WP 5000 - Final Report

Objectives:

To establish active links with climate scientists in monsoon-affected countries and with international hydrological and agricultural research centres, and to develop a protocol for integrating the output of climate models into crop models to address impact issues.

Deliverables:

D5001: Publication of a brochure outlining the aims of PROMISE and establishment of a mailing list

D5002: Workshop with EU and non-EU partners (held during the second year of the project) focused on the collaborative aspects of model validation and hydrological/agricultural impact studies

D5003: Establish an international network of scientists concerned with the impacts of monsoon climates on cropping systems of Africa and India

D5004: Report on the protocol for integrating information from seasonal forecasts of monsoon climates with impact assessments of crop productivity in India and Africa

Summary

WP5000 has progressed well and all deliverables have been achieved. PROMISE has been promoted widely to scientists in monsoon-affected countries through the project web site, brochures, ICTP conferences, an ICTP workshop, posters and oral presentations and the project mailing list. The two conferences at ICTP associated with PROMISE provided good opportunities for all the partners to interact with scientists from monsoon-affected countries.

The visits carried out by Andrew Challinor and Tim Wheeler to the CGIAR centres have succeeded in establishing an international network of scientists involved in impact assessments of crop productivity. The information gained from these visits about the integration of seasonal forecasts with crop models has proved highly relevant to PROMISE research on the agricultural impacts of climate variability and change (see report on WP3100).

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1. PROMISE brochures *(Emily Black and Julia Slingo)*

Two brochures have been produced and distributed widely within the scientific community. The first four-page brochure consisted of a general section on monsoons, a description of the aims of PROMISE, a list of the European partners and a highlighted section on the data archive. It was used to publicize the project and establish the mailing list. The second eight-page brochure contained more detailed examples of the project results and provided the basis for the publicity for the final conference. Both brochures are available to be downloaded from the project web site.

2. PROMISE web site *(Emily Black)*

Informal discussions at a World Meteorological Organisation workshop in the first year of the project revealed that the majority of scientists from monsoon-affected countries have access to the internet. The "project work" and "people" parts of the web site (http://ugamp.nerc.ac.uk/promise/research and http://ugamp.nerc.ac.uk/promise/people) were subsequently developed with these users in mind. The project work part of the site includes a summary of the results for each work package, a list of publications, reports submitted to the EU and presentations made at conferences by the PROMISE partners. The people section contains information about the PROMISE partners. The website receives several hundred hits per month, many of which originate from users in monsoon-affected countries.

3. Presentations on PROMISE to scientists from monsoon-affected countries
(Emily Black, Andrew Challinor and Franco Molteni (ICTP))

A poster about PROMISE was displayed at the International Conference and Workshop on Forecasting Monsoons from Days to Decades, held in New Delhi between 21 and 26 March 2001. At the meeting, brochures were distributed to forecasters and researchers from India and other monsoon-affected countries in Africa and Asia. The conference was followed by a WMO workshop on monsoon forecasting which provided opportunities to promote PROMISE informally and for us to learn about the data needs and interests of forecasters and researchers from developing countries.

In 2002, Emily Black and Franco Molteni made a presentation on PROMISE to the inter-departmental committee for climate change at the FAO. The presentation was attended by FAO specialists in agriculture, hydrology, forestry and economic analysis. The discussion was wide-ranging and included issues such as down-scaling, the reliability of future climate scenarios, the PROMISE data archive and the relevance of PROMISE to user communities. The meeting led to the final ICTP/PROMISE conference being publicized widely within the FAO and subsequently to several of FAO employees attending the meeting.

ICTP

1. Deliverable D5002: Workshop with EU and non-EU partners *(Franco Molteni)*

A workshop on "Land-atmosphere interactions in climate models" followed by a conference on "Climate variability and land-surface processes: Physical Interactions and regional impacts" have been held at ICTP with the co-sponsorship of PROMISE. These activities were attended by over 130 scientists, including about 80 from developing countries some of whom were sponsored by ICTP through the PROMISE contribution to the meeting. During the workshop, the overall structure and goals of the PROMISE were presented, and a demonstration was held on the use of the data archive. The conference doubled as the annual PROMISE and this provided an opportunity for the partners to disseminate PROMISE research to participants from monsoon-affected countries.

