commitment experiments extending to the 22nd century, for the IPCC Fourth Assessment Report (AR4). This will require a considerable expenditure of human and computer resources to complete these experiments. The resulting multi-model dataset will be a unique and valuable resource that will enable international scientists to assess model performance, model sensitivity, and model response to a variety of forcings for 20th, 21st, and 22nd century climate and climate change.

There will be an international process to collect, compile, and analyze output from this multi-model dataset for direct input to the IPCC AR4. Any interested person or group can participate in this multi-model analysis activity. Though there is a tight time schedule, this is a way for anyone to become involved with the IPCC AR4 process. A person or group can pick an analysis topic, and email the chair of the Working Group on Coupled Models (WGCM) Climate Simulation Panel, Gerald Meehl (IPCC_analysis@ucar.edu), a one paragraph description including the person or persons who will be doing the analysis, the subject of the intended analysis, the objective of the analysis, and the model data required. This information will be registered by the WGCM Climate Simulation Panel [Meehl, chair (NCAR, USA), members John Mitchell (Hadley Centre, U.K.), Bryant McAvaney (BMRC, Australia), Curt Covey (PCMDI, USA), Mojib Latif (MPI, Germany), and Ron Stouffer (GFDL, USA)] and posted to the CMIP web page. The Panel will strive to enhance communication among analysis investigators to avoid overlap as much as possible.

The registration process is open now, with a deadline of September 1, 2004. At that time, the Panel will have a list of investigators and analysis topics, and this list will be turned over to the lead authors of the relevant IPCC AR4 chapters at the First IPCC Lead Author Meeting in late September, 2004. This material will serve as a place holder for results that can be incorporated into the first draft that will be prepared for the Second Lead Authors Meeting in May, 2005.

Meanwhile, modeling groups will complete the bulk of the climate model simulations by September, 2004. Around the time of the First IPCC Lead Author Meeting in late September, the contact people who have registered for analysis projects will be notified via email concerning model data availability, and instructions will be given for accessing the multi-model dataset from PCMDI. The multi-model analyses will then proceed for the next five months leading up to the **International Workshop on Analyses of Climate Model Simulations for the IPCC AR4**.

The workshop will be held from March 1 – 4, 2005, and will be convened by U.S. CLIVAR and hosted by the International Pacific Research Center (IPRC) at the University of Hawaii in Honolulu. Scientific papers describing the results of the multi-model analyses for IPCC will be presented at the workshop. There will be a workshop report summarizing the presentations that will be furnished to the lead authors of the relevant chapters for the AR4. Results from the analysis projects must then be written up by the respective investigators, and submitted to peer-reviewed journals by the time of the Second Lead Author Meeting in May, 2005, in order to be fully included and assessed in the AR4 as specified by the guidelines of IPCC.

The workshop organizing committee consists of members of the US CLIVAR Scientific Steering Committee [Gerald Meehl (NCAR), James Hurrell (NCAR), Lisa Goddard (IRI), and Dave Gutzler (Univ. New Mexico)] who will organize the workshop in consultation with the WGCM Climate Simulation Panel.

Below is a list of runs being performed by modeling groups for the AR4:

1. 20th century simulation to year 2000, then fix all concentrations at year 2000 values and run to 2100 (CO_2 ~ 360ppm)
2. 21st century simulation with SRES A1B to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 720ppm)
3. 21st century simulation with SRES B1 to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 550ppm)
4. 21st century simulation with SRES A2 to 2100
5. 1% CO_2 run to year 80 where CO_2 doubles at year 70 with corresponding control run
6. 100 year (minimum) control run including same time period as in 1 above
7. $2XCO_2$ equilibrium with atmosphere-slab ocean
8. Extend one A1B and B1 simulation to 2300
9. 1% CO_2 run to quadrupling with an additional 150 years with CO_2 fixed at 4XCO2
10. 1% CO_2 run to doubling with an additional 150 years with CO_2 fixed at $2XCO_2$

PCMDI will collect data from the runs above for a subset of fields as noted on the CMIP web page (http://www-pcmdi.llnl.gov/cmip/). PCMDI also has archived a collection of forcing datasets for 20th and 21st century climate simulations.

As noted above, the scale of this ambitious exercise is unprecedented in our community, and the timetable is tight. However, if an individual or group desires to become involved in the IPCC AR4, this is a very accessible way to do that. All that is required is to choose an analysis topic by September 1, 2004, and register with the WGCM Climate Simulation Panel, perform the analysis on the multi-model dataset that will be available in late September, 2004, write up and submit the results to a peer-reviewed journal prior to May, 2005, and the results will be made available to the lead authors of the IPCC AR4.

If you desire to register an analysis topic, please be as specific as possible. For instance, “ENSO” as a general topic is too general, but it should be narrowed down to something like, for example, “ENSO effects on the Indian monsoon in 20th and 21st century climate”.

The WGCM Climate Simulation Panel:
Gerald Meehl (chair), Curt Covey, Mojib Latif, Bryant McAvaney, John Mitchell, Ron Stouffer

Climate Information and Prediction Services (CLIPS)

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CLIPS

Recognizing that improved climate prediction will not be effective unless the associated services are delivered in a framework that is useful to the affected sectors, the World Meteorological Organization (WMO) at its Twelfth Congress in 1995, established the Climate Information and Prediction Services (CLIPS) Project to help National Meteorological and Hydrological Services take advantage of recent advances in climate science. A major objective of CLIPS is to stimulate the use of sector-specific information in an ongoing, iterative dialogue between the producers of climate information and the multitude of users in government, academia, private industry and the media. To this end, CLIPS is an active partner in the Regional Climate Outlook Fora which are now held regularly at various locations in Africa, South East Asia, Central and South America. These fora bring together international researchers with scientists, various users, decision makers and representatives of the media in the region. The objectives of the fora are, inter alia, to develop a consensus climate prediction for the region covering the months ahead. One of the goals of the CLIPS project is to help end-users to better understand and use such products.

Demonstration and pilot projects

CLIPS initiates demonstration and pilot projects around the world to evaluate the value of climate information in decision processes. For the project ‘Seasonal Weather Forecasting for the Food Chain’, CLIPS and the UK Foresight Programme brought together climate scientists and specialists from the United Kingdom food chain industry (retailers, agronomists, farmers and processors) to investigate the scientific and economic benefits of collaboration. Increasingly useful climate forecasts, and better understanding of them within the whole food chain, have great potential to improve supply-chain management, reduce losses and contribute to lessening the impact of agriculture on the environment. Other applications projects are being developed in collaboration with international and regional centres to address production and dissemination of climate information and products to various sectors. CLIPS works in cooperation with the global forecast centres, specialized meteorological centres such as the Drought Monitoring Centres in Africa, and international agencies concerned with agriculture and food security, health and water resources; aid and disaster response; science and social research; and funding and development (amongst others the Food and Agriculture Organization of the United Nations; the United Nations Environment Programme; the International Federation of Red Cross and Red Crescent Societies (IFRC); the World Health Organization; and the World Bank).

Capacity Building

CLIPS organizes training sessions and workshops to promote capacity building of both producers and users of long range forecast products. WMO Members are developing a global network of climate scientists who will serve as CLIPS Focal Points and will work to coordinate the production and use of climate information and products at a national and regional level.

ANNOUNCMENT

An Atlas of XBT Therma–Structures and TOPEX/POSEIDON Sea Surface Heights in the North

The National Institute of Oceaongraphy, Dona Paula, Goa, India, the National Remote Sensing Agency, Bala Nagar, Hyderabad, India and The Ohio State University, Columbus, Ohio, USA have produced “an atlas of XBT Thermal Structures and TOPEX / POSEIDON Sea Surface Heights in the North Indian Ocean” from observations made under the Tropical Ocean and Global Atmosphere (TOGA) program. Copies are available free of charge on application to the National Institute of Oceanography, Dona Paula, Goa - 403 004, India quoting “Special Publication N10-NRSA-SP-01-03.

To what extent can climate information contribute to solving problems?

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Introduction

It has emerged over the last few decades that climate variability has a degree of predictability seasons in advance, especially in parts of the tropics. But this capability has been slow to result in organic uptake of the information, or demonstrable benefit by decision makers (e.g. Glantz, 2001). There are many valid reasons for this, and this motivates a significant amount of research at the International Research Institute for Climate Prediction (IRI). Much work by many contributors has demonstrated there are few quick remedies. From the experience of the IRI, the answer to the question 'to what extent can climate information contribute to solving problems' becomes substantially more positive when working from the outset with the perspective of the problem itself. Important questions include:

• From the perspective of experts or leaders in the region, what are the most important problems?

• What institutions, policies, and decision systems are in place to address problem factors, and in what areas could they make positive use of additional information?

• How does climate variability interact with the environment to create societal impact, and how can impacts be evaluated over time using historical data?

• What kinds of monitoring and prediction products may be developed in the context of all of the above?

In this contribution, we provide an overview of on-going work by way of case studies primarily centered in a cluster of research at IRI known as decision systems research. It is recognized that for climate monitoring and forecasts to robustly inform sectoral decisions, a basic understanding of climate impacts in those sectors is a prerequisite. Furthermore, fostering effective uptake within society, especially scaling up from demonstration pilots, requires an understanding of, and full involvement of, institutional and policy systems. The fundamental climate predictability and environmental monitoring capability are of course other prerequisites. In seeking to accelerate the uptake of scientific advances, capacity building is also a critical component of arriving at sustainable use in society through ownership, especially in developing-country settings. This also means that, for a research institute like IRI, partnering with institutions is the only way to achieve the desired goal.

Within this broad vision, the remainder of this contribution reports some examples of place-based demonstration initiatives focusing on sectoral decisions and their enhancement with climate information and forecasts. A critical component of the work is participatory definition of the decision problem. Others include identifying the information needed, the flexibility to adapt the existing decision systems, understanding of how decisions are made under risk and uncertainty, and how information may be communicated in real-time to best influence decisions (e.g. Hansen et al., 2004). The discussion below focuses more on the technical aspects of examples of the creation of the information and the modeling of sectoral decisions, which highlights intersection with CLIVAR science, but nonetheless, this should not disguise that true value to society is best achieved through proper treatment of all components of the problem. Therefore, reflecting the full range of issues touched on in this introduction, there is much more work with partners that is not reported here and that collectively forms more complete projects in each of these cases.

Water resource management in Northeastern Brazil

Predictability of the wet season's rainfall total is well established for Northeastern Brazil (Hastenrath et al., 1984, Moura and Shukla, 1981). Furthermore, compared to some parts of the tropics, the predictability appears to be quite uniform across small spatial scales. This has recently been successfully simulated using long runs of a regional climate model (Sun et al, 2004). The region therefore provides a good opportunity to explore potential benefits of incorporating seasonal prediction information into sectoral decisions.

An example that has been developed in some detail is the management of the Oros Reservoir in Ceara State, NE Brazil (Souza and Lall, 2003; Sankarasubramanian, a,b, in prep.). The information needed is the probability density function of the expected annual inflow (January to December). Based on the way the reservoir is currently managed, the information is needed in July of the preceding year. Research was undertaken to develop a forecast system to generate the needed information. Building on the well-established diagnostic understanding of the region's interannual variability, two empirical predictors were developed (one representing El Nino, the other the north-south gradient of Sea Surface Temperatur (SST) in the tropical Atlantic). These predictors were applied in a k-nearest neighbor analog method to generate probabilistic inflow forecasts for the reservoir. A decision system for the reservoir management was also modeled, including definition of trigger points for when water restrictions need to be implemented and the reservoir manager's choice of acceptable risk each year for needing to apply water restrictions. The latter is normally referred to as choice of reliability.

Using only information about climatological inflow values, the solid line in Figure 1a shows the amount of water that can be allocated for the upcoming year, versus the reliability. Obviously, if plans are made to draw larger amounts of water from the reservoir, the risk of needing to apply restrictions increases (i.e., the reliability decreases). The probabilistic inflow forecasts for each year have been injected into this problem. For example, relatively high inflows are expected for 1989 based on June 1988 SST predictors (Figure 1a), which allow a strategy of drawing more water from the reservoir, for the same level of reliability. For 90% reliability, the water that can be planned for rises from about 200 hm^3 (long-term climatology) to 275hm^3 (based on the probabilistic inflow forecasts). From this information, a rule curve can be derived to guide the reservoir manager on the amount of water to release each month during the year. The consequences of following these rule curves over the period 1949 to 1995 have been estimated for the reservoir. One problem for managing the reservoir is that in high inflow years, often water has to be released through spillage channels and is lost as a resource. The reduction in spillage when the reservoir is managed using the rule curves based on the seasonal forecast is shown in Figure 1b. In years when high inflow is successfully forecast, and plans are made to draw larger amounts of water from the reservoir, spillage can be substantially reduced. This is one example of the improvements that can be quantified through this type of analysis. Work is now underway with local partners to adapt this methodology to other regional settings, including basins in Philippines and Kenya, as well as to consider developing a more generally applicable tool to assist in the more widespread uptake of the methodology.

Farm decisions in Kenya

Agriculture is a sector greatly impacted by climate. Problem-driven interventions based on seasonal prediction information can be anticipated at a number of scales from farm-level to more national and regional issues. At the farm-level, there are special challenges concerning the level of predictability of climate at such small spatial scales. This is being addressed through downscaling research. In some regions of high prediction skill, such as East Africa in the October-December season (Ogallo, 1988, Goddard and Graham, 1999), good promise is emerging. A further challenge is the

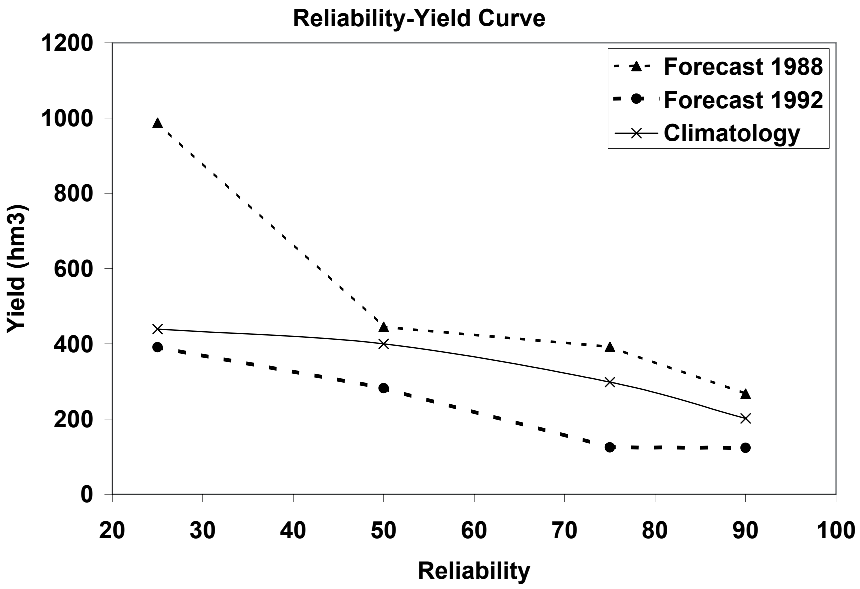

Figure 1a: Bulk Sector Water allocation (yield) for years 1988 and 1992 for the Oros reservoir using the 12-months lead semi-parametric K-NN forecast and using the climatological forecasts. The yield-reliability curves for both forecast and climatology are obtained by assuming the initial storage in the beginning of July 1988 and July 1992 to be 50 hm^3.

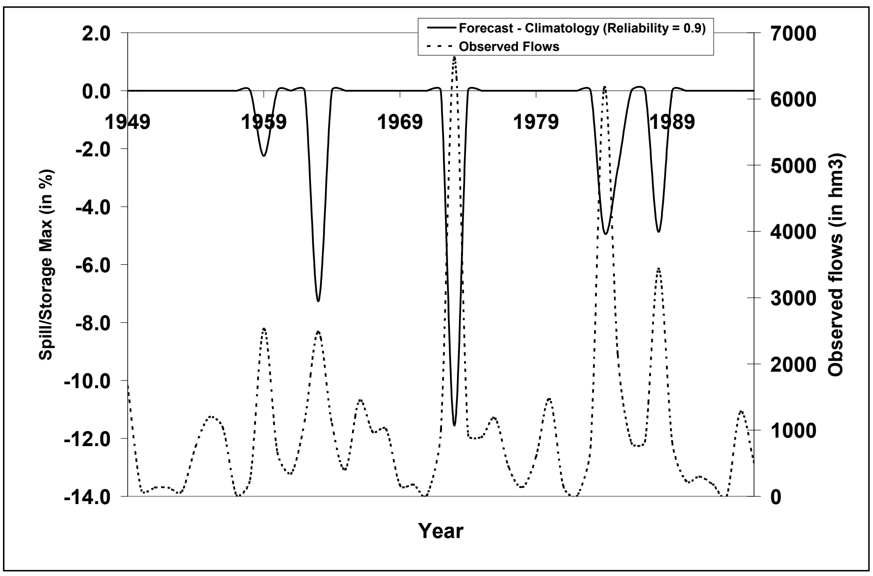

Figure 1b: Difference in spill obtained from 12 months lead K-NN forecasts and the Null forecast from 1949-1995. Spill is given as % of the maximum storage (Smax = 1940 hm3).

substantial dependence of crops on distribution of rainfall through the season. A methodological research area is the coupling of seasonal predictions with crop models. Figure 2 (page 8) provides an example of intercomparing a number of methods to predict crop yield at the widely researched agricultural site of Katumani in Kenya. Model output statistics (MOS) are applied to simulations made with a General Circulation Model (GCM) driven with observed SSTs (Hansen and Indeje, 2004). Five different approaches are tested. In this example, the result is quite robust across the methods tested. Further examples are needed to understand better the performance of different approaches to coupling seasonal forecasts to crop models in different ecological and climatological settings. Once the coupling is made, it allows injection of seasonal forecast information into farm-level models to explore a range of farming decisions (e.g., Mjelde et al., 1997; Jones et al., 2000). The output can lead to robust guidance to agricultural extension. A number of pilot efforts are underway around the world, to work in participatory ways with farming communities to advance this, including developing the work described above on Katumani with local partners and farming communities in the Machakos district of Kenya.

