IRI INTERNATIONAL RESEARCH INSTITUTE
FOR CLIMATE PREDICTION
PALISADES, NEW YORK, USA

Applications of Climate Forecasting to Agriculture

A REPORT FROM A REGIONAL TRAINING COURSE
Department of Primary Industries (DPI) Conference Center,
Toowoomba, Queensland, Australia

February 1-19th, 1999

Yves Tourre
Editor

IRI-CR-99/1

Collaborating and Co-Sponsoring Institutions:

Preface

The IRI regional training course on *Applications of Climate Forecasting to Agriculture*, was held at the Department of Primary Industries (DPI) Conference Center, in Toowoomba, Australia between 1 February and 19 February 1999. The course was organized by the International Research Institute for Climate Prediction (IRI) in collaboration with the Queensland Center for Climate Applications (QCCA), NOAA/OGP, the Australian Bureau of Meteorology (BoM) and co-sponsored by the World Meteorological Organization (WMO).

The objectives of the IRI training course were:

- to expose professionals of the climate and agriculture sectors from Australasia to state-of-the–art climate and agriculture science, climate and agriculture monitoring and seasonal-to-interannual climate predictions;

- to explore the linkages and physical mechanisms which involve climate variability, crop yields and livestock management;

- to evaluate the applications of seasonal climate prediction to preparedness and decision-making processes in the agricultural sector;

- to provide a cross-fertilization, exchange of ideas, expertise and analytical tools between climate and agricultural researchers from other countries and continents.

I would like to thank the members of the Australian organizing committee for their continued assistance. Special thanks to Graeme Hammer, Holger Meinke, Ms. Mackey Vogler, Greg McLean and the QCCA team for their logistic support and close collaboration. Thanks also to Ann Binder for keeping all the financial details on track, and to Antonio Moura for his guidance in overall planning.

Yves M. Tourre
Director, IRI Training program

Executive Summary

This report concerns the IRI regional training course on *Applications of Climate Forecasting to Agriculture* that was conducted at the Department of Primary Industries Conference Center, in Toowoomba, Queensland Australia, 1-19 February, 1999. (please see also http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/report) The course was organized by the International Research Institute for Climate Prediction (IRI) and the Queensland Center for Climate Applications (QCCA) in collaboration with OGP/NOAA and the Australian Bureau of Meteorology (BoM), and co-sponsored by the World Meteorological Organization (WMO).

The objective of the training course was to expose a multidisciplinary group of 21 professionals of the Australasia, East Africa and South America climate and agriculture sectors to state-of-the–art climate and agriculture science. Linkages between climate variability and crop yields were explored. Applications of climate prediction to preparedness and decision-making processes in the agricultural sector were evaluated. The latest results, including the recent development of climate forecast and products at the IRI, were presented by 34 experts from both fields.

The training course was theoretical and practical. Five regional teams, assisted by IRI, APSRU, QCCA, DPI, CSIRO, BoM lecturers staff and collaborators, conducted preliminary work which lead to joint research and some applications. A network of 22 laptops (from QCCA) was made available for the exclusive use by the trainees. The internet link and real-time access to the IRI Data Library, products and on-line tools from the IRI Homepage were performed in plenary, using a fast PC and a LCD projector provided by QCCA. Trainees were introduced to CLIMLAB 2000, a follow up of the application software developed initially for the Pilot training activities at IRI. Trainees brought weather, climate and agricultural (including pasture and grazing) data from their respective country/region for joint analyses with climate data (including SST) using CLIMLAB 2000 and IRI on-line tools. At the end of the training course each team gave a PowerPoint presentation of their respective Climate and Agriculture projects (please see http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/slideshow.html).

Summarized team reports, including preliminary results and ongoing efforts, are compiled in this report. Participants are exploring ways and means to parlay the knowledge and techniques learned in Toowoomba in a multidisciplinary environment. The preparedness and decision-making aspects in the agricultural sector using seasonal climate forecasts (scf hereafter) and climate monitoring products are to be developed locally. The mitigation of sectorial impacts linked to climate events should be demonstrated and developed in the near future. Finally, it is expected that the newly established network of Australasian, African and South American professionals from the climate and agricultural sectors will contribute to capacity building (e.g., Alaerts, 1991) by enabling environmental institutions with appropriate policy and legal frameworks; including local institutions and encouraging local community as part of larger, global participation; developing human resources and strengthening managerial systems.

Table of Contents

1. Course Trainees

Seven women and fourteen men from 6 Australasian, 1 African and 1South American countries participated in the training course. Trainees are listed by country with their respective institution and organization (names of the 15 trainees from the agricultural sector are highlighted in blue in the electronic version of this document):

Australia:
Craig White: Dryland Research Institute, West Australia
Jim Egan: SARDI
Bruce Haigh: Tamworth Center for Crop Improvement, North South Wales
De Li Liu: Wagga Wagga Agriculture Institute, North South Wales

Brazil:
Antonio Geraldo Ferreira: FUNCEME
Francisco Bergson Parente: FUNCEME
Nadir Dantas de Fales: Instituto Nacional de Meteorologia (INMET)

Fiji:
Janita Pahalad: National Meteorological Service

India:
R. Selvaraju: Tamil Nadu Agriculture University (TAMU)
V. Geethalakshmi: TAMU
N. R. Deshpande: Indian Institute of Tropical Meteorology (IITM)

Indonesia:
Widiastuty: CSAR
I. Amien: CSAR
Hatsachai Boonjung: Suranaree University of Technology (SUT)

Papua-New Guinea:
K. P. C. Rao**:** NARI
Anton Varvaliu: NARI

Philippines:
Grace Centeno: International Rice Research Institute (IRRI)
Nathaniel Cruz: Atmospheric and Geophysics Agency

Zimbabwe
Wish Marume: National Meteorological Service
Sikhalazo Dube: Matopos Research Station
Leonard Unganai: Drought Monitoring Center (DMC)

2. Rationale

The overall mission of the IRI Training Program is to train multi-disciplinary teams and individuals in applying and efficiently using climate and meteorological data and forecasts for development and societal benefits.

The specific objective of this training course was to foster the linkages and dialogue between two disciplines (i.e., climate forecasting, agricultural modeling and applications) for societal benefits. At the end of this training course, each team-project (trainees) were able to:

- Identify the data elements needed to address their particular climate and agriculture issues from national or global data sets or analytical models;
- Utilize their own regional climate data for agricultural applications;
- Demonstrate the value-added from applying climate forecasts and monitoring products to decision-making needs in the agricultural sector.

The conceptual basis for this training course was to use a *systems approach* to the agricultural-climate complex. Decision-making was the basis for discussion and targeted training by introducing effective applications. Five regional (or country) team projects were identified prior to the training course. The focus was on the methodologies used for predicting agricultural and climate systems in a particular area (and climate), prior to focusing on technologies and latest techniques from both sectors.

3. Lecturers and Participating Institutions

Thirty four lecturers and 21 trainees from a total of 10 countries were present in Toowoomba. The list of lecturers with their specialties and own institutions follows:

Climate

Chet Ropelewski, Yves Tourre (IRI); Warren White (ECPC/SIO); Raul Tanco (U. La Plata/Argentina); Neville Nicholls, Richard Kleeman, Scott Power (BoM/Australia);
Jack Katzfey (CSIRO/Australia); U. S. De (India)

Agriculture

Graeme Hammer, Roger Stone, Robert Young, Andries Potgieter, Alan Peacock, David Cobon, Rod Saal, Allyson Williams, Dave George, Zvi Hochman (APSRU/QCCA); Holger Meinke, P. Carberry (APSRU); Ken Rickert (U. Queensland); Dave Freebairn, Alan Beswick (DNR); Rohan Nelson, Dave Butler, Ian Partridge, Jeff Clewett, Nick Clarkson (DPI); Ken Brook, Ken Day, Creg McKeon, Wayne Hall (CIGS); Yahya Abawi (QCCA)

The following institutions and organizations have contributed to the course in
Toowoomba:

IRI: International Research Institute for Climate Prediction
NOAA/OGP: National Oceanic and Atmospheric Administration/ Office of Global Program
DPI: Department of Primary Industries
QCCA: Queensland Center for Climate Applications
BoM: Australian Bureau of Meteorology
SIO: Scripps Institution of Oceanography
APSRU: Agricultural Production Systems Research Unit
CSIRO: Commonwealth Scientific and Industrial Research Organization
CIGS: Center for Integrated Grazing Systems
UQ: University of Queensland; University of La Plata, Argentina; Indian Tropical Meteorological Institute (Pune)
WMO/CLIPS: World Meteorological Organization, Climate Information and Prediction Services

4. Data

Aspects associated with availability of climate and agricultural data, locally useful climate and agricultural models were considered. Trainees brought data (climate and agricultural time-series) which were analyzed to support the systems analysis approach. Time series were presented in a matrix format (rows represent time in years or months; columns represent spatial stations and analyzed using the IRI software package CLIMLAB 2000 (see Annex B). The analyzed data and the decision-matrix models using ensemble as well as probabilistic forecasts were also used in order to support the agricultural extensions and enhance preparedness associated with climate-driven variability.

The practical applications required in-depth discussion and consultation with QCCA staff on location. Preliminary results and reports (power point presentations) were delivered by each group during the last day of the training course. The potential for establishing long-term projects with the IRI and QCCA, DPI and other Institutions were discussed.

5. Working Teams and Results

Five regional application teams dealt with different climate regimes. Each team was supervised by an agricultural expert from Australia:

- The Tropical Rice Team (**TRT**) supervised by Yahya Abawi;

- The Monsoonal Cropping Team (**MCT**) supervised by David George and Graeme Hammer;
- The Grazing and Pasture Team (**GPT**) supervised by Ken Day;
- The Semi-Arid Cropping Team (**SACT**) supervised by Rod Saal;
- The Dry-land Temperate Cropping Team **(DTCT**) supervised by Holger Meinke.

The topics chosen by the five regional teams were:

Team #1: Tropical Rice Team (**TRT**)
Seasonal Climate Forecasting and Rice Management Decisions in Tropical Asia
Widiastuty: BMG/Indonesia; I. Amien: Bogor/Indonesia; H. Boonjung: Bogor/Biotrop-GCTE/Indonesia; G. Centeno: IRRI/Philippines; N. Cruz: Weather Service/Philippines.

Team #2: Monsoonal Cropping Team (**MCT**)
Managing Climate Risk in a Rainfed Production System in South India
K. P. C. Rao**:** NARI/PNG; R. Selvaraju: Tamil Nadu/India; V. Geethalakshmi: Tamil Nadu/India; J. Pahalad.:Weather Service/Fiji; N. Deshpande: Pune/India.

Team #3: Grazing and Pasture Team (**GPT**)
Livestock production in semi-arid grazing systems
W. Marume: Agro-Met/Zimbabwe; A. Varvaliu: NARI/PNG; S. Dube: Matopos/Zimbabwe; L. Unganai: DMC/Zimbabwe**.**

Team #4: Semi-Arid Cropping Team (**SACT**)
The Use of Seasonal Climate Forecasting in the Ceara State
A. G. Ferreira: FUNCEME/Brazil; F. B. Parente: FUNCEME/Brazil; Nadir Dantas de Fales: INMET/Brazil

Team #5: Dry-land Temperate Cropping Team (**DTCT**)
Seasonal Climate Forecasting: Can it improve management in Australian Dryland Winter Cropping Systems?
Craig White: Extension Agronomist in W Australia; Jim Egan: Department Primary Industries; Bruce Haigh: Agriculture in NSW; De Li Liu: Managing Farming Systems in NSW

Each team project results are presented hereafter. PowerPoint slides can be viewed at http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/slideshow.html

All participants can exchange ideas using the following IRI alias E-mailbox created for this training course: Agriri@iri.ldeo.columbia.edu

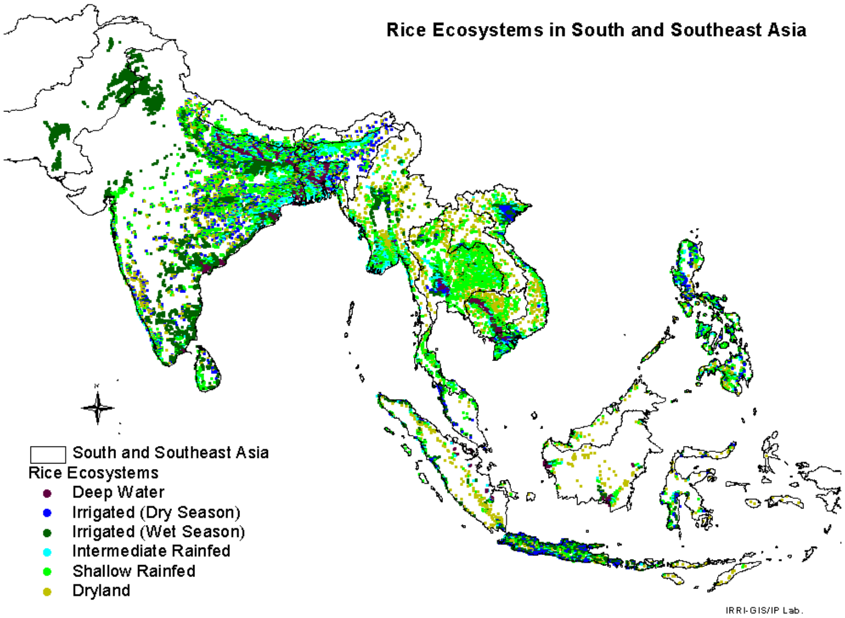
Team #1: **TRT**

Seasonal Climate Forecasting and Rice Management Decisions in Tropical Asia

Widiastuty; I. Amien; H. Boonjung; G. Centeno; N. Cruz

Background and rationale

Rice is the major staple food in the tropics. Ninety percent of rice production in the world is produced, and is also consumed in Asia. Currently, about 3 billion people eat rice. By the year 2025, the number of rice-eaters is expected to reach 4.6 billion. The need for an increase in rice production is evident. In the tropics, rice can be grown anytime of the year nevertheless the main cropping season is during the wet season. Many poor farmers practice rainfed rice farming. Farmers sow rice as they have accumulated certain amount of rain in the fields (e.g., 200 mm for irrigated rice). Most varieties are harvested in 3 to 4 months. The regional distribution of rice ecosystems is shown in the following map (for a color version of this figure, please see http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/report/rice.ecosystem):



Weather and climate variability greatly affect rice production. Under unlimited water and nutrient supply, radiation and temperature become important factors for rice potential production. Radiation supplies the energy for crop photosynthesis while temperature determines the duration of crop growth.

Extreme regional climate conditions are associated with phenomena such as El Niño or La Niña. As a consequence, the growth and development of rice is deeply affected. In the Asia-Pacific region, El Niño is usually associated with drought while La Niña is associated with floods. The southern oscillation index (SOI), which measures the atmospheric pressure difference between Tahiti and Darwin, has been used as a simple indicator of climate variability. El Niño is strongly linked with negative values of SOI while La Niña events are linked with positive SOI values. Colleagues from Queensland Center for Climate Applications (QCCA, http://www.dpi.qld.gov.au/qcca/Welcome.html) provided us with monthly values of five SOI phases (see Annex C for the definition of SOI phases). The SOI changes from April to May give the highest correlation ($r^2 = 0.6$) with rice yields. Yield data from SOI phases which are associated with drought years (SOI phase 1,3, and 5) are pooled together and compared with yield data from SOI phases associated with wet years (SOI phases 2 and 4).

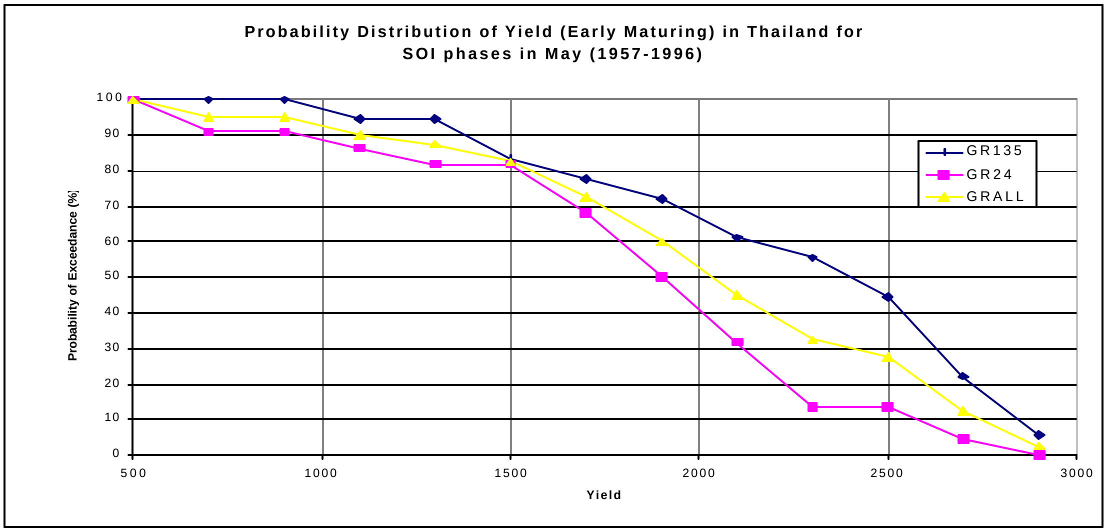


Fig. 1: Rice yields (tons) during different SOI phases associated with dry years (GR1,3 and 5), wet years (GR2 and 4) and averaged for all phases (GRALL).

As seasonal climate forecasts become more accurate and available, farmers can then take advantage in order to increase production. For example, in Indonesia and the Philippines, farmers can grow two rice crops in sequence, provided there is enough water in the soil. The wet season in the Philippines from June to October. Rainfall is most variable during the months of June (rainfall onset) and October (rainfall termination). However, it is possible to grow a second rice crop when the wet season lasts for more than 6 months. Because Thailand rice ecosystems are generally not irrigated (particularly in the northeast), farmers can only grow one crop a year. Thus, there is only one wet cropping season in Thailand (June-October) as compared to Indonesia and Philippines where two wet and dry cropping seasons prevail (September-March and April-August;

June-October and January-April, respectively). Finally, an average farm size is much smaller in the Philippines (0.5 ha) than in Indonesia and Thailand (4.0-5.0 ha).

The Weather Services of Indonesia, the Philippines and Thailand are already producing climate forecasts. Yet, these are not tailored to the needs of the agriculturists, or are too technically oriented for an Asian farmer to use efficiently. Advance knowledge of probable climate conditions will help farmers to make better decisions. This team study aims to further show the linkages between climate factors (including regional SST anomalies) and agricultural production in the region.

Preliminary results

Using the IRI CLIMLAB 2000 (Annex B) software, Figure 2 shows the correlation between rice production from September to March (1961-1993) in Indonesia and SST anomalies in the Indonesia-Borneo area (warm pool) during the same period. It is clear that large SST anomalies associated with ENSO have a profound effect on rice production. It is then extremely important to monitor regional SST anomalies and use the phases of the SOI as a predictors.

