The Consolidation Phase of the International Research Institute for Climate Prediction 2000 - 2005

'Linking Science to Society'

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1. Introduction

1.1 Vision and Implementation of an Emerging Institute

The vision for the IRI is that of an innovative science institution working to accelerate the ability of societies worldwide to cope with climate fluctuations, especially those that cause devastating impacts on humans and the environment, thereby reaping the benefits of decades of research on the predictability of El Niño Southern Oscillation phenomenon and other climate variations. By orchestrating a wide network of collaborations and comprehensive programs that couple physical science research and applications research with capacity building, it is foreseen that the IRI will become a unique institution in the international development of applications of climate prediction.

Through the foresight, initiative and financial support of NOAA, the IRI was established in late 1996. External support and endorsement of IRI efforts have swelled since the launching of the Institute (see Appendix A for historical context). Private foundation seed monies have supported efforts to explore how specific sectors and populations might better utilize climate prediction information. These activities have contributed to the involvement of the IRI in major application projects funded by USAID, IADB and the World Bank. The IRI has been able, by extensive invitation, to provide guidance and leadership in training, climate for a, and numerous other outreach activities around the world.

While NOAA funding does not support all of the IRI activities, we describe in this proposal the full range of activities given that the proposed NOAA funding will contribute to the full range of work on climate prediction science forecast technology, applications methods, demonstration projects, and training. Support from NOAA over the next five years will also enable the IRI to continue to actively pursue additional support from sources external to the US Global Change Research Program. It is anticipated that this will allow for the strengthening of the NOAA-supported activities and the addition of new activities, especially in the areas of applications development and capacity building. As this occurs, the shaping of IRI philosophy and strategy will evolve beyond that of NOAA alone and the IRI will progressively develop its own unique, and more international, identity.

During the first three years, one of the major accomplishments of the IRI was the hiring of a suite of young dedicated and superbly qualified team of scientists. A list of those scientists and technical personnel is found in Appendix B. In addition, during that time all IRI activities have been consolidated at a single site and the entire staff of the IRI staff now works under one roof in a newly built facility on Columbia University's Lamont-Doherty Earth Observatory campus.

The major achievements during the first three years include major developments in the operational prediction system, and climate application and outreach efforts, of the IRI. Advances in the operational prediction system evolved from a multi-model ensemble approach, and have resulted in the formalization of regularly published (quarterly) Net Assessments providing tercile-based estimates (http://tripred.ldeo.columbia.edu/forecast/net_asmt/images/jan2000/Afr_JFM00_pcp.gif) of anomalous temperature and precipitation, along with other forecast products specific to particular regions where impacts of climate variability are anticipated. These products have formed a major contribution to Climate
Outlook Fora held in Africa, South and Central America, Australia, and the near East, for which IRI provides a leadership role in the dissemination of its forecast products and their utilization in regional climate prediction installations. In support of improved future forecast developments, the IRI has entrained (through direct hiring and through collaborative advances with applied research centers (ARCs) and other partners) recognized experts in areas of extended simulations, retrospective forecasts, validation techniques, and downscaling systems, among others. In parallel with these efforts, the IRI has continued to expand and develop the IRI data library and other areas of the IRI Climate Information System (IRICIS).

Advancements in climate application over the last three years have occurred in parallel with outreach and training efforts through that time, with increased planning since the hiring of a Director for Applications Research and Development in mid-1999. Through this time, training courses in the application of climate information to water resources, agriculture, and health were held at ACMAD (Africa), Australia, and Mali. Developments in applications sector programs and participant networks evolved largely through project-specific advancements (see also box below). From these efforts, the IRI has become a major contributor to capacity building efforts relating to the use of climate information in the Greater Horn of Africa (USAID), Latin America and the Caribbean (WMO/IADB), and Peru (World Bank). In addition, the IRI now has international ties (MOUs and Cooperative Agreements) with the National Science Council and Central Weather Bureau (Taiwan), ACMAD (Africa), Frontier Research System for Global Change (Japan), IRD (France), United Nations Educational, Scientific and Cultural Organization (UNESCO), the Center for Weather Prediction and Climate Studies (CPTEC, Brazil), the State of Ceara (Brazil), and the Agency for the Assessment and Application of Technology (BPPT, Indonesia). The IRI now has an energetic staff with specialties in areas of climate prediction, agriculture, health, water resources, policy, and the social sciences to address the many projects and programs in planning and underway. A detailed description of accomplishments, year by year, are contained in the IRI Annual Reports that are available upon request.

An important part of the vision for the IRI is its recognition that the benefits of climate predictions arise from the application of those predictions and not simply from their production. Climate predictions on their own are not enough! Research on climate prediction must be strongly coupled with research on applications science, and ultimately the measure of success of the IRI is the degree to which applications are successfully implemented. This "end-to-end" vision is more fully described in Section 2, and the following box on the IRI’s experience in Peru’s fishing industry illustrates its realization.

Lessons Learned from IRI Research on the Application of Climate Prediction Information in Peru’s Fishing Industry

This multidisciplinary project began in 1996 with an exploratory study in Peru of industries sensitive to climate and interested in researching ways of coping through use of climate prediction information. This led to a small project working with groups within the fishing industry, which is strongly affected by the El Niño. Supported by the Tinker Foundation, Columbia University and NOAA, the project gave equal attention to the climate/biological linkage and the societal aspects surrounding the use of climate information. Over the next two years, the large 1997-98 El Niño event began to emerge and create a turmoil of public misinformation and confusion. This provided a cauldron of opportunity for developing essential collaborative relationships and for rapid learning about the practicalities of climate forecast applications.

(continued on next page)
Despite the limited ability to predict fish biomass or fish catch at this stage, many potential uses of current climate forecasts were identified. Research identified societal constraints on the use of information, including differential access and understanding of forecasts by different social groups, the political manipulation of information, and potential unintended social and ecological consequences of forecast provision. Some of the lessons of the project were reported in Nature in an article “Who benefits from climate forecasts?”

However, the natural science aspects of the problem, particularly the behavior and prediction of the coastal ocean water bodies and their fish stocks, were found to be inadequately understood. This continues to be studied, with some success, and the Peruvian government is sending several scientists to IRI to collaborate more intensively on this component. The government of Peru is now directly applying the social science results as it intensifies its efforts to improve its climate services and develop a "culture of prevention" in respect to climate variability. A comprehensive strategy for information dissemination is being developed to help minimize the barriers to effective information use that were identified in the project. The IRI expects to continue collaborating closely with Peruvian institutions in these efforts.

The Peruvian fisheries project has led to a much clearer understanding of the knowledge gaps involved, has created extensive formal working relationships with Peruvian organizations in government, the NGO sector, and in academia, has directly influenced Peruvian policy on the production and dissemination of climate information, and has provided numerous practical lessons that the IRI can use as it embarks on new end-to-end projects in other sectors.

Late in 1999, the IRI took steps to re-examine and re-state its overall goals, in order to develop a more structured basis for its work program. Through this exercise, the IRI was able to reaffirm more coherently its aims to internationally advance both the knowledge and the institutional capabilities that are required by countries, organizations and individuals to:

- Research climate anomalies and their impacts;
- Develop climate prediction methodologies;
- Produce and disseminate climate forecasts;
- Develop and implement forecast applications methods; and
- Raise awareness and build management capacities.

It will be seen that these cover in a systematic way the main elements of an end-to-end chain. In the present proposal, the work programs are grouped around three main thrusts: prediction science, applications science, and integrated projects (the latter dealing with a selected topic along all points in the chain). These are described in section 2 and 3. Integrated projects are a new initiative and will be increasingly used by the IRI to develop and implement applications and to set priorities for internal research. It is expected that the choreography of these three thrusts, together with the end-to-end perspective, will mutually enhance all the projects and result in a unique character to the Institute outputs.

The portfolios of projects in the proposal have been selected for their expected contribution to IRI goals and on the basis of available expertise and activities of the IRI and its partners. A framework for choosing projects is described in Section 2. A mix of planned and opportunistic approaches is used. It is important to emphasize that many of the projects identified are in an evolving state and are very dependent on the future decisions of the external partners involved and on the unfolding lessons learned as the projects
Within any project area, research will be undertaken: to identify useful applications; to design, deliver and trial climate information products and applications methods; to identify and apply means and measures for evaluating both the success of applications and the research that led to them; and generally to build a knowledge base useful to both producers and consumers of climate prediction information. An underlying effort is required to advance the state of the art prediction capabilities that will be needed to support the next generation of applications.

The integrated nature of focus areas undertaken by the IRI requires day-to-day interaction among dedicated staff located at the core facility. Within these areas, the magnitude of specific problems requiring solutions is such that it can only be achieved through a more comprehensive implementation in partnership with an extensive network of collaborators. An important role of the IRI is to organize effective interactions with many partners across the diverse worlds of prediction science and applications science, sector groups, other producers of climate information and consumers of climate information. Only by fully engaging each other can both users and scientists develop the necessary comprehension of the opportunities available and the requirements of the other.

In the years to come, it is expected that the IRI will become an indispensable element of the global infrastructure for climate prediction and its application. The IRI will continue to actively contribute to WMO efforts to design and implement a global infrastructure for the exchange of data and dissemination of forecast products. The IRI will lobby for support of necessary atmospheric and oceanographic observing systems and for the free exchange of essential data. Finally, the IRI will strive to involve the National Meteorological and Hydrological Services in all IRI in-country activities and will foster close relationships between the NMHS and IRI in-country research partners.

IRI staff will play an active roll in the WCRP and the working groups of the WMO relevant to the IRI’s mission. IRI staff will contribute to planning and meetings of the CLIPS Project and other WMO applications programs, and will continue to play a prominent role in Climate Outlook Fora and related international meetings. Contributions to sector-related science coordination, such as through the CLIMAG program, will also be undertaken.

Through these and related efforts, the IRI will contribute to improved prediction models, develop forecasting systems, disseminate regular forecasts, lead and participate in the development of enduring and valuable applications, and provide training in these areas for the global community. The IRI will endeavor to foster extensive international efforts in all of these areas.

1.2 Proposal contents

This proposal requesting support for the continued development of the IRI during its consolidation phase from 2000-2005 consists of six sections. Following this introductory section, Section 2 describes the frameworks used to establish and integrate the priorities and content of the IRI programs. It includes discussions of the end-to-end concept and of integrated decision tools, and the development of a matrix
approach to problem solving. The matrix is composed of end-to-end programs together with programs addressing specific critical links along the end-to-end chain. Section 3 sets out the work of the IRI along the matrix approach, developing preliminary end-to-end programs as well as specific research topics based in applications or predictions. The evolution of the work programs through the five-year period is described with an emphasis on the first two years.

Section 4 provides a proposal for the overall management structure of the IRI under the current arrangement with Columbia University and describes a possible legal framework for the IRI as a multi-national partnership requiring more independent management. It contains proposed external advisory and internal management structures of the IRI, and depicts the idea of close working partnerships of the IRI with the members of a broad international network of modeling and application centers. This section also describes the growing need for international resource mobilization activities to provide wider support and to develop a truly multi-national base for the IRI as originally envisaged.