Livestock management in the Greater Horn of Africa

An agriculture issue that has potential regional level interventions is the risk of Rift Valley Fever (RVF) in livestock in the Greater Horn of Africa (GHA). It has been proposed that a useful indicator of risk is the normalized difference vegetation index (NDVI), which in some circumstances can act as a good proxy for the extent to which the environment is favorable for the development of RVF. The MOS approach has therefore been explored for predictability of the NDVI, a variable whose potential in seasonal forecast applications had been previously recognized (Verdin et al., 1999; Nicholson et al., 1990). Figure 3a (page 16) shows the predictability for each grid-box of NDVI. NDVI values are those for December and the GCM output was generated from runs that used persisted September SST anomalies. The information about December NDVI is therefore potentially available in early October. There is considerable spatial variation in the predictability, which requires further research to understand. The variations could be related to spatial variations in the climate-NDVI coupling, or spatial variations in the predictability of climate itself. The latter has been hypothesized to be present in the GHA region, and represents a substantial but critical climate research challenge. This is likely to be the case in many regions of complex land surface gradients, at least in terms of complex orography, but also possibly including gradients of vegetation type and land-sea and land-lake contrasts. Predictability is however encouragingly strong and uniform over northeastern parts of Kenya. Figure 3b shows the area average predicted and observed NDVI* for that region. This work forms a contribution to a broader effort with national and international collaborators to build a spatial early warning system using monitored and predicted information to support interventions based on risk assessments of RVF outbreak. The NDVI is indeed emerging as a variable that may be a useful proxy in a number of applications settings, including malaria early warning, for which work is underway in a number of regions, including West and Southern Africa.

Summary

The climate applications community, including the IRI, is gaining more experience at working with the potential of modern climate information and learning the breadth of research and activities needed to best enhance the use of information about climate variability. The approach at IRI is to combine the breadth of methodological research with specific problem-oriented, place-based projects, implemented in collaboration with research and operational partners. In this way, there is greater opportunity to demonstrate the benefits of climate information, integrated in a balanced way into specific climate-impacted problems, and laying the basis for scaling up and accelerating the attainment of wider benefits across society. One component of the needed work is focused on demonstrating the benefits of tailored climate information in sectoral decisions. This can highlight intersection with CLIVAR science and has been the focus of the case studies in this article. The examples have focused on using seasonal climate predictions, but it is clear from the problem perspective that uses of climate information are not bounded by timescale or type of information. Integrating environmental monitoring and information about longer timescales, and indeed shorter timescales down to weather forecasting, can be expected to provide the maximum benefit to society.

Acknowledgements

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References

Glanz, M. (ed), 2001: Once Burned Twice Shy, The United Nations University, Shibuya-ku, Tokyo, Japan, 294 pp.

Goddard, L. and N. E. Graham, 1999: The importance of the Indian Ocean for GCM-based climate forecasts over eastern and southern Africa. *J. Geophys. Res.*, **104**, 19099-19116.

Hansen, J.W. and Indeje, M., 2004: Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya. *Agricultural and Forest Meteorology* (in press).

Hansen, J.W., S. Marx, E. Weber, 2004: The role of climate

* Corrected NDVI data provided by USGS: USGS NDVI dataset: http://edcw2ks21.cr.usgs.gov/adds/readme.php?symbol=ne

perceptions, expectations and forecast in farmer decision making. IRI Technical Report 04-01, Palisades, NY.

Hasternrath, S. M.-D. Wu, and P.-S. Chu, 1984: Towards the monitoring and prediction of north-east Brazil droughts, *Q.J.R. Meteorol. Soc.*, **110**, 411-425.

Indeje, M., M.N. Ward, G. Davis, L. Ogallo, F.M. Dilley and A. Anyamba, in prep: Predictability of the Normalized Difference Vegetation Index (NDVI) In Kenya, An Indicator of Rift Valley Fever Outbreaks in the Greater Horn of Africa. *J. Climate.*

Jones, J.W., J.W. Hansen, F.S. Royce, and C.D. Messina, 2000: Potential benefits of climate forecasting to agriculture. *Ag., Ecosys. and Environment* **82**,169-184.

Mjelde, J.W., Thompson, T.N., Nixon, C.J., Lamb, P.J., 1997: Utilising a farm-level decision model to help prioritise future climate prediction research needs. *Meteorol. Applications*, **4**, 161-170.

Moura, A.D. and J. Shukla, 1981: On the dynamics of droughts in Northeast Brazil: Observations, theory and numerical experiments with a general circulation model. *J. Atmos. Sci.*, **38**, 2653-2675.

Nicholson, S. E., M. L. Davenport, and A. R. Malo, 1990: A comparison of the vegetation response to rainfall in the Sahel and East Africa, using Normalized Difference Vegetation Index from NOAA AVHRR. *Climatic Change*, **17**, 209-241

Ogallo, L.J., 1988: Relationship between seasonal rainfall in East Africa and Southern Oscillation. *J. Climatol.*, **9**, 39-43.

Roeckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida, 1996: The atmospheric general circulation model ECHAM4: Model description and simulation of present-day climate. Max Planck Institut für Meteorologie, Report No. 218, Hamburg, Germany, 90 pp.

Sankarasubramanian, A., Lall, U. and Sharma, A.,a: Dynamic Water Allocation Framework for multiple uses I: Performance under Reservoir Inflow Forecasts of Known Skill. *W. Resources Res*. (in preparation)

______, b: Dynamic Water Allocation Framework for multiple uses II: Performance under Climate Information based Reservoir Inflow Forecasts. *J. Climate*.(in preparation)

Souza FA, Lall U, 2003: Seasonal to interannual ensemble streamflow forecasts for Ceara, Brazil: Applications of a multivariate, semiparametric algorithm. *W. Resources Res.*, **39**, 1307.

Sun, L., D. F. Moncunill, H. Li, A.D. Moura, and F. A. Souza, 2004: Climate downscaling over Nordeste Brazil using NCEP RSM97. *J. Climate*.(submitted)

Verdin, J., C. Funk, R. Klaver, and D. Roberts, 1999: Exploring the correlation between Southern Africa NDVI and Pacific sea surface temperatures--results for the 1998 maize growing season. *Intnl. J. Remote Sens.*, **20**, 2,117-2,124.

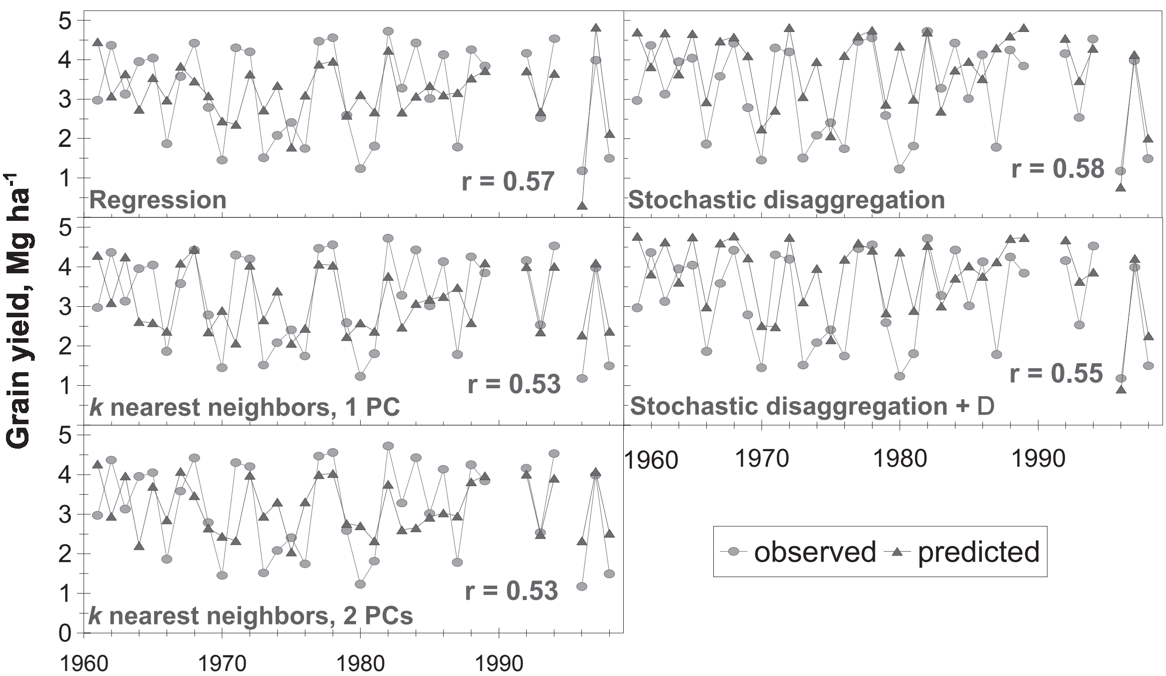

Figure 2. A case study comparing different methods for best-estimate predictions of maize yield in Katumani (Kenya), based on predictions from the ECHAM4.5 General Circulation Model (GCM) (Roeclmer et al., 1996). These methods could all be used in economic model analyses to consider the benefits of incorporating the forecast information into crop management decisions, such as cultivar selection, planting density and nitrogen fertilizer at a field scale; or allocation of land or labor at a farm scale. In the panels (a) to (e), the light grey line is the maize yield simulated with observed weather data (so these are treated as the verifying yields). The predicted series in (a) to (e) (dark lines) are each generated by a different method of transforming large-scale GCM output fields: a) non-linear regression, b) k-nearest neighbor using 1 GCM PC, c) k-nearest neighbor using 2 GCM PCs, d) stochastic disaggregation from hindcast monthly rainfall totals, e) same as d) but also using hindcast wet-day probabilities to condition weather generator parameters. (From Hansen and Indeje, 2004).

DEMETER: A first step or giant leap in the use of a seasonal ensemble prediction system for application users?

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Background

The research interests of the CLIVAR community in climate variability have direct application for the impacts groups whose recent work is included in this paper. Further, the importance of the user application community in the utilisation of climate forecasts (Pfaff et al., 1999 and Archer, 2003) and probabilistic seasonal forecasts (Hartmann et al., 2003; Zhu et al. 2002 and Palmer, 2002) is recognised. There is, however, limited literature on probabilistic application forecasts that apply some form of seasonal scale forecasts (Potgieter et al., 2003 and Franz et al. 2003) with few current reports of probabilistic application models or analyses running 'within' a seasonal scale ensemble prediction system. This paper reports on four such applications which have been run with the DEMETER probabilistic seasonal hindcasts.

The DEMETER project (www.ecmwf.int/research/demeter/) was funded under the European Union Vth Framework to assess the skill and potential economic value of multi-model ensemble seasonal forecasts. The DEMETER multi-model prediction system comprises of seven global coupled ocean-atmosphere models (Palmer et al., 2004). The DEMETER, 180 day, hindcasts were started four times a year from 1st February, 1st May, 1st August, and 1st November. Hindcasts have been produced over the period 1958-2001, although the common period to the seven models is 1980-2001. The seven models with nine ensemble members per model gave a total of 63 hindcasts for each start date. The performance of the DEMETER system has been evaluated from this comprehensive set of hindcasts (Palmer et al., 2004; Hagedorn et al., 2004). The ERA-40 reanalysis data is also used in this paper and the project is outlined by Uppala, 2002. ERA-40 has produced global reanalyses for the period 1957 to 2001.

The application groups featured here have interests in tropical health, agriculture and electricity demand; illustrating potential applications for malaria transmission simulation modelling, the potential application of European crop yield modelling, the potential application for local crop growth modelling and the potential prediction of winter climate regimes through cluster analysis. The three applications are all susceptible to the interannual variability of the climate system and particularly to anomalous years. Excess rainfall can lead to malaria epidemics in parts of Africa with unstable malaria transmission, weather conditions can have a large impact on wheat yields in Europe and a very cold winter or very hot summer can lead to unprecedented European electricity demand. Not only does demand (and consumption) for electricity depend on the prevailing climate but production capacities also depend on climate. Precipitation to drive hydroelectric schemes, cooling water from rivers for nuclear plants can only be abstracted at certain river water temperatures and finally the market prices are driven by prevailing climatic conditions.

What is common to all of these applications is a need for timely skilful probabilistic seasonal scale forecasts. These forecasts would then be processed through an application model or an application data analysis system and should retain the probabilistic approach of the original forecast. This probabilistic user's forecast could potentially be disseminated either within the application partner's organisation or on to a wider community where the information could be used for strategic planning purposes.

To give some idea of the potential of the application areas here are some examples of the issues faced by the respective application communities of health, agriculture and power production. It is estimated that malaria kills between 700,000 and 2,700,000 annually (MIM, 2001). In addition there are over 300 million acute malaria cases per year. The total value of EU agricultural production is around 200 billion € and the EU production of wheat is around 100 million tons (European Commission 1999), putting the EU as the second largest producer in the world after Asia (FAOSTAT 2001). In France, an additional 1200 MW of electricity demand is created each winter time by a negative temperature anomaly of one degree due to increased heating demand and in summer a positive anomaly of the same amount leads to a 200MW increase due to increased air conditioning demand.

Details on the use of DEMETER hincasts for malaria transmission simulation modelling, European wheat yield modelling, northern Italian wheat yield, and climate cluster analysis for potential electricity demand can be found respectively in Morse et al. (2004), Cantelaube and Terres (2004), Marletto et al. (2004) and Fil and Dubus (2004). All of these applications and their use of seasonal scale probabilistic forecasts are still in the development stage.

Outline of Methods and Results

Malaria transmission

The malaria transmission simulation model (MTSM), described by Hoshen and Morse (2004), uses DEMETER or ERA-40 two metre maximum temperature and daily precipitation to derive a daily malaria prevalence (the total number of cases within a simulated population at that day). The 63 DEMETER hindcast members were bias corrected using ERA-40. Data for 15 years for four grid points 17.5ºS 22.5ºE to 17.5ºS 30ºE, eastern Angola through to Zimbabwe, at 2.5 degree resolution were run through the MTSM and compared with ERA-40 driven MTSM runs. The seasonal forecasts of most interest were the February starts with the forecast windows of two to four months (MAM) and four to six months (MJJ), as these coincide with the development of mosquitoes and malaria transmission in the MTSM. The MSTM DEMETER prevalence forecasts, when using the ERA-40 run as a perfect forecast for comparison, were found to be skilful using the Brier skill score (Wilks, 1995) for both forecast windows. The upper tercile event malaria prevalence forecasts for the four to six month window the May, June and July average gave a Brier skill score of 0.178 and had potential economic value across a range of cost-loss ratios. Figure 1 shows a box-whisker plot of the MSTM prevalence forecast for the February four to six month window. It can be seen that for most years the ERA-40 derived MTSM prevalence value is captured within the DEMETER ensemble members. It must be made clear that this is not a ground validated result and malaria transmission validation will always be difficult due to the paucity and often uncertain quality of clinical data. This skilful prevalence result was surprising as the precipitation forecast for this region and season were not skilful but the temperature, particularly the upper tercile event, was skilfully predicted.

Crop yields

The two crop yield groups (JRC and ARPA) have used a similar methodology using a WOFOST based crop yield model (Supit et al., 1994) driven by precipitation, maximum and minimum temperature, global radiation and computed evapotranspiration. The current methodology used by the DEMETER groups for final crop yield prediction is a hybrid model system which runs a crop growth model (WOFOST) driven with actual meteorological observations to set dates and then uses a statistical regression model that can predict the yield using the simulated crop growth indicators. The two groups were both predicting wheat yields with ARPA working in northern Italy and JRC working across the EU wheat producing countries. Both groups have made probabilistic DEMETER driven crop model yield predictions and made comparisons of its performance versus the current hybrid methodology. For the northern Italian cases, ARPA have made additional crop model runs based both on the climatology, which would be the non seasonal forecast data alternative for WOFOST, and WOFOST run with the actual full growing season observed weather data; both were used for comparison with the DEMETER based runs. Both groups have made comparisons with actual wheat yields. The DEMETER ensemble members were downscaled from global model resolution using a singular value decomposition analysis technique (Feddersen and Andersen, 2004) using either the monthly means from the 50x50 km JRC gridded observational dataset or the MAP (Mesoscale Alpine Programme) data. These downscaled data were then redistributed on a daily basis with a weather generator based on the Richardson WGEN model (Richardson, 1981).