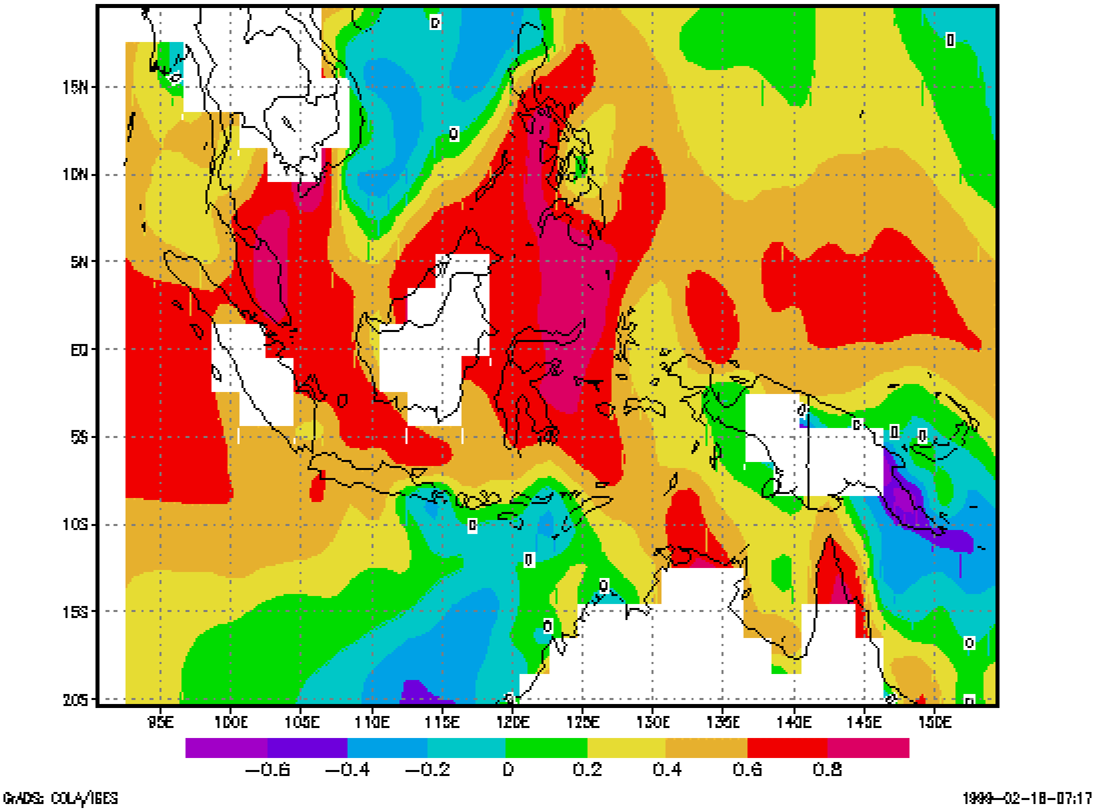


Fig. 2: Contemporaneous correlation (September to March) between SST anomalies and total rice production in Indonesia. Positive (negative) correlation in red (blue). Please see http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/report/sst.rice.correl for a color version of this figure.

Ongoing Efforts

General objective:

The general objective of this team study is toward:

- Maximizing production in each rice ecosystem for food security;
- Delivering of a more useful seasonal climate forecast to farmers;
- Minimizing risks associated with highly variable climate phenomena such as ENSO among others.

Data and Methods

1. Data collection

Twenty-five years (1961-94) of reported rice yields have been collected from the agricultural statistics bureaus of Indonesia, the Philippines and Thailand and compiled by the Social Science Division at the International Rice Research Institute (IRRI, http://www.cgiar.org/IRRI). 85% of rice area in northeast Thailand is still under rainfed condition, as compared to 72% and 60% irrigated farms in Indonesia and the Philippines, respectively. In spite of low yields from rainfed system (see next table) Thailand can still manage to produce and export rice.

Location Percentage of area	**Indonesia** (Java)	**Philippines** (Central Luzon)	**Thailand** (Northeast)
Irrigated	72	60	0
Rainfed	7	35	85

Table 1: Coverage (%) of water resources in three different locations.

Rice yields in the Philippines are consistently lower during the wet years than during the normal years. Increased rainfall during the wet years brings excessive cloudiness, and lower radiation that contribute to yield depression. Since reported yields from Indonesia and Thailand are not showing significant differences among years, it seems appropriate to use other indicator for climate variability. For example, rather than analyzing total rainfall for the whole crop season, analyzing monthly rainfall totals suggests that it is important for the crop to receive its required water at the right time.

Summary of climate datsets

Indonesia: 37 years (1960-1997);
Philippines: 30 years (1979-1998);
Thailand: 30 years (1967-1996).

Indonesia, Philippines and Thailand: 25 years (1961-1994) of reported rice production.

2. Data analysis

Rice models: Simulated yield in Thailand

For Northeastern Thailand, 40 years of daily weather data from Chiaphum (15.8^{o}N, 102.0^{o}E) will be used as inputs to a rice crop model. A Thai rice simulation model has been used as a tool to test possible farm practices. This rice model uses evaporation, soil and crop parameters as additional input. For example, a rainfed rice farmer adjusts his date of sowing based on the onset date of rainfall and waits until a sufficient amount of rainwater is collected to puddle the land. With simulation model yield can be estimated for a normal planting and compare it with an estimated yield if planting is delayed A farmer may also choose between using a short- or long-duration rice variety. When less rainfall is expected, the farmer can harvest 30% more if he opts to plant an early-maturing variety instead of sowing a late-maturing variety. If a wet year is expected, it would be more advantageous to sow a late-maturing variety (see next table).

SOI Phases	Late-Maturing	Early-maturing
Phases 2 and 4 (wet years)	2.2	1.9
Phases 1, 3 and 5 (dry years)	1.8	2.4

Table 2: Median yields (Ton/ha) in Thailand as a function of SOI phases with two kind of rice species (early maturing and late maturing)

For Indonesia, the DSSAT rice model uses rainfall, temperature and radiation as climate input. For the Philippines the ORYZA rice model uses also rainfall, temperature and radiation as climate input. Using SOI phases, each year may be classified as a dry or a wet year. SOI phase can then be used in the models. When the forecast is then used with crop simulation model (DSSAT or ORYZA), a farmer may assess predicted yield changes, then eventually opt for a more profitable farming practice. This somewhat simple approach, needs a lot of polishing. Data inadequacy both in quantity and quality still hamper the application of forecast in southeast Asia (SEA). SOI shows strong signal in the Philippines and parts of Indonesia but no clear signal as yet in Thailand. Seasonal forecast should be tailored for local specific purpose i.e. Monsoon termination in the

Philippines, onset of rainy season in Indonesia and probable rainfall in Thailand. Since majority of rice in SEA are irrigated, study on the effect of climate variability to hydrology and water management will very important. For higher precision in regional application, validated regional crop models (RCM) are required.

Ongoing Collaborations

Close collaborations between IRRI and IRI have been established through Ms. A. Centeno. It is hoped that datasets will be exchanged between the two institutions for further analyses. IRI is also participating in an Indonesian rice-yield study, a project initiated by CERC of Columbia University.

Team #2: **MCT**

Managing Climate Risk in a Rain-fed Production System in South India

K. P. C. Rao; R. Selvaraju; V. Geethalakshmi; J. Pahalad; N. Deshpande

Background and rationale

As a consequence of this training course on agricultural applications, significant opportunity to develop agricultural applications in India has arisen. A sound basis for a project of this type is developed herein. Team members with considerable background in agricultural modeling and systems analysis had an opportunity to connect their expertise with forecast expertise developed at the IRI and at the Department of Primary Industries (DPI) (agricultural modeling and decision analysis; climate forecasting). From these efforts, it appears possible to develop a sound approach to applications for southern India, where a strong forecasting signal is evident.

One of the team members, R. Selvaraju, is also participating in an existing project funded by the Australian Center for International Agricultural Research (ACIAR), which aims to work closely with farmer groups in this part of India to discuss use of seasonal climate forecasts. Dr. S. Huda supervises this part of the ACIAR project at the University of Western Sydney. The ACIAR project involves preliminary activities in a number of countries and is coordinated by Dr. J. Clewett (DPI, Toowoomba). A project focussing on simulation analysis of agricultural decisions and the usefulness of seasonal climate forecasts would underpin the existing focus on delivery to farmers with sound climate and agricultural science framed in a decision analysis context. The use of the Agricultural Production Systems Research Unit (APSRU) agricultural system simulation capacity (APSIM, see Annex C) will be a plus when linked with relevant decision analysis expertise.

Preliminary results

Using Rainman version 2.2 (http://www.dpi.qld.gov.au/rainman/) we computed first the probabilities of monthly rainfall in Coimbatore using our historical data set. This is presented in Figure 1 where we can see the maximum variability do occur during July and Oct.-Nov. In Figure 2 we compared the percent chance of winter monsoon rain with the phase of the preceding summer SOI as defined by Stone in the Australian Rainman software package (see Annex C). We can see that extreme negative values of the SOI do increase both the probabilities as well as the amount. Similar analyses were performed for other periods of the year. This kind of analysis should help for the decision making process on crop selection. Should we sow cotton in August or not? Should we use double skip or single skip criteria?

In Figure 3 we try to analyze the probability of exceeding maximum water holding capacity as a function of SOI phases. We see that the best scenario is again linked with the negative SOI phases.

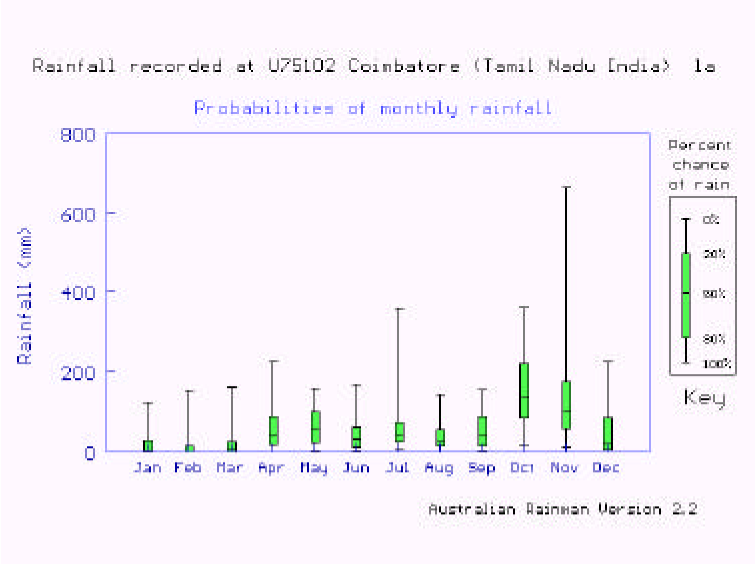


Fig. 1: Probabilities with percentiles of monthly rainfall in Coimbatore

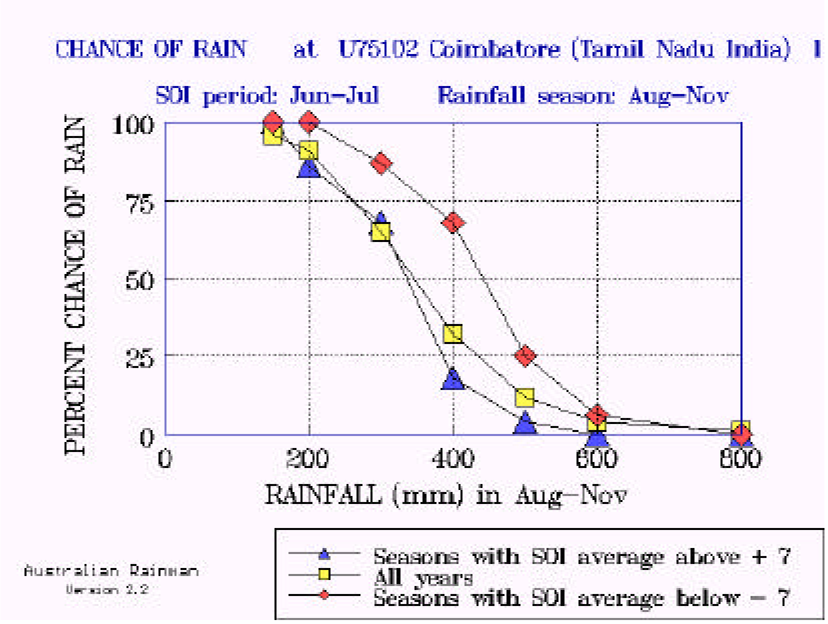


Fig. 2: Percent chance of winter monsoon rain (with total amount in mm) when using summer phases of SOI.

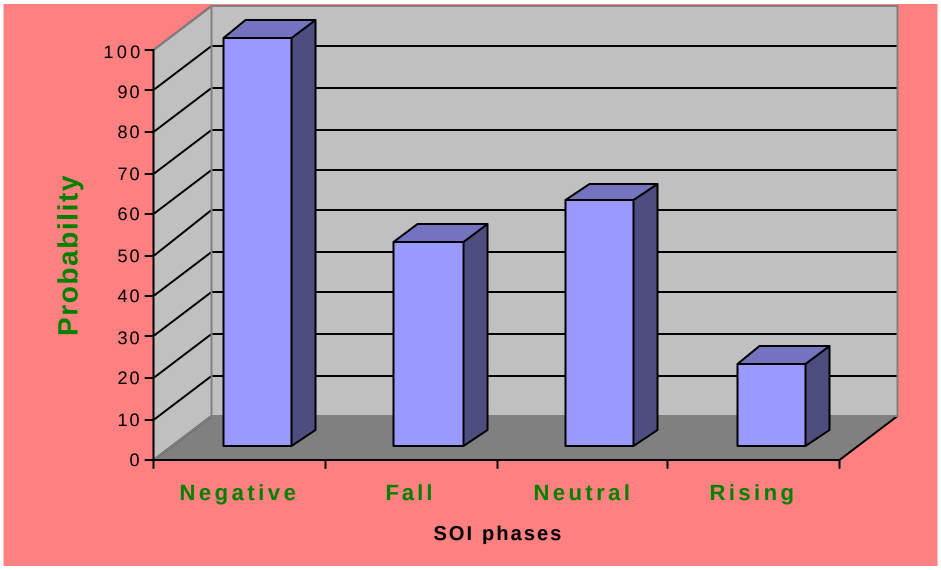


Fig. 3: Probability of exceeding maximum water holding capacity as a function of SOI phases.

Ongoing Efforts

Objectives

The objectives of this project are to analyze in details the value of seasonal climate forecast in cropping system management decisions in Tamil Nadu (TAMU), India; to connect analysis on potential decision responses to a forecast with existing projects that are working with farmer groups in the region; to develop appropriate methods for connecting climate forecasting methods with agricultural systems modeling and decision analysis methods.

Data and Method

1. Data collection

We will use our data sets on cotton, sorghum, cowpea crop yields, water requirement satisfaction index (%), maximum water holding capacity indices (%), stress index, investment returns ($) available at TAMU. We will also use SST anomalies in the Indian Ocean from the IRI Website as well as the SOI phases (see Annex C) to evaluate local climate effects against global ENSO forcing. The use of range of seasonal climate forecasting approaches will be a key input in our model. Use of the SOI phases has already shown significant skill and value in our preliminary analysis.

2. Data analysis

Analysis of Indian Ocean SST's and GCM output could also be tested provided forecasts are prepared in a manner suitable for use in the decision analysis. Below is the seasonal amount of rainfall in the Tamil Nadu region. It is interesting to see that the amount associated with the NE monsoon is almost twice the amount of the summer monsoon.

Season	Period	Rainfall (mm)	% total rainfall
Winter	Jan-Feb	30	5
Summer	Mar-May	120	18
SW monsoon	June-Sep	172	27
NE monsoon	Oct-Dec	321	50

To undertake this project requires collaborative effort on forecast generation and forecast evaluation in agricultural systems. The methodology would be as follows:

-Agricultural system decision analysis and forecast evaluation;
-Identify feasible range of agricultural systems and decisions for forecast evaluation studies (e.g., farm scale at several locations and regional scale – production and policy);
-Outline decision analysis/modeling approach;
-Assist in configuring forecasts for use with decision analysis models and identify connectivity issues;
-Evaluate forecast in target systems using simulation analysis;
-Evaluate value of feasible improvements in forecast capability in the range of target systems;
-Identify feasible improvements in forecast capability likely to give greatest increase in value to agricultural systems;
-Forecast generation for agricultural applications;
-Identify feasible range of forecasting systems for use in evaluation studies (e.g., SOI phases, SST phases, atmospheric model forced with SST's, coupled model);
-Develop methods for translating existing forecast to meet input needs of forecast applications and identify issues;
-Generate forecast products tailored for use in applications evaluation studies;
-Consider possibilities for improving forecasting systems and derive synthetic forecasts with varying degrees of improvement that are tailored for use in applications evaluation studies

Ongoing Collagorations

In the near future, the effort is anticipated to continue with Dr. R. Selvaraju at Tamil Nadu providing the local agricultural modeling expertise. Graeme Hammer and Holger Meinke could provide connection to APSRU to facilitate access and technical support in relation to simulation capacity of APSIM and decision analysis procedures. IRI would need to provide a link person for forecast development and linkages to application needs. This could have significant impact on a number of IRI divisions in relation to forecast development and delivery methods (EFD and CMD divisions at IRI). The project team will need to get together at least annually (probably more frequently initially) and some technical support costs will be needed. The project will be totally a computing/desk study that connects to existing delivery and agricultural research projects. However, it will be necessary to test crop models on local data and develop good databases of climate data, which will require support resources. Access to APSIM (Annex C) and training in its use will also require support resourcing. Visits between India, Australia, and IRI will be required for various aspects of the project.

Team #3: **GPT**

Livestock Production in Semi-Arid Grazing Systems

Ms. W. Marume; A. Varvaliu; S. Dube; L. Unganai

Background and rationale

The grazing system in Zimbabwe is communal in nature, has been steadily increasing since 1940 (Figure 1) and is one of the key elements for family subsistence.

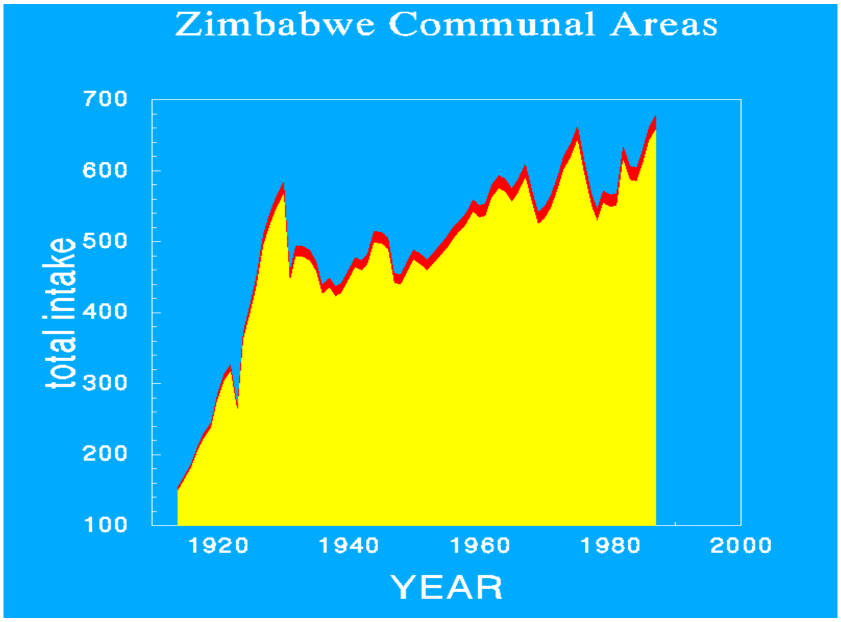


Fig.1: Grazing System in the Zimbabwe communal areas.

While there is extensive livestock production of cattle goat and sheep, the semi-arid rangelands of this part of Africa are characterized by a high year-to-year variability in rainfall and forage production. The key issues to be addressed is grazing management in terms of climate variability, land degradation and consequences from low pasture productivity. There is some evidence of a relationship between the SOI phases and Zimbabwean rainfall (see preliminary results). Moreover Dye and Spear (1982) measured two to eight-fold difference in forage production between dry and wet years at four locations in southern Zimbabwe. This has major implications for livestock production and resource condition. Zimbabwe has also experienced two major drought periods (1981-1985 and 1991-1992) in the last two decades resulting in severe loss of livestock and range land degradation. Better knowledge in the climate relationship, including the use of seasonal climate forecast, will definitely improve on decision making on implementation strategies. In addition, knowledge of historic variability in forage supply can help determine better drought management strategies and test rules for flexible grazing in relation to seasonal climate forecast or scf hereafter (Dye and Walker, 1987).

Forage production models such as VELD (Dye, 1983) and GRASP (Littleboy and McKeon, 1997) can be used to calculate historic pasture production while grazing systems models such as GRASP also allow various grazing strategies to be evaluated in terms of maintaining forage supply, livestock production and range land conditions (Ash et al., 1998).

Somewhat problematic is that fact that few data are available for tropical and sub-tropical grasslands to validate model calculations of annual forage production for periods longer than ten years. Ongoing land degradation and low productivity of the range land's pastures must also be taken into consideration. Finally, the cattle goat and sheep market is subject to fluctuation and is presently extremely low.

