Summary Report of the Workshop: Linking Climate Prediction Model Output with Crop Model Requirements

Palisades, New York

28 - 29 April 2000

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INTERNATIONAL RESEARCH INSTITUTE FOR CLIMATE PREDICTION

START

IHDP • IGBP • WCRP

Summary Report of the Workshop: Linking Climate Prediction Model Output with Crop Model Requirements, April 28 - 29, 2000, Palisades, New York

FORWARD

A number of research groups around the globe are seeking to apply seasonal climate forecasts to improve management of food production systems and security of farmer livelihoods in the face of climatic risk. One of the tools frequently employed by these efforts is dynamic crop simulation models. Promising results have been obtained using categorical indices of climate teleconnenctions (e.g., ENSO phases). Growing interest in incorporating climate forecasts from dynamic atmospheric models into these efforts has been hampered methodological barriers, particularly the mismatch between the coarse spatial and temporal resolution of climate prediction model outputs, and the fine resolution of crop model input requirements and predictions. Participants of the CLIMAG Geneva Workshop (Geneva, Switzerland, 28-29 September 1999) identified the appropriate methodology for linking climate prediction and crop simulation models as a critical knowledge gap.

John Ingram (GCTE) conveyed a request to the IRI, on behalf of the CLIMAG community, to host a one-day workshop that would bring climate prediction scientists, crop model users and other interested scientists together to clarify and address the relevant technical issues. The IRI recognizes the relevance of these issues and, in line with its mission, is interested in advancing efforts within the agricultural community to apply seasonal climate prediction. We therefore organized the workshop in conjunction with the International Forum on Climate Prediction, Agriculture and Development. START (on behalf of CLIMAG) shared the cost of the workshop with the IRI.

The workshop was quite successful in terms of clarify issues; communicating relevant crop model requirements climate model characteristics, capabilities and limitations; and highlighting some existing and potential approaches for addressing scale mismatches – the first three workshop goals. The fourth goal – developing a strategy for continued progress – was more elusive. Some progress was made in planning a limited collaborative study focused on Australia. However, participants generally felt constrained by resource limitations. The IRI remains committed to improving utility of dynamic model-based forecasts for use with crop and other simulation models used for impact prediction and decision support. We have initiated a limited, exploratory study within the IRI. As we gain experience and identify additional resources, we plan to again engage the broader community in this endeavor.

James Hansen
Coordinator

Sponsored by the International Research Institute for Climate Prediction (IRI), and
Global Change SysTems for Analysis, Research and Training (START)

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RATIONALE AND OBJECTIVES

Within the many research initiatives around the world that seek to use seasonal climate forecasts to improve management of agricultural production systems, there is growing interest in linking seasonal climate forecasts based on atmospheric models with dynamic crop simulation models for impact prediction and decision-support applications. Although the utility of the general approach has been demonstrated using categorical indices of climate teleconnenctions (e.g., ENSO phases), direct use of predictions from dynamic atmospheric models have been hampered by the mismatch in spatial and temporal scale between these climate models and the point (i.e. station) spatial scale and daily time step of the crop models. The IRI and START cosponsored a workshop that brought climate prediction scientists, crop model users and other interested scientists together to identify and address the technical issues related to the mismatch between the format and spatial and temporal scale of output from seasonal climate prediction models, and the requirements of crop simulation models.

A long-term objective of the workshop is to contribute to the development of techniques for linking climate model outputs that the IRI can implement either for routine use in house, or distribute to interested agricultural users of seasonal climate forecasts. Specific workshop objectives were to:

1. Clarify issues related to the use of climate prediction model output as input to crop simulation models.
2. Communicate relevant crop model requirements to climate prediction community, and climate model characteristics, capabilities and limitations to crop model application community.
3. Describe existing and potential approaches for addressing the spatial and temporal scale mismatches between dynamic climate prediction and crop simulation models.
4. Develop a strategy for further developing, evaluating, and implementing promising approaches.