Section 5 describes the personnel and budget needed from NOAA/OGP to carry out the activities presented in the proposal. It also depicts, in modular form, the important short-term activities needed for the proper functioning of the IRI and its projects. The anticipated supercomputing requirements are not incorporated in this budget. Section 6 is a brief statement that reflects on how the Institute as a whole can be expected to develop over the next five years.

2. Framework and Integration

2.1 Researching the whole process

The climate forecast information that a decision-maker uses is the result of the flow and continuous transformation of information along a path starting with climate system observations and working its way through various physical, chemical, biological and socio-economic contexts. The quality and relevance of the information to the user depends on the effectiveness of all of the steps in the process and this in turn depends on a good understanding and management of the whole process. This concept is often referred to as the “end to end” chain, as discussed in the box below.

The “End-to-End” Concept in the Development of Effective Applications Climate Prediction Information

The end-to-end concept has been used throughout the evolution of the IRI to emphasize, especially to the physical science community that the IRI must be concerned with much more than climate models and forecasts alone. The concept not only links the chain of components that lead to outcomes: Climate Observations-Prediction Models-Forecast Information-User Systems (Biophysical and Socio-Economic)-Decision-making, but also includes all the multitude of interactions and feedbacks involved. It implies that to obtain desired outcomes, attention is needed to all processes throughout the chain. Of course, the metaphor of a chain has its limitations, particularly in the user setting, where the chain becomes a web of complex interactions that filter, transform and entrain other information.
A broad international program aimed at enhancing society's capability to understand, predict and respond to the impacts of seasonal climate fluctuations requires institutions like the IRI in order to maximize the benefits of the predictive information available. For that, the IRI needs to take an integrated, holistic approach that addresses all features of the chain and its complex interactions and feedbacks. Such an approach requires many working partnerships for implementation. This suggests a matrix treatment, where efforts are focused along two main formats:

- Fully integrated end-to-end research efforts focused on a particular end-user problem, such as regional food security.
- Research on critical individual elements of the end-to-end chain. Examples include the use of SST forecasts in ensemble forecast generation, and the role of risk perception in the utilization of climate information.

These two intersecting formats become the basis for the work plan that is described in Section 3.

Another metaphor that is especially applicable at the user end of the chain is that of a web of interactions, between individuals, institutions and sectors within society. The user who is making a decision involving climate is subject to many influences and many types of information. The degree to which a climate forecast is useful at that moment will depend on how it is shaped to fit the context of the decision-maker. To understand how to achieve this fit, research is needed on a wide spectrum of important influences – social, economic, biological, chemical and physical.

The concept of the integrated decision tool provides another framework for analyzing the application of climate prediction information to whole systems. In this approach, an existing or potential decision process is formally described in a way that allows the influence of particular factors (e.g. a climate forecast, or a risk-adverse decision maker) to be systematically explored or acted upon. Example uses include environmental policy options for a Canadian river basin, and the operational management of Australian wheat farms. Where these systems are used primarily for research and exploration, they are called envisioning tools. Where a system is well defined and the decisions involve relatively simple options, such as in the management of a reservoir’s water level, the system is known as a decision support system. Integrated decision systems are generally computer based.

The multidisciplinary task of building and testing an envisioning tool or decision support system is itself a potent means to learn about the system under consideration and the decision-makers’ needs and to develop the mutual understandings that are necessary to effective decision-making. In many cases these gains may be the primary value of the approach.

In some instances, such as in cropping agriculture, the available knowledge and data resources have enabled the development of a variety of well-tested decision support systems and some of these are now in widespread use for research and in some operational settings. Decision support systems are also common in some hydrological management situations. They are, however, generally not available for use in the plethora of climate-influenced decision-making that lies beyond these uses.
Additional IRI activities that will assist in the goal of end-to-end integration include the following: first, the IRI’s web-based climate information system (IRICIS) provides a means to describe and actively support integrated projects; second, training similarly can be used to promulgate and actively support integration; third, the design and production of climate forecasts will integrate forward to respond to user needs and backward to shape prediction science research; and fourth, the pivotal role that IRI is increasingly taking in the global development of climate prediction provides a basis for expanding its contact with parties from all parts of the chain (or web) and for representing their interests to other parties.

2.2 Framework for program choice

The potential scope of work implied by the IRI’s overall goal is very large. A key challenge is to establish an appropriate framework for deciding work program content and for setting priorities. Formal decision analytic framework (DAF) approaches such as cost-benefit analysis cannot be easily applied owing to the undeveloped nature of the field and the lack of data for the numerous factors involved in any situation.

The use of formal decision analysis will be used, where appropriate, in the future, as the IRI’s experience develops, and in balance with the innovative approach that the IRI intends to take. At the present stage of development, the IRI is using the following pragmatic framework of principles in choosing programs and priorities.

- All program activities will be assessed on their potential to enhance knowledge of the whole chain of information flow and web of interactions and thereby to advance the application of climate predictions.
- Work activities will be identified and selected on the basis of quantitative evidence where available, and otherwise on the basis of anecdotal evidence from scientists and practitioners. Work will be undertaken to develop the quantitative information needed to underpin programs.
- Serendipity and political concern will be accepted as legitimate factors in program choice where relevant to maintaining a portfolio that is well balanced by geographical region, sector, time-frame, stakeholder interest, etc.
- Effort will be focused on those geographical regions where there is greatest potential for achieving beneficial results. This potential will be assessed on the basis of the (i) strength of climate fluctuations, (ii) predictability of these climate fluctuations, (iii) significance of the impacts of the climate fluctuations, and (iv) receptivity of local institutions to proposals to research and apply climate forecast information. The geographical scales of interest will be dictated by the scales for which there are scientifically useful prediction information.
- Effort will be put into those sectorial problems where there is greatest potential for achieving beneficial results. This potential will be assessed on the basis of (i) sensitivity of the problem to climate variations, (ii) the ease of modeling this sensitivity, and (iii) the potential for incorporating modeled predictive information into user decision-making.
- The potential for IRI collaboration and coordination to leverage other organizations’ efforts toward IRI goals will be a key factor in program choice.
• Research and development priorities for IRI activities will be weighted toward on systems-level issues, such as standard methodologies, systems integration, global studies, decision tools, demonstration projects, and training curricula.

• The principal criteria for the IRI’s research will be relevance, quality and innovation.

• Operational services will be undertaken only where this acts as an advanced test bed for learning and development and to provide authoritative forecast information where otherwise not provided (e.g. global coverage.)

• An important objective will be the development of the IRI as a specialized component of the international institutional framework required to achieve effective generation and application of climate predictions.

During the start-up phase of the IRI, the primary focus has been on designing, operating, validating and communicating results from a real-time forecast system. The system was assembled from components available through the research community, and was progressively enhanced to achieve maximum utility. During late 1999, considerable progress was made in initiating longer-term development efforts, most notably through new hires and through the establishment of research partnerships with other groups working in the area of climate modeling and prediction. Attention is now turning to the question of how to respond to the demands of existing and future applications projects. This is a joint enterprise between applications and prediction scientists both within the IRI and among its external partners.

3. Proposed Work

The work plan of the IRI can be considered in two main formats - one that represents the end-to-end research objectives that strive to address specific needs of end users (section 3.3), and another that represents topics at discrete locations along the end-to-end chain (sections 3.1 and 3.2). The specific topic array of the matrix is more fully developed at this point in time. The proposed end-to-end projects of section 3.3 are, by necessity, still in the concept stage and still require considerable detailed development. Others projects are under consideration but cannot be committed at this point. These include public health management for dengue fever and for malaria, the efficiency of large hydro-electricity systems, the reduction of infrastructure damage from climatically extreme rainfalls, and the application of climate forecasts in the private sector.

It is intended to devote considerable attention to developing the concept and practice of the integrated end-to-end projects, and this will be a primary growth area as the IRI evolves.

3.1 Specific Research Topics: Applications

The IRI’s proposed programs on applications topics aim to provide as coherent a set of activities as possible to advance IRI's overall goals. Applications topics aim to internationally advance both the knowledge and the institutional capabilities required by countries, organizations and individuals to investigate
impacts of climate anomalies; develop and implement applications methodologies; disseminate climate forecasts and information and develop improved forecast products, and raise awareness and build capacities for impact management.

The proposed programs are structured to address the above five components. Wide collaboration is an essential requirement. Externally this will involve the input of experts and users to shaping and implementing the programs, the development of partnerships with individuals and organizations, and active participation in regional and international meetings related to applications. Internally, the integration of activities throughout the IRI will be critical since applications require attention to all steps along the information chain, including climate modeling and forecasting stages.

### 3.1.1 Climate forecast product design and dissemination

In order to better meet the needs of applications methods and users, the IRI will progressively develop improved designs of forecasts and improved means for presenting and disseminating forecast information. This activity will have a central role in the IRI, as it is the principal meeting place between the climate prediction science and the user applications, and it will be carried out jointly with parallel prediction science initiatives (see also section 3.2.1 and 3.2.2). Attention will be given to identifying user needs, communicating these to prediction researchers and forecast producers, and to studying and trying out different contents and formats of forecast products. A variety of dissemination services will be provided according to the different categories of users and collaborators.

**Years 1 - 2**

**Regular dissemination**

The IRI will continue to regularly disseminate IRI forecast information as it becomes available, mostly through the IRI web site and the Climate Information Digest. IRI staff will continue to provide expert input to the regional climate outlook fora, in collaboration with local forecast groups and OGP.

**Forecast and data dissemination policy**

Policy on the dissemination of IRI forecasts and high-resolution model data will be reviewed and updated. A dialogue will be established with regional and national forecasting centers, and with applications researchers, to identify how the IRI can best make authoritative information available while at the same time supporting the development of regional forecasting capacities. A number of sensitive issues are involved, such as how to manage any significant differences between IRI and regionally issued forecasts, and how the IRI products should be disseminated via the forecast products infrastructure that is being canvassed within WMO.

**New forecast products**

Applications scientists will cooperate with IRI prediction scientists in the development of new forecast
products such as the hurricane/typhoon risk predictions (see 3.2.2). A system will be developed to identify, document and review user needs for forecast information, and to provide input to IRI-wide research priorities for developing new forecast methodologies. Factors to be considered include forecast element (rain, wind, frost, timing and intensity of monsoon, extremes, etc), lead-
time, frequency of update, within-season distributions, spatial domain, spatial resolution, and statistical significance.

Forecast product presentation

Studies will be undertaken of how to best represent forecast information, by developing alternative ways of presenting probabilistic and mapped information and by examining user responses to these. Factors to be considered will include color, spatial scales, statistical terminology, the balance between text, map and graph, etc.

Media relations

Research will be undertaken on the role of the media in forecast dissemination, focusing mainly on how to interact with media partners to ensure accurate and interesting media coverage. A two-day multilingual workshop will be developed on “Training the Media” aimed at exposing the media at a level appropriate to their technical capacity to the latest developments and successful examples of seasonal climate forecast and applications.

IRI demonstration facility

A facility will be developed for the new IRI building to provide a public display of global climate information, including current and recent past conditions, outlook information and applications of this information. A more advanced interactive system will be developed within a classroom to support the routine monitoring, analysis and display of climate data and forecasts needed by IRI forecast analysts and applications researchers.