Preliminary results

The monthly rainfall distribution in Bulawayo with the percentile chances of rainfall for each month is presented below in figure 2. The amount of yearly rainfall from the start of the rainy season (Sept) is then compared with the SOI phases throughout the previous dry season:

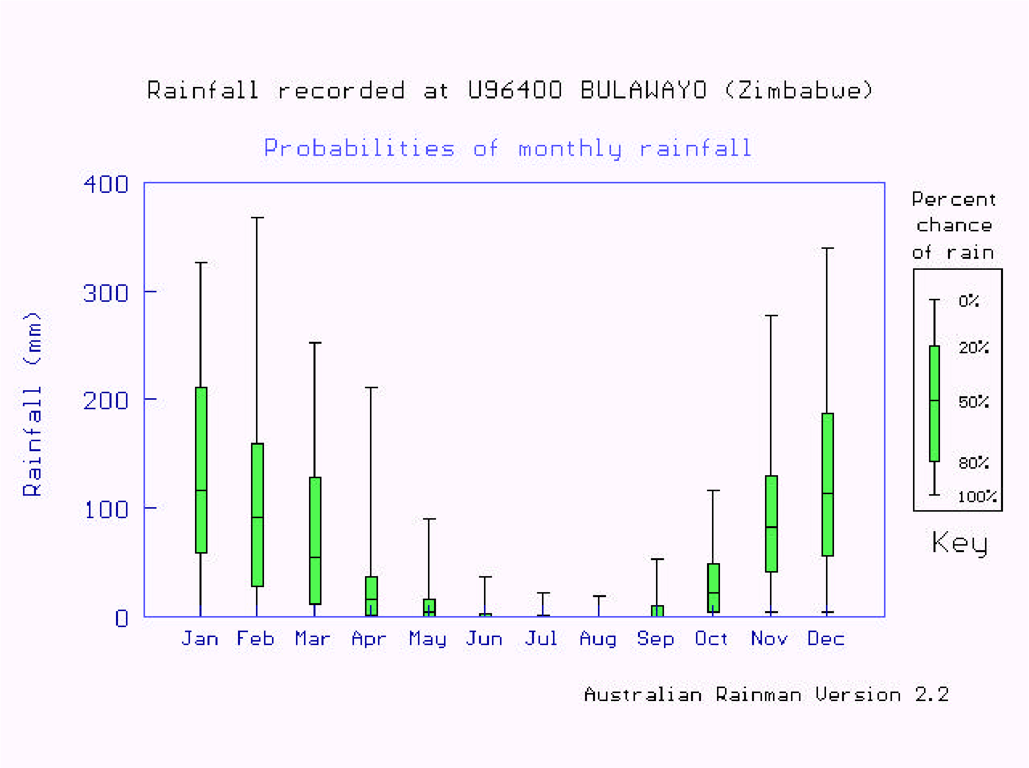


Fig. 2: Probabilities (percentiles) of monthly rainfall in Bulawayo.

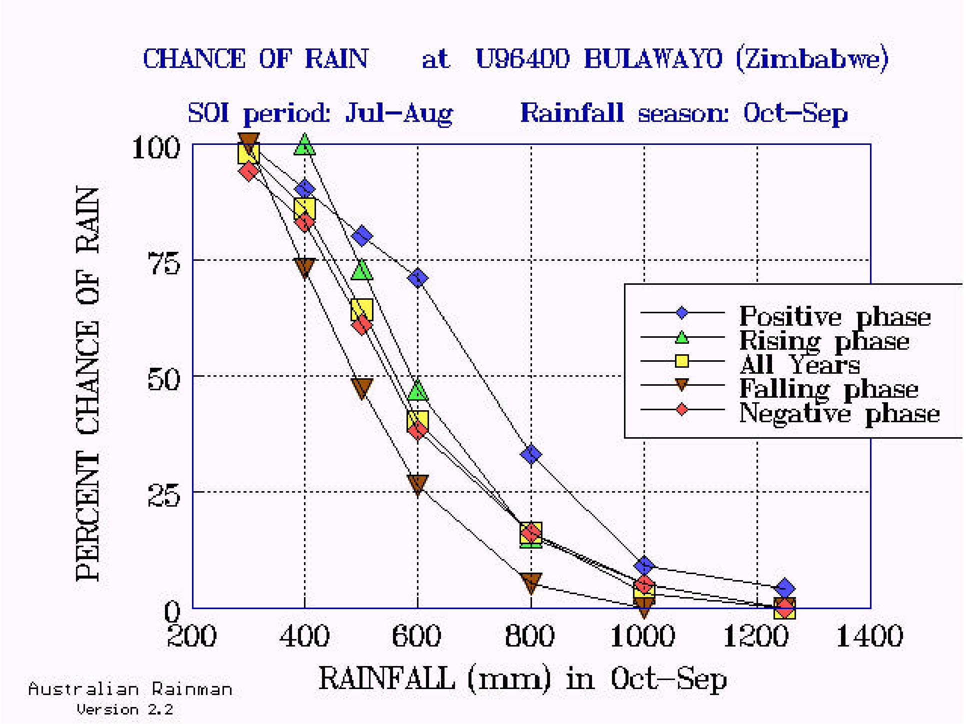


Fig. 3: Bulawayo rainfall at the beginning of the rainy season and SOI phases from the previous dry season (1897-1998). The median rainfall amount is 565 mm.

We also compared the recorded rainfall in Bulawayo since 1897 with the SOI phases as defined by Roger Stone (see Annex C):

	Falling	Negative	Neutral	Rising	Positive
Apr-May	562	501	461	561	565
May-Jun	459	513	559	604	580
Jun-Jul	502	533	541	584	673
Jul-Aug	462	563	551	590	735
Aug-Sep	590	543	550	537	736

Table 1: Bi-monthly amount of rainfall as a function of the SOI phases. Highest amount occur during the positive phase and from July to September.

Output from three different forecasting schemes, namely the SOI Phase scheme, the Rainman scheme and the Zimbabwean Meteorological Service are then compared:

PHASE SCHEME

Jul-Aug SOI	**Falling**	**Negative**	**Neutral**	**Rising**	**Positive**
Rain (mm)	462	563	551	590	735

RAINMAN SCHEME

Jul-Sep SOI	**SOI<-5**	**SOI>-5 <5**	**SOI>5**
Rain (mm)	527	548	737

ZIMBABWE MET SCHEME

Jul-Sep SOI	**SOI<-11.5**	**SOI>-11.5 <-6**	**SOI>-6 <6**	**SOI>6**
Rain (mm)	566	437	552	737

Surprisingly, the three schemes give very similar results particularly for the SOI positive phases

Ongoing Efforts

General objective

The general objective is to improve productivity. In this project we will compare output from the GRASP model to intensive weekly and long-term (16 years) annual observations of range land production, stock numbers and degradation assessment, for one site in Zimbabwe (Bulawayo). This is also to improve p off-take strategies.

Specific objectives

The specific objectives, which have been identified, are:

- Distinguish communal versus commercial production systems;
- Need to define a safe carrying capacity;
- Alter stock numbers through an adapted grazing management system;
- Rest the range land to minimize land degradation and livestock production;
- Source supplementary feed;
- Study the relationship between stock numbers and the SOI phases.

Data and Method

1. Data collection

   Climate data as well as livestock and pasture growth data from 1954 to 1987 in Bulawayo will continue to be used for all simulation.

2. Data analysis

The GRASP model has been calibrated and validated for moderately fertile red clay thornveld at Matapos Research Station, 17 km south of Bulawayo (1320 m). GRASP is calibrated to observations of soil water and pasture biomass in an area which had been previously cleared of trees and shrubs. The area was not grazed during the measurement period and was annually burnt or mown prior to the growing season. Annual forage production records from both cleared and bushed areas for the 16-year period from 1962-63 to 1967-68 and 1971-72 to 1980-81 were used to validate the model. These areas were not grazed and were annually mown prior to each growing season.

Bush clearing and rainfall regime have a major impact on species composition. For example when dry conditions prevailed during the decade following bush clearing in 1962 Urochloa mosambicensis and annual species dominated. From 1975-1976 onward during the wetter years Heteropogon contortus was the dominant specie.

The following shows as an example the Matopos simulation study from 1953 to 1998:

Rainfall & growth in SOI classes

	SOI <-5	**SOI >-5 <5**	**SOI>5**		**median**
Rainfall (mm)	461	555	758		565
Growth Open (kg/ha)	2460	3270	4220		3442
Growth Uncleared (kg/ha)	1761	2157	3053		2180

Percent difference from median

	SOI <-5	**SOI >-5 <5**	**SOI>5**		**median**
Rainfall (mm)	-18	-2	34		565
Growth Open (kg/ha)	-29	-5	23		3442
Growth Uncleared (kg/ha)	-19	-1	40		2180

Based upon previous calibration and calculation made in Matopos, we will need to calculate accurately the actual utilization of stocks, the utilization of a safe carrying capacity and the utilization of flexible stocks. Stock numbers and livestock density versus pasture growth will have to be finely evaluated. Finally we will have to calibrate models for various land types and fill in recent grazing history. The simulation studies need to progress to full grazing system simulation including scf input with reactive strategies. We need to understand what is driving a drought particularly apparent during decadal rainfall cycles. This will enhance the so-called reactive stocking policy strategies i.e., adjusting the livestock based on end of growing season pasture.

Ongoing Collaborations

The Matopos Research Center and the Drought Monitoring Center are continuing their collaboration with QCCA. IRI's participation in the newly funded USAID project for the greater horn of Africa should also bring new products (i.e., downscaled seasonal climate forecasts) in support of activities similar to the ones described in this project.

Team # 4: **SACT**

The Use of Seasonal Climate Forecasting in the Ceará State

Antonio Geraldo Ferreira; Francisco Bergson Parente Fernandes; Nadir Dantas de Sales

Background and rationale

The main rainy season in Ceará State (Northeast Brazil) occurs from February to May of each year and exhibits not only a large year-to year variability in the total precipitation (Kousky 1979), but also a high spatial and temporal variability in the precipitation within the rainy season itself. During this period, the Intertropical Convergence Zone (ITCZ, see Annex C) is the main atmospheric feature associated with rain in the Ceará State and others states in northeastern region of Brazil (hereafter referred to as NEB). Ceará´s territory is inserted in the semi-arid region of the NEB, where small farms and the agriculture are of the subsistence type. Climate variability affects the productivity and production of corn, bean and cotton, with major losses during drought events.

In this project, in order to explore the linkages between climate variability and crop yields and the use of seasonal climate forecasting in order to improve crop management, we choose the Banabuiu Basin (19000 km^2). This basin was chosen because of reliable source of rainfall data, soil data, farm distribution, cropping system management, among others.

Characteristics of the cropping system

The cropping system developed in the Banabuiu Basin is subsistence agriculture: bean, maize and cotton. The cotton farming, which suffered from over-production, is recovering slowly and probably will turn once again to be the main crop product of Ceará. The average farm size in this basin is approximately 5 ha.

The soils of the Banabuiu Basin are shallow with low infiltration rate that renders management difficult. The cropping system is traditional with little new technology and without climate information. Implementation of adequate techniques in cropping system needs improvement.

Climate data in the Banabuiu Basin:

Rainy Season: February to May; Number of years in historical record: 33;Highest rainfall on record: 995,2 mm; Lowest rainfall on record: 88,3 mm; Median rainfall: 505,4 mm; Annual average rainfall: 453,4mm; Mean Temperature: 26,6°C; Mean Evaporation: 2069,5mm

Preliminary results

From 1962 to 1997 we look first at the annual relationship (interannual variability) between rainfall amount at Quixeramobim in Ceará State and its impact on maize yield.

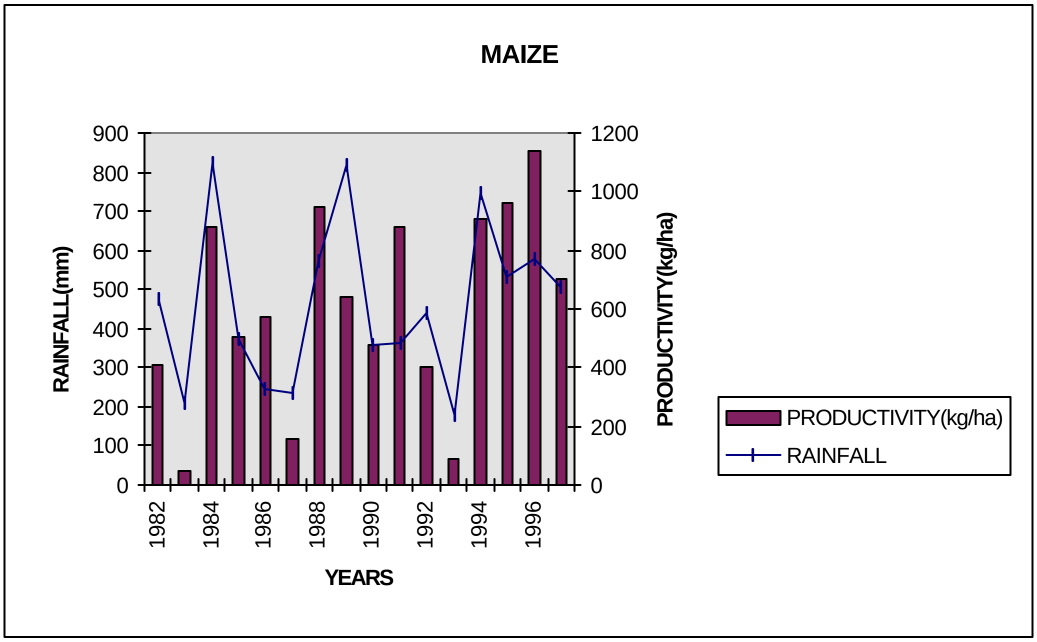


Fig. 1: Rainfall amount in Quixeramobim (Ceara, Brazil) and maize yield (Kg/Ha).

The yield can be affected by the total precipitation rate but also by its geographical distribution from February to May. Another parameter that has a strong influence on the farmers' decision making strategy is "evaporation". This could be shown by analyzing soil water availability. Maize crop is the most sensible to these variations. Cotton production is also a function of the selling price on the international market. Beans production is even more complex since there are two kinds of bean's recolts: the short term recolt (40 days) and the longer term recolt (90 days). To remain economically viable farmers must devise management procedures that can produce long-term, sustainable profits in such a complex environment. One key input for such managerial action is the knowledge of the likely seasonal climate conditions (Meinke and Hammer, 1997).

The graphs obtained with the Rainman (http://www.dpi.qld.gov.au/rainman/) package that relate rainfall data and the phases of the Southern Oscillation Index (SOI) display another good source of useful information to the decision makers. For example, when there is a strong El Niño, with a SOI phase consistently negative, the tropospheric subsidence over the Equatorial Atlantic and NEB regions inhibits cloud convection. The intensity of the negative SOI phases during the El Niño years deserves further investigation prior to incorporation in the decision marking process.

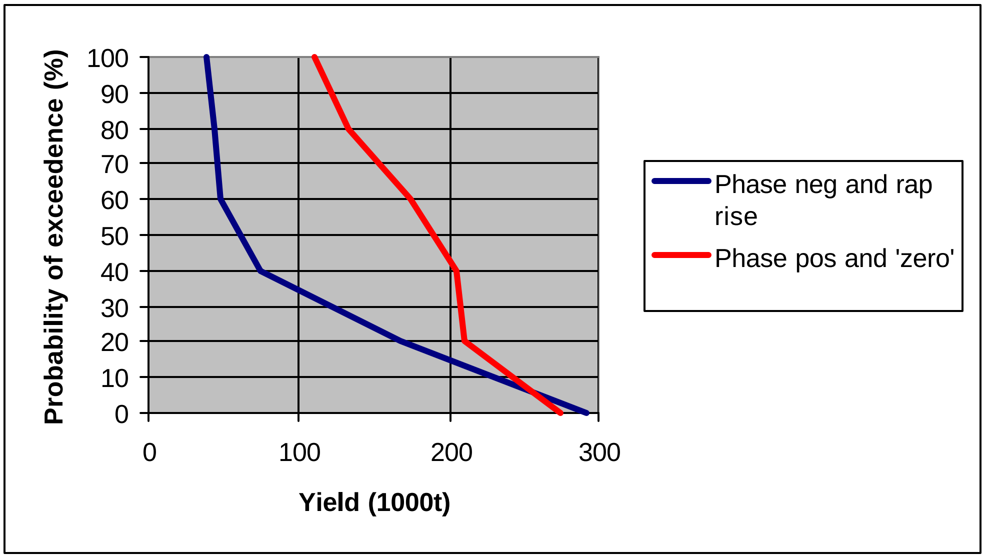


Fig. 2: Probabilities of maize yield in Ceará as a function of SOI phases.

Several works have already demonstrated strong relationship between seasonal mean precipitation and monthly tropical Atlantic SST anomalies from January to May. If, in particular, negative anomalies in the north-south gradient SST gradient across the ITCZ (the Atlantic Tropical Dipole Index or TDI, see Annex C) exist in March and persist through April and May a significant increase in precipitation will occur during the latter months (Uvo, 1998). Further studies elucidating the mechanisms of SST variability in the entire tropical Atlantic, are needed. During El Niño (La Nina) years both information must be evaluated: i. e., the intensity and trend of the SOI phases as well as the intensity and trend of the TDI must be evaluated for incorporation in the decision making process.

As we can see in the following table (for Ceará), farmers can have their risks minimized if they make decisions based upon probabilistic climate forecasts. Decision makers must also be informed about the forecasting skills.

	Below average rainfall forecast		
	Hit	Miss	
ACTION	$180	$360	
NO ACTION	$0	$800	
	Below average rainfall forecast		
	Hit	Miss	Value
ACTION	$180	$360	$234
Probability	0.7	0.3	
NO ACTION	$0	$800	$249
Probability	0.7	0.3	
	Above average rainfall forecast		
	Hit	Miss	

ACTION	$800	$0	
NO ACTION	$360	$180	
Above average rainfall forecast			
	Hit	Miss	Value
ACTION	$800	$0	$560
Probability	0.7	0.3	
NO ACTION	$360	$180	$306
Probability	0.7	0.3	

Conclusions

- Climate forecast information applied to agriculture area has been used in some countries has been successful (e.g. Ceará State);

- If climate forecast information is distributed adequately and timely applied to the reality of a particular region, the risks in the cropping system can be minimized while the production and productivity can be increased;

- The utilization of the SOI phases as an indicator should be done in conjunction with the SST, TDI for the case of Ceará;

- In order to take action, farmers need to know the climate forecast skills;

- We need to improve our knowledge concerning the state of the Tropical Atlantic and its links with the seasonal climate forecast for the Ceará State.

- We need to use the latest technological information of the several components of the cropping system including climatological information. This is to provide a better sustainable development of regions that are vulnerable to droughts.

- The knowledge obtained during this training will be used toward the development of an intra-seasonal precipitation forecast for the Ceará State. It is expected that such forecasts will become increasingly useful for agricultural planning in semi-arid region of the Ceará State where irrigation is almost non existent.

Future actions related to extension activities:

- Training farmers to the use of the seasonal climate information in order to reduce risks and increase productivity and food security;
- Improve our knowledge about the cropping system and the farmers needs;
- Investigate the inter-relationships between SOI, SST, evaporation and crop production with a view to developing a Seasonal Forecast System to feed climate data into cropping models. This system has to incorporate all of the above parameters and

modify its forecast based on the time of the year and the skills of each of the components;
- Determine opportunities for tactical management in response to seasonal forecast;

Ongoing Efforts

Objectives

- Reduce farmers risks associated with climate variability;
- Improve national food security (mitigation of impacts);
- Apply seasonal climate forecast in decision-making across the range of agricultural system and natural ecosystems;
- Training (extension) in the use of climate forecasting.

Data and Method

1. Study site and data availability

Select the key places representative of the Banabuiu Basin which have enough data on rainfall, soil, crops and soil water content.

2. Data analysis

Plot rainfall anomaly data against yields. Use Excel software to plot graphics concerning rainfall, annual production and productivity of the main crops (bean, maize and cotton). Correlate output with climate variables in the region under study; Make analyses between SOI, rainfall and their anomalies.