Workshop presentations highlighted the general issues, and discussed alternative methods to downscale seasonal climate prediction model output in space and in time. Participants then discussed a range of related issues, and explored options for evaluating the various methods using a common set of climate model hindcasts and associated data for a few regions where predictability is good. This report presents summaries of invited presentations, and highlights and recommendations based on the discussion.

PROGRAM

Friday, 28 April

1. The Issues **4:00 pm - 5:30 pm**

4:00 - 4:10 ***Welcome and Introduction*** James Hansen

4:10 - 4:30 ***The Challenge of Linking Climate Prediction and Crop Models*** Graeme Hammer

4:30 - 4:50 ***Capabilities and Limitations of Dynamic Climate Models*** Lisa Goddard

4:50 - 5:10 ***Input Uncertainties Related to Spatial Scale in Crop Model Applications*** Linda Mearns

5:10 - 5:30 ***Discussion***

Saturday, 29 April

2. Downscaling in Space **9:00 am - 10:30 am**

9:00 - 9:20 ***Statistical Downscaling of Atmospheric Circulation Model Output: A Primer*** Robert Wilby

9:20 - 9:30 ***Discussion***

9:30 - 9:45 ***Potential Predictability of Precipitation Forecasts in Southwestern Australia*** Bryson Bates

9:45 - 10:00 ***Generating "Super-Ensemble" Model Forecasts*** Balaji Rajagopalan and Upmanu Lall

10:00 - 10:30 ***Discussion***

Coffee Break **10:30 am - 10:45 am**

3. Downscaling in Time **10:45 am - 12:00 pm**

10:45 - 11:00 ***Downscaling Climate Models or Upscaling Crop Models?*** Mikhail Semenov and Peter Jamieson

11:00 - 11:15 ***Producing Weather Generators with Climates Matching Seasonal Forecasts*** Daniel Wilks – NOT PRESENTED

11:15 - 11:30 ***Generating Stochastic Daily Weather Constrained to Target Monthly Means*** James Hansen

11:30 - 11:45 ***K-nearest Neighbor Approach for Stochastic Daily Weather Generation*** Balaji Rajagopolan

11:45 - 12:00 ***Discussion***

Lunch Break **12:00 pm - 1:30 pm**

4. Conclusions and Future Plans **1:30 pm - 3:00 pm**

1:30 - 1:45 ***Evaluating Downscaled Climate Predictions in Agriculturally-Relevant Terms*** James Hansen

1:45 - 3:00 ***Discussion: Synthesis and Future Plans***

SUMMARIES OF PRESENTATIONS

The Challenge of Linking Climate Prediction and Crop Models

Graeme Hammer

Queensland Department of Primary Industries

Agriculturalists use crop models to examine options associated with risky decisions in the management of agricultural decisions. Such decisions (e.g., crop choice, crop management) are risky because outcomes depend greatly on the season that will be experienced after the decision has been made. Crop models and simulation analysis using historical climate data allow quantification and discussion of decision-making risks. Seasonal forecasts offer potential to modify outcomes, risks, and hence, decisions. But decision making under risk relies on quantification of the unexplained variability as much as it relies on any potential shift in mean outcome associated with a seasonal forecast. Can climate prediction models deliver faithful estimates of unexplained climate variability? Systems using historical analogues have become operational because they achieve this with a good degree of transparency. But the interaction of climate change with climate variability will ultimately limit utility of historical analogues. There are many possibilities for connecting needs of crop models and subsequent analysis with more sophisticated climate prediction models, but this will require greater attention to the needs of analysts and decision makers – and this is NOT a more accurate prediction of El Niño or La Niña! Rather, it IS an accurate specification of the distribution of climate possibilities – conditional on the current climate state. This has major implications for how we view usefulness of climate prediction models and the skill of their predictions.