International liaison

The IRI will actively contribute to WMO efforts to design and implement a global infrastructure for the exchange of data and dissemination of climate forecast information. The IRI will seek to involve National Meteorological and Hydrological Services in its in-country activities and will encourage close relationships between the NMHS and the IRI’s in-country applications research. IRI staff will take active parts in WMO activities relevant to the dissemination and application of climate forecasts, in particular as members of working groups and in the planning and meetings of the CLIPS Project.

Years 3 - 5

It is expected that all of the activities described above will continue into years 3 - 5, appropriately improved on the basis of experience.

3.1.2 Impacts of climate anomalies

The IRI will develop information resources and tools needed both by the IRI and by external parties to identify and assess climatic anomalies and impacts and to support applications research. The information is
necessary in the development and refining of IRI applications priorities. This task will involve the consolidation and improvement of a number of existing projects, and the development of new user-oriented information resources on impacts and vulnerability. The information generated will be disseminated mainly through the web-based IRI Climate Information System (IRICIS).

**Years 1 - 2**

**Climate system data and monitoring**

The information products currently being provided under the IRI Climate Information System (IRICIS) are popular with researchers in climate prediction and applications studies. The principal aim for this first period will be to consolidate the existing activities, as follows.

1. Monitor and summarize global climate anomalies (as in the monthly *Climate Information Digest*) and as appropriate monitor and summarize the impacts of these anomalies.
2. Provide basic tools to enable users to analyze anomalies and impacts.
3. Provide an information base for use in assessing the quality of operational climate forecast information.
4. Improve the real time analysis of temperature and precipitation by expanding the Data Library to include regional applications data sets and a larger suite of historical model analyses and forecasts.
5. Complete the first stage of the *Climate Calendar* and *Climate Dictionary*.
6. Redesign and implement the IRI’s Web site as the primary vehicle for the provision of climate information and tools.

**Vulnerability indices**

An initiative will be made to develop new user-oriented information resources on impacts and vulnerability. In particular, work will be undertaken to develop a geographical information database on regional-scale climate variation, climate predictability and climate impacts, as a tool for vulnerability studies and for IRI priority setting. Research will be undertaken to develop indices of vulnerability in respect to seasonal climate variation.

**Sector and region database support**

Web-based information resources will be progressively developed to support and accelerate research in priority sectors such as agriculture. Each of these sector information resources will contain tailored climate information, outlines of research goals in the field, and links to databases, projects and organizations. Similarly, web-based information resources will be developed as required to support specific IRI regional applications projects, commencing with the Integrated Food Security and Greater Horn of Africa projects (see also 3.3).

**Years 3 - 5**

With the continuation of the directions established in the first two years, particular attention will be paid to the identification and generation of the data and products needed by applications researchers and users, and
to the development of better forms of vulnerability indices. There will be continued expansion and refinement of information resources and of the tools needed by researchers and users to access, interpret and understand climate analyses and products.

3.1.3 Applications methodologies

The IRI will develop knowledge and specific methods needed for effective application of climate forecast information. Important initial tasks will be to develop a sound basis of program planning and policy, to develop a well-balanced portfolio of activities, and to complete existing commitments and build a track record of early tangible achievements.

Some sectors, in particular agriculture, water resources and health, are well known to be climate sensitive and specific programs will continue to be developed for each of these sectors. In these cases emphasis will be given to taking an integrated view along the information chain and to developing effective end-to-end applications, where possible through decision support system approaches.

Research also will be undertaken in the decision-maker context, working backwards to identify the potential for the application of climate prediction information and to more explicitly identify the user requirements. This will involve decision analysis studies as well as research on specific socio-economic factors in the dissemination, interpretation and use of information.

Research activities will be encouraged to cluster together, for example around a well-established regional project, in order to maximize the potential learning. In all of the applications research, there will be a need for close interaction with activities elsewhere in the IRI, and for extensive collaboration and coordination with the many other research groups in these fields.

Years 1 - 2

Agriculture Applications

This will be a dominant area of applications activity over the next few years. An Agriculture Applications Strategy has been developed in collaboration with external experts to provide a strategic overview of IRI applications efforts in this field, and to map out the activities proposed to be undertaken. In such an enormous field, which spans field trials to global food security planning, strategy is critical to steering the efforts of both the IRI and its collaborators.

Continued effort will be put into developing a network of collaboration with external researchers and organizations, such as the International Consortium for Agricultural Systems Application (ICASA) and the START-initiated CLIMAG research community, in order to build an effective agricultural applications program.

A major International Forum on Climate Prediction, Agriculture and Development with an expected attendance of 200 people is being organized for April 26-28, 2000. Among other things this will introduce
IRI forecast products and the agricultural applications strategy to a wide audience in these fields. It will also initiate and facilitate communication and collaboration between the climate prediction and agricultural communities. Feedback obtained during the forum will be used to refine the IRI Agricultural Applications Strategy.

Two associated meetings will also be hosted (subject to external funding); first, a two-day CLIMAG Workshop on Southeast Asia Rain Fed Lowland Rice, with potential participants from Indonesia, the Philippines and Thailand, to analyze the ENSO-related predictability of historic crop production from potential project regions in each country, and to explore the design of a potential demonstration project on this crop; and second, a technical Workshop on Linking Climate Model Output with Crop Model Requirements. The 1999 CLIMAG planning meeting in Geneva identified the linking of climate models to crop models as a critical knowledge gap in this field.

The IRI will be closely involved with several leading research groups in the design and execution of a set of regional projects to research and demonstrate the application of seasonal climate forecasts to agriculture. These projects are in various stages of development. Typically, they involve a decision support system approach. IRI inputs will include the support of a feasibility study for a multilateral project in south-east South America; participation in the design and implementation of a major project in Southern India; the leadership of a set of projects on mixed cropping and livestock farming in eastern and southern Africa; and participation in a project on the application of climate predictions to vegetable production in Florida and the U.S. Caribbean.

At the systems level, the IRI will coordinate the preparation of a guidance paper *Framework for Regional Applications of Seasonal Climate Prediction to Agriculture* on the design and implementation of regional field research projects. It is also planned to develop a network of researchers interested in these projects, and to coordinate a special issue of the journal *Agricultural Systems* on systems approaches for agricultural applications of seasonal climate prediction. A number of methodological issues such as the use of weather generators for the temporal disaggregating of climate forecasts and quantifying crop predictability and forecast value will also be addressed, making use of existing staff specialties.

**Health applications**

The health sector is also a very large research field, and the development of a successful program will require a good guiding strategy. Only minor exploratory discussions have been carried out by the IRI to date. The priority in the first year will be to develop the strategy and to build an initial program based on existing information and readily developed components and collaborations. Given the multiple environmental and sociological factors that influence disease patterns, morbidity and mortality, the program will most likely focus on pilot projects that elucidate key issues and identify potentially useful climate forecast products. External experts have identified infectious diseases and climatic disasters as priority health research areas. It is expected that there will be good payoffs in preparatory work such as the development of health-climate databases, the dissemination of forecast products, and the provision of basic training and capacity building in countries where predictable climate variability is known to affect health.
Research will be undertaken on dengue fever as this is a major disease and a specific is relatively simple to model. The climate-driven global dengue vector model developed by a post-doctoral fellow will be used to explore the potential for prediction of vector density and hence disease risk. There is also an IAI funded project to design a Collaborative Research Network (CRN) for climate and health in South America. Collaborative research on the application of climate prediction information in West Africa is under discussion with French tropical health scientists. Collaborative work will be undertaken with international partners to test and implement statistically based malaria risk forecasts, and similar work will be undertaken with the Center for International Earth Science Information Network (CIESIN) to research the climate-malaria link in Kenya.

Water resources applications

Preliminary discussions have been held and a draft program outline has been prepared. The scope and objectives of the program will be clarified by the end of the first year. An advisory committee will be formed to guide the program and its project prioritization. Key areas of interest will be water supply, floods and hydro-energy. A NOAA Global Change Fellow will work with the IRI to investigate the potential use of ENSO forecast models in reservoir management at the Itaipu Hydroelectric Power Station in Brazil. Collaborative work on the Nile River basin is currently under discussion with the Egyptian Ministry of Water Development and the US-based Hydrologic Research Center.

Fisheries applications

The current Peruvian fisheries project will be largely completed by the start of the next funding period, but it is expected that a new research project to support a major World Bank-funded development project in Peru will emerge during 2000. Several Peruvian scientists will be visiting the IRI during the first year. During the fall of 2000, a major three-week training workshop is planned on “Climate Prediction and Pelagic Fisheries”, in Noumea, New Caledonia. This is being co-organized and co-sponsored by NOAA/OGP, IRD, SPC and WMO.

Disaster management applications

At present, disaster issues are partly covered in other sectors, e.g. by the food security work of the agriculture program, the flood component of the planned water program, and the disease modeling work in the health program. The IRI will develop a systematic approach for this topic during the first two years. The first step will be to develop liaison with disaster management professionals and to assess the decision-making opportunities for the use of climate prediction information.

Environmental applications

The application of climate forecast information to biocomplexity issues and environmental management is a poorly studied field. Currently the IRI has no project on these topics, though there is an awareness of environmental considerations in most agriculture and water resources projects. It is likely that the greatest potential will be in (i) large regional scale environmental management where the aggregate of many small
local impacts is large, and (ii) local scale environmental risk management such as may arise from flooding of waste facilities. This is an area that the IRI will examine and develop a policy on during first two years.
Private sector applications

Research will be undertaken to identify how to advance the application of climate forecast information in the private sector. The focus will be on enhancing the application scientist’s knowledge of the decision-making circumstances of the private sector and on exploring generic issues in the application of the technology in the private sector.

Socio-economic research

Specific socio-economic research will be fostered, principally on decision-making processes, decision envisioning and support tools, risk perception and management, policy frameworks and their impact on the use of climate prediction information, and education and interpretation of information products. Plans for developing these research topics will be developed with the assistance of the IRI’s senior social science consultant.

It is expected that socio-economic study will become an integral part of most future applications projects. Toward this end, a social science assessment will be included in all application and dissemination projects to address the principal socio-economic factors relevant to the project, such as which parties gain access to the information generated, who is likely to benefit from or be disadvantaged by the information, what the benefits comprise, and what governmental policy and market factors impede or enhance project success. A guideline document will be developed to guide project leaders on how to implement the socio-economic assessment.

Within-IRI linkages and networking

Throughout all applications activities and projects there will be a concern for identifying and clarifying the needs of users and the requirements of the emerging applications technologies. It will be critical to actively communicate this information within the IRI to influence the directions of other IRI projects. To strengthen this process, it is planned to systematically document what has been learned about user needs in the first two years and to review this on an annual basis thereafter. The IRI will also actively foster networks of applications scientists and users in order to accelerate the development and dissemination of the knowledge and tools involved in climate prediction applications. The main task will be to manage the numerous links to organizations, researchers and users. The IRI web site will be the primary vehicle for doing so. IRI staff will also actively engage in the bodies and fora concerned with coordination, strategy formation and representation of user needs relevant to applications, such as the WMO, FAO, WHO, IRD and ACMAD.