Improve decision making processes by using the Rainman package with the data from Banabuiu Basin, based on SOI phases. Analyze in depth correlation and mechanisms linking Sea Surface Temperature (SST) in the tropical Atlantic Basin and rainfall in Quixeramobim.

With CLIMLAB 2000 (see Annex B) we will identify key areas in the North and South Tropical Atlantic influencing rainfall in the area under study. We will also need to make comparisons between previous climate forecasts and crop production (hindcasting) in order to gain knowledge about the climate influences on that region and the skill of the climate forecast. Finally, we will choose a representative farm from the region, learn its detailed cropping system and develop extension strategies geared towards greater benefits to the farmers.

Ongoing Collaborations

During this workshop, close links have been established between FUNCEME and INMET. Atlantic climate data (i.e., NAO, TDI,…) are being provided by the IRI for joint analysis using CLIMLAB 2000.

Team # 5: **DTCT**

Seasonal Climate forecasting: Can it Improve Management in Australian Dryland WinterCropping Systems?

Craig White; Bruce Haigh; De Li Liu; Jim Egan

Background and rationale

This project focuses on winter cropping systems in temperate dry-land (rain-fed) environments of Western Australia (WA). These are largely based on rotations of cereals (wheat, barley, oats and triticale), with oilseeds (canola), pulses (faba beans, field peas, lentils, chickpeas and lupins) and annual legume-based pastures. Other rotational options in certain environments include fallow (short or long-term), summer dry-land crops, multipurpose crops (forage/hay/grain, e.g. vetch) and perennial pastures (e.g. lucerne).

Annual rainfall in these cropping environments ranges from about 300 mm to 600 mm, of which 200-400 mm falls during the April to October growing season. Rainfall distribution ranges from summer dominant (northern North South Wales) to fairly even across the year (southern North South Wales) to highly seasonal marked winter dominance (WA and Southern Australia). High evaporation rates in summer mean summer crops are generally not an option, except where soils have high water holding capacity and following long fallow and/or high winter-spring rainfall.

Soil types are highly variable across the region, ranging from heavy clays to red-brown earth to light mallee soils to sand over clay (duplex) to deep sands. Soil water holding capacity (plant available) ranges from as low as 50 up to 200 mm. Soil pH ranges from about 5 to 9.

Winter crops are sown following sowing opportunities (rainfall events/break) from late April through to mid August. Harvest time is around November and December. Tillage options are: direct drill through to 2-3 workings pre-sowing. Weed control uses mainly herbicides, but some tillage is also used.

Climate constraints to production

The following are the main climate constraints associated to yields:

-Rainfall timing of the “break” of season; amount and spatial distribution of rainfall during the growing season; Spring rainfall (finish to season); excessive rain at harvest time.
-Frost timing, compared to flowering/grain fill stages.
-High temperatures at flowering/grain fill.

Preliminary results

The following are preliminary results, showing relationships between percentage chance of rain at 4 different sites, as a function of SOI phases, using APSIM (Annex C):

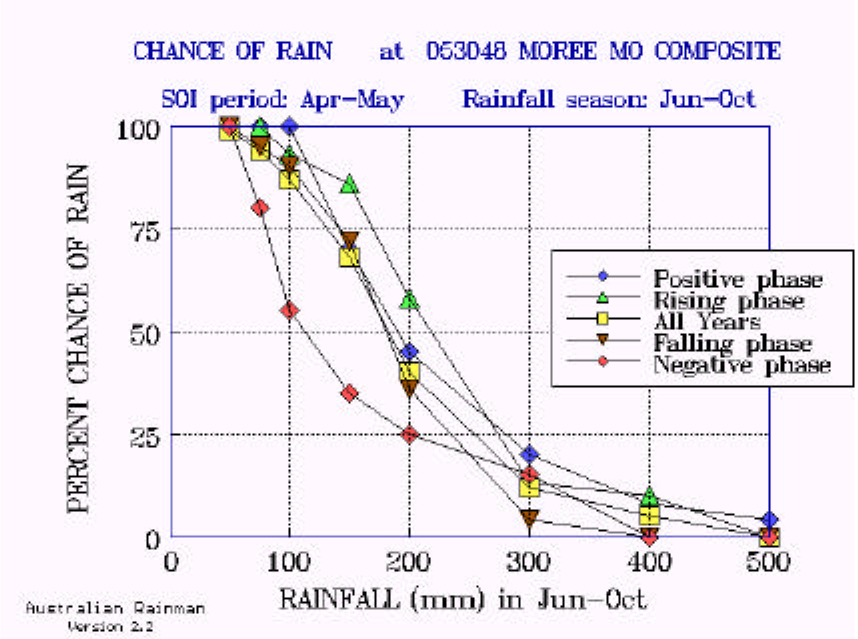


Fig. 1: Percent chance of rain and rainfall amount (mm) against SOI phases in Moree.

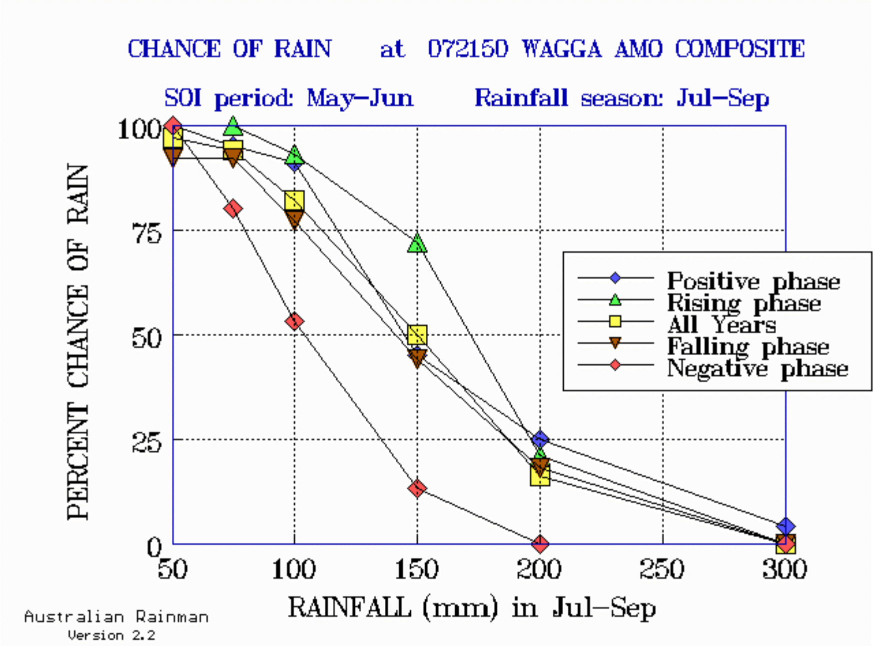


Fig. 2: Percent chance of rain and rainfall amount (mm) against SOI phases in Wagga

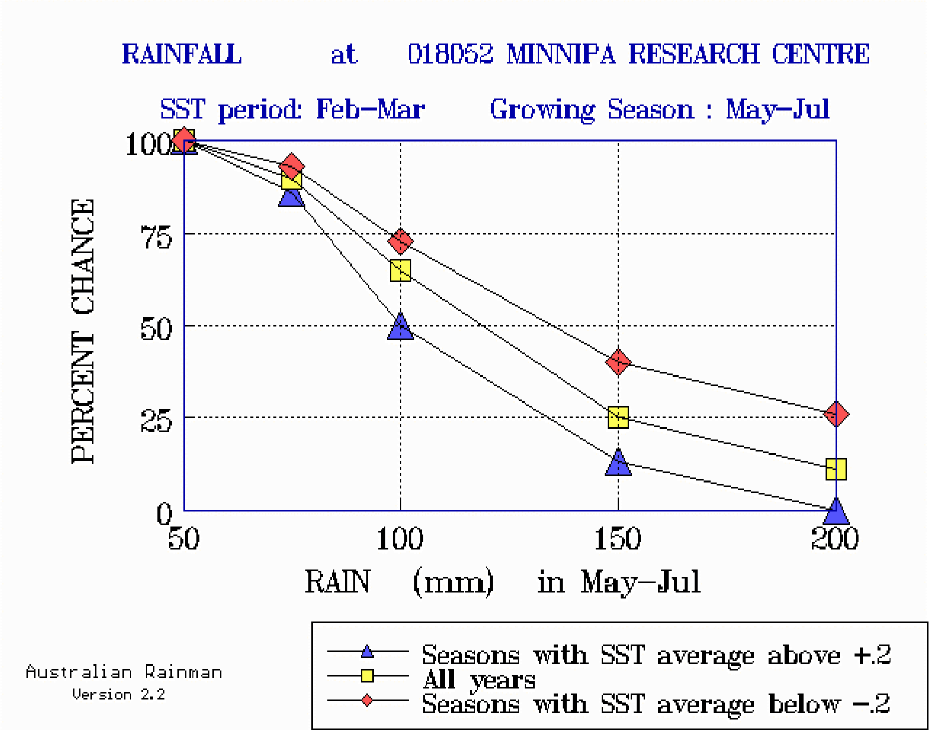


Fig. 3: Percent chance of rain and rainfall amount (mm) against SOI phases in Minnipa

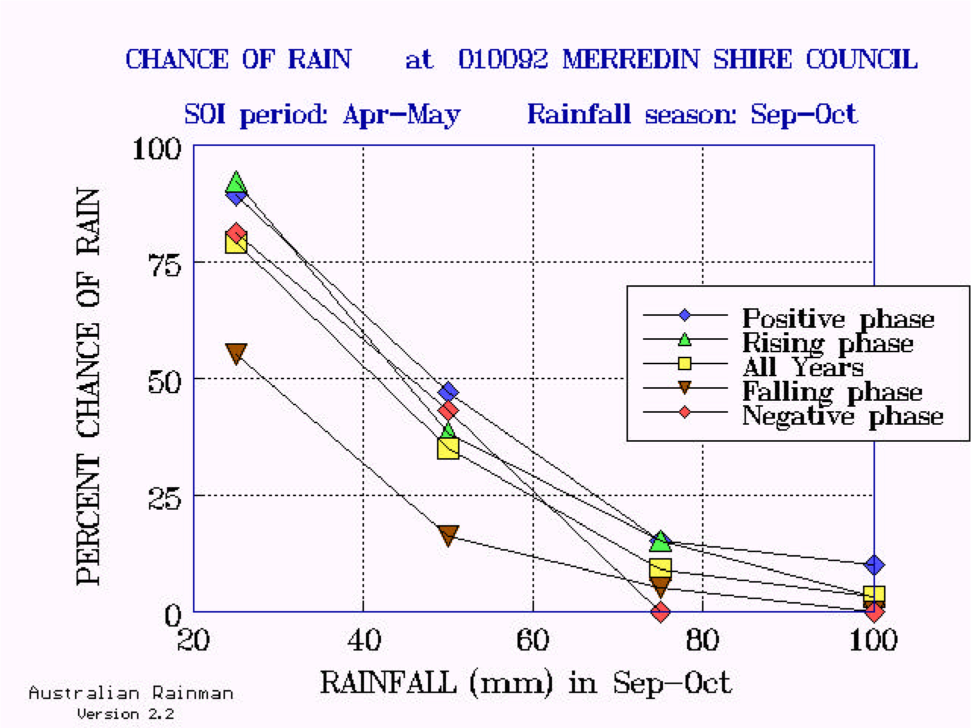


Fig. 4: Percent chance of rain and rainfall amount (mm) against SOI phases in Merredin.

Next we show the simulated wheat yield (using APSIM model) versus historical data, at different sites:

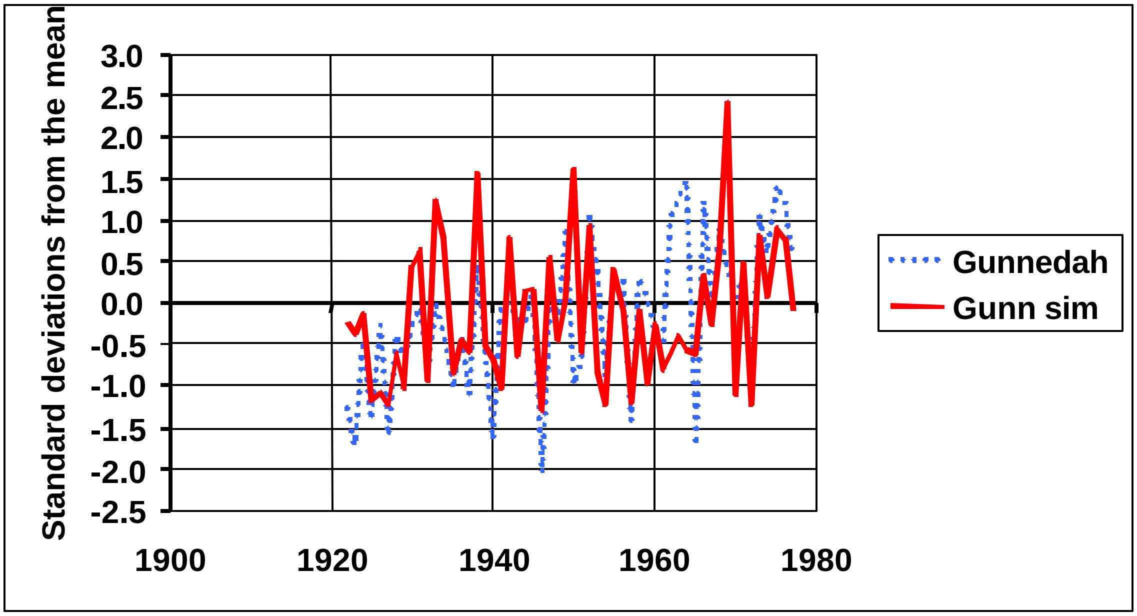


Fig. 5: APSIM simulation (red) against actual wheat yield at Gunnedah.

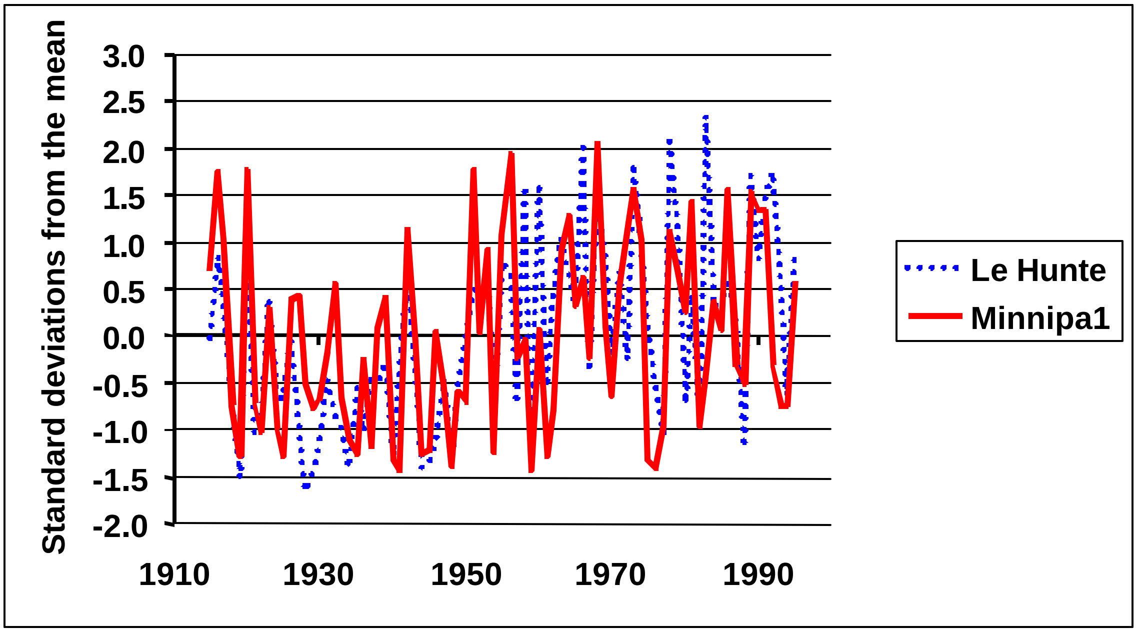


Fig. 6: APSIM simulation (red) against actual wheat yield at Le Hunte.

Finally we show an example of probability distribution of simulated wheat yields for May SOI phases in Minnipa:

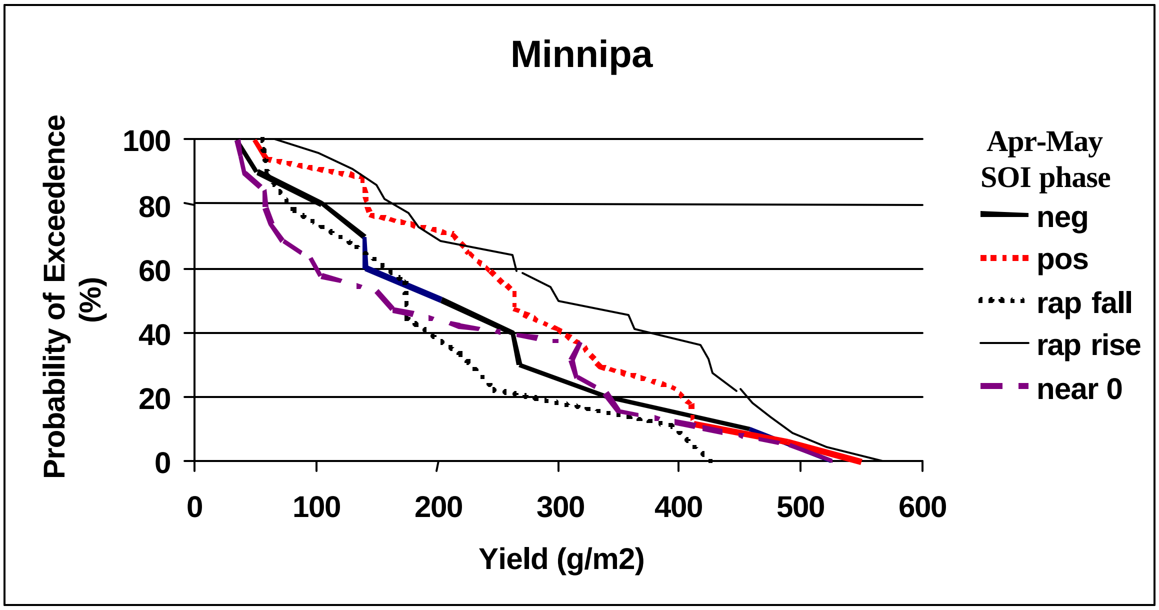


Fig. 7: Probabilities of wheat yield against SOI phases at Minnipa.

Ongoing Efforts

General Objective:

To assess the potential for seasonal climate forecasts to improve management decisions in southern Australian dryland cropping systems.

Specific objectives:

The specific objectives are to:

-Increase farm profitability.
-Maintain and/or improve the farm resource base.
-Minimize exposure to risk.

Data and Method

1. Study sites

The sites are within the southern Australian wheat belt depicted below:

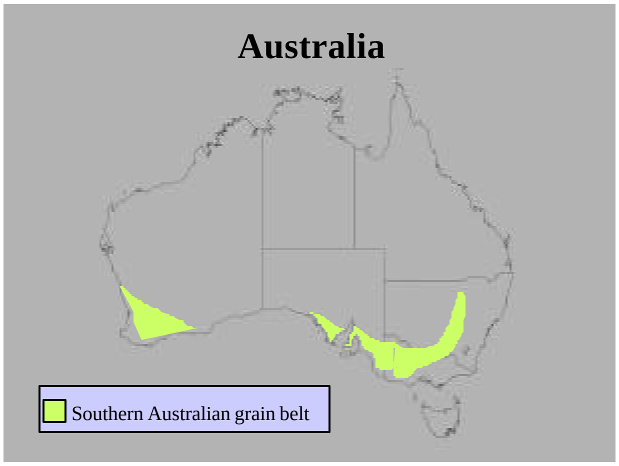


Fig. 8: The southern Australian wheat belt.