Capabilities and Limitations of Dynamic Climate Models

Lisa Goddard

International Research Institute for Climate Prediction

The presentation discusses characteristics, capabilities and limitations of dynamic climate models and their output relevant to their use with crop simulation models. Specific issues include: the spatial scale (e.g., point vs. areal mean) of the models, and temporal scale (i.e., daily, monthly mean, seasonal mean) at which the output can be considered reasonable; use and interpretation of ensemble runs; and prospects for improving climate model outputs and related products relative to agricultural applications, including intermediate downscaling and nested, high-resolution regional models. Existing IRI dynamical forecast products and their use in producing the Net Assessment forecast maps are also presented.

Input Uncertainties Related to Spatial Scale in Crop Model Applications

Linda Mearns

National Center for Atmospheric Research

The presentation discusses the effects of different scales of inputs, using examples from our Southeast work. Issues include uncertainties due to the scale of the meteorological data, and the source and scale of soils data. The crop models are sensitive to characteristics of input data that depend on the scales of the data.

Statistical Downscaling of Atmospheric Circulation Model Output: A Primer

Robert Wilby

Division of Geography, University of Derby

The raw outputs of atmospheric circulation models are too coarse for direct usage in station scale crop models. Statistical downscaling provides a means of bridging these temporal and spatial mismatches by using empirical relationships between synoptic scale predictor variables (such as geopotential heights or vorticity) and point scale climate variables (such as daily temperature or precipitation). This paper outlines the most important steps in the downscaling methodology (e.g. choice of predictor variables, downscaling domain size and location, transfer function form, standardization technique, season definition, etc.) along with an appraisal of the most important limitations of the procedures (e.g. unrealistic predictors, non stationary predictor-predictand relationships, weak inter-variable correlations, etc.). Finally, examples are given to demonstrate the "value-added" of downscaling above and beyond the direct use of climate model output.

Potential Predictability of Precipitation Forecasts in Southwestern Australia

Bryson Bates

CSIRO Land and Water

Interest in stochastic downscaling has grown from the inability of general circulation models (GCMs) and limited area models (LAMs) to reproduce observed daily precipitation statistics at local- and regional-scales under present climate conditions. Although GCMs and LAMs perform reasonably well in simulating synoptic atmospheric fields, they tend to over-estimate the frequency and under-estimate the intensity of daily precipitation. Stochastic downscaling techniques provide a means of overcoming these limitations as they link local- and regional-scale weather to large-scale atmospheric fields. Case studies in southwestern Australia involving a non-homogeneous hidden Markov model (NHMM), historical daily atmospheric and multi-site precipitation data, GCM (R21 resolution) and LAM (125-km resolution) simulations for present day (control) conditions, and simulations from a GCM (at T63 resolution) forced by historical sea surface temperature data for 1955 to 1991, were presented and discussed. It is shown that the NHMM can: reproduce historical daily precipitation statistics from GCM and LAM atmospheric fields for control conditions; provide insight into the atmospheric indices that influence precipitation occurrence in southwestern Australia; and provide reasonable simulations of historical year-to-year variability in precipitation for the period from the early 1970s to 1991.

Generating "Super-Ensemble" Model Forecasts

Balaji Rajagopalan and Upmanu Lall

International Research Institute for Climate Prediction

Numerical climate models are being used to generate forecasts of a suite of climate variables. Often, an ensemble of forecasts is generated from each model to account for uncertainty in initial conditions as well as variations in predictability over the horizon of interest. Tests of new methods for combining such ensemble forecasts for a specified region, into a composite probability distribution for the forecast states are presented. A discussion of the comparative attributes of different statistical methods is offered.

Downscaling Climate Models or Upscaling Crop Models?