2. PROMISE/ICTP conference on monsoon environments (see also WP6000) *(Franco Molteni)*

ICTP provided sponsorship and logistical support for over 50 participants from monsoon-affected countries to attend the conference on *Monsoon Environments: Agricultural and Hydrological impacts of seasonal variability and climate change***.** This enabled PROMISE research to be disseminated to scientists from monsoon-affected countries and cemented the links established during the project between the PROMISE partners and scientists from developing countries (see WP6000 report for further details)

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1. Deliverable 5003. Establish an international network of scientists concerned with the impacts of monsoon climates on cropping systems of Africa and India *(Andrew Challinor and Tim Wheeler)*

Introduction

Links with international scientists working within agriculture were established through a series of visits on behalf of the PROMISE project. Missions were undertaken to four key institutes of the Consultative Group for International Agricultural Research (CGIAR), to the Food and Agriculture Organisation of the UN, and to two key workshops (Table 1). The CGIAR institutes were chosen to include those scientists who are working with all the world's major cereal and grain legume crops. The FAO-JRC workshop provided an excellent perspective on the impacts of climate on food security in Africa, and also gave an opportunity to explore how PROMISE-related work could fit into a planned network of scientists concerned with food security in Africa. PROMISE researchers were invited to the UK-China meeting, and our participation was funded by DEFRA.

Table 1. *Key institutes visited and meetings attended during the PROMISE project*

Date	Institute visited / meeting attended	Main research items
March 2001	International Crop Research Institute for the Semi-Arid Tropics (ICRISAT, India)	Groundnut, millet and sorghum
Dec 2001	Food and Agriculture Organisation (FAO, Rome)	Irrigation and Agro-ecological Zones projects
Feb 2002	Centro Internacional de Agricultura Tropical (CIAT, Colombia)	Beans and cassava
March 2002	Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT, Mexico)	Wheat and maize
March 2002	International Rice Research Institute (IRRI, the Philipines)	Rice
Sept. 2002	Royal Meteorological society Quantitative precipitation workshop	Poster on WP5000 presented in the impacts session
Sept. 2002	DEFRA UK-China Climate change impacts workshop	The impacts of climate change on Chinese agriculture
Jan. 2003	JRC-FAO workshop on crop monitoring and early warning for food security	Food security on seasonal timescales in Africa

CGIAR Centres

The programme at each of the CGIAR institutes started with the presentation of a seminar entitled 'Seasonal weather forecasting for agriculture' to all the key staff of the institute. A number of potential applications of information from seasonal weather forecasts to agriculture were then highlighted in discussions and further explored in individual meetings.

At CIMMYT and CIAT a questionnaire was also distributed in order to obtain feedback on some of the opportunities provided by seasonal forecasting, and any foreseeable problems which this research area presents. An important issue is the matching of spatial the spatial scale of the forecast to the spatial scale of the application. Rainfall is the forecast variable of most interest, although this does vary with application. Another important research area is the exploitation of the probabilistic nature of seasonal forecasts; in some cases it was only after discussion that this was seen by agricultural specialists as an opportunity rather than a barrier. Much progress was made in such discussions as they opened up new possibilities for collaborative work. The following paragraphs summarise these ideas and opportunities, by giving examples of each type of application discussed.