Within the southern Australian wheat belt we will look specifically at the following sites:

- Moree, northern NSW, Growing season rainfall (April-October)

  No skill from Jan-Mar SOI. Best skill from May SOI phase on June-Oct rainfall. Negative phase gives lower rainfall, rising phase gives higher rainfall. No SST skill (from Indian Ocean, as per Rainman).

  Seasonal rainfall

  April-May (autumn) rainfall : all poor.
  June-Aug (winter) rainfall : some SOI phase skill.
  Sept-Oct (spring) rainfall : best predictive skill from August SOI phase.

  Best skill : May SOI phase for June-Oct rainfall.

-Wagga Wagga, southern NSW, Growing season rainfall (April-October)

  April SOI phase gives good skill for predicting May-Oct rainfall. Earlier SOI phase is poor for predicting total growing season rainfall. Later SOI phases give higher skill. Useful for in-crop management decisions (e.g. disease control).

  Seasonal rainfall

  April-May (autumn) rainfall : all poor.
  June-Aug (winter) rainfall : reasonable SOI phase skill.
  Sept-Oct (spring) rainfall : good predictive skill from positive and negative SOI phases.

  Best skill : June SOI phase for July-September rainfall.

-Minnipa, SA, Growing season rainfall (April-October)

Little skill for total period. Slight improvement for May-October (April SOI phase or Feb.-Apr. SST) and June-October (May SOI phase or March-May SST).

Seasonal rainfall

April-May (autumn) rainfall : all poor.

June-Aug (winter) rainfall : negative May SOI phase gives lower rainfall. No SST skill.

Sept-Oct (spring) rainfall : positive/rising SOI phase gives higher rainfall. No SST skill..

Nov-Dec (summer) rainfall : slight SOI skill.

Best skill : Feb-Mar SST for May-July rainfall.

-Merredin, WA, Growing season rainfall (April-October)

Minimal/insignificant skill using SOI/SST).

Seasonal rainfall

April-May (autumn) rainfall : small increase in median rainfall in positive March SOI phase.

Sept-Oct (spring) rainfall : small increase in median rainfall in falling May SOI phase.

Issues : Significance of timing and amount of rainfall; need to identify other predictors for WA.

Figure 9 shows the summary of monthly rainfall distribution at the sites.

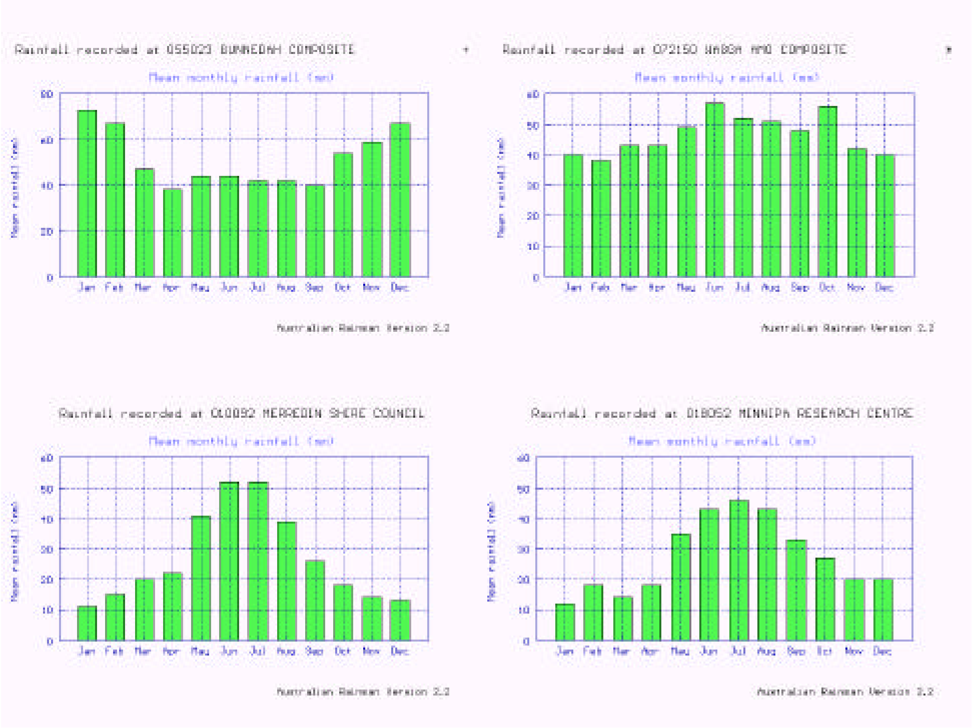


Fig. 9: Monthly rainfall distribution at the four sites.

2. Data Collection

Date of last frost and number of frosts in the season (Based on the work of Stone et.al (1996) and Willcocks). SOI phases in January-February and April-May indicate the probability of the date of last frost and the number of frosts for north eastern Australia.

Preliminary results for Western Australia suggest that there is value in pursuing this analysis for other areas of Australia, as a shift of 10-15 days in the date of last frost can have significant benefits to farmers when planning their sowing strategy. Investigation of the use of this analysis for Western Australia will be undertaken in 1999.

3. Data analysis

The data analysis will be based upon some key decision points, namely:

-Crop choice
-Crop variety / time of sowing
-Crop area
-Nitrogen application
-Seedbed preparation
-Phosphorus application
-Agronomic management, e.g seeding rates
-Crop protection – weeds, diseases, insects.

The first 4 points above are considered as priority areas for attention based upon thorough analyses.

We will use Rainman software package to examine the effect of SOI and SST on seasonal rainfall and frost risk at representative sites across the southern Australian wheatbelt. In particular we will examine the:

-Effect of SOI on historic regional wheat yields at representative locations across the Australian wheatbelt.

-Effect of SOI phases on historic wheat yields for Gunnedah (NSW), Minnipa (SA) and Kulin (WA). Skill in separating years of higher and lower yields with May SOI phase identified at all locations.

-Effect of SOI on simulated wheat yields for representative locations across the Australian wheatbelt**.**

Wheat yields simulated for Gunnedah and Minnipa using APSIM (Annex C) wheat model, showing good agreement with actual yields (see preliminary results). These simulated yields then sorted on basis of May SOI phase, to indicate good skill in identifying high and low yielding seasons.

We will also develop potential management response strategies to use seasonal forecasting skill. In particular we will examine the:

- Nitrogen fertilizer application rate

Recent work by Holger Meinke has indicated that simulation models like APSIM can be used to provide information on the likely yields for individual paddocks based on climatic and soil parameters. By running the model with a range of fertiliser inputs the nitrogen response curve can be calculated. A target yield can then be estimated which maximises gross margins. The SCF can then be used by farmers to tailor their fertiliser application rates.

- Choice of wheat varieties

Drought tolerant wheat varieties are now available. These wheat varieties have the ability to reduce transpiration rates and so use soil water more effectively. These varieties maybe considered as an alternative to conventional varieties when SCF indicate a high probability of dry conditions.

- Choice of herbicides for weed control

Pre-emergent residual herbicides can provide, cheap, long-term weed control throughout the growing season. The disadvantage of using these herbicides is that they may limit the choice of rotational crops if excessive residues persist after harvest.

During dry years post-emergent herbicides may be used when the soil is trafficable. However during wet years there may be little opportunity to be able to use ground based spraying rigs on the heavy clay soils. SCF could influence the decision on which herbicide to use.

- Crop type and area adjustment

The growing of wheat can be considered a low risk enterprise when compared with other winter crops. However during wet years there is the possibility of growing higher valued (higher gross margins) crops such as canola. The use of a pay-off matrix enables various factors such as sowing area, prices and probability of correct forecasts to be changed and the effect on the expected average value calculated. See tables below.

Decision to make:

Whether to use 20% of Area to grow Canola in response to above average Rainfall Forecast

No Response:	Plant 100% of area Wheat
Response:	Plant 80% of area to Wheat and 20% of Area to Canola

Expected Yields (tonnes/hectare)	**Rainfall**	
Crop	Wet Years	Dry Years
Wheat	1.0	0.5
Canola	0.8	0.2

Gross Margins=Yield X Price - Costs ($/ha)	**Rainfall**	
Crop	Wet Years	Dry Years
Wheat	60	-15
Canola	74	-94

Cost of Production ($/hectare)	
Crop	Cost
Wheat	90
Canola	150

Price ($/tonne)	
Crop	Return
Wheat	150
Canola	280

Forecast Probability	**Actual**	
Forecasted	Wet Year	Dry Year
Wet Year	0.7	0.3
Dry Year	0.3	0.7

Crop Area - Percentage	**Crop**	
	Wheat	Canola
No Response	100%	0%
Response	80%	20%

Payoff Matrix ($/hectare)	**Season Type**		
	Wet	**Dry**	**Value**
No Response	$ 60.00	-$ 15.00	$ 37.50
Prob	0.7	0.3	
Response	$ 62.80	-$ 30.80	$ 34.72
Prob	0.7	0.3	

The potential constraints to management responses to seasonal forecasts are:

-Costs and returns of alternative strategies
-Farmer management skill with new crops and technology
-Machinery requirements
-Rotational considerations.

Other important issues to be examined are:

-Current limitations in predicability of autumn rainfall using SOI and SST. What other predictors may be suitable?
-Effect of SOI phase on the probability of frost.
-Run APSIM simulations for other locations, crops and management options.
Learn with growers how to use and apply seasonal climate forecast information for on-farm decisions.

Ongoing Collaborations

Closer attention will be paid to the possible influence of the Indian Ocean on climate variability and crop yields in western Australia. To that purpose, links are being established between the Dryland Research Institute of western Australia and the IRI.

6. References

Alaerts, G., Blair, T. Hartvelt, Frank (eds), 1991, A Strategy for Water Sector Capacity Building, IHE, Report Series 24, Delft, The Netherlands.

Allan, R. J., 1991. Australasia, In Glantz, M., Katz, R., and Nicholls, N. (eds.), Teleconnections linking worldwide climate anomalies, Cambridge: Cambridge University Press, 73-120.

Allan, R. J., G. S. Beard, A. Close, A. L. Herczeg, P. D. Jones, and H. J. Simpson, 1996. Mean sea level pressure indices of the El Niño – Southern Oscillation: Relevance to stream discharge in south-eastern Australia. Divisional Report 96/1, CSIRO Division of Water Resources, Canberra, Australia, pp 23.

Austin,M.P. and Williams,O.B. 1988. Influence of climate and community composition on the population demography of pasture species in semi-arid Australia. Vegetatio, 77: 43-49.

Bate, P.W., 1997. The tropical circulation in the Australian/Asian region – November 1996 to April 1997. Aust. Met. Mag. 46: 237-246.

Bliss, E. W. and Walker, G. T., 1932. World Weather V. Memoirs of the Royal Meteorological Society, 4, 52-84.

Coughlan, M. J., 1979. Recent variations in annual-mean maximum temperatures over Australia. Quart. J. Roy. Meteorol. Soc., 105, 707-719.

da Cunha, E., 1995. Rebellion in the backlands. University of Chicago Press, 751pp.

Drosdowsky, W., and Chambers, L., 1998. Near global sea surface temperature anomalies as predictors of Australian seasonal rainfall. BMRC Research Report No. 65, January 1998, 39 pp.

Hammer, G.L., Woodruff, D.R. and Robinson, J.B., 1987. Effects of climatic variability and possible climatic change on reliability of wheat cropping - A modelling approach. Agric For. Meteorol., 41: 123-142.

Hammer, G.L. and Muchow, R.C., 1994. Assessing climatic risk to sorghum production in water-limited subtropical environments. I. Development and testing of a simulation model. Field Crops Res., 36: 221-234.

Hammer, G.L., Holzworth, D.P. and Stone, R., 1996. The value of skill in seasonal climate forecasting to wheat crop management in a region with high climatic variability. Aust. J. Agric. Res., 47: 717-737.

Hammer, G.L., Chapman, S.C. and Muchow, R.C., 1997. Modelling sorghum in Australia: The state of the science and its role in the pursuit of improved practices. Proceedings of the Third Australian Sorghum Conference (M.A. Foale, R.G. Henzell and J.F. Kneipp, eds), Tamworth, February 1996, Australian Institute of Agricultural Science, Melbourne, Occasional Publication No. 93.

Jones, D. A., 1998. The prediction of Australian land surface temperatures using near global sea surface temperature patterns. BMRC Research Report No. 70. November 1998, 44 pp.

Keating, B.A. and Meinke, H. 1998. Assessing exceptional drought with a cropping systems simulator: a case study for grain production in north-east Australia. Agric. Syst., 57: 315-332.

Khandekar, M.L., 1996. El Niño/Southern oscillation, Indian monsoon and world grain yields - a synthesis. Adv. In Natural and Technological Hazards Res., 7: 79-95.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P. and Freebairn, D.M., 1996. APSIM: A novel software system for model development, model testing, and simulation in agricultural research. Agric. Syst. 50: 255-271.

Meinke, H. and Hammer, G.L., 1997. Forecasting regional crop production using SOI phases: a case study for the Australian peanut industry. Aust. J. Agric. Res., 48: 789-793.

Meinke, H. and Ryley, M., 1997. Effects of sorghum ergot on grain sorghum production: a preliminary climatic analysis. Aust. J. Agric. Res., 48: 1241-1247.

Meinke, H. and Stone, R.C., 1997a. The chances of receiving planting rain. ProFarmer 5(14); 4.

Meinke, H. and Stone, R.C., 1997b. On tactical crop management using seasonal climate forecasts and simulation modelling - a case study for wheat. Scientia Agricola, 54: 121-129.

Meinke, H., Stone, R.C. and Hammer, G.L., 1997. The climatic outlook and its likely impact on the forthcoming wheat crop. ProFarmer 5 (17); 4.

Meinke, H., Hammer, G.L., van Keulen, H. and Rabbinge, R., 1998. Improving wheat simulation capabilities in Australia from a cropping systems perspective. III. The integrated wheat model (I-WHEAT). Europ. J. Agron., 8: 101-116.

Meinke, H., Stone, R.C. and Hammer, G.L., 1996. Using SOI phases to forecast climatic risk to peanut production: a case study for northern Australia. Int. J. Climatol., 16: 783-789.

McBride, J. L. and Nicholls, N., 1983. Seasonal relationships between Australian rainfall and the Southern Oscillation. Monthly Weather Review, 111, 1998-2004.

McKeon, G. M., K. A. Day, S. M. Howden, J. J. Mott, D. M. Orr, W. J. Scattini, and E. J. Weston, 1990. Management of pastoral production in northern Australian savannas. J. Biogeog., 17, 355-72.

Nicholls, N., 1978. A possible method for predicting seasonal tropical cyclone activity in the Australian region. Mon. Weath. Rev., 107, 1221-1224.

Nicholls, N., 1979. A simple air-sea interaction model, Quarterly Journal of the Royal Meteorological Society, 105, 93-105.

Nicholls, N., 1983. Predictability of the 1982 Australian drought. Search, 14, 154-155.

Nicholls, N., 1985. Impact of the Southern Oscillation on Australian crops. J. Climatology, 5, 553-560.

Nicholls, N., 1986. A method for predicting Murray Valley Encephalitis in southeast Australia using the Southern Oscillation, Australian Journal of Experimental Biology and Medical Science, 64, 587-594.

Nicholls, N., 1988. More on early ENSOs: evidence from Australian documentary sources, Bulletin of the American Meteorological Society, 69, 4-6.

Nicholls, N., 1989a. Sea surface temperatures and Australian winter rainfall. J. Climate, 2, 965-973.

Nicholls, N., 1989b. How old is ENSO?, Climatic Change, 14, 111-115.

Nicholls, N., 1991. The El Niño - Southern Oscillation and Australian vegetation. Vegetatio, 91, 23-36.

Nicholls, N., and F. Woodcock, 1981. Verification of an empirical long-range weather forecasting technique. Quart. J. Roy. Meteorol. Soc., 107, 973-976.

Nicholls, N., and Kariko, A. P., 1993. East Australian rainfall events: Interannual variations, trends, and relationships with the Southern Oscillation. J. Climate, 6, 1141-1152.

Nicholls, N., McBride, J. L., and Ormerod, R. J., 1982. On predicting the onset of the Australian wet season at Darwin. Mon. Weath. Rev., 110, 14-17.

Norman, F. I., and N. Nicholls, 1991. The Southern oscillation and variations in waterfowl abundance in southeastern Australia. Aust. J. Ecology, 16, 485-490.

Pittock, A. B., 1975. Climatic change and the patterns of variation in Australian rainfall, Search, 6, 498-504.

Quayle, E. T., 1910. On the possibility of forecasting the approximate winter rainfall for Northern Victoria. Bulletin No. 5, Commonwealth Bureau of Meteorology, Melbourne, March 1910, 9 pp.

Quayle, E. T., 1929. Long range rainfall forecasting from tropical (Darwin) air pressures, Proceedings of the Royal Society of Victoria, 41, 160-164.

Rolls,E.C. 1981. A million wild acres. Nelson, Melbourne.

Ropelewski, C. F. and Halpert, M. S., 1987. Global and regional scale precipitation patterns associated with the El Niño - Southern Oscillation, Monthly Weather Review, 115, 1606-1626.

Ropelewski, C. F. and Halpert, M. S., 1989. Precipitation patterns associated with the high index phase of the Southern Oscillation, Journal of Climate, 2, 268-284.

Stone, R.C. and Auliciems, A., 1992. SOI phase relationships with rainfall in eastern Australia. Int. J. Climatol., 12: 625-636.

Stone, R. C., Hammer G. L., and Marcussen, T., 1996a. Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. Nature 384: 252-55.

Stone, R., Nicholls, N. and Hammer, G., 1996b. Frost in NE Australia: trends and influences of phases of the Southern Oscillation. J. Climate, 9: 1896-1909.

Streten, N. A., 1981. Southern Hemisphere sea surface temperature variability and apparent associations with Australian rainfall. J. Geophys. Res., 86, 485-497.

Suppiah, R., and K. J. Hennessy, 1996. Trends in the intensity and frequency of heavy rainfall in tropical Australia and links with the Southern Oscillation. Aust. Met. Mag., 45, 1-18.

Whetton, P., Adamson, D., and Williams, M., 1990. Rainfall and river flow variability in Africa, Australia and East Asia linked to El Niño – Southern Oscillation events, Geological Society of Australia Symposium Proceedings, 1, 71-82.

Williams, M. A. J., Adamson, D. A. and Baxter, J. T., 1986. Late Quaternary environments in the Nile and Darling basins, Australian Geographical Studies, 24, 128-144.

Woodruff, D.R. and Tonks, J., 1983. Relationship between time of anthesis and grain yield of wheat genotypes with differing developmental patterns. Aust. J. Agric. Res., 34: 1-11.

Annex A

Course Syllabus

Week 1: Monday, February 1-Friday, February 5 1999.

9:00 am-9:45 am: Welcoming remarks, Presentation of IRI Training Program and CLIPS (Yves Tourre, Director IRI Training Program, Geoff Love/Deputy Director-BoM, WMO/CLIPS report, Graeme Hammer/QCCA)

Presentation of the five applications projects and 21 trainees by Yves Tourre (IRI) and Graeme Hammer (QCCA)

Climate and the Systems Approach in Agriculture

Monday, February 1: Global Climate:

09:45 am-12:30 pm: Atmospheric Global Climate and forcing factors (Chet Ropelewski/IRI; Yves Tourre/IRI)
2:00 pm-5:00 pm: Pacific-Indian Oceans Climate and forcing factors (Warren White/SIO; Yves Tourre/IRI)
Indian Monsoon and its Impact on Agriculture (U. S. De/Pune)

Tuesday, February 2: ENSO, and Seasonal Climate Forecasting (scf)

9:00 am-12:30 pm: Understanding ENSO (Chet Ropelewski/IRI; Warren White/SIO; Yves Tourre/IRI)
2:00 pm-5:00 pm: ENSO and scf in Australasia (Panel Discussion: Neville Nicholls (leader)/BMRC-BoM, Roger Stone/APSRU-QCCA, Warren White/SIO, Chet Ropelewski/IRI, U. S. De/Pune, Yves Tourre/IRI)

Wednesday, February 3: Systems Approaches to Using scf in Agricultural Decision-Making

9:00 am-10:30 am: General systems approach to using seasonal forecasts in agricultural systems (Graeme Hammer/APSRU)

11:00 am-12:30 pm Agricultural Decision-Making: Farm scale

Decision-making under risk (Rohan Nelson /DPI- QCCA
2:00 pm-5:00 pm: Scf, crop and cropping system management: case studies (Panel Discussion: Graeme Hammer (leader), Holger Meinke, Rohan Nelson/APSRU-QCCA, U. S. De/Pune)

Thursday, February 4: Agricultural Decision-Making: Farm scale (Cont'd)

9:00 am-12:30 pm: Scf and pasture systems management (panel: Greg McKeon, Ken Day (leader), David Cobon/CIGS-QCCA)
2:00 pm-4:00 pm: Extension systems for farm-scale scf applications (Rod Saal, Syd Plant, Dave George + regional extension staff/QCCA)
4:00 pm-5:000 pm: Impediments to the use of scf (Neville Nicholls/BMRC-BoM)

Friday, February 5: Decision Making Methodologies: Regional scale

9:00 am-12:30 pm: Regional scale applications of scf-Drought alerts, policy, commodity
(Panel Discussion: Roger Stone/ CIGS-QCCA, Ken Brook (leader), Ken Day, Andries Potgieter/QCCA, Chet Ropelewski/IRI, Scott Power/ BoM-CLIPS)
2:00 pm-3:30 pm: Decision Making Methodologies-Regional scale (Cont'd).