Mikhail Semenov[1] and Peter Jamieson[2]

[1] *IACR Long Ashton Research Station, Dept. Agricultural Sciences, University of Bristol*

[2] *New Zealand Institute for Crop & Food Research*

The chief difficulty in linking global climate model (GCM) scenarios with crop simulation models is a substantial mismatch between GCM output spatial and temporal scales and crop simulation model input requirements. A resolution of this conflict may be achieved in two ways. One is to downscale GCM output spatially and temporally to provide weather data at the resolution required by a crop model. Alternatively, a crop model may be scaled up to take weather input at lower resolution data, but without losing important responses to environment. The first method would link GCM output with a stochastic weather generator. This should allow the production of climate scenarios with high spatial and temporal resolution for agricultural impact. Such linking was demonstrated in recently published climate change studies. Spatial downscaling from GCMs has been shown to be site-specific, data-intensive and time-consuming. A plausible alternative to statistical spatial downscaling would be the use of regional climate model (RCM) with a spatial resolution of about 50 km. The alternative method is to use a substantially simplified meta-model developed from the Sirius wheat simulation model. The meta-model was developed from a sensitivity analysis of Sirius, predicts both potential and water limited production, and provides very similar yield predictions to its more complex parent. Its major advantages are that it is able to run on monthly, rather than daily weather data and requires fewer model parameters to be calibrated. Consequently the meta-model has the potential to be a valuable tool for regional agricultural impact assessments using seasonal climate predictions.

Producing Weather Generators with Climates Matching Seasonal Forecasts†

Daniel Wilks

Cornel University

The problem of bridging the timescale differences between seasonal climate models and the daily time step of many crop simulation models can be approached using "weather generators," through an understanding of the relationship of the artificial climate simulated by a weather generator to the specific parameters controlling its daily variations. Probabilistic seasonal forecasts such as the IRI "net assessments" imply a shifted mean and altered (often compressed) variance for the forecast quantity relative to the respective climatological values, and these moments of the implied forecast distributions can be computed. Comparatively simple expressions exist for time-averaged (e.g., seasonal) means and variances of the synthetic daily values produced by weather generators, in terms of their parameters. Using these expressions, baseline weather generator parameters can be altered to produce synthetic series that exhibit the long-term statistics implied by the forecasts. These alterations to the weather generator parameters are not uniquely defined (i.e., there exist multiple weather generator parameter sets which produce the same seasonal means and variances, because there are more than two parameters), so that other information must be brought to bear. An observed climate record can be bootstrapped in a way that is consistent with a particular climate forecast, to yield estimates of daily weather generator parameters consistent with that forecast. Which of these bootstrap-estimated parameters would best constrain the weather generator's parameter set, or indeed whether it would be preferable to construct weather generator parameter sets solely through bootstrapping (without explicitly constraining the synthetic seasonal climates), has not been investigated but would be of practical interest from the standpoint of running crop simulation models in conjunction with the forecasts.

† Daniel Wilks was not able to attend. His summary is included for completeness.

Generating Stochastic Daily Weather Constrained to Target Monthly Means

James Hansen

International Research Institute for Climate Prediction

Monthly predictions from atmospheric models are generally better than their daily output. Spatial averaging within model grid cells distorts daily precipitation frequency and intensity in a manner that is particularly serious problems for dynamic crop models. A weather generator has been developed that can generate stochastic realizations of daily weather with statistical behavior consistent with the historical record for a station, but whose monthly means match a time series of monthly targets from, for example, monthly climate model output corrected for biases with respect to local station climatology. Generated temperatures and solar irradiance are rescaled to match the target through a simple additive adjustment. Precipitation can be divided into occurrence and intensity processes. To ensure that generated precipitation is consistent with both the parameterized occurrence and intensity process, daily precipitation for a given month is generated iteratively until the monthly total is close to the target. A multiplicative adjustment achieves an exact match.