1. Yield forecasting: CIAT scientists expressed an interest in using seasonal forecasting in conjunction with their crop modelling expertise to develop a risk analysis tool for beans in Central America. Depending on the density of sites available, a downscaling and/or regional modelling study could be performed in order to obtain the input data required for the crop model. The probabilistic seasonal forecast output could be used to assess the risk associated with the growing of different varieties. Whilst drought tolerant varieties are ideal in low-rainfall years, they produce reduced yields (when compared to standard varieties) if rainfall is nearer to climatology. A forecast lead time of a few months would be required in order to assess the risk associated with each of these varieties.
2. Crop scheduling: A knowledge of when dry spells are likely to occur would allow growers to plan planting for a suitably dry spell just prior to rain. Planting could also be scheduled such that the risk of water stress at critical development stages such as flowering is minimised. Discussions at CIMMYT revealed that dry spells of three weeks or more are the most significant for this type of planning.
3. Disease control: If the potential spread of crop diseases could be more accurately predicted, spraying could be undertaken earlier, and damage to the crop limited. Specific example for the case of cassava were discussed at CIAT. The principle diseases for cassava are correlated with rainfall and humidity, and lead times of three weeks could be useful for this application. The need for high spatial resolution presents the greatest challenge in this case. There was also an interest expressed in assessing the impacts of climate change on the pattern and spread of crop diseases. Another example, discussed at CIMMYT, is the use of seasonal forecasting to determine years for which maize streak virus is likely to present a serious problem. This virus can reduce yield to near-zero, and in one third of seasons it has an important impact on productivity.
4. Participatory research: An idea that arose from more than one source was to use local growers knowledge in conjunction with forecast information in order to maximise the value and accuracy of the forecasts. The integration of scientific agricultural knowledge and local knowledge is being explored by a group of scientists at CIAT. A day was spent at a participatory research meeting in a school house in rural Colombia (in the Cali area), where a scale model of the local area was used to facilitate this integration of knowledge. A collaboration where this idea is applied to seasonal forecasting is being explored.

Applications to rice and groundnut, as well as other crops, were discussed at ICRISAT and IRRI. Forecast accuracy was seen to be an issue, as was spatial scale. A summary of the outcome of discussions at ICRISAT and IRRI is presented in Table 2.

Table 2. *Examples of potential applications of seasonal weather forecasts for crop production in semi-arid regions identified by staff at ICRISAT, India.*

Application	Background	Information required	End-users
Aflatoxin contamination of groundnut	Aflatoxin is a carcinogenic toxin produced by a fungus which grows on groundnut seeds during crop growth under certain climatic conditions, and in subsequent seed stores. It is a major risk to human health and livestock, and restricts access of agricultural products to global markets.	Soil temperature and rainfall during crop growth required up to 60d ahead	Agricultural planning agencies and extension services. The livestock feed industry.
More efficient use of agricultural inputs	Inorganic fertilis ers are expensive inputs for semi-arid crop production. Fertilisers are less effective in promoting crop growth and yield in dry compared with wet seasons.	Crop water balance up to 120d ahead	Government extension services and larger-scale farmers
Livestock feed quality of sorghum	The quality of sorghum grain for livestock is reduced drastically if the crop is infected by grain molds during crop growth. The spread of grain molds in sorghum crops is linked to rainfall and humidity, but infection is only apparent after harvest.	Rainfall and humidity up to 30d before harvest	National livestock feed industry. Possibly, short-term (7d) information for farmers
Soil salinity forecasting for crop impact assessment	Coastal and inland salinity area affected by storms and droughts. Salinity in turn affects rice physiology, which can have an impact upon yield.	Storminess / rainfall on seasonal timescales	Farmers
Water level forecasting for paddy rice	Paddy rice is affected by the level of water in which it is grown. For example, deep-water tolerant varieties can be sown if high rainfall is forecast.	Soil water balance 1-2 months ahead	Farmers
Transplanting vs. direct seeding for rice	If rainfall at the start of the season is low then direct seeding methods are favourable. For higher rainfall seedlings transplanted into standing water will fare better.	Soil water balance 2-4 weeks ahead	Farmers

Workshops

The FAO-JRC workshop in Kenya aimed to summarise the state-of-the-art in crop monitoring and yield forecasting at the regional level, and to then establish an informal network for improved information dissemination and method development. PROMISE work on the methodology for combining seasonal weather forecasting and yield forecasting was presented.