4:00 pm-5:00 pm South African Maize case study (A. Potgieter)

Week 2: Monday, February 8-Friday February 12

Climate Prediction and Agricultural Management

Monday, February 8: Farm Visits

8:00am-6:00pm: Visit to James Clark farm: “North Star” where scf is used for cropping systems

Tuesday, February 9: Climate Modeling and Prediction

9:00 am-12:30 pm: Global climate modeling and downscaling, scf potential (Scott Power/BoM, Richard Kleeman/BoM, Jack Katzfey/CSIRO, Robert Young/QCCA)
2:00 pm-5:00 pm: Seasonal outlook and scf using SST, GCM and downscaled output (Discussion Panel: Scott Power (leader) /BoM, Richard Kleeman /BoM, Jack Katzfey/CSIRO, Robert Young/QCCA)

Wednesday, February 10: Agricultural Systems Modeling and Prediction

9:00 am-12:30 pm: Modeling cropping systems: APSIM (Holger Meinke, P. Carberry/APSRU)
Modeling grazing systems (Ken Rickert/UQ)
2:00 pm-5:00 pm: Modeling tools for simple systems (Brett Robinson/DNR)

Modeling on regional scale (Dave Butler-Graeme Hammer/DPI)
Hydrology project applications (Yahya Abawi/QCCA)

Thursday, February 11: Regional Climate Data, Analysis and Prediction

9:00 am-12:30 pm: Climate data storage, generation, access and analysis (Alan Beswick/DNR, Nick Clarkson/DPI)
2:00 pm-5:00 pm: *Hands-on applications*: Communicating rainfall data, analysis and prediction: Australian Rainman (Ian Partridge, Jeff Clewett/DPI)

Friday, February 12: Team-Projects Discussion

Trainees team projects (5) are formed of 3-5 (1-2 Climate, 2-3 Agriculture trainees per team). Regional teams consider an application of scf in their agricultural system of interest including: tropical, temperate, semi-arid, arid conditions.

9:00 am-12:00 pm:	Teams 1, 2 and 3: Climate, scf and agricultural issues
2:00 pm-5:00 pm:	Team 4 and 5: Climate, scf and agricultural issues

Week 3: February 15-February 19

Practical Applications

Monday, February 15: Data, Analysis and Statistical Tools

9:00 am-12:30 pm:	IRI CLIMLAB 2000 (http://iri.ldeo.columbia.edu/iri/programs/training/climlab2000/) (Raul Tanco and Yves Tourre/IRI)
2:00 pm-5:00 pm:	The World Wide Web: IRI Data Library (http://ingrid.ldgo.columbia.edu/), LongPaddock products (http://www.dnr.qld.gov.au/longpdk/), On-line tools (Yves Tourre/IRI; Alan Peacock/QCCA)

Tuesday 16-Friday 19:

Trainees develop a practical example (at least conceptually). This should draw on learning from the first two weeks and include a system analysis to define:

-the system management and managerial issues;
-the potential role for scf to influence management and outline the achievement procedure.

Presentation of Team projects, by participants, will be during the last day of the training course.

Annex B

CLIMLAB 2000

CLIMLAB 2000 was developed in conjunction with IRI Training Courses. It is a tool that can be used to perform statistical analysis, data management (i.e. compute anomalies, seasonal values, etc.) display data and results (x-y plots, time series, histograms, contour plots, etc.), and compute more complex statistical analysis (i.e. EOF [Empirical Orthogonal Function Analysis] and CCA [Canonical Correlation Analysis]) A database of global sea surface temperatures is included with the software, along with instructions on how users can add their own datasets.

CLIMLAB 2000 combines the power of Octave (developed by Univ. of Wisconsin) for numerical calculations/statistics, and the ability of GrADS (developed by COLA) to perform spatial plots (contours) drawing coastlines and political boundaries. The program features a user friendly interface with pull down menus in a Windows environment.

History of CLIMLAB 2000:

In 1993 and 1994, two nine-month training courses were developed and implemented to train scientists from countries impacted by ENSO events as part of the IRI Pilot Project. The course presented state-of-the-art capabilities in coupled ocean-atmosphere climate modeling and prediction and introduced concepts on tailoring forecasts for practical applications to regional and local user communities. Participants were instructed with the aid of MATLAB, a powerful computational and statistical software package.

In view of the experience gained from the first two courses, the IRI Pilot Project expanded its training activities by organizing shorter courses aimed at exploring practical applications of seasonal-to-interannual climate predictions to agriculture and hydrology.

To facilitate the shorter courses, participants would be required to quickly learn how to manipulate and analyze climate datasets. The necessary time to master MATLAB far exceeded the time allotted in the proposed shorter courses, so a user friendly interface was needed.

The original CLIMLAB software was developed to cut the learning curve time significantly. It introduced point and click menu options and provided a standard set of routines which could be used for a variety of computations and analyses. The graphical capabilities of GrADS (GRid Analysis and Display System; developed by COLA/Univ. of Maryland) were also incorporated so that users could produce spatial plots (contours) drawing coastlines and political boundaries. The original software package was developed to run on both Windows 3.x and Unix systems, but required users to purchase MATLAB. The high price of MATLAB made CLIMLAB available only to those who could afford it and prevented IRI from freely distributing the software.

In 1998, work began on a new, upgraded version of the software. The graphical user interface, now written in Visual Basic, interacts with a new computational engine called Octave. Developed by the University of Wisconsin, Octave performs high level computations and statistics, but unlike MATLAB, could be freely distributed. The software, while remaining powerful with many features, is able to run on a PC with minimal processing power and memory. Major tests for the improved software were performed during this training course.

CLIMLAB 2000 can be downloaded from the IRI Website at:
http://iri.ldeo.columbia.edu/iri/programs/training/climlab2000/

We submit suggestions on how to improve CLIMLAB 2000 for future releases to climlab@iri.ldeo.columbia.edu.

Annex C

Climate and Agricultural Parameters and Indices

What are the SOI and SOI Phases?

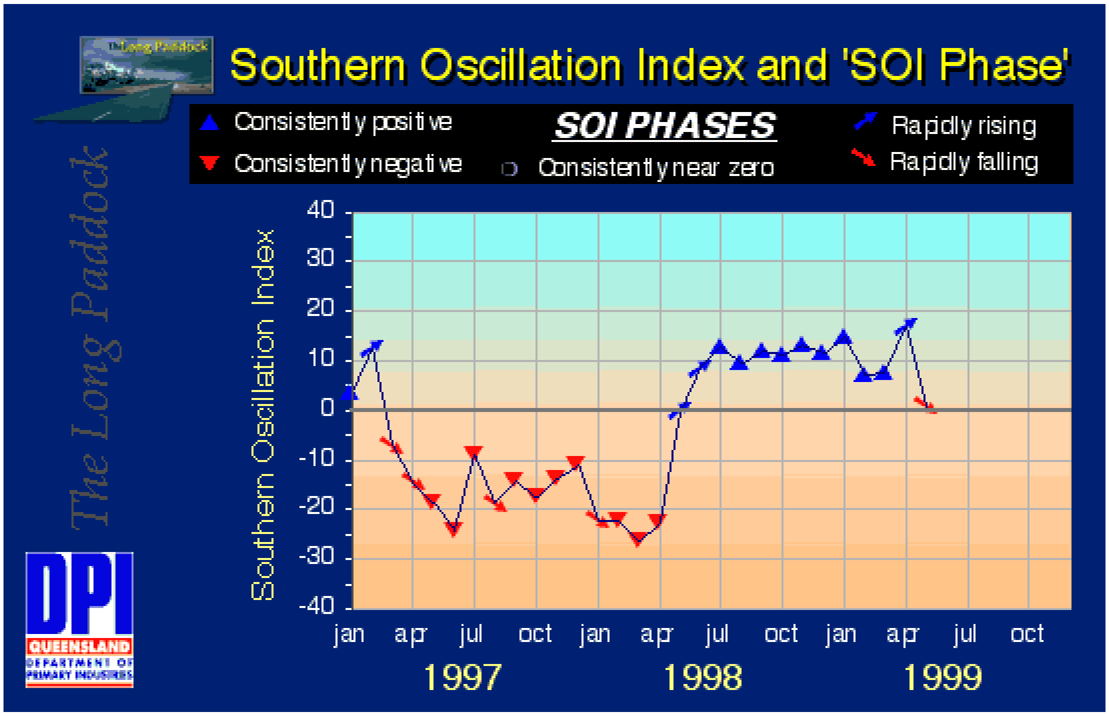


Figure1: The Southern Oscillation is a see-saw in air pressure between the central Pacific and Indian oceans. A high air pressure in the Indian ocean will generally correspond with a low air pressure in the Pacific region and vice versa. The Southern Oscillation Index (SOI) is simply the index that measures the differences in air pressure between Tahiti and Darwin. The index scale ranges from about +30 to -30. The SOI phases are self described in this figure.

How does the El Niño - Southern Oscillation affect Australian climate?

Before the 1972/73 El Niño episode, understanding of the impacts of the El Niño - Southern Oscillation on Australia was limited. Studies in the 1970s and 1980s documented its effects, but the 1982/83 event still caught the country by surprise. By the El Niño events of the early 1990s, a routine seasonal climate prediction service, based on the earlier work on the El Niño - Southern Oscillation, had been established.

Australian droughts generally accompany El Niño episodes (eg., Allan, 1991). Figure 1 illustrates the relationship between widespread Australian drought and low values of the Southern Oscillation Index (the SOI, a simple measure of the El Niño - Southern Oscillation, is the standardised difference in surface atmospheric pressure between Tahiti and Darwin), by comparing time series of the percentage of Australia with annual rainfall in the lowest decile, with annual averages of the SOI. The figure also indicates that years with little of the country in drought tend to have large positive SOI values, ie., La Niña episodes.

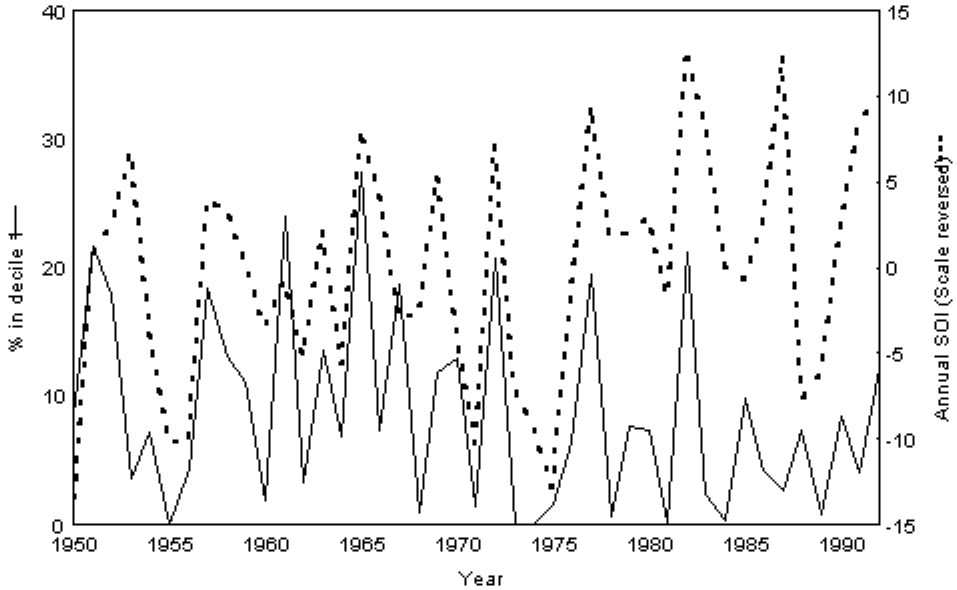


Figure 2. Annual mean SOI (full line) and the percentage of Australia with annual rainfall below the first decile, ie in drought, (broken line).

Figure 1 only uses data from 1950, for clarity. The relationship between the SOI and drought, however, is evident in data throughout the 20th century. Prior to the late 19th century there are insufficient data to allow a strict, quantitative comparison of widespread Australian droughts with the El Niño – Southern Oscillation. Nicholls (1988) examined reports of the governors of the colony of New South Wales to the colonial secretary of the British Government in London for references to drought in the early years of the colony and found that the coincidence of El Niño events and Australian droughts has existed from, at least, the start of European colonisation in 1788.

The El Niño - Southern Oscillation also enhances Australian rainfall variability, as it does wherever it impacts on climate (Nicholls et al., 1997). As well, many Australian droughts tend to last about a year because El Niño and La Niña episodes both tend to last about twelve months and this sets the time scale of Australian rainfall fluctuations (Nicholls, 1991). The link with the El Niño - Southern Oscillation is most consistent with east and north Australian rainfall (eg., Pittock 1975; McBride and Nicholls 1983; Ropelewski and Halpert 1987, 1989).

How was the effect of the El Niño - Southern Oscillation on Australia discovered?

India suffered a severe drought and famine during 1877. Sir Henry Blandford, the Director of the Indian Meteorological Service, noted the very high atmospheric pressures over Asia at the time and requested pressure information from other meteorologists around the world. Sir Charles Todd, the South Australian Government Observer noted that pressures were also high during 1877 over Australia, and much of the country suffered from drought that year. Todd compared earlier droughts and concluded that Indian and Australian droughts usually coincided. This observation has since been confirmed (eg., Williams et al. 1986) and forms part of the suite of climate linkages we now call the Southern Oscillation (SO).

When Sir Gilbert Walker named and documented the SO in the early decades of the 20th century, its close relationship with Australian rainfall quickly became apparent (e.g., Bliss and Walker 1932). Walker's work suggested that north Australian summer rainfall could be predicted with an index of the SO. Quayle (1910, 1929) suggested that rainfall farther south could be predicted in the same way. After that, a trickle of papers discussed the relationship between the SO and Australian climate, up to the mid-1970s, when the worldwide attention on El Niño led to a resurgence of interest among Australian meteorologists.

By the early-1980s attention had turned to the possible use of the El Niño - Southern Oscillation in prediction. Work on the physical cause of the phenomenon had commenced, and several papers describing patterns and relationships between the El Niño - Southern Oscillation, sea surface temperature, and Australian climate had been published (eg., Pittock, 1975; Streten, 1981; Coughlan, 1979). Some of the lag relationships suggested by Quayle and others had been validated and extended using new data (Nicholls and Woodcock, 1981; McBride and Nicholls, 1983). New relationships indicating that seasonal temperature, wet-season onset, and even seasonal tropical cyclone activity also were predictable, through the El Niño - Southern Oscillation, had been uncovered (Nicholls, 1978, 1979; Nicholls et al., 1982). The recognition in mid-1982 that a major El Niño episode was under way led to cautious statements regarding possible implications for Australian rainfall through the remainder of 1982, based on this work (Nicholls, 1983). The Bureau’s National Climate Centre began preparing and issuing regular monthly "Seasonal Climate Outlooks" in 1989, based on the SOI. These provide forecasts of 3-month rainfall anomalies, across the country. More recently, the possible influence of Indian Ocean sea surface temperatures on Australian rainfall, has been investigated (Nicholls, 1989a). This has led to the development and implementation of a seasonal rainfall forecast scheme based on Indian and Pacific Ocean sea surface temperatures which promises to be more accurate than forecast based solely on the El Niño - Southern Oscillation (Drosdowsky and Chambers, 1998).

Variables other than seasonal rainfall appear to be predictable though the use of the El Niño - Southern Oscillation. For instance, Stone et al. (1996) suggest that seasonal frost forecasts could be feasible in eastern Australia. Nicholls and Kariko (1993) and Suppiah and Hennessy (1996) found that rainfall events and intensity were related to the El Niño - Southern Oscillation. Whetton et al. (1990) and Allan et al. (1996) documented relationships of the El Niño - Southern Oscillation with stream flow variations. Jones (1998) has used the Drosdowsky-Chambers forecast system to develop a system for predicting seasonal temperature. This system promises to be more accurate than the predictions of rainfall.

The El Niño - Southern Oscillation and vegetation changes

Since the native Australian vegetation was adapted to the climate rhythms and variability induced by the El Niño - Southern Oscillation, it is not surprising that the introduction of plants and animals not so adapted led to rapid changes in vegetation (Nicholls, 1991). The best known of these changes is probably the area now known as the Pilliga Scrub in northern New South Wales (Rolls, 1981; Austin and Williams, 1988). Much of this area of 400,000 ha was open grassy country with only about eight large trees per hectare when Europeans arrived in the 1830s. Frequent burning by Aboriginals, and grazing by indigenous marsupials, restricted the opportunities for trees and shrubs to establish. Fire germinated the seed of the trees and shrubs but rat kangaroos ate many of the resulting seedlings before they could establish.

The introduction of sheep reduced the numbers of rat kangaroos, by destroying their cover and their food. A severe drought during the major El Niño of 1877/78 further reduced the numbers of indigenous marsupials. The following year, a major La Niña event, was very wet. The few large trees seeded well and when stock owners burnt to destroy grasses with seeds that got into their sheep's wool, seedlings came up thickly, unhindered by the grasses which would usually compete with them for space. This time there were no rat kangaroos to eat the seedlings either and the trees grew unchecked.

Over the next decade there were several further periods of establishment, again synchronised with El Niño – La Niña oscillations. The European rabbit, also an enthusiastic eater of seedlings, arrived in the area in the late 1880s and prevented further establishment until myxomatosis in 1951 reduced the rabbit population. The first successful release of myxomatosis occurred in 1950. Earlier releases of the disease had not led to widespread establishment. The extensive rains and flooding in 1950, associated with a major La Niña, contributed to the successful establishment of the disease by providing ideal breeding conditions for the insects that spread it.

In 1917 the Forestry Commission stopped burning in the Pilliga and by 1950 large amounts of forest litter had accumulated. So had decades of seed production. The forest dried in the El Niño event of 1951, following good growth during the La Niña of 1950, and a major fire started in November 1951. In the absence of rat kangaroos and rabbits, the new growth induced by the fire had nothing to stop it.

In less than a century Europeans had unintentionally transformed the area from grazing land into the dense Pilliga Scrub supporting sustained timber harvesting. The El Niño - Southern Oscillation phenomenon played a critical role in this transformation. McKeon et al. (1990) cite other examples where the extreme climate events associated with both extremes of the El Niño - Southern Oscillation resulted in major long-term vegetation degradation. In western Queensland there was a rapid increase in sheep during the above-average rainfall years of the early 1890s. Major El Niño events between 1899 and 1902 resulted in very low rainfall and a rapid drop in animal numbers. Heavy utilisation of edible grasses and shrubs during this drought led to a spread of inedible plants and carrying capacities seem to have been permanently. In the subtropical grasslands of southern coastal Queensland, rapid change in species composition to bunch spear grass appears to have resulted from overgrazing with sheep during the El Niño-related drought of 1881-82. More recently, low beef prices in the mid-1970s led to increased stocking rates in Queensland. These years were wet, the result of the 1973-75 La Niña, but attempts to maintain the high stocking rates into the 1980s with their drier, El Niño conditions have led to pasture degradation, species changes and soil erosion.