K-Nearest Neighbor Approach for Stochastic Daily Weather Generation

Balaji Rajagopolan

International Research Institute for Climate Prediction

A multivariate nonparametric time series simulation method is provided to generate random sequences of daily weather variables that "honor" the statistical properties of the historical data of the same weather variables at the site. A vector of weather variables (solar radiation, maximum temperature, minimum temperature, average dew point temperature, average wind speed, and precipitation) on a day of interest is resampled from the historical data by conditioning on the vector of the same variables (feature vector) on the preceding day. The resampling is done from the *k* nearest neighbors in state space of the feature vector using a weight function. This approach is equivalent to a nonparametric approximation of a multivariate, lag-1 Markov process. It does not require prior assumptions as to the form of the joint probability density function of the variables. An application of the resampling scheme with 30 years of daily weather data at Salt Lake City, Utah, is provided. Results are compared with those from the application of a multivariate autoregressive model similar to that of Richardson (1981). The method also allows ready adaption to conditioning on large scale climate indices (e.g. ENSO, NAO etc.).

Evaluating Downscaled Climate Predictions in Agriculturally-Relevant Terms

James Hansen

International Research Institute for Climate Prediction

Possible follow up to this workshop might be a comparison of alternative approaches to downscaling climate predictions at a few locations. Hindcast evaluation entails analysis of model-based climate “forecasts” from a number of previous years to evaluate error distributions relative to historic climate observations. Agriculturally-relevant evaluation goes beyond analyzing climate statistics, and may include predictability of crop response, and the value of forecasts for some relevant, well-defined decision, such as optimal field-scale crop management or allocation of farm land among cropping systems. Locations for an evaluation study should have good predictability of climate, crop production that is vulnerable to predictable climate variability, good data and tested crop models. Candidate locations may include Kenya, Northeast Brazil, Southeast USA and Australia.

SUMMARY OF DISCUSSION: SYNTHESIS AND FUTURE PLANS

Participants spent the final two hours of the workshop discussing the nature and importance of the problem, the various options for addressing it, and possible strategies for advancing. Much of the discussion focused on the broad issues of scale, including the range of scales of crop model applications.

A Taxonomy of Downscaling Pathways

Jim Jones proposed a framework for discussing and classifying alternative approaches for addressing mismatches of scale between climate model output and crop model requirements. The taxonomy is based on space and time scales of climate forecasts, crop models, and resulting prediction and decision applications (Figure 1).

Global-scale, dynamic atmospheric models used for climate prediction typically run on a sub-daily time step at spatial resolutions on the order of 10,000-100,000 km^2 (point **A** in Fig. 1, ellipses indicate a range of possible scales). However, because the high-frequency (daily or weekly) output of these coarse-spatial-resolution models is considered quite unreliable, output is aggregated in time, and interpreted on a monthly or seasonal (**B**) basis. Although this can, in principle, be done directly, IRI net assessments and regional outlook fora filter dynamic forecast model output through statistical and subjective adjustments to provide operational forecast products, typically expressed as probability shifts of tercile categories of precipitation and temperature.