Years 3 - 5

During this period the consolidation of basic knowledge about how to design and implement good applications research projects, the development of a pool of generic lessons about issues in effective applications, and the commencement of implementation by third parties of operational applications will occur. Some specific intentions for the IRI include:
• A closer integration, especially through the development of end-to-end projects, of the physical, biological and social science elements involved in IRI applications efforts.
• The maturing of the agriculture, health and water sector programs and the populating of these programs with good projects.
• The development of strategies and programs for other sectors such as fisheries, disaster mitigation, energy, environmental management.
• The development of selected geographically focused strategies and programs that maximize cross-sector synergies.
• Well-established processes to enable applications studies to influence the design of forecast products and dissemination methods.
• The expansion of an active collaborator network and the support of their research through ready access to IRI information.

3.1.4 Capacity building

Experience at the forefront of applying climate prediction information has shown that progress is often significantly impeded by lack of awareness of the basic knowledge of the field, and by corresponding lacks of institutional capacities for both research and operations. This is to be expected of any emerging technology. Awareness raising and capacity building are therefore important ways the IRI can advance its goals. It will do this by concentrating as far as possible on leveraged approaches, for example by maintaining a publishing program and a visitor program; coordinating training with specialized sector groups; developing and disseminating curricula and training materials; and undertaking high profile capacity building and demonstration projects. An important shift in approach during 2000 will be to more closely integrate training activities into the IRI’s programs.

Years 1 - 2

Analysis and application tools

The IRI will continue to develop and provide access to tools such as the CLIMLAB 2000 multi-disciplinary statistical data analysis software, for use by researchers and practitioners. These will be made available principally through the IRI web site and also will be built into training activities. CD versions of CLIMLAB 2000 will be produced and distributed worldwide to minimize problems associated with real-time downloading from the web. As applications methods and models become formalized following proving in research projects, they similarly will be made accessible.

Training

The training requirements of the applications programs will be systematically identified and training activities will be more closely integrated and targeted to these requirements. Most training activities have significant awareness raising and capacity building roles. Where appropriate, training activities also will be used to test forecast products, dissemination methods and applications tools and to provide feedback to other IRI
programs. Trainees can provide an important source of local expertise and future potential points of contacts for collaborative research and capacity building.

On-site training activities will include regular training of IRI visitors (fellowship and visiting programs) and new staff to cover the latest climate databases and products, as well as latest software and tools developed at the IRI.

A number of plans for training are under discussion with NOAA/OGP and other international organizations (WMO, IRD and ACMAD). These are designed to support existing sector strategies or capitalize on available opportunities. They include:

- **Spring 2000**: “Use of downscaled products in the Greater Horn of Africa”, 3 weeks, IRI headquarters
- **Fall 2000**: Executive Program on “Climate Variability and Managerial Decision-Making”, 2 days, at Columbia University in collaboration with the Columbia Earth Institute and the Columbia Graduate Business School.
- **Fall 2000**: Two-week training in the potential uses of climate forecasts, a component of the IADB study on the prediction and amelioration of socio-economic impacts of ENSO in Latin America and the Caribbean, to be held in central America at a location to be finalized.
- **Fall 2000**: “Climate Prediction and Pelagic Fisheries”, Noumea, New Caledonia, three weeks, co-organized with IRD, SPC, NOAA/OGP, WMO and NASA.
- **Early 2001**: “Disaster management and Climate Prediction”, 1 month at IRI for managers, decision and policy makers on a rotating basis based upon disciplines.
- **Year 2001**: “Regional Climate Forecast Applications”, 1 month workshop in collaboration with WMO/CLIPS during which interactions between IRI scientists and representatives of the regional scientific and “user” groups will be fostered. Experts from governmental, university, industry and NGO from GHA are expected to participate.

**Greater Horn of Africa Project**

This USAID-funded capacity building project based at the regional Drought Monitoring Centre, Nairobi, is being closely coordinated with a WMO-coordinated project on regional meteorological service development. The project commenced at the end of 1999 and will continue until 2002. From mid-2000, the computer equipment will be on location at the IRI, and the installation and testing of code and the training of local personnel will begin. Efforts will focus on development of an effective locally sustainable operation for producing useful regional forecasts, and on the outreach, dissemination and training activities required to develop and promote local applications research. Because the project will be a model that might be replicated in other climate-sensitive areas, the IRI will pay special attention to ensure its success. It is planned to promote the project as a nucleus around which other R&D projects may develop (see also section 2.2). An important first step for the project to be undertaken within the IRI prediction program will be to research and design an operational strategy for the regional climate model, in respect to domain location, domain size, grid spacing, nesting levels, run frequency, and output products, as required by applications and users (see also section 3.2.1).
Infrastructure development projects

The major development banks, particularly the World Bank and the Inter-American Development Bank, have begun to support multi-million dollar investments in infrastructure for climate monitoring and prediction services in the regions of South and Central America that were badly affected by climate anomalies over the past few years. They are now looking to the IRI to help the recipient countries and organizations in the detailed design and implementation of the projects, covering mainly consultancy advice, training services and applications development. These projects are expected to be self-funding and they provide excellent opportunities for the IRI to advance its mission in capacity building.

NOAA-OGP projects

For many years, NOAA’s Office of Global Programs has been the advance guard in the development of awareness raising and capacity building, through regional meetings, pilot programs and publications. There is great potential for the IRI and OGP to orchestrate a coordinated approach to build on the experience of OGP and the new capabilities of the IRI. The IRI will maintain a close dialogue with OGP to advance this cooperation.

Years 3 - 5

It is expected that all of the activities described above will continue into years 3 - 5, appropriately consolidated and improved on the basis of previous experience. The principal differences by then will be the establishment of a more systematic policy for choosing project elements and allocating resources, and a shift toward higher-leverage projects.

3.2 Specific Research Topics: Predictions

The overriding objective of the IRI’s prediction research agenda is the provision of a suite of high quality climate information and predictions to support practical applications. This requires research and innovation at many levels, and the delivery and continual development of the best possible forecast system and user-tailored forecast products. This requires careful attention to the production of forecasts, and to deriving the maximum utility from them; it equally requires continual attention to the improvement of existing systems, the incorporation of new ideas and new methodologies, and the development of new products that serve the user communities’ needs. The research and development issues are numerous and complex. The IRI does not propose to address them all on its own. Rather, we are establishing research partnerships that can effectively engage a broader range of expertise, and greater computational and human resources. The primary activities under prediction will be focused around three areas: operations, forecast systems, and development.

The IRI’s forecasting experience over the past few years has identified the following requirements: more efficient and objective forecast procedures, greater regionalization of prediction products, more frequent prediction updates, better estimates of skill levels, and assessment and evaluation of products. An overarching need for all regions (to varying degrees) is greater accuracy. Particularly those areas distant
from the tropical Pacific suffer currently from limited ability to predict ocean temperature variability in the other tropical basins.

To meet these needs, the IRI will dedicate personnel toward improvements in forecast operations algorithms and procedures, data management, and more extensive and regular validation. Approximately forty percent of the prediction science effort will be devoted to operational activities. The near-term research program will address the major current limitations by working toward: improved dynamical (and statistical) downscaling methods, ensemble forecast methods, and coupled models encompassing ocean/land/atmosphere interactions throughout the entire tropics, eventually toward global domain coupling.

A considerable effort will be devoted toward the design and delivery of products better tailored to user needs, through close collaboration among application and climate prediction staff (see also section 3.1.3). This collaboration will help educate climate prediction scientists about user needs, and inform applications scientists about prediction capabilities and prospects, and will ensure the close coordination of research directions and efforts in both areas.

The IRI prediction research effort must:

• Engage the maximum number of available, potentially useful tools, and ensure that they are well tested;
• Find the best methods of integrating these tools toward an optimal forecast system (or systems) tailored to the needs of users;
• Promote further development and improvement of tools along the lines dictated by practical needs.

Because of the enormous scale of effort, the prediction research strategy requires a distributed approach. In order to promote improvements in downscaling, ensemble forecasting, and coupled models, for example, it is vitally important to engage the larger research community working toward these problems. By all indications, the most capable prediction systems will be derived from ensembles of many models, rather than any one model, and hence successful tool identification and utilization will depend on the development of linkages with leading development centers. The IRI will therefore continue to forge the links with major development centers worldwide interested in climate prediction and its application. Already, partnerships have been established with several of the NOAA Applied Research Centers; NCAR, USA; CPTEC, Brazil; Frontier Program, Japan; Central Weather Bureau, Taiwan; MPI, Germany; and the ECMWF. Others are also needed and will be sought. Ongoing collaborative efforts with the climate researchers at the Lamont-Doherty Earth Observatory of Columbia University are also key to mutual advancements in specific research topics.

But the short-term needs require IRI to do more than assemble outputs from other centers. Component models, and particularly coupled models, are still extremely limited in capabilities. Many have not been evaluated extensively and rigorously in the ways that matter most for IRI. None have had development priorities set with serious input from the applications community. The IRI can and should play an important role here, as the common element in a network of collaborating centers seeking to contribute toward its applied mission.

The IRI is in an excellent position to provide leadership in organizing a community effort toward more controlled, rigorous experimentation with the suite of existing tools. The goals will be to determine
performance according to appropriate metrics, as well as aid in diagnosis of problems. This will benefit not only IRI, but also the broader research community, which has not had the benefit of such coordination to date. In addition, IRI will benefit from some in-house efforts in testing/evaluation and systems-level development of tools, integration methods, and specialized product development, as discussed below.

### 3.2.1 Forecast operations

Regular forecast operations will continue, and these will be incrementally improved as required. The IRI Net Assessment forecast effort will continue throughout the period 2000-2005. A description of the current status of the prediction system was published in the September 1999 issue of the *Bulletin of the American Meteorological Society*. Significant enhancements in the capabilities, content and timeliness of the operational activities are planned. The important operational issues that must be addressed as soon as possible (in Year 1) include:

- **Forecast suite.** Automate the production of all current forecasts, products and diagnostics, where feasible. This requires extensive software and systems development.

- **Downscaling system.** A regional climate model has been tested and validated in a research mode for East Africa, but many questions remain about the most suitable choices of domain, resolution, nesting strategy and run frequency need to meet local operating conditions and user needs. To address these questions, regular production of the regional downscaled forecasts for the region will be undertaken, in parallel with a corresponding effort at the Drought Monitoring Centre in Nairobi under the USAID-funded project for East Africa (see 3.1.4). Once a stable operation is established in the region, and maintained through a few forecast seasons, this system may be discontinued as part of IRI operations, so that other prototype systems can be implemented.

- **Forecast process.** At present, the Net Assessments are prepared quarterly, and are completed approximately one-half month into the first season being forecast. During Year 1, the date of preparation of the Net Assessments will be gradually advanced so that, by the end of the year, the forecast products will be available for dissemination before the beginning of the first season being forecast. The possibility of an increase in the frequency of preparation and release of the Net Assessments, from quarterly to monthly, will be explored. Further, a process will be instituted to extend the participation in the Net Assessment process across the major focus areas of IRI; namely, operations, modeling and prediction research, monitoring/dissemination, applications research, and training. While final responsibility falls to the Head of Operations, the participation of others will help to ensure the two-way flow of information between developers and users that is central to IRI’s mission.

- **System Documentation.** The forecast process will continue to be closely documented for quality assurance.

Longer-term issues (Year 2 and beyond) include additionally the following issues.