Table 1

Model Run	Weighted Yield Error (%) ± standard error
JRC February	7.1 ± 0.9
JRC April	7.7 ± 0.5
JRC June	7.0 ± 0.6
JRC August	5.4 ± 0.5
DEMETER (Feb. start)	6.0 ± 0.4

Table 1 above, shows the results from JRC of the forecast errors from official figures, comparing the JRC model operational system at different dates during the growing season (from February to August, real time forecasts) and the JRC model driven by a mix of observed data (until February) to which were added the DEMETER 63 member ensembles (from March to July, for the seasonal forecasts from the February start date). At the European level, the percentage error obtained with DEMETER at the end of February (5.9%, Portugal excluded and weighted by the contribution of each member states in the EU wheat production) lies between the average error found at the end of June (7%) and the error found at the end of August (5.4%) using JRC operational system. It demonstrates the prediction skill of DEMETER ensembles and the ability to make the forecast earlier in the season than with the current methods. Figure 2 shows the results from ARPA of a DEMETER ensemble 'completed' WOFOST yield prediction for the years 1977 to 1987 for a site near Modena, Italy. The WOFOST based model was run up to the end of March with observed data and then a prediction was made to the end of the growing season in June using DEMETER as a predictor. The DEMETER ensemble members from four of the global models with two downscaling replicates were used giving 72 ensemble members in total. For comparison, firstly a run based on the actual observed weather conditions for that year, a perfect forecast, and secondly a run based on climatology for the months of April, May and June were used with both model runs initiated in the same way as the DEMETER runs. Model runs (not shown), using the method above were also started at the end of April and end of May. The predictive power of crop yield increases, perhaps not surprisingly, as the runs start later in the season and the DEMETER results gave generally better

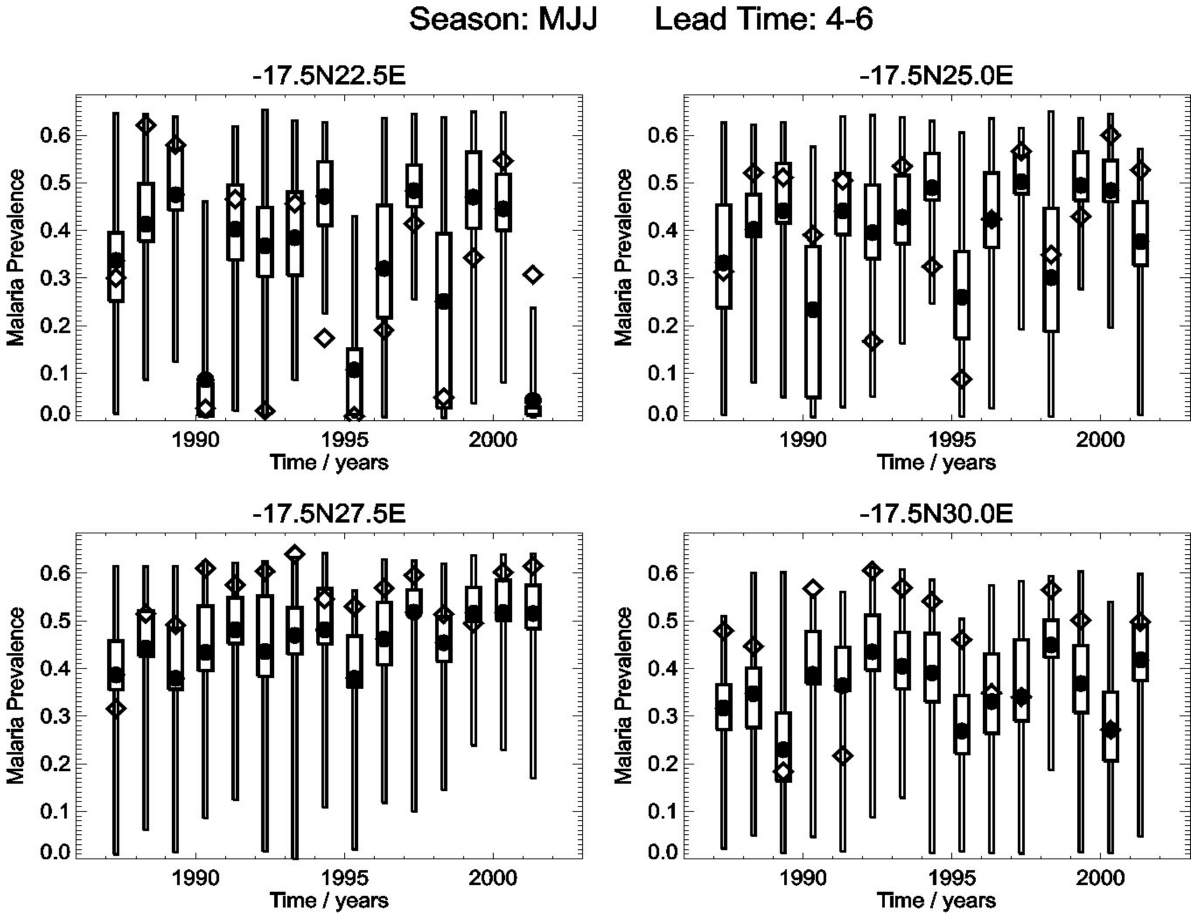

Figure 1. Prevalence from the Malaria Transmission Simulation Model as a box-whisker plot for the four grid points for Feb 4-6 (MJJ) forecast window, showing the ERA value (hollow diamond) and ensemble mean (solid circle) where the range of the box is the middle tercile and the upper and lower whiskers the upper and lower terciles of the ensemble distribution respectively.

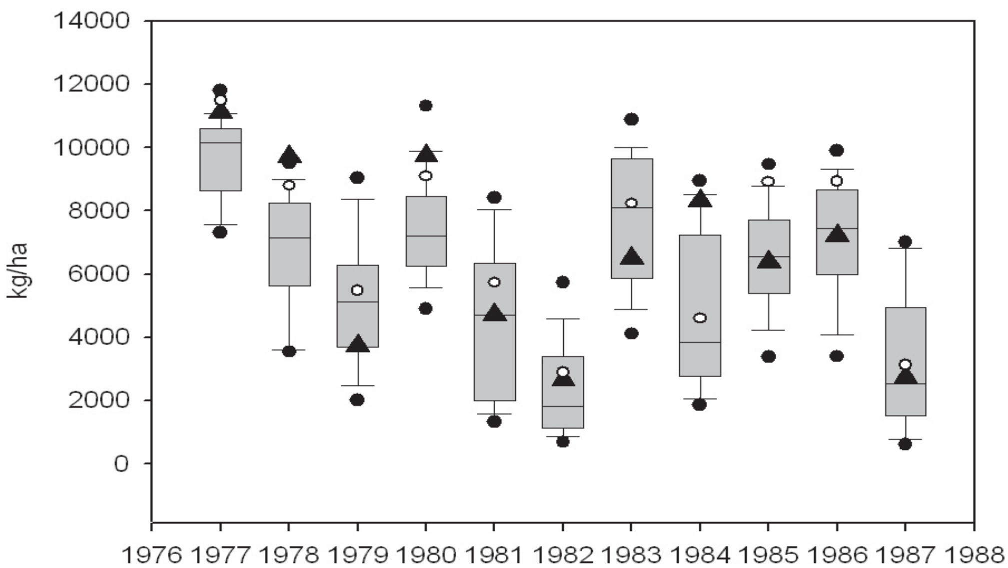

Figure 2. Box (interquartile range) and whiskers (10th and 90th percentiles) distributions of predicted water-limited wheat yields (kg ha-[1]) simulated using downscaled multi-model ensemble DEMETER hindcasts for the years 1977-1987 in a location near Modena, Italy. Ensembles of 72 runs of the WOFOST based crop growth model were performed using four global models and two downscaling replicates for each member. The crop model was provided with observed weather data up to the 31st of March and supplemented with DEMETER downscaled hindcasts up to harvest date (typically end of June in Northern Italy). Wheat yields simulated with observed weather data, solid triangle, and median yields simulated with climatology, hollow circle are provided for comparison.

or similar results in the majority of cases when compared with the two non DEMETER model runs.

Electricity demand

Medium range operational forecasts are routinely used for planning purposes by electricity companies including Electricité de France. To examine the potential of seasonal forecasts for power planning ERA-40 reanalysis and DEMETER hindcasts for the winter season were examined for regime type using cluster analysis of the monthly pressure fields (Cassou et al., 2004) over the North Atlantic and European region. The four clusters are named NAO+, NAO-, Ridge and GS. Where NAO+ and NAO- are the positive and negative phases of the North Atlantic Oscillation, Ridge is the situation with a strong anticyclonic ridge over the North Atlantic basin and GS a zonal pressure dipole between Greenland and Scandinavia. These regimes were found in the ERA-40 reanalysis data for 1958-2001. The DEMETER data were then examined using each of the nine ensemble members for each of the seven global models. In addition a multi-model ensemble of 27 members was constructed for three of the models, with the greatest data holdings, which covered the 1959 to 2001 time period. The pressure patterns for the three winter months (DJF) were taken from the DEMETER November forecast start date model runs. The DEMETER model runs were found to produce the clusters seen in the ERA-40 analysis. The position and intensity of the characteristic anomaly centres vary from model to model but were found to correlate with the ERA-40 values. The best correlations between the DEMETER and ERA-40 were found for the NAO+ and NAO- regimes, however, there was more variability with the GS and Ridge clusters. The best correlations are found with the ECMWF model. The potential prediction of winter time climate regimes could be useful if they relate to surface conditions. In fact, the four climate regimes correspond to specific general atmosphere states and are characterised by specific temperature anomalies. These temperature impacts are also well simulated by the DEMETER models. Figure 3 displays at each grid point the regime that occurs more often in case of warm event (defined by the 20% extreme values of 850hPa temperature) and show clear and distinct zones influenced by one or another regime. At present little skill was found in the seasonal forecasting of the winter time regimes because of the large spread within the ensemble but a potential application has clearly been demonstrated.

Discussion and Conclusions

Further challenges remain for the impact groups to improve their application models and analysis methods, and to continue to make use of the probabilistic nature of seasonal scale ensemble prediction systems. There is also room for improvement in the seasonal forecast skill for some variables notably, and not surprisingly, precipitation; current seasonal forecast skill for temperature in some regions is surprisingly high even for the four to six month forecast window. Downscaling techniques improve the reliability of the forecasts in Europe. However, techniques developed for areas with both an available and dense station network, such as Europe, will not work for other parts of the world, such as Africa, with its paucity of station data.

Importantly it will be the user community that can provide vital feedback to the seasonal forecast providers, to help to improve an end-to-end seasonal forecasting system. An application model provides an integrated estimate of the skill, often the non-linear product of several forecast variables, versus the traditional skill assessment in climate prediction carried out for separate variables. This further illustrates the importance of the end-to-end approach of integrating application models within probabilistic forecasting systems. It is the user group that can define the potential cost-loss benefit for their application within a seasonal multi-model forecasting system. Further, it will be the application users who will help to set the forecast skill targets that would allow their application models and analysis to be of use for the user communities with which they are associated. Given the non linear nature of the application models it is not easy to 'guess' what these seasonal scale forecasts levels might have to achieve to reach their skill targets.

A first step or giant leap? The authors believe this brief review shows that the application groups have made a very credible and scientifically sound first step with a number of results showing real potential for the use of probabilistic seasonal scale forecasts. The giant step is still mid-stride but through DEMETER the two communities now have a much better understanding of each other's needs, skills and limitations and it is this spirit of co-operation that we shall go forward into the forthcoming EU ENSEMBLES probabilistic forecasting project.

Acknowledgements

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References

Archer, E. R. M. 2003: Identifying Underserved End-User Groups in the Provision of Climate Information. *Bull. Ameri. Meteorol. Soc*., **84**, 1525-1532.

Cantelaube, P. and J.M. Terres, 2004: Use of Seasonal Weather Forecasts in Crop Yield Modelling. *Tellus* (submitted).

Cassou, C., L. Terray, J.W. Hurell, C. Deser, 2004: North Atlantic winter climate regimes: Spatial asymmetry, stationarity with time and oceanic forcing, *J. Climate*, **17**, 1055-1068.

European Commission (DG Agriculture), 1999: La politique Agricole commune, synthèse 1999. Luxembourg: Office des publications officielles des Communautés européennes, 2000 – 30p.

FAOSTAT, 2001: FAO Statistical Databases. Food and Agriculture Organisation of the United Nations. Rome, Italy.

Feddersen, H. and U. Andersen, 2004: A method for statistical downscaling of seasonal ensemble predictions, *Tellus* (submitted).

Fil, C. and L. Dubus, 2004: Winter Climate Regimes over the North Atlantic and European Region in ERA40 Reanalysis and DEMETER Seasonal Hindcasts. *Tellus* (submitted).

Franz, K.J., H.C., Hartmann, S. Sorooshian, and R. Bales, 2003: Verification of National Weather Service Ensemble

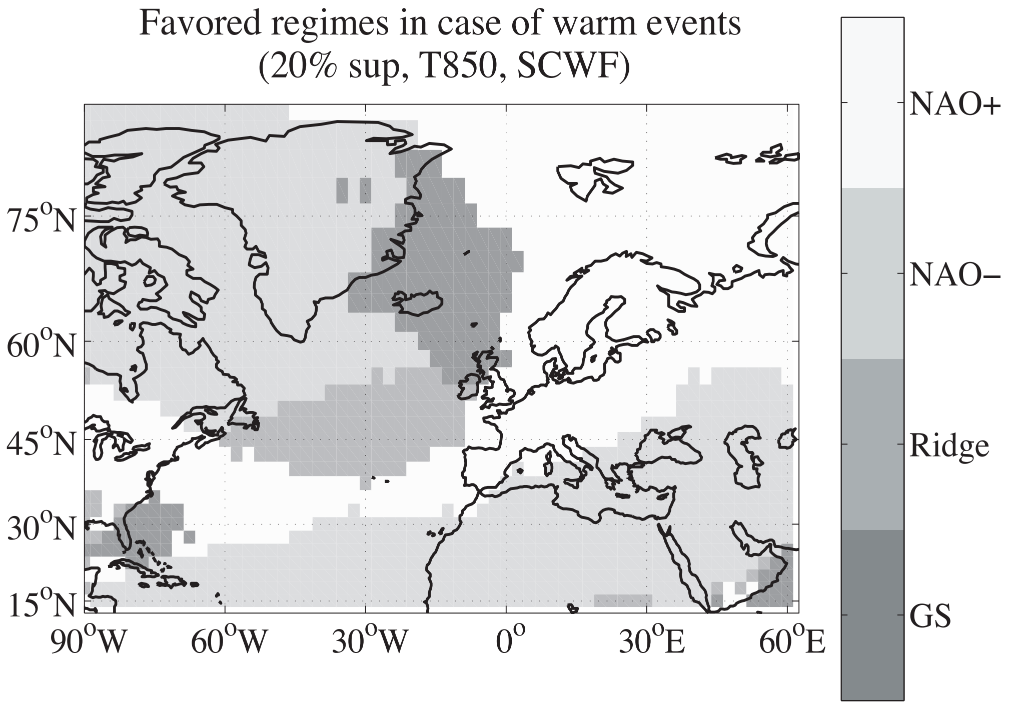

Figure 3. The upper quintile events for the 850hPa temperature for each grid point and the corresponding cluster type. This shows a distinct regional pattern for the different cluster types and thus the potential to forecast forthcoming seasonal cluster and thus near surface temperatures.

Streamflow Predictions for Water Supply Forecasting in the Colorado River Basin. *J. Hydrometeorl*., **4**, 1105-1118.

Hagedorn, R., F. Doblas-Reyes and T.N. Palmer, 2004: The rationale behind the success of multi-model ensembles in seasonal forecasting. Part I: Basic concepts. *Tellus* (submitted).

Hartmann, H. C., C. Pagano, S. Sorooshian, S. and R. Bales, 2003: Confidence Builders – Evaluating Seasonal Climate Forecasts from User Perspectives. *Bull. Ameri. Meteorol. Soc*., **83**, 683-698.

Hoshen, M.B. and A.P. Morse, 2004: A weather-driven model of malaria transmission. *Malaria Journal* (submitted).

Marletto, V., F. Zinoni, L. Criscuolo, G. Fontana, S. Marchesi, A. Morgillo, M.R.M. Van Soetendael, E. Ceotto and U. Andersen, 2004: Evaluation of downscaled DEMETER multi-model ensemble seasonal hindcasts in northern Italy by means of a model of wheat growth and soil water balance. *Tellus* (submitted).

MIM 2001: NIH News Release August 2001 (http://mim.nih.gov/english/news/newsrelease_080201.html)

Morse, A.P., F.J. Doblas-Reyes, M.B. Hoshen, R. Hagedorn, M. Thomson, and T.N. Palmer, 2004: First steps towards the integration of a dynamic malaria model within a probabilistic multi-model forecasts system. *Tellus* (submitted)

Palmer, T.N. 2002: The economic value of ensemble forecasts as a tool for risk assessment: From days to decades. *Q. J. R. Meteorol. Soc*., **128**, 747-774.

Palmer,T.N., A. Alessandri, U. Andersen, P. Cantelaube, M. Davey, M. Déqué, E. Díaz, F.J. Doblas-Reyes, H. Feddersen, R. Graham, S. Gualdi, J.-F. Guérémy, R. Hagedorn, M. Hoshen, N. Keenlyside, M. Latif, A. Lazar, E. Maisonnave, V. Marletto, A.P Morse, B. Orfila, P. Rogel, J-M Terres and M.C. Thomson, 2004: Development of a European Multi-Model Ensemble System for Seasonal to Inter-Annual Prediction (DEMETER), *Bull. Ameri. Meteorol. Soc*., (in press).

Pfaff, A., K. Broad and M. Glantz 1999: Who benefits from climate forecasts? *Nature*, **397**, 645-646.

Potgieter, A.B., Y.L. Everingham and G.L. Hammer 2003: On Measuring Quality of a Probabilistic Commodity Forecast for a System that Incorporates Seasonal Climate Forecasts. *Int. J. Climatol*., **23**, 1195-1210.

Richardson C.W. 1981: Stochastic simulation of daily precipitation, temperature and solar radiation, *J. Appl. Meteor*.,**17**, 182-190.

Supit, I., A.A. Hooijer, C.A. van Diepen (Eds), 1994: System description of the WOFOST 6.0 crop simulation model implemented in CGMS. Publication EUR 15956 EN of the Office for Official Publications of the EU, Luxembourg.

Uppala, S. 2002: ECMWF Re-analysis 1957-2001, ERA-40. ERA-40 Project Report, Series No. 3, 1-10.

Wilks, D. 1995: Statistical methods in the atmospheric sciences. London, Academic Press Limited.

Zhu, Y., Z. Toth, R. Wobus, D. Richardson, K. Mylne, 2002: The Economic Value of Ensembles-based Weather Forecasts. *Bull. Ameri. Meteorol. Soc*., **83**, 73-83.

The development of combined weather and crop yield forecasting systems for the tropics

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1. Introduction

The provision of food for an increasing global population presents huge challenges to governments worldwide. Much of the world's population rely for their food supply on annual crops grown in the tropics under rainfed conditions. The productivity of crops in these regions is highly vulnerable to inter-annual and sub-seasonal climate variability. Moreover, accurate productivity forecasts to aid planning of food supplies in these countries are very difficult to produce. Climate change adds further uncertainty, with changes in mean climate and variability expected to have non-linear impacts on crop yields. Forecasting how risks to food production in the tropics may change over the coming decades thus presents a major research challenge. Understanding the impact of climate variability and change on crop yields is fundamental to the success of such research. It is also an essential step towards the development of key adaptive strategies to cope with climate change.