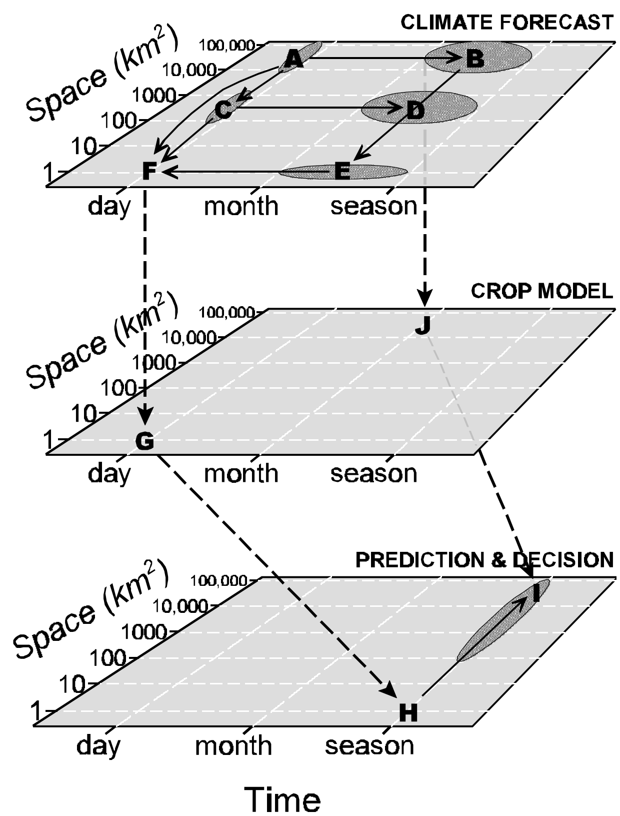

Figure 3. Proposed space-time framework for discussing and classifying methods for scaling from climate model output to crop model requirements, to prediction and decision application.

The dynamic, process-oriented crop simulation models that are the focus of this workshop operate near the other extreme of the time-space scale. These models operate at the spatial scale of a "homogeneous" plot – perhaps 100 m^2 to 1 km^2 – and integrate state variables on a daily time step (**G**). They require time series of daily weather data at the scale of a recording station (**F**). Although crop models provide information on dynamics of soil, and crop growth and development, prediction and decision applications are usually concerned with timing, quantity and quality of final yield at the end of the growing season (**H**).

Nested regional-scale atmospheric models offer potential improvements over the global-scale models. A high-resolution, dynamic atmospheric model nested over a portion (usually sub-continental) of the globe obtains boundary conditions from global-scale model output. Spatial resolution is increased to generally 100-1000 km^2 (**C**). Again, a sub-daily time step is used. The process (Fig. 1, line ***AC***) is known as dynamic downscaling. Regional model output is also generally aggregated and interpreted on a monthly or seasonal (**D**) basis, although evidence suggests that regional climate models may offer some useful information on within-season variability.

Statistical downscaling methods offer several options for providing daily weather inputs (**F**) to crop models that are consistent with dynamic climate model predictions (**A** or **C**). A two-step approach entails downscaling monthly or seasonal forecasts in space, then in time. Downscaling in space (line ***BE*** or ***DE***.) would use local station data to identify optimal predictors of local monthly or seasonal climate fluctuations (**E**) from monthly or seasonal output from a global (**B**) or regional (**D**) climate model. The resulting local-scale monthly or seasonal predictions would then need to be downscaled in time via some stochastic procedure to obtain realizations of daily weather data (**F**) that are consistent, in some statistical sense, with the downscaled monthly or seasonal (***EF***) forecasts.

Alternatively, the daily output from a global (**A**) or regional (**C**) climate model could be input to a statistical model for obtaining local-scale daily weather data. Local daily station data would be used to identify optimal predictors of local weather from daily or sub-daily global or regional climate model output. The procedure (***AF*** or ***CF***) could be regarded as simultaneous statistical downscaling in space and time.

Spatial aggregation of simulation results (***HI***) is necessary when prediction and decision applications of crop models are at spatial scales broader than the homogeneous plot (**I**). Although the objectives of this workshop focused on a class of crop models with particular spatial and temporal characteristics, participants correctly pointed out that a valid alternative is to reformulate crop models to use, for example, monthly climate inputs to directly predict spatially-aggregated yields (**J**).

The spatial and temporal scales in Figure 1 are not the only relevant differences among approaches to downscaling. Dynamic vs. statistical approaches were already mentioned. In his presentation, Robert Wilby addressed several relevant differences among statistical approaches, including choice of predictor variables (i.e., identical vs. non-identical predictor and predictand; categorical weather type vs. continuous predictors, point vs. spatial field predictors) and type of transfer function (e.g., regression relationships, neural networks, sampling of nearest neighbors from historic data). Approaches can also be differentiated between those that downscale to particular points (i.e., individual stations) vs. those that downscale to a contiguous spatial grid.