- **Prototype enhancements.** As the forecast and development research efforts identify promising revisions/additions to the current forecast system, forecast products, and validation tools/methods, a process for actual implementation must be developed. For a period of time, the operations group will implement the proposed system or product in parallel with current operations. After a period of time, a second evaluation by operations and research management will determine whether current operations...
are updated, or whether a proposed new product becomes part of current operations. If a proposed system requires inputs from external sources (for example, in the event of implementing a multi-model forecasting system, without successfully acquiring the necessary computing resources at IRI), operations personnel will work closely with the appropriate centers to ensure reliable and timely delivery of data.

- **Facilities development.** Currently the IRI is operating three different computing platforms: Cray-J90, SGI Origin 2000, and NEC SX-4. Of these the oldest and soonest to be obsolete are the Cray machines. All forecast operations use these machines at present. Development of new systems will be done on the other platforms, and by Year 2, all codes run within operations must be ported to one of the two other machines (or their successor). IRI is much in need of significantly greater computing power and associated support personnel, and will seek under separate proposals to establish a new facility to support research and operations. Furthermore, the forecast operation relies on an extensive mass store capability. The present forecast archive at the San Diego Supercomputer Center is about 6 Terabytes in size, and expands by about 500 Gigabytes each month. Comparable archive capability will be established at LDEO for IRI use, and the existing archive will be transferred.

### 3.2.2 Forecast system integration and product development

A systematic program of system integration and product development will be undertaken. Topics will include multi-model ensembling (coupled, uncoupled, nested models); statistical enhancements; probabilistic forecast products, downscaling or regionalization methods. These are all fundamental to IRI in ensuring the ability to produce the best possible forecast products from more basic tools available at any given time. This work will be ongoing, as it is envisioned that the IRI forecast systems will always involve the synthesis of multiple inputs, combined in ways optimized to the needs emerging from particular applications. Approximately thirty-five percent of the prediction research effort will focus on addressing these issues.

**Years 1 – 2**

- **Post-processing and products.** Work will continue to design additional output diagnostics, and enhancements to existing products to meet needs articulated by user communities and by the product dissemination team at IRI.

- **Hurricane/Typhoon frequency forecasts.** Preliminary work has already been done on inferring large-area hurricane or typhoon frequencies from circulation indices in moderate resolution climate models. Work will be continued in this area toward a prototype forecast system, possibly during year 2.

- **Regional downscaled forecasts.** The system tested for East Africa will be targeted for other regions of interest. The choices will be dictated in part by needs associated with evolving applications projects. Likely candidates are areas of eastern and southeast Asia, meso-America, and southern Africa. Work will also begin with a version of the MM4 regional model (or the NCAR regCM, which is closely related, but has different physical parameterizations). Separate work will begin to examine for one or more of the same regions a statistical downscaling based on both the global and regional model inputs, and high-resolution climatic data. This will permit an assessment of the baseline against which the dynamical products must be judged, and may lead to additional products.

- **Ensemble forecast systems.** Several projects are planned. First, investigations of how best to use multiple SST forecasts in tier 1 of the 2-tier system will begin. The additional forecasts available are
from ECMWF; they consist of ensembles of 30 SST forecasts initialized from each month. Numerous experiments will be needed to examine the use of ensemble means, individual ensemble members, ensemble extremes, and statistical weighted averages of different SST products, all as inputs to the tier2 AGCM’s used for actual climate forecasts. Secondly, a collaborative project aimed at multi-model 1-tier ensemble forecast systems would begin. One aspect of this will begin to examine real-time ensembles based on the COLA and NCEP coupled predictions (eventually other systems could be added, including one or more the IRI may run). As a preliminary component to this work, AGCM ensembles from IRI and several other centers will be analyzed to estimate the value of the multi-model ensemble methodology.

- **Higher resolution forecasts.** As resources permit, limited tests of operational forecast models at higher resolution (up to T106) will be continued, and initial assessments made of changes in performance associated with resolution alone. Until much improved computational resources are secured, a serious effort at this resolution will not be possible.

**Years 3 - 5**

Most of the above projects will continue. Since we plan to have one or more state-of-the-art coupled systems identified from a collaborative project (see below) by Year 2, additional inputs can then be provided to the 1-tier ensemble investigations. Additional results will also be obtained from the real-time ensemble project, allowing a prototype ensemble system to be developed in Year 3. During Years 3-5 it is expected that enough results from the collaborative regional model studies may be obtained to begin investigating ensemble-based probabilistic forecasts at regional scales.

**3.2.3 Systems-level development and diagnostics**

The continual refinement and application of most appropriate metrics of evaluation, based on evolving understanding of user-based needs, is an important role for the IRI. Effort will also be devoted to systems-level issues such as coupling between major components (atmosphere, ocean, land), coupling of data and models within major components; and methods of prediction initialization. These systems-level issues can be addressed with modest personnel investments, but have very large impacts in performance. By contributing a few, capable scientists specializing in systems-level research, IRI will be able to leverage the contributions of its partners greatly. Some partners offer very viable tools, but are not in a position to apply them to seasonal prediction, or need assistance to carry out the necessary experimentation. Some partners offer promising component models that have not been tested in the context of prediction. Some partners are developing models with different goals, and are not in a position to make choices in, for example, coupling strategies that may give improved performance for seasonal prediction. By making some selective
investments, IRI can bring additional tools to the table, and can help extract the greatest benefit from the contributions of its many partners.

Choices will need to be made, as only a very few avenues can be pursued. The instincts of the group should be the guide here, but with the caveat that any effort at the systems level must involve partners who can provide the comprehensive development of the underlying component models, as IRI will not attempt to engage in development at this level. Some initial choices are mentioned in the proposal details for the next year, but these and all choices will be reviewed and revised regularly. Approximately twenty-five percent of Prediction Systems effort will be devoted to this area.

IRI Core staff working in integration systems/product development and diagnostics/system development offers the opportunity to hasten the process of response at the development level to the needs of users. It also provides expert guidance in technology transfer, and contribution to capacity building and training - all are important aspects of most applications activities. Finally, these IRI Core staff will provide critical local knowledge and expertise that allows effective dialogue with the network of partners, ensuring more active and effective collaboration.

**Years 1 - 2**

- **Coupled models.** Several new coupled models will be studied in experiments to be undertaken in an intercomparison project with colleagues at NCAR, NCEP, COLA, and perhaps GFDL. The atmospheric models of each group will be coupled to a new version of the MOM ocean GCM. IRI will add to the project by experimenting with a recent version of the ECHAM model. As the project continues (years 2 and beyond), we anticipate the continued development of several coupled systems among the groups; these can serve as the basis for a “super-ensemble” system – by current reckoning the most promising tool for improved probabilistic forecasts.

- **Ocean data assimilation.** The current operational system at NCEP has been ported to IRI, and will be run as a baseline against which to measure the new systems under development. Together with colleagues at LDEO, a reduced state space Kalman filter approach is being developed. Initial work will focus on error models and specifications. The system will be adapted for the MOM ocean model, while the LDEO group is pursuing the same methodology in a simpler model. Colleagues at NCEP and GFDL are pursuing aspects of adjoint methods for the same model (but most likely will not have an adjoint assimilation system implemented for at least 2 years). By the end of year 1, a prototype system for the Kalman filter is expected to be ready to employ in an ocean analysis, which can serve to initialize a set of forecast runs.

- **Regional downscaling.** An initial project will compare several current regional models in one or more common settings. The geographical regions of choice will be set by applications needs. Partner groups at GISS, FSU, SIO, and CPTEC will run the FSU, RSM, and ETA models, and IRI will additionally test the MM4 or NCAR regional models. The first task is to document the relative performance of these models in the regions of interest, with tight controls on downscaling methodology, resolution, domain boundaries, and boundary conditions. This will help identify the most promising models and/or parameterizations for particular regions of interest.
Climate variability/predictability. Studies of the tropical Atlantic will continue, with collaboration from colleagues at CPTEC. Coupled experiments with both the hybrid models and a coupled GCM will be undertaken in an effort to understand the impact of the Pacific on Atlantic predictability at seasonal to interannual time scales, and to estimate the degree of predictability afforded by the local atmosphere, ocean, and land surface interactions in the sector.

Years 3 - 5

All of the above are ongoing. It is expected that by the start of Year 3 a 4-D assimilation system can be tested in actual forecasts; in subsequent years sensitivity experiments concerning observing systems, model resolution, and physical parameterizations will be conducted. We estimate that by the end of Year 3 a set of several coupled models will have undergone sufficient development and testing/validation to be used for research on super-ensemble forecasting.

Methodological issues of downscaling, concerning the nature of boundary conditions and land surface initialization begun in Year 2 will be continued as needed. By Year 3, or as soon as enough results are available, we will begin to investigate the issue of super-ensembles of regional forecasts.

An important aspect of collaborative development is modeling infrastructure. Efforts have begun at the national level in the US to create a common infrastructure for development. IRI has played a leading role in this, and will continue to support it. By Year 2, depending on progress of the initiative, some significant investment in new infrastructure is planned.

3.3 Integrated end-to-end projects

The IRI plans to develop a set of end-to-end integrated research projects that will be strongly focused on achieving results in respect to critical end-user issues such as food security. Each project will be designed and implemented by a multidisciplinary team of IRI and external scientists and will build on existing and planned subject-focused research. The projects are expected to not only develop useful applications, but also provide a mechanism for enhancing the IRI’s internal collaboration processes. Some proposed focus areas are:

Regional food security

Food security is of global concern but it manifests itself on a regional scale. Although it is well known that famine is often caused by human factors unrelated to climate, it is often the case that the triggering factor is climate, either through drought and water stress or climate-related pests and diseases. Also, rainfall excess can cause dislocations in transport systems and hence in food distribution.

In this research, we will examine the system of international food security warning and management and its use of climate predictions, especially over the last few El Niño and La Niña events, and the potential for use of currently available climate forecast information in the decision-making processes involved. We will identify the key actors and their roles in relation to food security decision-making, the key information
sources that are relevant and how this information is generated and used. We will survey the key actors’ knowledge of climate and its impacts and will study how predictions and other climate information have been used in the past. We will identify, develop and test different strategies for introducing climate prediction information to the decision-making processes, including the development of new tailored prediction products. To underpin these tasks we will attempt to develop a formal decision system tool for the decision process. This research will be carried out in close collaboration with organizations active in the food security field, especially FAO and USAID.

Part of the project will involve examination of the ENSO sensitivity of national food production data and the potential use of these results for predicting global food production anomalies. Particular attention will be given to the Greater Horn of Africa, in association with the USAID-funded IRI project there, and in support of the third project listed below.

Multi-sectorial sustainability in the Greater Horn of Africa

This regional project aims to elucidate the role of climate and the potential of climate prediction information in selected aspects of sustainability management in the countries of the Greater Horn of Africa. It will orchestrate a cluster of existing and planned projects in key sectors built around the existing USAID-funded IRI project to upgrade the capabilities of the Nairobi based regional Drought Monitoring Centre and the application of climate information in the region, and an associated USAID-funded WMO project to upgrade the climate capabilities of the region’s meteorological services (see section 3.1.2).

The project begins with a survey of the region’s sustainability and vulnerability in relation to climate, and of existing policy making and decision-making processes. In the sectors being addressed, studies will be made to identify how the different types of climate information and forecast products might assist to improve sustainability policy and management. Research strategies and forecast products will be developed as required. Currently, most of the component projects concern agricultural production, though a health project is also present. Regional food security issues will be linked with the overarching food security project described above.