A key issue in modelling crop production over large areas is dealing with the disparity in spatial scale between the crop model and the climate prediction model. Crop models are generally designed to operate at the field level, and they rely on detailed field-scale inputs, such as the soil, plant genotype and weather, to predict yield and other crop variables at that scale. In contrast, climate prediction models have a much coarser resolution, typically from tens (in regional models) to hundreds of kilometres (Figure 1 page 19). These disparities need to be resolved in order for a coupled crop/climate modelling system to produce plausible results. A common approach is to adopt some form of downscaling of the climate, but this assumes stationarity in the statistics of the climate (and weather variability) which may not be appropriate for a changing climate.

Our group has been developing a combined crop and climate forecasting system over the last four years which takes a different approach. This modelling system couples crop simulation and numerical weather models on a common spatial scale based on observed weather/yield relationships (Figure 1; see also Challinor et al., 2003). As a result we have simulated crop yield on a regional scale using output directly from Regional Climate Model (RCM) scenarios.

2. The General Large Area Model (GLAM) for annual crops

The General Large Area Model for annual crops (GLAM) is process-based crop model with a daily time-step which can resolve the impacts of sub-seasonal variability in weather. The objective of the model is to reproduce the impact of weather on observed crop yield. This aim leads to two particular model characteristics. Firstly, complexity at a level far-removed from yield-determining processes is omitted so that in general, simple parameterisations are favoured over more complex methods. Hence, for example, photosynthesis is not modelled directly, but is represented by a transpiration efficiency. Secondly, of the impacts on yield due to factors other than weather (pests, diseases, management factors, etc), only two are currently modelled explicitly: planting date and soil type. The rest, whilst in reality complex and varied, are modelled using a single yield-gap parameter. However, the modelling framework provided by GLAM will enable future development of more complex approaches to representing crop management and other factors which affect yield.

GLAM aims to combine the benefits of more empirical modelling methods with low input data requirements and validity over large areas, with the benefits of a process-based approach (the potential to capture variability due to different sub-seasonal weather patterns). This means that the model is more likely to produce valid results under climate change than the pragmatic empirical models currently used in forecasts of seasonal productivity. The model is flexible: changes in crop-specific parameter values allow simple and transparent operation across many annual crops. The development of GLAM has benefited from the detailed knowledge of crop behaviour in response to weather variability (e.g. temperature extremes at flowering) and climate change (e.g. CO_2 fertilization effects) obtained from experimentation at the Plant Environment Laboratory at The University of Reading (http://www.rdg.ac.uk/pel/). To date GLAM has been used to simulate groundnut, wheat, and maize. GLAM is fully described in Challinor et al. (2004a) and more details of the rationale can be found at http://www.met.rdg.ac.uk/~ajc/.

3. Key results

3.1 A twenty-five year simulation of crop productivity in India

GLAM has been run at a sub-regional scale across India, in order to provide a simulation of groundnut crop yield from 1966 to 1989. The optimal crop parameters were within observed reported ranges and were also stable over space and time, implying that crop growth and development were simulated realistically. The model accurately reproduced yields over large areas where there was a climate signal in the observed yields. The upscaled all-India yields matched very well the yields recorded in national yields statistics (figure 2). Of particular note is the ability of GLAM to reproduce much of the interannual variability in yield: this is a rare feat for

continued on page 19

From Webster et al (page 21): Regional application of Monsoon Dynamics

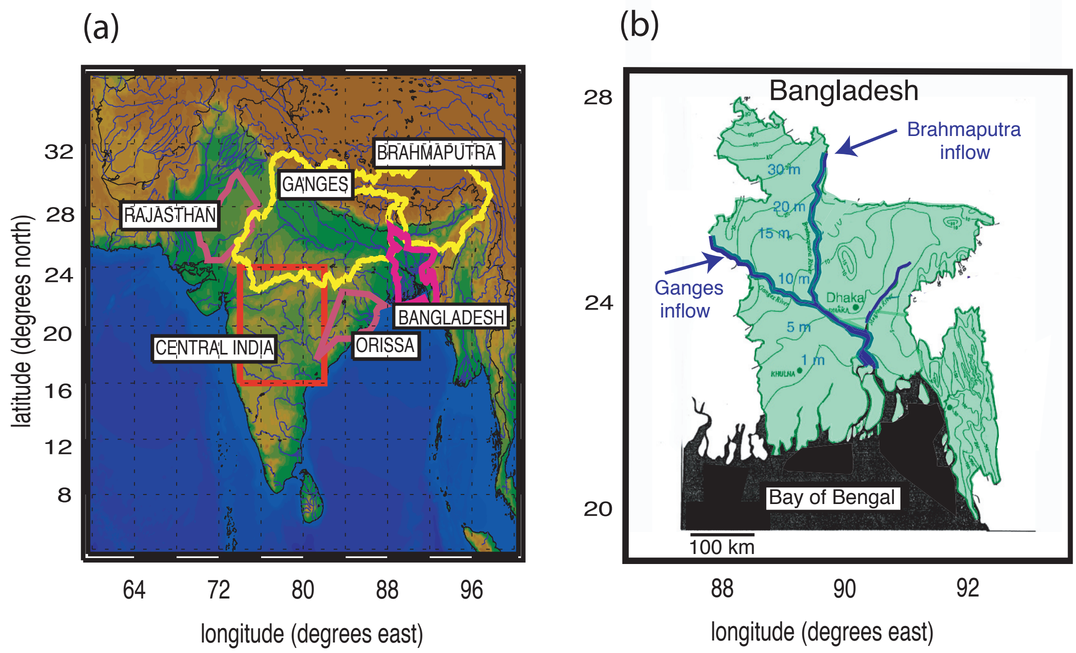


Figure 1: (a) The South Asian region showing the Brahmaputra and Ganges catchment areas and Bangladesh. Areas for which precipitation forecasts are routinely made (Central India, the Indian states of Orissa and Rajasthan, Bangladesh and the two major river catchment areas) are indicated on the map. (b) Entry points of the Ganges and the Brahmaputra into Bangladesh. River discharge is forecast on all three time scales at these points.

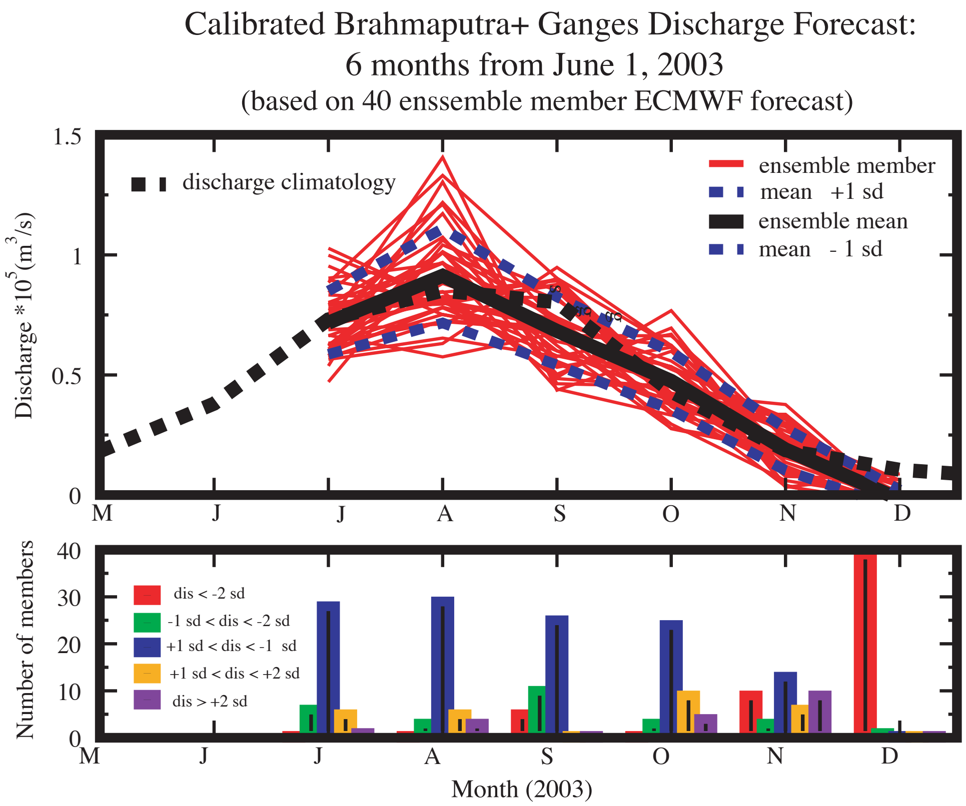
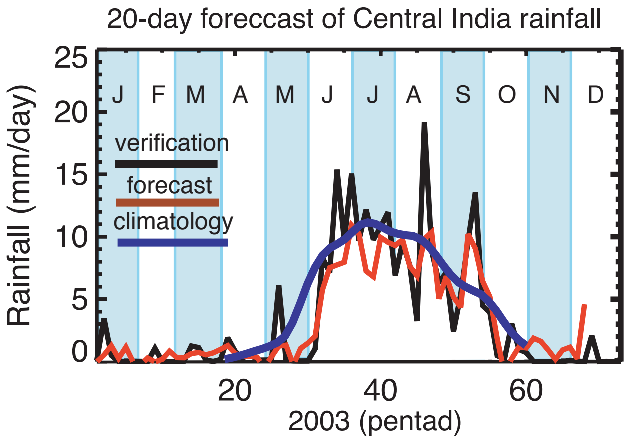


Figure 2: Six-month forecast of the Ganges plus Brahmaputra river discharge into Bangladesh for June through November, 2003, commencing in May 2003. Forecasts are made every month for a six-month period using the 41 members of the ECMWF coupled climate model. Red lines show the behavior of eachj ensemble member. The ensemble mean is shown as the solid line and the two dashed lines indicate plus and minus one standard deviation (sd) about the ensemble mean. The dotted line is the climatological river discharge. The lower panel shows the pdfs of river discharge relative to the colour coding

From Webster et al (page 21): Regional application of Monsoon Dynamics



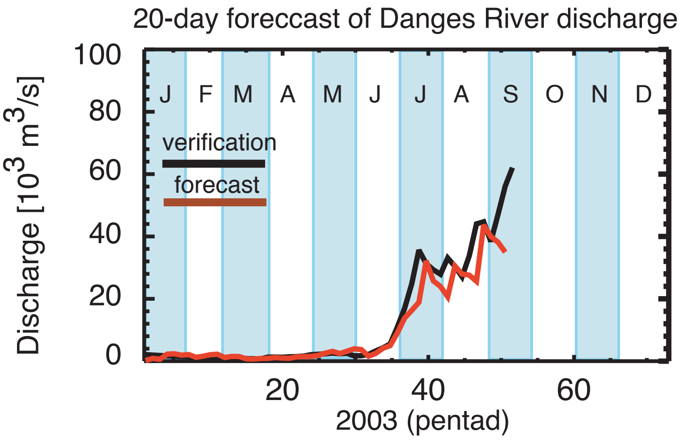
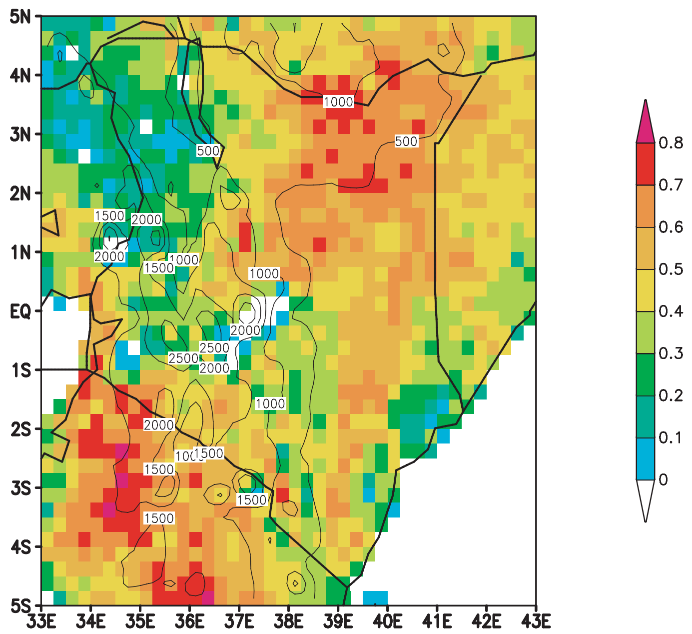


Figure 3: (a) 20-day forecast of Central Indian rainfall rate for the year 2003 using the Bayesian scheme developed by Webster and Hoyos (2004). The scheme predicts quite well the phase of the intraseasonal oscillations but underestimates the amplitudes of the peak periods. (b) Same but for Ganges discharge into Bangladesh. Forecast incomplete because of data problems. Time scale is in pentads

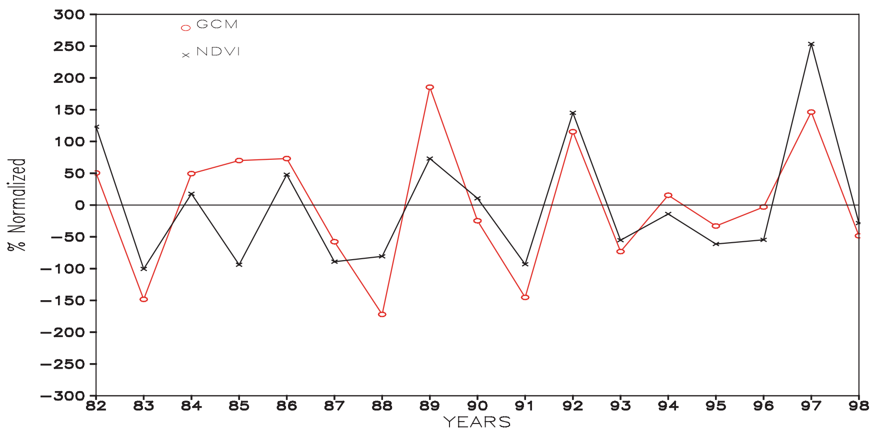
From International Research Institute (page 5)

Fig. 3. Predicting December values of the Normalized Difference Vegetation Index (NDVI) in East Africa using output from the ECHAM4.5 General Circulation Model (GCM) (Roeneckner et al., 1996). Establishing a methodology to generate information that can match with decision needs for managing Rift Valley Fever in livestock in the region. (a) Correlation between cross-validated predictor and observed NDVI. Contours show land elevation in meters. Areas of skill >0.5 are widespread with some pockets >0.7. (b) Graphical presentation of the accuracy of the forecasts: Time-series of the predicted and observed NDVI for an area average across Eastern Kenya (Correlation = 0.76). Predictions are made using large-scale GCM fields of rainfall and low-level winds. The GCM experiments are based on persisted September sea-surface temperature information, so the forecast information would be available in early October. Corrected NDVI data provided by USGS. (Indeje et al, in preparation)

(a)



(b)



From Caires et al (page 27) Wave climate and its change - The KNMI/ERA-40 wave atlas

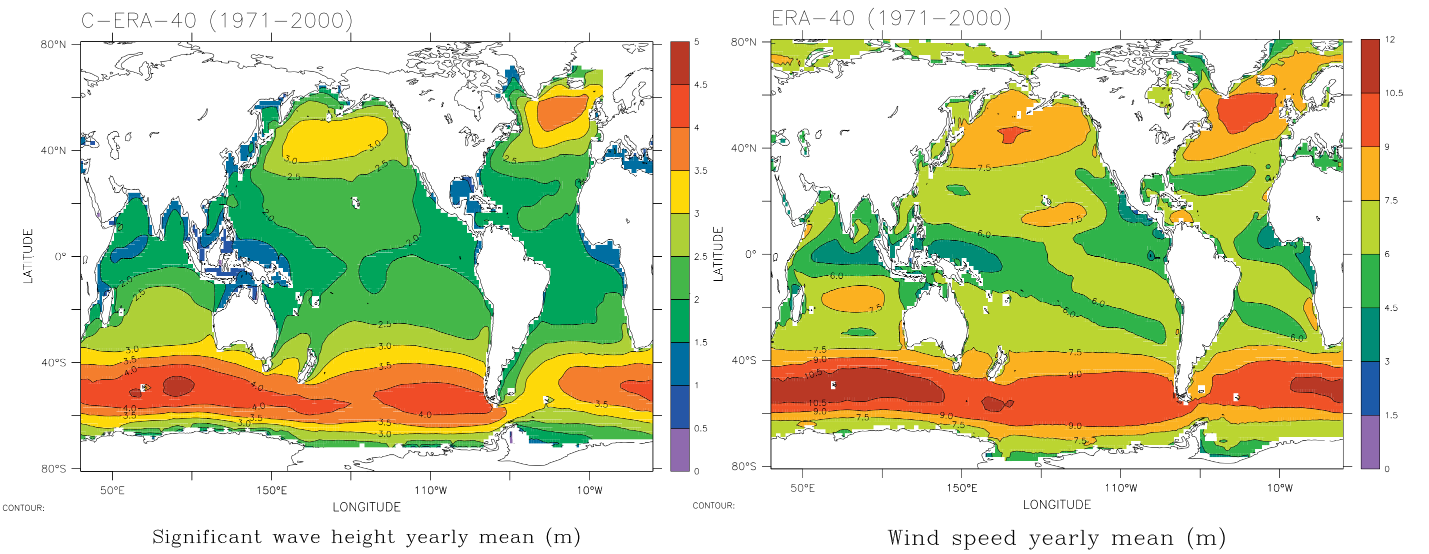


Figure 1: C-ERA-40 H_S (left) and U_{10} (right) annual mean climate.