There was much discussion on the way in which crop monitoring and yield forecasting (CMYF) can contribute to the goal of increased food security. Who are the potential users of such information? This is not a clear-cut matter, but the final consensus seemed to be that it is NGOs and local planners who are the immediate users, with farmers being both important sources of information, and the beneficiaries of CMYF. Some users expressed concern at the number of CMYF systems available, especially given that crop yield is one of many factors affecting food security. In some regions accurate CMYF systems cannot contribute to improved livelihoods since there are too many other variables such as access to food, imports and exports, market prices, serious conflicts, nutrition levels etc. Some of these regions experience a lack of basic data e.g. Eritrea, whose population is estimated to be somewhere in the region of 3.2 to 4.2 million. In this context some users advocated a CMYF intercomparison to determine the best tool for the job. Model developers pointed out that all models have inherent uncertainties, and that a convergence of results is likely to imply reliability. They advocated a standardisation of (input) data, not of models, and also asked for more and more-accurate data. (An example was cited of a sudden increase in reported yields in one country attributable to a visit from an important foreign figure).Various working groups were set up in order to look at some of the emergent issues, and one of these groups (looking at crop modelling methods for food security) is highly relevant to PROMISE research, and PROMISE scientists are involved.

The DEFRA-funded UK-China project is seeking to assess the impacts of climate change on Chinese agriculture. This is being achieved by the development of climate change and socio-economic scenarios, crop models, land use change scenarios and integrated assessment modelling. Amongst the objectives of the workshop attended was an increase levels of international coordination and the provision of a forum for experts from China and the UK. A number of useful contacts were made during the course of the visit, and this has resulted in increased collaboration between PROMISE partners at Reading and DEFRA, ADAS (UK) and the Agro-Meteorology Institute in Beijing. Links with the parallel UK-India project are also being explored.

Both of these workshops contributed to the PROMSE goal of the establishment of an international group of scientists concerned with monsoon impacts.

2. Deliverable 5004. Report on the protocol for integrating information from seasonal forecasts of monsoon climates with impact assessments of crop productivity in India and Africa. *(Andrew Challinor and Tim Wheeler)*

Weather and climate are key determinants of the productivity of crops grown in many regions of the world. Our understanding of the effects of weather on the growth and yield of crops continues to improve through the efforts of crop scientists and agrometeorologists. Forecasts of crop production for the coming season require accurate seasonal weather forecasting. In recent years substantial progress has been made in the development of operational seasonal weather prediction systems, such as that at the European Centre for Medium Range Weather Forecasting (ECMWF; http://www.ecmwf.int/services/ seasonal/).

The continuing development of both crop simulation models and numerical weather prediction models presents an opportunity to combine these models into a single crop and weather forecasting system. However, reliable output will not result from simply linking two such models. Consideration must be given to the spatial and temporal scales on which the models operate, the relative strengths and weaknesses of the individual models, as well as the nature and accuracy of the model predictions. The resulting improvements in forecasting would support agricultural planning, and give government bodies and aid agencies time to respond to impending shortages. On longer timescales, such process-based forecasting has the potential to provide skilful forecasts of food production for possible future climates, where empirical methods would not necessarily be expected to perform well.

Many of the less economically developed countries are the most vulnerable to weather and potential climate change. They are often in regions with high seasonal and subseasonal variability in weather. Hence in these regions weather variations pose a threat to food security, especially given the limitations on economic resources faced by these countries. This need for reliable seasonal prediction in both current and future climates, coupled with the recent and ongoing increase in the skill of both crop models and seasonal forecast models, make seasonal crop productivity forecasting a timely and important research topic.

METHODOLOGY FOR THE DEVELOPMENT OF A COMBINED SEASONAL FORECAST SYSTEM

The overall methodology proposed here is to take an integrated approach to the forecast system to address the research issues outlined above. This involves using known relationships to develop models which can be combined optimally to produce results of known accuracy. An important part of this is to take advantage of the probabilistic methods used in seasonal weather forecasting to both optimise and quantify accuracy. The following sections describe in more detail the methodology advocated.

1. Proof of concept

An understanding of the nature of the relationship between observed weather variables and crop yield or crop quality is central to the development of a combined weather/ crop system. ***If there is no correlation between these variables on the scale at which the system operates, then the system is not feasible***. As this relationship is likely to vary geographically, a method needs to be found to account for this - perhaps by using large scale patterns as a key to understanding the response of yield.