Most component projects involve wide collaboration, with some components led by partners from other institutions and/or from the region. It is intended that the GHA program will provide a framework for the addition of other key components such as water resources projects.

Eastern Pacific coastal fisheries

Previous IRI work on the application of climate forecasts in Peru’s fishing industry provides a rich background of experience in this topic (see box in Section 1 of the proposal). Many parts of the end-to-end chain have been investigated and an extensive network of collaborations and relationships has been developed.

The project will now develop a more formal integrated description and will foster research strategies for the parts of the problem that require more explicit investigation. These are likely to include a stronger focus on
regional ocean modeling and prediction, fish stock modeling, interactions with other sectors and other countries, and capacity building in forecast generation and dissemination.

4.0 Institutional Development

During 1999, the IRI conducted a global search for talent, interviewed many excellent candidates, made hiring decisions, and began to welcome our new associates. The total IRI staff, which was 21 at the beginning of 1999, is now 49 (early 2000, excluding the five Columbia University Faculty hired in affiliation with IRI). At this level, the IRI, together with an expanding array of domestic and international partners, expects to make significant progress. Following the endorsement and advice of the External Review Panel (conducted in June 1999), the core activities of the IRI have been consolidated at LDEO so as to improve the coordination and cooperation among the components of the IRI. As part of its contribution to the IRI, Columbia University has completed a new $12 million building to enable all of these activities to be concentrated in a single modern facility.

4.1 Governance

4.1.1 Overall Management

The Director, who is the Chief Executive Officer and has overall responsibility for the ongoing operation of the Institute, leads the IRI. The Director is selected by, and reports to, the IRI Board of Directors. The Board of Directors is comprised of representatives of the organizations that provide significant funding to the IRI, currently including the NOAA Office of Global Programs, Columbia University, and soon the Central Weather Bureau of Taiwan. The current Board is still developing the details of mechanisms for expanding the Board and characterizing its operation.

In discharging his (her) responsibility, the IRI Director will be supported by an internal Executive Committee, composed of the Senior Scientific Managers of the organization who will work closely with the Director towards achieving the overall mission of the IRI.

The IRI was originally organized into four Divisions (Model Development, Experimental Forecasting, Monitoring and Dissemination, and Applications Research), and a Training Program. Recent experience has shown that these components are better considered as part of an integrated whole comprised of two general themes – Applications and Predictions. In order to focus on these two themes, the internal structure of the Institute will be simplified. The Applications part will comprise monitoring and dissemination, applications research and training. The Predictions part will comprise model and forecast system development and forecast operations.

The senior management staff of the IRI will thus be composed of the Director, Deputy Director and Science Program Coordinator, and the leaders of the component efforts. Both the Prediction and Application parts will have identified coordinators who will ensure that the efforts within each area, and between areas, are well integrated and harmoniously working together.


4.1.2 Advisory Structure

The initial advisory structure for the IRI included an Advisory Committee and two Working Groups that all reported to the Director. The IRI and the Board of Directors are currently considering modifications to this advisory structure that would enable the Board to guide the development of the IRI more efficiently and effectively. One option being discussed is the creation of a Scientific and Technical Advisory Committee (STAC), with membership from both the prediction and applications communities with experience in institutional building, which would report to the Board of Directors.

4.1.3 Evaluation and Review

The IRI will undergo programmatic reviews at the request of the Board of Directors. These will be organized by the standing advisory mechanism - the Science and Technical Advisory Committee. The IRI staff will provide logistic support for these reviews when necessary and appropriate.

4.2 Networks and Partnerships

In all of its efforts, each element of the Institute works closely with all the other elements, and with the greater application and prediction research community of which it is a member. The actions and products of the organization are all closely coupled across the organization and to our partners, without rigid boundaries.

Networks can be driven by resource requirements as well as by problem emphasis. An example of a resource driven network involves the ongoing integration of IRI into a broader community-wide effort devoted to the improved prediction of seasonal-to-interannual climate variations. There is a pressing need for supercomputing capability for this prediction community as the IRI and its partners require access to such a facility for modeling research and development as well as for the production of forecasts. Various embryonic efforts to address this resource requirement are underway. These include a community-driven effort to coordinate model software development, and participation in the Advanced Climate Prediction Initiative (ACPI) of the U.S. Department of Energy.

Similarly, a broad network connecting various efforts to apply climate predictions to the real problems facing societies is being constructed. The IRI is actively involved in the evolution of this network, both through participation in workshops and planning meetings and through direct support. The IRI is also engaged in a number of international programs that are beginning to develop real applications of climate predictions. One example is CLIMAG, a program being developed by START with co-sponsorship from the WMO and other international organizations with the objective of developing projects to demonstrate the application of climate forecasts to agriculture. Other programs, in health and water resources, are in development as well.

In either case, the aim of the IRI network is to accelerate the development and dissemination of the knowledge and tools involved in climate prediction and its application. The network will be the IRI’s means to manage its numerous links to organizations, researchers and users. Following the first year of network development a review will be undertaken to identify ways to increase its efficiency and completeness. A
component of the effort will involve the utilization of web statistics to better quantify user interests. It is expected that existing sectorial or regional organizations will play an important role in this assessment.

The IRI is also in the process of formalizing relationships with many partners through Memoranda of Understanding. Among these are the Central Weather Bureau in Taiwan, the BPPT in Indonesia, the Frontier Program in Japan, the French Institute of Research for Development (IRD), the National Centers for Environmental Prediction in the U.S., the Center for Weather Prediction and Climate Studies (CPTEC/INPE) in Brazil, the Foundation for Meteorology and Water Resources (FUNCEME) in Brazil, the African Centre for Meteorological Applications to Development (ACMAD) and the Drought Monitoring Centre in Nairobi, Kenya. We are also deeply involved in the effort, coordinated by the World Meteorological Organization, to develop a process and structure that will facilitate the international exchange and evaluation of operational forecasts of seasonal-to-interannual (S-I) climate variations. In addition, IRI training courses in the applications of climate forecasts have already led to collaboration with many national, regional and international organizations, and such interactions are expected to continue.

4.3 Outreach

The IRI has an obligation to communicate its fundamental message, that climate predictions can be used to benefit human societies, to a wide variety of communities in many ways. A resource of substantial potential value here is the Columbia University academic community, which is of exceptional quality in many fields. However, it will be important for the IRI to search out and take advantage of all possible means for spreading the word. This will include media contacts, publications, attendance at public meetings and seminars, a visitors program, and other efforts. Specific programs in support of outreach follow.

Visitor program

The Visitors Program allows the IRI to engage visitors from a variety of sources in varying capacities. The program represents a mechanism to assure intellectual ventilation and vigor to the IRI through the continued circulation of personnel from institutions around the world. Shorter duration visits (days to weeks) accommodate individuals who hold key roles in countries and organizations and are central to the implementation of climate prediction applications. These persons are invited to visit the IRI, its project sites, or its meetings. As far as possible, these visits engage the visitor in presentations, focus groups, program reviews, or project designs, with complementary visits by IRI staff to key meetings, organizations and individuals to carry out similar activities. Such visits have been key in the development of elements of end-to-end programs discussed in section 3.3.

Longer-term (months to a year or two) visits allow international experts to share regional methodologies and practices, and to collaborate in the exploration of different methods and tools that could further advance efforts in their region. Scientists who have circulated through this program to date have made important contributions in their areas of expertise while at the IRI, and have also contributed to establishing mechanisms (through MOU or other informal arrangement) of continuing ongoing collaborative activities between their home institution and the IRI.
Visitor placement will continue along two main themes. A nation or institution anywhere in the world, following the establishment of an appropriate working relationship or MOU, can sponsor a scientist from their organization, or from another organization, to spend a limited tour at the IRI, ranging from 6 months to 2 years. The IRI, depending upon the availability of funds, will also advertize opportunities for fixed term appointments of experienced visiting scientists.

The Visitors Program is an important element of the IRI, and increasing support of this program though efforts of the international development team is anticipated.

Publications

An IRI publications program will be implemented. This will include both internal publications and external activities. IRI publication series will comprise three levels, to cover professional-level science material, technical methods for practitioners, and popular articles for the public. As much of this as possible will be made available through the IRI web site. Articles will be prepared for identified target audiences through their professional journals and magazines. A review article on the climate prediction and application field will be completed by the end of 2000. Encouragement will be given to translating important publications into other languages.

IRI Seminars and Lecture Series

The IRI hosts an ongoing and regular seminar series consisting of speakers from the IRI and partners on topics of mutual interest. This is intended to improve communication and cross-fertilization in research topics among researchers within the IRI. It also serves as an informal opportunity to explore new domains, of which there are likely to be many at the IRI.

The IRI will also continue the annual distinguished lecture series, where world-renowned speakers are invited to give keynote presentations or to partake in discussion panels on important themes of interest to the IRI and the greater Columbia Earth Institute consortium of which it is also a part.

4.4 Resourcing

The IRI, to accomplish its mission, must obtain substantial resources other than those requested from NOAA through this proposal. The necessary resources include direct financial contributions, and various in-kind contributions (for example, personnel and computational resources), and will be obtained in varying ways.

4.4.1 Fund-raising

The IRI Board of Directors (meeting of mid-1999) has indicated that, by the year 2005, approximately 50% of the support for the Institute must be obtained from outside sources. Outside financial sources include any support for IRI activities that comes from sources other than the NOAA Climate and Global Change Program. The possible sources for such support include other US government agencies, non-US
governments or government agencies, international or regional agencies, private foundations, and private companies. The support might come in the form of direct unconstrained financial contributions, funding or co-funding of specific projects or programs, support for individuals while working at the IRI core, or provision of products or services to the IRI at no or subsidized cost. In each case, the donor organization may impose conditions upon the exchange, and the IRI will have to determine in such cases what conditions are acceptable. As a part of this proposal, the IRI is requesting support for an international development effort, operated with the assistance of the Office of the Executive Vice Provost of Columbia University, to take on the task of motivating national governments and other institutions around the world to join the current sponsors in supporting the IRI. The continuing support of NOAA is essential to the leveraging of this additional funding.

4.4.2 Recruiting

By the start of the proposed funding period, the IRI will be nearing completion of a very rapid expansion in staff to enable it to carry out the work it is committed to accomplish. However, additional recruits are anticipated to be necessary to achieve specific program and project objectives. The recruiting process has been made flexible to ensure that the necessary number and quality of employees can be brought into the organization. Possible entry points into the Institute include permanent hires through Columbia University, post-doctoral research scientists and other temporary CU positions, a post-doctoral program operated for IRI by UCAR, and a Visitors Program yet to be fully developed.

4.4.3 Computing

The IRI computing resource will consist of several elements, and will need to be supplemented by shared resources in some form. The elements will consist of a network of desktop machines, a set of superworkstations within the IRI, and a set of mini-supercomputers. The desktop network will consist of moderate cost workstations of three types: Windows, Linux, and terminals using one of the superworkstations as a computational base. Each workstation will be capable of executing both Windows and Linux/Unix software through its own processor or a server on the local network. Terminals will be used for visitors and trainees.