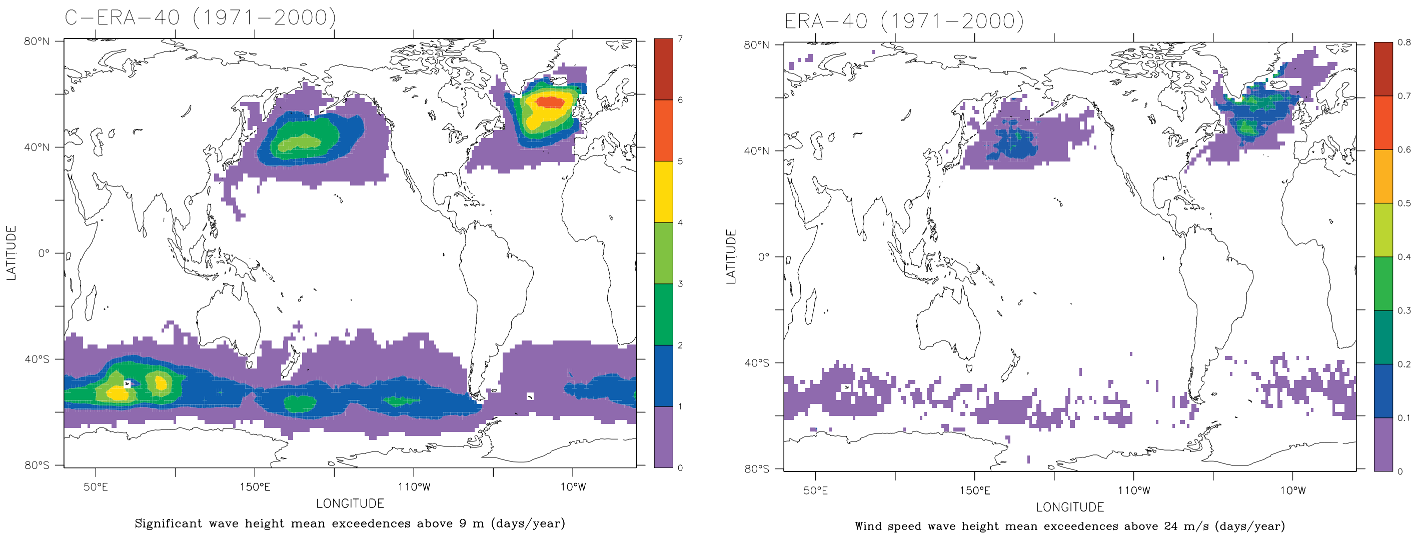


Figure 2: Mean annual exceedences of 9 metres of C-ERA-40 H_S (left) and of 24 m/s of U_{10} (right) in days per year

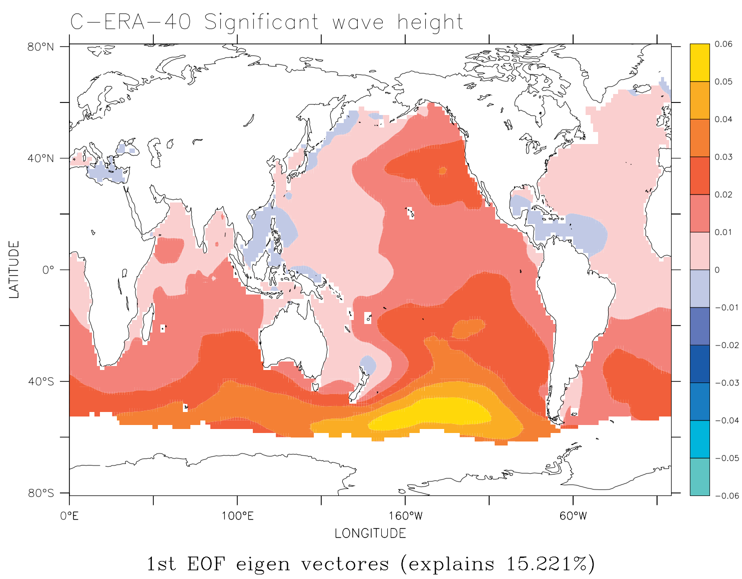


Figure 4: First pattern of the global EOF analyses of C-ERA-40 $_{HS}$ data.

From Caires et al (page 27) Wave climate and its change - The KNMI/ERA-40 wave atlas

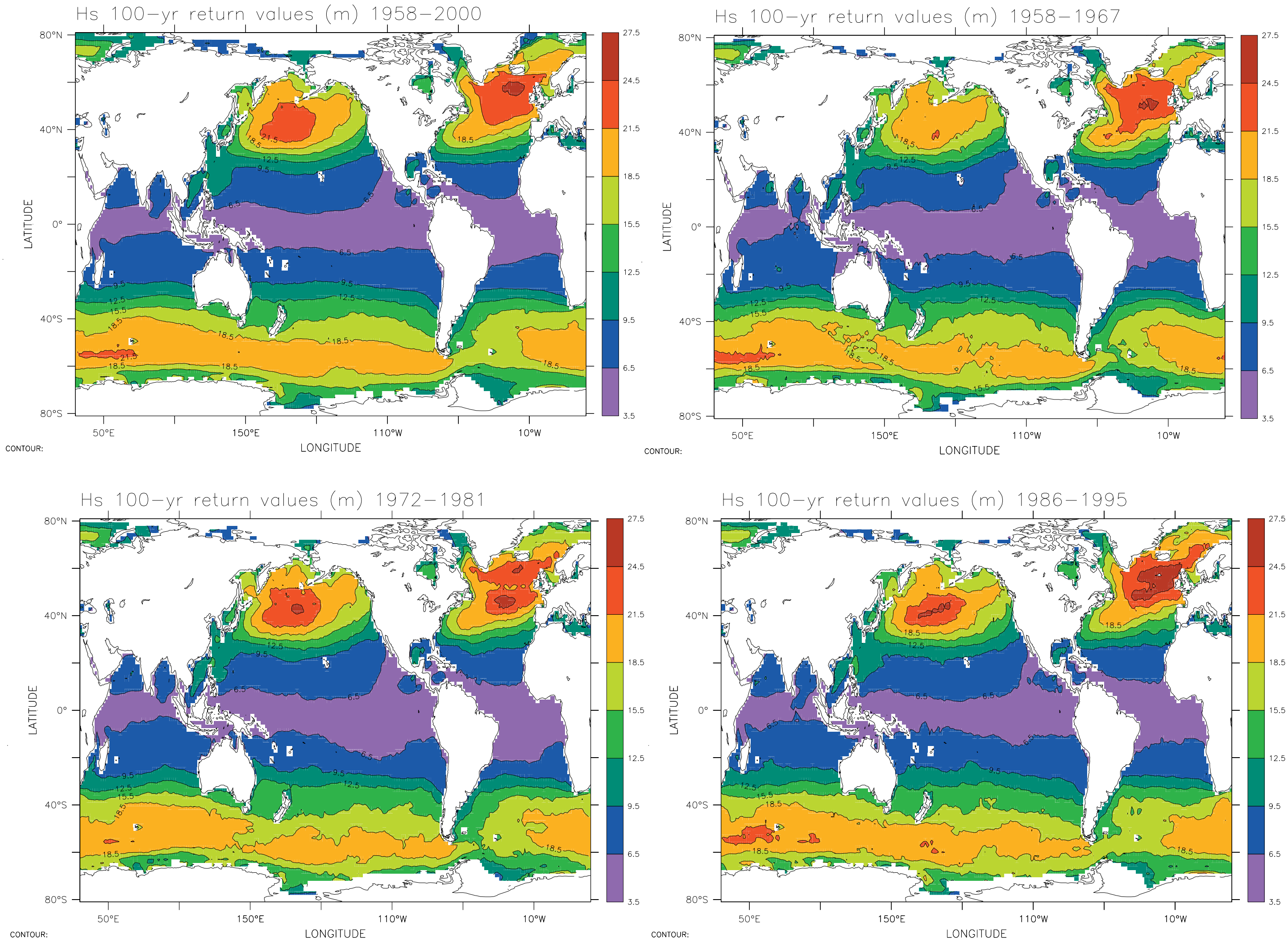


Figure 5- Corrected 100-year return value estimates of H_s based on ERA-40 data from three different 10-year periods and the whole ERA-40 period as indicated

From Higgins et al (page 29): The North American Monsoon Experiment (NAME)

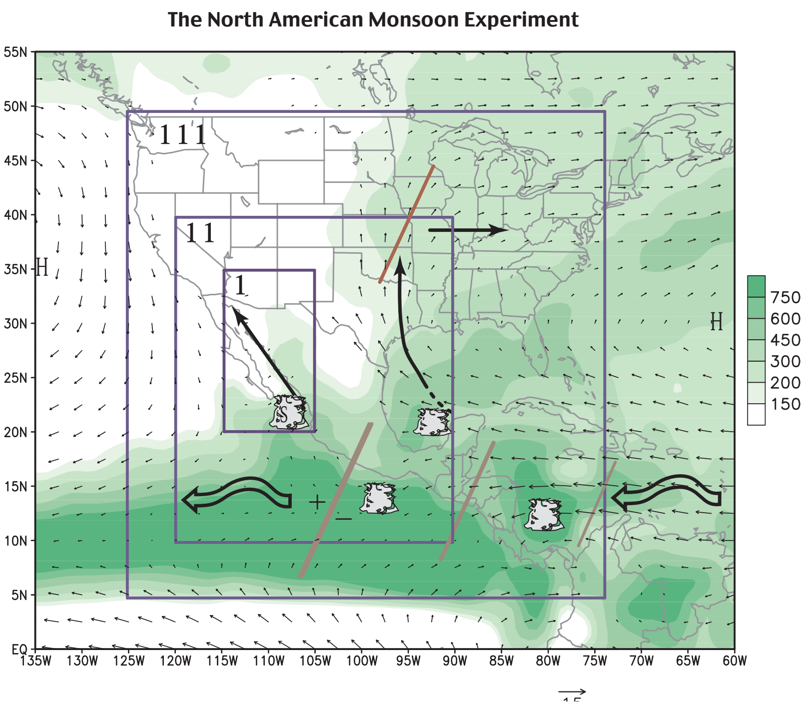


Figure 2. Schematic Illustrating the multi-tiered approach of the North American Monsoon Experiment (NAME). The schematic also shows mean (July-September 1979-1995) 925-hPa vector wind and merged satellite estimates and raingauge observations of precipitation (shading) in millimeters. Circulation data are taken from the NCEP/ NCAR Reanalysis archive.

continued from page 14

crop simulation models. For example, predictions in the extreme years of 1972 and 1975 are very good. Hence this simulation provides confidence that the GLAM system is able to capture the sensitivity of crop productivity to climate over a long time series.

3.2 The use of Reanalysis data in yield simulations

Accurate productivity forecasts will rely not only on crop simulation, but on the quality of the input weather data. The simulation shown in Figure 2 used observed gridded data as input. However, climate model output is unlikely to be this accurate. Reanalysis data is output from General Circulation Models (GCMs) which have had observations assimilated into the analysis (see e.g. Annamalai et al. 1999). Hence reanalysis data are an ideal test-bed for a combined forecasting systems such as this. A study using GLAM with reanalysis data (the European Centre for Medium Range Weather Forecasts forty--year reanalysis, ERA40; http://www.ecmwf.int/research/era/) has shown that, where there is a climate signal, general circulation model output can also result in accurate simulation of the relationship between weather and yield (Figure 3), as well as accurate simulation of yield (Challinor et al. 2004b). Whilst the issue of GCM/RCM skill in representing the mean climate and its variability remains, it is encouraging to note that gridded model output can be used with some success. This is a particularly pertinent point when one considers that rainfall is the least reliable reanalysis output, whilst often being the most important weather variable for the simulation of crops and vegetation.

3.3 Probabilistic forecasting

GLAM has also been used with a multi-model ensemble of seasonal forecasts from the DEMETER project (http://www.ecmwf.int/research/demeter/). Ensembles of forecast simulations contain probabilistic information regarding the evolution of the weather over the season. These were used to create ensembles of yield, by running each weather ensemble member through GLAM. The potential for probabilistic forecasting of crop failure was demonstrated by a probabilistic analysis of ensemble members. The Relative Operating Characteristics, constructed from dichotomous (failure / no failure) contingency table analyses, showed that crop failure was most predictable with either bias correction of input weather data or crop model calibration on ensemble mean data (Figure 4). In addition, more severe yield failures showed greater predictability. Ensemble mean yields also proved skillful, having, overall, higher correlations with observations than simulations carried out using reanalysis (ERA40) data. Furthermore, the impact of uncertainty in the sowing window was greater in the ERA40 case than in the multi-model ensemble mean case (Challinor et al. 2004c).

3.4 Coupling GLAM to a General Circulation Model

There is increasing evidence that the land surface can significantly affect the overlying atmosphere and that changes in land use may have a substantial impact on the local climate (Pielke et al 1998). Global crop area has increased dramatically in the last few decades and now occupies a major part of the Earth's land surface. Therefore, a realistic representation of crop growth and development as part of the land surface of atmospheric models is required. Furthermore, research has shown that crop yield can been significantly impacted by sub-daily temperature variations (e.g. Wheeler et al. 2000), suggesting that the use of daily GCM output in offline crop yield simulations may not be sufficiently accurate.

The development of GLAM, a crop model that works at a spatial scale similar to that of GCMs, presents an ideal opportunity to model and, hence investigate, the coupled

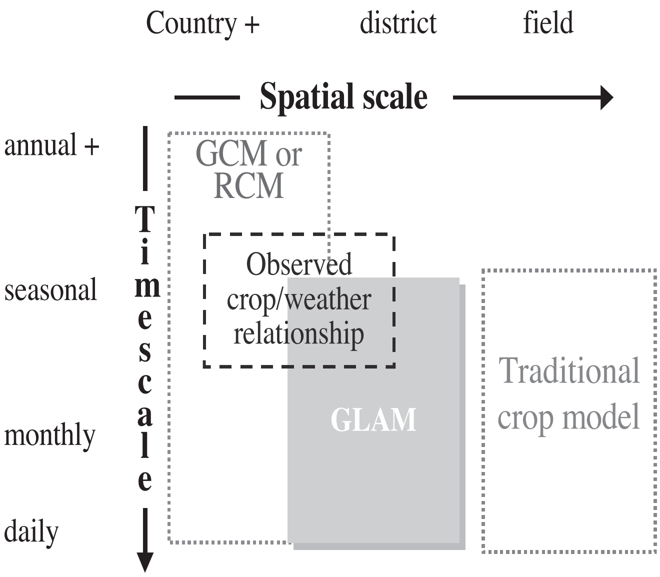


Figure 1: Schematic of the spatio-temporal scales of traditional crop models, General Circulation Models (GCMs), and the General Large-Area Model for annual crops (GLAM), which operates on the scale of the observed crop/weather relationship.

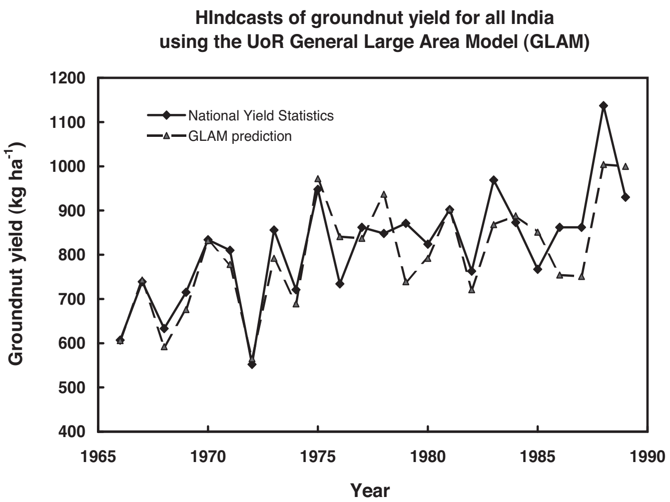


Figure 2: All-India groundnut yields simulated by GLAM on a 2.5o by 2.5o grid (Challinor et al., 2004a) using daily rainfall and monthly interpolated temperature data from the Indian Institute of Tropical Meteorology (http://www.tropmet.res.in/) and interpolated monthly radiation data from the Climatic Research Unit (http://www.cru.uea.ac.uk/). The simulation includes a specified linear technology trend.

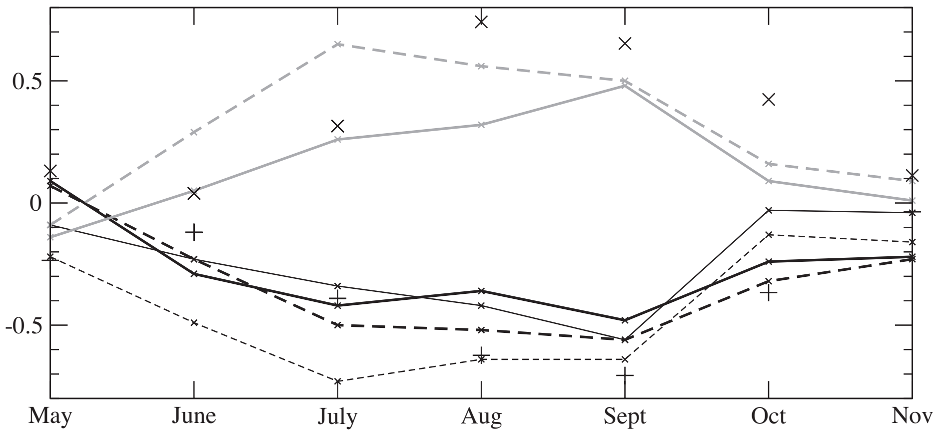


Figure 3 (left): Observed (solid lines) and simulated (dashed lines) correlations, averaged over western Gujarat (13 grid points), between yield and ERA40 (i) net radiation (thin black lines), (ii) vapour pressure deficit (thick black lines) and (iii) precipitation (thick grey lines). Crosses show observed June and July precipitation correlations for a delayed sowing. Pluses mark the corresponding net radiation correlation. See also Challinor et al. (2004b).