This first stage, then, investigates the relationship between weather and crops on a relevant common spatial scale. A successful proof of concept will demonstrate a correlation on this scale. A link must then be established between the data on the scales at which they are available, and for the common spatial scale. Once this has been done, only one hypothesis is required - that subsequent modelling work at the common spatial scale can provide useful information on weather and yield.

2. Crop modelling

The type of crop model used in the system will be determined by the spatial scale of interest. Highly calibrated, comprehensive models (of the type often used for research, teaching and for studies of crop management at a particular site) have a large input data requirement. These data may have inherent uncertainties, or may not be available at all. These models are often site-specific and the meteorological inputs will require some kind of downscaling from the weather prediction scale. Crop models operating on larger scales (meta-models) are more easily transferred between regions. However, the level of detail in these models must be adequate for the application - processes which impact upon crops should be included, whilst processes which do not should be excluded, as they will merely add to the uncertainty in the output.

3. Testing the combined system (hindcasting)

Re-analysis data consist of output from a weather prediction model into which observations have been assimilated. They are generally considered to represent the most consistent global description of the state of the atmosphere at any particular time and have been widely used to study the mean and variability of the current climate. Reanalysis data covering a large range of atmospheric and surface variables are usually output on the weather prediction grid with a resolution typically of about 200km. Hence, the meteorological input to the crop model is on a spatial scale typical of that expected for a seasonal forecast.

Re-analysis data can be used to drive the chosen crop model(s) and the output can be compared to measured crop performance. This is seen as an important step in the evaluation of the combined system. Although absolute predicted values of crop yields are important, it is also crucial to assess how well the system is capturing spatial and temporal variability in yields. If surface and/or satellite data exist for the relevant region, these can be used to test the seasonal weather forecasts directly.

4. Probabilistic forecasting using the combined system

Before the crop model is run within the combined seasonal prediction system, methods need to be developed which exploit the probabilistic nature of seasonal weather forecasts. Uncertainties in the forecast are inevitable, and every effort needs to be made to quantify uncertainties. Subseasonal information may also be useful, such as the distribution of rainfall through the season. A crop model of suitable complexity could predict the effect of subseasonal weather variations on crop development and final yields.

5. Dissemination of Information

It is important to ensure that the form of the information that is output from the combined seasonal weather/crop forecast matches the requirements of the end-user(s) at an early stage of the development of the forecasting system. Consideration should also be given to how uncertainties in output are best presented to the end-user. How these uncertainties in forecasts are interpreted will depend to some degree on how great the uncertainties are, and how quantifiable they are. The probability of extreme events is likely to be one of the useful products of the system. The costs and losses associated with the user's response to forecasts of varying skills also needs to be determined.

6. Future climates

The impacts of future climate change, whether natural or anthopogenic on the food chain are vital to agencies concerned with the use of natural resources for food. By their very nature, predictions of future climate cannot be validated. Therefore, confidence in the predictions must be based on the skill of the forecast system in reproducing the current climate and its variations. Thus accuracy in the numerical seasonal forecasting of crop productivity will provide a sound basis for the prediction of crop productivity in future climates. Demonstration of skill at the seasonal timescale, where the results can be properly validated, is seen as a prerequisite for any prediction system used for future climate change prediction.

CONCLUSION

A framework has been proposed (Figure 1) which details the research issues which need to be tackled as part of the development of a combined seasonal weather and crop productivity forecasting system. Firstly, a link must be established between weather and crop yield or crop quality. Consideration should be given to which of the climate variables to use in this investigation, so that no strong responses to climate are omitted. Crop modelling must then use the proven climate link on the relevant spatial scale. Re-analysed weather data can be used as a best-case test of the crop model at the grid resolution typical of the weather prediction model. The system can then be run within a weather prediction system in order to make forecasts of productivity for the coming season. It should be ensured that the information output from the forecasting system is compatible with the needs of the end users. Probabilistic methods should be used throughout the system, so that the expected accuracy of the output can be assessed. Once these stages have been completed, forecasting for future climates can begin.

Figure 1. The development of a seasonal crop productivity forecasting system. Italicised text illustrates links between the various stages.