The super-workstations will provide a set of more capable computing and data handling platforms optimized for specific tasks. The workstations will typically be multiprocessor, large disk array systems. They will support the forecast post-processing and Net Assessment preparation, the updating and access to the IRI Data Library, the IRI web site, and the medium-scale computational and visualization needs of the staff.

The mini-supercomputers include the SGI Origin 2000 and NEC SX-4 systems at Lamont, and 2 Cray J90 systems operated at the University of California, San Diego. The J90s will be used for the model runs needed for the operational forecasts, while the Origin 2000 and the SX-4 will be used for model and forecast system research and development.

In the long run, the IRI computer capacity, even with enhancements as technology advances, will not be adequate for the forecast task contemplated. One of two options must be accomplished: either a large-
scale supercomputing facility, comparable to those required for operational numerical weather prediction, must be installed and operated at the IRI, or the same amount of computational resources must be obtained elsewhere. The first choice is problematic – the IRI is not prepared to install and operate such a system, and Lamont could not presently host such a system. However, the requisite computing capacity could be obtained from a variety of sources away from the IRI site. This item requires special attention in the months ahead.

5. Personnel/Budget

Budget increases over the five-year period reflect the growth in the permanent core staff and equipment anticipated to be necessary to support the core component of activities described within section 3. The success of these activities obviously requires significant in-kind (or cash) contributions from numerous other sources, dominantly in support of application-based efforts, as previously discussed (section 4.4).

The allocation of requested funds to support personnel over this period is approximately 40% to applications-based efforts, 40% to prediction-based efforts, and 20% to administrative support, including relation and resource building by the directorate. A significant portion of administrative support represents investment efforts to gain increasing financial support, including the hiring of a senior person to lead the effort. As new sources of funds are identified, the greatest total percentages of funds are anticipated to flow into application-based advancements.

Budget tables show the roster of IRI personnel by their primary affiliation with either application or prediction research (including computer support personnel), or administration/management (directorate). Present staff carries out the range of work previously discussed in this proposal. Additional staff to be hired are discussed briefly below.

Within applications research are reserved positions for three associate research scientists. Hiring of experienced, relatively senior scientists in primary focus areas will be an important element of developing programs in applications, as well as in developing end-to-end projects (see also section 3). Positions are also reserved for a Web Programmer and Media Specialist. The search for the Web Programmer is ongoing and it is anticipated that it will be filled by the start of year 1. The search for media specialist will commence early in 2000.

Within predictions research are reserved positions for the Head of Forecast Operations and the Head of Forecast Integration. The Head of Operations will be responsible for ensuring the regular production of high quality, usable climate forecasts, whereas the Head of Integration will work very closely with applications researchers to ensure appropriate design and release of new forecast products of greater use to specific communities. An additional Senior System Analyst/Programmer will be hired to ensure greater stability within the IRI computing network and platforms required for operational and experimental advances. A senior secretary will also be added to provide day-to-day clerical support of the prediction effort.

Within the IRI Administration/Management, partial funding is reserved for a Deputy Director, and full
funding for the Secretariat. The Deputy Director has been a seconded position since 1998, and some exploration is required to see whether this is a mode of operation that will be workable through the budget period. In any case it is necessary that the Directorate have strong representation and support during the ongoing growth of the Institute anticipated to occur through the duration of this budget request. The Senior Secretariat is a position intended to provide leadership to the international and financial development of the IRI. The search for this position is ongoing. Columbia University has engaged a professional search firm to seek out exceptional candidates and their availability. It is anticipated this position will be hiring near the start of year 1.

Other expenditures include permanent equipment, travel, training, subcontracts, and miscellaneous support costs (materials, publications, network subscriptions, communications, service contracts, and so forth). Permanent equipment includes replacements or upgrades of all existing desktop equipment (PCs, workstations, printers, etc.), mass storage upgrades, and the acquisition of computer servers (in duplicate) to ensure the computation network is always accessible and operable.

Travel is an important element of IRI activities, as reflected in the growth from approximately $.4M in year 1 to nearly $.5M in year 5. This allocation represents approximately 50% of anticipated travel expenses. Another 25% of anticipated travel expenses are borne through a (annually negotiated) travel fund provided by NOAA directly to UCAR. The remaining 25% of travel is supported from external sources, or by collaborators. The travel supports foreign and domestic program/project meetings and scientific conferences/meetings, and is essential to ensure ongoing collaborative advancements in the many focus areas of the IRI and its partners.

Three major training programs (two off-site, one on-site) are budgeted per year. Funds requested reflect approximately one-third cost of training programs proposed. Training activities are always conducted in collaboration, and shared expense, with other institutes and/or programs.

Subcontracts include UCAR, who manages an IRI Postdoctoral Scientist Program as part of the visiting scientist program. Subject to fund availability, UCAR may in future years also manage a part of the IRI Visitor Program (a vigorous program requires additional resource development from other sources). Scripps Institute of Oceanography is subcontracted to maintain the two CRAY J-90 supercomputers, and associated mass storage, through the end of year two. The CRAY system will be retired by the end of year two, and IRI mass storage will be fully functional at its headquarter location. Subcontract funds for the Weizmann Institute of Science reflect year two of an ongoing partnership through the ARC program managed by Mark Eakin of NOAA.

The budget incorporates a Columbia University overhead rate of 53%. Overhead collected is being used in part to offset a portion of the debt incurred by Columbia University to construct IRI's new headquarters (as of 1/2000) in the Monell Building of Lamont-Doherty Earth Observatory, located in Palisades, NY. Not included in the budget are cash and in kind contributions from the host, Columbia University. Columbia University will contribute approximately $1.9 - $2.5M in cash and in kind support including five IRI-affiliated Faculty positions, $.25M in Research Development Funds, and $.5M funds to be used at the discretion of the Director.
Also not included in the budget are anticipated international contributions. Final negotiations with Taiwan for significant direct and in-kind contributions are underway (December 1999). In 1999/2000 IRI attained about $4M in international memberships and special projects. Additional support will be achieved through aggressive fundraising involving development banks, private and public research foundations, and other potential sources.

Notably missing from the budgets is the full cost of a supercomputer adequate to support the full IRI mission in modeling and prediction. We believe that such a facility, in keeping with our intention of forming a component of a larger community-wide effort, should be provided for the seasonal-to-interannual prediction community as a whole, with IRI as an important, but not sole, user.

6. Concluding Statement

The core IRI began operations in 1996 and spun up to reasonable size by the end of 1999. Not many end-to-end activities could be instituted because the IRI inevitably grew unevenly and had not achieved its full capabilities. The next five years should see the IRI transitioning to an integrated end-to-end institution with a unified approach to new prediction and applications activities. We expect the later three years of this five-year proposal to have the IRI in final enough form so that the end-to-end approach will be clearly institutionalized in the IRI structure and in its approach to problems and a multitude of 'end-to-end' examples fully demonstrated. Beyond this five-year period, when the IRI core and its partners have achieved near final form, we expect the uniqueness and value of the end-to-end approach to become clear to the world.
Appendix A: History and Background

The concept of an IRI

The International Research Institute for climate prediction and society (IRI) evolved from a remarkable convergence of advances in observing systems, theoretical understanding of the El Niño/Southern Oscillation (ENSO) phenomenon, and modeling of the coupled ocean-atmosphere system. Until recently, seasonal-to-interannual variations in climate were not considered predictable in any useful fashion. However, beginning in the late 1970s, diagnostic studies of the ocean and atmosphere began to make it clear that certain behaviors of the coupled system might indeed be predictable, including the ENSO phenomenon. In 1985, the international Tropical Oceans/Global Atmosphere (TOGA) program was initiated. Its main focus was the development of physical/mathematical models of the ocean and atmosphere in the tropical Pacific Ocean, and the establishment of observing systems to provide the data such models required. As TOGA progressed, the Tropical Atmosphere Ocean (TAO) Array was designed and implemented, and models began to show evidence of capability for useful predictions. Observations from meteorological and oceanographic satellites became available to complete the global observing system.

The concept of an IRI emerged around 1989 from a general consensus in the international climate research community involved in TOGA. It was persuasively argued that experimental forecast information could only be valuable if an international institutional mechanism was in place to continually advance research and modeling related to the forecast capabilities, to disseminate forecasts on a routine basis, and to provide a centralized location for feedback on model forecast results. In 1991, these research results inspired an international group of scientists, led by Dr. A. D. Moura of Brazil, to prepare a plan for an International Research Institute for Climate Prediction. This plan was presented at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, and the Inter-governmental TOGA Board pursued further actions towards implementation.

The enormous impacts of ENSO in the less-developed tropical countries of the globe, and the emerging consciousness of the need for scientists to not only develop the science of climate prediction, but also to make that knowledge readily and properly available to decision-makers in those countries, naturally led to the proposal to implement an IRI. The proposal that was put forward in 1992 contains the backbone of the current IRI strategic vision as well as its fundamental mission: to provide the best possible climate forecasts, while at the same time seeking the best applications of that forecast information for the benefit of societies, particularly those in the developing countries of the tropics.

A Pilot Project to demonstrate feasibility was initiated by NOAA's Office of Global Programs in 1993, with training and application activities located at the Lamont-Doherty Earth Observatory (LDEO) of Columbia University and forecasting research located at the Scripps Institution of Oceanography (SIO) of University of California, San Diego. Over one hundred scientists from 46 countries were trained, and development and regular production of global and regional experimental forecasts, was developed during that time. The successful results of these activities, together with the conclusions of the International Forum on Forecasting El Niño: Launching an International Research Institute (6-8 November 1995; Washington, DC), provided the impetus for the launching of the IRI in 1996. An open competition resulted
in selection of a proposal submitted jointly by LDEO and SIO. The IRI was established, through a cooperative agreement, in late 1996.

During the initial implementation phase, from 1996-1999, the collaborative LDEO-SIO effort built effectively on the pilot phase. The Experimental Forecast Division, located at SIO, developed and implemented a forecast system that enabled IRI to produce regular Net Assessments of expected climate variations beginning in mid-1997, with global extreme event prediction defined and developed in mid-1998. The LDEO component developed more slowly due to the need for extensive recruiting, but was able to initiate preliminary activities in applications and climate monitoring and dissemination. Planning in support of the next prediction system, and programs for training, and regular publication of the IRI Climate Information Digest was well underway by mid-1998, with contributions in all areas gaining significant momentum by mid-1999. At present, all efforts are being integrated into two primary components (Application System and Prediction System) of a single IRI Core Facility to be located on the LDEO campus. The future looks promising, with the new Columbia-financed IRI building on track for occupancy late in 1999, at approximately the same time that operational status will be achieved across the entire organization.

The early years of the IRI have been extremely challenging, not only because of the need to grow and integrate the institution, but also because of the occurrence of the strongest El Niño of the historical record in 1997/98, followed immediately in 1998/99 by a moderate La Niña. This combination of circumstances required the IRI to attempt actions for which it alone was not fully prepared. However, with the collaboration of partner institutions in the US (NOAA Climate Prediction Center and Office of Global Programs), and elsewhere (national meteorological and hydrological services and the World Meteorological Organization, among others), the IRI succeeded in making a substantial, even critical, contribution to the global effort to foretell and mitigate the effects of seasonal to interannual climate variability.