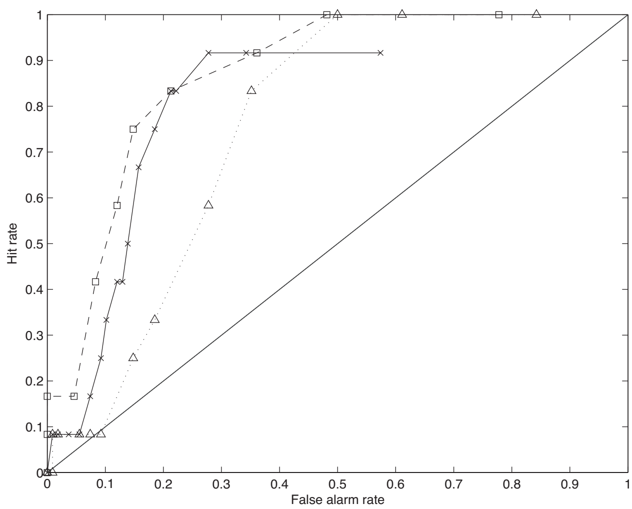


Figure 4 (right): Relative Operating Characteristic (ROC) curves for hindcasts of crop failure (yield<400 kg/ha) in western India over the period 1987-98, using ten 2.5 degree square grid cells. Three configurations are shown: (i) no bias correction of input weather data, and crop model calibration based on ERA40 simulations and yield data over the 1966-86 period (dotted line); (ii) bias-correction (towards ERA40) of input weather data with the same calibration (solid line); (iii) calibration by cross-validation using the ensemble mean and yield data over the two halves of the 1987-98 period, without bias correction (dashed line). Skill is proportional to the area above the 1:1 line

crop-climate system. In order to model this two-way interaction, the crop model (GLAM) must first be able to respond to the weather and climate of the atmospheric model, in our case the Met Office atmosphere-only GCM, HadAM3. The simulated crop growth must then feed back into the surface characteristics of the land surface scheme of HadAM3 (MOSES2: the Met Office Surface Exchange Scheme). Initial simulations of the coupled GLAM-HadAM3 model have just been completed. The results show that realistic crop growth is simulated in response to the climate of the atmospheric model. For instance, in the seasonally arid tropics of India, only one growing season is simulated, while in the humid tropics of Papua New Guinea the climate is such that crop growth is possible throughout the year, resulting in the simulation of two full growing seasons per year.

4. Conclusions

The studies summarised in this article show that an integrated seasonal weather and crop yield forecasting system using a large-area crop model is capable of high quality simulations. Ongoing work on probabilistic methods and future climate scenarios should further capitalise on the predictability which has been found. This work also presents new challenges: the magnitude of changes in mean precipitation and in sub-seasonal and inter-annual climate variability in future climates are not certain, and the resulting impacts on crop production are also uncertain. Additionally, temperature thresholds, when transgressed for even short periods of time, can significantly impact crop productivity (e.g. Wheeler et al 2000). Studies of the impact of climate change on crop productivity will need to incorporate relevant uncertainties and processes such as these.

References

Annamalai, H, J. M. Slingo, K. R. Sperber and K. Hodges (1999). The mean evolution and variability of the Asian summer monsoon: comparison of ECMWF and NCEP--NCAR reanalyses. *Monthly Weather Review*, **127**, 1157-1186.

Challinor A. J., J. M. Slingo, T. R. Wheeler., P. Q. Craufurd and D. I. F. Grimes (2003). Towards a combined seasonal weather and crop productivity forecasting system: determination of the spatial correlation scale. *Journal of Applied Meteorology*, **42**, 175-192.

Challinor A. J., T. R. Wheeler, P. Q. Craufurd, J. M. Slingo and D. I. F. Grimes. (2004a). Design and optimisation of a large-area process-based model for annual crops. *Agricultural and Forest Meteorology*, in press.

Challinor, A. J., T. R. Wheeler, J. M. Slingo, P. Q. Craufurd and D. I. F. Grimes (2004b): Simulation of crop yields using the ERA40 reanalysis: limits to skill and non-stationarity in weather-yield relationships. *Journal of Applied Meteorology*, submitted.

Challinor A. J., J. M. Slingo, T. R. Wheeler, and F. Doblas-Reyes (2004c). Probabilistic simulations of crop yield over western India using the DEMETER seasonal hindcast ensembles. *Tellus A*, submitted.

Pielke, R. A., R. Avissar, M. Raupach, A. J. Dolman, X. Zeng and A. S. Denning (1998). Interactions between the atmosphere and terrestrial ecosystems: Influence on weather and climate. *Global Change Biology*, **4**, 461-475.

Wheeler T. R., Craufurd P. Q., R. H. Ellis, J. R. Porter and P. V. Vara Prasad (2000). Temperature variability and the yield of annual crops. *Agriculture, Ecosystems and Environment*, **82**, 159-167.

Regional application of Monsoon Dynamics: Implementation of a three–tier flood and precipitation forecasting scheme for Bangladesh and surrounding regions

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1. Overview

CLIVAR's scientific objectives include the need to understand the dynamics of the atmosphere-ocean-land system of the monsoon and how the coupling between these components produce climate variability from a single summer to the next and within one season. Whereas we are starting to understand monsoon variability and are turning this understanding into predictions of the gross-scale monsoon, there remains the significant problem of bridging "broad-brush" with applications at the regional level. The problem goes beyond downscaling of a forecasts, itself a major problem, but also to providing forecasts of relevant climate variables. Such problems are especially acute in countries such as Bangladesh.

Bangladesh is a deltaic country that lies at the confluence of three major rivers: the Ganges, the Brahmaputra and the Meghna. Because of its location it is susceptible to flooding during the summer monsoon. Flooding occurs each year but in different parts of the country and irregularly through summer. Occasionally the flooding is severe and prolonged as in the summer of 1998 where 90% of the country was inundated for nearly 3 months.

We discuss briefly the progress that has been made during the last three years in developing a three-tier forecast system of river discharge, flood warning and precipitation for Bangladesh and surrounding regions based upon our increasing understanding of the monsoon system and an improving ability of models to simulate the system. The Climate Forecasting Applications in Bangladesh (CFAB) project was formed as a joint effort between Georgia Institute of Technology, University of Colorado, the Asian Disaster Preparedness Centre (ADPC) and the European Centre for Medium Range Weather Forecasts (ECMWF). The basic aims of CFAB lie in three main areas:

(i) The generation of a river discharge and precipitation operational forecasting system available in real-time with forecasts provided on a three-tier time system: seasonal outlooks (1-6 months), intermediate (20-30 days) and short term (1-10 days);

(ii) The development of an infrastructure that allows the application of the forecasts by Bangladeshi scientists, engineers, agricultural extension, disaster relief organizations and other user groups;

(iii) The development of methods and tools for the transfer of forecast information to the user community, and;

(iv) The transfer of the forecasting technology to Bangladesh in a form that is immediately useable in an operational sense and modifiable for other uses

Considerable progress has been achieved in the implementation of (i), (ii) and (iii). During the summer of 2003, operational forecasts were made available for the long-term and short-term forecasts during the entire season on an experimental basis. Seasonal outlooks (i.e., river discharge forecasts at 1, 2, 3 … 6 months were provided each month. Short-term forecasts (1-10 days) were issued each day. These latter forecasts were used extensively by various water resource groups in Bangladesh. Starting in April 2002, 6-month outlooks were also made available. Intermediate 20-30 day forecasts were issued every five days starting in the middle of the season. Short-term and long-term forecasts use data from various ECMWF models. The medium range forecasts are made using a Bayesian statistical model. Examples of each of the three forecast streams are presented. Finally, the concept of the User Metric, a means of combining forecast probability density functions with user information to provide a visual depiction of an optimal decision strategy, is introduced.

2. The Bangladesh Problem

If floods in Bangladesh can be forecast with sufficient lead-time and accuracy, actions could be taken across the country that could lessen the impact of the floods. However, until recently, the ability to forecast floods in Bangladesh has not existed for the following reasons:

(i) Floods can be forecast at a point downstream by knowing the river flow at some point upstream in conjunction with a hydrological/land use model. Based on this information, simple regression forecasts can give fairly accurate short-term estimates of river discharge. However, Bangladesh does not receive any upstream river flow information from India. Bangladeshi authorities measure river flow at staging points where the two major rivers enter Bangladesh and at other points downstream (Figure 1 page 15). From these data is has been possible to forecast flood levels in the interior and in the south of Bangladesh only 2 days in advance.

(ii) The physical factors that determine the rainfall over the Ganges/Brahmaputra catchments have only recently been understood. Hitherto, numerically-based deterministic (or probabilistic) forecasts of rainfall on any time scales have not been available to Bangladesh. In fact, to date Bangladesh does not have any numerical meteorological facility or capability. India has some but this is restricted to relatively short range.

The Climate Forecast Applications in Bangladesh (CFAB) Project was instigated in 2000 to:

(i) Create a collaborative effort between international (US and Europe) and Bangladeshi partners for the forecasting of the probability of floods on time scales of days to months leading to the transfer of the techniques and technology to the appropriate Bangladeshi partners;

(ii) Apply start-of-the-art advances in the knowledge of the monsoon physical system and weather and climate forecasting to the development of probabilistic flood forecasts:

(iii) Work with user communities in Bangladesh for the rendering of the probabilistic forecast product into useful information for the region;

(iv) Develop techniques for the application of flood forecasts to various sectors within Bangladesh (e.g., agriculture, warning and hazards and etc.);

(v) Seek ancillary uses of the flood forecasting scheme such as the forecasting of precipitation (or the lack thereof), disease (especially cholera) etc. and,

(vi) Instigate a rapid technology transfer of the flood prediction techniques to Bangladesh.

3. Progress in the Climate Forecast Applications in Bangladesh (CFAB) project

(a) Infrastructure Development:

During the first three years of the project, a major focus has been the development of an infrastructure within Bangladesh so that forecasting techniques could be developed concurrently between Bangladeshi and international partners. In addition, such an infrastructure ensures that useful forecast schemes useful to the Bangladeshi context are created and that the forecasts are disseminated to stakeholders. A starting point in these goals has been a series of workshops which allowed a stock taking of climate forecasting applications needs and priorities within Bangladesh. Furthermore these initial workshops allowed feedback and guidance from a range of stakeholders including government and non-government institutions and user groups. The workshops also identified the partnerships necessary for effective implementation of this project and to come up with a broad implementation plan. Out of these workshops, and with the aid of ADPC, a Steering Committee with representatives from a number of Bangladeshi organizations (Flood Forecasting and Warning Center, Bangladesh Meteorological Department, Agricultural Extension, Disaster Management, and a number of NGOs) in addition to the Asian Disaster Preparedness Center (ADPC). The Steering Committee is based in Dhaka, Bangladesh. This committee has overseen the generation of the forecast suite described below and their incipient experimental use in Bangladesh during the summer of 2003.

(b) The Forecasts:

CFAB has produced the elements of a forecasting system for Bangladesh that provides information with sufficient lead time for stakeholders to react to either impending flood or drought, thus minimizing food and disaster vulnerability while, at the same time, maximizing opportunity to take advantage of favourable forecasts. To accomplish these goals a three-tier overlapping forecasting scheme has been developed. These schemes take advantage of knowledge of the physical state of the atmosphere-ocean-land system developed over a number of years and the ability of models to describe the monsoon system.

(i) Seasonal Outlook: The long-term forecast (1-6 months) provides a "broad brush" or overview of the coming season. These forecast are made every month for the next six months and provide probabilities of above or below average river discharge into Bangladesh, allowing long-term agricultural (e.g. crop selection), water management planning and the necessary budget allocation for disaster relief. Normally, seasonal forecasts for an area as small as Bangladesh (1.4 x 105 km^2 or roughly the size of Wisconsin) are not considered reliable as forecast uncertainty increases in time as the inverse of the area of the forecast. However, as the water that passes into Bangladesh is collected in a catchment area that is 12 times the size of Bangladesh, and as discharge is essentially a weighted spatial and temporal integral of the rainfall over the catchment, considerable skill can be expected in seasonal outlooks of river discharge. In essence, the skill of river discharge forecasts into Bangladesh is the integrated skill over the much larger catchment areas of the Ganges and the Brahmaputra.

The system uses the output of the coupled ocean-atmosphere model developed by ECMWF coupled with a simple hydrology model. It takes into account the influence of local Indian Ocean sea-surface temperature (SST) variability, as well as remote influences such as El Niño-Southern Oscillation (ENSO), and ground hydrology on the monsoon rains. Discharge into Bangladesh is calculated using a statistical hydrological model with data from the ECMWF coupled ocean-atmosphere model as input. From this system forecasts of river discharge into Bangladesh (sum of the Ganges, Brahmaputra and Meghna) were prepared in real time and updated every month. Forecasts are given in the form of probabilities of a particular intensity of discharge occurring. Last year, 2003 was relatively normal and less active than the great flood year of 1998. However, July/August had above average discharge and flooding occurred in the north of the country. The excessive discharge is apparent in the forecasts initialized in May and June (Figure 2, page 15). The forecasts exhibit a systematic error later in the season. We have developed a technique for diminishing this systematic error which we will discuss later.

(ii) Intermediate Forecasts: If forecasts of 20-25 days were available, it is thought that they would be of the greatest utility to agriculture, water resource and disaster management of all three of the tiers. Discussing the mid-season drought of India in 2002, A. Subbiah of the Asian Disaster Prevention Center (ADPC 2004) noted: "…Assuming that a prediction of the July drought had been available by the third week of June 2002, and of the revival of the monsoon rains by second week of July 2002, the forecasts would have ……. helped to preserve farm income and ensured food security and reduce relief expenditure by at least 60% of the present cost (i.e., around 6 billion US$). ….. a 20-day forecast during monsoon 2002 in India could have mitigated the impacts of the droughts in several parts of India to a significant extent..…"

Using techniques derived by Webster and Hoyos (2003), a scheme for the production of forecasts on 20-30 days has been developed and tested for both areal estimates of precipitation and river discharge. The system is an empirical scheme that rests heavily on the identifiable physics of the slow variability component of the monsoon. In essence, the Webster-Hoyos scheme forecasts the slow manifold of the monsoon giving 5-day average precipitation 20-30 days in advance. This technique became available during the summer of 2003 but was not used in experimental operational mode. As described below, it is planned to use the system in real time for the 2004 summer season. Figure 3 (page 16) shows the 20-day forecast of precipitation over central India for the 2003 summer monsoon. Currently, the forecasts are deterministic but it is hoped that they will soon become probabilistic.

(iii) Short-term Forecasts: Using a statistical hydrological model and ECMWF ensemble operational forecasts, probabilistic river discharge forecasts were made for both the Brahmaputra and the Ganges at the Bangladesh points-of-entry. The statistics were compiled from 51 member ensembles. These forecasts were used as input to the Bangladeshi flood forecasts. Together, the CFAB forecasts and the Bangladeshi Forecasts contributed to provide 1-10 day river discharge estimates and were provided each day. In addition, probabilistic forecasts of precipitation for Bangladesh and the Ganges and Brahmaputra catchments were also provided. These short-term forecasts are the most accurate of the three tiers. They are extremely useful for determining the details of where in Bangladesh floods may occur and the probability of the occurrence, duration and magnitude of the river discharge. Such forecasts can be used for determination of planting and harvesting strategies and short-term deployment of relief facilities. Figure 4 (page 24) shows examples of short-term forecasts for the 2003 summer.

(c) Communication of the Forecasts

There are two critical criteria for the communication of forecasts:

(i) The forecast must be of relevant parameters that are important to the user community. For example, a forecast of the Southern Oscillation some months in advance is of little use unless it is downscaled to some quantity that the user community needs such as regional precipitation variability.

(ii) The forecast needs to be in probabilistic form so that a cost/loss risk analysis can be undertaken by the user community.

Clearly, providing an understandable probability forecast is a challenge in both developed and developing societies. We have approached this problem by the development of a utility called the User Metric (Figure 5 page 24). The principal aim of a User Metric is to allow the transformation of probabilistic forecasts (difficult to understand and apply) to a usable assessment of aggregate risk (easy to understand) so that a deterministic decision of future action can be made (easy to apply). A User Metric must have the following properties:

(i) Incorporates a probabilistic forecast of some pertinent parameter (e.g., river discharge, rainfall variability (upper left panel Figure 5). These are supplied by the physical scientists/forecasts offices using the forecast modules described above. The pdf forecast will change each forecast.

(ii) Incorporates local knowledge of the impact of a particular event of a given severity. A costing factor provided by the user community (top right panel Figure 5). This assessment factors in the impact of a range of meteorological events of different severity on a particular application. For the same probabilistic forecast, the user information may be different. For example, the same forecast at the time of planting (when no rainfall is disastrous, moderate rainfall is beneficial, too much rainfall may cause floods) will be very different to the costing the user community would place on these events if it were at harvest time.

(iii) An easily comprehendible and visually decipherable representation of risk. An aggregate risk analysis (bottom panel: Figure 5) which combines the forecast probabilities (upper left panel) with the user community information (upper right panel) of a particular meteorological event to produce an optimal decision (bottom panel) for the user community. This visual analysis will aid the user community in making reasoned decisions by the generation of an aggregate risk analysis.