Impacts of the El Niño - Southern Oscillation on Australian crops

Not surprisingly, given its effects on Australian climate, the El Niño - Southern Oscillation has a major impact on crop yields. Figure 2 shows time-series of wheat yields, averaged across Australia, and the SOI. The year-to-year differences in the two variables are plotted, to remove the effects of trends and changes such as the introduction of new cultivars. The relationship is clear – negative values of the SOI lead to widespread drought (Figure 2) which leads to low crop yields (Nicholls, 1985).

Rimmington and Nicholls (1993) demonstrated that wheat yields in all states were correlated with values of the SOI from before and near sowing date, which therefore can provide skilful yield forecasts of Australia's major crop. These forecasts would be available several months before harvest starts, require little data, and are quick and simple to prepare. Strong negative relationships also exist with the SOI in the year before the crop is planted, ie an El Niño episode is often followed by good crops the following year. This partly reflects the biennial nature of the El Niño - Southern Oscillation, but may also reflect a tendency for a drop in pests in the droughts associated with negative SOI values. This would amplify any response of the crops to good rains in the following year.

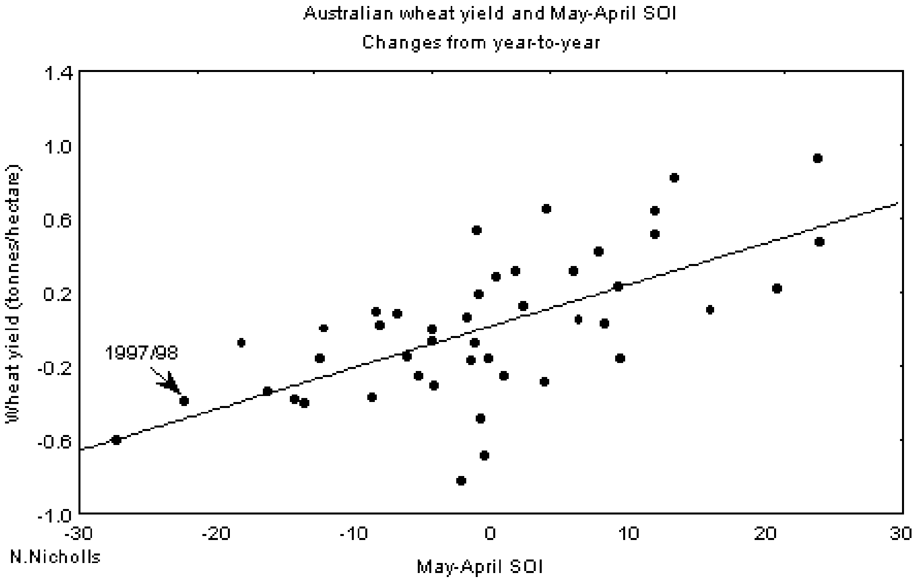


Figure 3. Annual mean SOI (full line) and the yield (tons per hectare) of wheat, averaged across the country. Differences from year-to-year in SOI and yield are plotted, to remove long-term variations such as the effects of changes in cultivars.

Hammer et al. (1996) examined the value of El Niño-Southern Oscillation based forecasting methodologies to wheat crop management in northern Australia, by examining decisions on nitrogen fertiliser and cultivar maturity using simulation analyses of specific production scenarios. The average profit and risk of making a loss were calculated for the possible range of fixed (ie., the same each year) and tactical (ie, varying depending on the El Niño–Southern Oscillation based seasonal forecast) strategies. Significant increases in profit (up to 20%) and/or reduction in risk (up to 35%) of making a loss were associated with the tactical (forecast-based) strategies. The skill in seasonal rainfall and frost predictions, based on the El Niño - Southern Oscillation, generated the value from using tactical management. This study demonstrated that the skill obtainable in Australia was sufficient to justify, on economic grounds, their use in crop management. Presumably, these forecasts could also be useful in drought-management decision making, for instance in determination of appropriate stocking rates on pastoral properties (McKeon et al., 1990).

What is APSIM?

APSIM stands for Agricultural Production Systems sIMulator. The APSIM modelling framework has many advantages. One of the main benefits, and also one of the most important design specifications, is the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or sub-models on a common platform.

This functionality has been achieved via the implementation of a "plug-in-pull-out" approach to APSIM design. APSIM has been developed in a way that allows the user to configure a model by choosing a set of sub-models from a suite of crop, soil and utility modules. Any logical combination of modules can be simply specified by the user "plugging-in" required modules and "pulling out" any modules no longer required.

As with any system, there are logical boundaries in that a system being simulated will require the necessary elements (in this case, modules) of that system to be valid, but the possible valid permutations of sub-models are many and varied. For example, APSIM couldeasily allow the user to simulate a cropping system using 2 different water balances, 2 different soil Nitrogen balances and 3 wheat models. The user would be able to try all 12 permutations of cropping system sub-models. However, it would be nonsense to try a simulation without a water balance (or surrogate). The simulation would fail due to lack of information for other modules. It is possible to create this invalid system in APSIM but it is destined to fail due to specification inadequacies.

In short, APSIM will allow the coupling of models from separate research efforts but it is up to the designers and users of the sub-model to ensure that it will operate correctly as a component of the system described in conjunction with other APSIM modules.

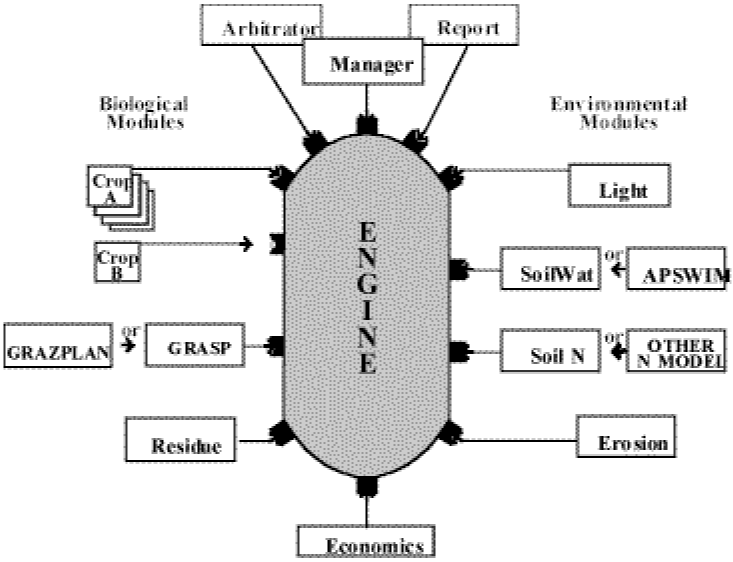


Figure 4. The APSIM engine and its modules. The climate module is embedded within the Environmental Modules.

Annex D

Addresses of Participants

Name	Institution	Address	E-mail
I. Amien	CSAR	Jolan Junanda 98 Boyor, 16123, Indonesia	Csar@bogor.wasantara.net.id
H. Boonjung	SUT	100 University Ave. Suranaree, Muang, Nakhon Patchasima, Thailand 30000	boonjung@ccs.sut.ac.th
G. Centeno	IRRI	Los Banos, Laguna Philippines	g.centeno@cgiar.org
N. Cruz	PAGASA	1424 ATB Bldg. Quezon Ave, Quezon City Philippines	Natcruz@philonline.com.ph
De Li Liu	WWAI	Wagga Wagga Agr. Institute PMB. Wagga Wagga NSW 2650	de.li.liu@agric.nsw.gov.au
N. De Sales	INMET	Instituto Nacional De Meteorogia EIXO Monumental Sul-via SI - Cruzeiro Brazil - Brasilia - DF CEP: 70765-400	NDSales@inmet.gov.br
N. Deshpande	IITM	IITM, Pune 8 India	Nrdesh@tropmet.ernet.in
S. Dube	DRSS	Matopos Research Station Private Mail Bag K 5137 Bulawayo Zimbabwe	Matopos@cgnet.com
J. Egan	SARDI	PO Box 1783, Port Lincoln, SA, 5606	egan.jim@pi.sa.gov.au
A. Ferreira	FUNCEME	Av. Bezerra de Menezes, 1900 Cep. 60.350-002 Fortaleza-CE Brazil	Geraldo@funceme.br
V. Geethalakshmi	TNAU	Dept of Agricultural Meteorology Tamil Nadu Agricultural University Coimbatore - 641003, Tamil Nadu, India	Kcrk@md2.vsnl.net.in Drtnau@md3.vsnl.net.in

B. Haigh	TCCI	Tamworth Center for Crop Improvement RMB 944 Calala Lane Tamworth NSW 2340 Australia	Bruce.Haigh@agric.nsw.gov.au
W. Marume	DMS	Box BE 150, Belvedere Harare, Zimbabwe	Zimmeteo@harare.iafrica.com
J. Pahalad	FMS	Fiji Meteorological Service Private Mail Bag NAP0351 Nadi Aiport, Fiji	Janita.Pahalad@met.gov.fj
F. Parente	FUNCEME	Av. Bezerra de Menezes, 1900 Cep. 60.350-002 Fortaleza-Ce Brazil	Bergson@seproce.ce.gov.br
K.P.C. Rao	NARI	NARI - Aiyura PO Box 384, Kainantu EHP, PNG	Kpcrao@hotmail.com
R. Selvaraju	TNAU	Coimbatore - 6410003, Tamil Nadu, India	Kcrk@md2.vsnl.net.in
L. Unganai	DMC	PO Box BE150 Belvedre, Harare Zimbabwe	Dmc@weather.utande.co.zw
A. Varvaliu	NARI	NARI - Aiyura PO Box 384, Kainantu EHP, PNG	bjwatson@online.net.pg
C. White	DRI	Dryland Research Institute PO Box 432 Merredin WA 6415	cwhite@agric.wa.gov.au
Ms. Widiastuty	MGA	MGA Indonesia JL. Angkasa I # 2 Jakarta, Indonesia	bmg@cbn.net.id

Annex E

IRI Background and Training Activities

To fulfill U. S. commitments to the United Nations Conference on the Environment and Development (UNCED, Rio de Janeiro, Brazil, 1992), National Oceanic and Atmospheric Administration (NOAA) undertook a Pilot Project to demonstrate the functioning concepts of an International Research Institute for climate prediction (IRI). The Pilot Project, which started in 1993, was designed to provide practical experience and generate products useful in implementing a multinational Institute. Activities of the Pilot project included:

- Training courses for scientists from the climate, hydrology and agricultural communities. The courses provided insight on the latest climate models and products as well as the potential for practical applications;
- Workshops to initiate multidisciplinary dialogue in regions around the world, evaluate the potential for practical application of seasonal to interannual climate prediction including decision-making;
- Projects to compare experimental simulations obtained from several ocean-atmosphere coupled models.

The purpose of training courses is to expose experts from different sectors with some familiarity with seasonal to interannual climate variability and the El Nino Southern Oscillation (ENSO) phenomenon and related impacts in agriculture and water resources, to state-of-the-art climate prediction. Most of the scientists were trained at the Lamont-Doherty Earth Observatory (LDEO) of Columbia University.

In an effort to develop linkages between the climate forecasting community and users, the NOAA Office of Global Programs (OGP) sponsored 15 regional workshops in Argentina, Australia, Brazil, Costa Rica, Indonesia, Italy, Peru, United States, Uruguay and Zimbabwe. More than 500 scientists, resource managers and government decision-makers have participated in these workshops.

Research and development activities were carried out at the Scripps Institution of Oceanography (SIO) of University of California San Diego (UCSD). These efforts were aimed at evaluating predictive skills and providing probabilistic forecast products on a timely fashion.

An International Forum on Forecasting El Nino, convened by the White House Office of Science and Technology and chaired by NOAA officers, took place in Washington DC. during November 1995. One of the purposes of the Forum was the launching of the IRI. More than 40 countries and 20 governmental and non-governmental organizations attended. During the Forum the progress from the pilot activities were reported. The U.S. confirmed its commitment to provide initial support for a central facility to support the IRI mission and encouraged the participants to join this effort in pursuing the establishment of a multi-national Institute.

During 1996 the IRI was established under a cooperative agreement between NOAA/OGP, LDEO of Columbia University and SIO. The IRI is now completing the development of a workable structure to combine worldwide research capabilities with explicit operational and applications objectives. Its core facility, located at LDEO, comprises social-science and physical-science elements and serves as the nucleus for partnerships within an international network of research and modeling institutions and application centers. Central to the role of the IRI is the continuation of a vigorous training program. The program has engaged nearly 150 persons from around the globe in the possible applications of predictable elements of climate to a range of sectors.

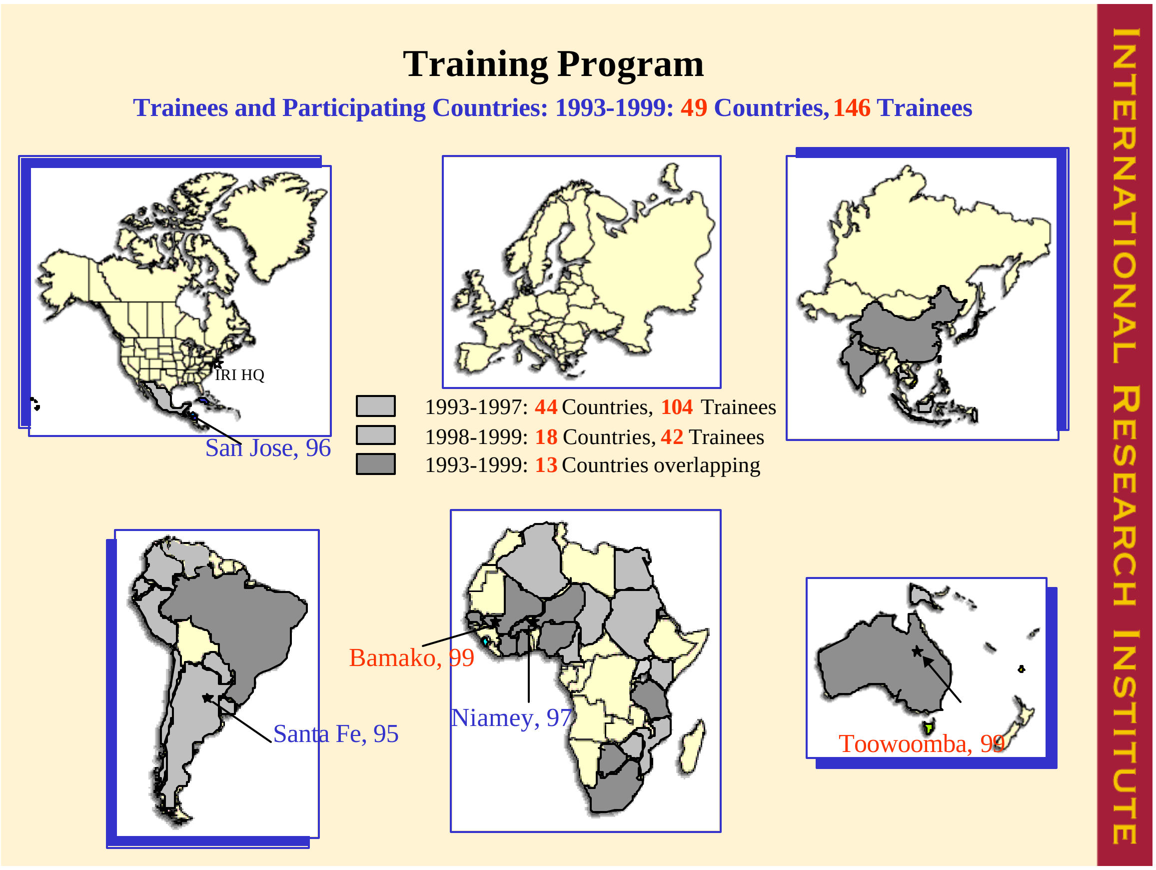


Figure 1. Maps showing participating countries and number of trainees since 1993

Topics for the 9 IRI training courses to date (1993-1999) include:

1. March 1993- January 1994:

First International Training Course on Practical and Theoretical Aspects of Short term Climate Prediction, LDEO of Columbia University, Palisades, NY.
9 Trainees, 5 Countries

2. March 1994- December 1994:

Second International Training Course on Practical and Theoretical Aspects of Short term Climate Prediction, LDEO of Columbia University, Palisades, NY.
10 Trainees, 9 Countries

3. March 1995-June 1995:

First International Training Course on Practical Applications of Short Term Climate Prediction to Agriculture, LDEO of Columbia University, Palisades, NY.
9 Trainees, 7 Countries

4. November 1995- January 1995:

First International Training Course on Practical Applications of Short Term Climate Prediction to Water resources Management, LDEO of Columbia University, Palisades, N.Y.
8 Trainees, 7 Countries

5. July 1995:

Regional Training Course on Practical Applications of Short Term Climate Predictions to Hydrology and Water Resources Management in Central and South America, Santa Fe, Argentina.
23 Trainees, 10 Countries

6. August 1996:

Regional Training Course on Practical Applications of Seasonal to Interannual Climate Predictions to Water Resources and Agriculture in Mesoamerica and the Caribbean, San Jose, Costa Rica.
20 Trainees, 8 Countries

7. July-August 1997:

First Regional Training Course on Practical Applications of Seasonal to Interannual Climate Predictions to Decision Making in Agriculture and Water Resources Management in Africa, Niamey, Niger, Africa.
25 Trainees, 20 Countries

8. February-March 1999:

Applications of Climate Forecasting to Agriculture, Toowoomba, Australia.
21 Trainees, 8 Countries

9. March-April 1999:

Climate Prediction and Diseases/Health in Africa, Bamako, Mali, Africa.
21 Trainees, 12 Countries

Annex F

IRI Training Publications

(Countries and regions are highlighted in blue in the electronic version of this document)

1993

Voice, M.E., 1993: *A Significant Start: Multinational and Regional Collaboration in the Development of Tools for Seasonal to Interannual Climate Forecasting*. IRIP-TL-93/1.

Bertacchi Uvo, C., and Repelli, C.A., 1993: *A Study on the Influence of the Pacific and Atlantic SST on the Northeast Brazil Monthly Precipitation Using Singular Value Decomposition (SVD)*. IRIP-TL-93/2.

Repelli, C.A., 1993: *Principal Component Analysis of the Precipitation over Semi-Arid Region of the Northeast Brazil*. IRIP-TL-93/3.

Montecinos, A., 1993: *On the Predictability of the Austral Winter Rainfall in Central Chile (30°S - 40°S) Using Sea Surface Temperature in the Pacific Ocean*. IRIP-TL-93/4.

Yu, Z-P., 1993: *On the Prediction of Rainfall Variability in the Hawaiian Islands*. IRIP-TL-93/5.

Roswintiarti, O., 1993: *Climate Anomaly of the Indonesian Archipelago Related with El Niño/Southern Oscillation and Its Short-Term Prediction*. IRIP-TL-93/6.

Cornejo, A., 1993: *On the Feasibility of Forecasting Precipitation Over the Peruvian Andes*. IRIP-TL-93/7.

Landman, W., 1993: *A Study of the Rainfall Variability of the summer Rainfall Regions of Soutern Africa, As Revealed by Principal Component Analysis*. IRIP-TL-93/8.

Diaz, A. and Studzinski, C., 1993: *Main Features of Rainfall Variability in Uruguay-Southern Brazil Region and Prediction Experiments Through Statistical Models*. IRIP-TL-93/9.

1994

Tanco, R., 1994: *Relationship Between ENSO Cycle and Rainfall in Argentina and Its Short Term Prediction Using Canonical Correlation Analysis*. IRIP-TL-94/1.

Zhang, B-L., 1994*: Predicting Precipitation and Temperature Anomalies over China by Use of Cane-Zebiak Model Output*. IRIP-TL-94/2.

Zhao, Z-C., 1994: *Practical Applications of Short-Term Climate Forecast to Crop Yield Predictions in China*. IRIP-TL-94/3.

Silva Guerrero, G., 1994*: Marine Productivity Seasonal Forecast Along the Ecuadorian Coastal Zone Based on Physical Models of ENSO*. IRIP-TL-94/4.