Scientific context

The fundamental basis for climate prediction on seasonal-to-interannual time scales emerged from the concept that, on these scales, the tropical oceans and atmosphere are coupled. The slowly varying sea surface temperatures provide boundary conditions for the overlying tropical atmosphere and feedback for global climate variations. The evolution of the atmospheric circulation provides, in a coupled sense, the mechanical and thermal forcing for the three-dimensional oceanic circulation. This was the paradigm behind the outstanding success of the TOGA program. Among the achievements of TOGA was the first successful model in which the tropical Pacific Ocean was coupled to an overlying atmosphere. This model, developed by Cane and Zebiak in 1985, was responsible for a successful forecast of the 1986-87 El Niño. That forecast, when verified, provided an important stimulus for the international meteorological and oceanographic communities to support further research into modeling, process studies (the TOGA Coupled Ocean-Atmosphere Response Experiment) of the coupled system, and greater investments in observational technology such as the TAO array.

With its mission, the IRI assumes a fundamental role in the advancement of an end-to-end climate prediction system in support of climate applications. This system spans the full range of global oceanic (surface and sub-surface) and atmospheric observations, needed process studies, model developments, the
actual production of forecasts, and the application of those forecasts to benefit societies, including the appropriate feed-backs from the user communities. The IRI is a central focus in some areas, such as forecasting and the development of applications, an important contributor in others, such as the modeling activities of the international CLIVAR program and other related science and climate application programs, and an enthusiastic proponent in still others, such as the observing system.

The IRI is a strong supporter of oceanic and atmospheric observational programs and services such as TAO, GCOS, GOOS, and PIRATA, and new technological developments such as the Argo observing system for real-time ocean observations, as these provide critical information for improved climate predictions. As is well known, oceanic data and data assimilation techniques pose significant limitations on existing climate prediction systems. The evidence suggests that these are at least as important as model errors in limiting current forecast skill. Of particular concern is the vast area of the world ocean for which almost no observations are available. Satellite data are valuable, but must be used in conjunction with in situ three-dimensional thermal and salinity oceanic data. It is also important to recognize that predictability associated with ENSO is well established for many regions, including North America, western South America, and Indonesia. Nevertheless, recent studies have consistently pointed to the role of climate variability in the tropical Atlantic and Indian Oceans - not associated with ENSO - in determining seasonal and longer term climate variations for regions of South America, Africa, and Australasia.
Appendix B - IRI Personnel

Below are brief biographical statements on senior personnel at the IRI. In addition to the personnel listed below are five Columbia University Faculty (Rayner, Lall, Sobel, TBD, TBD) hired in support of IRI activities, eight post-doctoral scientists (Ammisah-Arthur, Agriwala, Barlow, Cullen, Hopp, Landman, Uvo, Zubair) with backgrounds in agriculture, human health, policy, large-scale climate variability, hydrologic linkages, regional downscaling, rainfall and stream flow, and landform influences. Four additional staff (Barone, Hoch, Li, Rosen,) provide support to the needs of the IRI over a range of network and computational requirements.

Not included in this list are positions that remain open as of January 2000, but that are anticipated to be filled close to the start of the proposed funding period. These include the Secretariat (June, 2000), the Head of Forecast Operations (March, 2000), the Head of Forecast Integration (April, 2000), Web and Media specialists (February, 2000), and a few associate and/or post-doctoral researchers and technical staff (March - June, 2000).

Senior Management

Antonio Divino Moura - Director, IRI

As Director, Dr. Moura is responsible for the development and expansion of the complex and growing research and application environment of the IRI, as well as the management of its institutional relationships with its sponsors and partners around the world. Dr. Moura arrived at the IRI in December 1996 following a distinguished career in science and administration in Brazil and Italy, with extensive experience in the management of international climate research programs.

Phillip A. Arkin - Deputy Director

Dr. Arkin is Deputy Director of the IRI, and assists the Director in all aspects of the development and implementation of IRI programs. He represents the Director as needed at international fora, and carries out specific projects that involve the entire IRI. Prior to coming to the IRI in February 1998, Dr. Arkin worked in NOAA as a research scientist and administrator in various climate-related efforts for more than 20 years.

Reid Basher - Director, Applications

Dr Basher is Director of the IRI’s applications research programs, and is responsible for the development of the IRI’s strategies for the applications of climate predictions and the development of the necessary extensive collaboration and coordination with other researchers, applications specialists and users worldwide. Before joining the IRI in July 1999, he was responsible for a broad range of climate research and applications work in New Zealand’s National Institute of Water and Atmospheric Research (NIWA), including the leadership of public and commercial climate services and the direction of the national cooperative climate network and national climate database.

Chet Ropelewski - Director, Climate Monitoring and Dissemination

Mr. Ropelewski leads the IRI effort to develop methods and data sets to improve monitoring of the climate system, to disseminate climate information for the IRI, and to implement the IRI Climate Information System (IRICIS). Before arriving at the IRI in January 1998, Mr. Ropelewski worked at NOAA in a variety of research and management positions. He is well known for having discovered the spatial distribution of precipitation and temperature anomalies associated with the El Niño/Southern Oscillation.
Yves Tourre - Director, Training Program
Dr. Tourre works closely with the rest of the IRI in designing and executing all IRI training courses and activities and in the identification of potential IRI partner institutions for experimental applications activities. Prior to arriving at the IRI in November 1997, Dr. Tourre was a Professor at the Southwest Connecticut State University, and has worked on research topics related to climate variability associated with the Atlantic Ocean.

Steve Zebiak - Director, Modeling Research
Dr. Zebiak coordinates IRI coupled model development, data assimilation/forecast system development, predictability, and climate dynamics research for seasonal-to-interannual time scales. He also helps to foster active collaboration between IRI and other national and international centers engaged in climate modeling and prediction. Prior to joining the IRI in May 1998, Dr. Zebiak spent nearly 15 years at the Lamont-Doherty Earth Observatory engaged in research on a variety of topics in the understanding of climate variability. While there, he participated in the development of the first model to successfully predict an El Niño event.

Carolyn Mutter - Science Program Coordinator
Dr. Mutter provides science program management for the IRI, coordinating program components and assisting in the preparation, development and implementation of planning documents, reports, proposals, and budgets for fiscal and operational program management. She also provides project management for specific Institute-wide efforts, most recently for the construction, furnishing and occupation of the new Monell Building that now houses the IRI, and for contract negotiations with the WMO. Prior to coming to the IRI in August 1997, she spent 6 years as a research scientist at the Lamont-Doherty Earth Observatory specializing in marine geophysics.

IRI Research Staff

Benno Blumenthal - Senior Staff Associate and Data Library Manager
Dr. Blumenthal facilitates data exchange and multidisciplinary access to data worldwide through the creation and development of a large and growing library and website for the study of short-term climate variability. Dr. Blumenthal has been at the IRI since August 1997, following 10 years of research at LDEO after receiving his Ph.D. at MIT.

Kenneth Broad - Associate Research Scientist
Dr. Broad identifies potential uses of climate forecast products in the management strategies of different sectors in S. America (e.g., fisheries, agriculture, energy, health), and coordinates multinational, multidisciplinary teams of social, physical and natural scientists. He has worked at the IRI since 1997, and completed his Ph.D. in Anthropology at Columbia University in early 1999.

Dave DeWitt - Associate Research Scientist
Dr. DeWitt specializes in the construction and use of coupled atmosphere ocean general circulation models (GCMs) with emphasis on seasonal to interannual predictability research. Prior to arriving at the IRI in July 1999, Dr. DeWitt spent 5 years engaged in similar research at the Center for Ocean-Land-Atmosphere Studies.

Lisa Goddard - Associate Research Scientist
Dr. Goddard is part of a team that studies climate dynamics and potential predictability, assesses climate prediction tools, advances strategies for research, development and implementation of climate forecasts, and
produces quarterly Net Assessment forecasts for the IRI). She has worked with the IRI since receiving her Ph.D. in Atmospheric and Oceanic Sciences from Princeton University in 1995.

**Xiaofeng Gong - Senior Programmer/Analyst**

Dr. Gong performs global and regional climate simulations and plays a central role in the execution of model predictions for use in the IRI forecast system. Prior to arriving at the IRI in January 1999, he obtained his Ph.D. in Meteorology at the University of Oklahoma in 1998.

**James Hansen - Associate Research Scientist**

Dr. Hansen investigates climate prediction applications to agriculture, including simulation and analysis of agricultural production systems, farm-level economic risk and sustainability analysis, stochastic weather generation, agricultural weather data management, tropical agronomy and soil fertility. Prior to arriving at the IRI in August 1999, he conducted similar research at the University of Florida for 8 years.

**Bradfield Lyon - Associate Research Scientist**

Dr. Lyon works on understanding the short-term climatic variability of the atmospheric circulation as it relates to the mission of the IRI. He received his Ph.D. from the Massachusetts Institute of Technology in 1991, and worked in several research and applications positions prior to joining the IRI in June 1999.

**Simon Mason - Associate Research Scientist**

Dr. Mason engages in a variety of research topics related to the IRI’s forecasting effort, and oversees the production of the GCM predictions and assists in the production of the Net Assessment forecasts. He arrived at the IRI in late 1997, following several years of research experience in South Africa.

**Jennifer Phillips - Associate Research Scientist**

Dr. Phillips works to advance applications of climate information in agronomic settings. Prior to joining the IRI in January of 2000, she obtained her Ph.D. in Environmental Biophysics and plant/water relations in the Department of Soil, Crop and Atmospheric Sciences at Cornell University in 1994. Dr. Phillips is a former Fulbright scholar and NATO research fellow, and spent several years conducting research on the interaction of climate variability and agriculture at the Goddard Institute for Space Studies.

**Balaji Rajagopalan - Associate Research Scientist**

Dr. Rajagopalan engages in research related to the prediction of climate variability and the use of predicted information to hydrologic applications. Prior to arriving at the IRI in July 1999, Dr. Rajagopalan conducted similar research for 4 years at the Lamont-Doherty Earth Observatory of Columbia University.

**Anji Seth - Associate Research Scientist**

Dr. Seth is involved research on the role of regional processes in climate and climate variability, particularly on seasonal time scales. She is also part of a team developing the IRI Climate Information System (Digest, Maprooms, and Applications Resources). Prior to arriving at the IRI in June 1999, Dr. Seth conducted similar research for 4 years at NCAR.

**Liqiang Sun - Associate Research Scientist**

Dr. Sun performs research on forecast methodology and the application of nested regional models to higher resolution forecasts. Prior to joining the IRI in October 1997, Dr. Sun received her Ph.D. from North Carolina State University.

**Michael Tippett - Associate Research Scientist**

Dr. Tippett works in the area of ocean data assimilation, to addresses the question of how best to introduce
observational data into numerical models, a vital element in producing better forecasts of coupled ocean-atmosphere variability. Prior to joining the IRI in June of 1999, Dr. Tippett obtained his Ph.D. in Mathematics from New York University and spent several years working at the Max Planck Institute for Plasma Physics in Germany, and the Center for Weather Prediction and Climate Studies in Brazil.

**Rong-Hua Zhang - Associate Research Scientist**

Dr. Zhang engages in modeling of large-scale ocean circulation and air-sea interaction associated with interannual and decadal climate variability, and has performed extensive and intensive studies in modeling and data analyses. Prior to arriving at the IRI in July 1999, Dr. Zhang conducted similar research for 4 years at the University of Rhode Island.