A basic tenet of our work is that we believe that there is important and valuable information in estimating risk of the occurrence of some event to which the user community is sensitive (e.g., floods), even when this risk is small but non-zero. Probabilistic forecasts offer the only way in which reasoned decisions can be made by the user community or relief organization. There appears to us no need to make decisions without computing probabilities of occurrence and ascertaining the cost/benefit relationship of a particular event (Zhu et al. 2002). Finally, the User Metric offers a simple way to incorporate information from the user community, combine it with probabilistic forecasts from numerical or statistical models, and provide an easily interpretable

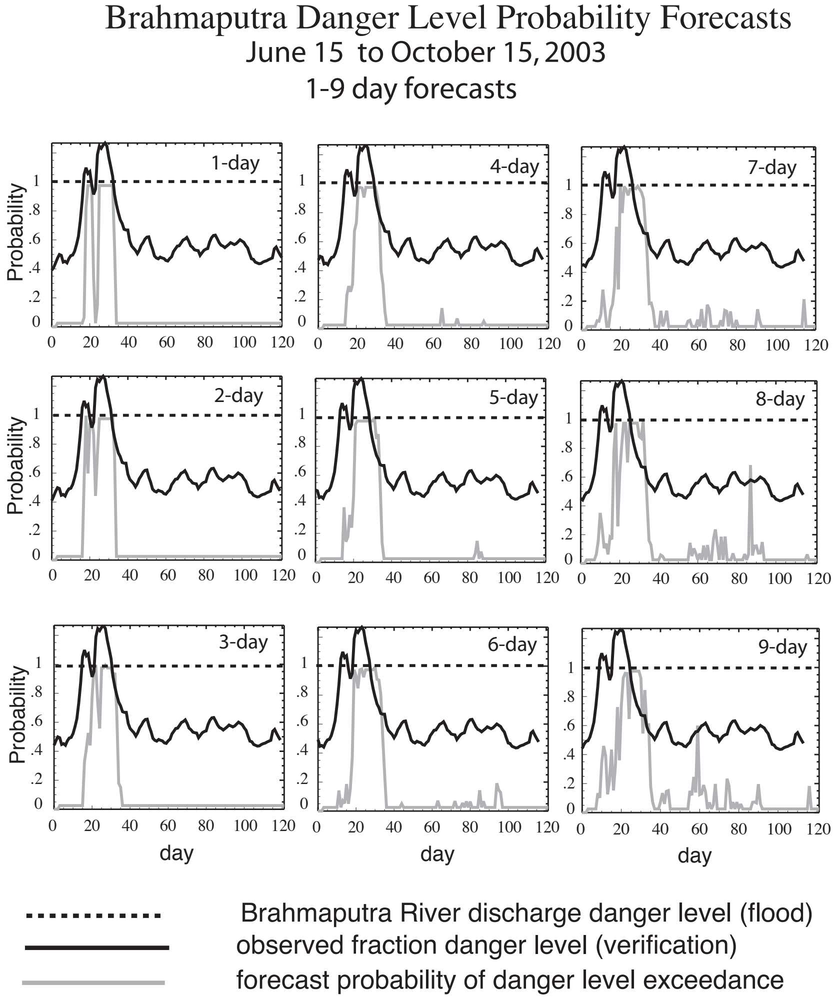

Figure 4: Example of short-term discharge forecasts into Bangladesh for Brahmaputra. The forecasts use the ECMWF ensemble precipitation forecasts in combination with a combination of statistical and distributed The grey curve is the forecasts probability of the discharge being above danger levels which would indicate severe flooding. The black curve shows the percentage of the observed flow relative to the danger level.

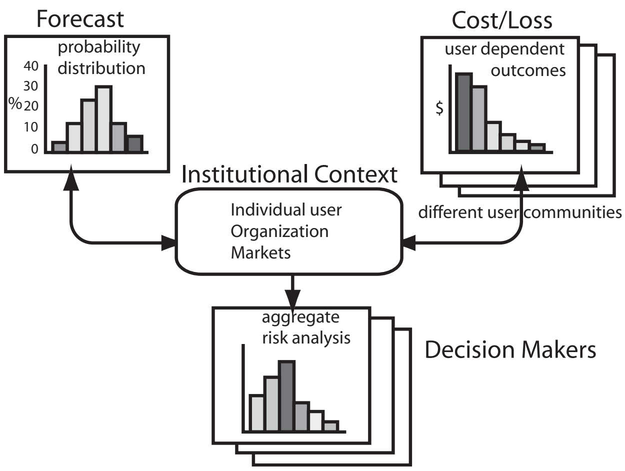

Figure 5: The components of the User Metric. The upper left panel shows the probability density function of some phenomenon (e.g., rain rate) produced by an environmental prediction group. Different user groups or the same user group at different times will have a cost/loss function associated with each of the probabilities. This family of user dependent outcomes can be seen in the upper right hand panel. Using some institutional context (e.g., individual, market based and etc.) a family of aggregate risk analyses can be made which reflect the optimal decision for the particular user group. For the same forecast pdf, the aggregate risk analysis will be different. On the other hand, For one user group and a different forecast, there will be a different optimal strategy. The purpose of the bottom panel is to provide the user with one readily understandable diagram that takes into account the forecasts pdf and the particular user circumstances

graphic from which the reasoned decisions can be made. Examples of the User Metric can be found at http://webster.eas.gatech.edu.

4. Concluding Remarks:

We plan to instigate the complete three-tier system into Bangladesh this summer in full experimental operational mode. We are also exploring the viability of the system for other deltaic regions such as the Mekong and the river systems in China.

Acknowledgements:

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References:

Webster P. J., and C. Hoyos, 2004: Forecasting monsoon rainfall and river discharge variability on 20-25 day time scales. *Bull. Amer. Meteor. Soc.* (accepted)

ADPC, 2004: Initial Report on the Indian Monsoon Drought of 2002. (Ed. A. Subbiah), available from Asian Disaster Preparedness Center, Bangkok, Thailand.

Zhu Y. J., Toth Z., Wobus R., Richardson D. and Mylne K., 2002: The economic value of ensemble-based weather forecasts *Bull. Amer. Met. Soc.* **83**, 73-83

The influence of climate research on water managers in Western Australia – lessons for climate scientists

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Introduction

The Water Corporation of Western Australia (WA) is the major supplier of water to Perth's 1.4 million residents. Demand has been close to, and on occasions, exceeded supply over the past thirty years as the city has grown and as a long dry spell has unfolded. Inflow into Perth's dams has dropped by a massive 50% since the mid-1970s from the 1911-1974 long-term average. This unprecedented decline has severely tested water managers.

The drying has been accompanied by increased understanding of climate science and we will see that this has influenced water management in Perth. Most of this influence is due to a research program called the Indian Ocean Climate Initiative (IOCI) that was implemented largely in response to the drying. The purpose of this note is to analyze the reasons for this influence and to outline what climate scientists have learnt about helping decision-makers in the wider community. These issues are discussed in more detail by Power et al. (2004).

Background

In the mid-1980s water managers viewed the drying that had unfolded over the previous decade as an unfortunate run of dry years that was very likely a natural occurrence. At the same time awareness of global warming as an issue was growing worldwide. Following the Villach climate conference in 1985, Australia's largest scientific research agency (The Commonwealth Scientific and Industrial Research Organization, CSIRO) held a national conference called Greenhouse 87. The scenarios at the time included a 20% decline in rainfall by 2040 over southern Australia that extended to the southwest. This decline was linked to storm tracks shifting south away from Australia. Water managers estimated that this scenario would lead to a 40% decline in river flow. They proposed a gradual "de-rating" of the expected supply from the existing water sources as an appropriate response. De-rating is the term water managers use to describe a downgrading of the long-term mean inflow expected from the system. A de-rating of approximately 13% was subsequently imposed. This meant that water sources had to be developed more quickly than previously planned - at significant additional cost - and efforts to conserve water had to be stepped up.

De-rating would have occurred in the absence of new information from climate science because of the drying. However, water managers believe that the magnitude of the de-rating would not have been as large without the climate science information. Drying due to global warming was clearly identified as a risk, albeit an uncertain one, that needed to be considered in subsequent planning. Given the uncertainty, water managers at the time recognized the need to review the level of de-rating from time-to-time as they gained more experience and as advances in climate science occurred.

By the early 1990s the water managers were deeply worried because rainfall and inflow remained low over the interim. The managers instigated a national climate variability workshop. The participants recommended that more climate research be conducted as one strand of a broader risk management strategy. The State Government subsequently established the Indian Ocean Climate Initiative (IOCI) in 1998. IOCI is a partnership between various state agencies and the national research institutions (The Bureau of Meteorology Research Centre (BMRC) and CSIRO. IOCI is led by the IOCI Panel, which is comprised of water managers, scientists and other representatives of the partner agencies. The Panel set out a strategic program of research in support of major decision-making. Five years later IOCI drew upon research it funded, together with results from the IPCC and CSIRO, to conclude that: "most likely, both natural variability and the enhanced greenhouse effect have contributed to the rainfall decrease".

Did climate science influence or help water managers?

Water managers are in no doubt that climate science and IOCI have influenced their decision-making and have been of assistance to them:

1. Water managers want the best available advice and want to be seen taking the best available advice to reassure the public that restrictions on water use were not because of poor management but necessary because the dry spell began abruptly and was unusually large and long-lived.

2. IOCI provided water managers with ready access to climate information relevant to the region and tailored for the region. Water managers used this information when they informed the wider community on issues related to water management. The "localized" nature of the information was much more newsworthy and this helped to generate media interest and a great deal of discussion in the wider community.

3. Water managers have a strong socio-political and financial need to avoid complete bans on using sprinklers in private gardens. Bans can result in the loss of hundreds of millions of dollars and thousands of jobs. They create widespread public discontent with both water managers and the state government. Scrutiny of the planning process can become intense after restrictions are imposed. At these times it would probably be unacceptable to many people if a known risk to supply (e.g. drying driven by global warming) was ignored in earlier planning, even if the evidence at the time was regarded as inconclusive.

4. The involvement of water managers in IOCI, and an increased awareness and understanding of climate issues generally, has had a substantial impact on the culture of the Water Corporation. The main changes were associated with the establishment of global warming as a threat to supply.

5. The WA State Government has been strong in its praise for IOCI and has recently announced that IOCI will be funded for an additional 3-5 years.

6. IOCI is now being discussed as a model for a climate research program aimed at assisting water management in eastern Australia.

Lessons for climate scientists

1. Water managers do not defer important decision-making on the presumption that climate science will bring clarity to the issues. Indeed water managers recognize that this might never occur. Nevertheless the potential that climate science will offer greater assistance to decision-making in the future is clearly recognized.

2. Effective communication between decision-makers and climate scientists has been crucial in underpinning IOCI success. IOCI has provided the opportunity to explain jargon and to promote realistic expectations e.g. to explain why there are fundamental limits to predictability and that research won't necessarily reduce uncertainty but can help to clarify levels of uncertainty. Interaction between scientists and water managers led to a shift in research priorities for some of the scientists involved. This shift in focus to better meet the needs of decision-makers can take a long time and require sustained effort over an extended period.

3. Water managers prefer certainty but do not always require it. They are well practiced in making use of uncertain information in their planning.

4. Sometimes the climate information provided does not fit in with their decision-making processes. It might be too uncertain or it might not have a clear link with their decision-making. Climate science alone will rarely dictate policy especially if the information is uncertain. There are usually many other relevant and important issues to consider.

5. Water managers want explanations, clarification of issues and uncertainties, perspective and balance. They do not just want formalized predictions or technical information about a scientist's favourite niche in climate research.

Caveats

Some of the conclusions we have drawn need not be relevant or correct in other contexts. For example, in some contexts scientists routinely provide scientific information to the wider community that is easily factored into decision-making. In some contexts a strict independence between scientist and decision-maker is required.

This paper should not be interpreted as a naïve claim that all research should be user-driven. Often issues of fundamental or technical importance to a particular field are not seen as a high priority to any major user. Users might recognize the importance of a research topic but may believe that it is not their responsibility to fund the research. IOCI, for example, has not funded climate model development even though they recognize the importance of this development.

History also tells us that research perceived to be esoteric in one generation can sometimes have a major influence on society years or even generations later.

We should also recognize that humans are curious - we value advances in understanding for their own sake.

Reference

Power, S.B., B. Sadler, and N. Nicholls, 2004: The influence of climate science on water management in WA. In: Report on the CRCES-IPRC Workshop on Decadal Climate Variability, Kona, Hawaii, Feb. 23-26, 2004, V. Mehta (Ed.)

Wave climate and its change—The KNMI/ERA–40 wave atlas

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Introduction

The European Centre for Medium Range Weather Forecasts (ECMWF) has recently finished ERA-40, an atmospheric reanalysis covering the period from September 1957 to August 2002. The ERA-40 reanalysis was produced using a cheaper version of ECMWF's operational Integrated Forecasting System (IFS). A distinguishing feature of IFS is its coupling to a wave model, the well-known WAM model (Komen et al., 1994, and Janssen et al, 2002), making ocean wave information a natural product of ERA-40. The model resolution is 1.5°1.5°, and the output of results takes place at the common synoptic hours 00, 06, 12, and 18 UTC. Using the 6-hourly global fields of wind speed at 10 metres height (U_{10}) and wave parameters, such as significant wave height (H_S), mean wave period and mean wave direction the authors have created the KNMI/ERA-40 global wave climatology atlas available at http://www.knmi.nl/waveatlas. Caveats on the data are that due to the spatial resolution of the model grid the results are not valid in coastal regions and tropical cyclones may be missed. Furthermore, bottom effects are not included, so that the results are not valid in shallow water regions.

The objective of web-based global wave climatology atlas is two-fold. On the one hand, it aims at providing a global description of the ocean wave climate by means of simple statistical measures. On the other hand, it aims at revealing the existence of decadal variability in the wave climate and showing the extent to which this variability affects the estimates of parameters such as the H_S 100-year return value (a quantity that is exceeded on average once every 100 years), used in the design of ships and of coastal and offshore structures. The atlas is aimed at ocean and naval engineers, ship classification societies, people involved in ship routing and wave modelling, and climate research scientists. It allows the improvement of the safety of live and structures at sea by the use of a detailed, global and accurate climatology, and at the same time it identifies the effects and implications of existing climate changes.

Validation and correction of ERA-40

The ERA-40 ocean wind and wave data used in the atlas have been extensively validated against measurements and products from other reanalyses (Caires and Sterl, 2003a, c; Caires et al., 2004). Compared with competing datasets, the ERA-40 data is of high quality, especially in terms of monthly means and other longer-term statistics.

Here is a very brief summary of the validation. The monthly mean wave fields compare well with observations, but the H_S synoptic time series exhibit peaks that are lower than those measured, and at the same time low troughs tend to be slightly overestimated. The mean wave period is overestimated in some situations, with monthly root-mean square errors below 2 seconds. The ERA-40 data benefited from the assimilation of ERS-1 and ERS-2 altimeter H_S measurements from December 1991 onwards to May 1996 (with one interruption) and from June 1996, respectively. The way this has influenced the quality of ERA-40 wave data is explained in detail in Caires and Sterl (2003c). The quality of U_{10} data is not affected by the assimilation of the altimeter H_S measurements; however, it seems to depend on the assimilation of relevant satellite data, which became available in 1979, but this dependence is difficult to quantify. Apart from some underestimation of high peaks, U_{10} data compare quite well with observations, with monthly root-mean-square errors below 2 m/s.

Motivated by deficiencies in the ERA-40 H_S dataset, the data were corrected through a non-parametric method that predicts the bias between H_S ERA-40 data and TOPEX altimeter measurements (Caires and Sterl, 2003c), thus creating a new 45-year global 6-hourly H_S dataset _ the C-ERA-40 dataset. Comparison of the corrected data with H_S measurements from buoy and global altimeter data shows clear improvements in bias, scatter and quantiles over the whole range of values.

Atlas description and highlights

The atlas is divided into 5 main parts: introduction and background; description of the data sources; data validation; description of climate and climate variability. Here we will describe in some detail how the information on climate and its variability are presented in the atlas.

Climate

Climate is by definition the synthesis of weather conditions in a given area, characterized by long-term statistics of the meteorological elements in that area. According to the World Meteorological Organization (WMO) it should preferably be based on 30 years of data. To conform with this recommendation the wave climate information provided was based on 30 years of ERA-40 data from 1971 to 2000. It includes monthly and annual means, standard deviations, 90% and 99% quantiles, the annual mean time of exceedence of certain thresholds, tabulated frequency histograms of H_S and mean wave period, and estimates of 100-year return values. Based on the application of the Peak Over Threshold method we have obtained global 100-year return value estimates from the ERA-40 data. In order to maximize their accuracy, these estimates were computed using the whole data set. Since the ERA-40 data underestimates the high peaks of H_S and U_{10}, we have applied a linear correction to the estimated return values based on buoy and altimeter data (Caires and Sterl, 2004).

Figure 1 (page 17) shows the annual mean climates of C-ERA-40 H_S and U_{10}. They are characterized by high values in the Northern and Southern Hemisphere storm track regions and by low values in the Tropics. The highest means occur in the Southern Hemisphere storm track region. On the other hand, the most extreme wave and wind conditions are found in the North Atlantic. Figure 2 (page 17) shows the annual mean exceedences of the 9 m and 24 m/s thresholds of H_S and U_{10}, respectively. They are both more frequently exceeded in the Northern Hemisphere storm track regions, especially in the North Atlantic, where the H_S (Figure 5 page 18) and U_{10} 100-year return value estimates are also higher.

Climate variability

The atlas describes the wind and wave climate variability in several ways. The variability in a given ocean basin is summarised by the time series of the average of the monthly means over the region in question. Figure 3 shows the C-ERA-40 H_S and U_{10} average of monthly means over the globe using latitude correction and a smoothing of 12 months to remove the annual cycle. The most prominent feature of the H_S time series is a minimum in September 1975, which also seems to signal a change in regime since the level of the time series after the minimum is higher than that before. This feature is also present in the U_{10} time series and can be traced to chances in the Antarctic and South Pacific, since it is only found in the time series of average for those basins. Due to swell propagation it affects the average of H_S in all basins with exception of the North Atlantic. We cannot trace this turning point in the time series to changes in the observation system of ERA-40 and therefore it is possible that it is a sign of a climate change. However, the change in the level of the time series before and after the minimum is most likely due to the assimilation of satellite data from 1979 onwards.

One of the ways in which variability can be revealed is through the detection of trends. For this reason the atlas presents maps of monthly trends of the mean, and of the 90% and 99% quantiles. The trends vary per month and from location to location with some regions characterized by negative and other by positive trends. The trends in the 90% and 99% show the same spatial patterns as those in the mean, but have higher slopes. Maximum trends in the mean H_S are of about 4 cm/year and in the 99% quantiles of about 7 cm/year quantiles and occur mainly in the North Atlantic, North Pacific and in the region between Australia and Antartica. For wind speed the upper limits are about 6 cm/s/year for the mean and 12 cm/s/year for the 99%. The trends found in the North Atlantic and their spatial patterns are in line with the results of Günther et al. (1998).