Scales of Crop Model Prediction and Application

Part of the discussion addressed the general issue of crop model prediction and application at various scales. Several participants argued that dynamic crop models that operate on a daily time step are not the most appropriate means of predicting yields at spatial scales larger than individual plots or fields. Mikhail Semenov and Peter Jamieson presented a simplified crop "metamodel," calibrated to the Sirius wheat model, that uses monthly climate time series to make predictions at the spatial scale of a GCM grid cell. They argued that monthly output from a coarse-scale climate prediction model can used directly for large-area yield predictions, eliminating the need for downscaling. The issue of appropriate matches between crop model complexity and spatial scale of prediction elicited lively discussion. However, participants generally agreed that applications of climate prediction to crop management call for a detailed crop simulation model with a daily time step, and therefore require some form of downscaling of dynamic climate forecasts.

Evaluation and Comparison Study

Interest. Workshop participants generally supported the desirability of some sort of comparative study. Those who use crop models within climate prediction application efforts – particularly Graeme Hammer, Jim Jones, Gerrit Hoogenboom and Guillermo Podestá – emphatically affirmed the need to find and evaluate ways to link climate prediction model output with crop model requirements. Robert Wilby suggested that past studies have already provided a great deal of information about characteristics of alternative approaches. However, the crop modelers present indicated that the link between statistical characteristics of weather and simulated crop response is sufficiently inconsistent to warrant evaluation of downscaling approaches in terms of crop simulation results.

Data. Data availability may be one of the factors that will dictate where such a study is feasible. Data requirements of available crop models are fairly well defined, and include reliable historical daily weather (precipitation, temperature maxima and minima, and solar irradiance), soil characteristics, cultivar characteristics and representative management practices. Statistical downscaling and evaluation will require, at a minimum, sea level pressure, geopotential heights, possibly a measure of atmospheric moisture, precipitation and 6m temperatures archived daily or possibly monthly from climate model output. Apparently modeled or interpolated "observed" time series data sets are available for these variables globally.

Participants wanted to know about the IRI policy on providing forecast and hindcast output of climate prediction models. Lisa Goddard discussed reasons for the IRI's cautious policy, but indicated that this is a topic of ongoing discussion. Several participants stressed the importance of having direct access to numerical model output, at least for their target regions.

People and resources. Jim Jones, Graeme Hammer and Gerrit Hoogenboom committed to help with crop simulation runs and analyses for any sort of study. Participants involved in statistical downscaling were generally less able to commit to such a study because of time requirements and resource limitations. Bryson Bates, Robert Wilby and Graeme Hammer indicated that they could participate in a study only if it focused on Australia. Several participants expressed interest in a broader study, but indicated that their involvement would require additional resources due primarily to time requirements for statistical downscaling in a new region using new data sets.

Conclusions and Recommendations

There is a very strong interest within the agricultural research community in evaluating potential applications of model-based climate forecasts to improve prediction and management of crop response to climate variability. Use of crop simulation modeling is an integral part of many of these efforts. Cited barriers to using model-based forecasts include (a) inadequate quantitative information about the skill and reliability of model-based forecasts (b) difficulty in obtaining climate model hindcasts (closely related to a), and (c) the mismatch of spatial and temporal scale between climate model output and crop model requirements. The third barrier motivated this workshop. Interest in developing, identifying and evaluating techniques for addressing the scale mismatches is strong and broad with the agricultural research community. Several recommendations can be derived from the workshop and ensuing discussions:

1. *Build on existing research to identify or develop, and implement practical tools for downscaling climate forecasts tailored to needs of crop model users.*
2. *Design and seek funding for the type of comparative study of potential and existing downscaling methods discussed in the workshop.* There may be sufficient interest among workshop participants to conduct and publish a limited comparative study in Australia.
3. *Develop a mechanism for facilitating communication among researchers interested in pursuing this area further*.
4. *Clarify and communicate a positive IRI policy for sharing climate model output with researchers working on downscaling and agricultural applications.*

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