Krishna Kumar, K., 1994: *Forecasting of Indian Summer Monsoon Rainfall on Smaller Regional Scales Using Canonical Correlation Analysis Technique*. IRIP-TL-94/5.

Ishii, M., 1994: *A Statistical Forecast Experiment for Seasonal Air Temperature in Japan Using a Model Identification Criterion*. IRIP-TL-94/6.

Indeje, M.B., 1994: *Diagnostics of East African Rainfall 1951-1990 and Forecasting of the September-November Seasonal Rainfall Using Empirical Methods*. IRIP-TL-94/7.

Vazquez, M.A., 1994*: Diagnostic and Prognostic Study of Rainfall Variability in Paraguay in Connection with ENSO Events*. IRIP-TL-94/8.

Chang, J-C.J., 1994: *An Exploratory Study of the Relationship between Annual Frequency of Invaded Typhoons in Taiwan and El Niño/Southern Oscillation*. IRIP-TL-94/9.

Zhakata, W., 1994: *Relationships between Sea-Surface Temperature and Seasonal Rainfall in Southern Africa*. IRIP-TL-94/10.

1995

Diaz, R.A., 1995: *Seeking Practical Applications for Short Climate Predictions in the Agriculture of Argentina*. IRIP-TL-95/1.

Fontana, D.C., 1995: *The Influence of the ENSO Phenomenon Over Maize Yields in the State of Rio Grande do Sul*. IRIP-TL-95/2.

De Oliveira, S.B.P., 1995: *The Impact of Interannual Climate Variability on Maize Yield in Northeast Brazil*. IRIP-TL-95/3.

Currie, W., 1995: *Short Climatic Prediction and Wheat Production in Chile, a First Approach*. IRIP-TL-95/4.

Dai, X., 1995: *Preliminary Modeling of ENSO Impacts on Wheat Yields in China*. IRIP-TL-95/5.

Kitheka, S.K., 1995: *Relating the ENSO Phenomenon to Seasonal Precipitation Variability and Maize Production in Semi-Arid, Eastern Kenya*. IRIP-TL-95/6.

Lecler, N.L., 1995: *Generation of Composite Daily Weather Sets for Climate Prediction Applications*. IRIP-TL-95/7.

Pedocchi, R., 1995: *Short-Climatic Prediction and Wheat Production in Uruguay*. IRIP-TL-95/8.

Mutikani, V., 1995: *A Study of ENSO Impacts on Crop Production in Zimbabwe*. IRIP-TL-95/9.

Cacik, P.A., 1995: *Relationship Between Climate Variability in the Pacific and Atlantic Oceans and River Flows in the Upper Parana River Basin*. IRIP-TR-SF95/1. (Spanish)

Carril, A. and Doyle, M. 1995: *Study of the River Flows in the Provinces of San Juan and Mendoza and its Relationship with the Southern Oscillation Index*. IRIP-TR-SF95/2. (Spanish)

Flamenco, E.A., 1995: *Prediction of Seasonal Volumes of Mountain Rivers in Argentina Due to Snow Melt*. IRIP-TR-SF95/3. (Spanish)

Ghietto, M.A., 1995: *Relationship between ENSO Events and River Flows in the Iguazu River Basin*. IRIP-TR-SF95/4. (Spanish)

Moyano, M.C., 1995: *Relationship Between the Variability of River Flows in the Buenos Aires Province, Argentina, and ENSO Indices*. IRIP-TR-SF95/5. (Spanish)

Vanlesberg, S.B., 1995: *Relationship Between Climate Variability and Water Levels at Puerto Parana, Argentina*. IRIP-TR-SF95/6. (Spanish)

Vila, D.A., 1995: *Introductory Study of the Relationship Between Enso Cycles and Mean Temperature in Argentina*. IRIP-TR-SF95/7. (Spanish)

Zucarelli, G.V., 1995: *Relationship Between Climate Variability and River Flows in the Paraguay River Basin*. IRIP-TR-SF95/8. (Spanish)

Althoff, D.A. and Moura de Andrade, F.C., 1995: *The Relationship Between the Sea Surface Temperature Anomalies in the Pacific Ocean and Precipitation and River Flow Anomalies at Chapecó, Brazil, and its Utility in Soil Conservationist Practices*. IRIP-TR-SF95/9. (Portuguese)

Moura de Andrade, F.C., 1995: *Influence of El Niño on the Variability of River Flows in Ceará State, Brazil*. IRIP-TR-SF95/10. (Portuguese)

Risso, A., 1995: *Preliminary Study of the Uruguay River Flow Predictions as a Function of Sea Surface Temperatures in the Equatorial Pacific and the South Atlantic Oceans*. IRIP-TR-SF95/11. (Spanish)

Benitez, G.D., 1995: *River Flow Anomalies in Chile: An Attempt at Forecasts Based on the Influence of ENSO.* IRIP-TR-SF95/12. (Spanish)

Castro A., G., 1995: *Study of the Relationships Between ENSO and the Hydrological Regime of Basins in Central Chile*. IRIP-TR-SF95/13. (Spanish)

Cadavid M., E., 1995: *Estimation of River Flow Prediction Models for the Colombian Electrical Sector Using Macroclimatic Indices Associated with ENSO*. IRIP-TR-SF95/14. (Spanish)

Pizarro D., H. and Salazar V.,J., 1995: *Practical Applications of Climate Prediction to River Flow Forecasts for Hydroelectricity Generation by the Public Companies Of Medellin*. IRIP-TR-SF95/15. (Spanish)

Villagomez del Pozo, W.M., 1995: *River Flow Predictions for the Planning and Management of the Paute and Agoyan Hydroelectric Plants of Ecuador*. IRIP-TR-SF95/16. (Spanish)

Sanchez-Sesma, J., 1995: *Statistical Interannual Forecast of Summer and Winter Accumulated Rainfall in Mexico Using Geophysical and Astronomical Teleconnections.* IRIP-TR-SF95/17. (Spanish)

Mendez, A., 1995: *Preliminary Study on the Influence of El Niño in Forecasting River Flows in the Chiriqui River Basin of Panama*. IRIP-TR-SF95/18. (Spanish)

Portocarrero, R.C., 1995: *Introduction to the Study of the Relationship Between ENSO Cycles and River Flows from Glaciers in the Cordillera Blanca of the Peruvian Andes*. IRIP-TR-SF95/19. (Spanish)

Salcedo B., J., 1995: *Preliminary Study of the Relationship Between El Niño and the Flow of the Chira de la Costa River*. IRIP-TR-SF95/20. (Spanish)

Rojas P., M.I., 1995: *The Influence of Enso on the Yaracuy River Basin of Venezuela*. IRIP-TR-SF95/21. (Spanish)

1996

Flamenco, E.A., 1996: *Seasonal Volume Forecasts Originating from Snowmelt - Diamante River*. IRIP-TL-96/1.

Ghietto, M.A., 1996: *Diagnostic and Prediction of the Volume Anomalies in La Plata Basin - South America*. IRIP-TL-96/2.

Sanchez, J., 1996: *Pantanal Region in Brazil: SST and Its Relation with the Hydrology of the Area*. IRIP-TL-96/3.

Geng, Q., 1996: *Prediction and Assessment of the Impacts of Short-Term Climate Variabilities on the Water Resources of China*. IRIP-TL-96/4.

Salazar Velasquez, J.E., 1996: *A Study of the ENSO Effect on the River Streamflow in the Colombian Hydroelectric Generation System*. IRIP-TL-96/5.

Karoki Njogu, A., 1996: *Relationship Between Runoff and Ocean-Atmospheric Variables and Seasonal Runoff Prediction in the Lake Basin in Kenya*. IRIP-TL-96/6.

Portocarrero, C.A., 1996: *The Pacific Ocean Sea Surface Temperatures Variability and Its Relationship with Three Regions in Peru: Trial of a Project of Climate Prediction*. IRIP-TL-96/7.

Madamombe, E.K., 1996: *A Preliminary Study of the Relationship Between ENSO Events and Runoff on Some Selected Catchments in Zimbabwe*. IRIP-TL-96/8.

Granados C., J., 1996: *Practical Application of Climate Prediction to Hydrologic Forecast for the Hydroelectric Generation System of the Costarican Institute of Electricity*. IRIP-TR-SJ96/1 (Spanish).

Herrera Soto, H., 1996: *Preliminary Study of the Relationship Between Sea Surface Temperatures in the Equatorial Pacific Ocean and the Number of Days of Rain in the Central Valley of Costa Rica*. IRIP-TR-SJ96/2 (Spanish).

Machado, P.J., 1996: *Relationship Between Climate Variability Associated with ENSO and Streamflows in the Grande de Terraba River, Costa Rica*. IRIP-TR-SJ96/3 (Spanish).

Murillo Vargas, R., 1996: *On the Prediction of Low River Discharges in the Cañas River, Costa Rica, for Irrigation Planning and Drought Mitigation*. IRIP-TR-SJ96/4 (Spanish).

Retana, J.A., 1996: *ENSO as a Potential Predictor for the Grasshopper Plague*. IRIP-TR-SJ96/5 (Spanish).

Sandoval Vazquez, J.F., 1996: *Climatic Variability and Black Bean Crop Yield in Southern Costa Rica*. IRIP-TR-SJ96/6 (Spanish).

Stolz España, W.R., 1996: *Relationship Between Macroclimatic Variables and Precipitation Anomalies over the Caribbean Drainage Region of Costa Rica*. IRIP-TR-SJ96/7 (Spanish).

Ureña Elizondo, F., 1996: *Relationship Between the Sea Surface Temperatures, Sea Level at Quepos, and Fisheries on the Pacific Ocean*. IRIP-TR-SJ96/8 (Spanish).

Centella Artola, A., 1996: *Preliminary Linear Regression Forecast Model for the Winter Rains in Western Cuba*. IRIP-TR-SJ96/9 (Spanish).

Portuondo Lopez, Y., 1996: *Preliminary Study of the Prediction of Underground Water Levels in the Jaruco Sub-Basin, Cuba*. IRIP-TR-SJ96/10 (Spanish).

Murillo, R.A., 1996: *The Impact of Climatic Variability on Rains in the Central Region of El Salvador*. IRIP-TR-SJ96/11 (Spanish).

Castro Loarca, O.R. and Bautista Godinez, M.R., 1996: *Preliminary Study of the Effect of Sea Surface Temperature Anomalies in the Equatorial Pacific Ocean on Sugar Cane Yields in the Southern Coast and Wheat Yields in the Western Plateau of Guatemala*. IRIP-TR-SJ96/12 (Spanish).

Paz, R.E. and Carbajal, M.J., 1996: *Preliminary Study on the Prediction of High River Flows in the Humuya River, Honduras and the ENSO Phenomenon*. IRIP-TR-SJ96/13 (Spanish).

Conde, C., 1996: *Forecast of Water Storage in the Tacotan Dam, México, Considering Sea Surface Temperature Anomalies in the Niño3 Region*. IRIP-TR-SJ96/14 (Spanish).

Palacio Ruiz, L.S., 1996: *Statistical Diagnosis of Riverflows at Centroamericana Plant, Nicaragua, and its Relationship with ENSO During the Period 1965-1991*. IRIP-TR-SJ96/15 (Spanish).

Picado Traña, F., 1996: *Relationship Between Sea Surface Temperature Anomalies in the Niño3 Region of the Pacific Ocean and Rainfall Anomalies in Managua, Nicaragua*. IRIP-TR-SJ96/16 (Spanish).

Rivas Videa, J.R., 1996: *Preliminary Diagnosis on the El Niño Influence on Black Bean and Corn Yields in Nicaragua*. IRIP-TR-SJ96/17 (Spanish).

Olmedo, B.A., 1996: *A First Approach to the Study of the Relationship Between Sea Surface Temperature Anomalies in the Niño3 Region of the Pacific Ocean and Rainfall Anomalies in the La Cordillera Station, Panama*. IRIP-TR-SJ96/18 (Spanish).

1997

Salah S. Abed, 1997: *Seasonal Rainfall Prediction at the NW of Africa*. IRIP-TR-N97/1

Lazreg Benaichata, 1997: *Prediction of Seasonal to Interannual Rainfall Variability in Algeria as an Early Warning Tool in Agricultural Production.* IRIP-TR-N97/2

Akintayo Adedoyin, 1997: *The Impact of Climate Variability on the Tourism Industry in Botswana*. IRIP-TR-N97/3

Frederic N. Ouattara, 1997: *Predictability of Seasonal Rainfall in Burkina Faso Using Sea Surface Temperature Anomalies*. IRIP-TR-N97/4

Mbainayel Samuel, 1997: *Seasonal Rainfall Variability Prediction in Chad*. IRIP-TR-N97/5

Yaya Berte and Fofana Ibrahim, 1997: *Seasonal Forecast of Rainfall Amount in Cote d'Ivoire Using Equatorial Atlantic Sea Surface Temperature Anomalies*. IRIP-TR-N97/6

Mohammed A. A. Dawod, 1997: *Long Range Forecast of Seasonal Rainfall in the North Coast of Egypt*. IRIP-TR-N97/7

Tsehaie Tseghe, 1997: *Seasonal Rainfall Prediction in Eritrea*. IRIP-TR-N97/8

Z. Minia, E. O. Martin and G. K. Banini, 1997: *Applying Statistical Methods to Develop a Seasonal Rainfall Prediction Model for Ghana Using Sea Surface Temperatures as Predictors*. IRIP-TR-N97/9

Barry A. Boubacar, 1997: *Predicting Seasonal Rainfall in Guinea*. IRIP-TR-N97/9

João L. Tchedna, 1997: *Seasonal Rainfall Prediction in Guinea-Bissau*. IRIP-TR-N97/10

Simon T. Gathara, 1997: *Early Warnings of Extreme Climate Anomalies for Enhanced and Sustainable Agricultural Production in Kenya*. IRIP-TR-N97/11

Samuel W. Kahuha, 1997: *Seasonal to Interannual Climate Prediction at the Kenyan Coast*. IRIP-TR-N97/12

Jolamu L. Nkhokwe, 1997: *Prediction of Malawi Seasonal to Interannual Rainfall Variability, as an Early Warning Tool in Agriculture, Water Resources and Health Management Decision Making*. IRIP-TR-N97/13

Maiga A. Sagayar, 1997: *Forecasting July to September Seasonal Rainfall over Mali Using Sea Surface Temperature Anomalies*. IRIP-TR-N97/14

Deve D. Orkuma, 1997: *An Attempt to Predict the Seasonal Rainfall Variability of Northern Nigeria*. IRIP-TR-N97/15

Cheikh Toure, 1997: *The Interannual Rainfall Variability of Senegal and its Interconnections with Sea Surface Temperature Anomalies: Climate Forecast Applications*. IRIP-TR-N97/16

Ahmed M. Abdelkarim, 1997: *The Relationship Between Sea Surface Temperatures and the Seasonal Rainfall of Sudan*. IRIP-TR-N97/17

Cleophas G. B. Tibanyenda, 1997: *Seasonal Rainfall Forecasting in South West Tanzania Using Sea Surface Temperatures*. IRIP-TR-N97/18

Abushen W. Majugu, 1997: *Developing Sea Surface Temperature Based Rainfall and River Discharge Seasonal Statistical Prediction Models for Uganda*. IRIP-TR-N97/19

Joseph Merka, 1997: *Predictability of Seasonal Runoff in Zimbabwe*. IRIP-TR-N97/20

Takawira C.Temba, 1997: *Determination of the Degree of Influence of Sea Surface Temperatures on Rainfall in Zimbabwe*. IRIP-TR-N97/21

1999

Electronic Publications (Power Point Presentations)

Widiastuty, I. Amien, H. Boonjung, G. Centeno, and N. Cruz, 1999: Seasonal Climate Forecasting and Rice Management Decisions in Tropical Asia.
http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/Rice_Team_TRT.ppt

Rao, K.P.C., R. Selvaraju, V. Geethalakshmi, J. Pahalad, and N. Deshpande, 1999: Managing Climate Risk in a Rainfed Production System in South India.
http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/Monsoon_1.ppt
http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/Monsoon_2.ppt

Marume, W., A. Varvaliu, S. Dube, L. Unganai, 1999: Livestock Production in Semi-Arid Grazing Systems.
http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/Africa_GPT.ppt

Ferreira, A.G., F. B. Parente, and N. Dantas de Fales, 1999: The Use of Seasonal Climate Forecasting in the Ceara State.
http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/Brazil_SATC.ppt

White, C., J. Egan, B. Haigh, and D.L Liu, 1999: Seasonal Climate Forecasting: Can it improve management in Australian Dryland Winter Cropping Systems?
http://iri.ldeo.columbia.edu/iri/programs/training/toowoomba1999/Australia_DTCT.ppt

Bagayoko, M., M. B. Niamele, M. N. Sogoba, D. Maiga, and A. Toure, 1999: Monitoring and Predicting Malaria Epidemics in Sahelian Zone.
http://iri.ldeo.columbia.edu/iri/programs/training/bamako1999/MALI.ppt

Moodley, I., B. Nawn, R. Thomson, and W. Zhakata, 1999: Using Climate Data to Predict Malaria Epidemics in Southern Africa: A Retrospective Study.
http://iri.ldeo.columbia.edu/iri/programs/training/bamako1999/ZAMO.ppt

Gikangu, D., J. Omoumbo, A. Githeko, and F. Salum, 1999: Multi-Centre Study on the Effect of Climate Variability on Malaria in Eastern Africa
http://iri.ldeo.columbia.edu/iri/programs/training/bamako1999/KETA.ppt

Fondjo, E., MacAuley I. Babila, R. Beida, L. Issa, and M. Djangare, 1999: Effects of Climatic Factors upon Malaria Incidences
http://iri.ldeo.columbia.edu/iri/programs/training/bamako1999/CANI.ppt

Mabri, T., A. S. Moura, O. N'Diaye, and D. Ouedraogo, 1999: Effects of Climate Variability on Human Health in West Africa and Brazil
http://iri.ldeo.columbia.edu/iri/programs/training/bamako1999/C2BS.ppt

IRI Training Project Reports

1994-1999

Berri, G.J., 1994: *Applications and Training Activity Report No.1*, September 1994, 14 pp., IRIP-CL-94/1 .

Berri, G.J., 1995: *Applications and Training Activity Report No.2*, June 1995, 40 pp., IRIP-CL-95/1.

Berri, G.J., 1995: *Recent Advances in Practical Applications of Short Term Climate Predictions to the Regional Impacts of El Niño*, November 1995, 52 pp., IRIP-CL-95/2.

Kushnir, Y., 1995: *An Introduction to Atmospheric Data Analysis*, June 1995, 36 pp., IRIP-AL-95/1.

Tanco, R.A. and Berri, G.J., 1995: *CLIMLAB - CLIMate LABoratory*, December 1995, 56 pp., IRIP-AL-95/2.

Berri, G.J. (ed.), 1996: *The impact of El Niño on Water Resources in the American Continent and New Methodologies of Practical Use to Seasonal and Interannual Hydrologic Forecast*, 1996, 114 pp., IRIP-CR-SF96/1. (Spanish version)

Berri, G.J. (ed.), 1996: *The Impact of El Niño on Water Resources and Agriculture in Mesoamerica and the Caribbean and New Methodologies of Practical Use to Seasonal and Interannual Climate Prediction,* 1996, 94 pp., IRIP-CR-SJ96/2. (Spanish Version)

Berri, G.J. (ed.), 1997: *El Niño Impact on Water Resources in Central and South America, and New Methodologies of Practical Use to Seasonal and Interannual Hydrologic Forecasts,* 1997, 99 pp., IRIP-CR-SF96/1. (English version)

Berri, G.J. (ed.), 1998: *Practical Application of Seasonal and Interannual Climate Prediction to Decision Making In Agriculture and Water Resources Management in Africa.,* 167 pp., IRIP-CR-N97/1.

Tourre, Y. M. (ed.), 1999: *Applications of Climate Forecasting to Agriculture*. 69 pp., IRI-CR-99/1

Tourre, Y. M (ed.), 1999: *Climate Prediction and Diseases/Health in Africa.* 73 pp.,IRI-CR-99/2.