We have used empirical orthogonal function (EOF) analysis to obtain main patterns of variability, in order to investigate whether they are linked to known dynamic mechanisms. The atlas presents, for each ocean basin considered, the two most important EOF spatial patterns and the time series of their coefficients. Interesting comments arise from the patterns and respective coefficients obtained considering the whole globe, the North Atlantic and Pacific:

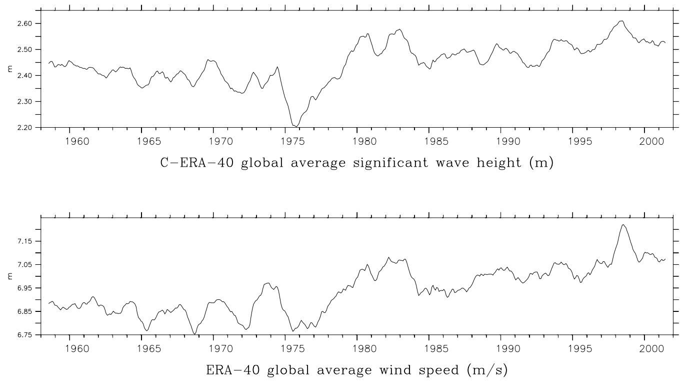

Figure 3: Average of C-ERA-40 HS (top) and U10 (bottom) monthly means over the globe using latitude correction and a smoothing of 12 months to remove the annual cycle.

• Figure 4 (page 17) shows the first pattern of the global EOF analyses of C-ERA-40 H_S data, which explains 15% of the global variability. The pattern clearly represents swell propagating from the Southern Hemisphere storm track region. Its coefficients have a correlation of about 0.80 with the global mean of C-ERA-40 H_S. This means that 15% of the global wave variability is due to swell traveling from the Southern Hemisphere storm track region and it governs the variability of the global mean.

• The coefficients of the first EOF coming from the analysis of the North Pacific, which explains 31% of the variability in that basin, has a correlation of about -0.76 with the Pacific-North American Index (PNA, Wallace and Gutzler, 1981).

• The coefficients of the second EOF coming from the analysis of the North Atlantic, which explains 24% of the variability in that basin, has a correlation of about 0.80 with the North Atlantic Oscillation (NAO, see e.g. Rogers, 1984).

Finally, the effect climate decadal variability has on the *extreme statistics*, namely on the annual mean time of exceedence of certain thresholds and on the 100-year return values, is described. Figure 5 (page 18) shows corrected H_S 100-year return value estimates based on three different 10-year periods of ERA-40 data. The estimates obtained from these periods differ in the Northern Hemisphere storm tracks; specifically, there has been an increase in the estimates in the roughest part of the North Pacific storm track region, and the spatial location of the roughest conditions in the North Atlantic have been changing. These differences can be attributed to the decadal variability in the Northern Hemisphere, and linked to changes in the phase of the North Atlantic Oscillation (NAO); see Caires and Sterl (2003b). They have implications for the safety of life and structures at sea, as design criteria based on pre-1980 data may prove to be insufficient.

References

Caires, S. and A. Sterl, 2003a: Validation of ocean wind and wave data using triple collocation. *J. Geophys. Res.*, **108**(C3), 3098, doi:10.1029/2002JC001491.

Caires, S. and A. Sterl, 2003b: On the estimation of return values of significant wave height data from the reanalysis of the European Centre for Medium-Range Weather Forecasts. Safety and Reliability, Bedford and van Gelder (Eds.), ISBN 9058095517, 353-361.

Caires, S. and A. Sterl, 2003c: Validation and non-parametric correction of significant wave height data from the ERA-40 reanalysis. KNMI Preprint 2003-10. *J. Atm. and Oceanic Tech*. (Submitted)

Caires, S. and A. Sterl, 2004: 100-year return value estimates for wind speed and significant wave height data from the ERA-40 data. KNMI Preprint 2004-01. *J. Climate*. (Submitted)

Caires, S., A. Sterl, J.-R. Bidlot, N. Graham, and V. Swail, 2004: Intercomparison of different wind wave reanalyses. *J. Climate* (in press).

Günther, H., W. Rosenthal, M. Stawarz, Carretero, J.C., M. Gomez, I. Lozano, O. Serano and M. Reistad, 1998: The wave climate of the Northeast Atlantic over the period 1955-94: the WASA wave hindcast. *Global Atmos. Ocean System,* **6**, 121-163.

Janssen, P. A. E. M., J. D. Doyle, J. Bidlot, B. Hansen, L. Isaksen, and P. Viterbo, 2002: Impact and feedback of ocean waves on the atmosphere. In W. A. Perrie (Ed.), Atmosphere-Ocean Interactions (I, 155--197.), Advances in Fluid Mechanics.

Komen, G. J., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann, and P.A.E.M. Janssen, 1994: Dynamics and Modelling of Ocean Waves. Cambridge Univ. Press, 532 pp

Rogers, J.C., 1984: The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. *Mon. Wea. Rev.*, **112**, 1999-2015.

Wallace, J. M., and D. S. Gutzler, 1981: Teleconnections in the geopotential height field during the Northern Hemisphere Winter. *Mon. Wea.Rev.*, **109**, 784-812.

The North American Monsoon Experiment (NAME)

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The North American Monsoon Experiment (NAME)

NAME is an internationally coordinated, joint CLIVAR-GEWEX process study aimed at determining the sources and limits of seasonal-to-interannual predictability of warm season precipitation over North America. NAME has a major emphasis on the role of the land surface and the role of the Great Plains and Gulf of California low-level jets (Figure 1 page 31). NAME integrates these activities with studies of the role of oceanic forcing of continental climate anomalies, since ocean memory components evolve slowly and are to some degree predictable in their own right, and warm season correlations between SST and continental precipitation are at least marginal.

The scientific objectives of NAME are to promote a better understanding and more realistic simulation of:

• warm season convective processes in complex terrain;

• intraseasonal variability of the monsoon;

• the response of the warm season atmospheric circulation and precipitation patterns to slowly varying, potentially predictable surface boundary conditions (e.g. SST, soil moisture);

• the evolution of the North American monsoon system and its variability.

To accomplish these objectives, NAME is implementing an international (U.S., Mexico, Central America), multi-agency (NOAA, NASA, NSF, USDA) field experiment during the summer of 2004 (called NAME 2004).

NAME employs a multi-scale (tiered) approach with focused monitoring, diagnostic and modeling activities in the core monsoon region, on the regional-scale and on the continental-scale (Figure 2 page 18). NAME is part of the CLIVAR/VAMOS program, US CLIVAR Pan American research, and the GEWEX Americas Prediction Project (GAPP).

NAME research is overseen and directed by a Science Working Group (SWG) that has been approved by the US CLIVAR Pan American Panel and SSC, the GAPP SAG and the International CLIVAR VAMOS panel. The SWG is charged with developing and leading cooperative international research to achieve the science objectives of NAME.

The SWG has established the NAME Forecast Operations Centers (FOC's), organized jointly between the United States National Weather Service (Tucson WFO as lead) and the Mexican Weather Service (SMN). The NAME FOC director coordinates planning and preparations for the Tucson NAME FOC, and directs Forecaster Support activities for the NAME 2004 EOP. The FOC's have rotational teams of forecasters from the NWS, SMN, NCEP and DOD (possible) as well as private and retired forecasters. In support of the FOC, NAME is organizing a composite precipitation dataset that includes a wide variety of estimates (gauge, satellite, radar, multi-sensor) for comparative analysis and forecast verification during NAME 2004.

The NAME 2004 Field Campaign

The NAME 2004 field campaign will operate for a period of four summer months (JJAS 2004) to coincide with the peak monsoon season and maximum diurnal variability. The NAME FOC forecaster rotation will occur from June 15-August 31, 2004 during which briefings, discussions and forecasts will be available on a daily basis. Intensive Observing Periods (IOP's) totaling 20 days will take place during this period when all NAME networks are operational. The NAME FOC Science Director will be key to decision-making relative to the IOP's. The NAME FOC Science Director rotation will consist of PI's from the US and Mexico, who will participate for 2 week stints with overlap.

Proposed NAME 2004 field networks include the NAME Tier I Instrumentation and regional enhancements (Tiers II and III). The NAME Tier 1 network includes wind profilers, radars (SMN and NCAR S-Pole), radiosondes, research vessels, buoys, event logging raingauges, in situ soil moisture sensors, and research aircraft operations (Figure 3). Regional enhancements include radiosondes in Mexico and the Southwest United States, a network of PIBALS and a cooperative network of simple raingauges. Some enhanced monitoring activities (e.g. simple raingauge network; event logging raingauge network) will operate before, during and after the NAME 2004 Field Campaign. It will be important to assess which components of the enhanced observing system must be maintained operationally to meet CLIVAR science goals, as well as the goals established by other programs or agencies.

Several recent international developments are indicative of a growing momentum in the meteorological, oceanographic, and hydrological communities of Mexico and Central America to improve observational networks and promote new products in the region. The timing for the NAME field campaign in 2004 appears to be right for the synergism of international efforts in the region. The Mexican National Weather Service (SMN) has already made several major contributions to the NAME project, including Meteorological Infrastructure (synoptic stations, radiosonde observations, and radars), historical and real-time data, and a rotating team of forecasters for the NAME FOCs. NAME has also developed strong international partnerships with universities and institutions in northwest Mexico, who are contributing equipment and personnel for NAME and participating in data collection and research activities.

The VAMOS/NAME Project Office has been established at the UCAR Joint Office for Science Support (JOSS). The Project Office is providing the requisite infrastructure for the design and implementation of the NAME 2004 field campaign, managing the NAME program field operations for the accomplishment of the NAME scientific objectives, and providing scientific data management services to NAME, including data collection and dissemination.

More information about all of these activities is available on the NAME webpage, hosted by UCAR/JOSS at the URL: http://www.joss.ucar.edu/name.

NAME Modeling and Data Assimilation

NAME has organized a modeling-observations team, charged with

• Providing guidance on needs and priorities for NAME 2004 field observations;

• Identifying the path to improved warm season precipitation prediction; and identifying additional process studies necessary to reduce uncertainties in coupled models.

The NAME team has conducted a North American Monsoon Assessment Project "NAMAP" involving six global and regional modeling groups. Results are summarized in an Atlas also available on the NAME webpage. It is anticipated that a NAMAP follow on activity will emerge following the NAME 2004 field campaign.

In order to identify the path to improved warm season precipitation prediction, the team assembled a "White Paper" entitled "NAME Modeling and Data Assimilation: A Strategic Overview" that will serve as a roadmap for NAME modeling, data assimilation and analysis, and predictability and forecast skill activities. The latest version of the white paper is also found on the NAME web page.

NAME Deliverables

The NAME Program will deliver the following:

• Observing system design for monitoring and predicting the North American monsoon system;

• More comprehensive understanding of North American summer climate variability and predictability;

• Strengthened multinational scientific collaboration across Pan America;

• Measurably improved climate models that predict North American monsoon variability months to seasons in advance

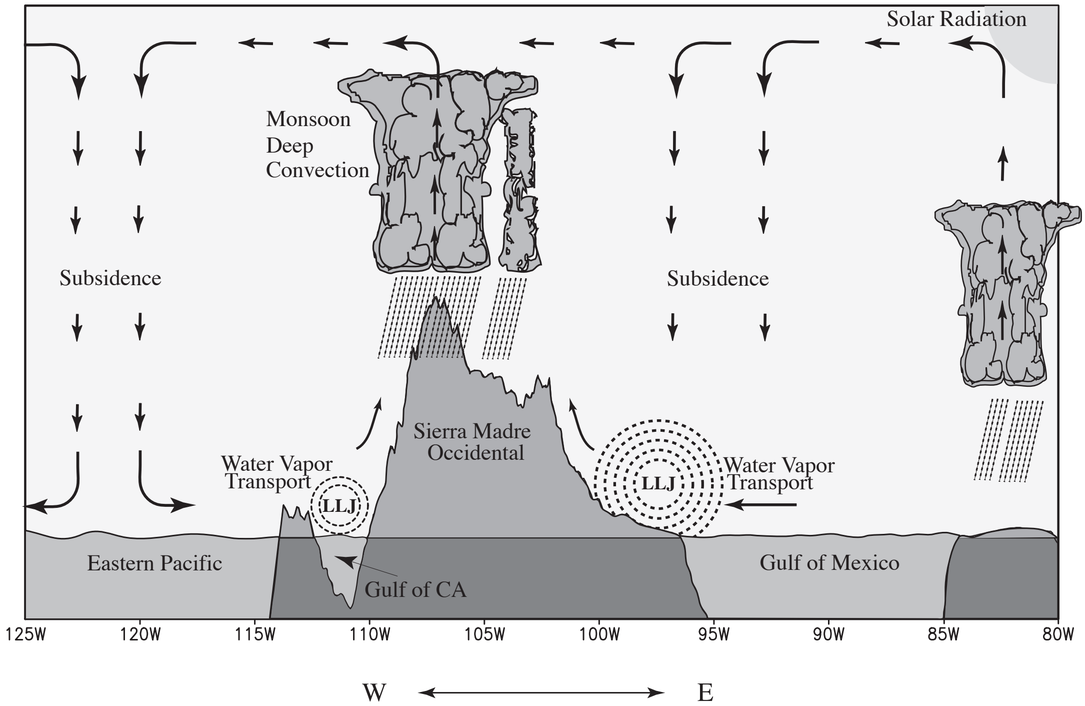

Figure 1. Schematic vertical (longitude-pressure) cross section through the North American Monsoon System at 27.5°N showing the locations of key elements of the North American Monsoon system, including both low-level jets. Topography data was used to establish the horizontal scale and NCEP/NCAR Reanalysis wind and divergence fields were used to establish the vertical circulations.

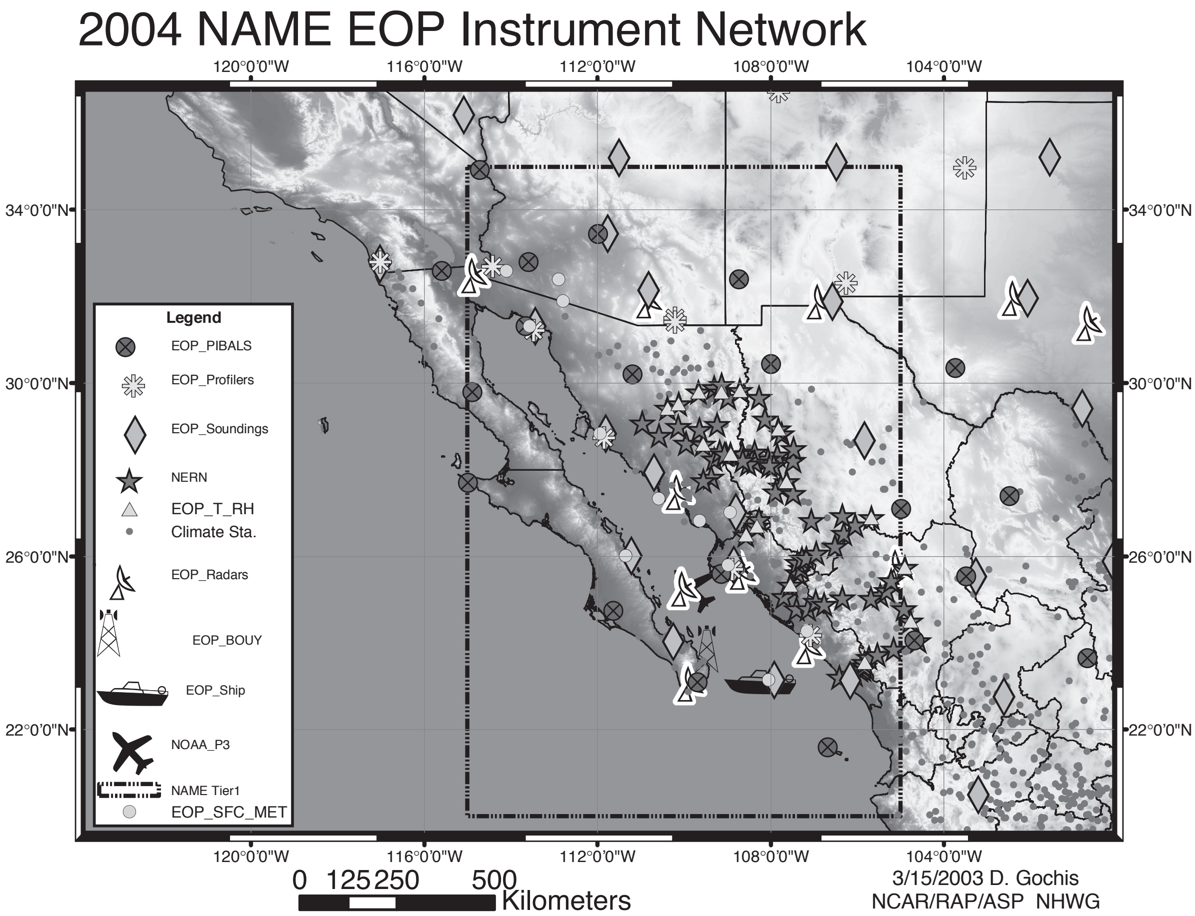

Figure 3. Schematic illustrating the proposed observing system enhancements for the NAME 2004 Enhanced Observing Period scheduled for June-September 2004

Contents

Call for Contributions

We would like to invite the CLIVAR community to submit papers to CLIVAR Exchanges for issue 32 (December 2004). The overarching topic will be on Seasonal Predictability. The deadline for this issue will be October 29th 2004.

Guidelines for the submission of papers for CLIVAR Exchanges can be found under: http://www.clivar.org/publications/exchanges/guidel.htm

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